FRESHWATER under THREAT

A F R I C A

Vulnerability Assessment of Freshwater Resources to Environmental Change

UNEP

United Nations Environment Programme

Every drop counts
AMCOW
Count every drop

African Minister's Council on Water

Freshwater Under Threat: Vulnerability Assessment of Freshwater Resources to Environmental Change - Africa

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UNEP
P.O. Box 30552
Nairobi 00100
Kenya
Tel: +254 20 7622015
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E-mail: dewainfo@unep.org

WRC
Private Bag X03
Gezina
0031 South Africa
Tel: +27 12 3300340
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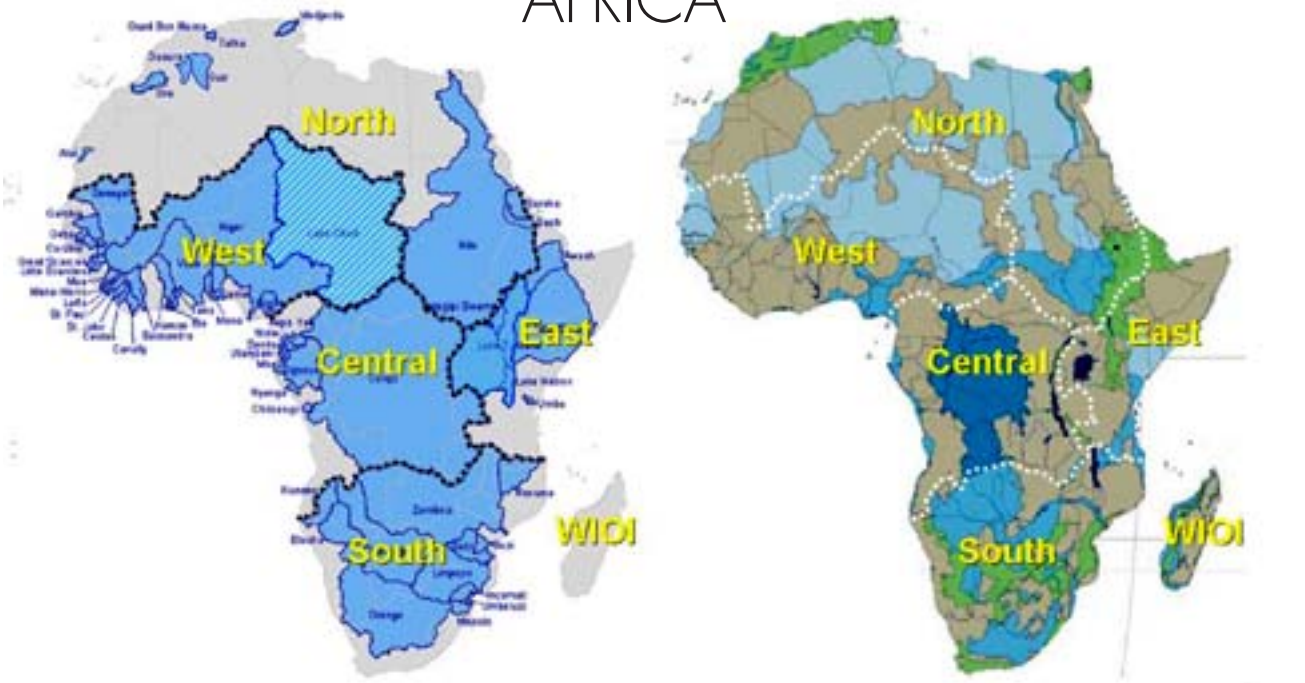
AFRICA



Southern Africa: Limpopo, Okavango, Orange and Zambezi River Basins, Basement Aquifers, Coastal Areas and Karoo Groundwater Basins

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Eastern Africa: Abbay, Awash, Pangani and Rufiji River Basins, Lake Malawi, Lake Tanganyika, Lake Turkana and Lake Victoria Basins

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Northern Africa: Moulouya, Nile, Sebou, Seybouse, Souss, Tafna and Tensift River Basins, North Western Sahara and Nubian Sandstone Aquifer Systems

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PREFACE

The Fourth Assessment Report of IPCC (2007) concludes:

> *Warming of the climate system is unequivocal, as is now evident from observations of increase in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level. (Emphasis added)*

There is a clear and intimate relationship between climate change and freshwater since climate affects hydrological cycles at all geographical scales from global to local. According to available scientific knowledge, climate change is leading to substantial changes in precipitation over time and space.

In Africa, changes in precipitation are already leading to more frequent and devastating droughts and floods, changes in the replenishment of groundwater resources, variations in the surface flow of rivers, alterations in the water levels of lakes, and high evaporation rates throughout the freshwater hydrological systems. The IPCC report also recommends that an integrated approach to adaptation measures is necessary for dealing with climate change.

It must be recognized that Africa as a whole is a very minor contributor to the recognized drivers that are leading to climate change, being responsible for only 3-5% of the global emissions of greenhouses gases while being home to nearly 18% of the world's population. Yet it is the poorest countries and people in Africa who will likely suffer first and most from the adverse effects of climate change. African governments must therefore continue to press vigorously in the UN and other fora for developed countries to reduce their greenhouse gas emissions and to meet and even exceed the internationally agreed targets and timetables.

However, with the exception of a few developed countries, progress on reducing greenhouse gas emissions has not been encouraging over the last decade. Facing a scenario where action may be too little and too late, African governments must now assign much higher political priority and allocate more budgetary resources for adaptation measures.

This scientific assessment therefore focuses on adaptation measures to be undertaken on the political, socio-economic, institutional, behavioral and other measures necessary to accommodate and adapt to climate change. Adaptation to, climate change, especially in the area of prudent and sustainable management of the region's freshwater resources, therefore remains the crucial challenge for our region in the near and foreseeable future.

Combined with threats to freshwater resources due to population growth, food insecurity, urbanization, industrialization, pollution of water resources, poor governance and management structures, and deficient of scientific and technical capabilities, the region faces a bleak future indeed if appropriate measures for adaptation are not put in place in a timely manner.

The African Ministers' Council on Water (AMCOW), which comprises all the water ministers of Africa has clearly recognized the urgency of the situation and begun to put in place measures to address this critical challenge facing the region. AMCOW recognizes therefore that a scientific assessment of the

threats to the freshwater resources of the region resulting from climate change and other environmental causes must be the basis for developing adaptation strategies at the local, national, sub-regional, regional and international levels.

At this critical juncture for our region, we at AMCOW greatly welcome the partnerships that have evolved with several regional entities like the African Union (AU), the African Development Bank (AfDB), New Partnership for Africa's Development (NEPAD), The African Ministerial Conference on the Environment (AMCEN), African Ministerial Conference on Science and Technology (AMCOST), The Forum of Energy Ministers of Africa (FEMA) and others), UN agencies, Governments, development cooperation partners, and local, regional and international NGOs, all devoted to tackling the climate change-freshwater challenges that the region faces. This publication is a fine example of this collaborative endeavor.

We hope that the publication will raise awareness at all levels regionally and internationally, and facilitate informed and enlightened dialogue, decision-making and actions.

S.E. Bruno Jean-Richard Itoua,
President
African Ministers' Council on Water (AMCOW)
Ministère de l'Energie et de l'Hydraulique

BP 2120, Brazzaville
Republic of Congo
Tel. + 242 810 290
Email: meh_cabyyahoo.fr,
bjr_itoua@yahoo.fr

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- **Chapter 1 – Background to vulnerability assessment**
  Hans E. Beekman (lead author), Irené C. Saayman and Simon Hughes
- **Chapter 2 – Southern Africa**
  Kevin Pietersen (coordinator southern Africa), Hans E. Beekman (deputy coordinator and lead author), Samuel Sunguro, Shirley Bethune, Simon Hughes, Flenner Linn†, John Mendlesohn, John Pallett, Irené C. Saayman and Rian Titus
- **Chapter 3 – Western Indian Ocean Island States**
  Hans E. Beekman (lead author)
- **Chapter 4 – Eastern Africa**
  Eric O. Odada (coordinator Africa and lead author), Alfred Opere (deputy coordinator eastern Africa and lead author), Tenalem Ayenew, Dagnachev Legesse, Simon H. Mkhandi, William O. Ogembo and Kassim A. Kulindwa
- **Chapter 5 – Central Africa**
  Luc Sigha-Nkamdjou (coordinator central Africa and lead author), George T. Mafany (lead author), Takounjou A.L. Fouépé, Wilson Y. Fantong, Dorice K. Kengi and Gloria T. Eneke
- **Chapter 6 – Western Africa**
  Lekan Oyebande (coordinator western Africa and lead author), Alioune Kane (deputy coordinator and lead author), Abel Afouda, Awa Niang-Fall, Gabriel E. Oteze, Lamine Konate, Kwame Odame-Ababio, Isaac I. Balogun, Olusegun Adeaga, Samba Ba and Shakirudeen Odunuga
- **Chapter 7 – Northern Africa**
  Abdelkader Allali (coordinator and lead author northwest Africa), Maria Snoussi (coordinator and lead author northwest Africa), Larbi Djabri, Attia B. Bayoumi (coordinator and lead author northeast Africa), Khaled Abu-Zeid, Osman M.A. Mirghani, Charles Baubion and Sadek Kadri

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EXECUTIVE SUMMARY

Africa's high dependence on natural resources makes its people vulnerable to environmental changes. This vulnerability relates to natural and human phenomena, inter alia, climate change and variability, pollution, population growth, competition for water, data availability and quality, and knowledge gaps. Vulnerability assessments of water resources are urgently needed in Africa, since ecosystems are already at high risk, thereby threatening the livelihoods of the many poor who are least capable of adapting to environmental change.

Acknowledging the urgency of the vulnerability issues affecting the livelihoods of Africa's people and environment, UNEP-DEWA and START initiated a study in February 2003 to assess the "Vulnerability of Water Resources to Environmental Change in Africa." The goal of the study was to facilitate the management of vulnerability risks at transboundary, national, and local river/lake/groundwater basin levels, by assessing the impacts of environmental and human-driven changes on water resources. The study should be of great interest to governments, policy- and decision-makers at various levels, and to affected communities since it provides insights into these critical issues and how they could be mitigated.

This publication documents the findings of the second phase of the study, which was completed in May 2006. The aim of this phase was to accomplish a wider, continental, coverage of river/lake/groundwater basins (i.e., building upon the first phase), and expanding the network of researchers. Regional groups of researchers addressed vulnerability issues for their respective regions (southern, eastern, central, western, and northern Africa and the Western Indian Ocean Island States) by assessing major river/lake/groundwater basins on the basis of natural (physiographic), anthropogenic (socio-economic) and management criteria. To this end, the study is unique, as it was previously not undertaken for Africa as a whole. Assessments were carried out for:

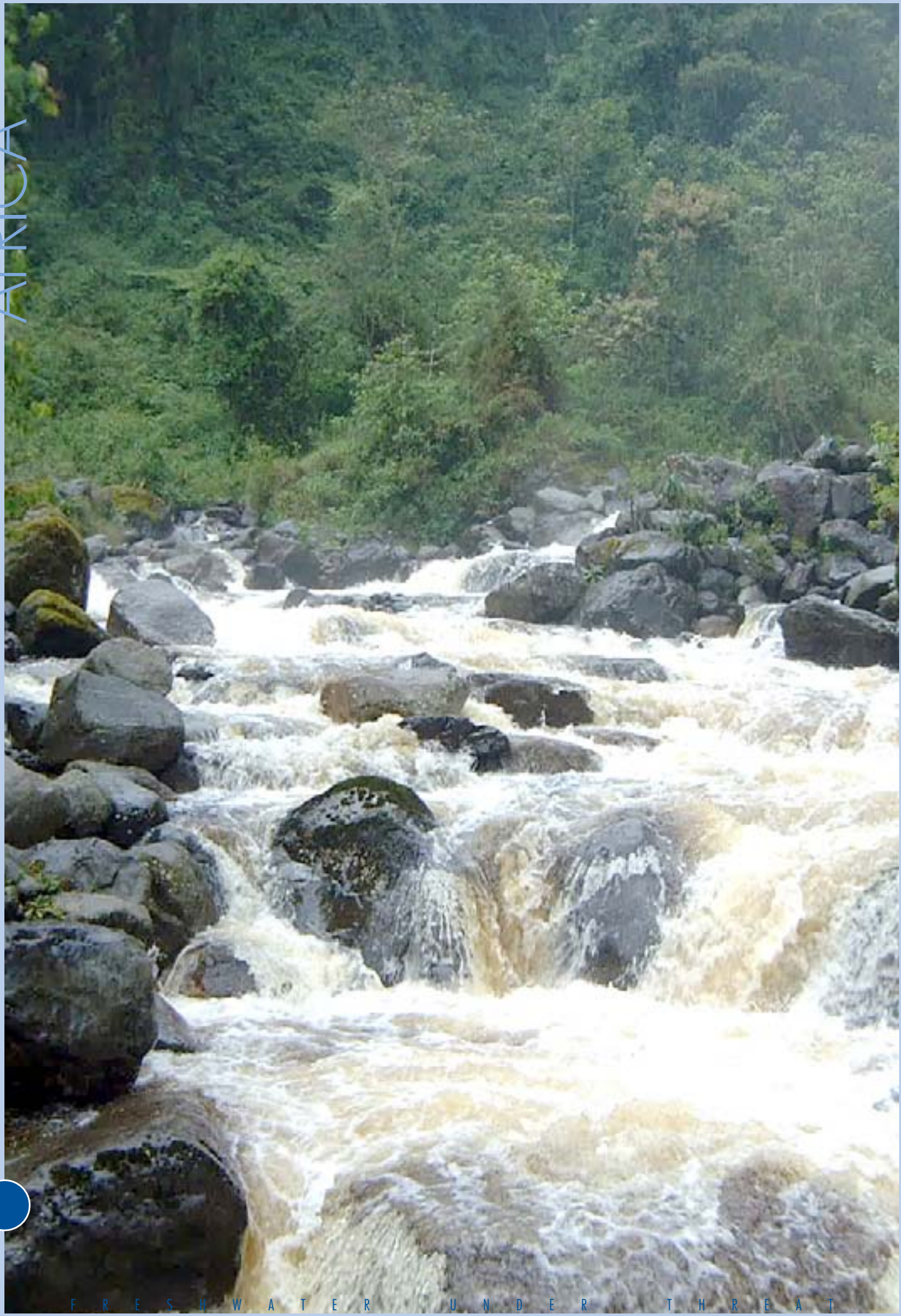
- *Southern Africa:* Limpopo, Okavango, Orange and Zambezi River Basins, Basement Aquifers, Coastal Areas and Karoo Groundwater Basins
- *Western Indian Ocean Island States:*
- *Eastern Africa:* Abbay, Awash, Pangani and Rufiji River Basins, Lake Malawi, Lake Tanganyika, Lake Turkana and Lake Victoria Basins
- *Central Africa:* Congo and Sanaga River Basins, Lake Chad Basin and Douala Multi-Aquifer System
- *Western Africa:* Gambia, Komadugu-Yobe, Mano, Niger, Senegal and Volta River Basins, Nigerian Coastal Areas Aquifer System and Sokoto Groundwater Basin; and
- *Northern Africa:* Moulouya, Nile, Sebou, Seybouse, Souss, Tafna and Tensift River Basins, North Western Sahara and Nubian Sandstone Aquifer Systems.

The level of detail of the vulnerability assessments was determined by the study objectives and resource availability. A rapid approach was adopted to provide a summarized overview. Key issues of vulnerability of water resources to environmental change emanated from the assessments,

being summarised for each of the basins. They are grouped under three broad areas: physiography (increased frequency of droughts and floods, which are affecting water supplies and livelihoods, wetland/land degradation, desertification, water pollution, over-exploitation of aquifers, etc.), socio-economy (high population growths and urbanisation, HIV/AIDS and water-related diseases, poverty, increased water demands, etc.), and management (lack of or weak river basin institutions, weak legislation, lack or limited data and/or monitoring, human resources training, etc.). Means of addressing these issues through appropriate adaptation and mitigation options are subsequently discussed.

The assessments clearly illustrate that Africa's water resources are already facing serious risks, with the situation expected to worsen in the future. Thus, the results of this study should be regarded as a vital starting point for comprehensive vulnerability assessments of Africa's river/lake/groundwater basins, to inform the management of vulnerability risks at various levels.

AFRICA



Christian Lambrechts/UNEP

BACKGROUND TO VULNERABILITY ASSESSMENT

The availability of, and access to, water strongly influences economic growth and social development patterns (Allan 2002). In this regard, Africa faces considerable challenges in meeting the social and economic needs of its populations (Hirji et al. 2002). It has become increasingly important that water resources development takes place within the context of Integrated Water Resource Management (IWRM), with its main principles of equity (regarding access), efficiency and sustainability. Africa's high economic dependence on local natural resources makes the continent particularly vulnerable to changes in the availability of water as a function of environmental changes.

1.1 VULNERABILITY OF WATER RESOURCES TO ENVIRONMENTAL CHANGE

The UNEP Project "Vulnerability Assessment of Water Resources to Environmental Change in Africa" was launched in February 2003 to address the vulnerability issue in a broad sense (i.e., in terms of physiographic, socio-economic and management-related changes). This publication presents contributions from 6 (southern, Western Indian Ocean -sland States, eastern, central, western and northern) African regions (see cover page) in this project. It builds upon a previous publication (UNEP 2005) that considered only 4 regions.

These assessments focus on river, lake and groundwater basins, being carried out within the context of the recent World Summit on Sustainable Development (UN 2002), at which the international community made a renewed commitment to sustainable development, as outlined in the Rio Declaration (UN 1992), and to advancement of the Millennium Development Goals (UN 2000). Within this context, it is internationally recognized that sustainable development in Africa can only be achieved by addressing peace, security and development concerns including environmental issues, human rights and governance. This overlaps with efforts in implementing a "programme of action for Africa's re-development" through the New Partnership for Africa's Development (NEPAD) initiative (www.nepad.org.)

1.2 FRAMEWORK FOR VULNERABILITY ASSESSMENT

1.2.1 Definitions

The degree to which a system is susceptible to, or unable to cope with, adverse effects of environmental change defines its **vulnerability**. With regard to climate change, the vulnerability of a natural and socio-economic system is determined by the character, magnitude, and rate of climate variation on the one hand, and the sensitivity and adaptive capacity of the system on the other hand (IPCC 2001). Of particular relevance to discussions on the vulnerability of water resources are spatial and temporal changes in precipitation.

Water demands outstrip available freshwater resources in many countries. Countries or regions in which such conditions limit development are said to experience **water stress**. Water stress may cause deterioration of freshwater resources, in terms of quantity (over-exploitation, environmental

degradation, etc.) and quality (eutrophication, pollution, saline intrusion, etc.). Water withdrawals exceeding 20 per cent of renewable water supply have been used as a water stress indicator (IPCC 2001). Annual renewable freshwater availability of less than 1,000 m^3 per person is defined by hydrologists as **water scarcity**. Appropriate **water resource legislation and management** is a means of addressing vulnerability issues.

1.2.2 Basin perspective

Increased incidences of water stress have resulted in the adoption of new approaches to managing water resources in a holistic and integrated manner. A paradigm shift from water resources management based on administrative boundaries to hydrological boundaries followed from the Rio+10 and Dublin conferences.

The (river/lake/groundwater) basin was chosen as the key assessment unit. The basin represents a hydrologic unit that incorporates both surface water and groundwater, therefore taking into account different components of the hydrological cycle. It comprises watersheds or catchments, which are defined as "topographically delineated area[s] drained by stream system[s] - that is the total land area above some point on a stream or river that drains past that point".

The basin perspective helps to achieve a balance between the interdependent roles of resource protection and resource utilization (Ashton 2000). It incorporates the principles of sustainability, development, participation, and integrated water management, and is meant to denote desirable collective goals (e.g., equity; stakeholder engagement; self-reliance; healthy environment) (Turton and Henwood 2002). In effect, the basin perspective seeks to maintain a balance between the competing pressures exerted by the need to maintain resource integrity over the long term, and the compelling call for social upliftment and advancement, and the need for continuous economic growth and use of environmental resources.

The basin perspective represents a progression from supply-oriented water resources development to water demand management (Turton and Henwood 2002). This progression develops where water demands continue to outstrip water supply, even though all available water sources have been developed, or are prohibitively expensive to develop, resulting in competition between water use(r)s. At this point, water scarcity reaches such a level that the exploitation limits become evident, and finding the best possible use of water becomes imperative (Turton and Ohlsson 2000).

1.2.3 Parameters and indicators

Parameters and related indicators for assessing the vulnerability of water resources to environmental change were grouped into physiographic (natural), socio-economic (anthropogenic) and management clusters (see Table 1.1). They are linked to sub-clusters, and should be applied to various temporal and spatial scales. It is emphasized that this table is not exhaustive, but rather seeks to provide an overview of the parameters and indicators for which data and information is relatively easily available and accessible.

The table is structured into 3 main compartments (clusters) that define the sphere within which the drivers of change manifest themselves (i.e., physical, socio-economic or management), with a list of

measurable parameters that could be used, through integration or analysis, to arrive at vulnerability indicators. Water Scarcity is defined as an overarching vulnerability indicator. It is through assessing these indicators that the vulnerability of water resources at the sub-regional and basin scales was assessed (see Chapters 2 to 7).

Table 1.2-1: Parameters and vulnerability indicators (UNEP 2005)

Cluster		Parameter*	Vulnerability Indicator*	
Physiography	Climate	• Rainfall • Evapotranspiration	• Aridity	Water Scarcity
	Ecosystems	• Water dependency • Land cover • Land use	• Water availability • Desertification • Storage and supply infrastructure	
	Hydrology	• Stream flow		
	Hydrogeology	• Storage • Quality • Yield • Recharge		
Socio-Economy	Demography Economy	• Population size and distribution • HIV-AIDS/water-related diseases • Water demands • Water supply • Value of water	• Population density and growth • Poverty • Access to water • Water uses • Conflicts	
Management	Legislation	• Policies • Acts • Regulations • Guidelines	• Sector reform • Implementation and adaptive capacity	
	Institutional	• Adherence to IWRM principles • Human resources		
	Knowledge	• Literature/reports	• Data availability, gaps and quality	

**Temporal and spatial variability and trends*

1.2.4 Approach to vulnerability assessment

The level of detail of a vulnerability assessment is determined by the study objectives and availability of resources (human resources, finances, data and information, etc.). The following three-tiered approach was proposed (UNEP 2005):

- Rapid: Summarized overview, including inventory of sources of data and information;
- Intermediate: A more detailed overview; and
- Comprehensive: In-depth analysis, likely at a smaller spatial scale (pilot areas).

Based on the available resources, a 'rapid' approach was adopted, resulting in summarised overviews of the sub-regions as a whole, as well as major river/lake/groundwater basins. The assessments formed the basis for deriving key issues of the vulnerability of water resources to environmental change, and adaptation and mitigation options.

1.3 STRUCTURE OF PUBLICATION

The following chapters (2-7) present vulnerability assessments of water resources to environmental change for the 6 African sub-regions as a whole, as well as more detail regarding major river/lake/groundwater basins ('rapid' approach). The assessments concentrate on various aspects of vulnerability, including physiographic, socio-economic and management perspectives. For each assessment, key issues related to the vulnerability of water resources to environmental change and adaptation and mitigation options are formulated.

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SOUTHERN AFRICA

2.1 OVERVIEW

The economies of the southern African countries depend mainly on natural resources, in the form of agriculture, mining, industry and tourism. Climate variability and change have an impact on these countries because they are generally less developed, and heavily dependent on natural resources. Climate variability and change may be defined in terms of the total quantity of precipitation received, its frequency of recurrence, the persistence of wet or dry-day combinations, the onset and duration of the rainy season (Schulze et al. 2001), or in terms of the quality of the available resources. The water resources, environment and economies may be impacted in varying degrees by changes in water availability.

The four largest southern African river basins south of the Democratic Republic of Congo are (from large to small) the Zambezi River Basin, Orange River Basin, Okavango River Basin and Limpopo River Basin (Figure 2.1-1).

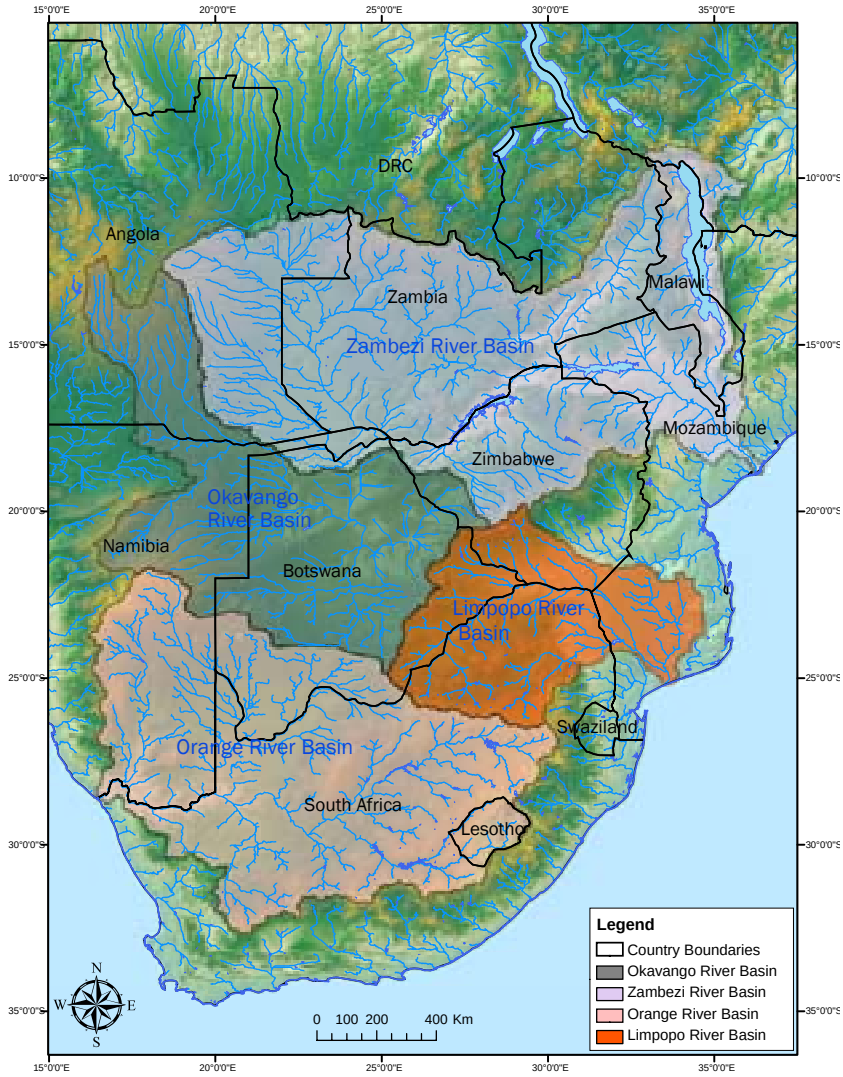


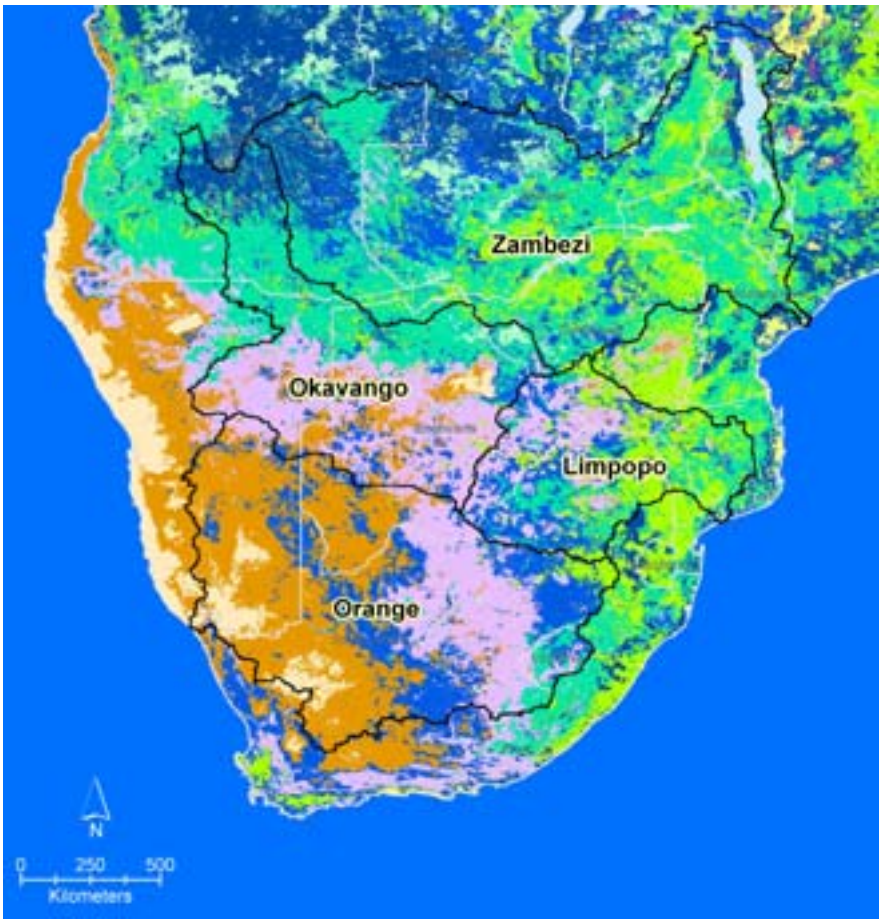
Figure 2.1-1: Major river basins of southern Africa

2.1.1 Physiography

The annual rainfall is highest in the north and along the east coast, and decreases southward and westward. It ranges from 100 mm (3.9 in) in the western parts, to 1,500 mm (59 in) in the east. The potential evapotranspiration exceeds the average annual rainfall in most of the region.

Southern Africa has relatively large areas in which the natural systems are protected and not impacted by human interventions. Recent developments have included the establishment of transfrontier parks, for example, and there also are 25 wetlands of high ecological importance under the Ramsar Convention of 1971.

The land cover largely mirrors the climate, with grasslands and open shrub lands in the west and southwest, savannah in the southeast and evergreen broadleaf forests in the north. Large areas of cropland are found in eastern and northern South Africa and Zimbabwe (Figure 2.1-2).



Land Cover

- Barren or sparsely vegetated
- Closed shrublands
- Cropland/Natural vegetation mosaic
- Croplands
- Evergreen broadleaf forest
- Evergreen needleleaf forest
- Grasslands
- Mixed forests
- Open shrublands
- Permanent wetlands
- Savannas
- Urban and built-up
- Water bodies
- Woody savannas
- Major river basins

Figure 2.1-2: Land cover in southern Africa (IGBP legend)

Source: USGS Africa Land Cover Characteristics Data Base: http://edcdaac.usgs.gov/glcc/glcc.html

The renewable freshwater resources of southern Africa are estimated to be 650 billion m^3, distributed in rivers, lakes and groundwater (Chenje and Johnson 1996). The distribution, occurrence and availability of water resources are uneven in the region. The surface runoff is available in sufficient quantities in some parts throughout the year, while it only occurs with extreme episodic rainfall events in other parts. Under such conditions, people rely largely on dams and groundwater for their water supply.

The renewable portion of groundwater resources (recharge) for the region typically ranges from 1 to 15 per cent of the average annual rainfall (Beekman and Xu 2003). Groundwater is the main water source for domestic drinking water and agriculture, particularly in rural areas. It occurs in the following hydrolithological domains: volcanic rocks (e.g. basalt); basement rocks (Precambrian crystalline basement); and consolidated (e.g., sandstone and dolomite) and unconsolidated (e.g., sands) sediments (Figure 2.1-3). Although the hydrolithological domains do not follow the river basin boundaries, the groundwater aquifers generally do fall within the boundaries.

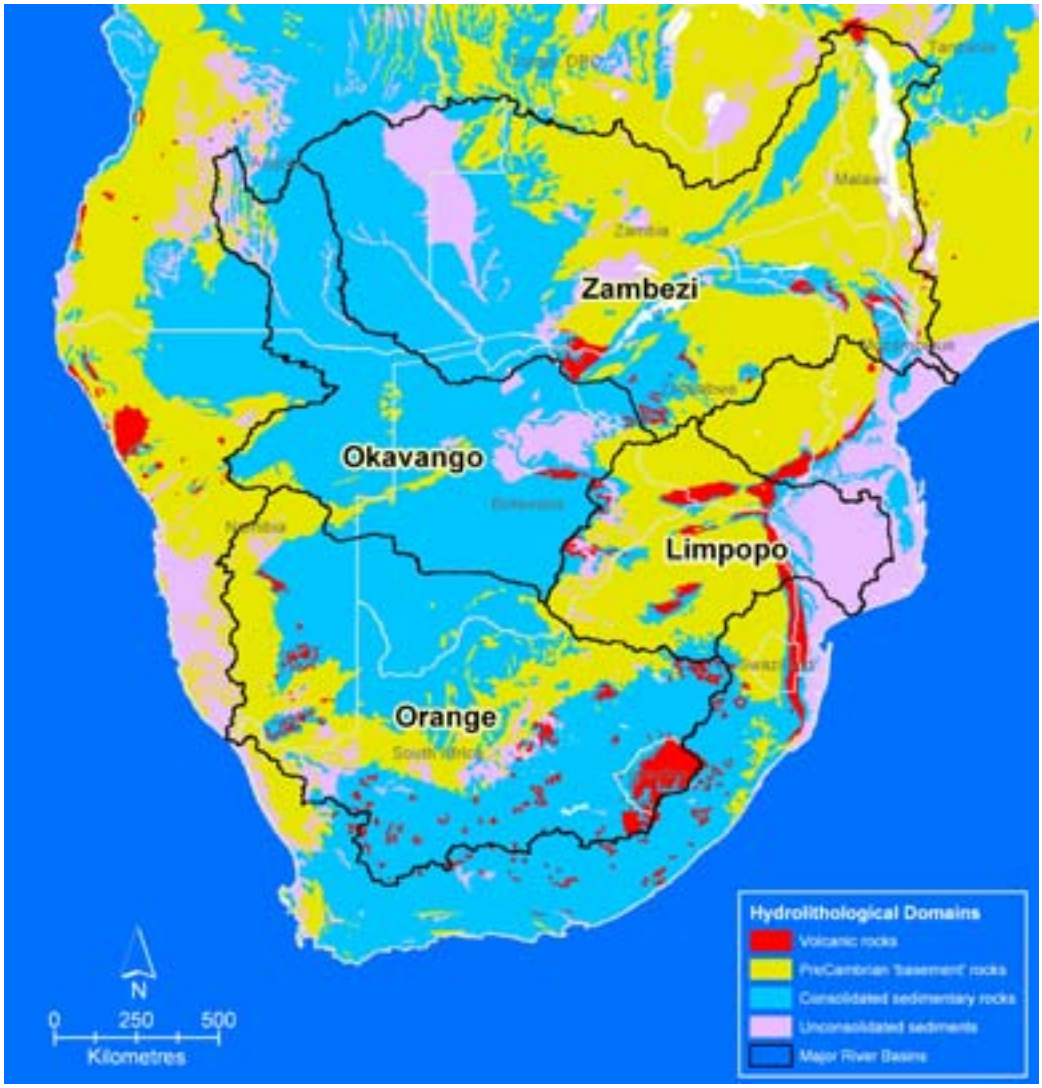


Figure 2.1-3: Hydrolithological domains of southern Africa

Source: Adapted from USGS World Energy Resources Products, Generalized Geology of Africa:
http://energy.cr.usgs.gov/oilgas/wep/products/geology/africa.htm
After MacDonald, A. M. and Davies, J. 2000

Aridity and water availability

The highest aridity[1] and vulnerability of water resources to environmental changes occurs in the western and southern parts of the region, decreasing to the north and east. Projected figures for 2025 (UN FAO 1995) suggest the per capita water availability will decrease, being attributed largely to increasing water demands, and a reduced resource availability and accessibility, because of such factors as increasing urban population, environmental changes (including climate change), and pollution. The projections for Malawi and South Africa look particularly bleak.

2.1.2 Socio-economics

The population of southern Africa (excluding the Democratic Republic of Congo) was estimated to be about 150 million people in 2000. The annual population growth rates are high, ranging from 1.5 to 3 per cent. A strong trend towards urbanization exists in all the southern Africa countries. As a result, the population growth rates of towns and cities are much higher than national population growth rates, placing further demands on clean water supplies and sanitation facilities.

Large disparities exist between levels of economic development in the southern African countries. Of the 11 southern African states, 5 are among the lowest-ranking countries in the UN Human Development Index. To advance human development, governments have adopted the targets in the Millennium Development Goals (MDGs) (UN 2000; UN-WWDR 2003). Among them is MDG 7, which requires governments to adopt sustainable resource management policies and to reduce by half the number of people without access to safe water and sanitation by 2015.

The economies of southern Africa are based largely on natural resources, with mining and agriculture contributing most to their economic outputs. Agriculture contributes 9 per cent to the region's GDP, but provides employment for 60 per cent of the region's active labour force. The impacts of social instability and war, however, have constrained growth and development. Large foreign debts also remain a problem, with Angola, Malawi, Mozambique and Zambia being among the most indebted countries in the world (Jubilee 2000).

Southern Africa has the highest incidences of HIV/AIDS in the world, particular in Botswana (35.8 per cent), Swaziland (25.3 per cent), Lesotho (23.6 per cent) and South Africa (22.6 per cent) (Ashton and Ramasar 2002). There has been a general decline in life expectancy for all the countries in the region between 1995 and 1999/2000. The implications of the disease are enormous, and affect the water sector in the southern African countries in terms of demand and supply, sanitation and human resource capacity (including service provision).

The pivotal role of women, as guardians of the environment and users and carriers of water, needs to be reflected in all aspects of water resources management.

[1] Can be broadly considered to be the dryness of the climate at a given location

Water resources demands

The increased water demands in southern Africa are driven by high population growth (2-3.5 per cent per year), urbanization, improved living conditions, and industrial and agricultural development. The main water user in southern Africa is the agricultural sector, accounting for 75 per cent of total water use. The industrial sector has the lowest water usage, although it is expected to increase in the future.

Access to water and sanitation

There has been significant improvement in the supply of safe drinking water in both the urban and rural areas. In contrast, an accelerated effort is needed to meet the MDG target for sanitation coverage by 2015 (see Figure 2.1-4).

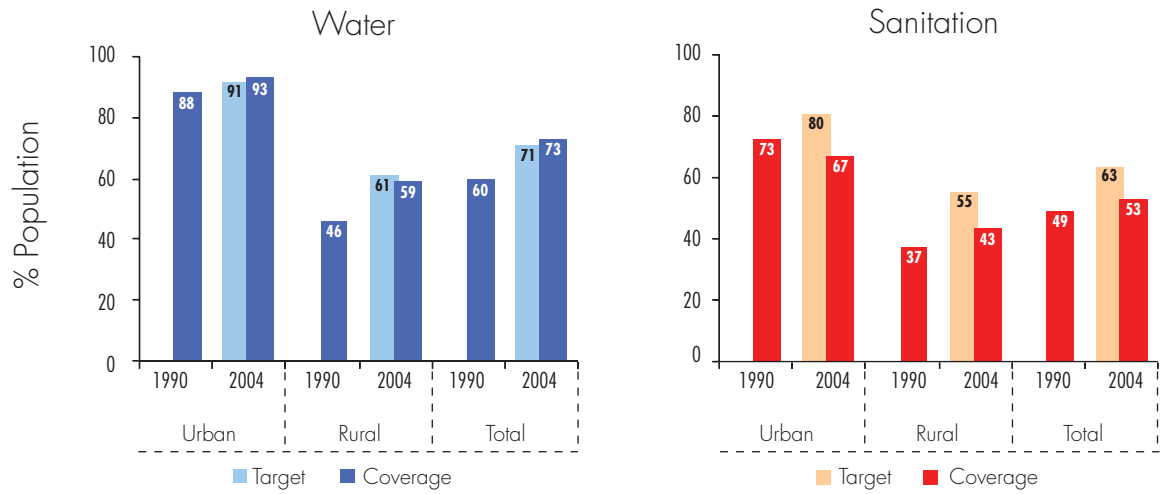


***Figure 2.1-4:** Water supply and sanitation coverage for southern Africa in rural and urban settings between 1990 and 2004 (Lesotho, Mozambique and Swaziland are excluded due to incomplete data)*

Source: WHO/UNICEF (2006), redrawn by UNEP

Water-related conflicts

The present population trends and water use patterns suggest more African countries will exceed the limits of their economically-usable water resources before 2025 (Ashton 2002). Water-related conflicts may be expected in relation to the Lesotho Highlands Water Project, Kariba and Cahora Bassa Dams, Limpopo River, and eastern Caprivi region.

2.1.3 Water Resources Management

Southern African countries are practising an increasingly integrated approach to water resources management, in that surface water, groundwater, socio-economic and other issues are dealt with in an integrated manner. The establishment of new institutions, with new functions, responsibilities, legislation and guidelines for water resources management and development, takes place at different paces and different scales within each country. South Africa and Zimbabwe promulgated their new Water Acts in 1998, whereas other countries (e.g., Namibia; Zambia) are in the process of revising their old Acts.

Water is a scarce resource in the region, and it is anticipated foreseen that 3 or 4 SADC (Southern Africa Development Community) states will be facing serious water shortages in the next

20-30 years. In recognition of the importance of a coordinated approach to the utilization and preservation of water, SADC member states signed the 'Protocol on Shared Watercourse Systems' in 1995. The main thrust of the protocol is to ensure equitable sharing and efficient conservation of water resources. The protocol describes the establishment, objectives, functions and financial and regulatory framework of River Basin Management Institutions.

Water sector reform

Since the late-1990s, there has been significant progress in water sector reforms in southern African countries, creating an enabling environment to mitigate the adverse effects of environmental changes on water resources.

Vulnerability studies in southern Africa

Because southern Africa is among the world's most drought-prone regions, most vulnerability studies have focused on the impacts of drought and climate change on water resources. The indications are that climate change may increase the periodic occurrence of droughts in the region (Ohlsson 1995). Recurring droughts continue to pose a serious challenge to food security, resulting in an increased reliance on groundwater. Certain studies have focused on groundwater recharge, a critical parameter in determining water availability and, therefore, water scarcity[2]. Changes in groundwater recharge will result from changes in effective rainfall, and in the timing of the rainfall season. Under a scenario of global warming, increasing temperatures generally result in decreasing precipitation over the central continental areas, causing decreasing recharge and, therefore, the depletion of groundwater resources.

Studies on vulnerability of water resources to climate change in southern Africa include:

- Hulme (ed.) (1996): Annual surface water runoff in the SADC region, at 0.5° resolution;
- Meigh et al. (1998): An assessment of water availability in eastern and southern Africa, at 0.5° resolution, including a demand/supply study (for both surface and groundwater);
- Cambula (1999): Impacts of climate change on the water resources of Mozambique;
- Schulze and Perks (2000): Detailed modelling exercises covering South Africa, Lesotho and Swaziland at 0.25° cell resolution, and applied to 1946 Quaternary catchments; and
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[2] Water scarcity occurs where there are insufficient water resources to satisfy long-term average water requirements. It refers to long-term water imbalances, combining low water availability with a level of water demand that exceeds the supply capacity of the natural system (Water Information System for Europe: www.eea.europa.eu).

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2.2 LIMPOPO RIVER BASIN

The Limpopo River Basin, with a total area of about 415,000 km^2 (160,232 mi^2) is located between latitudes 22°S and 26°S and longitudes 26°E and 35°E (Figure 2.2-1), and has South Africa, Botswana, Zimbabwe and Mozambique as the riparian countries (FAO, 2004). The largest section of the basin is within South Africa (45 per cent), followed by Mozambique (20 per cent), Botswana (20 per cent), and Zimbabwe (15 per cent).

Figure 2.2-1: Limpopo River Basin

The basin is drained by the Limpopo River and its tributaries, with the source of the Limpopo River being in the northern slopes of the Witwatersrand. The river ultimately drains into the Indian Ocean at the Mozambique coast. It is approximately 1,800 km (1,118 mi) long, with a large number of tributaries. The main characteristics of the basin are summarized in Box 2.2-1.

2.2.1 Physiography

Climate

The climate in the basin ranges from tropical dry savannah, to warm and cool temperate. It is controlled primarily by three factors (Ashton et al. 2001): (i) the position of the basin relative to the Inter Tropical Convergence Zone (ITCZ) and the associated high pressure systems; (ii) the distance of the basin from the Indian Ocean (the main source of moisture); and (iii) the altitude. The basin receives an average annual rainfall of 530 mm (21 in), ranging from about 200 mm (8 in) in the western parts, to about 1,200 mm (47 in) in the southeast. The annual rainfall variability is high. The potential evapotranspiration is high throughout the basin, reaching values as high as 2,000 mm.yr^{-1}(78.8 in.yr^{-1}) (CSIR 2003).

Box 2.2-1: Main characteristics of Limpopo River Basin

Basin

Surface area:	415 x 10^3 km^2 (160,232 mi^2)
MAP:	530 $mm.yr^{-1}$ (21 $in.yr^{-1}$)

Demography

Population:	14 million
Density:	25 – 50 $persons.km^{-2}$ (65-130 $persons.mi^{-2}$)

Water Use

Agriculture
Domestic
Industry
Mining

Increasing

Water Resources

River length:	≈ 1,800 km (1,118 mi)
MAR:	7,330 million $m^3.yr^{-1}$

Vulnerability

Climate variability and change
Industrial and agricultural pollution
Health
Poverty
Infrastructure

Major Dams (million m^3)

Zimbabwe

Manyuchi:	303.5
Zhove:	130.5
Ingwesi:	67.2
Mtshabezi:	52.0
Upper Ncema:	44.8
Lower Ncema:	18.2
Total dam storage:≈	**600**

South Africa (million m^3)

Roodplaat	41.2	Hartebeespoort	186.0
Vaalkop	56.0	Marico	27.0
Roodekoppies	103.0	Makolo	145.0
Klipvoor	42.1	Blyderivierpoort	55.2
Witbank	104.0	Glen Alpine	20.0
Loskop	362.0	Nzhelele	53.3
Arabie	99.0	Tzaneen	157.0
Ebenezer	69.1	Molatedi	201.0
Others	672.3		
Total dam storage ≈	**2,500.0**		

Botswana (million m^3)

Gaborone
Nnywane
Shashe
Bokaa
Letsibogo
Total dam storage:≈ 350

Mozambique (million m^3)

Massingir	2,300
Total dam storage:≈	**2,300**

Major Aquifers: Basement Complex, Alluvium, Karoo, Dolomite

Source: CSIR (2003); FAO (2004)

Aridity

Most parts of the basin can be classified as either arid or semi-arid (Figure 2.2-2). Rainfall in the basin varies over both long- and medium-term cycles, with the mean cycle from wet to wet being about 18-20 years. Severe droughts and flooding in southern Africa extend back to the 1920s in the historical records (SARDC/IMERCSA/ZERO 2002).

Ecosystems

The basin contains a diversified variety of fauna and flora species. Most wetlands occur in Mozambique. There are only two Ramsar sites in the basin situated in the South African portion, comprising 57 fish species, 2 fish endemics, 46 amphibian species and 3 endemic bird areas. The proportion of the protected area, relative to the whole basin, area is about 8 per cent (WRI 2003). The Limpopo River Basin is occupied mainly by savannah, cropland/natural vegetation mosaic, and some grassland and urban/industrial areas (SARDC/IMERCSA/ZERO 2002; WRI 2003).

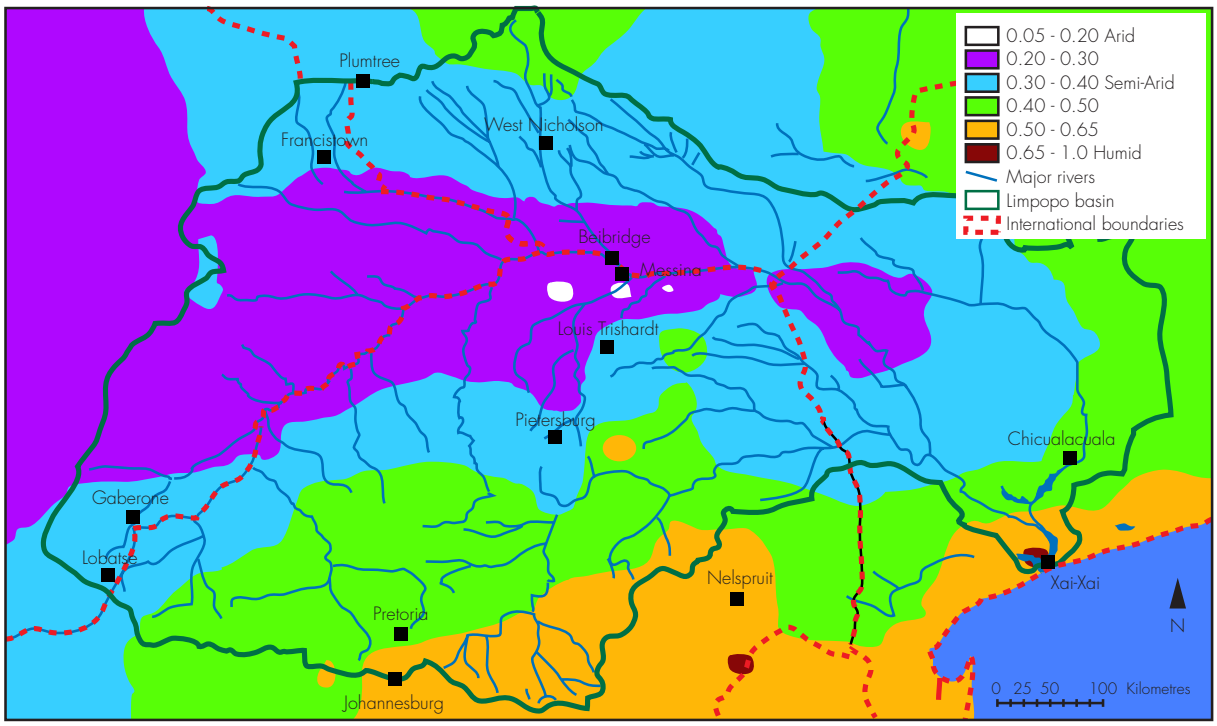

Figure 2.2-2: Distribution of the Aridity Index (MAP/PET) across the basin (CSIR 2003)

Source: FAO Land and Water Digital Media Series 13, redrawn by UNEP

Land degradation and desertification

Land degradation is a serious problem, and big threat to food security, in the Limpopo River Basin (FAO 2004). Several areas of degradation in the basin can be distinguished as follows: (Figure 2.2-3):

- No degradation, or stable terrain, along the lower northeast part of the Limpopo River Basin in Zimbabwe and Mozambique, and in a north–south zone roughly following the escarpment and associated mountains.
- Slight degradation along the upper Limpopo River Valley, in most of the adjacent southwest catchment in South Africa, and southeast Zimbabwe. Most areas coincide with private farms. Most of the remainder of Mozambique also falls into this class.
- Moderate degradation in northeast Botswana and adjacent Zimbabwe, a north–south zone covering northeast South Africa (including Kruger National Park), and the southern tip of the catchment.
- High degradation in the southwest upper catchment in Botswana and in an area southwest from Pretoria.
- Extreme degradation in three areas of Limpopo Province in South Africa, corresponding with densely-populated communal areas (former homelands of Venda and Lebowa).

Hydrology

The Limpopo River has been subject to flooding several times during the period of the historical record, mainly related to cyclone-induced high rainfall levels (CSIR 2003). Mozambique is usually the most affected country since it is at the downstream end of the basin, and at low altitude. Land clearance in the riparian countries, particularly South Africa and Botswana (FAO 2004), has caused increased soil erosion related to increased surface runoff, making the lower portions of the basin even more susceptible to flooding.

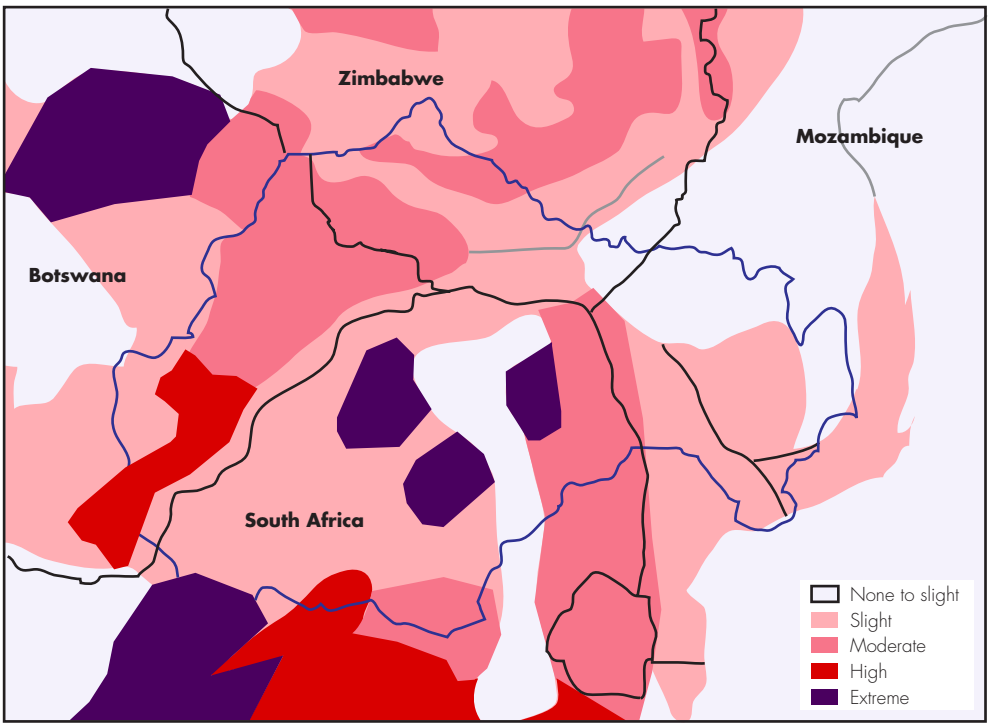

Figure 2.2-3: Severity of erosion in the Limpopo River Basin

Source: FAO 2004, redrawn by UNEP

Hydrogeology

Most parts of the basin in Botswana, South Africa and Zimbabwe are underlain by rocks of Achaean age (granite, gneiss and metamorphosed sedimentary successions), and the basin is covered by semi-consolidated to unconsolidated fluvial and aeolian deposits in Mozambique. Groundwater in the Botswana, South African and Zimbabwean parts of the basin occurs mostly in the fractured hard rocks and weathered zones, albeit with low potential (CSIR 2003). Groundwater occurs in the younger semi-consolidated formations to the east in Mozambique. Karoo sandstone formations and alluvial deposits are associated with present and palaeo-drainage lines. The groundwater quality is generally good, although high nitrate concentrations have been observed, being attributed to agricultural activities (CSIR 2003). High chloride concentrations occur within the Cretaceous sediments of Mozambique. Groundwater is mainly used for irrigation and rural water supply.

Water availability

The basin's water resources are almost fully utilized. Surface water is the main water source for most economic activities. The groundwater potential is quite low, being most developed in Botswana and South Africa. The basin has a naturalised MAR of about 8,000 x 10^6 m^3 (about 4,000 x 10^6 m^3 denaturalized MAR), and a unit runoff of about 10 mm (denaturalized MAR; 0.4 in) (FAO 2004).

2.2.2 Socio-economy

Demography

The basin exhibits a significant diversity between the rural and urban population. The Limpopo River Basin hosts a population of about 14 million people, with the rural population comprising over 50 per cent of the total basin population (FAO 2004). On a country basis, the basin population is approximately 1 million in Botswana, 1 million in Zimbabwe, 1.3 million in Mozambique, and 10.7 million in South Africa.

Population density

The population density in the basin is between 25 to 50 persons.km^{-2} (65-130 persons.mi^{-2}), making the Limpopo River Basin one of the most populated basins in Africa (CSIR 2003; FAO 2004; SARDC/IMERCSA/ZERO 2002). This high population density, against a backdrop of persistent droughts, extreme floods, and low or failed agricultural production, increases the rural to urban migration, as well as an influx of illegal economic migrants.

Economy

Economic activities within the riparian countries include livestock farming, irrigation, mining, industrial operations, forestry, tourism and eco-tourism, and game farming. Persistent droughts, extreme floods, and lack of employment are responsible for the illegal migration of people, particularly from Zimbabwe and Mozambique, into South Africa. Rain-fed subsistence farming remains a major farming activity for most basin communities.

Poverty

Poverty[3] in the basin averages 52 per cent (FAO 2004; SARDC/IMERCSA/ZERO 2002), and is a result of many factors, including:

- The indigenous population being forced historically onto barren unproductive land in most of the Limpopo River Basin riparian countries;
- HIV/AIDS killing parents, with the productive generation leaving behind children unable to fend for themselves;
- Persistent droughts and periodic floods;
- Limited or no agricultural inputs; and
- Infertile soils.

Water uses and water demands

The Limpopo River does not have any constructed dams. Major dams, located on its various tributaries, were built mainly for irrigation, domestic and industrial water supply, hydropower generation, as well as flood mitigation structures. South Africa, the main user of the river, and the region's largest irrigator (FAO 2004), is economically dependent on the river, with its water demands continuing to increase. The Limpopo River and its tributaries have been fully developed have been fully developed in Zimbabwe. The water use status on a country basis is as follows:

[3] Defined as living below a certain income or income-poverty threshold, but has many dimensions (IFAD 2001).

Botswana relies on groundwater as the main water source for all demand sectors of the economy. About 50 per cent of its domestic water supply also comes from groundwater. Rapid population and economic growth has led Botswana into a water supply deficit, calling for a change in water development strategies from using groundwater sources to the development and use of dams (LBPTC 2001). Urban and industrial drinking water supply is the largest, fastest growing sector of water use in the Botswana part of the Limpopo Basin. The increased demand for potable water between 1990 and 2020 is estimated to be close to 100 million m^3 (CSIR 2003). The current annual use is estimated to be about 65 million m^3.

In Mozambique, the Chokwe Irrigation Scheme is the major water user, with an annual abstraction volume of about 846 million m^3 (Boroto and Görgens 1999; FAO 2004). The Massingir Dam is the largest dam in the basin, with a storage capacity of 2,256 million m^3, and an annual discharge of 1,800 million m^3 (CSIR 2003; Ashton et al. 2001). The main purpose of the dam is to provide irrigation water, with groundwater being used primarily for domestic water supplies.

The available surface water resources in South Africa have been fully utilized, with a current estimated water deficit of about 600 million m^3 per year. Groundwater resources account for about 350 million m^3 per year, reducing the overall water deficit to about 250 million m^3 per year (GOSA-DWAF 2003a; CSIR 2003).

There are 2,168 dams on the Zimbabwean part of the Limpopo River Basin. The total capacity of the dams has fallen by about 29 million m^3 in the last three years, as a result of siltation. Currently, almost 99 per cent of the total MAR is already being harnessed and stored (GOZ-MRRWD-DWD 1984).

Water-related conflicts

The water deficit currently experienced in the basin is a recipe for possible future conflicts if the existing water resources are not managed efficiently and effectively. Mozambique, for example, is already experiencing water shortages as a result of upstream abstractions by neighbouring countries (FAO 2004).

Land tenure

Land tenure reform has taken different forms in the four countries, reflecting their socio-economic, political and historical background. In Zimbabwe and South Africa, where skewed land distribution existed along racial lines, tenure reform was combined with land redistribution and resettlement. In Mozambique, community land rights were recognized with a possibility of group registration. In Botswana, the decentralized Land Board system has provided an adaptable legal framework for customary land tenure reform (FAO 2004; Adams et al. 1999).

2.2.3 Management

Institutional and legislative frameworks

Varied institutional and legislative arrangements occur within the 4 Limpopo River Basin riparian countries. New legislation, policies and institutions were recently established, coincident with reforms in both the water and land sectors. Water resources management in all the riparian countries is the custodian of the national governments, represented by their appropriate ministries and departments and in certain cases by parastatals, (e.g., Zimbabwe National Water Authority

(ZINWA)). Zimbabwe and South Africa promulgated their new Water Acts in 1998, and a new water act is being proposed in Botswana. In Mozambique, the 1991 Water Law may have to be amended to accommodate IWRM (Integrated Water Resources Management) principles.

Inter-basin water transfers in the Limpopo River Basin are meant to be regulated by protocols on shared watercourse systems, such as the SADC Protocol on Shared Water Course Systems, which came into force in 1998 (revised in 2003) (SADC 1998; 2003). The introduction of proper water management demand systems could postpone future water transfer schemes and over-abstraction from international rivers. The protocol fails to incorporate water demand management, however, as an explicit strategy. Notwithstanding this omission, the agreement supports the requirement that national water resources be used as efficiently as possible, prior to international abstractions (IUCN 1999). Even though the Limpopo River Basin lacks a comprehensive treaty, the 4 riparian countries expressed a firm commitment to cooperate through the Limpopo Basin Permanent Technical Committee (LBPTC), established in Harare in 1986 (SADC 1998; FAO 2004). Proceedings are currently underway to elevate the status of the LBPTC to the Limpopo Basin Commission (LIMCOM).

Data availability standardization and monitoring

Meteorological, hydrological and hydrogeological monitoring varies among the Limpopo River Basin riparian countries (CSIR 2003; FAO 2004). Meteorological and hydrological monitoring is given precedence over hydrogeological monitoring. Thus, data on the latter is sparse, except for Botswana and South Africa, which have established monitoring networks for certain aquifers. Water resources databases in all 4 riparian countries are at various stages of establishment and management. In Botswana and South Africa, the national groundwater databases are fairly well-developed. In Zimbabwe, the surface water database is more established, compared to the groundwater database. In Mozambique, the databases need further development.

Information collection, archiving, collation, analysis and interpretation also vary in the Limpopo Basin riparian countries. Information-sharing is limited, being mostly obtained through research or investigation projects, or bi-lateral or multi-lateral groupings. The sharing of information improves the overall understanding among the 4 riparian countries of what is happening in the basin, and how to best mitigate any negative impacts.

2.2.4 Key issues, adaptation and mitigation

For all the key issues identified, the paramount adaptation and mitigation options relate to intensive extension work, which involves community training and education.

Physiography

Climate vulnerability

The Limpopo Basin is subject to extreme climatic conditions from droughts to severe floods.

Adaptation and mitigation

There is a need:

- To develop an early warning system for both impending droughts and floods. National governments have their own Civil Protection Units, which are more reactive than pro-active agencies. However, SADC has established an Early Warning System that needs further strengthening (SARDC/IMERCSA/ZERO 2002; Ashton et al. 2001);
- To develop and encourage appropriate crops and livestock for the region, and production technologies suitable for drought conditions and poor soils.

Land degradation

Land degradation is a serious problem and major threat to food security in the Limpopo River Basin.

Adaptation and mitigation

There is a need:

- To develop standardized legislation, policies and guidelines for holistic land management, and cropping patterns suited to various soil types;
- To involve communities in ecosystem management; projects that directly benefit the communities should be an integral part of the management process.

Socio-economy

Population growth and urbanization

Increased population growth and urbanization are placing continuing pressures on water supply in regard to demand and pollution. Urban populations also are increasing because of rural to urban migration

Adaptation and mitigation

There is a need:

- For governments to invest more resources in developing and upgrading infrastructure in both urban and rural areas;
- For governments to implement socially-acceptable measures that address high population growth.

HIV/AIDS and water-related diseases

HIV/AIDS and malaria are pandemics that exacerbate the existing poverty. The young and most-productive members of the communities are the most affected group, and orphaned households and poverty are increasing.

Adaptation and mitigation

There is a need:

- For community training, education and peer-to-peer training;
- To increase public awareness through the media;
- To launch anti-retroviral and malaria prevention programmes;
- To provide adequate domestic water resources to ensure general hygiene, in order to minimize disease transmission.

Water availability, use and demand

The basin's water resources are nearly fully developed, being extensively exploited for a variety of uses, including irrigation, energy and domestic use, the latter a rapidly-growing sector. The level of dependence on and development of the river varies between the basin countries. High water demands will soon outstrip the supply, as is already the case in Mozambique and some parts of South Africa, meaning that approaches for addressing these increasing water demands must be devised.

Adaptation and mitigation

There is a need:

- To institute IWRM in all the riparian countries in a coordinated manner, focusing on holistic water use, and balancing all land uses, including plantation forests, efficient irrigation systems, safe drinking-water, water for livestock, and water harvesting;
- For effective water demand management by all riparian countries;
- To carry out inter-basin and intra-basin water transfers (such initiatives are being implemented in the South African part of the Limpopo River Basin);
- To develop groundwater resources and implement conjunctive water schemes;
- To institute pollution monitoring and mitigation measures on the river basin level to ensure no water resources are lost because of pollution.

Land tenure

Lack of land ownership deprives occupants of security and agricultural production loan guarantees, forcing communal farmers to produce crops solely for subsistence. This inevitably results in persistent food insecurity and poverty among communities.

Adaptation and mitigation

There is a need:

- To ensure that farmers have some form of guarantee to land ownership, possibly in the form of long leases or title deeds. South Africa and Zimbabwe are currently instituting land reform programmes to address the land tenure issue.

Management

International protocols

The Limpopo Basin Commission (LIMCOM), which should administer the utilization and management of the basin water resources, is not yet ratified by all riparian countries. This commission is vital for the sustainable development, utilization and management of the basin's water resources. Issues relating to land management must be addressed by the riparian countries.

Adaptation and mitigation

There is a need:

- To expedite ratification and establishment of the LIMCOM;
- To address land management through developing basin policies.

Data availability, standardization and monitoring

Monitoring and database development are fragmented within the riparian countries, and information sharing is limited.

Adaptation and mitigation

There is a need:

- To establish standardized monitoring procedures and database development to ensure effective information collection, sharing and utilization. This can be done through the LIMCOM once it is fully established, or possibly other fora.

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2.3 OKAVANGO RIVER BASIN

The Okavango River Basin, including the Okavango Delta, covers an area of about 725,000 km^2 (279,924 mi^2) (Figure 2.3-1). The active drainage[4] part of the basin is about 200,000 km^2, (77,220 mi^2), covering parts of Angola (77 per cent), Namibia (5 per cent) and Botswana (18 per cent).

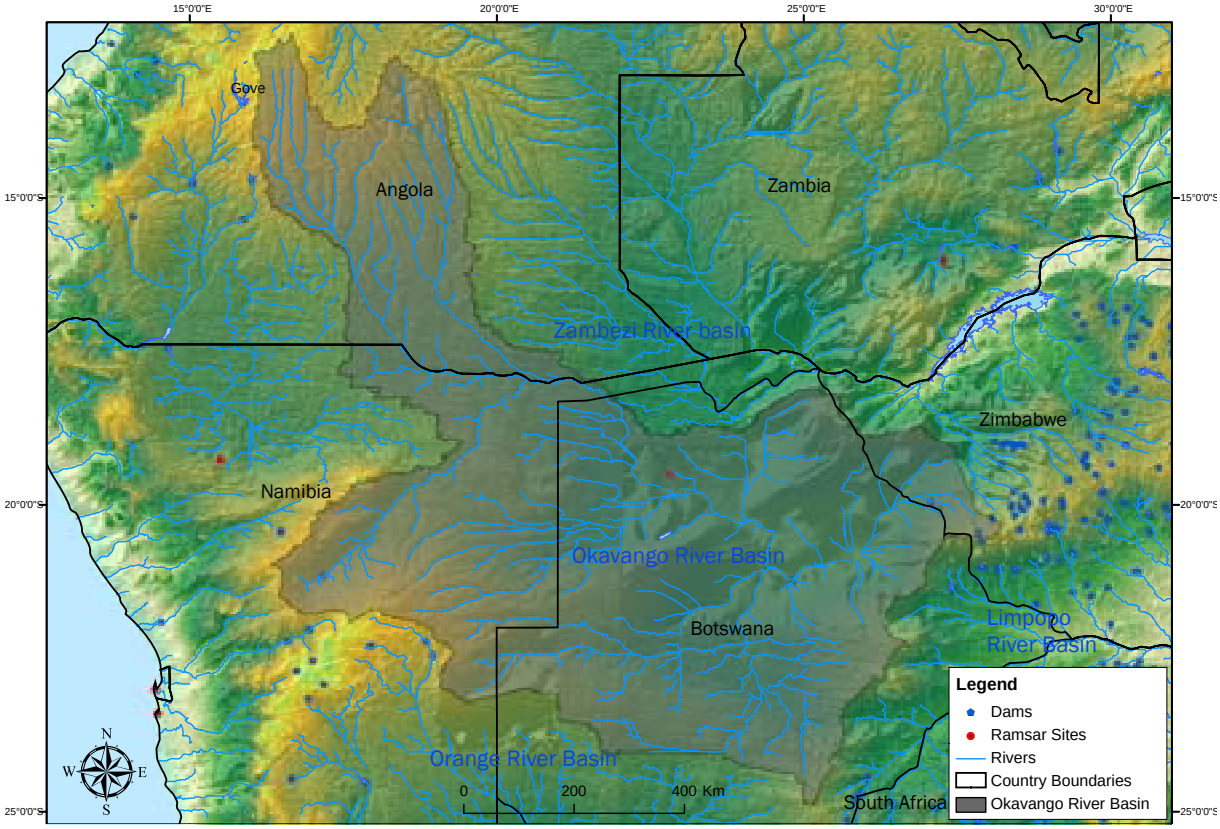

Figure 2.3-1: Okavango River Basin

The Okavango River Basin changes from a hilly upper catchment in southern Angola, above 1,500 m (4,921 ft) amsl, into low, flat land centred around Maun (Botswana) at an altitude of about 940 m (3,117 ft). There is a dense network of tributaries in the hilly northwest part of the catchment, where

[4] Area where there is surface runoff that contributes towards stream flow

bedrock is exposed and the mantle of Kalahari sand is thin. After draining this area, where much of the river's water is obtained, tributaries are spread far apart on a flatter landscape. River gradients become gentler downstream and, in Botswana, the river spreads out into the shallow depression of the Delta (Mendelsohn and Obeid 2004). The main characteristics of the active portion of the drainage part of the basin are summarized in Box 2.3-1.

2.3.1 Physiography

Climate

The Okavango River runs from a well-watered, humid environment in southern Angola, into progressively drier terrain with a semi-arid climate (Mendelsohn and Obeid 2004). The annual average rainfall in the upper catchment is over 1,200 mm (47 in), whereas it is only 450 mm (18 in) in Maun. The potential evaporation at Maun is more than six times greater than the precipitation, intensifying the dryness of the area.

Box 2.3-1: Main characteristics of active drainage part of Okavango River Basin

Basin		**Water Use**	
Surface area:	200,000 km^2 (77,220 mi^2)	Agriculture	Increasing
MAP:	1,200– 470 mm.yr-1 (47–18 in.yr^{1})	Domestic	
		Hydropower (not yet implemented)	
Demography			
Population:	0.6 million		
Density:	0 -100 persons.km^{-2} (0-259 persons.mi^{-2})		
Water Resources			
River length:	2,000 km (1,243 mi)	Biophysical vulnerability:	
MAR:	9.4 million m^3.yr^{1}	Rainfall variability	
		Sediment supply	
Major Dams		Socioeconomic vulnerability:	
None		High rate of HIV infection in Namibia and Botswana	
Major Aquifers:			
Shallow Kalahari bed aquifers			
Deeper bedrock aquifers			

Source: Mendelsohn & el Obeid (2004); OKACOM (1999)

Ecosystems

The Okavango Delta is the largest Ramsar site in the world, occupying about 4 per cent of the basin. It is a dynamic system, changing seasonally with the swell and ebb of water, as well as over the longer term, with water flows switching between channels. These changes are part of the process of self-renewal, essential to the functioning of the whole system (Tarr 1998). The ecological richness of the Okavango Swamps depends largely on the nutrient-poor water that promotes the growth of papyrus, and the supply of sandy sediment.

© Hans Beekman

The Okavango Delta
A World Heritage site

Differences in land cover from northwest to southeast are mainly due to the changing rainfall pattern. Grasslands, savannah and shrubland cover 91 per cent of the basin, whereas forests cover only 2 per cent (WRI 2003). The remainder of the basin is covered by woodland, including Brachystegia, Mopane and Acacia. Papyrus (Cyperus papyrus) dominates the deepest waters, forming margins to the major channels of the Okavango Delta.

Hydrology

Approximately 55 per cent of the total flow of the Okavango River is down the Okavango/Cubango and its tributaries, with the Cuito River and its tributaries providing the remaining 45 per cent. Namibia contributes no runoff water to the river, simply flowing along the country's border with Angola in this section, crossing the narrow Caprivi Strip, and continuing into Botswana. Although Botswana also contributes no runoff water to the system, direct rainfall onto the panhandle and delta contributes about one-quarter of the water in the delta itself.

Hydrogeology

The main types of groundwater within the Okavango River Basin are shallow aquifers associated with the Kalahari sediments, and deeper bedrock aquifers (Pallett 1997). Groundwater in the Kalahari sediments is complex because of variations in the sediment type and grain size. Deltaic sediments underlying most of the modern delta area have shallow aquifers with freshwater, and a transition to brackish and saline water at greater depths of 5-20 m (16-66 ft). Aquifers with varying groundwater capacity are found in the sediments beyond the limits of the Delta aquifers. Perched aquifers are common. Fractured aquifers in bedrock are important in the areas without Kalahari aquifers. Their capacity varies, depending on the degree of fracturing and weathering of the bedrock.

2.3.2 Socio-economy

Demography

The total population of the active drainage portion of the Okavango River Basin is approximately 600,000 people, with the distribution highlighted in Table 2.3-1 (Mendelsohn and Obeid 2004). The majority of people in the Namibian part of the basin are recent immigrants from Angola, or are the children of immigrants.

There are striking differences in settlement patterns across the basin. About 52 per cent is not populated, while about 30 per cent of the population resides in the 4 main towns of Menongue, Cuito Cuanavale, Rundu and Maun (Mendelsohn and Obeid 2004). The proportion living in urban areas is highest in Botswana, and lowest in Angola.

Table 2.3-1: Population statistics for Okavango River Basin

Country	Total population	Percent of basin population	Rural population	Urban population	Towns
Angola	350,000	58.2	300,000	50,000	Menongue, Cuito, Cuanavale
Namibia	163,000	27.1	121,000	42,000	Rundu
Botswana	88,000	14.6	44,000	44,000	Maun
Total	601,000	100.0	465,000	136,000	

The highest population concentrations are in the northwest part of the basin between the towns of Huambo and Kuito (which lie just outside the basin boundaries). There are many other villages and towns in Angola in which the population is concentrated. This is due partly to a government programme during the 1960s intended to control and concentrate people in centres in which social services could be more effectively provided.

The area immediately south of the river in Namibia is also densely populated. This is an area of relatively rich resources, compared to those further from the river and those in the dry parts of Namibia, and because of the previously-mentioned immigration from Angola. The population is concentrated in towns and large villages in Botswana, with areas outside these settlements being sparsely settled.

The Angolan civil war caused a large internal and external displacement of people. Both the Namibian and the Botswana components of the Okavango River Basin population have increased rapidly over the last century. From 1961 to 2001, Kavango's population grew by an average of 5.2 per cent per annum, largely due to the immigration of people fleeing the civil war in Angola and seeking economic opportunities in areas where Namibia's infrastructure and services are superior (Mendelsohn and Obeid 2003), being a major reason for the population concentration along the south bank.

HIV/AIDS and water-related diseases

The most important diseases in the basin are malaria, HIV/AIDS, acute respiratory infections, diarrhoea, scabies, TB, malnutrition and bilharzia (Mendelsohn and Obeid 2004). Namibia and Botswana are among the countries with the highest HIV infection in the world. Of the 250,000 people within 20 km (12.4 mi) of the Okavango River and Delta, it is estimated that at least 30,000 have HIV. Most deaths occur among people aged 25–40 years and who are often the most economically active. In Angola, the disease has not reached the epidemic levels of Namibia and Botswana. Nevertheless, the combination of inadequate and contaminated water, poor sanitation, and rapid urbanization, has created environments in Angola conducive to a high overall risk of disease.

Economy

Agricultural potential is extremely poor in most areas of the Kalahari sands. Rural life is difficult, with large numbers of people having moved to the better economic activities and social services offered in towns. As a result, urban settlements in the basin have increased rapidly in recent years. The basin has a wide variety of wildlife and fish that benefit its inhabitants.

Water-related conflicts

A lack of development along the Okavango River has allowed it to remain comparatively pristine. This absence of development is due to several factors, including: (i) the basin being located far from economic and political centres in Angola, Namibia and Botswana; (ii) a lack of mineral resources in the basin; (iii) relatively fewer people living there, compared to populations elsewhere; (iv) large areas were designated as traditional and tribal lands and, therefore, relatively neglected; and (v) Angola being embroiled in civil war between 1961 and 2002. Nevertheless, any future major water abstraction(s) from the Okavango River by either Angola or Nambia will have serious implications on the delta, increasing the potential for water-related conflicts.

2.3.3 Management

Institutional and legislative frameworks

The highest-level over-arching institutional body for the Okavango is the Permanent Okavango River Basin Water Commission (OKACOM), established by the 3 riparian countries in 1994. Three OKACOM commissioners are appointed by cabinet, being assisted by three senior technical staff from each country that serve on the Okavango Basin Steering Committee (OBSC). Steps are being taken to establish a permanent secretariat for the Commission.

Water sector reforms in all 3 riparian countries have recently resulted in the review and revision of national water policies and legislation. An example is initiation of the National Water Resources Management Review in Namibia in 1998, the subsequent adoption of a new National Water Policy in 2000, and the Water Resources Management Act in 2004 (Bethune 2004; NNF 2004). The opportunity was taken in all 3 countries to incorporate international water management concepts (e.g., Integrated Water Resources Management; Water Demand Management; Polluter-Pays-Principle; Environmental Flow Requirements; basin-wide approach to water resources management). Stakeholder participation is promoted, with recognition given to national obligations regarding shared waters. All 3 countries are signatories of the Ramsar Conventions, and both Namibia and Botswana have recently drafted their National Wetland Policies (Bethune 2004; NNF 2004).

The current challenge is to build on this sound policy and legislative framework, to draft guidelines and enabling regulations, and to implement activities to promote environmentally-sound management, sustainable development, and equitable utilization of shared watercourses.

Data availability, standardization and monitoring

While a considerable quantity of information is available on the basin as a whole, there is much more data available for the delta because of work undertaken over the years by the Harry Oppenheimer Okavango Research Centre (HOORC) in Maun, and a variety of associated research projects focused on the delta. Much less is known about the Angolan catchment, by comparison, mainly because of a lack of interest on this portion of the basin, the civil war occurring there, and the difficulties associated with working in this region. A relatively large body of information has been synthesized for the Namibia Kavango region between the Angolan catchment and the delta (McCarthy 1992).

Two major GIS and statistical databases (RAISON; Okavango Delta Information System (ODIS)) have been developed. Little effort has been made, however, to standardize data collection techniques and parameters across the basin.

In regard to monitoring, the Departments of Water Affairs in Namibia and Botswana maintain several river flow-gauging stations. HOORC also is carrying out hydro(geo)logical assessments, including monitoring in the Okavango Delta.

2.3.4 Key Issues, adaptation and mitigation

The Okavango River provides humanity with both environmental goods and services. The goods include such products as water, fish, timber and reeds, while services or functions include flood attenuation, water purification, and nutrient transport. The Okavango River Basin also supports a

growing number of people, many of whom rely on the water resources of the river to help meet their basic needs of water, food and shelter. Their livelihoods also are partly dependent on essential wetland ecosystem functions (e.g., flood retention; water purification; replenishment of soil nutrients). This dependence on the water and wetland resources and services makes many people along the Okavango River vulnerable to environmental change, mostly the poor.

Physiography

Climate variability and change

The Okavango River Basin is vulnerable to climate variability. Rainfall, particularly in the southern half of the basin is already highly variable both in time and space. Thus, climate change is expected to exacerbate the rainfall variability and the severity of droughts and flooding (MET 2002).

Adaptation and mitigation

There is a need:

- To strengthen drought and flood early warning systems;
- To assess and develop groundwater resources;
- To institute water demand management.

Okavango ecosystem

The Okavango River and its associated floodplains provide a wide range of natural resources that support local communities, and a rich diversity of plants and animals. Both the availability and quality of the water resources can be impacted by increased rainfall variability, changes attributed to increasing exploitation of natural resources, ongoing habitat destruction, and the proposed developments that can alter the timing, duration or quantity of flows, thereby affecting the productivity and diversity of this vulnerable ecosystem (Bethune 1994). Deforestation, overgrazing, erosion, and cultivation in marginal soils all contribute to habitat destruction, thereby increasing desertification along the Okavango River, particularly in Namibia and the panhandle section of the river in Botswana (McCarthy 1992). Interrupting the supply of sandy sediment into the Okavango Delta would have a profound effect on the ecological functioning of the system (Nampower 2004).

Adaptation and mitigation

There is a need:

- To monitor activities that adversely impact the ecosystem;
- For community education, training and awareness in land utilization and management;
- To involve communities in ecosystem management projects that directly benefit the communities, as an integral part of management efforts.

Water demands

Demand for water from the river is expected to increase to accommodate agricultural activities and expanding urban centres, some even outside the basin.

Adaptation and mitigation

There is need:
- For water demand management;
- To scale down water resources development projects on the river.

Socio-economy

Population growth and urbanization

Although little is known about population changes in Angola since 1975, the population numbers have increased greatly in the Namibian and Botswana sections of the basin. The population of the Kavango Region in Namibia grew by 5.2 per cent per year from 1961 to 2001, due mainly to immigration from Angola (Mendelsohn and Obeid 2003). As a result, the densely-populated south bank of the river in Namibia has been cleared of much of its natural vegetation and wildlife, except for protected areas (e.g., Muhango National Park).

Adaptation and mitigation

There is need for legislation:
- To combat land degradation;
- For investment in infrastructure development, particularly in urban centres;
- For investments in rural areas (e.g., tourism, agriculture, fishing) to combat rural-to-urban migration.

HIV/AIDS and water related diseases

Namibia and Botswana have the highest level of HIV/AIDS infections in the world. Malaria also is a major killer, and diarrhoea and bilharzia are among the most common ailments (Mendelsohn and Obeid 2004).

Adaptation and mitigation

There is a need:
- For anti-retroviral and anti-malarial programmes;
- For community education, training and awareness.

Water-related conflicts

Development of the Okavango River will inevitably result in conflict with downstream water users.

Adaptation and mitigation

There is a need:
- To strengthen the existing institutions and legislation (e.g., OKACOM) so that they can deal with potential areas of conflict;
- To develop regulations on development and management of basin water resources.

Management

Institutional and legislative frameworks

Institutional and legislative frameworks exist, and are being strengthened. Regulations for the holistic development and management of the basin's natural resources, however, are lacking.

Adaptation and mitigation

There is a need:

- For regulations for development and management of the basin's natural resources;
- For institutional capacity-building.

Data availability, standardization and monitoring

Data is lacking on the Angola portion of the basin. Botswana and Namibia have satisfactory data. Monitoring, however, is not uniform throughout the basin.

Adaptation and mitigation

There is a need:

- To establish monitoring networks in Angola, and to strengthen and expand existing ones in Namibia and Botswana;
- To standardize data collection and reporting;
- For database development and management.

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2.4 ORANGE RIVER BASIN

The Orange River is the main river in the basin, originating in the Lesotho Highlands in the east, and draining into the Atlantic Ocean in the west. The Orange River Basin is highly developed, with many dams and transfer schemes. About 60 per cent of the ~1,000,000 km^2 (386,102 mi^2) area of the Orange River Basin lies in South Africa, with the remainder being in Botswana (13 per cent), Namibia (25 per cent) and Lesotho (2 per cent), which it completely encapsulates (Figure 2.4-1).

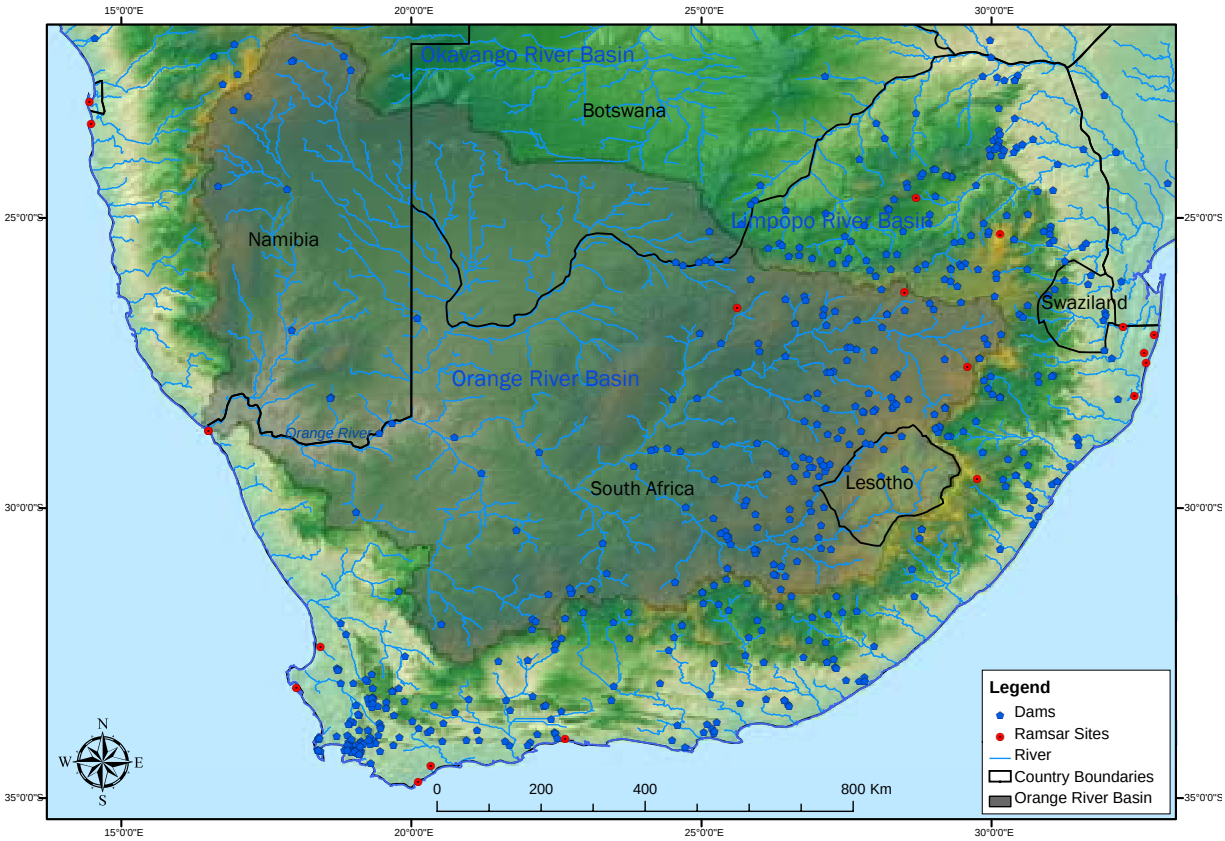

Figure 2.4-1: Orange River Basin

Although Botswana and Namibia are part of the basin, their roles in its management are less conspicuous, due to its remoteness and sparse population. Box 2.4-1 summarizes the main basin characteristics.

2.4.1 Physiography

Climate

The mean annual rainfall for the basin is about 400 mm (15.7 in), exhibiting a high degree of variability from approximately 2,000 mm (78.7 in) in Lesotho to about 50 mm (2 in) at the mouth of the Orange River. The potential evaporation is equally variable, ranging from 1,200 mm (47.2 in) per year in Lesotho, to 3,500 mm (139 in) per year at the rivermouth.

Box 2.4-1: Main characteristics of Orange River Basin

Basin

Surface area:	1,000,000 km^2 (386,102 mi^2)
MAP:	50–1,500 mm.yr^{-1} (2-59 in.yr^{-1})

Demography

Population:	11 million
Density:	12 persons.km^{-2} (31 persons.mi^{-2})

Water Resources

River length:	2,300 km
MAR:	11,500 million m^3.yr^{-1}

Major Dams

Gariep	5,675 million m^3
Vanderkloof	3,237 million m^3
Sterkfontein	2,617 million m^3
Vaal	2,122 million m^3
Katse	1,950 million m^3
Total dam storage:	20,412 million m^3

Major Aquifers: sedimentary

Water Use

Agriculture
Domestic
Industry
Mining
Hydropower

Increasing

Vulnerability

Climate variability and change
Pollution
Poverty

Source: Pallett (1997); Hirji et al. (2002)

Ecosystems

Among the more valued natural resources in the basin is a transboundary Ramsar site wetland at the mouth of the Orange River (Figure 2.4-1). Important nature conservation areas include the Kgalagadi Transfrontier Park, Ai-Ais-Richtersveld Transfrontier Park, and Augrabies Falls Nature Reserve. A review of biodiversity information by Revenga et al. (2000) reported 24 fish species being found in the basin, with 7 species being endemic, 2 of which are threatened with extinction. Two endemic bird species also exist in the basin.

The land cover of the river basin reflects the large variation in precipitation and change in elevation that characterizes this region. The largest part of the basin is (semi) arid, limiting agricultural activity to livestock husbandry. Analysis of Landsat imagery indicates that grasslands and shrublands dominate the land cover.

Hydrology

A wealth of information from the South African part of the Orange River Basin is available on surface water resources, both digitally and in various maps, books and data volumes (down to quarternary catchment scale) (Midgley et al. 1994). The data and map series span 70 years of monitoring (1920-1990). Valuable information also exists in Schulze's 1997 Atlas of agrohydrology and climatology.

Because of large-scale infrastructural development (dams, etc.) in the basin, only about half of the annual runoff of 11,000 million m^3 reaches the Orange River estuary in the west. Runoff extremes have been recorded, ranging from 26,000 million $m^3.yr^{-1}$, to as little as 1,100 $m^3.yr^{-1}$, attributed to climatic variations (Conley and Van Niekerk 1998). There are several dams and water transfer schemes, including:

- Orange River Project -- transfers water from the Caledon and Orange Rivers to the Modder and Riet Rivers of the Eastern Cape;
- Tugela–Vaal Water Project -- transfers water from the Tugela River into the Vaal River to meet the high water demands in the large industrial and population centres of South Africa's Gauteng Province;
- Orange-Fish tunnel Project -- Supplements flow of the Fish and Sundays Rivers of the Eastern Cape (Pallett 1997);
- Lesotho Highland Water Scheme -- transfers water from the headwaters of the Orange River to the Vaal River.

The surface water resources of the Orange River Basin are almost fully developed. The completion of the Mohale Dam in Lesotho will probably be the last large-scale water resources project in the basin. The large number of dams and transfer schemes in the Orange River Basin control river flows, and mitigate the occurrence of floods and the effects of drought. Climate change, however, may result in increased precipitation variability and, therefore, an increased frequency in floods and drought events.

Hydrogeology

The geology of the Orange River Basin is dominated by consolidated sedimentary rocks of the Karoo succession, volcanic extrusives of the Lesotho Highlands, dolomite successions, and Kalahari sand cover. Of these formations, only the Kalahari sands form primary aquifers. Groundwater occurs mainly in fractured rock. Hydrogeological information for the South African part of the Orange River Basin can be obtained from Vegter (1995; 2001).

Groundwater occurrence is controlled by:

- Dolerite contact zones within the Karoo sediments -- Water yields vary, but are generally less than 4 $m^3.h^{-1}$. The value of this type of aquifer is that it occurs in the semi-arid interior of the region in which few alternative water sources are available.
- Cavities in Karstic dolomite and limestone deposits -- These caverns are traversed by veins of dolerites and syenites at some places, dividing them into independent, water-bearing compartments containing considerable volumes of water. Examples of the storage in these compartments are the 730 million m^3 of water in the Oberholzer compartment, and 450 million m^3 in the Venterpost compartment.
- Beds of higher permeability in the Kalahari sand succession -- Groundwater quality is poor, however, in parts of the Kalahari and, in some places, may be too saline for human use.

Groundwater use in the basin is largely to serve agricultural demands (livestock watering), and water supply to rural towns and villages. Groundwater recharge is one of the critical parameters determining water availability and, when related to water use, to determine water scarcity. Figure 2.4-2 shows the mean annual recharge (mm) for the Orange River Basin, the map being a compilation

of the Vegter (1995) provisional recharge map of South Africa, and the recharge map published in the Botswana National Water Master Plan in 1992 (Department of Water Affairs Botswana 1992; Gabaake 1997). Despite the large number of recharge studies carried out in Botswana and South Africa (Beekman and Xu 2003), more work is needed to produce reliable maps indicating the spatial and temporal variability in recharge at local and regional scales. The recharge must be evaluated in terms of episodic events, particularly in semi-arid areas (e.g., western parts of the basin).

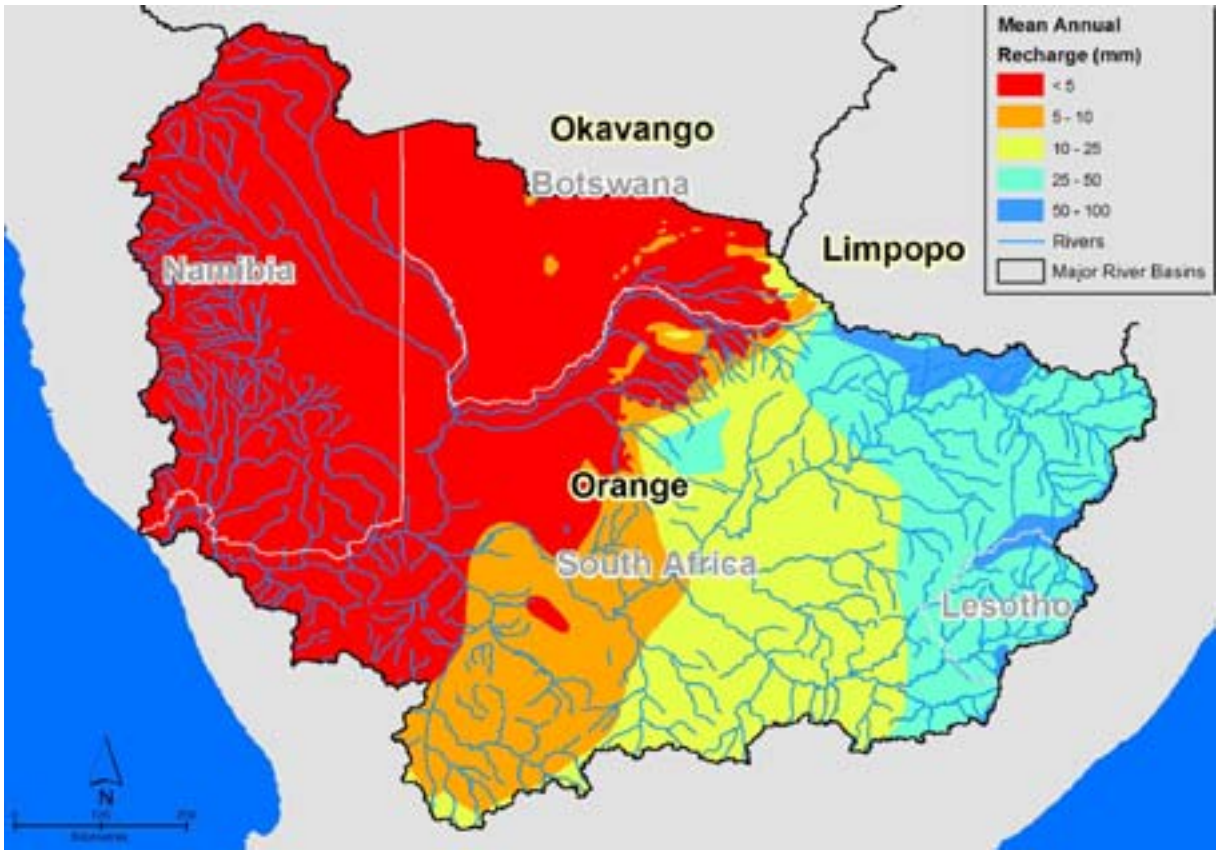

Figure 2.4-2: Mean annual groundwater recharge in Orange River Basin

Source: Department of Water Affairs Botswana 1992; Vegter 1995; Namibian part of the Basin: pers. comm. J. Wrabel – Department of Water Affairs

2.4.2 Socio-economy

Demography

The large industrial metropolitan area in South Africa's southern part of Gauteng Province dominates the population distribution in the Orange River Basin. The apparent lure of opportunity and wealth has resulted in an urban growth rate of 4.6 per cent. The northern and western parts of the basin are sparsely populated. The Orange River Basin is home to over 11,000,000 people, with an average population density of 12 persons.km^{-2} (31 persons.mi^{-2}).

Economy

Economic activity in the Orange River Basin is dominated by industrial and mining activity in the Gauteng Province. The highly-developed economy of this province contributes nearly 40 per cent of South Africa's Gross Domestic Product (GDP). Important economic sectors include mining, manufacturing and tertiary services. Much of the dam construction in the basin is geared toward

meeting the water demands of the Gauteng Province, and has impacted both the structure and functioning of the aquatic ecosytems.

2.4.3 Management

South Africa plays a key role in the management of water resources within the Orange River Basin. South Africa's water resources are governed by the Water Services Act of 1997, and the National Water Act of 1998. The Acts are complementary, providing a framework for sustainable water resources management, while also enabling improved and broadened service delivery. The National Water Act is founded on the principle that all water resources form part of a unitary, interdependent water cycle and, therefore, that all water should be governed in a consistent manner. An IWRM approach, recognizing the connection between water, land, human development and the natural environment, is being implemented in most southern African countries.

An agreement was signed in 2000 by the river basin states of Botswana, Lesotho, Namibia, and South Africa to establish the Orange Senqu River Commission (ORASECOM), aimed at developing the Orange River for the benefit of all respective basin states. The ORASECOM is the first formal body established for managing these shared water resources since the Protocol on Shared Watercourse Systems became an instrument of international water law in the Southern African Development Community. The Commission will develop a comprehensive perspective of the Orange River Basin, study the present and planned future uses of the river system, and determine the requirements for flow monitoring and flood management. It is expected to strengthen regional solidarity, to contribute to peace and harmony, and to enhance socio-economic cooperation. The multilateral Orange-Senqu River Commission will not replace existing bilateral commissions between any of the watercourse states, but rather provide a broader forum for overall consultation and coordination between the watercourse states for sound, integrated water resources management and development in the Orange River Basin.

2.4.4 Key Issues, adaptation and mitigation

The Orange River Basin is one of the driest basins in the southern African region. Over 50 per cent of the area can be classified as hyper-arid to semi-arid, with the aridity increasing toward the west. Because it is already water-stressed, the availability of water resources in the basin is of paramount importance.

Physiography

Climate variability and change

The Orange River Basin is highly vulnerable to climate variability and change. Rainfall throughout the basin is already highly variable, both in time and space. Climate change is expected to exacerbate the rainfall variability and, therefore, the severity of droughts and flooding.

Adaptation and mitigation

There is a need:

- For strengthening drought and flood early warning systems.

Ecosystems

Ecosystems, particularly the wetland at the estuary of the Orange River, are highly dependent on precipitation.

Adaptation and mitigation

There is a need:

- To strengthen land management (institutions, legislation, regulations and enforcement);
- To carry out education and awareness among the basin's human inhabitants, particularly rural communities;
- To create natural resources-based projects that benefit the communities and involve them in managing the basin's natural resources.

Water availability and pollution

The basin's surface water resources are almost fully developed, and additional water demands would be difficult to meet. The vulnerability of water resources to pollution is high, making pollution control critical for conservation of the scarce water resources.

Adaptation and mitigation

There is a need:

- To strengthen water resources management (e.g., water demand management);
- For further assessment and development of groundwater resources;
- For water recycling;
- To strengthen the focus on desalinization;
- For effective pollution control management (e.g., institutions, legislation, regulations, enforcement).

Socio-economy

Population growth and urbanization

The high population growth in the basin's urban areas, particularly in the Gauteng Province, has profound effects on water demand and pollution.

Adaptation and mitigation

There is a need:

- To improve and strengthen rural investments as a way to curb rural to urban migration;
- To develop further urban infrastructure (e.g., upgrading water supply and sewage systems);
- To further institute socially-acceptable measures that discourage rapid population birth rates (e.g., education, awareness, policies).

HIV/AIDS and water-related diseases

HIV/AIDS is a pandemic in the basin, mostly affecting the productive population, with severe effects on the economy and health-delivery systems. Waterborne and water-related diseases (e.g., malaria, typhoid, cholera) are affecting the population, particularly in the rural areas.

Adaptation and mitigation

There is a need:
- To further integrate HIV/AIDS into water and sanitation policy frameworks;
- To implement sustainable water and sanitation projects in rural areas, in order to improve access to water, health and hygiene;
- For enhanced implementation of anti-retroviral and anti-malaria programmes;
- For extensive education, training and awareness.

Water-related conflicts

The demands and competition for water is high in the basin, and will inevitably lead to conflicts between the various water users.

Adaptation and mitigation

There is a need:
- For increased community involvement in water resources use and management programmes;
- To ensure equity of access to water resources.

Management

Institutional and legislative frameworks

Institutional and legislative frameworks exist in the basin. Implementation of water resources management (e.g., IWRM approaches that recognise the linkages between water, land, human development, and the environment) should be accelerated.

Adaptation and mitigation

There is need:
- To strengthen existing institutions and legislations (e.g., ORASECOM; water-related legislation);
- To develop easily-implementable regulations in water resources development and management;
- To further strengthen the capacities of the basin institutions in regard to water resources development and management;
- For accelerated devolution of water resources management to lower levels, through the establishment of appropriate structures.

Data availability standardization and monitoring

Although South Africa has a wealth of available information on surface water resources and groundwater, the other riparian countries have very limited monitoring programmes and, consequently, limited availability of data.

Adaptation and mitigation

There is a need:
- To improve data collection and analyses in the basin riparian countries;
- To harmonize databases, and standardize procedures and data collection methods;

- To strengthen and expand monitoring parameters (including meteorological data) and networks (e.g., chloride deposition; water quality).

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2.5 ZAMBEZI RIVER BASIN

The Zambezi River Basin is the largest river basin in southern Africa (Figure 2.5-1), with a catchment area of about 1,390,000 km^2 (536,682 mi^2), being located south of the Congo River Basin. This river basin includes parts of Angola (18 per cent), Botswana (1 per cent), Malawi (8 per cent), Mozambique (12 per cent), Namibia (1 per cent), Tanzania (2 per cent), Zambia (42 per cent) and Zimbabwe (16 per cent).

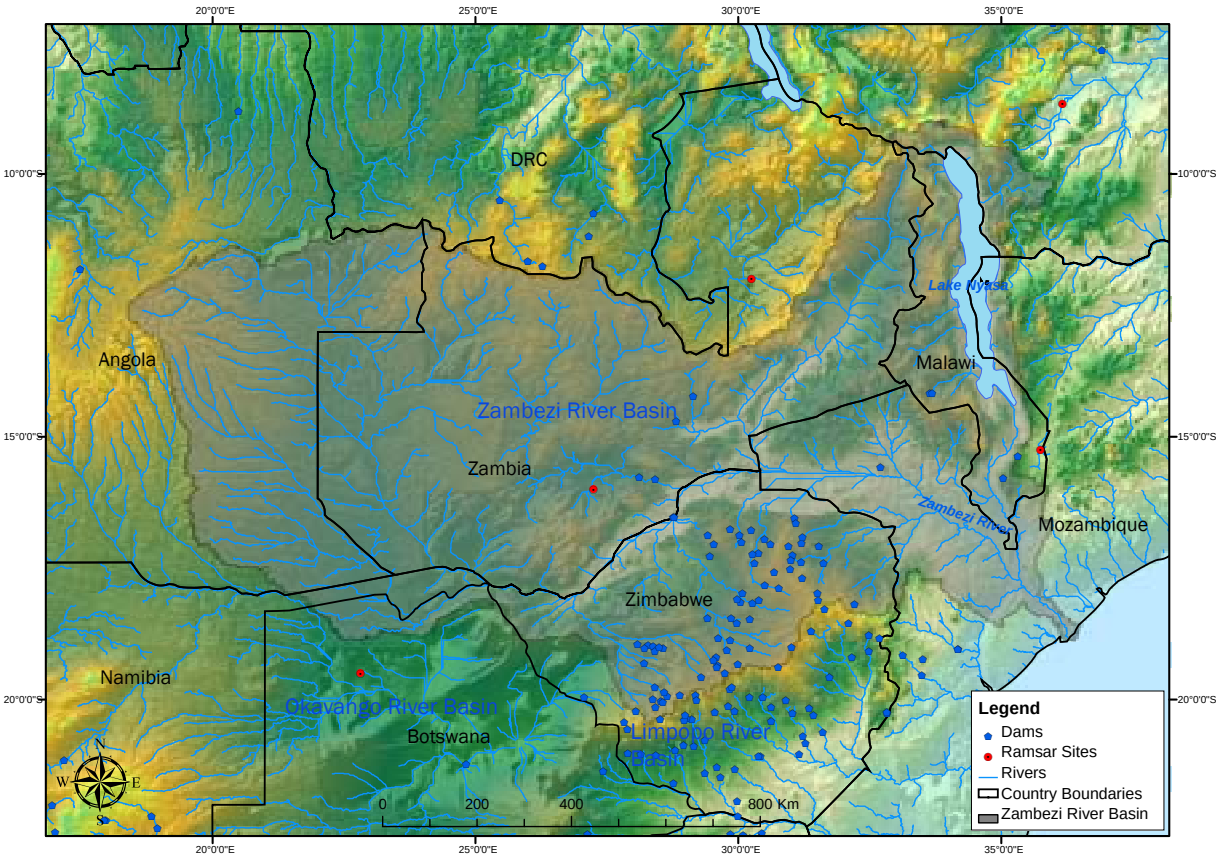

Figure 2.5-1: Zambezi River Basin

The Zambezi River is the major river in the basin, originating in the Angola highlands, and draining into the Indian Ocean. Its landscape features include floodplains, swamps, lakes, and dams. Box 2.5-1 summarizes the main basin characteristics. Over 30 large dams have been built in the basin, with an estimated total capacity of 221,000 million m^3. The existing water resources in the basin are sufficient to meet human demands, although this situation is expected to change with increased population growth and irrigation. The most significant increases in water consumption will likely be for large-scale irrigation projects.

2.5.1 Physiography

Climate

Most rainfall occurs during the summer season between October and April. The annual rainfall in the basin averages 990 mm (39 in) (Savenije and van der Zaag, 1998). The northern parts of the basin (Malawi, Tanzania, northern and western Zambia) receive an average annual rainfall of 1,200 mm (47 in), while the southern and southwestern parts receive 700 mm (28 in). The average annual

actual evapotranspiration is 870 mm (34 in), ranging from 1,000 mm (39 in) in the Luangwa, Shire and lower parts of the basin, to 500 mm (20 in) in the southwestern parts of the basin.

Box 2.5-1: Main characteristics of Zambezi River Basin

Basin

Surface area:	1,388,000 km^2 (535,910 mi^2)
MAP:	700–1,200 mm.yr^{-1} (28-47n.yr^{-1})
Demography	
Population:	25.4 million
Density:	18 persons.km^{-2} (47 persons.mi^{-2})

Water Resources

River length:	2,650 km
MAR:	94,000 million m^3.yr^{-1}

Major Dams

Kariba:	160,000 million m^3
Cahora Bassa:	52,000 million m^3
Itezhitezi:	5,600 million m^3

Total dam storage: 221,245 million m^3

Major Aquifers: crystalline basement

Water Use

Agriculture
Domestic
Industry
Mining
Hydropower

Vulnerability

Climate variability and change
Health
Poverty
Infrastucture

Source: Pallett (1997); Hirji et al. (2002)

Ecosystems

Kafue Flats is the only wetland in the Zambezi River Basin designated as a Ramsar site. National parks, game reserves and safari areas in the basin include the Kameha Park (Angola), Chobe National Park (Botswana), Chobe and Kasane Forest Reserves (Botswana), and Caprivi Game Reserve (Namibia). A total of 122 fish species are found in the basin, with 7 being intruder or alien species (World Resources Institute: http://www.iucn.org/themes/wani/eatlas/index.html). Twenty-five species are listed as endemic, with one being listed as threatened with extinction. There are 3 endemic bird species.

Savannas cover almost half the total land area, partly because of the removal of 43 per cent of the basin's original forest cover (Revenga et al. 2000). Population growth and agricultural development (at least 20 per cent of the basin is under crop cultivation) are expected to result in a continuation of this trend. Evergreen broadleaf forests still cover large parts of the basin (14 per cent), but are largely restricted to the Angolan and northern Zambian parts.

Hydrology

The estimated volume of annual renewable water resources in the Zambezi River is 3,600 m^3.s^{-1}, or 87 mm (3.4 in) of equivalent rainfall, which is just below 10 per cent of the average rainfall in the basin (Savenije and Van der Zaag 1998). Plans for further development of the Zambezi River

and its tributaries focus mainly on: (i) agricultural expansion to secure food supplies; (ii) tapping of hydroelectric energy; and (iii) construction of water transfer schemes to supply large urban centres. An estimated additional 500,000 hectares (1,930 mi^2) of agricultural land could be brought under irrigation by 2030 (Pallett 1997). No major dam projects are planned for the foreseeable future. The Zambezi River and its tributaries are vital to the livelihoods of the populations living in the river basin countries. Over 30 large dams in the Zambezi River Basin serve domestic, industrial and mining water supply, irrigation and power generation. The estimated hydroelectric power potential of the Zambezi Basin is 20,000 megawatts, of which about 4,500 megawatts have been installed to date (Pallett 1997).

Hydrogeology

The basin is underlain predominantly by basement rocks. Groundwater from basement aquifers is generally of good quality, although it may potentially be corrosive (Chilton and Foster 1995). The southern part of the basin is underlain by sedimentary rocks of the Karoo succession, with sandstone layers and dolerite intrusion forming the aquifers. Groundwater abstracted from these rocks tends to be of poorer quality, with higher dissolved solids than that from the hard-rock (basement) aquifers. The water quality usually varies spatially, both over short distances and with depth, often being a reflection of locally- complex groundwater flow regimes.

2.5.2 Socio-economy

Demography

Population data from 1994 indicate there are just over 25 million people living in the Zambezi Basin, which translates into an average population density of 18 $persons.km^{-2}$ (47 $persons.mi^{-2}$). The basin has 10 large urban centres, with the present growth rate of urban centres estimated to be 5 per cent.(Revenga et al. 2000). Major cities in the basin include Harare and Bulawayo in Zimbabwe, and Lusaka in Zambia.

Economy

The main economic activity in the Zambezi Basin is agriculture and mining. The region is largely underdeveloped, with high unemployment and widespread poverty in the basin. Main agricultural products include corn, sorghum and rice, while mining concentrates on copper deposits. Tourism provides a significant part of the government revenues. At the same time, the ecosystems of the Zambezi River offer a wide range of natural resources (including fisheries and forestry) that support local communities.

2.5.3 Management

Zimbabwe has only recently (1998) changed its water legislation and institutional framework, adopting an integrated approach to water resources management (GR Zimbabwe 1998; 2001). Legislative and institutional reform is currently underway in Zambia (GR Zambia 2003).

The riparian states formed and adopted the Zambezi River Basin Action Plan in the mid-1980s (ZACPLAN), to establish mechanisms for common management of the Zambezi River (Shela 1998). Only a few of the 19 envisaged projects of the Action Plan, however, have been financed and implemented to date. One of the projects – establishment of a basin treaty for common management – became redundant with development of the SADC Protocol on Shared Watercourse Systems in

1995. Establishment of a competent basin institution (inside the basin) tasked with coordination and implementation of the ZACPLAN, as well as capacity building, was not pursued. The failures of water resources management programmes, and the slow progress of implementation of the ZACPLAN (Shela 1998), can most likely be attributed to institutional weaknesses, and lack of budget provision.

Bilateral agreements between basin states (e.g., between Zambia and Zimbabwe; Zambezi River Authority), and major water-related projects, must be adequately integrated into the management strategy, and adopted by the basin states.

2.5.4 Key Issues, adaptation and mitigation

The Zambezi River Basin can broadly be considered as have sufficient water resources, although many parts of the basin also have acute water shortages.

Physiography

Climate variability and change

The Zambezi River Basin is vulnerable to climate variability and change, the former manifesting itself through frequent floods and droughts.

Adaptation and mitigation

There is a need

- To strengthen drought and flood early warning systems.

Ecosystems

There is a wide variety of ecosystems in the basin, containing diversified species that need to be conserved and protected. Some increased wildlife populations (e.g., elephants) have a negative impact on the habitats of other species. Further, rainfall variability will affect the functionality of the basin ecosystems.

Adaptation and mitigation

There is a need:

- To strengthen land and wildlife management (e.g., institutions, legislation, regulations, enforcement);
- To enhance education and awareness among the basin population, particularly rural communities;
- To create natural resources-based projects that benefit the communities and involve them in managing the basin's natural resources.

Water availability and pollution

The basin's surface water resources are not yet fully developed, although it has areas in which the water resources are scarce (e.g., catchments of the city of Bulawayo, Zimbabwe). Pollution, particularly from agrochemicals (agriculture) and urban and industrial wastes, remains a major concern. Thus, pollution control is critical for conserving the water resources.

Adaptation and mitigation

There is a need:
- To strengthen water resources management (e.g., water demand management);
- To assess and develop groundwater resources (especially for augmenting urban water supplies and irrigation);
- To recycle water;
- For effective pollution control (e.g., institutions, legislation, regulations, enforcement).

Socio-economy

Population growth and urbanization

High population growth in the basin occurs in urban areas (e.g., Harare and Bulawayo in Zimbabwe; Lusaka in Zambia). Urban population growth has profound effects on water demands, supply and pollution.

Adaptation and mitigation

There is a need:
- To improve and strengthen rural investments as a means of curbing rural-to-urban migration;
- To develop urban infrastructure (e.g., upgrading water supply and sewage systems);
- To institute socially-acceptable measures that discourage rapid population growth and high birth rates (e.g., education, awareness, policies).

HIV/AIDS and water-related diseases

HIV/AIDS mostly affects the productive population, with serious effects on the economy and health-delivery systems. Waterborne and water-related diseases (e.g., malaria, typhoid, cholera) are endemic during the rainy season, affecting mostly the rural population.

Adaptation and mitigation

There is a need:
- To integrate HIV/AIDS prevention into water and sanitation policy frameworks;
- To implement water and sanitation projects in rural areas, in order to improve access to water, and improve health and hygiene conditions;
- To implement anti-retroviral and anti-malaria programmes;
- For extensive education, training and awareness.

Water-related conflicts

Demand and competition for water is high in certain areas of the basin (e.g., Nyamandlovu Aquifer of Zimbabwe, from which the city of Bulawayo and local farmers abstract water from the same aquifer). This will inevitably lead to conflicts between the various water users when the available water resources are exhausted.

Adaptation and mitigation

There is a need:

- To enhance community participation in water resources use and management;
- To ensure equity of access to water resources.

Management

Institutional and legislative frameworks

Implementation of water resources management (IWRM approaches that recognise the inter-linkage between water, land, human development and the environment) is still weak, due in part due to limited institutional capacity. Only Zimbabwe has promulgated a new Water Act (1998), incorporating IWRM principles. The other riparian countries exhibit various stages of water sector reform.

Adaptation and mitigation

There is a need:

- To strengthen existing institutions and legislations (e.g., Zambezi River Authority; various water-related legislation);
- To develop easily-implementable regulations in water resources development and management;
- To build institutional capacity regarding water resources development and management;
- To devolve water resources management to lower levels through establishment of appropriate and well-equipped structures.

Data availability standardization and monitoring

Zimbabwe and Zambia have information on surface water resources, and limited information on groundwater resources. The other riparian countries have very limited monitoring programmes and, consequently, limited data availability.

Adaptation and mitigation

There is a need:

- To improve data collection and analyses in the basin riparian countries, including data on pollution and land degradation;
- To harmonize databases, procedures and data-collection methods;
- To strengthen and expand monitoring parameters (including meteorological data) and networks (e.g., chloride deposition, water quality).

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2.6 BASEMENT AQUIFERS

Basement aquifers constitute approximately 55 per cent of the southern African region. They occur in all 4 major river basins and in various proportions, including Limpopo (~65 per cent); Okavango (<2 per cent); Orange (~25 per cent); and Zambezi (~65 per cent) (Figures 2.1-3; 2.6-1). The topography of most of the areas in which basement aquifers occur varies from flat to hilly terrain. Box 2.6-1 highlights some of the characteristics of the basement aquifers.

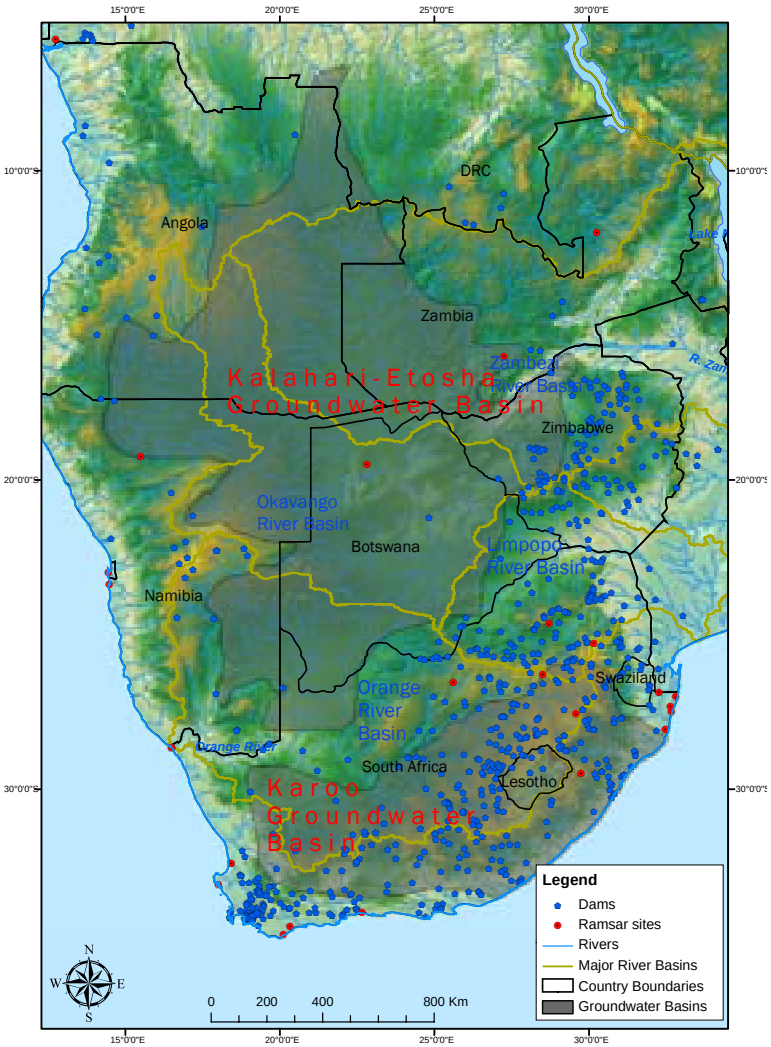

Figure 2.6-1: Basement aquifers

Box 2.6-1: Main characteristics of basement aquifers

Basement Aquifers

Surface area:	~50 per cent of southern Africa
Climate:	Arid to tropical

Demography

Population:	~80 million
Density:	Low to high

Aquifer characteristics

Heterogeneous
Low storage potential
Low permeability

Groundwater occurrence

Saprolite/weathered overburden (humid regions)
Saprock and fractured bedrock (temperature to arid regions)

Water Use

Domestic
Industry
Agriculture

Increasing

Vulnerability

Climate variability and change
Pollution
Over-exploitation

2.6.1 Groundwater occurrence

Basement aquifers are developed within the weathered overburden and fractured bedrock of crystalline rocks of intrusive and metamorphic origin, and mainly of Precambrian age (Wright 1992). They have widespread occurrence in areas of relatively high densities of rural population (Chilton and Foster 1995). Figure 2.6-2 illustrates a conceptual hydrogeological model of a weathered crystalline – basement aquifer. The aquifers are essentially phreatic in character, but may respond to localized abstraction in a semi-confined fashion, if the rest water level occurs in a low permeability horizon (e.g., in a clayey regolith) (Wright 1992).

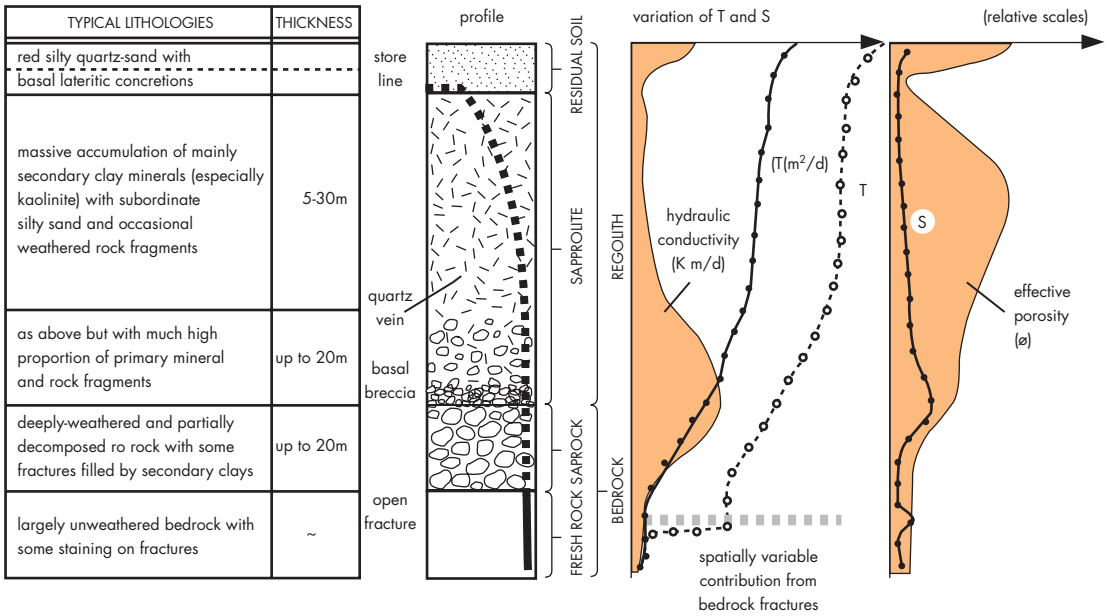

Figure 2.6-2: Conceptual model of weathered crystalline – basement aquifer

Source: Chilton and Foster 1995, redrawn by UNEP

The regolith is the main groundwater storage compartment, with its hydraulic properties largely controlled by such structural features as faults and shear zones. The groundwater table is shallow, and a relatively thick regolith develops, especially under tropical, wet conditions. Fracture permeability, a characteristic of the saprock and fresh bedrock, is dependent on aperture and connectivity, as well as the frequency of the fracture systems (Chilton and Foster 1995).

2.6.2 Groundwater development

Basement aquifers are very important for small-scale water supply, providing water for villages and small towns in areas that often lack alternative sources of perennial water (Wright and Burgess 1992). Their groundwater is sufficiently shallow to allow exploitation at relatively low cost, and with simple technology, appropriate to the low level of economic development (Chilton and Foster 1995).

A direct relation exists between increasing water yields and increasing thickness of the weathered overburden. The average water yield for wells and boreholes in fractured and weathered basement rocks located in humid and sub-humid tropical climatic sub-regions is higher than the average yields for boreholes located in semi-arid to arid climatic regions. The water yields in Zimbabwe, for example, typically range from 0.1-2 $L.s^{-1}$.

Basement aquifers generally have the lowest development potential, being primarily suitable for rural domestic and livestock water supply, with comparatively higher development costs for exploration for larger supplies (after Foster et al., 2000). Main constraints in the development of basement aquifers are summarized by Wright and Burgess (1992), as follows:

- The frequent high failure rate of boreholes (commonly in the range of 10-40 per cent), with higher rates in drier regions, or where the weathered overburden is thin;
- The shallow occurrence and fissure permeability of the bedrock aquifer component, making it susceptible to surface pollutants;
- The low water storage capacity of basement aquifers, which may deplete significantly during sustained drought periods; the recharge also is sensitive to certain land use changes, notably those associated with desertification.

2.6.3 Groundwater management

Key management issues pertinent to basement aquifers (Lovell, 2000; Titus et al., 2002; Pietersen, 2004) include:

- Access to basic water supply;
- Water supply for productive use;
- Reliability of supply (sustainability of groundwater from basement aquifers, particularly during extended drought periods / low storage potential / heterogeneity);
- Inadequate legislative framework (regulation for protection and use of resources);
- Weak institutional arrangements and capacity.

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2.7 COASTAL AREAS

A large proportion of the population lives along the coast (~20 million; Figure 2.7-1). The main economic activities along the coast include tourism, fishing and mining. Most of the coastal population and economic centres are in areas associated with unconsolidated sedimentary deposits because of water accessibility and the relative flatness of the areas. High population growth, urbanization and economic expansion are threatening the sustainability of the natural resources base.

Figure 2.7-1: Coastal areas

Source: CSIR

The climate of the west coast varies from semi-arid to hyper-arid, while that of the east coast is tropical. With the exception of some urban centres along the Namibian and South African west coast, the population distribution tends to mirror the water availability, including Cape Town, Saldanha and Walvis Bay. Although the southern African east coast is better endowed with water resources, its low level of development, and lack of technical, financial, infrastructural and social capital, especially in the rural areas, makes populations in these areas much more vulnerable to the effects of environmental change. Box 2.7-1 summarizes the characteristics of the coastal areas.

Box 2.7-1: Main characteristics of coastal areas

Coastal Areas

Surface area:	400,000 km^2 (154,440 mi^2)
MAP:	50–3,000 mm.y^{-1} (2-118 in.yr^{-1})

Water Use

Domestic
Industry
Mining
Agriculture

Increasing

Demography

Population:	20.1 million
Density:	~50 persons.km^{-2} (~130 persons.km^{-2})

Surface Water Resources	**Major Dams**
Berg River	Voëlvlei, Wemmershoek
Umgeni	Inanda, Albert Falls, Midmar
Save	

Major Groundwater Abstraction Schemes

Omdel Scheme:	8.2 million m^3.yr^{-1}
Kuiseb Wellfields:	4.5 million m^3.yr^{-1}
Atlantis Welfield:	6.2 million m^3.yr^{-1}
Langebaan Road Scheme	1.5 million m^3.yr^{-1}

Major Aquifers:

Cape Flats Aquifer
Langebaan Road Aquifer
Paleo channels of several rivers (e.g., Kuiseb; Koichab; Buffels)
Maputoland Coastal Aquifer
Alluvium deposits along several rivers (e.g., Buffalo; Nondweni; Mfolozi)

2.7.1 Physiography

Climate

The climate of the coastal areas of southern Africa varies widely between its west and east coasts. It ranges from semi-arid to hyper-arid along the west coast. The evaporation is high, exceeding the limited and highly-variable rainfall. The southwestern tip of the continent falls under the influence of seasonal cold fronts. The climate is largely Mediterranean, with the western parts characterized by winter rainfall and hot, dry summers. The climate becomes summer precipitation dominated (November and April) as one moves further to the east. A sub-tropical to tropical climate characterizes the east coast, with high rainfall (e.g., rainfall quantities greater than 3,000 mm.yr^{-1} (118 in.yr^{-1}) have been recorded in Mozambique (UNEP 2002). The mean annual temperatures vary between 19 °C (66 °F) on the Namibian coast and 26°C (79 °F) in northern Mozambique.

Ecosystems

Namibia is one of the driest countries on earth. A distinctive feature of Namibian biodiversity is the high level of endemism among its animal and plant life, much being associated with the arid coastal plains constituting the Namib Desert. The vegetation is generally sparse and low, being adapted to xeric conditions. South Africa ranks as the third most biologically-diverse country in the world (UNEP 2002), largely because of its rich plant diversity. The high floral species diversity characterizes the Cape Floral Region, which occurs on the south-western tip of South Africa. The South African east coast and Mozambique are covered by grasslands and tropical forests. Mangrove forests occur along the coast, and at rivermouths, in northern Kwazulu-Natal Province and Mozambique.

An expanding human population threaten ecosystems of the southern African coastal areas. Population pressures, particularly around urban areas, lead to disorganized land use, and the exploitation of natural resources far above their carrying capacity, resulting in increased soil erosion, mangrove depletion, and loss of biodiversity. The Cape Floral Region is particularly vulnerable because of its high endemism. A particular threat to the Cape flora is the spread of alien vegetation, which also is invading montane and lowland areas. Further, mangroves are under threat in Mozambique (Chemane et al. 1997).

The coastal areas of southern Africa host important bird habitats, including several Ramsar sites.

Hydrology

The rivers draining the southern African coastal area strongly influence the landscape and ecological systems, through processes such as erosion, sedimentation, nutrient transport, and estuary flushing. Modifications of surface water runoff, in the form of impoundments and abstractions, have caused changes to the flows and flood regimes of many rivers and their related estuaries (UNEP 2002). Although the rivers on the southern African east coast are perennial, those on the west coast are largely ephemeral, being important corridors for biological diversity (Barnard 1998). Many of the large population centres of the coastal areas (e.g., Cape Town, Durban, Maputo) rely on surface water (lagoons and lakes), which also provide important habitat for migratory bird species, while also contributing to local economies through fishing and tourism.

The scarcity of water is compounded throughout the region by pollution of surface and groundwater resources. Typical pollutants include industrial effluents, domestic and commercial sewage, acid mine drainage, agricultural runoff, and solid wastes (DEAT 2002).

Hydrogeology

Groundwater is abstracted in the western coastal areas from unconsolidated sediments along river channels (e.g., towns of Henties Bay, Swakopmund, and Walvisbay) (Christelis and Struckmeier, 2001). Groundwater from unconsolidated sediments is abstracted for municipal water supply (domestic and industrial use) and irrigation in the southern coastal areas. The major aquifer systems are: Atlantis, Cape Flats, Langebaan Road; and Sandveld. Because of their often-shallow water tables, these aquifers also sustain ecosystems, including Phreatophytes. Large groundwater abstraction schemes in the eastern coastal area are mostly located in river alluvium (e.g., Buffalo; Nondweni; Mfolozi) (King 2003). Rural communities rely on wells and boreholes for their water supply. These shallow aquifers are vulnerable to pollution (e.g., from pit latrines and animal wastes). Another threat to the sustainability of coastal aquifers is their vulnerability to seawater intrusion, especially in areas where over-exploitation occurs.

2.7.2 Socio-economy

Demography

A number of large cities are located in the southern African coastal areas, including Cape Town, Port Elizabeth, and Durban in South Africa, Maputo and Beira in Mozambique, and Walvis Bay in Namibia. These cities are experiencing rapid population growth (e.g., the annual population growth rate in Cape Town is 2.5 per cent).

HIV/AIDS and water-related diseases

HIV/AIDS, malaria, thyphoid and cholera are prevalent in the urban centres of the coastal areas. These diseases severely impact health delivery services and, indirectly, also economic productivity and limited resources.

Economy

Most of the economic activity of the southern African coastal areas occurs in, and near, the major urban centres (e.g., Cape Town; Durban; Maputo; Walvis Bay). Diamond mining and fishing along the west coast contribute substantially to both the Namibian and South African economies. South Africa has the strongest, most diverse economy of southern Africa, being based primarily on manufacturing, mining, agriculture and financial services. Efforts to accelerate economic growth include encouragement of direct foreign investment, and growth of the tourist industry. The MOZAL aluminium smelter on the outskirts of Maputo, and the exploitation of the Pande gas fields in Inhambane Province, are examples of large industrial developments in Mozambique.

2.7.3 Management

Legislation and institutional frameworks

A number of international agreements exist among the countries of the southern African coastal areas relating to the environment, water resources and their protection. There also are national policies and legal frameworks in each country, aiming to protect the natural environment and water resources. These national legislations tackle broad issues surrounding healthy and unpolluted natural environments, water and sanitation, as well as more specific issues (e.g., exploitation and management of fish and other living resources; mandatory environmental impact assessments; environmental protection from pollution, oil and gas exploration and exploitation; mining activities) (Prochazka, et al. 2005). South Africa promulgated a new Water Law (National Water Act [NWA]) in 1998, which removes private ownership of water, and allows an ecological reserve to be set aside for any water resources. There also is a trend toward stricter water management by local authorities, as well as investigations into the feasibility of desalination and wastewater recycling. Mozambique, Namibia and South Africa have launched integrated coastal zone management (ICZM) initiatives that, among other things, strive to build regional cooperation in research, monitoring and management of coastal resources. Coastal zone management in each of these countries has focused on strengthening local governance and management structures to enable sustainable coastal resources use, and to enhance equity of access.

2.7.4 Key issues, adaptation and mitigation

Physiography

Climate vulnerability

Rural communities, especially those reliant on subsistence agriculture, are particularly vulnerable to water shortages caused by drought. Even where communities rely on hand-dug wells, these may dry out during extended periods of drought. The unsustainable development of coastal resources has progressively increased vulnerability to both the natural dynamics associated with present-day climate variability, and the anticipated impacts of climate change (Klein 2002).

Adaptation and mitigation

There is a need:

- To strengthen the provision of water from constructed boreholes, as a way of increasing community resilience to drought;
- For proper groundwater resources management, to avoid over-exploitation or contamination as a result of inappropriate land-use practices;
- To further cultivate and strengthen closer cooperation between the governments of Mozambique, South Africa and Swaziland, in order to ensure dam releases from South Africa and Swaziland also favour water users in Mozambique (IncoMaputo Agreement 2002).

Ecosystems

Ecosystems of the southern African coastal areas are under threat from an expanding human population. Population pressures, especially around urban centres, leads to disorganized land use, and the exploitation of natural resources beyond their carrying capacity. This has resulted in increased soil erosion, alien plant invasions, mangrove depletion, and biodiversity loss. Mozambique, Namibia and South Africa have launched integrated coastal zone management (ICZM) initiatives that, among other things, strive to build regional cooperation in research, monitoring and management of coastal resources.

Adaptation and mitigation

There is a need:

- To strengthen local governance and management structures to enable sustainable use of coastal resources, and equity of access. Success has been achieved in South Africa through establishment of the 'Working for Water' programme, which aims to clear alien vegetation from catchments, create jobs for rural communities, and educate the public in water conservation.

Socio-economy

Poverty

Poverty has been, and remains, a major cause and consequence of environmental degradation and resource depletion (UNEP 2001).

Adaptation and mitigation

There is a need:

- To ensure that efforts at poverty reduction in the coastal areas coincide with initiatives to enhance food security through expansion of agricultural production
- To strengthen initiatives that focus on reducing activities that cause land degradation, thereby shifting traditional agricultural production to irrigation agriculture.

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Cape Town area

HIV/AIDS and water-related diseases

These diseases have a crippling effect on education and health services, and have destroyed households and affected business productivity. Waterborne diseases (e.g., cholera; typhoid) particularly impact people lacking water supply and sanitation services, and community members with immune system deficiencies.

Adaptation and mitigation

There is a need:

- To increase water supply and sanitation provision, in order to reduce the occurrence of waterborne diseases and mortality among those suffering from HIV/AIDS;
- To provide anti-retroviral drugs to pregnant mothers, and focus education and awareness initiatives on reducing the spread of HIV/AIDS.

Water availability, uses and demands

The scarcity of water is compounded by pollution of surface water and groundwater resources throughout the region. Typical pollutants of South Africa's freshwater environment include industrial effluents, domestic and commercial sewage, acid mine drainage, agricultural runoff, and solid waste (DEAT 2002).

Adaptation and mitigation

There is a need:

- For concerted initiatives to establish water supply alternatives (e.g., seawater desalinization (Ashton 2002); recycling);
- For stricter water management by local authorities (e.g., through water demand management; the City of Cape Town has enjoyed considerable success in reducing water consumption through implementation of water demand management measures (Colvin and Saayman 2005)).

Management

Governance

Sustainable resources management is a prerequisite if natural and social capital is to be exploited in a sustainable manner. It will depend on policy choices enabling effective and accountable governance at all levels, an educated population, and adequate economic growth (Scholes and Briggs 2004). Water stresses in southern Africa have coincided with a growing awareness of water scarcity, and the need to conserve water resources.

Adaptation and mitigation

There is a need:

- To accelerate efforts in Mozambique, Namibia and South Africa to facilitate sustainable resource use, equitable resource access, and poverty reduction;
- To strengthen local level resource governance and management structures.

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2.8 KAROO GROUNDWATER BASINS

The Karoo and Kalahari-Etosha Groundwater Basins are defined as the areas directly underlain by the bedrock formations of the Karoo Supergroup in southern Africa (Figure 2.8-1). They include portions of the Okavango, Zambezi, Congo, Limpopo, and Orange River Basins.

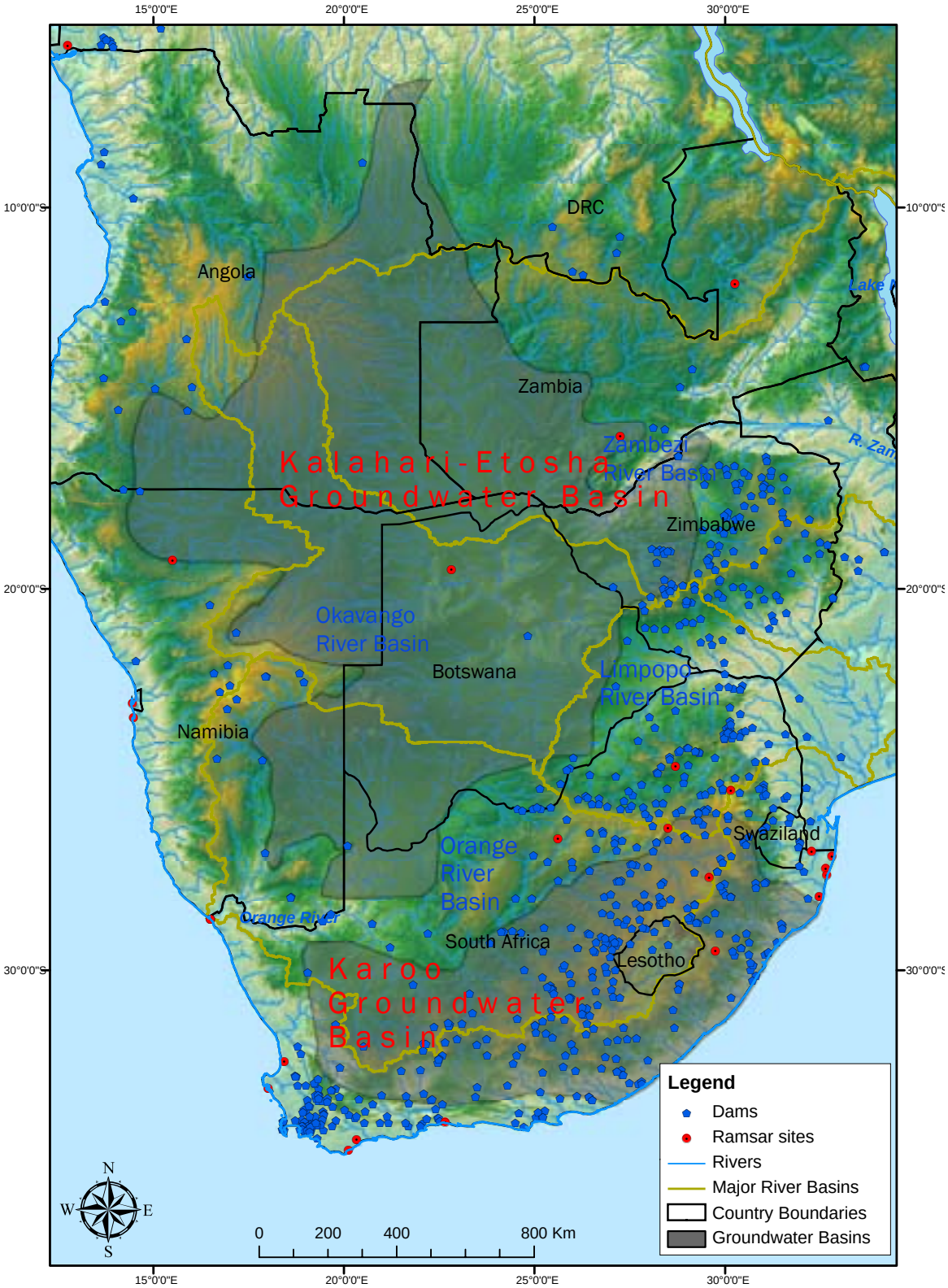

Figure 2.8-1: Karoo and Kalahari-Etosha groundwater basins

2.8.1 Karoo Basin

The Karoo Basin lies within South Africa, and covers all of Lesotho (Figure 2.8-1). Box 2.8-1 summarizes the main characteristics of the basin. The topography is moderate over the central and western areas, becoming mountainous southward and eastward along the escarpment, with elevations ranging from 800 m (2,625 ft) in the west to more than 3,000 m (9,843 ft) in the east, aside from small fringing coastal zones.

Box 2.8-1: Main characteristics of Karoo Groundwater Basin

Basin

Surface area:	630,000 km^2 (243,244 mi^2)
MAP:	50–1,500 mm.yr^{-1} (2-59 in.yr^{-1})

Demography

Population:	9.2 million
Density:	0-150 persons.km^{-2} (0-388 persons.km^{-2})

Surface Water Resources

Main River:	Orange River
	11,500m^3.yr^{-1}

Major Groundwater Abstraction Schemes

Sedimentary aquifers
Volcanic aquifers
Minor alluvial aquifers
Primarily secondary porosity (fractured and dual porosity (fractured/porous)

Recharge: <5-50 mm yr^{-1} (0.2-2in.yr^{-1})

Renewable Resource: Approximately 2.1 x 105 million m^3.yr^{-1}

Water Use

Agriculture
Domestic
Industry
Mining

Increasing

Vulnerability

Increasing aridity to the west
Over-abstraction
Limited aquifer storage
Shallow systems
Pollution

2.8.1.1 Physiography

Climate

Rainfall is maximum, being 1,400 mm.yr^{-1} (55 in.yr^{-1}) to the east, decreasing to the west, with nearly half of the basin being semi-arid (<450 mm.yr^{-1} [<18 in.yr^{-1}]), and more than a quarter being arid (<250 mm.yr^{-1} [<9 in.yr^{-1}]). The majority of the basin is within the summer rainfall zone, other than the coastal area to the southeast, which experiences year-round rainfall conditions.

Hydrogeology

The geology of the Karoo Basin consists of a layered sedimentary fill, which was deposited primarily in a shallow sea surrounded by remnant highlands of Gondwanaland, much in prograding delta and fluvial environments. The last stage was characterized by extensive dolerite intrusion, and the outflow of extensive flood basalts capping the sequence. Structurally, much of the central and northern portions of the basin are primarily flat, lying with minor warping and local faulting. The formations are tightly folded and truncated along the Cape Fold Belt toward the southern margins.

The hydrostratigraphy of the Karoo Basin can be simplified into seven major units (Table 2.8-1).

Table 2.8-1: Hydrostratigraphy of Karoo Basin

Unit	Main aquifer type	Comments
Alluvium; colluvium	Porous	Limited extent; associated with rivers
Dykes; sills; intrusions	Fractured	Aquifers developed in fracturing associated with baked margins
Stormberg basalt	Fractured	Layered flood basalt; low primary porosity
Molteno; Elliot; Clarens	Fractured; porous	Molteno and Clarens are sandstones; Elliot is primarily mudstone
Beaufort	Fractured	Sandstones are generally lenticular; limited in extent
Ecca	Fractured; porous	Often laterally extensive; poorly sorted sandstones present
Dwyka	Fractured	Generally low yielding; non-productive

Although many of the lithostratigraphic units of the Karoo Supergroup are moderately porous, even shales and mudstones (>12 per cent; Woodford and Chevallier 2002), the low permeability often limits borehole water yield. Thus, most productive boreholes are associated with fractured zones, where the permeability is locally enhanced. This is particularly true for aquifers associated with dykes and intrusions. In the fractured aquifers of the Karoo, fractures provide conduits for water flow to the borehole, while aquifer storage is provided by the less-permeable matrix in contact with the fracture system.

Groundwater recharge

Recharge of the consolidated aquifers occurs primarily through preferential pathways from the ground surface to the aquifer matrix (i.e., via fracture zones exposed at the surface), as well as direct infiltration to the matrix through the existing soil or weathering profile. In the relatively shallow, freshwater aquifers exploited in the basin (>100 m [328 ft] depth), the recharge is primarily active, being related to present rainfall conditions. Although rivers in the basin are largely gaining (groundwater discharge zones), locally unconsolidated (alluvium) and alluvial and bedrock composite aquifers can also be significantly recharged through river infiltration. In these cases, the renewable groundwater resource is closely tied to the hydrology, and to the present and planned uses of the surface water resources. In addition, abstraction often increases effective recharge, thereby increasing the renewable groundwater resource. Examples of these aquifer relationships are often observed when major fractured dykes cross a river, with abstraction from nearby boreholes fed largely by induced infiltration from the river.

Due to the inherent heterogeneity in the Karoo Basin, no basin wide recharge studies have been conducted, although numerous studies of particular areas have been carried out (e.g., Xu and Beekman 2003). Regional assessments also have been carried out that cover all of South Africa. The general recharge magnitudes in the basin, considering soil cover conditions, are provided in Table 2.8-2.

Table 2.8-2: Recharge in Karoo Basin (Kirchner et al., 1991).

Soil cover	Recharge (per cent of annual rainfall)
Thick, clayey soils	~ 1 - 2
Thin soil cover	~ 2 - 4
No soil cover	~ 4 - 7

(recharge will be higher in areas associated with rivers and streams)

Another national level assessment of recharge (Vegter 1995) also provides an indication of groundwater recharge in the basin.

Renewable resources

From the broad recharge estimations given in Table 2.8-2, the renewable resources of the Karoo Basin are estimated to be in the order of 2.1 x 10^5 million $m^3.yr^{-1}$, (using an average recharge rate of 35 $mm.yr^{-1}$ [1.4 in/yr^{-1}] across the whole basin). However, the vast majority of the estimated recharge occurs in the eastern third of the basin (east of Lesotho), where estimated recharge rates are above 65 $mm.yr^{-1}$ (2.6 $in.yr^{-1}$) and the renewable resource approximately 1.6 x 10^5 million $m^3.yr^{-1}$, about 75 per cent of the estimate for the whole basin. The western two thirds of the basin receives the remaining 0.5 million $m^3.yr^{-1}$, only approximately 12 $mm.yr^{-1}$ (0.5 $in.yr^{-1}$).

Groundwater development

The aquifers typically developed in most of the Karoo Basin are moderately shallow, up to 150 m (492 ft) depth. Water strikes in many areas start near 20 m (66 ft) depth, with deeper water strikes and water levels toward the west. The water quality is generally good, with EC (electrical conductivity) values generally well within acceptable limits. In some deeper or isolated sandstones within marine shales (i.e. Dwyka Gp), aquifers can have high EC values. The main naturally-occurring constituents affecting quality are fluoride and nitrate (which can also have anthropogenic sources).

Groundwater pollution

The Karoo aquifers, considering the relatively fine-grained and argillaceous nature of the common lithologies, are less vulnerable to contamination. However, aquifers associated with fracture zones extending to the surface (e.g., dykes; intrusions) can be highly vulnerable to pollution in the outcrop areas of the fracturing, since water movement from surface to aquifer can be very rapid.

2.8.1.2 Socio-economy

Demography

The major cities located within the basin are Bloemfontein, East London, Kimberly, Welkom, and Beaufort West. The approximate population within the basin is 9.2 million, with the population density being much less than 55 $persons.km^{-2}$ (142 $persons.mi^{-2}$) over most of the basin, and with areas of more dense population (155 $persons.km^{-2}$ [401 $persons.mi^{-2}$]) to the east. The population density of Lesotho is 71 $persons/km^2$ (184 $persons.mi^{-2}$).

Economy

The vast majority of the basin is located within agricultural and ranching areas, and both rainfed and irrigated agriculture are practised. Approximately 33 per cent of the South African maize production in the basin comes solely from the Orange Free State, more than any other province. Approximately 5 to 10 per cent of the commercial maize is irrigated in South Africa, with nearly 60 per cent of water use in the Orange River Basin consumed by agriculture. Further, considerable areas of subsistence farming are present within the basin, particularly in the eastern portions. Given its semi-arid to arid conditions, much of the western part is used for ranching.

2.8.1.3 Management

Water resources management is undergoing extensive, and far-reaching changes and improvements in South Africa, beginning in the mid-1990s. The institutional, legal and management reforms are based firmly on Integrated Water Resources Management (IWRM) principles, including catchment-based management, a specified minimum level of water supply for all citizens, and equity in water use. A crucial aspect of the new water laws is the specific consideration of water resources, both surface and groundwater, as part of a single unified resource requiring integrated management. The Department of Water Affairs and Forestry (DWAF) completed a draft National Water Resources Strategy (NWRS) in 2004 that lays out the fundamental policy and management strategies for water resources. In addition to catchment-based management, it envisages a transition for DWAF, from its present multiple roles as operator, developer and regulator, to sector leader, policymaker, regulator and monitoring body. These transformations should lead to improved, more locally-appropriate management of groundwater resources in the Karoo Basin. This will be especially important in developing locally-derived and accepted water allocation levels based on more area- specific recharge and resource conditions.

The water sector of Lesotho also has undergone significant restructuring, including development of the Lowlands Water Supply Unit, which has responsibility for water supply development and management in the western lowlands areas of the country, in which more than two-thirds of the population reside. Recent creation of the Environmental Secretariat, with specific responsibilities for water quality and pollution control, also is improving the monitoring and protection of water resources in the country.

2.8.2 Kalahari-Etosha Basin

The Kalahari-Etosha Basin is approximately 1,800,000 km^2 (694,984 mi^2), about three times the size of the Karoo Basin. The basin covers parts of South Africa, Botswana, Namibia, Zimbabwe, Zambia, Angola, and the Democratic Republic of Congo (Figure 2.8-1). Its main characteristics are summarized in Box 2.8-2. The topography is varied, nearly flat over much of the south and southwest of the basin, and moderately hilly in the centre and toward the east and north. Elevations range from 800 m (2,625 ft) amsl in the Zambezi Valley, to more than 1,500 m (4,921 ft) amsl in the highlands to the north in Angola and Zambia.

Box 2.8-2: Characteristics of Kalahari-Etosha groundwater basin

Basin

Surface area:	1,800,000 km^2 (694,984 mi^2)
MAP:	<50–1,500 mm.yr^{-1} (2-6 in.yr^{-1})

Water Use

Agriculture
Domestic
Industry
Mining

Increasing

Demography

Population:	3 million
Density:	0.6 persons.km^{-2} (1.6 persons.mi^{-2}; Botswana, Namibia)
	9 persons.km^{-2} (23 persons.mi^{-2}; Zimbabwe)
	6-14 persons.km^{-2} (16-36 persons.mi^{-2}; Zambia)
	0.7-1.4 persons.km^{-2} (1.8--3.6 persons.mi^{-2}; Angola)

Surface Water Resources

Main Rivers:	Zambezi, Okavango Rivers
MAR:	94,000 million m^3.yr^{-1} (Zambezi)
	10,000 million m^3.yr^{-1} (Okavango)

Vulnerability

Catchment degradation
Loss of wetlands
Pollution (agricultural)

Groundwater Resources

Sedimentary rock aquifers
Unconsolidated aquifers
Volcanic aquifers
Aquifers primarily porous and also fractured

Recharge: 0-25 mm.yr^{-1} (0-1 in.yr^{-1})

Renewable resource: 2,100 million m^3.yr^{-1}

2.8.2.1 Physiography

Climate

Rainfall is extremely variable within the basin, ranging from arid conditions in Namibia, with less than 200 mm.yr^{-1} (8 in.yr^{-1}) northward to the southern Congo Basin, with more than 1,500 mm.yr^{-1} (59 in.yr^{-1}) rainfall. The basin falls within the summer rainfall zone, with maximum annual rainfall occurring during January-March.

Hydrogeology

The Karoo Supergroup stratigraphy in the Kalahari-Etosha Basin is largely similar to that found in the Karoo Basin, although it is less well-defined in many areas because of limited exposure, and sparse lithological information (Table 2.8-3).

Table 2.8-3: General lithostratigraphy and correlations across Kalahari - Etosha Basin

Namibia	Botswana	Zimbabwe	Zambia
Stormberg Group Kalkrand Basalt	Stormberg Group Stormberg Lava	Stormberg Group Batoka Basalt	Stormberg Group
Unconformity	Lebung Group Ntane Formation, Msolotsane Formation	Forest Sandstone	
	Beaufort Series Thlabala Formation		
Ecca Group Prince Albert Fm.	Ecca Group Otshe Formation Kobe Formation	Ecca Group Upper Hwange Formation Lower Hwange Formation	
Dwyka Group	Dwyka Group Dukwi Formation		

Although the bedrock geology is represented by the Karoo Supergroup, the Kalahari Beds form regionally-extensive unconsolidated cover over much of the basin and, in many areas, form important aquifers. The Kalahari Beds (Cretaceous to Recent) are a heterogeneous continental assemblage, including aeolian, lacustrine, pan and fluvial deposits that are difficult to correlate regionally. The deposits are up to 600 m (1,968 ft) thick in Namibia, and 300 m (984 ft) thick in northwestern Botswana. Well-developed alluvial deposits also are present along the upper Zambezi River at the Barotse Floodplains.

As discussed below, the broad extent of the Kalahari-Etosha Basin results in a wide variety of groundwater occurrence and potential across the various regions of the basin.

Western Zambia - Caprivi - northwestern Botswana

Most of the region is overlain by an often thick cover of Kalahari Beds (up to 300 m [984 ft]), where fresh aquifers are often developed. Porous unconsolidated aquifers are developed for both rural and urban (e.g., Mongu in Zambia) water supplies. Borehole yields are generally low-to-moderate in Caprivi (1-20 $m^3.hr^{-1}$), although higher yields (30-70 $m^3.hr^{-1}$) often occur in Zambia. The water quality in the shallow aquifers is generally acceptable, although deeper aquifers are often brackish-to-saline.

The seasonal and perennial wetlands of the Okavango Delta, a large alluvial fan, form the major physiographic feature in northwestern Botswana. Nearly 98 per cent of the inflow of the Okavango River is lost to evapotranspiration and recharge of aquifers across the delta. Aquifers are present in unconsolidated alluvial sands of the Kalahari Beds underlying the delta. Away from actively-flowing river channels, however, the groundwater quality is consistently brackish-to–saline, due to high evapotranspiration rates and no significant rainfall recharge. High arsenic concentrations (up to 3 $mg.L^{-1}$) have recently been measured in several semi-confined aquifers in the lower delta (Water Resources Consultants, 2004). Borehole water yields are moderate, in the range of 5 to 60 $m^3.hr^{-1}$.

Western Zimbabwe - northeastern Botswana

Upper Karoo sandstones form important aquifers in western Zimbabwe, northeastern Botswana, and the Tuli Block present across Botswana, Zimbabwe and South Africa. The sandstones are recharged where they outcrop or sub-crop, and become confined under overlying basalts away from basin edges. It forms an aquifer known as the Nyamandlovu Aquifer on the Zimbabwean side, and augments the water supply of the city of Bulawayo. Some areas near Sawmills have artesian groundwater conditions. Groundwater levels have declined significantly in certain localities. The aquifer also has been explored in adjacent northern Botswana (Maitengwe Wellfield; Water Surveys 2002), where it has been considered as a regional resource for future water supply. Borehole yields are moderate, being approximately 30 $m^3.hr^{-1}$. A major well field southeast of Francistown has supplied water for diamond processing at the Orapa Mine for over 30 years.

The Tuli Block straddles Botswana and Zimbabwe, and includes part of South Africa. The groundwater resources are relatively undeveloped, being primarily used for rural village water supply. Recent exploration in Botswana has indicated an extensive artesian aquifer (hydraulic heads up to 4 m [13 ft] above ground), with high yield potential (>150 $m^3.hr^{-1}$) and good water quality (Water Resources Consultants 1998).

Eastern Nambia - western Botswana

The Ecca Group sandstones in this region form a laterally-continuous and mostly freshwater aquifer system from eastern Namibia to eastern Botswana (Figure 2.8-2).

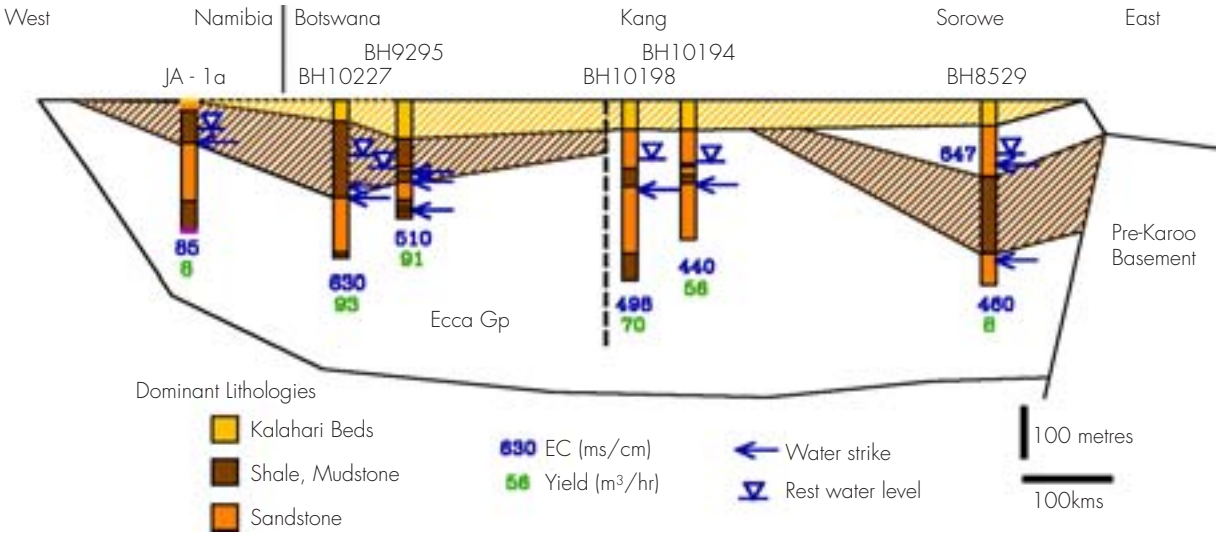

Figure 2.8-2: Hydrogeological cross section - central Kalahari Basin

Source: WRC 2002, adapted by UNEP

Part of the aquifer system in eastern Namibia is referred to as the Stampriet Artesian Basin. This basin was the subject of a major study (JICA 2001), and two major groundwater exploration projects are currently underway on the aquifer system in Botswana (i.e., Matsheng and the Kang–Phuduhudu Groundwater Development Projects).

The Stampriet Aquifer (mostly from the Auob Formation of the Ecca, and the overlying Kahari formation) has been extensively developed for irrigation and ranching since the 1980s. In localized areas (e.g., near Stampriet), over-abstraction has resulted in significant water level declines, and numerical modelling indicates that overall abstraction should be reduced by approximately 30 per cent for sustainable use of the resources (JICA 2001; Christelis and Struckmeier 2001). Borehole water yields are moderate (10-15 $m^3.hr^{-1}$). The groundwater quality is generally good, although groundwater becomes saline to the southeast in the 'saltblock.' Intermittent recharge is observed in areas of outcrop and shallow subcrop on and near the eastern margins of the basin.

There has been limited development of the contiguous aquifer system in Botswana to date, since the groundwater was largely considered to be of poor quality. Recent studies of the Ecca Aquifer in both western and central Botswana, however, have indicated large areas of good quality groundwater and high borehole water yields. The fresh Ecca Aquifer in many areas is beneath saline aquifers in Kalahari Beds, and beneath thin sandstones in the upper Karoo. In areas where Ecca sandstones are located beneath relatively-thin Kalahari Beds, recharge is evident in water level records (Water Resources Consultants 2005; Verhagen 2003). Borehole yields in Botswana Ecca sandstone aquifers can be high when sited along fracture zones (50-100 $m^3.hr^{-1}$).

Upper Karoo Sandstones are developed extensively on the eastern margin of the basin in Botswana, for both water supply for Serowe, and industry at the Botswana Power Corporation Morupule Power Plant. Borehole water yields in the upper Karoo sandstones are moderate where fracturing enhances permeability (10-30 $m^3.hr^{-1}$). Water quality is generally good, although limited saturated thickness often reduces sustainable abstraction.

Groundwater recharge

Although the basin is large, a considerable number of quantitative recharge studies have been carried out in various riparian countries, particularly Namibia, Botswana and Zimbabwe. An overview (not exhaustive) of estimated recharge rates for different regions of the basin is provided in Table 2.8-4.

Table 2.84: Recharge estimates for Kalahari - Etosha Basin

Area	Recharge	Method	Reference	Comment
W. Zimbabwe	82 mm.yr^{-1} (3.2 in.yr^{-1}) 25 mm.yr^{-1} (1 in.yr^{-1})	Water level fluctuation Chloride mass balance	Chikomwe and Sibanda (2001) Larsen et al. (2001)	Forest Sandstone
Botswana	0.7 mm.yr^{-1} (0.03 in.yr^{-1})	^{14}C	WCS (2001)	Western Botswana
	20 mm.yr^{-1} (0.8 in.yr^{-1}) 18 mm.yr^{-1} (0.7 in.yr^{-1}) 4 mm.yr^{-1} (0.02-0.2 in.yr^{-1})	Chloride mass balance; Hydrograph analysis; (high rainfall year: 2000); Hydrograph analysis (typical rainfall year: 2001)	Rahube (2003)	Karoo Sandstone aquifers; western Botswana
	0.6-4 mm.yr^{-1} (0.02 -0.2 in.yr^{-1})	Chloride mass balance; ^{18}O, ^{3}H, ^{14}C	Beekman et al., (1997); Selaolo (1998); Verhagen (2003)	Karoo Sandstone central Botswana
	3-6 mm.yr^{-1} (0.12-0.24in.yr^{-1})	^{14}C	Verhagen, 2003	Karoo Sandstone NE Botswana
	1-6 mm.yr^{-1} (0.04-0.24in.yr^{-1})	Chloride mass balance; Groundwater model; ^{14}C, ^{4}He	Beekman et al. (1997); Selaolo (1998); WCS (1994)	Karoo sandstone eastern Botswana
Namibia	2-7 mm.yr^{-1} (0.08-0.24in.yr^{-1}) 1.3 mm.yr^{-1} (0.05 in.yr^{-1}) 4.4 mm.yr^{-1} (0.17 in.yr^{-1}) 1-5 mm.yr^{-1} (0.04-0.2in.yr^{-1})	^{18}O Water balance typical year Water balance, wet year Chloride mass balance	JICA, 2001	Kalahari aquifer Ecca aquifers Ecca aquifers Kalahari aquifer

A crucial factor in much of the basin, particularly the arid-to-semi-arid areas, is the episodic nature of recharge. The heavy rains of 2000, interpreted as a 1-in-50 year rainfall event (JICA 2002), resulted in major recharge of both shallow and deeper aquifers.

Renewable resources

The basin is divided into areas of active recharge, areas of ancient or only intermittent recharge, and areas of low potential and often poor groundwater quality (Table 2.8-5; Figure 2.8-3). Table 2.8-5 provides estimates of groundwater resources of the basin. These estimates may be useful when considering the regional resource within the context of increasing vulnerability and demand on water resources.

Table 2.8-5: Groundwater resources of Kalahari - Etosha Basin

	Region	Area (km²)	Parameters	Resource
	Active recharge	1.400.000	Recharge 15 mm.yr^{-1} (0.6 in.yr^{-1})	2,100 million m^3.yr^{-1}
	Limited recharge	105,000	Aquifer thickness: 200 m (656 ft) [a] Storativity: 10^{-4} [b] Abstraction percent: 30 per cent	630 million m^3
	Low potential	100,000	-	-

[a] *Ntane Sandstone plus Ecca Sandstones;*

[b] *Van Rensburg and Bush (1995)*

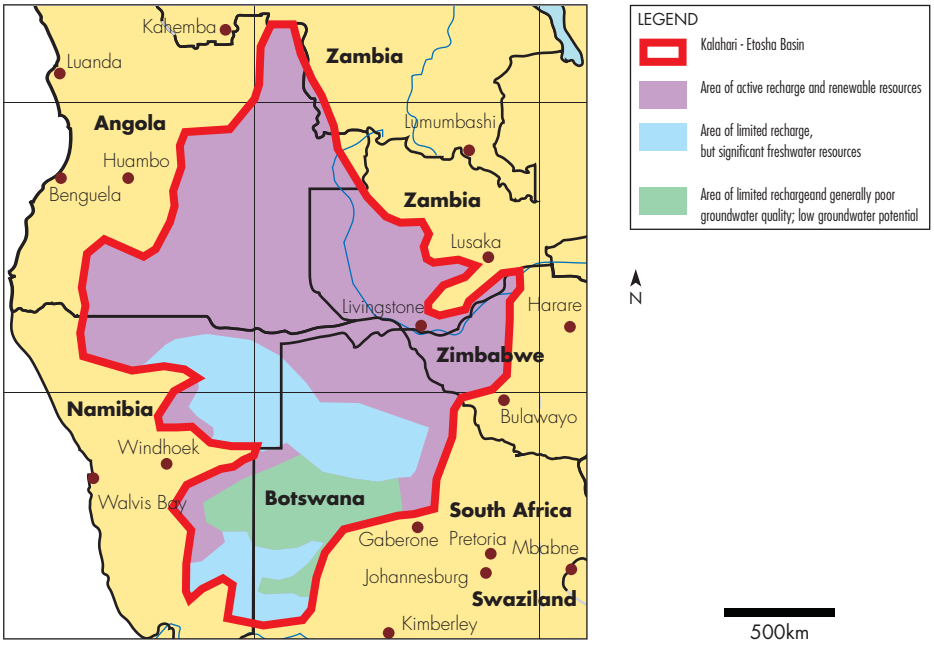

Figure 2.8-3: Groundwater resources potential map

Source: Water Resource Commission (2002), redrawn by UNEP

2.8.2.2 Socio-economy

Demography

Much of the basin area in Botswana, Namibia and Angola has population densities of less than 1 person.km^{-2} (2.6 persons.mi^{-2}), while western Zambia has densities of less than 5 persons.km^{-2} (13 persons.mi^{-2}). There are no large cities (greater than 100,000 people) within the basin.

Economy

In the arid and semi-arid portions of the basin, livestock rearing and ranches form the basis of the local economy, with groundwater being the sole water source for human and animal supply. Some local irrigation is developed in the Stampriet Basin in Namibia, because of the good quality and borehole water yields in the Kalahari/Ecca Aquifer system. Dry land and irrigated agriculture increases northward, with primarily small scale farming, although some larger commercial farms are present in western Zimbabwe and the Zambezi floodplain. Diamond mining in the basin constitutes the major contribution to the Botswana economy.

2.8.2.3 Management

Zambia is in the process of water sector reform, with a new Water Act being before the Parliament. Institutional and legislative restructuring in Zimbabwe has been completed, and integrated catchment management is being implemented. Water resources are still managed centrally in Namibia and Botswana, although natural resources management, including some components of water resources management, is being decentralized in Namibia.

2.8.3 Key issues, adaptation and mitigation

The Karoo and the Kalahari-Etosha groundwater basins constitute vast, largely freshwater resources underlying 9 nations (Figure 2.8-1). The basins represent a significant future resource as the populations and water demands in the region continue to increase.

Physiography

Climate variability and change

Based on recent trends in climate change, research suggests that the southern African region will become drier over time.

Adaptation and mitigation

There is a need:

- To carry out groundwater resources assessment and development, since groundwater resources by their nature are more subtly impacted by variations in rainfall and recharge; as such, they can offer an important buffer against the negative impacts of climate variability on water availability.

Ecosystems

River and wetland systems along many rivers (e.g., Okavango and Zambezi Rivers) are the primary sources of recharge to the Kalahari Beds aquifers. Diminished river recharge will have impacts both on ecosystems and abstractions for water supply (Linn et al. 2005).

Adaptation and mitigation

There is a need:

- To institute proper natural resources development to safeguard the ecosystems.

Water availability, distribution and pollution

There are areas within the basins where groundwater overdrafts have resulted in observed groundwater level declines (e.g., parts of the Stampriet in Nambia (Christelis and Struckmeier 2001); Jwaneng Well field in Botswana (van Rensburg and Bush 1995)). There is extensive scope for increasing development in most of the basins.

Fresh groundwater resources are present in close proximity to brackish to saline aquifers in many areas in the basin, with boundaries in a quasi-equilibrium condition. With changes in rainfall and river flow that may result from climate change, saline groundwater can migrate toward, and mix

with, fresh groundwater. Natural water quality is good in Karoo Sandstone aquifers, and their often-confined occurrence protects them from pollution. The major pollution threat in the basins is nitrate from human and animal waste, a common anthropogenic pollutant already found in Karoo aquifers (Tredoux et al. 2005). Because of their shallow occurrence and often-unconfined nature, Kalahari Bed aquifers are generally much more susceptible to pollution than bedrock aquifers. In the lower Okavango Delta, high concentrations (>3 $mg.L^{-1}$) of naturally-occurring arsenic have been measured in semi-confined aquifers (Water Resources Consultants 2004).

Adaptation and mitigation

There is a need:

- To carry out effective groundwater resources development and management strategies that control overexploitation, irreversible groundwater level decline, and brackish/saline water intrusion;
- To control pollution of groundwater resources from agricultural, human and industrial waste.

Socio-economy

Urbanization

With much of the area being located far from large urban centres, there is less vulnerability to the impacts of urbanization and rapid increases in water demands. Increasing use of groundwater for irrigation in the basins, however, may lead to local overdraft and water conflicts between users.

Adaptation and mitigation

There is a need:

- To carry out groundwater resources assessment and development, in order to ensure equity of access to groundwater resources.

HIV/AIDS

Groundwater resources are the major water supply source for rural communities in the basins, with the availability of safe water a crucial part of maintaining the health of both the HIV-positive population, as well as caregivers and heads of households. The continuing development of improved and safe water supplies will be an important component in the fight against the pandemic. Another crucial issue is the loss of trained groundwater professionals to the disease, depleting an already-limited human resources base.

Adaptation and mitigation

There is a need:

- To integrate HIV/AIDS prevention into water and sanitation policy frameworks;
- To implement water and sanitation projects in rural areas, as a means of improving access to water and health and hygiene conditions;
- To implement anti-retroviral and anti-malaria programmes;
- For extensive education, training and awareness.

Water use and economy

Groundwater use in the basin is used for rural water supply, small-scale stock watering, and irrigation. Major well fields are developed to support diamond mining in two areas of Botswana.

Adaptation and mitigation

There is a need:

- To effectively develop and manage groundwater resources to ensure sustainability of the basin economy.

Water-related conflicts

No significant conflicts regarding groundwater resources in most of the basin have yet occurred. In regard to the Nyamandlovu Aquifer in Zimbabwe, however, there is potential for conflict between the city of Bulawayo and local farmers.

Adaptation and mitigation

There is a need:

- To involve all stakeholders in water resources development, allocation and management.

Management

Institutional and legislative frameworks

The institutional and legislative frameworks in most of the riparian countries need to evolve and adapt to the changing climatic and environmental conditions in the basin.

Adaptation and mitigation

There is a need:

- To include the agricultural sector in the water resources management framework;
- To enhance capacity building of the various institutions in the riparian countries.

Data availability standardization and monitoring

Data availability is relatively extensive, with major resource assessment and exploration projects completed in the South Africa, Botswana, Namibia and Zimbabwe portions of the basin. Digital groundwater databases exist in South Africa, Botswana, Namibia and Zimbabwe. Well-established groundwater monitoring networks (groundwater levels) exist in Botswana, Namibia, South Africa and Zimbabwe.

Adaptation and mitigation

There is a need:

- To establish monitoring networks (e.g., for water abstraction; rainfall; chloride deposition; groundwater quality);
- To establish standardized data monitoring, collection and groundwater databases among the riparian countries.

Inter-basin transfers

Increasing conjunctive use of surface and groundwater will become increasingly important as surface flows are reduced because of changing climatic conditions. Similar to major dams, groundwater from areas of good quality and high-yielding aquifers in the basin may be transferred out of the basin to water-demand centres.

Adaptation and mitigation

There is a need:

- To institute inter-basin transfers to meet the growing water demands in the sub-region.

Artificial recharge

Artificial recharge is already being carried out at both large and small scale on bedrock aquifers in southern Africa (e.g., city of Windhoek) and at the community level (e.g., Karkams in South Africa). These schemes have demonstrated the economic and technical feasibility, and critical advantages of managed recharge in southern Africa.

Adaptation and mitigation

There is a need:

- For studies and further application within the basin, particularly in the semi-arid-to-arid regions, as an important mitigation strategy to address increasing water demands within the context of climate and environmental change in the region.

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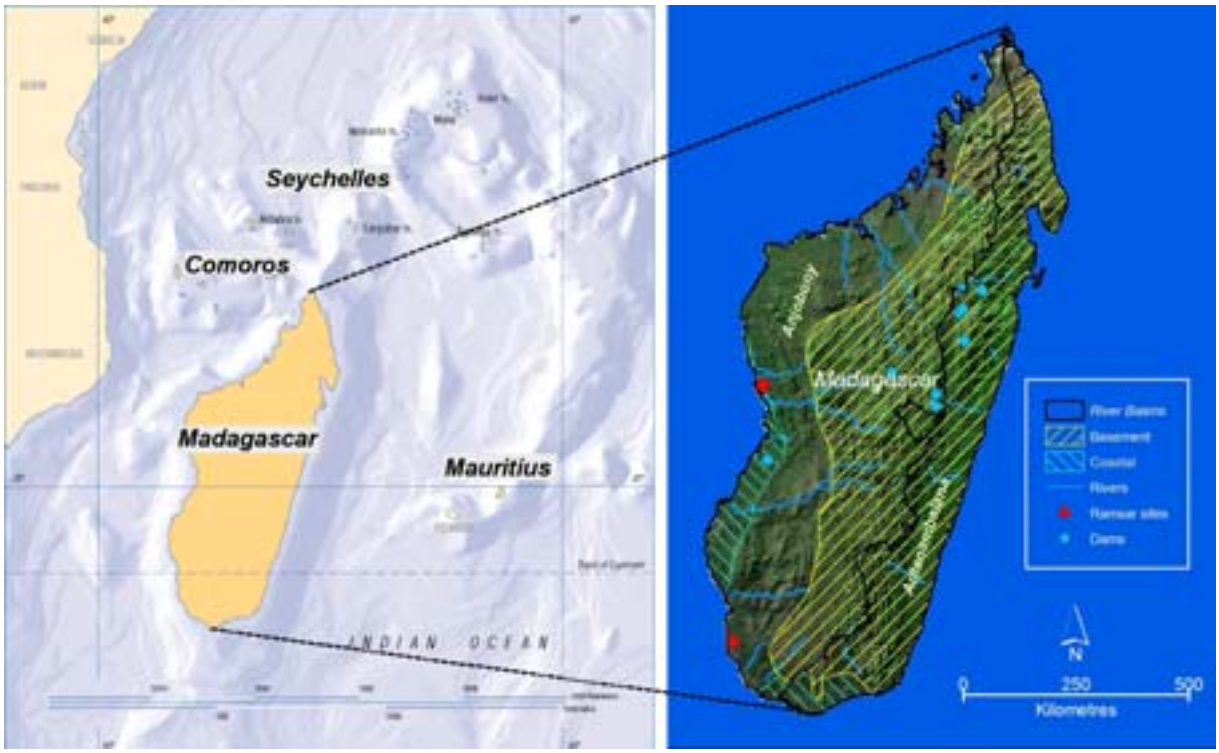
WESTERN INDIAN OCEAN ISLAND STATES: Sub-Regional Overview

The Western Indian Ocean Islands (WIOI) sub-region of Africa comprises the island states of Comoros, Mauritius, Madagascar and Seychelles (Figure 3.1a). These island states are separated by large expanses of ocean, and do not share any coastal marine environments or any freshwater resources. They do, however, have commonalities, in terms of natural resources, cultural linkages, export commodities and vulnerability to environmental changes. The island states also have great physical differences and contrasts – they are a melting pot of races, religions and cultures that have followed very different development paths (UNEP 1999).



3.1a: Western Indian Ocean Island States *3.1b: Madagascar's river basins*

Figure 3.1: Western Indian Ocean Island States and Madagascar's major river basins

Source: Left map - UNEP, 1999; Right map - Satellite Image: USGS MODIS, 28 December, 2001; Rivers and Dams: FAO Atlas of Water Resources and Irrigation in Africa, Aquastat, FAO 2001; Ramsar Sites: Ramsar 2003: www.ramsar.org

These 4 island states are briefly described below (UNEP 1999; WRI – Earth Trends 2003), with their vulnerability to environmental change being discussed in more detail in the subsequent sections. Box 3.1 summarizes the main characteristics of these island states.

- *Comoros* is an archipelago of 3 islands (Grande Comoro, Anjouan and Mohéli), with a predominantly rural, largely homogenous, population that is highly indebted and dependent on agriculture and external assistance.

- Madagascar is the world's fourth-largest island, with unique flora and fauna, rich in natural resources, including minerals, and exhibits considerable development potential, but also high levels of poverty and population growth. Madagascar has 2 major river basins: the Anjobony River Basin in the western part of the island, and the Antanambelana River Basin in the eastern part (Figure 3.1b).
- Mauritius, one of the most densely-populated countries in the world, has been transformed over the past few decades from an agrarian economy with a high population growth, to a modern, medium-income country with a lower population growth and high levels of education and welfare. The republic includes the islands of Rodrigues, Agalega and the Chagos Archipelago.
- Seychelles, made up of 115 small islands, has a unique ecology, pristine environment and tourist attractions, and the highest Human Development Index ranking in Africa. It is particularly vulnerable to external economic conditions, however, because of its small size and high dependence on external markets.

Box 3.1: Main characteristics of Western Indian Ocean Island States

Island States	**Comoros**	**Madagascar**	**Mauritius**	**Seychelles**
Surface area (km^2) [mi^2]:	2,230	587,040	2,040	450
MAP ($mm.yr^{-1}$) [$in.yr^{-1}$]:	900	1513	2,041	2,330
Rainfall range ($mm.yr^{-1}$) [$in.yr^{-1}$]):	1 200-5 900	400-3 000	900-4 000	1 300-3 500
Water Resources				
TRWR[1] ($10^3 Mm^3.yr1$):	1.20	337	2.75	-
Total dam storage (Mm^3):	-	493	93	0.97
Major Aquifers:	Volcanic	Sediment/Basement	Volcanic	Basement
Demography (2004)				
Population (million people):	0.79	17.90	1.23	0.08
Rural population (per cent):	64	73	56	50
Economy (2003)				
GDP[2]/capita/a (US$):	421	307	4259	8890
HDI[3] (1 is highest)	0.55	0.50	0.79	0.82
Population Density (2004) ($persons.km^{-2}$) [$persons.mi^{-2}$]:	354	30	604	182
Water Availability (2004) ($m^3.capita^{-1}.yr^{-1}$)	1,519	18,826	2,231	
Water Access (2004)				
Urban Population (per cent):	92	77	100	100
Rural Population (per cent):	82	35	100	75
Water Use	Domestic Agriculture Industry	Agriculture Domestic Industry	Agriculture Domestic Industry	Domestic Industry Agriculture

Vulnerability
Climate variability and change (cyclones and sea level rise)
Pollution (from agriculture and wastes)
Health (mostly water related)
Poverty (widespread in Madagascar and also in Comoros)
Infrastructure (inadequate storage and leakage)

[1]Total Renewable Water Resources; [2]Gross Domestic Product; [3]Human Development Index

Source: FAO - Aquastat (2005) and WRI - Earth Trends (2003) country profiles ; UNDP (2005) – downloaded March 2006 ; WHO/UNICEF (2006)

3.1 PHYSIOGRAPHY

Climate

Rainfall and evapotranspiration are highly variable across the island states of the sub-region. The climate in Madagascar ranges from semi-arid to tropical forest conditions, with precipitation ranging from less than 400 mm.yr^{-1} (16 in.yr^{-1}) in the southwest to 3,000 mm.yr^{-1} (118 in.yr^{-1}) in the mountainous eastern part of the island. For the other island states rainfall ranges from 900-5,900 mm.yr^{-1} (35-232 in.yr^{-1}). All the countries experience extended dry seasons with periods of heavy rain, which presents technical problems for water storage, treatment and distribution. The islands are affected by around 10 tropical storms or cyclones from November to May each year (UNEP 2005a).

Climate variability and change

Global warming is primed to intensify the vulnerability of the Western Indian Ocean Islands to extreme weather events, threatening their sustainable development. IPCC's (2001) projected worst-case scenario of a 1m (3.3 ft) sea level rise by 2100 would result in the loss of coastal land and infrastructure, loss of agricultural opportunities and groundwater resources (due to salinisation), loss of biodiversity critical to community support, and loss of livelihoods.

Ecosystems

Madagascar has 5 Ramsar sites for the protection of wetland habitat. Comoros, Mauritius and Seychelles each have 1 site (Ramsar 2006). Madagascar's land cover in the Anjobony River Basin is dominated by savannah, whereas the Antanambelana River Basin is covered mainly by evergreen broadleaf forest and cropland/natural vegetation mosaic (Figure 3.2).

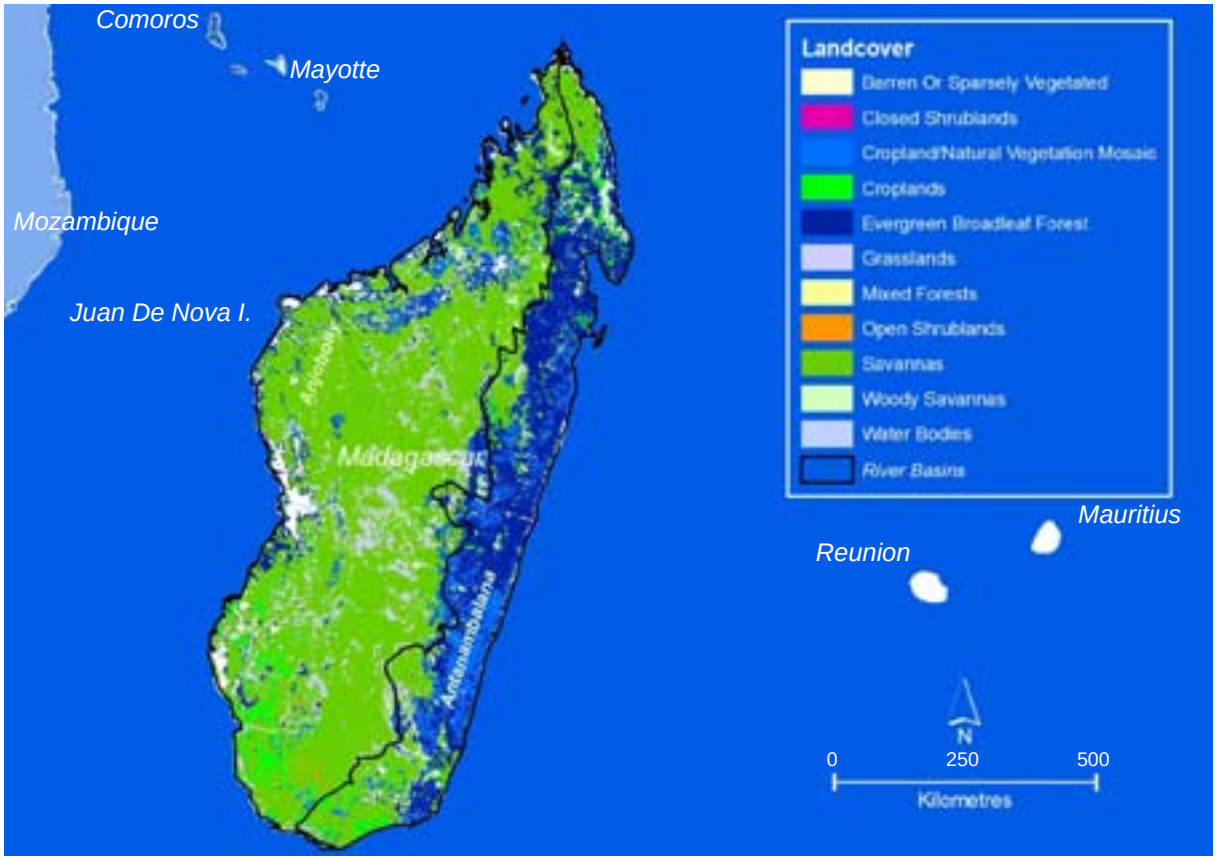


Figure 3.2: Land cover of Madagascar (IGBP legend)
Source: USGS Africa Land cover charactersistics data base: http://edcdaac.usgs.gov/glcc/glcc.html

Hydrology and Hydrogeology

The characteristics of the water resources of the islands' catchments range from the large, continental landmass of Madagascar, to the small granitic islands of Seychelles, and the steep volcanic islands of Comoros and Mauritius. Water in Madagascar, Mauritius and Seychelles is primarily extracted from dams and reservoirs on the main inhabited islands, while the Islands of Comoros depend heavily on groundwater resources.

Madagascar can be divided into two major river basins, one that drains into the Mozambique Channel to the west (Anjobony River Basin), and the other draining into the Indian Ocean to the east (Antanambelana River Basin). The Anjobony Basin is underlain by both Precambrian basement and consolidated sedimentary rocks, while the Antanambelana Basin is predominantly underlain by Precambrian basement rocks (Figure 3.3).

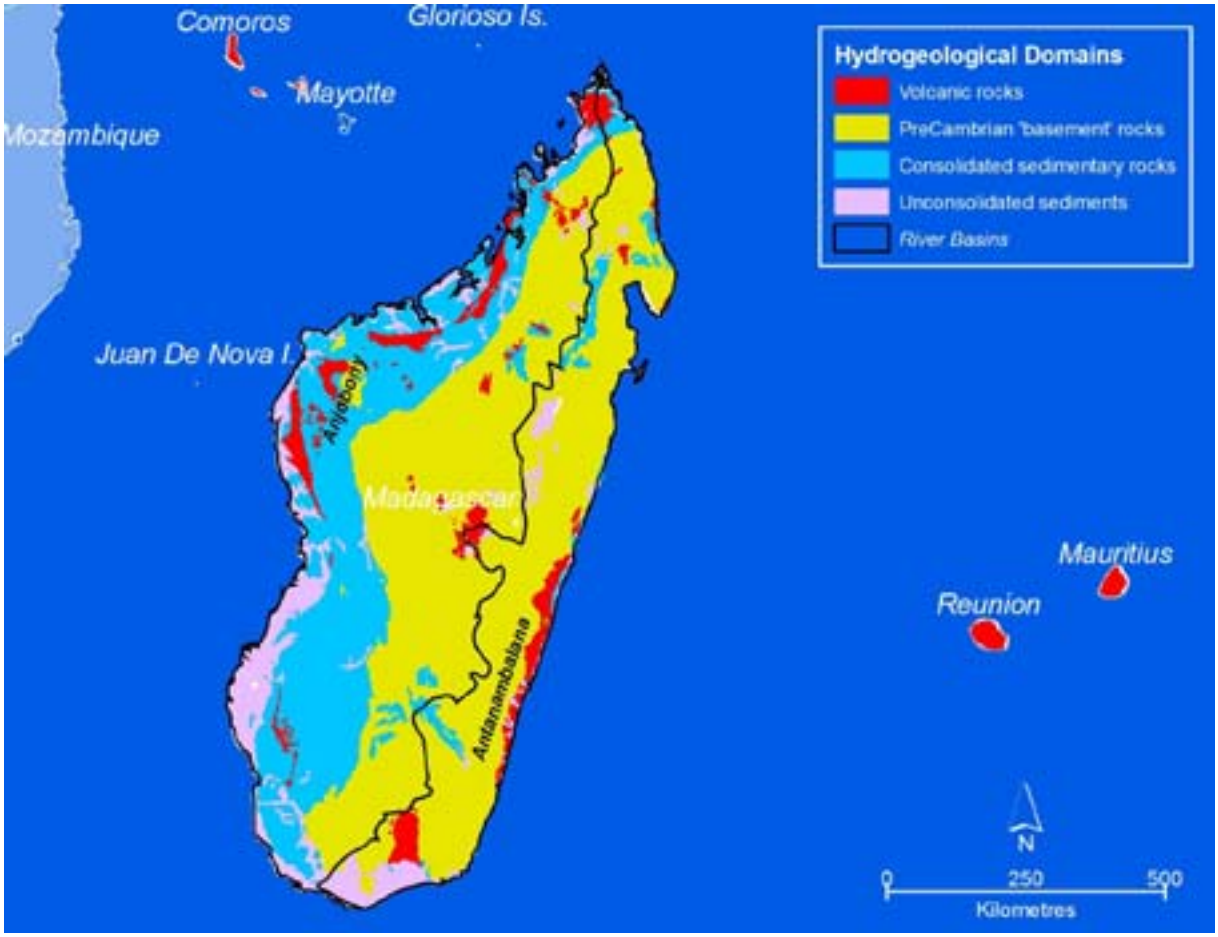


Figure 3.3: Hydrolithological domains of Madagascar

Source: Adapted from USGS World Energy Resources Products, Generalized Geology of Africa: http://energy.cr.usgs.gov/oilgas/wep/products/geology/africa.htm; After MacDonald, A.M. & Davies, J. 2000.

Water availability

The total internal renewable surface water and groundwater resources of the Western Indian Ocean Island States are estimated to be 341 $km^3.yr^{-1}$ (FAO-Aquastat 2005). Surface water is the main source for most of the economic activities.

Pollution from improper disposal of solid wastes, and eutrophication as a result of poor treatment facilities, was identified by UNEP (2004a) as one of the most severe issues in the sub-region. In addition to exacerbating adverse health effects, pollution also reduces the availability of freshwater resources. Intensive agriculture and industrialisation in Mauritius, for example, has led to pollution of water resources, especially within the coastal areas (ERM 1999).

Freshwater availability also is affected by climate change, and an increased frequency and intensity of extreme weather events. The impact of sea level rise attributed to global warming is already evident. Seawater has intruded 2 km (1.2 mi) inland, for example, in Comoros (UNEP 2005a). Over-exploitation of groundwater resources in coastal areas further aggravates the situation. Increased wave intensity and abnormal tidal ranges has caused coastal erosion affecting several beaches in Comoros and Seychelles (UNEP 2005a). The effects of sea level rise in Madagascar are not reported here, due to lack of monitoring capacity.

Improvements in water supply systems in all the Western Indian Ocean countries have not kept pace with increasing water demands (especially from increased population). Since 1988, the annual available per capita renewable water resources have declined by 29 per cent in Madagascar, 29 per cent in the Comoros, and by 12 per cent in Mauritius (FAO – Aquastat 2005). About 1 million $m^3.yr^{-1}$ of desalinated water is produced for potable use in Seychelles, to compensate for the water shortage that occurs during the dry period. Water losses from domestic water distribution systems also account for significant wastage (e.g., up to 50 per cent in the case of Mauritius) (UNEP 2005a).

3.2 SOCIO-ECONOMY

Demography

The total population of the region in 2004 was 20 million, including 790 thousand in Comoros, 17.9 million in Madagascar, 1.23 million in Mauritius, and 80 thousand in Seychelles (Box 3.1; FAO - Aquastat 2005). Most people live in rural areas: in Madagascar (73 per cent of total population), whereas the rural population comprises between 50-64 per cent of the total population in the other island states.

Population density and growth

The population density of the island states varies from 30 $persons.km^{-2}$ (78 $persons.mi^{-2}$) in Madagascar, to ~200-600 $persons.km^{-2}$ (518-1554 $persons.mi^{-2}$) in the other island states (Box 3.1). The average annual population growth rates during 1980-2000 were 2.9 per cent for Comoros, 2.9 per cent for Madagascar, 0.9 per cent for Mauritius, and 2 per cent for Seychelles (WRI–Earth Trends 2003). Except for Mauritius, the annual urban population growth rates more than doubled, compared to the rural population growth rates, thereby exerting pressures on the existing infrastructure, particularly water and sanitation.

The coastal population density is expected to increase in all the island states. In Comoros, the population density is expected to increase from 223 $persons.km^{-2}$ (578 $persons.mi^{-2}$) in 1995 to 648 $persons.km^{-2}$ (1,678 $persons.mi^{-2}$) by 2020. In Madagascar, it will increase from 20 $persons.km^{-2}$ (45 $persons.mi^{-2}$) in 1995, to 45 $persons.km^{-2}$ (117 $persons.mi^{-2}$) by 2020. In Mauritius, the population density will increase from 548 $persons.km^{-2}$ (1,419 $persons.mi^{-2}$) in 1995, to 699

persons/km^2 (1,810 person.mi^{-2}) by 2020. Finally, it will increase from 161 persons.km^{-2} (417 persons.mi^{-2}) in Seychelles in 1995, to 203 persons.km^{-2} (526 persons.mi^{-2}) by 2020 (UNEP 2004a). These anticipated increases will put a further strain on the limited water resources.

HIV/AIDS and water-related diseases

Although HIV/AIDS is much less prevalent on these islands than on the African mainland, its increasing incidence is an emerging problem. The percentage of HIV/AIDS infected in the age group of 15 to 49 years for Madagascar and Mauritius was less than 0.3 per cent in 2001 (WRI-Earth Trends 2003). No data are available for the Comoros and the Seychelles. Water-borne and tropical communicable diseases are widespread, as a result of contaminated water supplies from domestic effluents, storm runoff, untreated sewage and stagnant waters.

Cholera epidemics occurred in Comoros, for example, in 1975, 1998 and 2001 (UNEP 2004b). The impact of solid waste pollution on water resources and the environment is of increasing concern. Only about 6 per cent of the rubbish and wastes are routinely collected in Madagascar, for example, while waste collection and disposal is virtually non-existent in the Comoros. Uncontrolled dumping of waste materials creates ideal breeding opportunities for disease-carrying organisms, especially malaria and dengue fever-spreading mosquitoes.

Malaria is one of the principal causes of morbidity and mortality in Comoros, where it results in 25 per cent of hospital admissions, and 10-25 per cent of deaths in children under 5 years. Madagascar has health problems associated with stagnant water in rice field irrigation canals, which promote mosquito breeding, and are host to the spread of the parasites that produce bilharzias. Mauritius and the Seychelles are relatively free of these diseases (UNEP 2004b).

Economy

Large variations exist between the economies of the Western Indian Ocean island states. Agriculture employs 80 per cent of the working population in Comoros and Madagascar, producing 35-40 per cent of the Gross Domestic Product (GDP; WRI-Earth Trends 2003; UNEP 2004a). The domestic sector dominates in the Seychelles, with 18 per cent of the GDP coming from tourism. The Mauritian economy is more evenly balanced between agriculture, industry, tourism and services. Limited land and water severely constrain agricultural and industrial development, especially in Comoros and Seychelles (UNEP, 1999).

Both Seychelles and Mauritius have experienced solid economic growth in recent years, with annual growth rates in GDP of 2 and 5 per cent, respectively, during 1991-2000, and similar increases on a per capita basis (WRI-EarthTrends, 2003). The GDP per capita for Seychelles and Mauritius in 2003 was more than ten-fold the GDP per capita for Comoros and Madagascar (Box 3.1). The annual per capita GDP growth rates for 1991-2000 were negative for Comoros (-3 per cent) and Madagascar (-1 per cent).

Poverty

The UN Human Development Index (HDI; 0-1), a comparative measure of poverty, literacy, education, life expectancy, childbirth and other factors, was highest for Mauritius and Seychelles in 2003, being 0.791 and 0.821, respectively (UNDP 2005). It was much lower for Comoros and Madagascar, at 0.547 and 0.499, respectively. Despite relatively high ratings, compared to the Sub-Saharan Africa countries, the island states still have high levels of poverty in both rural and

urban areas (UNEP 2005a). Poverty is most widespread in Madagascar, where over 70 per cent of the population lives on less than US$1.d^{-1} (UNEP 1999).

Water uses and water demands

Agriculture is the greatest water user in the region, accounting for 99 per cent of all withdrawals in Madagascar, and for 77 per cent in Mauritius (UNDP et al. 2000). In contrast, On the other hand, the shift to tourism has reduced the importance of the agricultural sector in Seychelles.

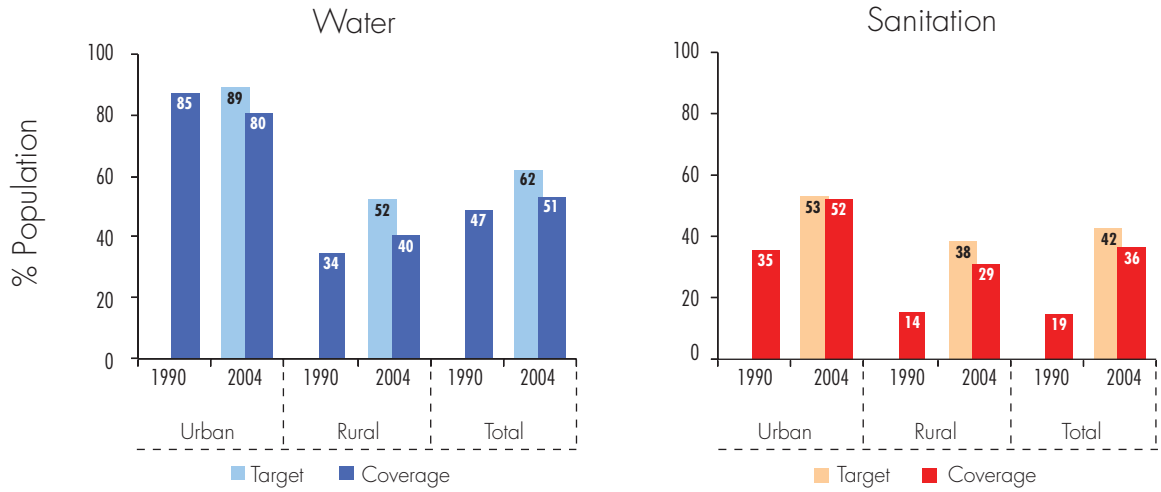


Figure 3.4: Water supply and sanitation coverage in Western Indian Ocean Island States between 1990 and 2004 (Seychelles are excluded due to incomplete data).

Source: WHO/UNICEF (2006), redrawn by UNEP

The freshwater demand is expected to rise for all the islands over the next 25 years because of growing populations, and expanded tourism and other industrial sectors. Future projections, based on an average annual population growth of 2.5 per cent, would place Mauritius in a water-stressed category (~1,300 m^3.capita^{-1}.yr^{-1}, or between 1,000-1,700 m^3.capita^{-1}.yr^{-1}), and places Comoros in a water-scarce category (~900 m^3.capita^{-1}.yr^{-1}, or less than 1,000 m^3.capita^{-1}.yr^{-1}) by 2025. Although precise figures for the Seychelles, where most water comes from rivers, are not available, water shortages were so severe during 1998 (partly because of the extreme El Nino event), that the brewing and fish canning industries were forced to close (UNEP 2005a).

Access to water and sanitation

About 46 per cent of the population in Madagascar had direct access to potable freshwater in 2004, whereas the situation in Comoros and Seychelles this percentage was 86 and 88 per cent, respectively. Mauritius had over 99 per cent coverage (WHO/UNICEF 2006). An accelerated effort is needed in Madagascar and Comoros, in both rural and urban areas, to meet the Millennium Development Goal (MDG) water coverage targets (see Figure 3.4). Despite advances made in recent years, 9.9 million people (49 per cent) in the sub-region were without improved water supplies, and 12.9 million people (64 per cent) without improved sanitation in 2004.

3.3 MANAGEMENT

Institutional and legislative frameworks

Table 3.1 provides an overview of the institutional setup and relevant legislation for managing water resources in the sub-region. An integrated, holistic approach toward water resources management is urgently needed to address the major issues facing the island states. One of the obstacles for implementing an IWRM approach, however, is that responsibilities for water resources management are scattered among multiple public sector institutions, which lack appropriate co-ordination and resources.

Despite the absence of national-level integrated water management policies, separate efforts are undertaken to manage freshwater resources supply and demands. Seychelles and Mauritius, for example, apply water desalination to improve water availability. Reforms in Mauritius include diversification of crops, and conversion to more efficient irrigation techniques. Public awareness and education, as well as economic measures (e.g., metering and charging water uses), results in effective, efficient water use and water conservation.

Although the island states are separated by large expanses of the ocean, and do not share any coastal marine environments or freshwater resources, certain issues (e.g., long-range transport of pollutants; impacts of climate variability and change) must be dealt with in a bilateral or multilateral context.

Table 3.1: Institutional setup and supporting legislation in Western Indian Ocean countries (Roberts 2005; FAO-Aquastat 2005)

	Comoros	Madagascar	Mauritius	Seychelles
Operational management	• General Directorate for Agriculture and Rural Development	• Directorate for Water and Sanitation • (Water sources nationalised in 1999) • Directorate for Rural Development	• Central Water Authority (controls use of water, development schemes, conservation and distribution) • Irrigation Authority (design, implement and manage schemes)	• Public Utilities Corporation – Water and Sewage Division (all water resources) • Rivers Committee (various ministries; abstraction rights) • Ministry of Environment and Natural Resources (wastewater and water pollution control) • Ministry of Agriculture and Marine Resources (small reservoirs and communal irrigation schemes)
Ministerial responsibility	• Ministry of Production, Agriculture, Marine Resources and Environment	• Ministry of Water, Forests and Environment	• Ministry of Public Utilities	• Various ministires (See above)
Legislation and regulation	• National Environment Policy and Plan of 1993		• River and canal Act of 1863 • Groundwater Act of 1970 • Irrigation Authority Act of 1979 • Abstracting water from rivers requires agreement of Supreme Court.	• Public Utilities Corporation Act of 1985
Planning and development	• Institute for Agricultural Research, Fisheries and the Environment	• National Centre for Applied Research and Rural Development		
Implementation	• Enforcement mechanisms not yet fully developed	• No charges for water	• Water metered and charges for use	

Mauritius strategy

The Mauritius Strategy was adopted by the Small Island Developing States and international community in January 2005, concerning further implementation of the Barbados Programme of Action (prepared in 1994) for sustainable development. The strategy elaborates on a wide variety of actions (e.g., climate change and sea-level rise; natural and environmental disasters; waste management;; coastal and marine resources; freshwater resources; capacity development and education for sustainable development). Selected challenges and actions related to freshwater resources were formulated as follows (www.un.org/smallislands2005/pdf/sids_strategy.pdf):

- Small Island Developing States continue to face water management and water access challenges, caused partly to deficiencies in water availability, water catchment and storage, pollution of water resources, saline intrusion, and leakage in the delivery system. Sustained urban water supply and sanitation systems are constrained by a lack of human, institutional and financial resources.

- Further action is required by Small Island Developing States, with necessary support from the international community, to meet the 2015 MDG targets on sustainable access to safe drinking water and sanitation and hygiene, and the World Summit on Sustainable Development Plan of Implementation (new) target for IWRM and water efficiency plans.

- The international community is requested to provide capacity-building assistance for development and further implementation of freshwater and sanitation programmes, and promotion of IWRM

- Seek international support to build self-reliance and implement their agreed priority actions, including IWRM; water demand management; water quality capacity-building; water governance; regional water partnerships; and inter-Small Island Developing State water partnerships.

Disaster management

Small islands and low-lying coastal areas are among the most vulnerable bodies in the world to extreme climatic events and environmental disasters, as highlighted by the Indian Ocean tsunami of 26 December 2004 (Figure 3.5). Among the 4 Western Indian Ocean Island States, only the Seychelles received the full force of the tsunami (UNEP 2005b). All affected countries identified an early warning system as a high priority. Such an early warning system should cover not only tsunamis, but also such threats as storm surges and cyclones, in order to alert people living on these vulnerable small islands and low-lying coastal areas. A regional multi-hazard early warning system should be linked to well-coordinated emergency and evacuation plans established by each individual country. Mauritius and Seychelles have taken steps towards disaster management, including early warning systems. Mauritius has an early warning system in place since the 1950s for extreme climatic events, allowing for preparations and evacuation. There are fully-equipped shelters and emergency procedures that are regularly tested. The Seychelles have made significant progress in preparation of a National Strategy for Risk and Disaster Management. There remains, however, a serious need for capacity building.

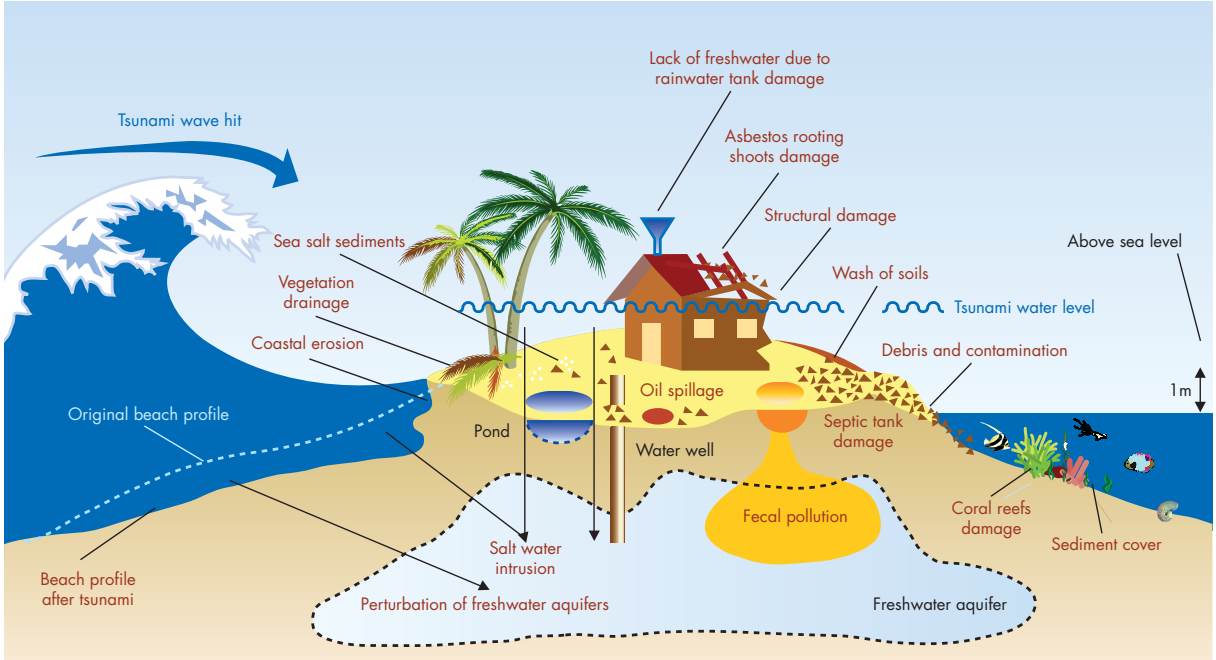


Figure 3.5: Environmental impacts of tsunami of 26 December 2004

Source: UNEP 2005b, redrawn by UNEP

Monitoring, databases and data availability

Meteorological and hydro(geo)logical monitoring, as well as data collection, archiving and analysis, varies from country to country. Thus, national water resources databases are at various stages of establishment or development. Data availability and advancement of database development appears to be related to the role a particular water source plays in a country's overall water supply.

In Mauritius, for example, groundwater contributes 21 per cent of total domestic and non-domestic use (excluding hydropower). Groundwater is used mainly for municipal water supplies, with a 50 per cent share of total water use. Mauritius has a good groundwater monitoring network that has been in existence for over 20 years (SADC-WSCU 2001). Approximately 350 boreholes spread across the country are monitored monthly for groundwater levels, water abstraction rates, and other basic physical and chemical parameters. Water sampling for monitoring water quality is carried out regularly for drinking water and pollution control. Analyses are conducted by two qualified laboratories, and there is a computerized database and GIS (GEOLAB), and a hydrogeological map of the country (scale of 1:50 000) was recently compiled.

Groundwater plays a minor role in the Seychelles (~3 per cent of total abstractions), compared to surface water and desalination plants for water supply (only 2 per cent during the dry season). Some groundwater monitoring for water levels, and basic physical and chemical parameters, of about 60 boreholes is carried out on a fairly regular basis, although the last published data dates back to the period 1985-1989. There is no groundwater database or information system (SADC-WSCU 2001).

3.4 KEY ISSUES, ADAPTATION AND MITIGATION

Island developing states are amongst the most environmentally- and economically-vulnerable nations in the world. Many are geographically remote, and dependent upon limited natural resources (e.g., freshwater; land; forests). Many are threatened by climate change in the form of more extreme weather events and rising sea levels.

Physiography

Climate variability and change

Global warming, and increased frequency and intensity of extreme weather events, are among the top concerns threatening the health and wealth of the Western Indian Ocean Island States (UNEP, 2005a). Rising sea levels not only result in loss of coastal land and infrastructure, deterioration of groundwater resources, and loss of biodiversity, but will also cause migration and displacement of the population, water-related diseases and water supply problems.

Adaptation and mitigation

There is a need:

- For an integrated system of protection against the impacts of extreme weather events, part of which is an early warning system to alert small islands and low lying coastal areas in the Indian Ocean. An early warning system also is needed for both impending droughts and floods, particularly for Madagascar.
- For development of a system that allows for rapid deployment of humanitarian aid (food, shelter, medicines, water, power) to relieve the suffering for countries hit by tidal waves and cyclones.
- To assess and mitigate environmental impacts (e.g., contamination of land; water sources; and damage to coral reefs; mangrove swamps; and other important coastal habitats).

Ecosystems

The Western Indian Ocean wetlands are seriously threatened by urban and coastal development, since they offer flat ground for rapid provision of roads, bridges and other infrastructure, including housing and tourist facilities. Management of such sites is subject to continuing pressures of conflicting developments because of population growth, expansion of tourism, and growth in agriculture, through improvements and extension of irrigation systems.

Adaptation and mitigation

There is a need:

- For development of protected areas (e.g., building embargo on wetlands).
- For monitoring activities that adversely impact ecosystems.
- For education, training and awareness on the importance of wetlands.
- To involve communities in managing ecosystems, with projects that directly benefit the communities forming an integral part of the management.
- For commercial development of wetland tourism.

Water availability and pollution

The availability of freshwater is expected to further decline in the coming years, mainly because of rising demands resulting from a growing population (and urbanisation), and expanded tourism and other industrial sectors. Comoros will soon fall under the category of water-scarce countries, whereas Mauritius is projected to become water stressed before 2025. Even rainy islands (e.g., Seychelles) are experiencing problems, because up to 98 per cent of the rainwater is lost to the sea, or through evaporation. Freshwater shortages in Madagascar are due mainly to inadequate, poor water storage and supply infrastructure. Pollution of water resources, particularly from agrochemicals, and solid wastes, further aggravates the situation, remaining a major concern for the Western Indian Ocean Island States (UNEP 2004a).

Adaptation and mitigation

There is a need:

- For public awareness and education of effective, efficient water use, and water conservation techniques.
- For strengthening water demand management.
- For integrated water supply planning, with urban and rural planning systems.
- For additional groundwater resource assessments to establish alternative water sources.
- For effective pollution control management, adopting the "polluter pays" principle, and including waste collection and disposal (e.g., institutions; legislation; regulations; enforcement). The situation in Madagascar and Comoros should be drastically improved. Both Mauritius and Seychelles have established organized waste collection and disposal schemes.
- For increased water storage facilities, and improved water distribution systems (e.g., reduce leaks; improve maintenance).
- For extending alternative water sources (e.g., water recycling; desalinisation in coastal areas; rainwater harvesting).
- For increased investments in sewage treatment and disposal facilities.

Socio-economy

Population growth and urbanization

Population growth and urbanisation are exerting increasing pressures on water supply in regard to water demands and pollution. Urban populations also are increasing because of rural–to-urban migration. Comoros experienced the highest urban population growth, from 28 to 36 per cent of the total population during 1990-2004 (WHO/UNCICEF 2006).

Adaptation and mitigation

There is a need:

- To increase investments in developing and upgrading infrastructure, particularly in urban centres.
- For governments to implement measures that curb high population growths (e.g., education; awareness; policies).
- For investments in rural areas (e.g., tourism; agriculture; fishing) to combat rural-to-urban migration.

HIV/AIDS and water-related diseases

The increasing incidence of HIV/AIDS is an emerging problem. Comoros and Madagascar are the poorest countries of the sub-region, being most affected by waterborne- and water-related diseases (e.g., malaria; typhoid; cholera). In Madagascar, malaria is often associated with stagnant water in irrigation canals in rice fields.

Adaptation and mitigation

There is a need:

- For extensive education, training and awareness.
- For anti-retroviral and malaria prevention programmes.
- To implement sustainable water and sanitation projects in rural areas, as a means of improving access to water, health and hygiene.

Water-related conflicts

The agricultural sector is competing with the domestic (including tourism) and industrial sectors for access to water. Further, the demands and competition for water are high in the coastal fringes of the small island states, where most of their people live. Thus, there are possibilities for conflicts in both areas. Given the future projections of climate and demographic changes that result in increasing pressures on natural resources, this situation is expected to worsen.

Adaptation and mitigation

There is a need:

- For increased stakeholder involvement in water resources use and management programmes.
- To ensure equity of access to water resources.

Management

Institutional and legislative frameworks

Institutional and legislative frameworks for water resources management exist in the Western Indian Ocean Island States. Implementation of an integrated approach to water resources management, however, is very weak, due partly to limited institutional capacity. Nevertheless, some progress was with regard to harmonisation of institutions and legislation, metering and charges and prosecution for illegal water use.

Adaptation and mitigation

There is a need:

- To implement the Mauritius Strategy (2005) for Small Island Developing States.
- To institute Integrated Water Resources Management (IWRM) in a coordinated manner, focusing on holistic water use, with a balance between all land uses, efficient irrigation systems, safe drinking-water, and water harvesting. Based on a recent survey, Mauritius is one country in the process of preparing national strategies or plans, but which requires additional work to meet the requirements of an IWRM approach (GWP 2006).
- For devolving management of water resources to lower levels, through establishment of appropriate and well-equipped structures.

- For urgent implementation of capacity enhancement programme at various levels to address the shortage of knowledge and institutional "strength," particularly in the area of IWRM.

Monitoring, databases and data availability

Monitoring, database development, and data availability of water resources varies among the 4 countries, appearing to be related to the role that a particular water source plays in the overall water supply.

Adaptation and mitigation

There is a need:

- To urgently establish, strengthen and expand monitoring networks for disaster management (e.g., extreme weather events), and to strengthen the countries' monitoring capacity. In Madagascar, for example, the effects of sea level rise are not reported because of lacking monitoring capacity. In contrast, Mauritius has established a monitoring and analysis capacity for sea levels as part of a pilot project on coastal impacts of climate change. There also is a need for information and experience sharing between the Island countries.
- For establishing and improving existing monitoring networks for meteorological and hydro(geo) logical parameters.
- For developing and managing (meta)databases.

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EASTERN AFRICA

4.1 OVERVIEW

More than 70 per cent of the population in eastern Africa (Figure 4.1-1) is rural, and practises subsistence agriculture (WHO/UNICEF 2000). Rapid population growth and increasing demands for food, combined with high rainfall variability and frequent droughts, put pressures on natural resources. Analyses of current economic and environmental trends reveal increasing competition for access to, and use of, freshwater resources. At the same time, population growth, industrialization and climate change are further stressing these resources.

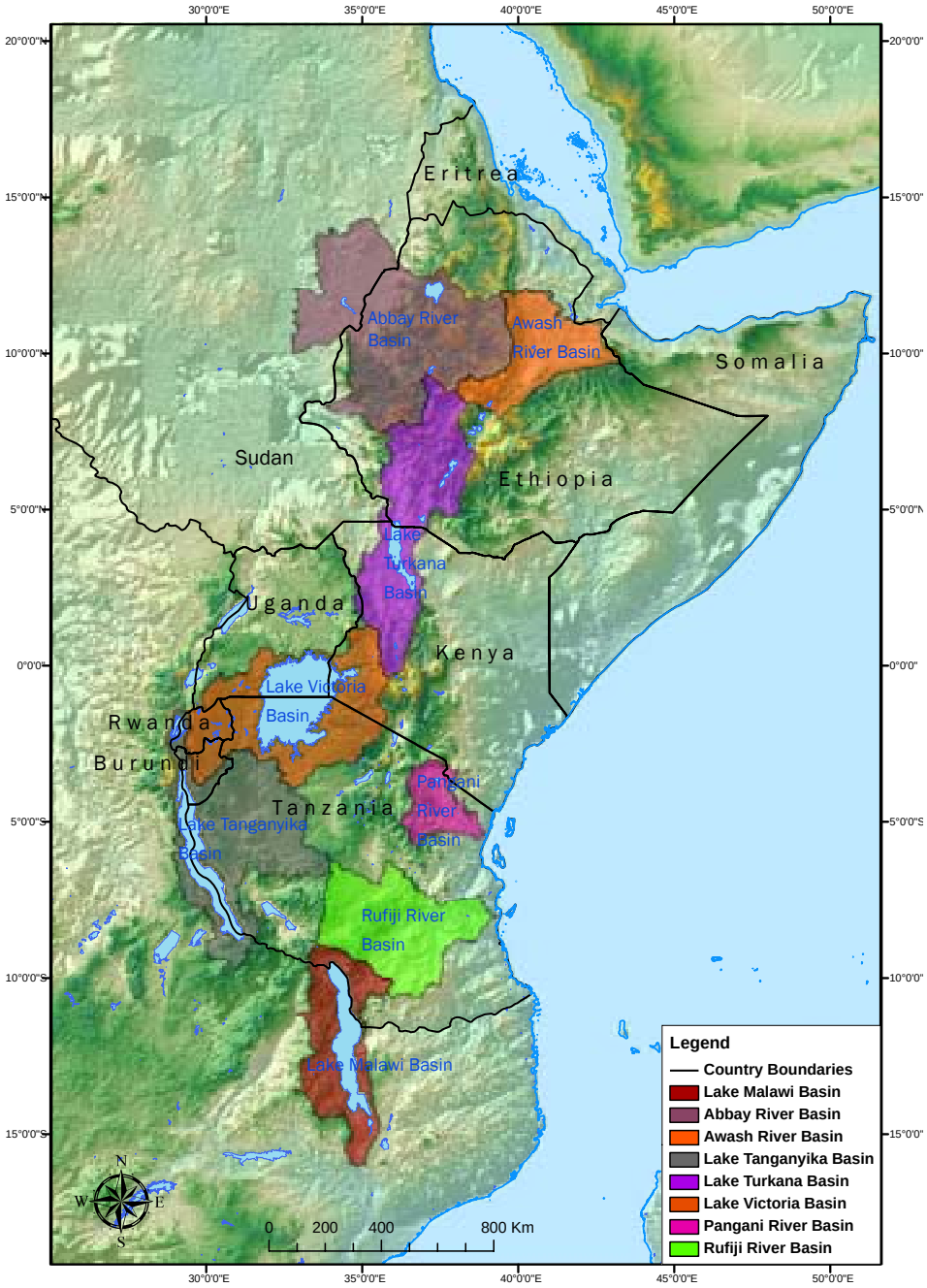

Figure 4.1-1: Major river and lake basins and drainage areas of eastern Africa

There is also competition for access to water resources between countries, some of which depend on these freshwater resources not only for domestic, agricultural and industrial consumption, but also for hydropower generation. Thus, both freshwater availability and access are priority issues for the region. Major internationally-shared river and lake basins in eastern Africa include Jubbainter; Malawi; Tanganyika; Turkana; and Victoria/Upper Nile (Figure 4.1-1). River and lake basins not internationally-shared include Abbay and Awash (Ethiopia); Pangani (Kenya); and Rufiji (Tanzania).

East African Rift Valley System

The lake basins of Malawi, Turkana and Victoria form part of the wider East African Rift Valley System, which is associated with shallow seismics. The eastern arm of the Kenya Rift System (KRS) extends from southern Ethiopia through Kenya, and into Tanzania, with the structural trend highly controlled by the underlying basement rocks. Figure 4.1-2 illustrates the location of the lakes within the East African Rift System.

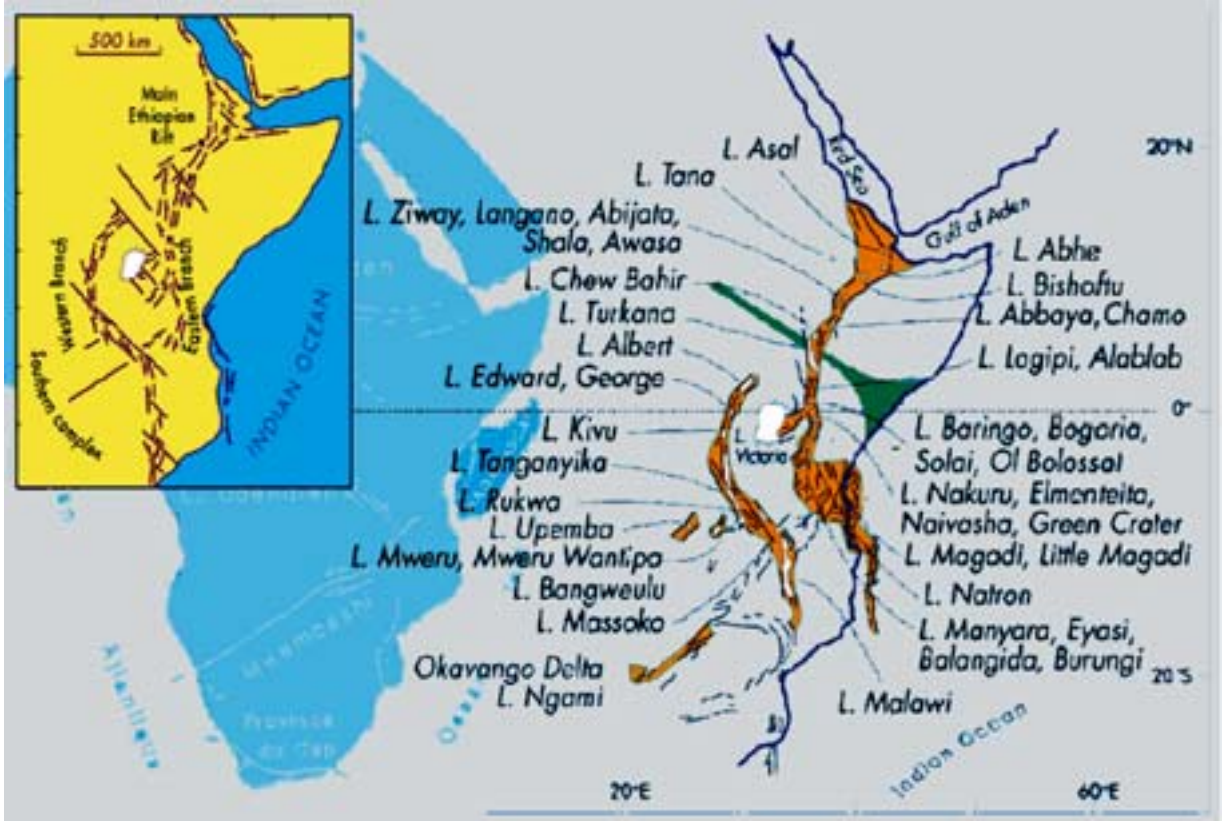

Figure 4.1-2: Lakes of East African Rift System (after Tiercelin 2002).

Source: Africaness 2007, adapted by UNEP

The rift system has provided the highlands with good climate and rainfall, leading to the formation of good water-yielding aquifers. Both the lithology and tectonics control the occurrence and availability of groundwater in the rift system. The Great Lakes Basins are the most densely-populated regions in eastern Africa. The Lake Victoria Basin, for example, has a population of 30 million people, which is expected to double by 2025. The Rift Valley System is not only of tourism and scientific interest, but also is used for agricultural and horticultural activities.

4.1.1 Physiography

Eastern Africa receives most rains from the monsoon system. The climate is equatorial, with large variation in the distribution of rains from the Indian Ocean front toward central Africa, and from north-to-south, as a result of different altitudes and latitudes. The annual rainfall ranges from 255 mm (10 in) in the drier areas in the north, to 1,245 mm (49 in) in the Lake Victoria Basin. The rainfall is highly unpredictable, both in terms of quantities from year-to-year, and of its distribution within a year. Persistent low rainfall in the region has resulted in persistent low water levels in rivers, reservoirs and aquifers, thereby influencing the hydrology, biodiversity, and water use for domestic, industrial and irrigation purposes. Figure 4.1-3 illustrates the distribution of the average seasonal rainfall over the eastern African region during the four main seasons. The potential evapotranspiration generally exceeds the average seasonal rainfall.

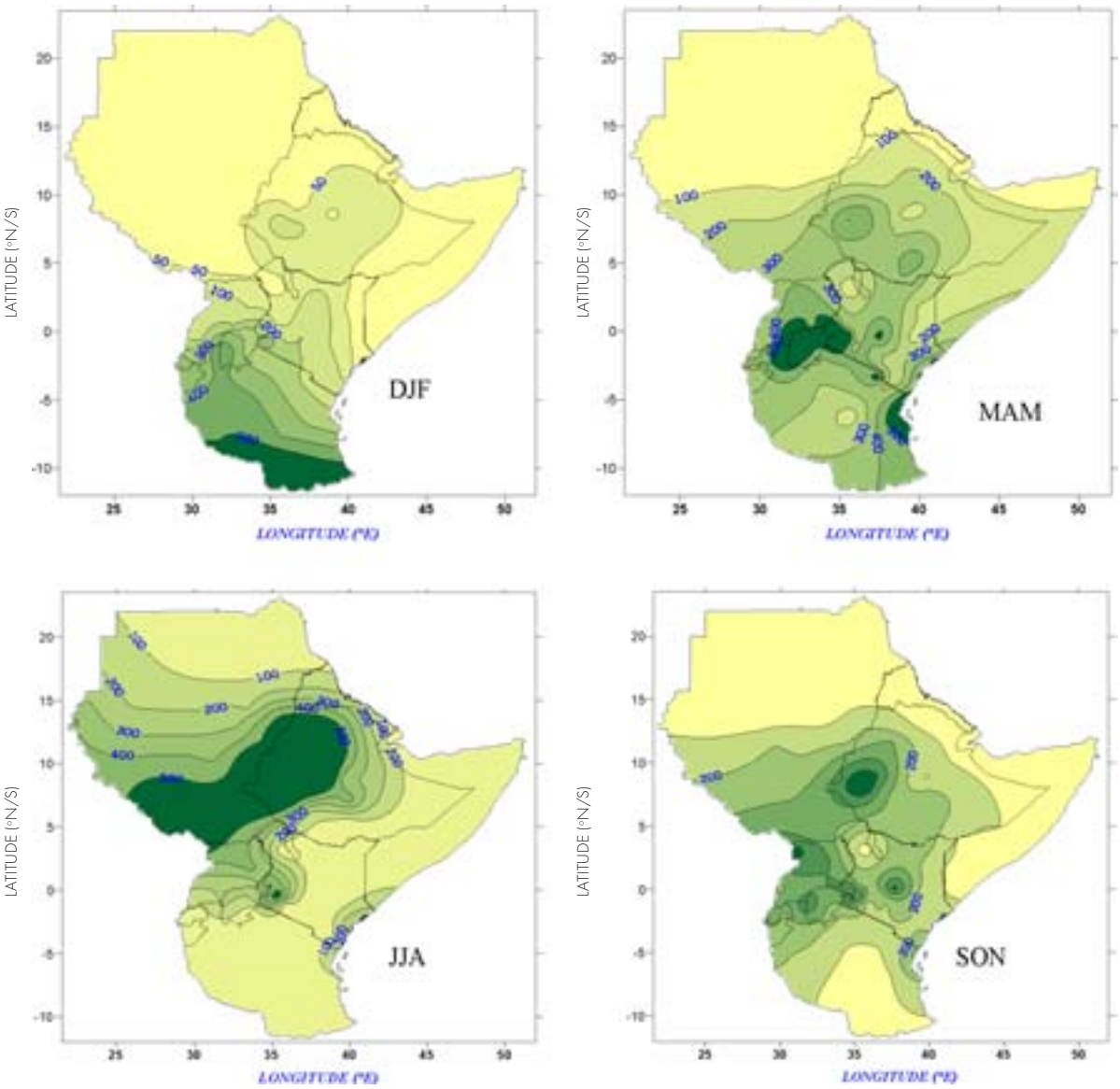

Figure 4.1-3: Distribution of seasonal rainfall over eastern Africa

Source: FAOSTAT (2000)

Eastern Africa is characterized by two fragile ecosystems: (i) the mountains and hilly areas of Burundi, Rwanda, Uganda, Kenya, and Ethiopia; and (ii) the semi-arid or arid (dry-land) areas of Djibouti, Eritrea, Ethiopia and Somalia. These ecosystems support most of the region's population, with densities of more than 200 people.km^{-2} (518 people.mi^{-2}), and are centres of crop cultivation. They have been seriously affected by deforestation, due both to urban and agricultural expansion. During the 1980s, Africa lost an estimated 47 million ha (181,468 mi^2) of forest. By 1995, another 19 million ha (73,359 mi^2) had been lost (FAO 1997). These losses have been particularly high in countries such as Uganda, where forest and woodland cover has shrunk from an estimated 45 per cent of the total land area in 1900, to only 7.7 per cent by 1995 (Ministry of Natural Resources, Uganda 1995). Deforestation has changed the rate of rainfall infiltration and evaporation, soil moisture, and temperature conditions. Further, due to increased sunlight, combined with nutrient enrichment in streams, eastern African lakes are threatened by filamentous algae (favoured by schistosomiasis-carrying snails) and weeds.

Surface water drainage in the eastern African region is controlled mainly by the African Rift Valley (Figure 4.1-2), which has an internal drainage. The area to the east of the Rift Valley drains its waters into the Indian Ocean while the remainder of the area forms the headlands and middle areas of the Nile River, which subsequently drains into the Mediterranean Sea. Freshwater resources in eastern Africa are dominated by surface water, with Lake Victoria being the single largest source. Surface water resources are also important for electric power generation.

The groundwater potential in the region is extremely variable in quality and quantity, both spatially and temporally, and in the depth of the groundwater level. The groundwater recharge varies from less than 5 per cent of the annual rainfall in the arid and semi-arid lands, where evapotranspiration losses are high, up to 30 per cent in areas of deep sandy soils and unconsolidated rocks, where evapotranspiration losses are low. The recharge rates may be higher in the humid and semi-humid regions.

Aridity and water availability

Eastern Africa has experienced at least one major drought during each decade over the past 30 years. There were serious droughts in 1973-74, 1984-85, 1987, 1992-94, and 1999-2000. There is evidence of growing climatic instability in the region, in terms of increasing frequency and intensity of droughts (FAOSTAT 2000).

Eastern Africa is fairly well endowed with freshwater, with a total average renewable volume of 187 km^3.yr^{-1} (UNDP et al. 2000). Uganda has the largest share of this volume with 39 km^3.yr^{-1} (1,791 m^3.capita^{-1}.yr^{-1}) while Eritrea has the least, with 2.8 km^3.yr^{-1} (data on per capita resources are not available; UNDP et al. 2000).

Desertification

Long droughts, overgrazing and poor agricultural practices, deforestation, and reclamation of wetlands for agriculture, all contribute to desertification, even in the coastal areas of eastern Africa. Ecosystem degradation (i.e., depletion of drinking water sources; degradation of vegetation) also is caused by overstocking of animals associated with pastoralism.

4.1.2 Socio-economy

The estimated total population of eastern Africa is 137 million people (Table 4.1-1), with the average population growth of 3 per cent being slightly higher than the sub-Saharan average of 2.9 per cent. The largest growth rate of 3.8 per cent is observed in Tanzania. On average, 52 per cent of the total population is under the age of 18 years. Population growth and human activities impact negatively on the availability of water resources (see Figure 4.1-4 for the Kenyan situation), the state of aquatic ecosystems, and water quality.

Because of high poverty levels in almost all rural areas, the region experiences a large migration of people into urban centres in search of employment and better living standards. The region's unemployment rates, however, are still very high. The few, isolated humid areas in eastern Africa are extensively overpopulated, resulting in over-utilization and degradation of land and forests, loss of biodiversity, and diminishing freshwater resources, leading to increased water-use conflicts.

Table 4.1-1: Population for eastern Africa countries for 1999.

Country	Population	Country	Population
Djibouti	434 116	Malawi	9 609 081
Eritrea	3 589 687	Somalia	6 590 325
Ethiopia	58 732 577	Tanzania	29 460 753
Kenya	28 803 085		**Total: 137 219 624**

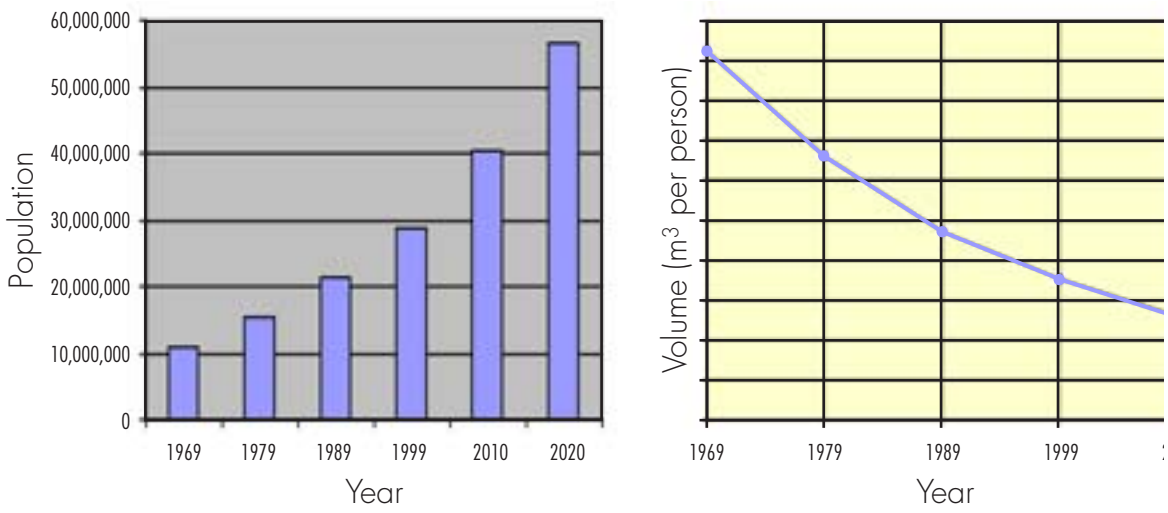

Figure 4.1-4: Population growth and per capita water availability for Kenya

Source: Ministry of Water Development, Kenya - Water Master Plan 1992

The average annual GDP growth rate of the eastern African countries of Tanzania, Kenya, Uganda, Rwanda, Burundi, Eritrea and Ethiopia was 4.2 per cent for the period 1992-2002 (ww.earthtrends.wri.org 2007). It should be noted, however, that diverse performance trends exist in the different countries. Discounting such factors as the slump in tourism and trade, and a decline in Foreign Direct Investments and donor assistance, the overall economic performance of eastern Africa also is heavily influenced by the agricultural sector and agricultural development. Food production was particularly impacted by erratic weather conditions and the El Nino effect in 1997, demonstrating eastern Africa's vulnerability to climate variability and change.

In many African countries HIV/AIDS surveillance is now registering infection rates of 15-25 per cent among adults, being higher in urban areas, and also increasing in rural areas. The most heavily-impacted group is the working population (age group of 15-45), with more women infected than men, and at earlier ages. The impact of HIV/AIDS has overwhelmed communities, governments and countries in eastern Africa, having crippled education and health services, destroyed households and affected business productivity.

Water demands and water uses

Annual freshwater withdrawals are a small percentage of the total available quantity of water, ranging from less than 3 per cent of the total resources available in Burundi, to 12 per cent in Rwanda (UNDP 2000). The water demands, however, frequently exceed the supply because of rainfall variability. Water for agricultural use, currently being 88 per cent of available water resources, will continue to command the highest demand. Domestic water demands will increase as a result of rapid population growth and urbanization. In Uganda, for example, the per capita urban water use was 90 $L.d^{-1}$ in 1980, and was expected to almost double by the year 2000 (NEMA 1999). Countries expected to experience severe water scarcity by 2025 are Ethiopia, Kenya and Somalia. Increased water stress[5], such as that caused by prolonged periods of low rainfall, and increased domestic and agricultural water demands, also affects countries dependent on hydroelectric power (e.g., Tanzania; Kenya; Uganda). Increased domestic water demands in Uganda in 1999, for example, resulted in a drop in power supply from the 162-megawatt (MW) capacity hydroelectric station at the Owen Falls Dam on the River Nile to its neighbour Kenya.

Access to water and sanitation

Eastern Africa has the lowest safe drinking water and sanitation coverage in Africa. It also has made the least progress in regard to the Millennium Development Goal for sanitation coverage since 1990 (see Figure 4.1-5). In 2004, Ethiopia had the lowest total water coverage in Africa of 22 per cent in 2004, and Eritrea had the lowest sanitation coverage of 9 per cent (WHO/UNICEF 2006). There should be an accelerated effort to reduce the delay in meeting both targets, especially in rural areas.

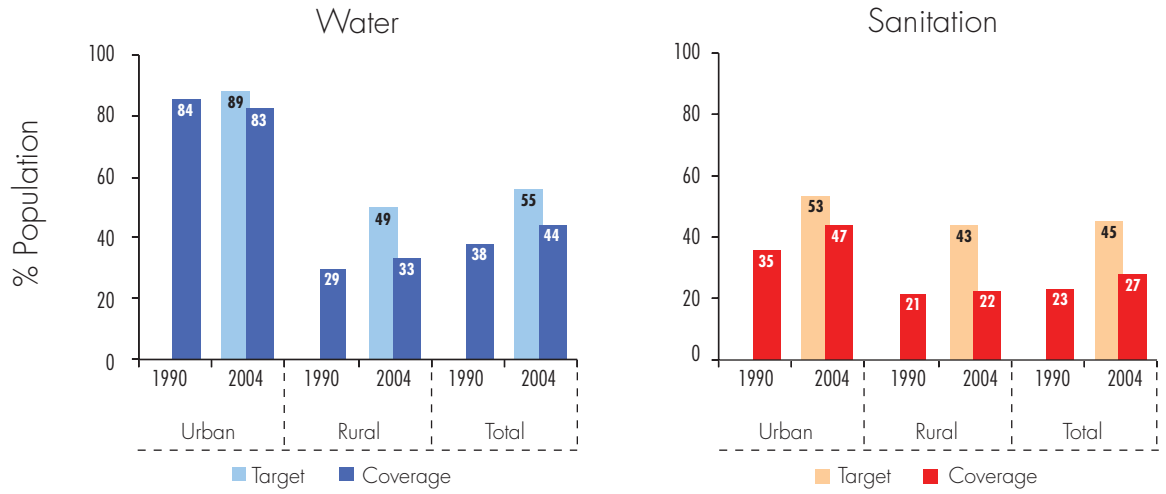

Figure 4.1-5: Water supply and sanitation coverage in rural and urban settings for eastern Africa between 1990 and 2004 (Somalia is excluded because of incomplete data)

Source: WHO/UNICEF 2006, redrawn by UNEP

[5] Water stress occurs when the water demands exceed the available quantity during a certain period, or when poor quality restricts its use (GreenFacts; 2008: www.greenfacts.org).

4.1.3 Management

Water legislation exists at the national level in Ethiopia, Kenya, Tanzania and Uganda (Sharma et al. 1996). Responses to water stress include: (i) revision of water resources development policies; (ii) improved reticulation and treatment; and (iii) greater involvement of stakeholders in water management and supply, with some examples being:

- Ethiopia initiated a process in 2001 to develop a sectoral strategic action plan for the realization of national water policy objectives. The strategy prioritizes the interest and roles of different stakeholders invited to make inputs to the strategy development.
- Kenya commercialized water supply and sanitation schemes in the Kericho, Eldoret and Nyeri pilot areas. These pilot studies will test whether or not privatization contributes to meeting the goals of the Kenyan Water Act (Cap. 372) (i.e., to enhance the provision, conservation, control, apportionment and use of water).
- Tanzania's revised National Water Policy has been based on 7 guiding principles that include the recognition of water as a social, economic and environmental good, the 'polluter pays' principle, and a basin approach in water resources planning and management.
- Uganda's long-term goal for the water sector is a system of full cost-recovery for services provided, but also with provision of cross-subsidized safe water services for low income groups. A National Wetlands Policy was formulated and passed by the Ugandan government in 1994, calling for capacity building for wetlands management, public awareness and wetland resource assessment.

Governments recognize that water stress problems are not confined solely within their national borders. Issues related to management of international waters are addressed at various fora, with regional bodies having been formed for such purposes. Major international programmes for water resources management in the region include the Lake Victoria Environmental Management Programme (LVEMP) and the Nile Basin Initiative (NBI), as follows:

- The LVEMP was established in 1995, with a focus on creating baseline data and information to guide future action plans, especially in regard to fisheries management, pollution control, invasive weeds control and catchment land-use management. The first phase of the programme was seen as an initial step in a long process that should lead to the improvement of sustainable use of the natural resources of the Lake Victoria Basin. Achievements to date include: (i) bio-control of water hyacinth *(Eichornia crassipes)*; (ii) involvement of local communities in fisheries research and management; and (iii) afforestation in the surrounding catchments. For the second phase, identified priority areas are socio-economic development, management and research, and major transboundary issues (e.g., increase of water hyacinth; siltation and deforestation associated with the upstream counties of Rwanda and Burundi).
- Over the last decade, efforts towards cooperation on the Nile have intensified, with the Technical Cooperation Committee for the Promotion of the Development and Environmental Protection of the Nile Basin (TECCONILE) being established in 1993, with the goal of promoting a development agenda. A transitional mechanism for cooperation was officially launched by the Council of Ministers of Water Affairs of the Nile Basin States (Nile-COM) in Dar-es-Salaam in February 1999. The process was officially named the Nile Basin Initiative (NBI) in late-1999, with a secretariat being established in Entebbe, Uganda, in November 2002. Within this framework, plans have been designed to harness the basin's waters for irrigation, and also

to establish an energy policy to provide power to all the countries in the region. Some NBI projects, including those aimed at harnessing energy, and those designed to make the optimal use of fisheries resources, are nearing their implementation stage.

Water sector reform

There has been progress in water sector reforms in eastern African countries that will create an enabling environment to mitigate the adverse effects of environmental change on water resources. Stakeholder engagement, including community responses to water stress, is critical in this context.

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4.2 ABBAY RIVER BASIN

The Abbay River (Blue Nile) Basin lies in the west of Ethiopia, between 7^0 45′N and 12^0 45′N, and 34^0 05′E and 39^0 45′E (Figure 4.2-1). The basin extends about 400 km (249 mi) from north to south, plus an extension in the south formed by the Didessa Valley; and about 550 km (342 mi) from east to west. The total area of the basin is about 199,812 km^2 (77,148 mi^2) (Bceom 1998). The main characteristics of the basin are summarized in Box 4.2-1.

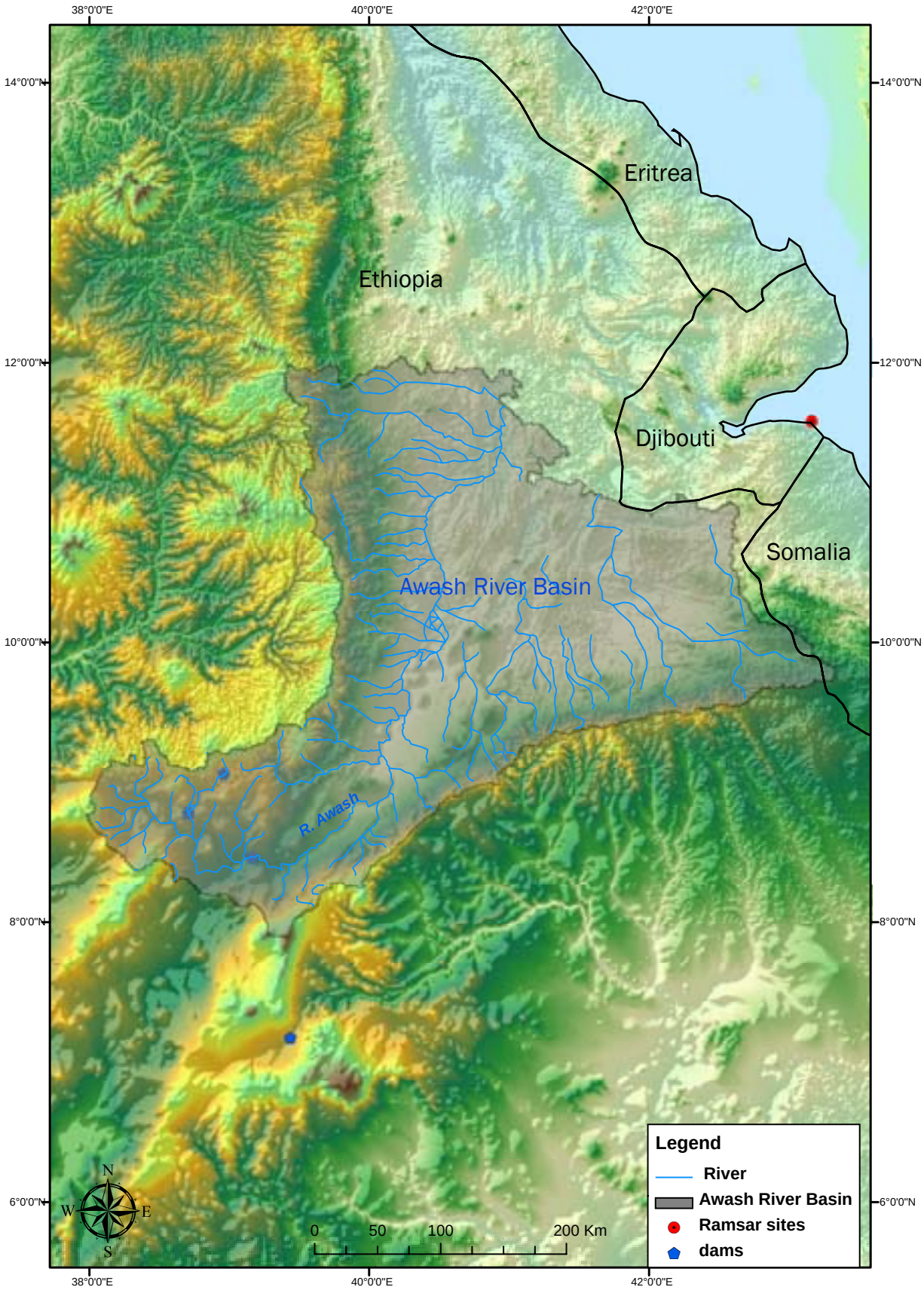

Figure 4.2-1: Abbay River Basin

Box 4.2-1: Main characteristics of Abbay River Basin.

Basin
Surface area: 199,812 km^2 (77,149 mi^2)
MAP: 800-2,200 mm.yr^{-1} (31-87 in.yr^{-1})

Demography
Population: 16 million
Density: 80 persons.km^{-2} (207 persons.mi^{-2})

Water Resources
River length: 992 km (616 mi)
MAR: 49,000 Mm^3.yr^{-1}

Major Dams
Finchaa –Amerti: 780 Mm^3

Major Aquifers: Amba Aradom Sandstone and Antalo Limestone

Water Use
Hydropower
Agriculture
Domestic
Industry
Mining

Vulnerability
Increases down the valley

The water resources in the basin are dominated by the Abbay River, which runs through the centre of the catchment, developing its course in a clockwise spiral (Figure 4.2-1). It has a number of tributaries along its 992 km (616 mi) length before reaching the Sudanese border above the Roseires Dam. Lake Tana, which is Ethiopia's largest freshwater lake, is in the north end of the basin, and covers about 3,000 km^2 (1,158 mi^2). It is also the source of the Abbay River. The river has an average annual runoff of about 49 billion m^3. On average, the rivers of the Abbay Basin contribute about 62 per cent of the total Nile River at Aswan (Halcrow 1989).

Irrigation development covers an area of about 20,000-30,000 ha (77-116 mi^2), excluding traditional small-scale irrigation. Other than the recently-completed Finchaa Stage 1 project (6,200 ha [239 mi^2]), modern irrigation occurs entirely in small and medium-scale schemes. Hydropower in the Abbay Basin is underdeveloped, with an installed capacity of 214.50 megawatts, which is less than 2 per cent of the potential of the basin. (Halcrow 1989).

Current water use in the basin is only a small fraction of the available water resources and there are few, if any, water conflicts. The water resources have been exploited to a very limited extent to the present time, and no shortage is anticipated, based on the planned development programmes and projected population growth in the basin.

4.2.1 Physiography

The annual rainfall varies between about 800-2,220 mm (31-87 in), with a mean of about 1,420 mm (56 in). There are three distinct seasons. The main rainy season *(Kiremt)* lasts generally from June to September, during which about 70-90 per cent of the total rainfall occurs. The mean annual evapotranspiration is about 1,300 mm (51 in). The mean temperature of the basin is 18.5 °C (65 °F), with minimum and maximum average daily temperatures of 11.4 °C (53 °F) and 25.5 °C (78 °F). The temperatures generally decrease with altitude (about 0.7 °C per 100 m [0.1 °F per ft]). In

contrast, the rainfall tends to increase with altitude, while also being greatly affected by local rain shadow and related effects.

In many respects, the physiography defines the basin, the steep slopes and frequent dissection posing constraints to both activity and communications. Conversely, the physiography also underwrites significant potential (e.g., hydro-power development). The basin physiography reflects its geology and geological history. A general uplifting of the highland plateau, followed by tilting, provided an initial highland altitude range between 1,500-3,000 m (4,921-9,843 ft). Volcanic activity produced peaks (volcanoes) rising to over 4,000 m (13,123 ft) amsl, being 4,230 m (13,878 ft) at the summit of Mount Guma, while the associated extrusions of lava covered the plateau with a thick basalt cap. Wherever this protective basalt layer has been broken to expose the underlying sedimentary rocks, however, the dissection has been deep, as runoff cuts to the base level of the western lowlands. Noticeable is the gorge of the Abbay River, which completes a clockwise semi-circle along its 922 km (3,025 mi) length from Lake Tana to the Sudanese border.

The basin can be divided into three broad physiographic areas, related directly to the three above-noted geologic divisions. The highland plateau is dominant, with its basalt cap, deep clay soils, and overall gentle slopes and broad shallow valleys (sitting on top of the basalt), although it is frequently punctuated by ancient volcanoes whose steep slopes reach elevations of over 4,000 m (13,123 ft) amsl. Dissection and associated erosion, however, have reduced the gentle plateau areas to remnants, divided from each other by deeply entrenched rivers and their tributaries, with associated steep-to-very-steep slopes. This reaches its zenith in the northeast part of the basin, in the upper Abbay gorge, where remnant level plateau areas are perched and isolated on interfluves between the numerous entrenched drainages. These drainages, and associated steep slopes and shallow soils, with exposure of the sedimentary rocks and wide ranges of altitude, form the basin's second physiographic division. Finally, the western lowlands, developed on ancient Precambrian rock form an area of dominantly low slope and low altitude, with an altitude of about 490 m (1,608 ft) at the Sudanese border.

The land cover of the basin essentially follows the divide between highland and lowland. The highlands were once predominantly covered with forests. However, these montane sub-humid tropical forests have been reduced to remnants, with the land having been converted to cultivation and grazing land. Almost the entire highland area is now under farmland. Further, nearly all cultivation (about 90 per cent) occurs in the highlands, a strong indicator of the problems faced by small land holders in extending cultivation into the lowlands. Forest remnants remain in the southwest, where they are either under active conversion to cultivation, or are 'protected' through serving as shade for coffee trees.

Other forest remnants exist along the highland-lowland divide, generally on steep slopes, and often in micro-climates below their optimal altitude. The other major highland land cover is grassland, which occurs primarily either in poorly-drained depressions, or on level (and often poorly-drained) and exposed high altitude locations. Extensive grassland areas also occur within farm land areas. Similarly, bush and shrub occur as inclusions throughout the landscape, although rarely comprising significant areas.

Interventions in the water sector fall into three main areas: irrigation, hydro-power, and water supply and sanitation. The total net area included as identified potential large and medium scale

irrigation schemes is 526,000 ha (2,031 mi^2), comprising 123 schemes of various sizes. Possible development within the master plan period (50 years) is largely based on projected development rates, taking into account an increase in capacity in planning and implementation in the public sector (Halcrow 1989). Two scenarios have been formulated, assuming different growth rates: (i) a conservative scenario, with a total area of about 235,000 ha (907 mi^2); and (ii) an accelerated development scenario, with a total area of about 350,000 ha (1,351 mi^2).

Large-scale hydropower projects have a national and regional significance, and will impact individuals indirectly through the provision of energy. Accordingly, projects with a total installed capacity of about 1,535 megawatts are planned to be built by 2025.

The groundwater resources are almost exclusively included in consolidated rocks; namely, basalts, limestone and sandstone, and metamorphic basement. The groundwater potential of these rocks is low, thereby linking groundwater occurrence to secondary features (e.g., fracture zones). It is anticipated, however, that the porosity of some geological formations may make a significant contribution to groundwater storage (probably Amba Aradam and the Adigrat sandstones). Most groundwater is obtained from 60-100 m (197-328 ft) deep boreholes in volcanic rocks. Although the Adigrat sandstone outcrops in the southern part of the basin, most of the geological strata, as well as the other sedimentary formations (e.g., Antalo limestone and Amba Aradam sandstones) are generally overlain by thick basaltic rocks that impede infiltration. The groundwater resources are generally utilized mainly for drinking purposes.

4.2.2 Socio-economy

Population figures from 1999 indicate there are just over 16 million people living in the Abbay River Basin, which represents an average population density of 80 $persons.km^{-2}$ (207 $persons.mi^{-2}$). Almost 85 per cent of the population is rural, with houses often distributed across the farming area, rather than being concentrated in villages. The present growth rate of urban centres, mostly situated on the periphery of the basin, is estimated to be low. This settlement pattern, and the low rates of urbanization, is associated with an ill-developed infrastructure and low levels of services. The road density is among the lowest in Africa, the housing standards are poor, and access to water supply and electric power is below the national average (Devecon Engineers and Architects 1992).

The Abbay Basin is, by most criteria, the most important river basin in Ethiopia, accounting for almost 20 per cent of Ethiopia's land area, 50 per cent of its total average annual runoff, 25 per cent of its population, and over 40 per cent of its agricultural production. With more than 85 per cent of the basin population being rural, agriculture and livestock dominate the economy. Agriculture accounts for more than half the GDP, more than 80 per cent of the labour force, and most of the country's exports, although production (crops; livestock) is very low. Some of the reasons for this situation include low soil fertility; very small land holding size; lack of improved agricultural inputs; climatic variability; and subsistence orientation.

Compared to the total hydropower and irrigation potential of the basin, very limited development has taken place, as reflected in the extreme poverty level of the population. The region is largely underdeveloped, with high unemployment and widespread poverty. Its main agricultural products include coffee, cereals, fruits and vegetables.

4.2.3 Management

The Federal Ministry of Water Resources is in charge of water sector policy formulation and planning, and water resources development and use. It also is responsible for the creation of water resources regulation policies, and for the implementation of large-scale irrigation and hydropower projects. Further, it has responsibility for building water resources development capacity, and for preparing plans for their proper utilization. The ministry also supervises basin development departments responsible for conducting studies and research on natural and water resources in the country's river basins. The proposed Blue Nile Basin Authority will be responsible for implementing and managing the water resources in the Abbay River Basin.

4.2.4 Key Issues, adaptation and mitigation

Physiography

About two-thirds of the Abbay Basin is located above 1,500 m (4,921ft), being an area that usually gets adequate rainfall for crop production. Upland erosion has occurred, however, because of the removal of vegetation and forest cover.

Adaptation and mitigation

There is a need:

- To develop and implement land management policies that abate land degradation.

Socio-economy

Rapid population growth is resulting in a very high population density, particularly in the uplands (above 1,500 m [4,921 ft] amsl). This growth further exacerbates land degradation, and the lack of infrastructure, poor access to roads and other social infrastructure, and health problems related to malaria, are dictating the settlement patterns. The basin poverty levels are high.

Adaptation and mitigation

There is a need:

- To invest in rural infrastructure to raise the standard of living of the communities. This also will be an incentive for organised settlement that will mitigate land degradation.
- To develop and implement anti-malaria programmes that encourage communities to move to lower areas of the basin, thereby relieving pressures on the uplands.

Management

An institutional framework and water-related legislation and guidelines are currently being organized in the basin. The Blue Nile Basin Authority will be established to implement and regulate water-related programmes and projects in the basin.

Adaptation and mitigation

There is a need:

- To expedite formation of the Blue Nile Basin Authority, in order to ensure early intervention in managing the basin's resources, thereby abating continued environmental deterioration.

- For the Authority to develop implementable guidelines and regulations for land and water resources development and management.
- To set up and strengthen standardized information collection and sharing systems among the basin stakeholders. The proposed formation of the Water Resources Information Centre by the Ministry of Water Resources should be given priority, so that vital historical information, essential to effective management of the basin, is not lost.

4.2.5 References

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4.3 AWASH RIVER BASIN

The Awash River Basin is situated between latitudes 8^0 30′ N and 12^0 0′ N and longitudes 38^0 E and 43^0 25′ E in Ethiopia (Figure 4.3-1), and its main characteristics are summarized in Box 4.3-1. The basin covers a total area of about 110,000 km^2 (42,471 mi^2), of which 64,000 km^2 (24,711 mi^2) constitutes the western catchment of the basin. This catchment drains to the main Awash River or its tributaries. The remaining 46,000 km^2 (17,761 mi^2), most of which comprises the so-called eastern catchment, drains into a desert area, thereby not contributing to the main course of the Awash River.

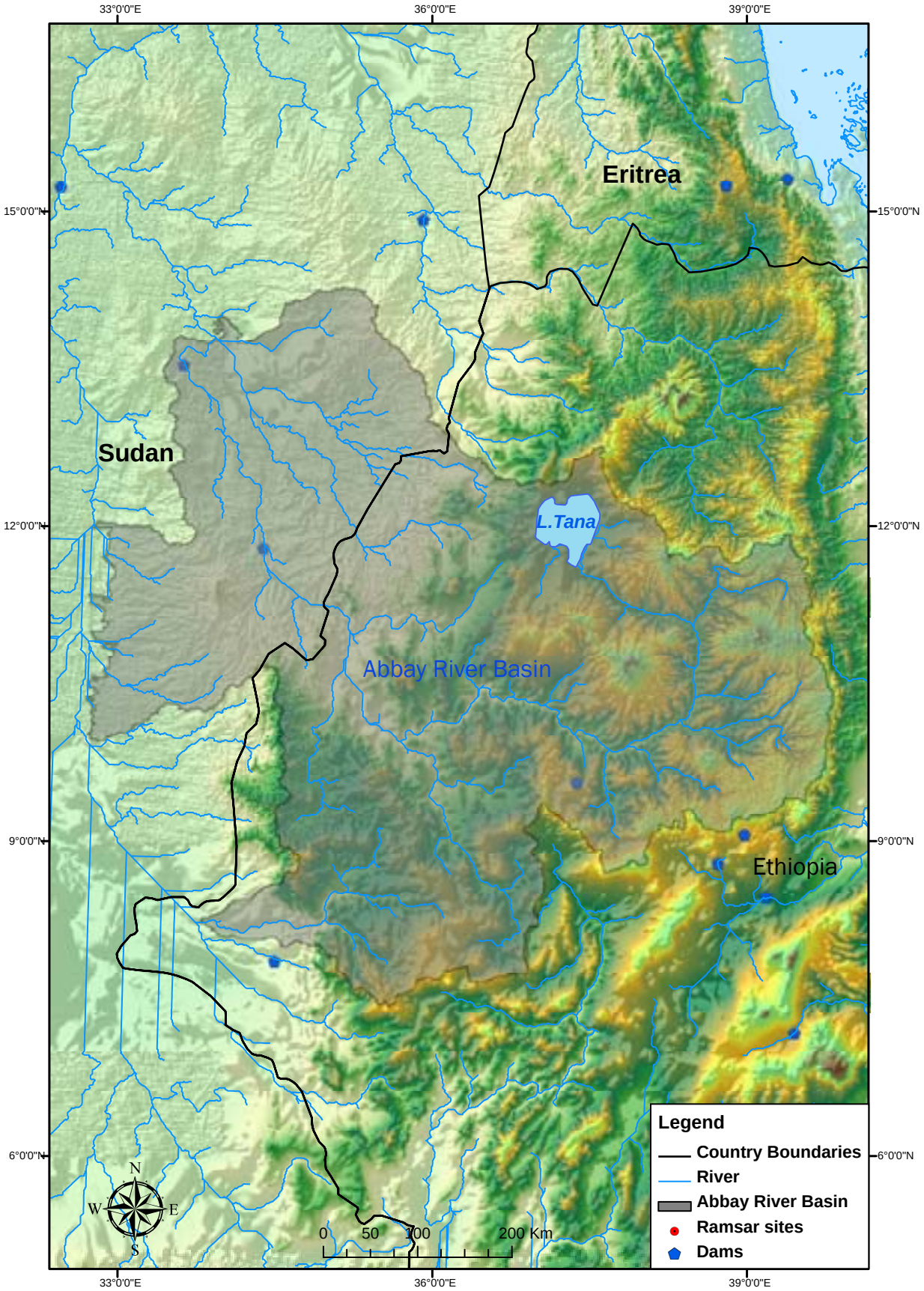

Figure 4.3-1: Awash River Basin

Box 4.3-1: Main characteristics of Awash River Basin

Basin

Surface area:	110,000 km^2 (42,471 mi^2)
MAP:	160-1600 mm.yr-1 (6.3-63 in.yr^{-1})

Demography

Population:	10.5 million
Density:	95 persons.km^{-2} (246 persons.mi^{-2})

Water Resources

River length:	1,200 km (746 mi)
MAR:	4,600 Mm^3.yr^{-1}

Major Dam

Koka:	1,850 Mm^3

Water Use

Agriculture
Hydropower
Domestic
Industry
Mining

Vulnerability

Increasing to the east

The Awash River rises at an altitude of about 3,000 m (9,843 ft) amsl in the central Ethiopian highlands west of Addis Ababa, flowing northeast along the Rift Valley into the Afar Triangle, where it terminates in a series of salt lakes, the last one being Lake Abe at an elevation of 250 m (820 ft) amsl (Halcrow 1989). The length of the main river is about 1,200 km (746 mi).

Among all the river basins in Ethiopia, the Awash is the most developed. The potential net irrigable land resource of the upper and middle valley, and the lower plains area, has been estimated to be on the order of 150,000 ha (579 mi^2), of which 69,000 ha (266 mi^2) is currently irrigated. Further, small and medium-scale irrigation development areas total about 35,000 ha (135 mi^2), and lie within the main river catchment. The area listed as being under small-scale irrigation is on the order of 20,000 ha (77 mi^2), most being in the uplands. The basin's water resources are still adequate to meet the existing large irrigation projects, although this situation is expected to worsen in the future with the expansion of irrigation schemes.

Constructing large reservoirs, improving irrigation water management, and transferring water from neighbouring catchments, are proposed solutions for water shortages during future irrigation expansion (Devecon Engineers and Architects 1992; Halcrow 1989). The groundwater yield in the basin is estimated to be on the order of 200 million m^3.yr^{-1}, which is a low value meaning that no major groundwater resources-based irrigation development is envisaged for the basin. Groundwater use in the basin largely provides domestic water supply to rural towns and villages, and could be developed to address livestock watering, and both domestic and industrial demands.

4.3.1 Physiography

The mean annual rainfall varies from about 1,600 mm (63 in) at Ankober, in the highlands northeast of Addis Ababa, to 160 mm (6.3 in) at Asayita on the basin's northern limit. Addis Ababa receives 90 per cent of its annual rainfall during the rainy period of March to September. The mean annual rainfall over the entire western catchment is 850 mm (33 in), and the annual runoff is about 1,216 mm (48 in) over the headwaters of the Awash, as gauged at Melka Hombole. The mean

annual rainfall over the eastern catchment is estimated to be 465 mm (18 in), with the annual and monthly rainfalls characterized by high variability. The mean annual temperatures range from 20.8 °C (69 °F) at Koka, to 29 °C (84 °F) at Dubti, with the highest mean monthly temperatures at these stations, 23.8 °C (75 °F) and 33.6°C (92 °F), respectively, occurring in June.

Forest and woodland habitats in the Awash River Basin are limited because of climatic controls, edaphic controls, and land clearance. Much of the highlands have been cleared for cultivation, although natural or semi-natural forest is found in the less-accessible areas (e.g., along the steep slopes on the western escarpment). A rapid, predominantly rural-based, population increase over recent decades has been widely cited as the key driver behind environmental degradation in the basin. A second driver is the spatial distribution of the population, with approximately 49 per cent of the population residing above 2,200 m (7,218 ft) amsl, and 89 per cent residing above 1,500 m (4,921 ft) amsl. There are two main environmental problems in the basin; namely (i) serious soil erosion and land degradation in the uplands; and (ii) sedimentation, flooding and river aggradations in the middle and lower valleys.

The two main physiographic components of the Awash Basin are the Ethiopian Plateau and the Rift Valley, which widens to the north into the Afar Triangle. The dominant rocks on the plateau are Tertiary volcanics (basalt tuffs). The volcanic rocks are mainly basalts and ignimbrites on the floor of the Rift Valley. During the Pleistocene pluvial period, very large lakes were formed on the floor of the Rift Valley, and on the flat plains of Wonji, Metahara. The Lower Awash Plains contain a thick succession of lacustrine deposits. The plateau comprises the denuded surface of Precambrian basement rocks atop of which lie near the horizontal Mesozoic sediments and covered, in turn, by Tertiary flood basaltic extrusions. Exceptions on this flat plateau area are the deeply-incised river valleys and the volcanic masses, the latter rising to over 3,000 m (9,842 ft) amsl.

Interventions in the water sector fall into three main areas, including (i) sedimentation and flood control in the middle and lower plains; (ii) soil conservation in the upland areas; and (iii) irrigation and water supply development, with due consideration for, and integration of, the trans-human pastoralists and livestock development.

4.3.2 Socio-economy

The current population of the Awash River Basin is estimated to be 10.5 million. The main population centres lie in the upper basin, and in the upland areas above 1,500 m (4,921 ft), which is nominally considered to be the lower threshold limit for rainfed agriculture. This corresponds to an average population density of about 95 persons.km^{-2} (246 persons.mi^{-2}). The main population centres are Debre Zeit and Nazaret, with populations of 97,300 and 144,300, respectively. There are no significant centres below Nazaret. A number of small towns and villages have been developed along the road network in response to irrigation developments.

The Afar Region, predominately populated by nomadic and semi-nomadic pastoralists, is generally not known for settled agriculture. The riverside land, however, especially the flat lowlands, is fertile, being intensively cultivated and relatively densely-populated in parts. Certain areas were developed by the former government into large irrigated state farm plantations for producing cotton, sugar and other cash crops and, in recent years, some of these farms have been taken over by private entrepreneurs. These big farms have attracted a considerable number of migrant workers, mostly from overpopulated areas in the southern part of the country.

Agriculture is the most important economic sector in the Awash River Basin, engaging more than 85 per cent of the households. Mixed farming is the major practice, involving cotton and cereal growing, the cultivation of perennial crops, pastoralism and agro-pastoralism. The major cereal crops are wheat and barley, although pulses are also grown. Sorghum, maize, and some vegetables and fruits are cultivated in irrigated fields, and in the small strips of flooded land along the main rivers, using residual moisture.

4.3.3 Management

The Federal Ministry of Water Resources is in charge of water sector policy formation and planning, and water resources development and use. It also is responsible for creating water resources regulation policies, as well as implementing large-scale irrigation and hydropower projects; and for building regional capacity regarding water resources development, as well as preparing plans for the proper utilization of water resources. The ministry also supervises basin development departments responsible for conducting studies and research on natural and water resources in the country's river basins.

The Awash Basin Water Resources Administration Agency ABWRAA was established as an autonomous public agency by Proclamation No. 129/1998, to administer the available water resources of the Awash Basin, and regulate the flow of water in its rivers.

4.3.4 Key Issues, adaptation and mitigation

Physiography

Over 75 per cent of the river basin area is classified as being arid-to semi-arid, with the rainfall being inadequate for crop production. The situation is compounded by recurrent droughts and uneven rainfall distribution. Land degradation is caused by steep slope cultivation, and deforestation for agricultural land.

Adaptation and mitigation

There is a need:

- To develop an early warning system for both impending droughts and floods.
- To develop and encourage appropriate crops and livestock and production technologies suitable for drought conditions.
- To develop legislation, policies and guidelines for holistic land management, and cropping patterns suited for various soil types.
- To involve communities in ecosystems management, with projects that directly benefit the communities forming an integral management component.

Socio-economy

Rapid population growth is resulting in a very high population density. Poverty also is prevalent within the basin population.

Adaptation and mitigation

There is a need:

- To invest in rural infrastructure to raise the standard of living of the communities, which also will act as an incentive for organised settlement, thereby mitigating land degradation.
- To implement measures that curb high population growths.

Management

The Awash Basin Water Resources Administration Agency is responsible for regulating and implementing water-related projects in the basin. Basin management, however, appears to be weak, since there is a serious land degradation problem in the basin.

Adaptation and mitigation

There is a need:

- To strengthen the Awash Basin Water Resources Administration Agency to effectively and efficiently manage the basin's natural resources. The proposed formation of the Water Resources Information Centre by the Ministry of Water Resources should be given priority, so that vital historical information, essential for effective management, is not lost.

4.3.5 References

Devecon Engineers and Architects, 1992: *Feasibility and design works of the water supply system of Gondar town*. Volume I report, Phase I, Ministry of Water Resources, Addis Ababa, Ethiopia, 115pp.

Halcrow 1989: *Masterplan for the development of surface water resources in ten Awash basin*, Vol.6. Ministry of Water Resources, Addis Ababa.

Halcrow 1989: *Rift valley lakes integrated natural resources development master plan*. Unpublished Report, Ethiopian Valleys Development Studies Authorities, Addis Ababa.

4.4 PANGANI RIVER BASIN

The Pangani River Basin covers an area of 43,650 km^2 (16,853 mi^2), with 3,914 km^2 (1,511 mi^2; 5 per cent) being in Kenya, and the remainder being in Tanzania, ultimately draining into the Indian Ocean (Figure 4.4-1). The administrative centre of the Pangani Basin is in northeast Tanzania. The basin consists of the Umba, Sigi, Msangazi, and Pangani Rivers. The Pangani River dominates the basin, with its catchment covering the regions of Kilimanjaro, Manyara, Arusha and Tanga. A small part of the catchment is located in Kenya, being entirely within the district of Taita-Taveta. The main characteristics of the Pangani River Basin are summarized in Box 4.4-1.

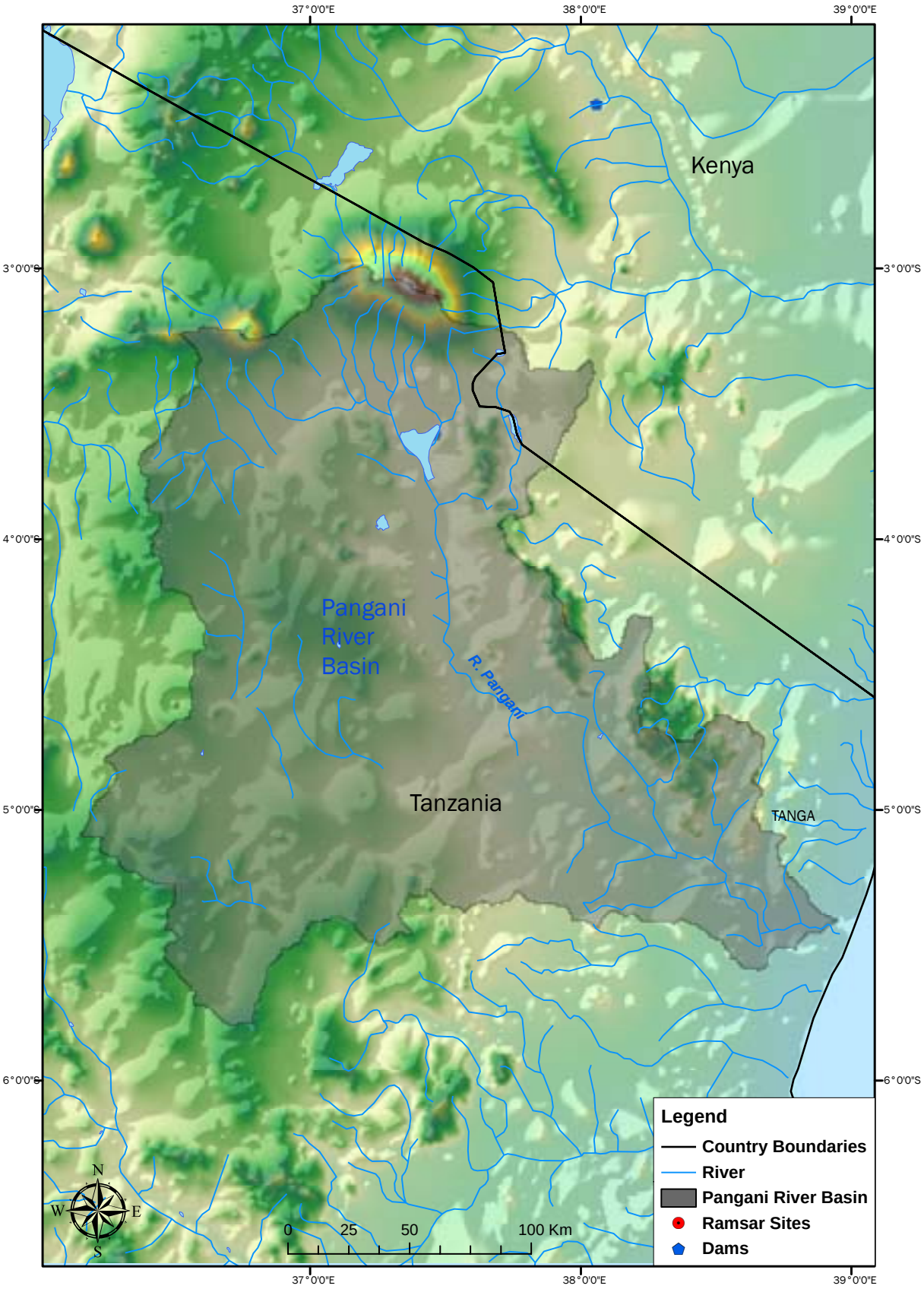

Figure 4.4-1: Pangani River Basin

Box 4.4-1: Main characteristics of Pangani River Basin

Basin

Surface Area:	43,650 km^2 (16,853 mi^2)
MAP:	1,001.9 $mm.yr^{-1}$ (39 $in.yr^{-1}$)

Demography

Population:	3.7 million
Density:	up to 300 $persons.km^{-2}$ (777 $persons.mi^{-2}$)

Water Resources

River Length:	432 km
MAR:	1,773.5 $Mm^3.yr^{-1}$

Major Dams:

Nyumba ya Munga:	1.140 Mm^3
Kalimawe:	24.7 Mm^3

Water Use

Agriculture (1,205.1 million m^3)
Domestic (57.6 million m^3)
Industry (NK)
Mining (NK)
Hydropower (422.7 million m^3)

Source: National Irrigation Master Plan 2002; IUCN 2003

The basin generally comprises a small slope that drops gently south and southeastwards towards the Indian Ocean. On average, this landscape of 'Maasai steppe' lies at 800 m (2,625 ft) amsl, with much of it receiving little more than 500 mm (20 in) of rainfall per year. Rising up out of the plain, in stark contrast, are a series of mountains, which may receive 2,000 mm (79 in) of rainfall per year. These mountains are islands of spectacular biodiversity and biotic endemism, while the plains around them display an unremarkable biodiversity and difficult livelihood conditions.

Humans early appreciated the qualities of these mountains and, even before the advent of Tanzania's colonial administration, the mountains of the Pangani River Basin (PRB) were the most densely-populated areas on the plain.

As the Pangani River curves eastwards, and descends onto Tanzania's coastal plain, it again encounters enigmatic climatological and environmental conditions. Unlike the climates of the north, which have changed substantially over millennia, the climate generated from the Indian Ocean has remained remarkably stable. The entire coastal plain of eastern Africa exhibits forest patches of great antiquity, with its climate ensuring that these forests have been preserved.

The Pangani River has two main tributaries, including the Ruvu, which rises on the eastern slopes of Mount Kilimanjaro, and the Kikuletwa, which rises on Mount Meru and the southern slopes of Mt. Kilimanjaro. The Nyumba ya Mungu Dam lies at the confluence of the Ruvu and Kikuletwa Rivers, with its reservoir covering about 140 km^2 (54 mi^2) (Røhr and Killingtveit, 2002). The water flow into the reservoir is estimated to be 43.37 $m^3.s^{-1}$. As the river leaves the reservoir, it becomes the Pangani, flowing thereafter for 432 km (268 mi) before emptying into the Indian Ocean, with an annual discharge of about 0.85 km^3 of water (Vanden Bossche and Beracsek, 1990). Mount Kilimanjaro is the single most important hydrological feature within the Pangani River Basin (PRB) (Lambrechts et al. 2002).

Rainfall onto the mountain surface is estimated to provide 60 per cent of the inflow to the Nyumba ya Mungu (NYM) Reservoir, and 55 per cent of the basin's surface water (Røhr and Killingtveit, 2002). Although unquantified, water derived from melting glaciers on the massif also is important. Snowmelt from the mountain's glaciers recharges the main spring in Kenya's famous Amboseli National Park. The snowmelt also recharges springs upon which Kenya's Turesh Water Supply scheme relies, and which supplies water to several major Kenyan towns, including Machakos and Kajiado.

The basin's water supply is mainly derived from rainfall, which is very unevenly distributed within the basin. On average, the basin receives 34,773.4 m^3 annually, with its average yearly potential evapotranspiration being 1,410 mm (56 in).

4.4.1 Physiography

The climate in the catchment varies considerably, with the Pangani River Basin comprising several sub-catchments of widely differing characteristics. The upper parts of the slopes of Mount Kilimanjaro and Mount Meru receive a high precipitation quantity of 1200-2000 $mm.yr^{-1}$ (47-79 $in.yr^{-1}$), with the remaining portion of the catchment area (the main river channel running through the dry Maasai Steppe of northern Tanzania) receiving only about 500 $mm.yr^{-1}$ (20 $in.yr^{-1}$). There are two distinct rainy seasons, the short one from mid-October to December, and the long one from mid-March to June.

Climate change has had a significant effect on the basin, with the situation expected to worsen in the future. The glacial ice caps of Mount Kilimanjaro, which tower over the basin, are expected to disappear completely by 2020, with increased temperatures expected to result in a 6-9 per cent annual reduction in surface flows (OECD 2003). Climate change and abstractions over the past decades have reduced in-stream flows from several hundred to less than 40 $m^3.s^{-1}$ (IUCN 2003) and, as reported by Chikozho (2005), the mean annual flow of the Pangani River has decreased over the last four decades.

The highland area is considered to be the land lying above 900 m (2,953 ft) amsl, such as the slopes of Mounts Meru and Kilimanjaro, as well as areas in the Usambara and Pare Mountains, which receive between 1,200-2,000 mm (47-79 in) of rainfall each year. The rainfall is bimodal in these areas, peaking between March and May, and with a smaller peak between October and November. Rainfall in the former season may exceed 600 mm (24 in) per month, and 300 mm (12 in) in the latter. The rainfall has generally declined above the Nyumba ya Mungu (NYM) Dam since record-keeping began in the early-1930s. The present rainfall patterns typically vary around 10 per cent from the mean value (Mkhandi and Ngana, 2001). Land lying below 900 m (2,953 ft) receives the least rainfall in the basin, declining to as little as 500 $mm.yr^{-1}$ (20 $in.yr^{-1}$) (Mkhandi and Ngana, 2001). Indeed, 50 per cent of the basin is considered arid or semi-arid (Røhr and Killingtveit 2002).

The Pangani River is the water source for the Nyumba ya Mungu (NYM) Dam. The river is polluted from the catchment upstream of the NYM Dam. The dam is used for generating electricity, as well as domestic, industrial and irrigation uses in three regions of Tanzania (Arusha; Tanga; Kilimanjaro).

The main pollution sources to the Pangani River are domestic wastes, and agricultural and industrial wastewaters from Arusha and Moshi. The fast-growing population, and the uncontrolled establishment

of industries, are the major challenge in the catchment, contributing substantially to the pollution of the river, which eventually ends up in the NYM Dam. Because of the catchment's complex ecosystems, and the need for quality water in the river and NYM Dam at large, it is necessary to determine the pollutant load reaching the river and eventually the NYM Dam.

The main water abstractions in the Pangani River Basin are from surface water (about 95 per cent). There is a significant quantity of potential groundwater use, compared to the other basins in the country. Irrigation is the main user of groundwater, accounting for 80 per cent of the total groundwater abstractions. Boreholes yielding more than 100 $m^3.h^{-1}$ have been drilled in the Kahe Plains, while boreholes yielding between 10-50 $m^3.h^{-1}$ are located in Sanya Plains and Karoo rocks of Tanga. The groundwater recharge is mainly from rainfall and rivers (Makule 1998).

Large portions of the Kirua Swamp, the largest wetland in the basin, have dried up as a result of the regulation of water flows issuing from the NYM Dam. Streamflows also have been affected because of siltation resulting from deforestation. Rivers have dried up in some cases, affecting the ecology of the system.

A large part of the Pangani River Basin's ability to deliver water is related to its forests. An estimated 96 per cent of the water flowing from Mount Kilimanjaro, for example, originates from the forest belt alone (Lambrechts *et al.,* 1992), and Mount Kilimanjaro is estimated to provide 60 per cent of the inflow to the Nyumba ya Mungu (NYM) Dam, and 55 per cent of the basin's surface water (Røhr and Killingtveit, 2002).

About 5 per cent of all the water used in the basin is derived from groundwater sources. Boreholes yielding more than 100 $m^3.h^{-1}$ have been drilled in the Kahe Plains, while boreholes yielding between 10-50 $m^3.h^{-1}$ have been drilled in the Sanya plains and Karoo Rocks of Tanga. The groundwater recharge is mainly direct from rainfall, and indirectly from rivers.

4.4.2 Socio-economy

The problems facing the use of resources in the Pangani River Basin relate to an increasing population, against a background of high levels of poverty. Poverty and environmental degradation are perceived to be interlinked (cf. WCED 1987). Further, the problems of managing common property resources are often thought to increase when large numbers of people involved, particularly when their cultural homogeneity is be weak (cf. Ostrom 1990). The structure and function of rural livelihoods may become imperilled when the ability of rural people to control and secure adequate sources of livelihood are threatened.

The major interests within the basin comprise industrial interests (electricity; mining); farming (large and small scale farming, both associated with considerable reliance on irrigation); pastoralist interests (particularly in lowland areas); and growing urban interests. Operating between these diverse interests, and the multiplicity of natural resources within the basin, are NGOs and international donor agencies. The mandate of these entities is primarily conservation, and development and enhancement of rural livelihoods.

It is important to note that much of the basin's population depends on farming for its livelihood, and that there is much to suggest they are economically vulnerable. Further, the diversity and richness

of the basin's resources means that large(er)-scale interests may be attracted to the basin, with substantial investments having already been made. There is room for conflict between these large-scale interests and small-scale livelihood security.

Thus, it is clear that the diversity of resources in the Pangani River Basin brings with it an equal diversity of conflict types. A major concern within the basin is the extent to which management is able (or not) to deal with conflicts of all degrees of intensity, and the natural resources allocation problems that underlie them.

There are an estimated 3.7 million people in the basin, 80 per cent of which rely, either directly or indirectly, on agriculture for their livelihoods. Ninety percent of the basin's population lives in its upper portions. This settlement concentration yields population densities of up to 300 persons.km^{-2} (777 persons.mi^{-2}). In the highland areas of Kilimanjaro, there are some 900 persons.km^{-2} (2,331 persons.mi^{-2}), with average farm holdings of just 0.2 ha (0.001 mi^2) per household. There are only 65 persons.km^{-2} (168 persons.mi^{-2}) in the lowland areas, however, with each household farming an average area of 10.4 ha (0.04 mi^2) (Lein 2002). The basin's urban and industrial economies are not sufficiently large to absorb this labour force. As a result, its burgeoning population seeks livelihoods in agriculture, a large part of which is irrigated. As the number of claims for water resources increase, so too will be the number of potential conflicts. Demands for access to water are symptomatic of wider demands for access to a whole variety of resources, including land, forest products, pasture, mineral deposits and, ultimately, economic livelihoods.

Serious pollution of the water sources has occurred in those parts of the catchment in which both population and industrial densities are high. Discharges of organic matter, nutrients, microorganisms, and micro-pollutants not only affect the ecology, but also human health. Thus, municipal and industrial wastewater outlets are in conflict with almost all other water user interests in the catchment, especially those concerning drinking water, crop irrigation, and the food and beverage industry. The main pollutant in the basin however, originates from the sisal fibre production industry. Water pollution from agrochemicals, sediments and turbidity has also occurred downstream. Some of these agrochemicals (e.g., pesticides; herbicides; fertilizers) are toxic to flora and fauna if present in excessive quantities. Further, sedimentation and siltation in river channels occur due to erosion from poor agriculture practices, and leading to reduced water depth. In addition, large nutrient inflows into Lake Jipe have encouraged excessive growths of papyrus and *Typha*.

HIV/AIDS and water-related diseases

The HIV/AIDS pandemic in the Pangani River Basin has been a bottleneck to economic development, since useful manpower is lost. Efforts are being undertaken to combat the disease.

Water uses

Water resources in the basin are integral to its agricultural economy, power generation, urban, industrial and domestic demands, and livestock. The greatest water use in the basin, however, is for agricultural irrigation. Electricity generation and fishing are important additional uses, as are urban and industrial demands.

Water-related conflicts

Water users within the Pangani River Basin are legally obliged to hold water rights issued by the Pangani Basin Water Office. The cost of a water right depends on the purpose for which the water

is to be used. Small-scale users are often reluctant to apply and pay for water rights, arguing that water is a 'gift from God.' There are 1,028 water rights in the basin, with a capacity to abstract 30.7 $m^3.s^{-1}$. There are, however, an additional 2,094 abstractions, with a capacity to abstract about 40 $m^3.s^{-1}$. The present and potential water use conflicts in the basin are the result of past uncoordinated and increased development of its water resources, especially above Nyumba ya Mungu Dam. Most conflicts currently exist between water users because of insufficient water supply, especially in the areas where irrigation is practised. Proper integrated water resources management is needed to control water use conflicts within the basin.

Access to water and sanitation

As with other places in Tanzania and Kenya, the access to water and sanitation is poor in the Pangani River Basin, being less than 5 per cent. This has resulted in human illnesses, thus affecting socio-economic activities. Much is being done in the basin to supply people with clean and safe water, consistent with Tanzania's vision for 2025 and the Millennium Development Goals (MDGs). The MDGs and Tanzania's vision are ambitious, and significant investment is needed to improve the current situation in the basin.

4.4.3 Management

The principal legislation governing water resources in Tanzania is the Water Utilization Act No.42 of 1974, the Amendment Act No.10 of 1981, the Written Laws (Miscellaneous) Act No.17 of 1989, and the General (Regulations) Amendment. According to this Act, Tanzania is divided into 9 hydrological areas, which have been declared river basins. Among these areas, the Pangani River Basin was identified to be the one needing immediate attention, since serious user conflicts, deterioration of water resources because of misuse, and lack of comprehensive planning and management mechanisms, were evident in the basin. Thus, the water resources in Pangani River Basin are managed by the Pangani Basin Water Board (PBWB), and Pangani Basin Water Office (PBWO).

Pangani Basin Water Board (PBWB) and Pangani Basin Water Office (PBWO)

The functions of the Pangani Basin Water Board are the same as those of the Central Water Board in their areas of jurisdiction. Six members of the board drawn from public, private and women's organizations and NGOs, are appointed by the minister responsible for water affairs. The 2 boards coordinate water resources management and water pollution efforts in the basin, in cooperation with governmental and regional authorities. They also are fulfilling an urgent need of the involved ministries to make better use of the existing water resources, and to avoid serious pollution problems.

From district to village levels the boards promote participatory planning and systematic stakeholder involvement in decision-making. The communities are educated on the need for management, protection and conservation of water resources. They also are made aware of the factors contributing to the reduced Pangani River flows, thereby affecting their socio-economic livelihoods, and are encouraged to form Water User Associations (WUA). Amazingly, the communities, users and stakeholders are responding positively whenever their cooperation is needed. As a result, the PBWO has made significant progress toward improving the situation in the basin.

The PBWO reports to the Pangani Basin Water Board (PBWB). The PBWB initially consisted of representatives from government departments with a stake in the Pangani River Basin. Members of the

board increasingly come from the private and NGO sectors, however, with nominal representation by community interests. The board's task is to advise the basin water officer on all matters concerning: (i) the apportionment of water supplies; (ii) the determination, diminution or modification of water rights; (ii) measures to be taken in case of drought; and (iv) priorities to be given to different uses of water in the basin.

4.4.4 Key issues, adaptation and mitigation

Physiography

Large portions of the Kirua Swamp, the largest wetland in the Pangani River Basin, have dried up as a result of the regulation of water flows issuing from the Nyumba ya Mungu Dam.

Adaptation and mitigation

There is a need:

- To consider ecosystems in water allocation.
- To develop monitoring networks.

Socio-economy

Poverty in the basin is high because secondary and tertiary forms of employment are typically unavailable in its commercial and industrial sectors. Thus, many of its inhabitants seek livelihoods in primary activities, such as agriculture, the harvesting of forest products and fishing. Further, the HIV/AIDS pandemic in the river basin has been hampering economic development.

Adaptation and mitigation

There is a need:

- To institute IWRM in a coordinated manner, focusing on holistic water use, with a balance between all land uses, including plantation forests, efficient irrigation systems, safe drinking water, water for cattle, and water harvesting.
- To develop irrigation infrastructure to ensure productive use of water resources, thereby reducing poverty levels.
- To develop water demand management.
- To institute pollution monitoring and mitigation measures at the basin level to ensure that no 'precious' water resources are wasted because of pollution.
- For community training and education in HIV/AIDS.
- To increase awareness of HIV/AIDS through all the media.
- To implement anti-retroviral programmes.
- To provide adequate domestic water resources to ensure general hygiene and minimize disease transmission.

Management

The Pangani River Basin was identified as the basin needing immediate attention, since serious user conflicts, deterioration of the resource due to misuse, and lack of comprehensive planning and management mechanisms, were evident.

Adaptation and mitigation

There is a need:

- To strengthen the existing management structures (e.g., PBWB; PBWO) through capacity building.
- To upgrade monitoring networks.

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4.5 RUFIJI RIVER BASIN

The Rufiji River Basin is the largest river basin in Tanzania, with a total surface area of nearly 180,000 km^2 (69,498 mi^2; Figure 4.5-1; Box 4.5-1). The Rufiji River originates in the southern highlands, where the Great Ruaha River and Usangu wetlands are found. The importance of the Usangu catchment cannot be overemphasised. Although it represents only 12 per cent of the total Rufiji catchment area, it provides 56 per cent of the water runoff to the Mtera Reservoir through the Ruaha River (GOT 2000).

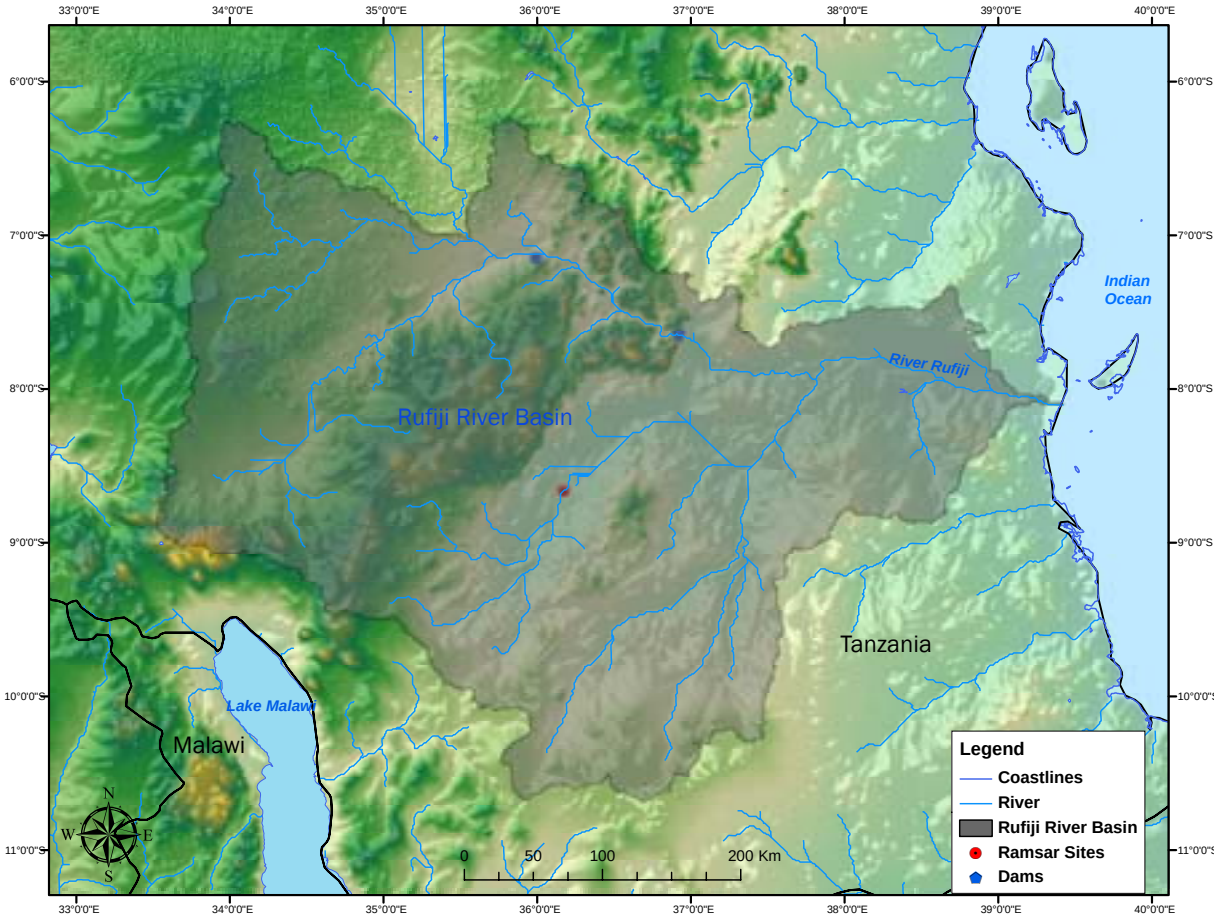

Figure 4.5-1: Rufiji River Basin

Box 4.5-1: Main characteristics of Rufiji River Basin

Basin

Surface area:	178,660 km^2 (68,981 mi^2)
MAP:	950 mm.yr^{-1} (37 in.yr^{-1})

Demography

Population:	3.4 million
Density:	19 persons.km^{-2} (49 persons.mi^{-2})

Major Dams

Mtera:	3,200 Mm^3 (80 megawatts)
Kidatu:	125 Mm^3 (204 megawatts)

Water Use

Agriculture
Hydropower
Industry
Domestic
Fishery
Mining

Increasing

Vulnerability

Climate variability and change affects catchment environment; competing users

Source: URT (1995): Rapid Water Resources Assessment Vol. I and II
URT (2001): A study of Hydrological Phenomenon and Floods and Drought in the Pangani and Rufiji Basins. Vol. I: Ministry of Water and Livestock Development - University of Dar es Salaam (WREP).

4.5.1 Physiography

The average annual rainfall ranges from 1,550 mm (61 in) in the southeastern parts of the Rufiji Basin, to 450 mm (18 in) in the north. Whereas the annual rainfall variability in the basin ranges up to 10 per cent, the evapotranspiration varies up to 20 per cent (Arnell 1999).

Grassland, savanna and shrubland together cover 77.4 per cent of the basin, dryland 20.4 per cent, and cropland 19.7 per cent. The coverage of wetlands is only 7.8 per cent (GOT 2000).

Agricultural development (irrigation) has been responsible for the reduced flooding and subsequent degradation of the Usangu wetlands and plains, and for a reduced grazing capacity. Other reasons for reduced riverflows include increased population pressures, land-use changes (rapid expansion of both rain-fed and irrigated agriculture), and increased cattle on the Usangu Plains (GOT 2000). Human-induced activities occur mostly upstream of the Rufiji River. These reduced flows adversely affect the fish populations of the wetlands and rivers, and disturb seasonal animal migrations in the Ruaha National Park. The continuing degradation may ultimately prevent the wetlands from performing their riverflow regulation function.

From a hydrological perspective, the most significant change in the basin has been the reduction in the dry season flow of the Great Ruaha River since the early-1970s. According to the project on the Sustainable Management of the Usangu Wetland and its catchment (SMUWC 2001), analyses of waterflow records do not indicate significant changes in either total or wet-season flows downstream of Usangu. Cessation of the Ruaha River flow in the Ruaha National Park has occurred frequently since 1993, with a progressively-expanding dry season.

There is a potential risk of water pollution from waste disposal from sugar industries in Kilombero, and the use of fertilizers in cultivated areas in Mbeya and Iringa (URT 1995). The few studies undertaken thus far on surface and groundwaters of the Usangu catchment have not yet revealed any evidence of pollution (GOT 2000).

An example of a water supply infrastructure project to alleviate water shortages is the major urban water supply project for the city of Dar es Salaam at the downstream end of the basin. Its water supply currently is vulnerable since it is solely dependent on the Ruvu River. It is the intention of the water authorities to ensure an adequate, continuous water supply by abstracting water from two different sub-basins, each being within different climatic regimes.

4.5.2 Socio-economy

The Rufiji Basin currently has 4.1 million people, compared to 3.4 million in 2002. The annual population growth in the Usangu wetland catchment is 11.1 per cent, averaged over the period since 1948 (GOT, 2000). The growth rate was highest in the Mbeya rural areas, where the population grew by 132 per cent during 1988-2002. Such significant population growth has major implications for the local water resources.

Irrigation and livestock farming are by far the most significant economic and water- consuming activities in the Rufiji Basin. Although most of the hydroelectric power for Tanzania is produced in the basin, there are no major industrial urban centres, and the industrial activity is relatively limited.

Irrigated farming is most prevalent in the Usangu catchment and the Kilombero Valley. Water use efficiency for irrigation is generally lower than 30 per cent. Rice is one of the main crops produced in the Usangu wetland area, where irrigation coverage has grown from 3,000 ha (12 mi^2) in 1958, to over 40,000 ha (154 mi^2) today. In Kilombero, an area of a similar size was irrigated for growing such crops as rice and sugarcane, using about 600 and 1,200 mm (24 and 47 in) of water per season, respectively, in 1995, which translates into a 20 per cent water use efficiency level.

Raising livestock also is a major water-consuming activity. The livestock population reached its peak of 540,000 head in the mid-1970s, having since declined to an estimated 366,000 animals, with 76.5 per cent being cattle. Pastoralists who migrated from Shinyanga, Arusha and other regions have settled on the Usangu plains, where some (particularly the Sukuma) also are engaged in farming.

Hydroelectric power is generated at the 200 megawatt Kidatu Dam, just before the Great Ruaha River enters the Kilombero Valley, and at the upstream 80 megawatt Mtera Dam. The reduced dry season flows have had a far-reaching impact nationwide because of power-rationing problems due to inadequate water levels in the Mtera Reservoir since 1995.

The development of irrigation projects along the Great Ruaha River, upstream of the Mtera and Kidatu power stations, will lead to high competition for water between irrigators and hydropower stakeholders (URT, 1995). Competition for land and water also has manifested itself between pastoralists and farmers in the Usangu area, particularly in the Utengule swamps. The expansion of cultivated areas, and corresponding shrinkage of pastureland, clearly calls for an integrated approach to future development and management of the area's water resources.

4.5.3 Management

A new National Irrigation Master Plan was formulated by the Ministry of Agriculture to increase water use efficiency for irrigation and, at the same time, increase the acreage of irrigated farmland in order to ensure food security in the Rufiji Basin. Thus, irrigation water demands will continue to rise, increasing water stresses in the area. The situation is expected to further worsen when climate variability and change are taken into account.

4.5.4 Key Issues, adaptation and mitigation

Physiography

Climate variability

The rainfall pattern in the basin is quite variable, with surface water availability reduced to the extent that rivers that used to be perennial are now intermittent. This situation also is coupled with increasing population.

Adaptation and mitigation

There is a need:

- To develop an early warning system, both for impending droughts (northern part of the basin) and floods (southern part of the basin).

Socio-economy

Land degradation

Agricultural development has reduced river flows, and caused degradation of wetlands and plains. Increasing population growth (11.1 per cent per annum in some catchments, and up to 132 per cent in others) is exerting pressures on the available land and water resources. Livestock production also is on the increase, causing extensive land degradation.

Adaptation and mitigation

There is a need:

- To invest in rural infrastructure in order to raise community living standards, which also will act as an incentive for organized settlement, and mitigate land degradation.
- To implement measures to curb high population growth.
- To develop and encourage appropriate crops and livestock, and production technologies suitable for drought conditions.
- To develop legislation, policies and guidelines for holistic land management, and cropping patterns suited for various soil types.
- To involve communities in ecosystem management, with projects that directly benefit the communities forming an integral part of the management.

Water demands and pollution

Although there is increased water demand for agriculture, hydropower generation, and human consumption, the water supply side is dwindling. Waste disposal from sugar industries, and the use of agro-chemicals (mostly fertilizers), is polluting the water resources. The water use efficiency is 20-30 per cent, which is very low.

Adaptation and mitigation

There is a need:

- To institute water demand management within the basin management scheme.
- To develop and install efficient water conveyance and irrigation systems.
- To develop appropriate legislation and monitoring mechanisms for waste disposal and pollution of water resources.

Water-related conflicts

The development of irrigation projects along the Great Ruaha River upstream of the Mtera and Kidatu power stations will lead to high competition for water between irrigators and hydropower stakeholders. Competition for land and water also exists between pastoralists and crop farmers.

Adaptation and mitigation

There is a need:

- For an integrated approach to future development and management of the basin's land and water resources.
- To develop an equitable water allocation system.

Management

Institutional and legal frameworks

There is no proper river basin authority mandated with management of the basin, and no clearly-defined legislation for managing the basin's natural resources for development.

Adaptation and mitigation

There is a need:

- To develop a basin agency or authority mandated with effective and efficient management of the basin's natural resources.
- To develop appropriate legislation empowering a basin authority to effectively discharge its duties in managing the basin's natural resources.

Data availability, standardization and monitoring

There are no effective systems in place for monitoring (e.g., hydrometric and water quality monitoring). Data collection also is inadequate.

Adaptation and mitigation

There is a need:

- To build capacity (human resources, material, logistics and equipment) for the basin authority to enable it to monitor and collect relevant data.
- To set up monitoring networks.
- To establish a data base for the basin.

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4.6 LAKE MALAWI BASIN

Lake Malawi (Figure 4.6-1), also known as Lake Nyasa or Lake Niassa, is shared by Malawi, Tanzania, and Mozambique, with the majority of the lake and its catchment lying within Malawi. The position of the Malawi-Tanzania border within the lake is contested. Malawi considers the border to be along the eastern shore of the lake, while Tanzania considers it to run through the lake.

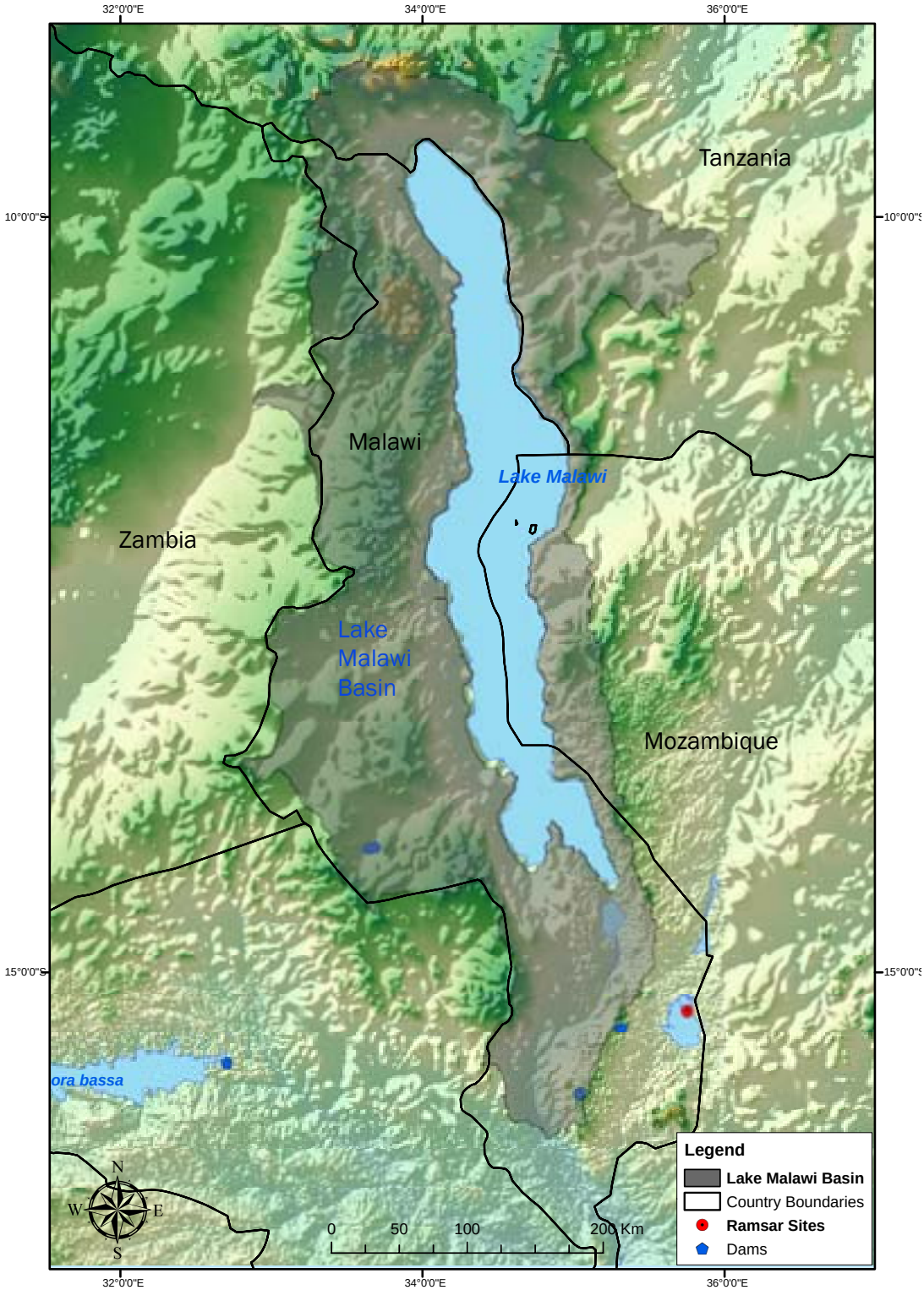

Figure 4.6-1: Lake Malawi Basin

The lake lies between 9° 30′ S and 14° 30′S, at an altitude of about 500 m (1,640 ft) in a tropical climate. It has a total surface area of 30,800 km² (11,892 mi²), including the part of the lake belonging to Mozambique; Figure 4.6-1). The lake is 570 km (354 mi) long, 16-80 km (10-50 mi) wide, and has a total storage of 1,000 km³. Its average depth is 426 m (1,398 ft), and its maximum depth is 706 m (2,316 ft). It is the most important single water resource in the region, and plays a vital role in its socio-economic development. The main characteristics of the basin are summarized in Box 4.6-1.

Box 4.6-1: Main characteristics of Lake Malawi Basin.

Basin

Surface area:	126,500 km² (48,842 mi²)
MAP:	800-1500 mm.yr⁻¹ (31-59 in.yr⁻¹)

Demography

Population:	8.1 million
Density:	Malawi - 106, Mozambique - 24, Tanzania - 33 persons.km⁻² (275, 62 and 85 persons.mi⁻², respectively)

Water Resources

Max lake length:	569 km (354 mi)
Inflow:	29 km³.yr⁻¹
Outflow:	12 km³.yr⁻¹
MAR:	>10,000 m³.km⁻² (25,900 m³.mi⁻²) in many areas

Major Dams

9: 7 water for supply; 2 for hydropower
Total dam storage: 43 Mm³

Major Aquifers

The quaternary alluvial aquifers of the lakeshore plains
The Lower Shire Valley, which is high yielding (up to 20 L.s⁻¹)

Water Use

Agriculture
Domestic
Industry
Navigation
Hydropower

Source: Jorgensen et al. (2003); National Irrigation Master Plan (2002)

Water draining from Lake Malawi flows down a single outlet, the Upper Shire River, into Lake Malombe and subsequently into the Middle Shire, the Lower Shire River and ultimately into the Zambezi River. Lake Malawi, the Upper Shire River and Lake Malombe constitute an eco-region, in that all comprise an integral part of the basin. They contain geographically-distinct assemblages of natural communities, sharing many species and ecological dynamics. They also share similar environmental conditions, and interact ecologically in ways that are critical for their long-term sustainability. Thus, this eco-region includes Lake Malawi, all inflowing rivers and streams, the catchments, the terrestrial component of the catchment, the Upper Shire River and Lake Malombe.

The largest tributary is the Ruhuhu River in Tanzania, with a catchment area of 14,070 km² (5,432 mi²), and then the South Rukuru in Malawi with a catchment area of 12,110 km² (4,676 mi²). The Bua and Linthipe Rivers of Malawi also are significant tributaries, with catchment areas of 10,700 km² (4,141 mi²) and 8,560 km² (3,305 mi²), respectively. Other tributaries include

the Songwe, Kiwira and North Rukuru Rivers, with the area of all these catchments being less than 5,000 km^2 (1,931 mi^2) each. The nature and size of the catchment indicate that a single tributary cannot dominate the lake catchment hydrology, whether with regulated or natural flows.

The Shire River is the outlet of the lake, flowing approximately 410 km (255 mi) from Mangochi to Ziu Ziu in Mozambique, where it drains into the Zambezi River. Its reach can be divided into upper, middle and lower sections. The Upper Shire lies between Mangochi and Matope, with a total channel bed drop of about 15 m (49 ft) over a distance of 130 km (81 mi). Within this reach, however, the uppermost reach from Mangochi to Liwonde is almost flat, with the channel bed dropping to about 1.5 m (5 ft) over a distance of 87 km (54 mi). The physiography of Upper Shire has offered opportunities for regulating river flows, and subsequently lake levels, with possible expansion. The Middle Shire is about 80 km (50 mi) long and steep, being characterized by the rock bars and outcrops from Matope to Chikwawa. With a total fall of 370 m (1,214 ft) in altitude, it represents a significant hydropower production potential.

4.6.1 Physiography

The lake basin has a tropical continental climate, with maritime influences from the Mozambique Channel to the east. The regional climate ranges from tropical, warm and semi-arid, to sub-tropical and humid, being strongly influenced by altitude and the lake's large surface area and water volume.

The annual rainfall averages less than 800 mm (31 in) in the Rift Valley area, 800-1,000 mm (31-39 in) in the Medium-Altitude Plateaux, and 1,000-1,500 mm (39-59 in) in the High-Altitude Plateaux. The prevailing winds during the wet season are northerly, with average daily air temperatures being 25 °C (77 °F). The lake level rises during the wet season from rainfall both onto the lake surface and in the catchment, resulting in annual lake level fluctuations between the extremes of 0.4-1.8 m (1.3-5.9 ft). Most of the region receives adequate rainfall for rainfed agriculture, although there is evidence that droughts have become more common in recent years (e.g., Clay et al. 2003). In the high altitudes of the mountains surrounding the lake, air temperatures are considerably lower, approaching zero at night at some particularly-high elevations of the Nyika Plateau and Livingstone Mountains.

While the current effect of climate warming on the lake is uncertain, air temperatures in this part of Africa are predicted to increase by approximately 4 °C (39 °F) this century, and will likely alter lake levels and hydrodynamics, and biogeochemical cycles. Based on historic trends regarding fisheries, water quality and hydrology, and recent data on river water quality, the main threats to the Lake Malawi ecosystem are: (i) over-fishing in some areas (nearshore, especially the southern end of lake); (ii) increased nutrient inputs and changes in phytoplankton composition; (iii) sediment loading; (iv) loss of biodiversity due to fishing and nearshore water quality impacts; and (v) water levels (e.g., regarding hydropower generation).

The ultimate causes of these threats, in addition to over-fishing, include deforestation; sub-optimal agricultural practices; biomass burning; and climate change. The widespread deforestation within the catchment, being done to pave the way for agriculture and urban settlements, has resulted in the loss of floral and faunal ecosystems. Further, the rich genetic flora and fauna pool in protected areas (e.g., national parks; game and forest reserves) are diminishing because of habitat destruction and poaching (Kasweswe-Mafongo, 2003). Habitat degradation of rivers, and overfishing, threaten riverine and potamodromous fish species (Chapman et al. 1992; Tweddle 1992; Ribbink 2001).

4.6.2 Socio-economy

The countries of Malawi, Mozambique and Tanzania, with populations of 10 million, 19.1 million and 31.2 million respectively (WWF 2003), share Lake Malawi. The Lake Malawi watershed constitutes 70 per cent of Malawi's land area. It is densely populated, having 116 persons.km^{-2} (300 persons.mi^{-2}) (UNEP-IETC 2003), with 80 per cent of the total lakeshore population being in Malawi (World Bank, 2003). The watershed is sparsely populated in Mozambique and Tanzania, due to the remoteness and isolation from the rest of the region (Ribbink 2001). Thus, most of the human impacts on Lake Malawi are from Malawi.

The population density is greatest in the southern part of the catchment within Malawi. According to the Malawi National Statistics Office, the total population of Malawi in 1998 was 9.9 million, with an annual growth rate of 2 per cent. The northern and central regions of the country, which make up most of the Malawian portion of the lake catchment, have 12 and 41 per cent, respectively, of the total basin population. The population growth rate in the northern region, however, is higher than the national average, being 2.8 per cent per year. Urban areas contain 14 per cent of the population, with the urban population growth rate being about 4.7 per cent per year. Within the 68 per cent of the population considered economically active, 78 per cent of this group are subsistence farmers, and 13 per cent are employees. In contrast to the Malawian portion of the catchment, the eastern, and parts of the northwestern shores of the lake, have relatively pristine vegetation, low population densities, and are much less exploited. These areas are relatively remote from the centres of Tanzanian and Mozambican government, and have been only slightly developed. The two governments are making attempts to raise the economic standards of these regions, however, through tourism and agricultural development.

Agriculture is the mainstay of Malawi's economy, accounting for almost half its GDP, and for almost all its export revenue. Agriculture accounts for half the GDP of Tanzania, and 35 per cent of the GDP of Mozambique. The fishing industry contributes between 1-2 per cent of the GDP within Malawi, employing almost 300,000 people either directly or indirectly. Fish are estimated to provide about 70 per cent of dietary animal protein (Bland and Donda 1995), with the majority coming from Lake Malawi.

In addition to fish and freshwater, the other economic benefits gained from the lake are electricity, transport, and an ornamental fish trade. The majority of electricity produced in Malawi comes from hydroelectric plants on the Shire River, which drains the lake. Fluctuations in river discharge, however, which are controlled by the lake level, make this power source precarious. A summary of the key macro socio-economic indicators of the economics of the ecoregion is provided in Table 4.6-1.

Table 4.6-1: Key socio-economic indicators of the Lake Malawi ecoregion (Lake Malawi/Nyasa/Niassa Ecoregion Socio-Economic Reconnaissance Report, 2000)

Key Socio-economic Indicators			
	Malawi	**Mozambique**	**Tanzania**
Total area (km^2)[mi^2]	118,480 [45,745]	801,590 [309,496]	945,090 [364,901]
Population (millions of people)	10	19.1	31.2
Population density (persons.km^{-2}) [persons.mi^{-2}]	106 [275]	24 [62]	33 [85]
Population growth rate	3.2	2.54	2.14
Birth rate/100 people	39.54	42.75	40.37
Death rate/100 people	23.84	17.31	16.75
Infant mortality/100 people	132.14	117.56	95.27
Life expectancy (years)	36.3	45.89	46.17
Fertility rate children/ women	5.48	5.88	5.40
HIV/AIDS (per cent)	total population = 7.4 15 to 49 age group = 14.92	total population = 6.57 15 to 49 age group = 14.17	total population = 4.4 15 to 49 age group = 9.42
GDP (US $)	2.47 billion	16.8 billion	22.1 billion
GDP growth (per cent)	3.2	9	3.8
GDP per capita (US $)	238	168	162
GDP per sector (per cent)	Agriculture = 45 Industry/services	Agriculture = 35Industry/services	Agriculture = 56 Industry/services
Population below poverty line (per cent)	54	?	51
Inflation rate (per cent)	52	2.5	13.5
External debt (US $)	2.3 billion	2.2 billion	8.3 billion
Debt per capita (US $)	239	115	256

HIV/AIDS and water-related diseases

The HIV/AIDS adult prevalence rate in the Lake Malawi Basin is estimated to be 14.2 per cent, while the number of people living with HIV/AIDS is estimated to be 900,000, based on 2003 estimates. HIV/AIDS has claimed about 84,000 lives. The effects of excess mortality related to AIDS result in lower life expectancy, higher infant mortality and death rates, lower population and growth rates, and changes in the population distribution by age and sex, compared to what would otherwise be expected.

Water demands and uses

Water demands in the basin will continue to increase with population because of agricultural irrigation, which is the major water-using sector. Further, the energy potential for riparian countries (i.e., Malawi) has not yet been achieved, meaning new sources of hydroelectric power will place more pressures on the already-existing water resource pressures.

Major water users in the country are the domestic sector, irrigation, hydropower, industry, navigation, recreation and tourism, fisheries and biodiversity. Water withdrawals for agricultural and domestic purposes have increased over the last decade, as a result of socio-economic development and population growth. Agricultural irrigation is still the major water-using sector, followed by domestic and municipal water supply and industry. However, an updated and comprehensive water resources and water use information database is not available.

4.6.3 Management

Until recently, there has been virtually no coordination among the three countries regarding research and management of the lake basin. In recognition of the need for such coordination, however, the three countries, with support from FAO, recently developed a draft convention on the sustainable development of the lake basin. This draft convention proposes establishment of a Lake Malawi Basin Commission, which would be made up of a Council of Ministers, Steering Committee, Permanent Secretary, and a number of Standing Committees dealing with fisheries management, water resources and catchment management. Further, each country will establish a National Committee made up of representatives of various natural resources management institutions, academic institutions, private sector, and local community representatives. The Commission's proposed mandate would include data dissemination, promotion of training, public education and research related to the lake and water resources, monitoring of environmental conditions, and enhancement of cooperation among various governmental and non-governmental agencies involved in activities related to natural resources management in the basin.

All three countries are currently implementing government 'decentralization.' Decentralization policy in Tanzania is enacted through the Regional Administration Act (1997). In a 1999 revision of the Local Government Act, it is stated that local authorities are to provide for protection and proper utilization of the environment for sustainable development. Decentralization was promoted in Malawi through the 1998 Local Government Act. The process of decentralization was initiated in the late-1980s in Mozambique, and has gone through a number of phases over the past 25 years. In 1998, Mozambique conducted its first local government elections.

Data availability, standardization and monitoring

A National Environmental Policy was approved in Malawi in 1996, being implemented through the Environment Management Act. It established a National Council for the Environment, with powers to mediate conflicts, and gave the Environmental Affairs Department responsibility for coordinating environmental monitoring, investments in natural resources sectors, and environmental education. Collaboration within Malawi, and to some degree between Malawi and the other two countries, also has been promoted by the National Aquatic Resource Management Programme (NARMAP), implemented through the Department of Fisheries, funded by GTZ (German Technical Cooperation), being completed in 2003. While this programme does not consider the terrestrial part of the ecosystem, it does attempt to promote collaboration and information-sharing among

various government and non-government agencies working on the lake, and a research approach that goes beyond the conventional focus on fisheries.

Knowledge gaps

There is currently no government agency in any of the three countries that is responsible for monitoring or management of Lake Malawi water quality. There are departments in each country responsible for overseeing water supply, although these agencies deal primarily with domestic water supply, and do very little monitoring of lake water quality. That no agencies are responsible for monitoring or managing lake water quality reflects the narrow focus of each of the natural resources management agencies.

Water quality and quantity problems in Lake Malawi cannot be managed within the lake area. Rather, they must be addressed upstream, in the forests, farmlands, parks and cities. Water quality management (thus, lake management) requires an ecosystem approach. This approach is currently very weak, however, in all three riparian countries. Because there was not a great need for the ecosystem approach until recently, it would be incorrect to state that recognition of the need for this approach is the result of a 'lesson learned' for the Lake Malawi ecosystem.

4.6.4 Key issues, adaptation and mitigation

Physiography

The dominance of precipitation and evaporation in Lake Malawi's hydrologic cycle means it is susceptible to climate changes. A small increase in the precipitation and evaporation ratio for Lake Malawi can result in flooding, as occurred in 1979-80. In contrast, a small decrease in the ratio can result in the basin becoming closed, with no outflow, as was the case between 1915 and 1937. Lake Malawi's water level has been declining in recent years, and the lake came near to being closed at the end of 1997.

Adaptation and mitigation

There is a need:

- To develop an early warning system for impending droughts and floods.
- To develop monitoring networks.

Socio-economy

The population density is greatest in the southern part of the catchment, where most of the pressures on water resources are exerted. Another key issue is that water withdrawals for agricultural and domestic purposes have increased over the last decade because of socio-economic development and population growth.

Adaptation and mitigation

There is a need:

- To institute IWRM by all the riparian countries in a coordinated manner, focusing on holistic water use, with a balance between all land uses, including plantation forests, efficient irrigation systems, safe drinking water, water for livestock, and water harvesting.
- For water demand management.

- To institute pollution monitoring and mitigation measures at the basin level, to ensure that no 'precious' water resources are wasted because of pollution.

Management

Unless there are interventions, and use of the naturalized data for lake levels and Shire River flows, the designed infrastructure will fail to provide sustainable utilization of Lake Malawi and Shire River system.

Adaptation and mitigation

There is a need:

- For land management, through developing basin policies.
- To establish standardized procedures for monitoring and database development, in order to ensure effective information sharing and utilization; thus, there is a need to develop a transboundary basin and catchment water resources database.

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4.7 LAKE TANGANYIKA BASIN

Lake Tanganyika (Figure 4.7-1) is an elongated lake located between 03°20′ S to 08°48′ S and 29° 03′ E to 31°12′ E. It is the longest lake in the world, ranging from 12-90 km (8-56 mi) in width, with a shoreline perimeter of 1,838 km (1,142 mi) (Hanek et al. 1993). It has an average depth of 570 m (1,936 ft), with a maximum depth of 1,320 m (4,331 ft) in the northern part of the basin, and 1,470 m (4,823 ft) in the southern basin, making it the world's second deepest lake after Lake Baikal (UNEP 2004). Burundi, the Democratic Republic of Congo (DRC), Tanzania and Zambia share the Lake Tanganyika Basin. The main characteristics of the Tanganyika Basin are summarized in Box 4.7-1.

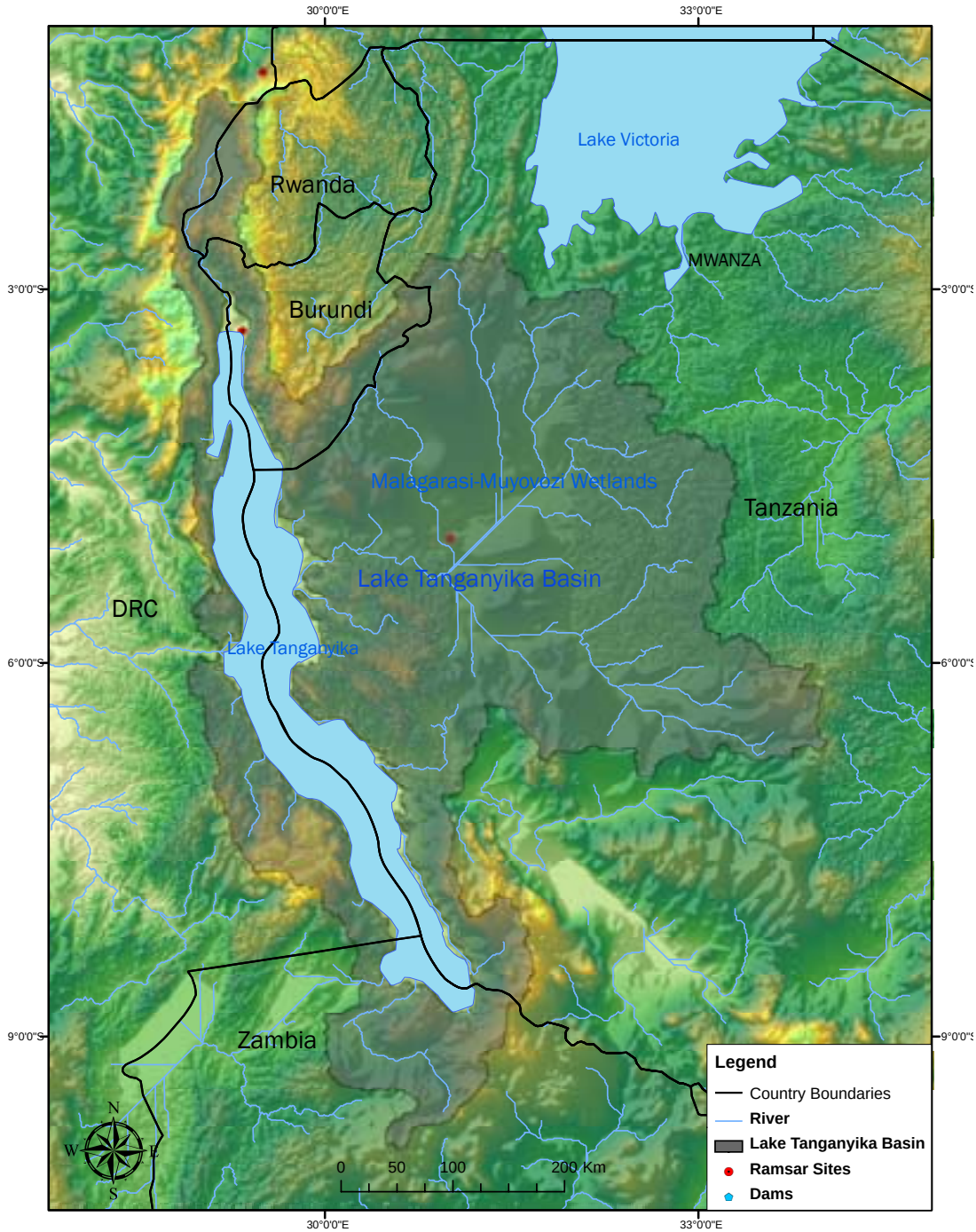

Figure 4.7-1: Lake Tanganyika Basin

Box 4.7-1: Main Characteristics of Lake Tanganyika Basin (Jorgensen, et al. (2003); National Irrigation Master Plan (2002))

Basin

Surface area:	151,900 km^2 (58,649 mi^2)
MAP:	1,173.6 $mm.yr^{-1}$ (46 $in.yr^{-1}$)

Demography

Population:	10 million
Density:	45 $persons.km^{-2}$ (117 $persons.mi^{-2}$)

Water Resources

River length:	670 km (416 mi)
MAR:	18,941.9 $Mm^3.yr^{-1}$

Major Dams

No major dams

Water Use

Agriculture	185.4 Mm^3
Domestic	77.1 Mm^3

Increasing

Of the lake's shoreline perimeter, 9 per cent is in Burundi, 43 per cent is in the Democratic Republic of Congo, 36 per cent is in Tanzania, and 12 per cent is in Zambia (Hanek et al. 1993). Lake Tanganyika has a catchment area of 220,000 km^2 (84,942 mi^2). The floor of the lake is at 358 m (1,175 ft) b.s.l., and is the second largest (~32,600 km^2 [12,587 mi^2]) of African lakes (http://www.geo.arizona.edu/nyanza/study.html). The surrounding areas are mostly mountainous with poorly-developed coastal plains, except on the eastern side. On the western coast, steep sidewalls of the Great Rift Valley reach 2,000 m (6,562 ft) in relative height from the shoreline.

4.7.1 Physiography

Lake Tanganyika has two wet seasons per year, being March-April and December, with the mean annual rainfall ranging from 1,200 mm in the northern part, to 1,600 mm (63 in) in the southern part (Nicholson 1996). Despite very diverse climatic mean conditions, the inter-annual rainfall variability is remarkably coherent throughout most of eastern Africa (Nicholson 1996). The largest portion of this variability is accounted for by the 'short rains' season of October-December (Nicholson 1996). The region's rainfall variability exhibits strong relations to the rest of Africa, and to the global tropics.

Most of the water loss from Lake Tanganyika is through evaporation. Water budget calculations suggest a water residence time of 440 years, and a flushing time of 7,000 years for Lake Tanganyika (Coulter 1991). With an approximate surface area of 32,600 km^2 (12,587 mi^2) and volume of 18,880 km^3, the lake contains 17 per cent of the earth's free freshwater (statistics from Hutchinson 1975; Edmond et al. 1993; Coulter 1994).

Since the 1960s, an increased air temperature has been measured at stations around Lake Tanganyika, including a mean increase of about 0.7 °C in the north, and 0.9 °C in the south. During the same period, the wind speed over the lake appears to have decreased, with the yearly mean wind speeds at Bujumbura fluctuating between 1.4-2.5 $m.s^{-1}$ from 1964 to 1979, and between 0.5-1.5 $m.s^{-1}$ from 1986 to 1990 (Plisnier 1997).

These climatic changes seem to have led to an increased surface water temperature of 0.40 °C during the dry season, and 0.28 °C during the wet season near Bujumbura, as well as a greater stratification (water upwelling becoming rarer, even in the south), a shallower thermocline and oxygenated layer, a decreased water transparency, and a higher surface primary production and zooplankton development in the north, compared to the south. These limnological changes, mainly lower water mixing and transparency, seem to have had a negative impact on the catchability of a visual predator *(Lates Stappersii)* in the north, and *Clupeids* abundance in the south (Plisnier 1997).

Over the last 10-15 years, climatic changes have probably reduced upwelling in the south, resulting in a decreased turbulence and wave amplitude for the whole lake. Thus, the lake has become less dynamic (Plisnier 1997). Climatic changes probably also affect other aspects of the ecology of the lake and its drainage area and, according to Verburg et al. (2003), there is no doubt climatic changes play a major role in these impacts.

Land use changes, land degradation, and deforestation in the catchment have had profound impacts that are propagated through the rivers from the land surface and atmosphere to the lowland wetlands and lake proper. Intense floodplain cultivation, cattle grazing, and burning of biomass during the dry season (Hughes & Hughes 1992) have caused a significant loss of wetlands (e.g., in Burundi). Land degradation and deforestation have increased the sediment flux to the lake, dramatically altering habitats, particularly in the littoral zone. Sediment input has transformed extensive stretches of shoreline from being rocky habitats to mixed sandy and rocky, or even wholly sandy, habitats. Coincident with this occurrence, the structure of the fish communities has changed over time, with some populations of cichlids and molluscs becoming locally-extinct over the past 30 years (UNEP 2004).

The pressures on land-based resources are likely to increase with the rapidly-increasing population. In addition, a perceived lack of a sustainability perspective on the part of farmers cultivating the steep slopes of Lake Tanganyika catchment may be more related to the present political insecurity, than to an inherently short-term view or ignorance of the environmental consequences of the failure to prevent soil erosion. If this is indeed the case, the rapid population growth and political instability in the region does not augur well for sustainable land management, soil conservation, and biodiversity in the future. The rate of loss and modification of ecosystems will increase as a result of increased sedimentation and reduced water-covered areas, leading to loss of wetlands and littoral vegetation, fish spawning grounds, local reduction in species diversity, loss of biodiversity, etc. There is already a significant loss of wetlands, local extinction of fishes and changes in population structure of vertebrate and invertebrate organisms in the lake. Economic impacts would become more severe as a result of further ecosystem loss and habitat modification. Subsistence fisheries would be most affected, as shallow spawning grounds and fisheries are lost to sedimentation, reducing the local population's capacity to meet basic food needs. In turn, this situation would increase health risks and result in the loss of jobs (UNEP 2004).

Although many rivers enter the lake basin, only one river (Lukuga River) flows out. One of the factors affecting water availability is siltation, which is due to erosion in the drainage area as a result of increased deforestation. The top soil is removed and transported to the lake, where it mixes with fertilizers and pesticides washed from the drainage area. An astounding 100 per cent of the northern drainage area, and around 50 per cent of the central areas, have been cleared of their natural vegetation, leading to increased soil erosion.

The Malagarasi and Rusizi Rivers provide a major share of the inflowing waters to the lake, also contributing most of the lake's suspended solids load. Siltation is the most damaging threat to the lake's biodiversity, especially siltation from the heavily-impacted smaller sub-watersheds of northern Lake Tanganyika. Large-scale deforestation and farming practices have led to a dramatic increase in soil erosion rates in these locations. The freshly-eroded sediments entering the lake adversely affect biodiversity, not only by decreasing species habitat, but also by efficiently changing certain essential nutrients and trace elements.

Untreated wastewater discharges, including industrial and domestic wastewaters from large cities (e.g., Bujumbura in Burundi; Kigoma in Tanzania; Uvira and Kalemie in Congo; Mpulungu in Zambia) are pollution sources to the basin. These discharges might contain nutrients, organic matters, heavy metals (e.g., mercury; chromium), pesticides, ash residues as cement, and fuel from ports, harbours, shipping places, and boats.

Agricultural runoff, particularly through the Malagarasi and Rusizi Rivers, has been observed. The agricultural expansion in the region could be accompanied by an increased use of agrochemicals.

Traditional attitudes and responses to land and water resource management, as well as waste disposal practice, unfortunately, are no longer sustainable because they cannot keep pace with the rapidly-increasing population density.

Pollution will inevitably lead to increased risks to human health associated directly with declining water quality. Further, the associated loss of fisheries, the traditional protein source, will increase the vulnerability of the people living in the region. The population of the region is expected to grow annually by an average of 2-3 per cent in the coming 20 years. This growth will inevitably increase the pressures on the aquatic environment by increasing fishery and water demands, as well as greater pressures on land, with increased farm-derived erosion resulting in more sediment transport to the lake.

4.7.2 Socio–economy

The main activity of the 10 million people living in the lake basin is agriculture. The main produce includes maize, tobacco, rice, sugar cane, coffee, beans, groundnuts, cassava, cattle and goats. The socio-economic statistics for the riparian nations of Lake Tanganyika are highlighted in Table 4.7-1.

Table 4.7-1: Socio-economic statistics for Lake Tanganyika riparian nations (Jorgensen et al. 2003)

	Burundi	Congo	Tanzania	Zambia
Population growth rate (per cent)	2.0	3.2	2.4	2.2
Population density (persons.km^{-2}) [persons mi^{-2}][	250 [648]	21 [54]	36 [93]	13 [34]
Adult literacy (per cent)	46	59	74	76
Population without access to safe water (per cent)	48	32	34	62
Health service	20	?	7	25
Sanitation	49	-	14	29
Per capita GNP (US $)	120	110	240	320
School enrolment (per cent of school age population)	51	78	67	89
Life expectancy (years)	42	51	47	43

Tanzania, Burundi, Zambia and the DRC have low levels of economic development, with per capita gross national incomes (GNIs) of US$ 250, 140, 320 and 110, respectively (http://www.afrodad.org/debt/burundi.htm). Human dependent on the lake, however, varies significantly. Agriculture, livestock raising, and the processing of these products, as well as mining, are the main industries in the Lake Tanganyika drainage basin.

The basin plays a crucial travel and trading role for the neighbouring countries of Tanzania, Burundi, DRC, and Zambia. Bujumbura, Kigoma and Mpulungu serve as shipping centres for trade among the riparian countries. Ship lines connect Kigoma (Tanzania), Kalemie (DRC) and other coastal towns as an essential part of the inland traffic system of eastern Africa. Although landlocked, Zambia has water resorts on the shores of Lake Tanganyika in the north part of the country. The Nsumbu National Park provides world-class game fishing, with Goliath tiger fish of over 35 kg (77 lbs) and giant catfish of over 50 kg (110 lbs) having been landed at three lodges. The lake basin also provides boating expeditions. A national fishing competition is held annually at Kasaba Bay in February or March each year, being attended by fishermen from all over the world.

Tanzania earns some income from tourist activities at Mahale Mountain and Gombe Stream National Parks. The park's forested mountain slopes, which help define the Great Rift Valley, are home to chimpanzees. Mahale is rich in plant species that have major influences on the life of chimpanzees, which utilize 328 food items from 198 plant species, with some of the plants used by chimpanzees as medicine and appetizers.

Burundi's capital (Bujumbura), with a population of 400,000, is the largest city at the northeastern end of Lake Tanganyika, hosting many tourist hotels. The Rusizi Delta National Reserve, the 'Musee Vivant' in Bujumbura, and Reptiles Park are some of the interesting tourist attractions. Uvira and Kalemie in the DRC also provide tourist attractions.

Increased population, urbanization and industrialization are affecting the basin's socio-economic status. The annual population growth rate of most countries in the region is 2.5-3.1 per cent. This progressive increase in population pressures (this region has among the world's greatest rural

population densities) has forced a change in land use, from pristine tropical forests to small agricultural plots located on steep, denuded slopes bordering the lake. As a result, accelerated erosion rates supply streams and rivers with an increased suspended particulate load, which is deposited as fine-grained silts and clays in the rocky deltas. Record sediment accumulation rates in highly-impacted river systems can reach up to 100 $cm.yr^{-1}$ (39 $in.yr^{-1}$).

If not properly planned, increased tourism will cause increased impacts in the basin, although some are of the opinion that the local infrastructure is not yet on a level to allow mass tourism.

The fisheries of the Lake Tanganyika basin are by far the most important source of animal protein for human consumption. The basin has traditionally supplied between 25-40 per cent of the protein needs of the local population in the 4 riparian countries. About 45,000 people are directly involved in the lake fisheries, operating from almost 800 sites. The main fishery product is the 'Tanganyika Sardine' *(Stolothrissa Tanganikae,* herring family), which also is very important for the local economy, constituting 55-90 per cent of the commercial fishery and 80-99 per cent of the traditional artisanal fishery (Rufli 2001).

In recent years, however, the Lake Tanganyika Basin, like many other biologically-sensitive areas, has begun to feel the effects of increased population pressures. Fishing practices have become much more efficient, for example, and consequently more destructive. Commercial fishing began in the mid-1950s, and has had an dramatic impact on the fish stocks and the majority of fish species.

A major increase of the number of fishermen has been observed throughout large parts of the lakeshore communities. Many people are now exploiting the more accessible shore waters richest in fish biodiversity, and the nursery for most pelagic fish.

HIV/AIDS and water-related diseases

The Lake Tanganyika Basin has been encroached by a large number of refugees, leading to high rates of HIV/AIDS, which is a new challenge to the basin. As refugees come to this basin, they live in shelters without sanitation facilities. This has been a significant cause of water-related diseases, and measures must be taken to solve this problem.

4.7.3 Management

The management of Lake Tanganyika and its basin is the responsibility of the riparian countries of Burundi, Democratic Republic of Congo, Tanzania and Zambia. These countries alone could not have set up a coordinated sustainable management mechanism for the shared resource except for important inputs from regional projects. These include: (i) FAO projects at the national level, and coordinated by the FAO Committee for Inland Fisheries for Africa (CIFA); (ii) FAO/FINNIDA (Finnish International Development Agency) Lake Tanganyika Research Project (LTR); and (iii) UNDP/GEF Lake Tanganyika Biodiversity Project (LTBP). FAO projects focused on fisheries management, while the LTBP focused mainly on biological diversity conservation, water quality and pollution control, and habitat protection.

Institutional and legislative frameworks

The Lake Tanganyika Basin management implementation arrangements are complex because the lake has four riparian countries. Thus, any approach to improve the understanding and subsequent

management of the lake must have both an international and regional perspective. The main problems to be addressed are: (i) lack of resources for the involved institutions; (ii) poor enforcement of existing regulations; (iii) lack of appropriate regulations for the basin; and (iv) lack of institutional coordination. The governments have ratified a convention necessitating the formation of Lake Tanganyika Management Authority (LTMA) in order to reduce the pressures on the lake resources.

National Institutions

It would be expected that the national institutions involved in management of the Lake Tanganyika Basin have the capability to manage biological stocks, biodiversity conservation, water quality and pollution control, and reducing sediment transport to the lake, and in a harmonized way between the other countries. What is common is that each government at least has agencies responsible for fisheries, with local offices located at or near the lake. Involvement in other aspects of lake management at the national level, however, is not well developed. Although there are a large number of local and international NGOs in the 4 countries, most do not have sufficient resources to undertake effect actions.

Data availability, standardization and monitoring

The Lake Tanganyika Management Authority (LTMA) is mandated with reducing pressures on the lake resources. It is responsible for harmonizing management policies, laws, monitoring of regulations and data exchange, and providing a forum for the countries to discuss lake basin management.

4.7.4 Key Issues, adaptation and mitigation

Physiography

Land use change, land degradation and deforestation in the catchment have profound impacts that are propagated through the rivers by the land surface and the atmosphere, to the lowland wetlands and lake.

Adaptation and mitigation

There is a need:

- To strengthen land management (institutions, legislation, regulations and enforcement).
- To carry out education and awareness among the basin's human inhabitants, particularly rural communities.
- To create projects based on the natural resources that benefit the communities and involve them in managing the basin's natural resources.
- To strengthen water resources management (e.g., water demand management)
- To effectively manage erosion and pollution control (e.g., institutions, legislation, regulations and enforcement).

Socio-economy

The main activity of the 10 million people living in the Lake Tanganyika Basin is agriculture, including maize, tobacco, rice, sugar cane, coffee, beans, groundnuts, cassava, cattle and goats. Thus, the water demands are high. The basin population also is increasing rapidly, with HIV/AIDS is becoming a major concern.

Adaptation and mitigation

There is a need:

- To improve and strengthen rural investment to curb rural to urban migration.
- To develop urban infrastructure (e.g., upgrading water supply and sewage systems).
- To further institute measures discouraging rapid population growth and high birth rates (e.g., education, awareness, policies).
- To further integrate HIV/AIDS issues into water and sanitation policy frameworks.
- To implement sustainable water and sanitation projects in the rural areas, in order to improve access to water and health and hygiene
- To implement enhanced anti-retroviral programmes.

Management

The management of the Lake Tanganyika Basin is the responsibility of the riparian countries of Burundi, DRC, Tanzania and Zambia, through the Lake Tanganyika Management Authority. The institutional and legal frameworks are currently weak.

Adaptation and mitigation

There is a need:

- To build the capacities of the Lake Tanganyika Management Authority and various institutions regarding water resources development and management.
- To develop easily-implementable regulations in water resources development and management.
- To accelerate devolution of water resources management to lower levels, through the establishment of appropriate structures.
- To establish or strengthen information collection and sharing systems.

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4.8 LAKE TURKANA BASIN

Lake Turkana, formerly known as Lake Rudolf, is situated in the Great Rift Valley in the northwestern part of Kenya (although the far northern end of the lake crosses into Ethiopia; Figure 4.8-1). The lake covers a surface area of 6,750 km² (2,606 mi²), and a catchment area of 130,860 km² (50,525 mi²), making it both the world's largest permanent desert lake, and the world's largest alkaline lake. Its average water depth is 35 m (115 ft), while the maximum depth is 115 m (377 ft), with a length of 250 km (115 mi).

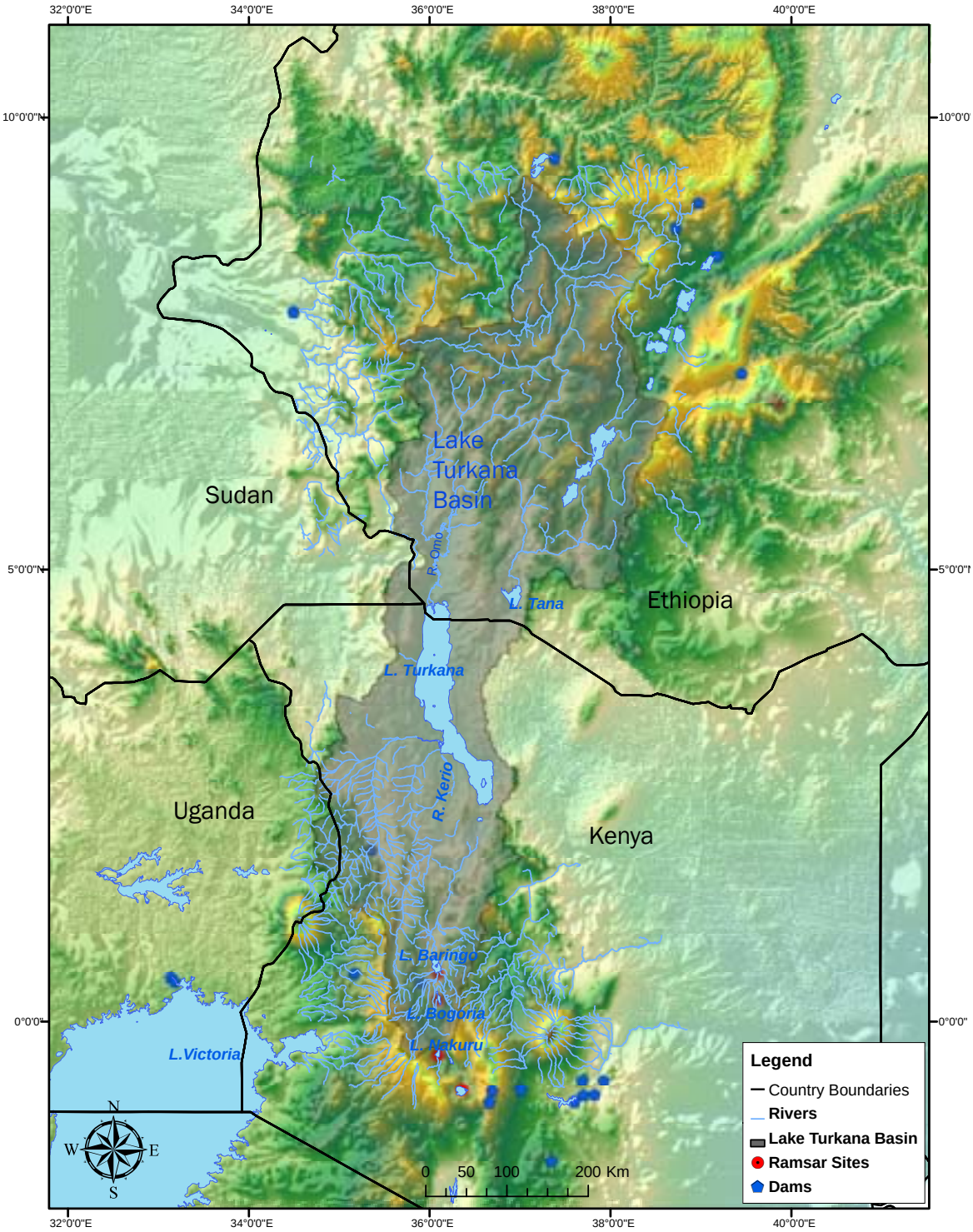

Figure 4.8-1: Lake Turkana Basin

Tertiary volcanic rocks are found in the south, and along most of the western side of the lake (Herlocker, D. et al. 1994) in the Lake Turkana Basin. The lavas are mainly alkaline, which has important implications for the chemical composition of the lakes in this area. Less than 3 per cent of the basin has agricultural potential (ETC EA 1999). The main characteristics of the basin are summarized in Box 4.8-1.

The most critical issue in the basin is deterioration of the water quality of the lake, rivers, springs and groundwater, resulting in water resources becoming unfit for human consumption and other uses, thereby making the water resources scarce.

Box 4.8-1: Main characteristics of Lake Turkana Basin

Basin		**Water Use**	
Lake surface area:	6,405 km^2 (2,473 mi^2)	Agriculture	Increasing
MAP:	<250 mm.yr^{-1} (10 in.yr^{-1})	Domestic	
		Industry	
Demography		Mining	
Population:	450,000	Hydropower	
Density:	59 persons.km^{-2} (153 persons.mi^{-2})		

4.8.1 Physiography

The Lake Turkana Basin is hot and very dry. The mean annual rainfall in most of the lake surroundings is less than 250 mm (10 in). The occurrence of rainfall is erratic and unpredictable, with only one year in four likely to bring adequate rain. The probability of rainfall is highest during the 'long rains' in March-July. Under normal conditions, the Lake Turkana Basin has more or less 2 distinct rainy seasons.

Temperatures are fairly uniform throughout the year, with an average daily range of about 24-38 °C (75-100 °F), and a relative humidity between 40-60 per cent

Even though Lake Turkana Basin is located in one of the driest places in eastern Africa, it is endowed with reliable, relatively abundant groundwater resources, which are recharged from the surrounding mountains. The water sources in the basin, unfortunately, are not evenly distributed, with some areas having a large number of water resources, while others have few or none (Herlocker, D. et al. 1994). The geology is predominantly volcanic.

The lake is alkaline, containing high concentrations of sodium chloride, sodium carbonate, iron and lead, which make it unsuitable for crop production and human consumption (Emuria 1992). Several major rivers flow into the lake.

Although 3 rivers (Omo; Turkwel; Kerio) flow into the lake, the only outflow is by evaporation. The estimated evaporation rate is 2,335 mm.yr^{-1} (92 in.yr^{-1}). The water level of this closed basin lake is determined by the balance between the water influx from inflowing rivers and groundwater, and the lake water evaporation. Thus, the lake's water level is sensitive to climatic variations, and subject to marked seasonal fluctuations, as well as long-term periodical changes.

The main tributary is the Omo River, which enters the lake from the north, contributing more than 90 per cent of the total water influx to the lake. Other rivers are temporary, flooding only during sporadic rains. The Omo River is an important river of southern Ethiopia, with its most important tributary being the Gibe River. Smaller tributaries include the Wabi, Mago and Gojeb Rivers. The river originates in the Shoan highlands, and is perennial. During its course of approximately 600 km (373 mi), it has a total fall of about 2,000 m (6,562 ft) (from about 2,300 m [7,546 ft] amsl at its source, to 484 m [1,588 ft] amsl at lake-level), consequently flowing very rapidly, and being broken by the Kokobi and other falls. It is navigable only for a short distance above where it empties into Lake Turkana.

The second largest river in the Lake Turkana Basin is the Turkwel River, which is now being dammed for hydroelectric power generation at Turkwel Gorge, 150 km (301 mi) west of the lake, followed by the Kerio River.

The habitats in the Lake Turkana Basin that are variously affected are the swamps, riparian belts, deltaic wetlands, river floodplains and the periodic standing water in Ferguson's Gulf. Ecosystem losses are occurring in these areas through habitat fragmentation, as a result of nutrient-rich soils being cleared for agriculture and settlement. Some swamps with lush vegetation also are being used as livestock grazing areas. At the Omo River entrance to Lake Turkana, a highly-complex and spatially-changing floodplain and delta have developed (Haack and Messina 2001).

4.8.2 Socio-economy

Based on the 2000 census, the population of the Lake Turkana Basin is estimated to be about 450,000 (2000 census) with an annual growth rate of 2.5 per cent, and a population density of approximately 59 persons.km^{-2} (153 persons.mi^{-2}). Of this total, approximately 70 per cent is nomadic or semi-nomadic pastoralists, although there is an increasing emergence of sedentary Turkana people, due particularly to drought impact, conflict and famine, (ETC EA 1999). The observed population growth is generally within the Turkana group, which lead a settled, urban life. On the other hand, the growth of the nomadic pastoralist population group is quite stable (Emuria, L.P. 1992; Van Den Boogaard, R. 1996).

There are significant water demands for livestock raising in this region, which is a pastoral area, and where surface water resources are scarce and long dry seasons experienced. The semi-nomadic pastoralists inhabiting these areas often encroach on natural reserves (e.g., Lake Mburo National Park in Uganda) in search of water and pasture areas. In past years, 425 medium-sized dams and valley tanks, as well as several small valley tanks, were provided. Most are now silted because of inadequate maintenance, poor animal-watering methods, and soil erosion resulting from overstocking.

Northern Kenya is an arid and semi-arid area, characterized by a scarcity of natural resources. Conflicts in this region between the Turkana people and other pastoralist groups are centred mainly on exploitation of these limited resources. These conflicts are related to limited access to water and pasture resources because of prolonged drought in the basin, loss of traditional grazing land, lack of alternative livelihood sources, the weakening role of traditional institutions in conflict management, political incitement, non-responsive government policy and inter-tribal conflict.

4.8.3 Management

New national environmental policies and Acts have been enacted in Ethiopia (1997) and Kenya (1999), and environmental authorities have been set up to implement them, which seek to promote sustainable environmental management and development. There are no specific laws relating to the use of Lake Turkana or its affluent river waters, although each country has a Water Act covering the use of waters from all waterbodies within the country. The new Kenya Water Act (2002) provides for establishment of a Water Resources Management Authority, and Catchment Area Advisory Committees, that will have wide-ranging powers to manage and protect water resources at the river- or lake-basin scales. One of the important new regulations in this Act is recognition of, and provision for, participation of the public and communities in managing the water resources within each catchment area.

4.8.4 Key Issues, adaptation and mitigation

Physiography

The Lake Turkana Basin is hot and very dry. The mean annual rainfall in most of the lake surroundings is less than 250 mm (10 in), and climate variability and change will impact on the available water resources.

Adaptation and mitigation

There is a need:

- To develop early warning systems for drought and pollution to enable effective responses.

Socio-economy

Livestock raising results in significant water demands in this pastoral region, where surface-water sources are scarce, and long, dry seasons are experienced.

Adaptation and mitigation

There is a need:

- To develop and implement an effective livestock management programme to ensure that communities realise optimum benefits, without compromising the ecosystem through land degradation from overgrazing.

Management

Water resources management within the basin is fragmented, with each riparian country having its own water management policies.

Adaptation and mitigation

There is a need:

- To establish a single basin management organization to ensure the development and management of the basin's water resources.

- To develop easily-implementable regulations in water resources development and management.
- To establish, or strengthen, standardized information collection and sharing systems

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4.9 LAKE VICTORIA BASIN

Lake Victoria lies astride the equator between latitude 2.5° S and 1.5° N, and longitude 32° E and 35° E, and is shared by 3 riparian states (Kenya [6 per cent]; Tanzania [51 per cent]; Uganda [43 per cent]). It is drained by a number of large rivers, including the Kagera, Nzoia, Gucha-Migori, Sondu Miriu, Mara, Yala, Issanga, Nyando, and Biharamulo Rivers, as well as many other small rivers and streams. The Nile River is the single outlet (Figure 4.9-1). The main characteristics of the Lake Victoria Basin are summarized in Box 4.9-1.

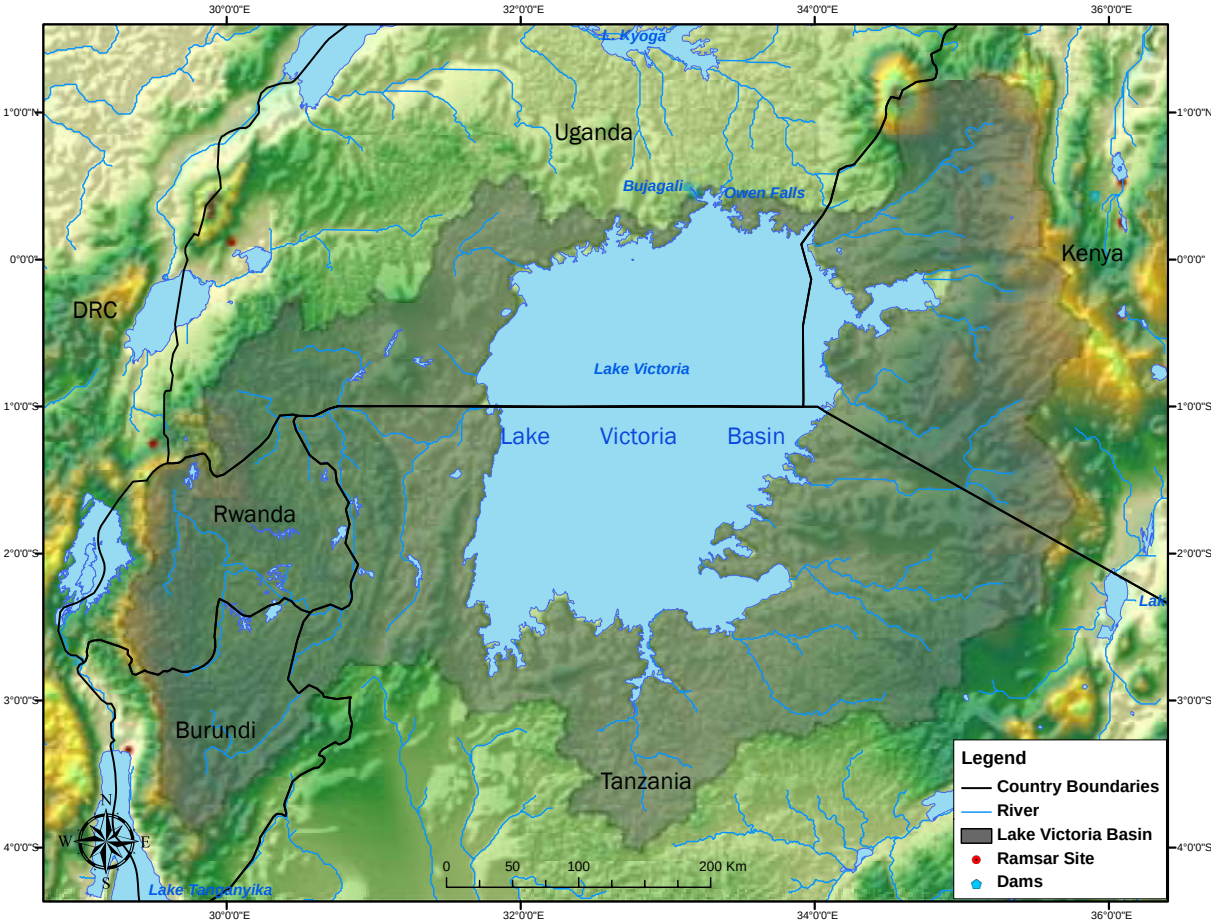

Figure 4.9-1: Lake Victoria Basin

Box 4.9-1: Main characteristics of Lake Victoria Basin

Victoria Basin
Surface area: 250,826 km^2 (96,844 mi^2)
Lake area: 68,800 km^2 (26,564 mi^2)
MAP: 450-2,450 mm.yr^{-1} (18-96 in.yr^{-1})

Water Use
Agriculture
Industry
Domestic
Fishery

Demography
Population: 30 million
Density: 165 persons.km^{-2} (427 persons.mi^{-2})

Vulnerability
Climate variability and change affect catchment environment

Major Dams
Owen Falls

Source: Water Resources Division, Ministry of Water and Livestock Development, Tanzania

Lake Victoria is the largest lake in Africa, with a surface area of 68,800 km^2 (26,564 mi^2), and an adjoining catchment area of 184,000 km^2 (71,043 mi^2) (Bucceri and Fink 2003), including areas in Uganda, Kenya, Tanzania, Burundi, Rwanda, and a small part of the Democratic Republic of Congo. The mean water depth in the lake is only 40 m (131 ft), and the maximum depth ranges from 84-92 m (276-302 ft) (Nicholson 1998). The flushing time is 138 years and the water residence time is 21 years (Kayombo and Jorgensen 2004). Lake Victoria surrounds several groups of large islands (e.g., Sesse or Kalangala and Buvuma of Uganda; Ukerewe of Tanzania; Rusinga of Kenya), and many small ones.

Lake Victoria is considered to be the second largest fresh waterbody in the world, after Lake Superior in North America, and the seventh largest freshwater lake by volume. It holds about 2,760 km^3 of water, equal to only 15 per cent of the volume of Lake Tanganyika, even though the latter has less than half the surface area. The lake's shoreline is long (about 3,500 km [2,175 mi]) and convoluted, enclosing innumerable small, shallow bays and inlets, many of which include swamps and wetlands differing a great deal from one another, and from the lake itself (Ewald et al. 2004). The lake is situated at an altitude of 1,134 m (3,720 ft).

4.9.1 Physiography

Most of the region around the lake can be classified as arid or semi-arid (Nicholson 1998; Yin & Nicholson 1998). The mean annual rainfall, based on rainfall data from 1950 to 2000, ranges between 886-2,609 mm (35-103 in) (Kayombo and Jorgensen 2004). The annual rainfall ranges from 450-950 mm (18-37 in) in the terrestrial part of the basin.

The precipitation exhibits a bimodal seasonal distribution, with peaks occurring during March-May and November-December (Conway 1993). Lake Victoria has a unique diurnal circulation system that enhances rainfall over the lake, as a result of a strong nocturnal land breeze (Yin & Nicholson 1998). This diurnal circulation system plays an essential role in understanding the lake's water balance. The circulation produces a strong convergence of flow directly over the lake at night. This occurs because the lake water is warmer than the overlying atmosphere, and cumulonimbus cloud clusters produced by lake breezes and thunderstorms develop over the centre of the lake.

The nocturnal rainfall caused by easterly winds is found on Lake Victoria's north and west shores, as evident in the rainfall data from stations on or near the lake (Yin et al. 2000). Most rainfall occurrence is nocturnal, generally being associated with strong thunderstorms (Yin & Nicholson 1998; Yin et al. 2000). About 85 per cent of the water entering the lake originates from rainfall directly onto the lake surface.

The mean annual temperature over the Lake Victoria Basin is about 23 °C (73 °F). The mean evaporation rate over the lake ranges between 1,108-2,045 $mm.yr^{-1}$ (44-81$in.yr^{-1}$) (COWI 2002).

The lake ecosystem has undergone substantial and, according to some observers, alarming changes that have accelerated over the past three decades. Massive algal blooms have developed, being increasingly dominated by the potentially-toxic blue-green variety. The water transparency has declined from 5 m (16 ft) in the early-1930s, to 1 m (3.2 ft) or less for most of the year in the early-1990s. The frequency of waterborne diseases has increased. Although water hyacinth was absent in the lake as late as 1989, it was choking important waterways and landings by the late-1990s, especially in bay areas in Kenya and Uganda (although it is presently under control). Over-fishing, exotic fish species and oxygen depletion at lower water depths in the lake threaten the artisanal fisheries and biodiversity (over 200 indigenous species are facing possible extinction). These extensive changes have been attributed to both the introduction of Nile perch that altered the food web structure, and to increased nutrient inputs to the lake, resulting in eutrophication.

Land use has intensified and human and livestock population increased, especially along the lakeshores, and on the islands in the lake. The rivers contribute only about 15 per cent of the water entering the lake, with the rest being from rainfall (Nicholson 1998).

The main rivers flowing into the lake from the Tanzanian catchment are Mara, Kagera, Mirongo, Grumeti, Mbalageti, Simiyu, and Mori Rivers (LVEMP 2001). The main rivers from the Kenyan catchment are the Nzoia, Sio, Yala, Nyando, Kibos, Sondu-miriu, Kuja, Migori, Riaria, and Mawa Rivers, while the Kagera, Bukora, Katonga, and Sio Rivers are the main ones from the Ugandan catchment (LVEMP 2003). The Kagera, which drains Burundi and Rwanda and part of Uganda, is the single largest river flowing into the lake, contributing roughly 7 per cent of the total inflow, or one-half of that over and above direct precipitation. Rivers entering the lake from Kenya, which contains the smallest portion of the lake basin, contribute over 37.6 per cent of the surface water inflows. About 86 per cent of the total water input falls as precipitation, with evaporative losses accounting for 80-85 per cent of the water leaving the lake (Okonga 2001; COWI 2002).

In addition to the water leaving the lake via direct evaporation, the remaining 15-20 per cent leaves largely by way of the Victoria Nile, which leaves the lake near Jinja in Uganda (with lake water drained at a rate of about 600 $m^3.s^{-1}$), and flows via the Owen Falls, Lake Kyoga, and the Murchison Falls to join the outflow from Lake Albert. These two outflows are the main sources of the 'White Nile.' The annual water outflow at Owen Falls is around 38 km^3. Before Lake Victoria's water reaches the lower parts of the Nile Basin, it is subjected to significant evaporation because of its passage through large swamps in the Sudan (Ewald et al. 2004).

Lake Victoria has faced abrupt water level fluctuations and anomalous hydrologic behaviour, with this variability affecting the Nile River flow. Thus, changes in the lake water balance can have far reaching consequences, in terms of their effects on the downstream countries dependent on the

Nile water; namely, Sudan and Egypt. Nicholson (1996; 1998) studied the historical fluctuations of Lake Victoria since 1800. He reported the lake water levels were low during the early-nineteenth century, with peak levels occurring in the late-1870s. They then declined to twentieth-century levels. It is worth noting that low lake levels result in a scarce water resource for the local people, not only in the immediate vicinity of the Lake Victoria Basin, but also along the stretch of the Nile River, resulting in human migrations (Nicholson 1998). The lake levels rose significantly from 1961 to 1962, continuing to be high to the present time. Conway (2003) investigated the climatological factors responsible for the increased lake levels, and found a significant correlation between the lake rainfall series and its water levels. It also was noted that there is a time lag of one to two years between rainfall episodes and water level peaks. Because the rainfall series is based on land-based observation, and the lake itself is roughly one-quarter of the whole basin, the lake water level variability is partially explained by the direct precipitation onto the lake.

Increased pollution from municipal and industrial discharges is visible in some rivers feeding the lake, and in urban areas along the shoreline (e.g., Kisumu; Mwanza; Kampala). The pollution sources include a number of basic industries (e.g., breweries; tanning; fish processing; agro-processing; abattoirs). Small-scale gold mining is increasing in parts of the Tanzanian catchment and, if wastes from mining activities are not well contained, might lead to mercury discharges into the lake. Increased nutrient flows also occur because of sediments eroded from the catchment, burning of wood-fuels, and human and animal waste loads from the areas surrounding the lake.

Land degradation and deforestation in the lake catchment area, and along the riverbanks, is contributing to ecosystem losses (Shepherd et al. 2000; Swallow et al. 2002). The acreage under cultivation for cash and food crops (tea; tobacco; rice; beans; coffee; sugar cane) in the Nyanza Province increased from about 15,400 ha (59 mi^2) in 1968, to 157,000 ha (606 mi^2) in 1991-1992 (Kairu 2001), although additional studies are needed to quantify the level of ecosystem loss. Much of the lake margin is swampy, and islands of Cyperus papyrus, with its typical associates, detach from the fringing swamps (Hughes and Hughes 1992). The continuous cropping of papyrus along the lake shore could have very serious ecological effects, including the loss of large quantities of nutrients removed with the harvested papyrus biomass which would otherwise be recycled (Muthuri et al. 1989).

Groundwater stored within the Lake Victoria catchment was estimated to be in the order of 70,000 million m^3 in 1979, while the total annual groundwater discharge was about 18 million m^3, of which 7.5 million m^3 was discharged to streams and 4.9 million m^3 was extracted by pumping (Ongwenyi 1979). Because no quantitative assessment of these components has yet been undertaken, these should be viewed as broad estimates. The groundwater is of excellent chemical quality in the Kenyan sector (total dissolved solids concentration is of the order of 500 ppm, and rarely exceeds 1000 ppm), and can be used for multiple purposes.. The only problem is that the groundwater contains excessive fluoride concentrations in some locales, far in excess of the 1.5 ppm stipulated for drinking water purposes (Ongwenyi 1979). The expansive, continual land degradation, soil erosion and deforestation that has been taking place over the past few decades within the Kenyan sector of the catchment (Swallow et al. 2002) provides indirect evidence of declining river base-flows. There have been reports of over-abstraction of water from some wells within the region, although the regional extent of this occurrence is not known. Studies are required to quantify river base-flows, and to establish the regional nature of the aquifers in the lake basin, and their quantity and yield, in order to be able to sustainably manage these resources.

4.9.2 Socio-economy

The population of the lake basin is about 30 million, constituting about one- third of the population of Kenya, Tanzania and Uganda. The population growth of the riparian municipalities in the 3 countries is greater than 6 per cent per annum, being among the highest numbers in the world (Kayombo and Jorgensen 2004). The population density is as high as 1,200 persons.km^{-2} (3,108 persons.mi^{-2}) in parts of Kenya (Hoekstra and Corbett 1995), while the average density in the basin is 165 persons.km^{-2} (427 persons.mi^{-2}).

The population growth rate on the Tanzanian side of Lake Victoria is about 3 per cent annually, and is expected to progressively increase, thereby leading to an increase of unplanned human settlements, agricultural activities and deforestation (Machiwa 2002). As demands for natural resources increase, and land-use changes continue to occur, pollution loading can intensify to the extent that Lake Victoria and its catchment are at serious ecological risk.

The gross economic product for the lake is in the order of US$ 3-4 billion annually, mainly from subsistence agriculture and fishing in Kenya, Uganda, Tanzania, and parts of Rwanda and Burundi.

Water uses

The lake basin provides resources for the economic livelihoods of the basin population. The lake is used as a source of food, energy, drinking and irrigation water, shelter, transport, and as a repository for human, agricultural and industrial wastes. The lake basin resources also provide amenities for cultural and leisure activities. The waters originating from the lake provide hydropower through its only outlet (Nile River), at Owen Falls in Uganda and other power plants downstream in the river. The power from the two plants at Owen Falls generates 260 megawatts, part of which is exported to Kenya. These waters also support extensive irrigated agricultural schemes in Egypt, ecological values in the Sudan and other wetlands, an important tourism industry on the Nile River, and navigation and transport over large distances in the lower river.

More than 80 per cent of the lake basin population is engaged in agricultural production, the majority being small-scale farmers and livestock owners, producing maize and cash crops (sugar; tea; coffee; cotton; etc.) and meat. The fish resources of the lake directly or indirectly sustain the livelihoods of about three million people engaged in subsistence, artisanal and commercial fishing. Lake Victoria supports the most productive freshwater fishery in the world with annual fish yields in excess of 300,000 tonnes (661,000 lbs), worth US$ 600 million annually (Kayombo and Jorgensen 2004).

Access to water

The number of people supplied with water has marginally improved at the national level, presently being around 60 per cent in urban centres, and lower at 40-50 per cent in rural areas. The reasons include the poor state of most of the water schemes established by the government, with the assistance of donor funds. To avoid this situation in the future, the new water policy includes a community participation in water projects component, as a means of ensuring sustainability.

HIV/AIDS

HIV/AIDS is a health problem for the fishing population living in the lake basin, with the Nyanza Province being noted for the highest share of the population with HIV/AIDS in Kenya. This has contributed to the poverty situation on the Kenyan side of Lake Victoria (Ewald et al. 2004).

4.9.3 Management

Institutional roles and management strategies

The East Africa Community (ECA) is the main regional forum for discussing Lake Victoria management issues by the 3 riparian countries, The other regional institution dealing with management of the lake is the Lake Victoria Fisheries Organization (LVFO). Projects undertaken in the lake basin include the Lake Victoria Environmental Management Programme (LVEMP), Lake Victoria Fisheries Research Project (LVFRP), and the Nile Basin Initiative (NBI).

The East African Community (EAC) is a forum representing Kenya, Tanzania and Uganda, being the main regional forum for discussing Lake Victoria management issues. Through the EAC, the 3 partner states have designated the Lake Victoria Basin as an economic growth zone to be exploited in a sustainable manner. The EAC and the Governments of Sweden, France and Norway, World Bank, and East African Development Bank (EADB) have joined in a long-term partnership on the promotion of sustainable development of the Lake Victoria Basin. This arrangement was formalized in 2001, through signing of a partnership agreement between the EAC and its development partners.

Lake Victoria Fisheries Organisation is an institution under the EAC established by the riparian states in cooperation with FAO, EU, and WB, with the vision of facilitating a common resource management system, with the goal of restoring and maintaining long-term ecosystem health. The LVFO is actively assisting national fisheries departments in managing fisheries, including monitoring sanitation at landing sights. LVFO also assists in harmonization of regional fisheries regulations.

The Lake Victoria Environmental Management Programme (LVEMP) is a comprehensive programme that covers Lake Victoria and its catchments in Kenya, Tanzania, and Uganda, with its main objective being rehabilitation of the ecosystem, using a regional transboundary approach. The LVEMP focuses on over-fishing, eutrophication and algae levels, pollution and the invasion of the water hyacinth. The LVEMP was commenced in 1994 with a tripartite agreement, and is funded by the GEF (Global Environment Facility) and IDA (International Development Association), in addition to national contributions. Following a recent evaluation and renegotiations, a follow up activity (LVEMP II) was launched. A major emphasis of the continued work with LVMP II is to ensure stronger connection to the EAC process, such that the direction of the future work depends on the outcome of the Lake Victoria Vision and Strategy Process.

Two non-governmental organizations, Osienala and Ecovic, were established by locally-based stakeholders. Osienala gathers and disseminates information on the lake environment, coordinates local-level initiatives, and provides capacity building. Expressing an ambition to gain a truly regional outreach Osienala has developed a regional 'alter ego,' in the form of Ecovic.

The Lake Victoria Fisheries Research Project was established in 1997, with the principal aim of assisting the LVFO in establishing a framework for the rational management of Lake Victoria's fisheries. The specific objectives were to undertake fish stock assessments, to train fisheries researchers, to rehabilitate and construct research vessels, to equip research institutes, and to investigate socio-economic issues related to the lake and its fisheries.

The Nile Basin Initiative (NBI) is an initiative by the 10 Nile Basin countries (Burundi; Democratic Republic of Congo; Egypt; Eritrea; Ethiopia; Kenya; Rwanda; Sudan; Tanzania; Uganda), with the goal of promoting the development potential of the Nile River in a way that focuses on gaining mutual benefits from development, rather than on defending water rights. The initiative is funded by a number of donors, including the World Bank, Norway and Sweden, with the Nile Council of Ministers (Nile-COM) serving as its highest decision-making body. Ministers of Water Affairs of the Nile Basin Riparian Countries make up the Nile-COM, with technical support being provided to it by the Nile Basin Initiative Technical Advisory Committee (Nile-TAC), and the execution of its decisions being undertaken by the Nile Basin Initiative Secretariat (Nile-SEC). The Nile Equatorial Lakes Subsidiary Action Plan (NELSAP) is a component of the NBI, concerned with transboundary development in the Nile equatorial lakes countries, including Burundi, Democratic Republic of Congo, Egypt, Kenya, Rwanda, Sudan, Tanzania, and Uganda.

4.9.4 Key issues, adaptation and mitigation

Physiography

The Lake Victoria ecosystem has undergone substantial changes that have accelerated over the past 3 decades, including massive algal blooms (especially the potentially-toxic blue-green variety), decreasing water transparency, increasing waterborne diseases, and increasing water hyacinth.

Adaptation and mitigation

There is a need:

- To strengthen land management, in the form of institutions, legislation, regulations and enforcement.
- To carry out education and awareness among the basin's human inhabitants, particularly rural communities.
- To create projects based on the natural resources that benefit the communities, and involve them in managing these resources.
- To strengthen water resources management.
- To effectively manage erosion and pollution control (institutions; legislation; regulations; enforcement).

Socio-economy

The population growth of the riparian municipalities of the 3 countries is greater than 6 per cent per annum, being among the highest numbers in the world. High population growth may lead to an increase in unplanned human settlements, agricultural activities and deforestation. Because of increasing demands for natural resources and land-use changes, pollution loading can intensify to the extent of placing Lake Victoria and its catchment at serious ecological risk.

Adaptation and mitigation

There is a need:

- To strengthen IWRM by all riparian countries in a co-ordinated manner, focusing on holistic water use, with a balance between all land uses, including plantation forests, efficient irrigation systems, safe drinking-water, livestock raising, and water harvesting,
- To develop water demand management to ensure efficient, effective use of water resources.
- To institute pollution monitoring and mitigation measures at the basin level to ensure no 'precious' water resources are wasted because of pollution.

Management

The EAC is the main regional forum for discussing the management issues of Lake Victoria by the 3 riparian countries

Adaptation and mitigation

There is a need:

- To strengthen existing management structures through capacity-building.
- To upgrade monitoring networks.

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CENTRAL AFRICA

5.1 OVERVIEW

The central African countries comprise Chad, Cameroon, Central African Republic (CAR), Democratic Republic of Congo (DRC), Republic of Congo, Gabon, Equatorial Guinea, and the Islands of the Gulf of Guinea (IGG) (Figure 5.1-1). The economies of these countries depend mainly on natural resources, with their principal economic activities including logging, agriculture, mining, industry and tourism. Because it is difficult for them to harness the resources required to cope with the adverse impacts of climate variability and change, the generally low level of economic development of these countries makes them very vulnerable to these issues. Climate variability and change may be described in terms of the total quantity of precipitation received, its frequency of recurrence, the persistence of wet or dry-day combinations, and the onset and duration of the rainy season. The extent to which water resources, the environment, and economies may be impacted by changes in water availability varies.

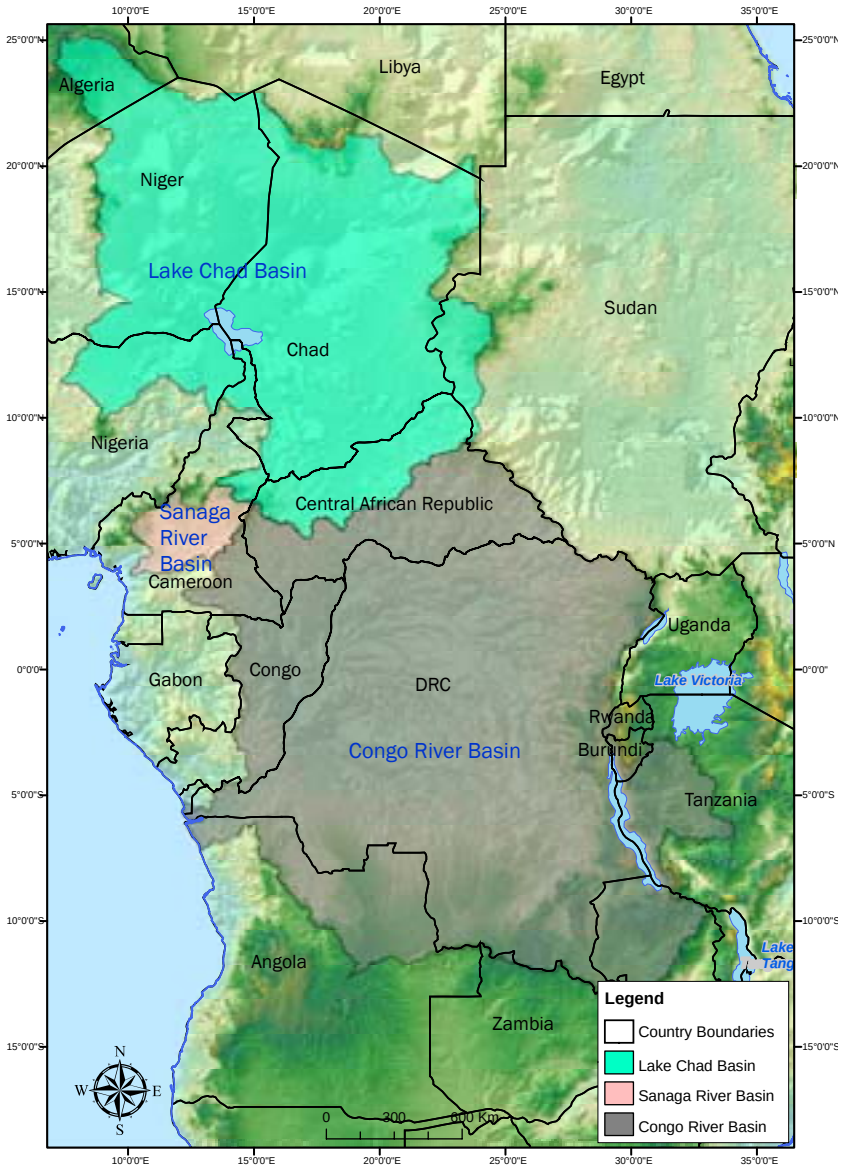

Figure 5.1-1: Major river and lake basins of central Africa

The main river basins in central Africa include the Congo and Sanaga River Basins, while the most important lake basin is Lake Chad (Figure 5.1-1). The coastal aquifers of the Douala Sedimentary Basin of southwest Cameroon constitute highly-solicited sub-surface water resources.

Islands of the Gulf of Guinea

The most important of these islands are São Tomé and Príncipe, a relatively small island state (~1,000 km^2 [386 mi^2]) about 275 km (171 mi^2) off the west coast of Africa. The population of Sao Tome and Principe is about 200,000, with an annual growth rate of ~3 per cent. Over 95 per cent of the population lives in Sao Tome, with 54 per cent being poor, and 15 per cent being extremely poor.

São Tomé and Príncipe form part of a chain of extinct volcanoes, with mountainous interiors and fertile soils. The islands experience a tropical humid climate of marked wet and dry seasons. Average annual temperatures are 27 °C (81 °F), with little daily variation. The evapotranspiration varies from 1,200 $mm.yr^{-1}$ (47 $in.yr^{-1}$) to 2,200 $mm.yr^{-1}$ (87 $in.yr^{-1}$), and the average annual rainfall ranges from 1,000-5,000 mm (39-197 in). Annual water availability per inhabitant is 15,279 m^3, being very high, compared to African (5,700 m^3) and world (7,000 m^3) values. Despite the abundance of water resources, however, only about 20 per cent of the country's population has access to safe drinking water. Water quality, and the lack of treatment facilities, are critical concerns that may indirectly undermine water availability. The water supplies are often contaminated at their source by human and hazardous wastes, and toxic pesticides used by households to control mosquitoes.

5.1.1 Physiography

The annual rainfall ranges from 500 mm (20 in) to more than 3,000 mm (118 in) among the central African countries, reaching 10,000 mm (394 in) at Debunscha, around Cameroon Mountain (Sigha et al. 2002). Although these values correspond to large rainfall volumes, the spatial and temporal variability of rainfall is high (although not as high as in drier regions like the Sahel). The countries experience humid to sub-humid conditions, being characterized by a relatively high blue/green[6] water ratio. This implies high water runoff rates, and a relatively large proportion of perennial water that results in very high per capita blue water availability of 10,000 to 17,000 $m^3.person^{-1}$ (SIWI 2000). In spite of the seeming water abundance in central Africa, the water resources, including rain, surface and groundwater resources, are unevenly distributed.

Water availability

The withdrawal to availability ratio in central Africa is less than 0.2 (Alcamo et al. 2003), indicating a significant availability of freshwater resources. However, because the level of water recycling and wastewater treatment is very low, intensive use of available water resources can cause severe degradation in water quality, and lead to heavy competition between water users.

[6] Blue water is defined as groundwater and stream flow, supporting aquatic ecosystems, that can be tapped for use elsewhere, including domestic and stock water, irrigation, industrial and urban use; green water is the water held in soil and available to plants. Although it is the largest freshwater resource, it can only be used in situ by plants.

5.1.2 Socio-economy

The population of central Africa, which is growing at an annual rate of 2.67 per cent, was estimated to be 95.5 million inhabitants in 2000, with a density of 77.6 persons.km^{-2} (201 persons. mi^{-2}) (Atlas de l'Afrique 2000). The projected increase in population of 163 million inhabitants in 2025 (Alcamo et al. 2003) is expected to significantly intensify the need for clean water supply and adequate sanitation.

Natural resources constitute the backbone of the economies of most central African countries. The main economic activities are agriculture and forest exploitation (especially logging). The region is also endowed with huge reserves of sub-surface resources. Examples of the geological resources include the petroleum deposits of the Gulf of Guinea, the more than eight strategic minerals found only in the DRC, the nickel-cobalt deposits of Cameroon (with a potential to supply more than 10 per cent of the world's cobalt), the diamonds of the CAR and the DRC, and the iron ore deposits of Cameroon and the Republic of Congo. Unfortunately, mining is poorly developed because of the absence of favourable infrastructure.

The main economic activities of the countries also are highly water-dependent and, because the central African countries are underdeveloped, changes in climate patterns and water availability will have tremendous impacts on their socio-economic situation. These impacts will differ with the basin or region, due to variations in such factors as geology, climate, hydrological regime, ecosystems, and demographic patterns.

It is purported that HIV/AIDS originated in the central equatorial region of Africa (Gallo 1987; Temin and Bolognesi 1993), and has an expected prevalence rate of between 4 and 13.4 per cent (Defoundoux 2004). The incidence of HIV has been accentuated by armed conflicts that plague the region. Excepting Gabon and Cameroon, all other central African countries have experienced civil wars, or violent political changes, resulting in population displacements. It is estimated that the number of war-displaced peoples in Congo Brazzaville (1997/2000) totalled up to 800,000, while that of the DRC as a whole was 3,000,000. The inherent permutation and combination of families involved in these displacements has facilitated the spread of HIV/AIDS. Women are particularly vulnerable, since the category of the population with the highest HIV/AIDS prevalence consists of soldiers, whether army or militia; (Defoundoux 2004), and rape is a commonly-perpetrated act of these soldiers. This situation has increased the vulnerability of the entire population.

Water demands

Total water withdrawals in central Africa have been estimated to be 1.9×10^9 m^3, with this abstraction projected to increase to 5.9×10^9 m^3 by 2025 (Alcamo et al. 2003). The most important water uses in central Africa at present are for agriculture, industry, power production, and household needs, with activities in these domains increasing as a result of a rapidly-growing population. In spite of increasing water withdrawals, however, the withdrawal to availability (w.t.a.) ratio are expected to remain below the 0.4 threshold value indicative of high or severe water stress. This situation exists because, while the pressures on water resources are growing, the intensity in water use does not increase significantly (Alcamo et al. 2003). Over 80 per cent of the population depends on rainfall in rural areas for food subsistence and farm economy.

Access to water supply and sanitation

Although there has been progress in the provision of safe drinking water and sanitation facilities for the central African population (see Figure 5.1-2), an accelerated effort is needed to meet the Millennium Development Goals for both water and sanitation coverage in rural and urban areas by 2015.

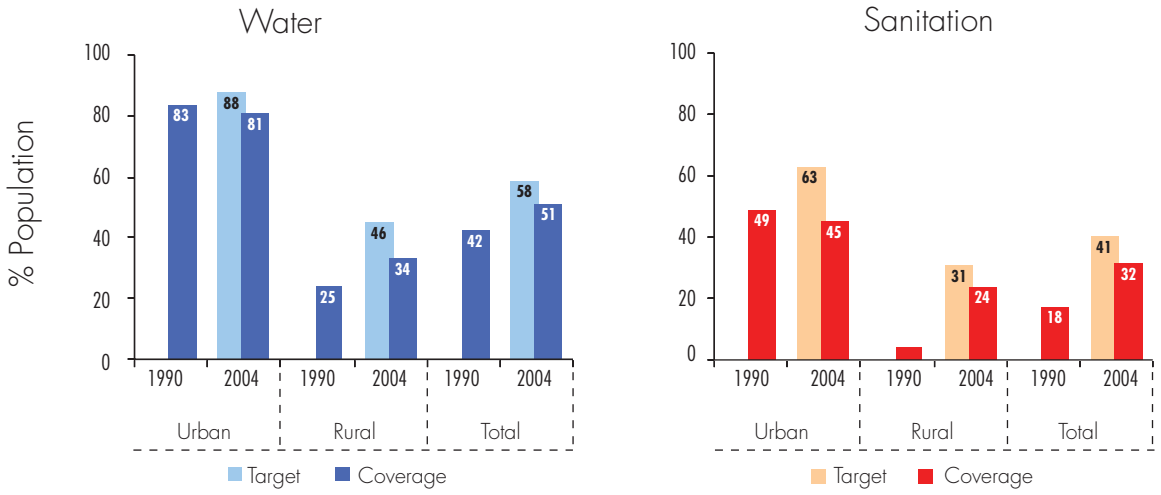

Figure 5.1-2: Water supply and sanitation coverage in rural and urban areas between 1990 and 2004 for central Africa (Republic of Congo, Equatorial-Guinea, Gabon, Sao Tomé and Principe are excluded because of incomplete data).

Source: WHO/UNICEF (2006), redrawn by UNEP

Water-related conflicts

Except for the Sanaga River Basin in Cameroon, all the other major river basins in central Africa are transboundary. The inequitable, uncoordinated use of shared water resources is expected to increase water-related conflicts. Although most conflicts are currently reported to be only verbal in nature, , they may escalate to physical or armed proportions if nothing is done to improve the equitable use and shared management of these water resources.

Vulnerability studies in central Africa

Analysis of the vulnerability of water resources in central Africa is largely inadequate and difficult to access because most of it has not been published. Further, the few who have discussed this topic have focused on components of vulnerability, without mainstreaming vulnerability as their main objective. Studies on vulnerability of water resources to climate variability change in central Africa include:

- Liénou G. et al. (2005): Régimes des flux de matières solides en suspension au Cameroun: Revue et synthèses à l'échelle des principaux écosystèmes, diversité climatique et actions anthropiques;
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- Sigha-Nkamdjou, L. et al. (2005): Impact des modifications climatiques et anthropiques sur les flux de matières de quelques bassins fluviaux du Cameroun.

5.1.3 Management

There has been an increasing trend towards joint management of water resources in central Africa. As an example, Cameroon and Nigeria, through the Niger Basin Authority, have established a basis for joint management of the resources of the Benoue River Basin, which is shared by both countries. Cameroon, Central African Republic, Democratic Republic of Congo and the Republic of Congo have created the International Commission for the Congo-Oubangui-Sangha Basin (CICOS) to oversee the joint management of the basin. Further, inter-basin water transfers are seriously being considered in central Africa. Proposals have been made, for example, to divert large volumes of water from the Oubangui River (part of the Congo River basin) northward through the Central African Republic and Chad, and into the Logone-Chari Rivers feeding Lake Chad. It is anticipated that the transferred water will dramatically increase the flooded extent of Lake Chad. However, this water transfer also poses several threats to biodiversity, noting that there is a risk of transferring an unrelated set of aquatic species into the Lake Chad Basin. Furthermore, while this water transfer could enhance the biodiversity of Lake Chad and its immediate surroundings, there also is a great likelihood that the scheme would have significant adverse effects on the Congo River system to the south.

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5.2 CONGO RIVER BASIN

The 4,700 km (2,920 mi) long Congo River (also known as River Zaire) is the fifth-longest river in the world, and the second longest in Africa (after the Nile in northeast Africa). The width of the river varies between 0.8-16 km (0.5-9.9 mi), depending on the location and time of the year. The riparian countries and their corresponding percentage area within the Congo River Basin are: Democratic Republic of Congo (61.1 per cent), Central African Republic (10.7 per cent), Angola (7.5 per cent), People's Republic of Congo (6.5 per cent), Tanzania (6.5 per cent), Zambia (4.7 per cent), Cameroon (2.5 per cent), Burundi (0.4 per cent), and Rwanda (0.2 per cent) (FAO 2001; Figure 5.2-1).

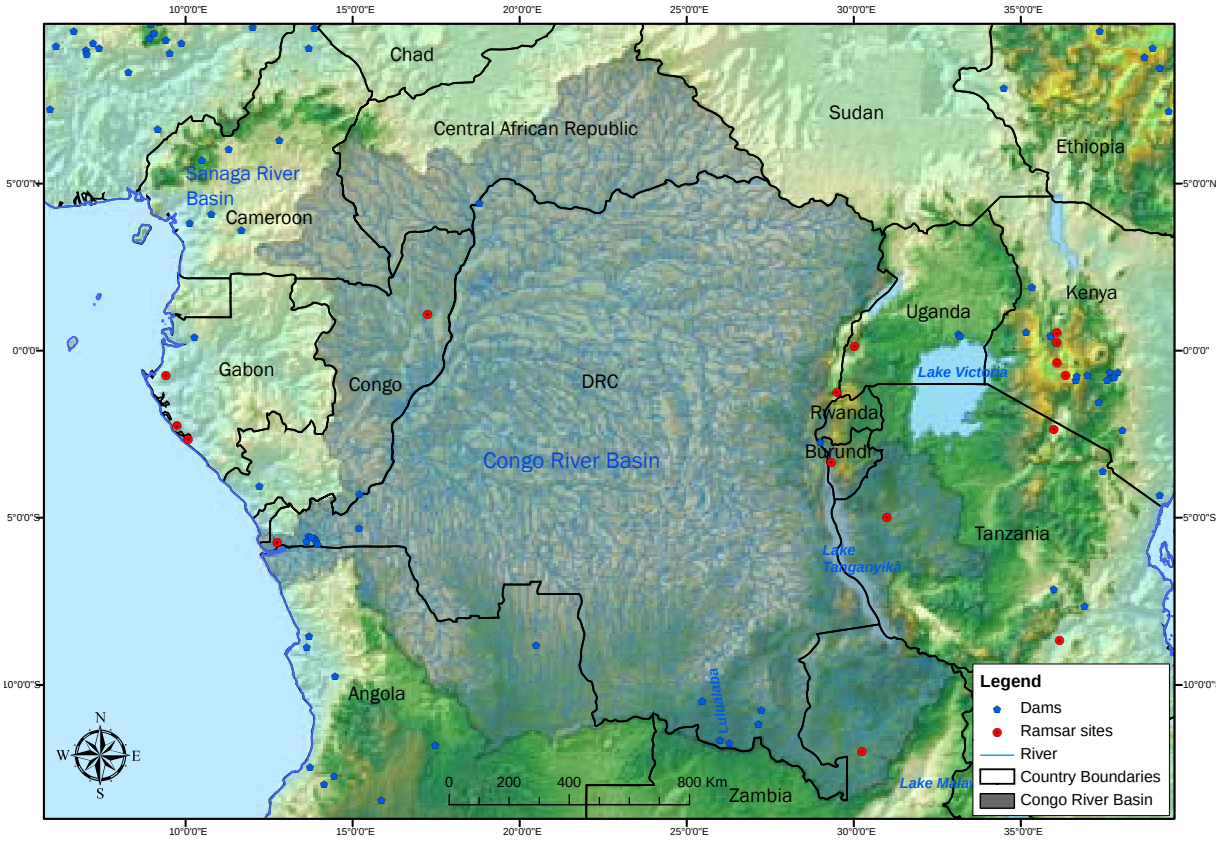

Figure 5.2-1: Congo River Basin

The Congo River originates principally from the southernmost part of the DRC, with the Lualaba and Luvua Rivers as the southern-most tributaries. It flows to Stanley Falls near Kisangani, then taking an anti-clockwise direction towards the northeast. At its confluence with the Rubi River, the direction changes westward, and finally turns southward, meeting the Ubangi River, and flowing into the Atlantic Ocean. The main characteristics of the basin are summarized in Box 5.2-1.

Box 5.2-1: Main characteristics of Congo River Basin

Basin
Surface area: 3,690,750 km^2 (1,425,0906 mi^2)
MAP: 720–2,115 mm.yr^{-1} (28-83 in.yr^{-1})

Demography
Population: 73 millions
Density: 20 persons.km^{-2} (52 persons.mi^{-2})

Water Resources
River length: 4,700 km (2,920 mi)
MAR: 1,269,000 Mm^3.yr^{-1}

Water Use
Agriculture
Hydropower
Industry
Mining
Domestic

Increasing

Vulnerability
Increasing all over the basin

Major Aquifers: Sandstone

5.2.1 Physiography

Climate

The DRC, which occupies more than 60 per cent of the total surface area of the Congo Basin, straddles the equator, and is typified by a heterogeneous climatic regime (Bultot 1971; Ossete 2003; Kabogo 2004), such as:

- A highly humid, equatorial climate (rainfall>1,700 mm.yr^{-1} [67 in.yr^{-1}]) in the north;
- A humid, tropical climate (rainfall>1,400 mm.yr^{-1} [55 in.yr^{-1}]) in the southwest;
- A subequatorial climate (rainfall>1,600 mm.yr^{-1} [63 in.yr^{-1}]) between the two regions above
- A mountainous climate usually found above 2,500 m (8,202 ft) with minimum temperatures of -3 °C (27 °F).

The remaining 40 per cent of the basin has climate attributes falling within one or more of the above-noted climate types.

Aridity

The basin is endowed with considerable water resources, making aridity little concern in the area. However, the surface area of the basin (about 20 per cent of the African continent) has pockets of aridity which, on a macro scale, are insignificant.

Ecosystems

The Congo River Basin is biologically diverse. Its two main types of vegetation are forest and savannah. The basin harbours the world's second largest contiguous forest, after the Amazon forest in South America. The basin alone represents 30 per cent of Africa's vegetation coverage, and 19 per cent of the world's tropical forests (Science in Africa 2006). The forest occupies more than 58 per cent of the basin area. Its plant diversity is high, being well over 10,000 species. Eight thousand of these species are found in the forest zone, with 80 per cent being endemic. There are several animal species, many being unique to the region.

Land degradation and desertification

Agriculture, timber harvesting and artisanal mining are primarily responsible for land degradation. The main causes for the progressive reduction of the basin's vegetation coverage, however, are logging and shifting agriculture. Fourteen million ha (54,054 mi^2) of forest is lost worldwide each year, 934,000 ha (3,606 mi^2) of which is from the Congo Basin (Science in Africa 2006). Between 1990 and 2000, the forest of the basin shrunk by 8.3 million ha (32,046 mi^2). Clearing of vegetation, and sinking of pits/trenches, are invariably associated with artisanal mining. Usually 90 per cent of these pits are not refilled. These activities bare the land, making it vulnerable to agents of erosion.

© Christophe Smets / Luna / VISUM / Still Pictures

Land degradation/deforestation caused by artisinal mining in the Cameroonian part of the Congo Basin

Hydrology

The Congo River has three distinct hydrologic sections: The Upper Congo, Middle Congo, and Lower Congo.

The Upper Congo is dominated by the Lualaba River. This river originates in southeastern DRC, flowing north over rapids and falling to Bukama. It then crosses a vast plain and flows through a series of marshy lakes (Kabwe, Kabele, Upemba) to Antora, where it merges with the Luvua River. The Luvua River has its most remote source in the Chambesi River, which rises from the north of Zambia, flows southwest into swamps around Lake Bangweulu, and then emerges as the Luapula River. It continues north along the DRC-Zambia border into Lake Mweru, where it exits as the Luvua River, flowing northward into the Lualaba River. The third most important river of the Upper Congo is Lukuga River, which drains from Lake Tanganyika to join the Lualaba River near Kabalo. From Kabalo, the Lualaba River flows north into Kasangani. This section is typified by a deep, narrow gorge below Kongolo, also known as the Gates of Hell, being a navigable stretch from Kasongo to Kibombo, a section of rapids, and then falls from Kibombo to Kindu, a shallow, but navigable, portion from Kindu to Ubundu, and finally a succession of seven cataracts (called Boyoma Falls) between Ubundu and Kisangani that mark the end of the Lualaba River and the beginning of the Congo River proper. Navigation is difficult because the numerous interruptions (rapids, falls, cataracts) require the use of other means of transport to supplement it.

The Congo becomes navigable below Kisangani, as it flows west and southwest in a great curve, unbroken by falls or rapids for about 1,750 km (1,087 mi), to Kinshasa. The beginning of the Middle Congo is marked by a narrowing of the river. The banks are about 0.8-1.6 km (0.5-1 mi) apart, and the river is much deeper and flows faster. The principal tributaries drain into the Congo River along this stretch, including the Ubangi, Sangha, and Kwa Rivers. Flows from these tributaries result in a drastic increase in water flow, from 250,000 $m^3.s^{-1}$ in Kisangani, to a maximum of 3,690,750 $m^3.s^{-1}$ in Kinshasa. The river widens as it enters the alluvial plain, so that it is 6.4--16.1 km (4-10 mi) wide, with many islands and sand bars, for most of its middle section.

From the Middle Congo, the river divides into two branches (Figure 5.2-2). One branch forms the Malebo (Stanley) Pool, which actually marks the end of the Middle Congo, and on whose banks Kinshasa and Brazzaville are located.

Figure 5.2-2: Middle Congo River, illustrating the location of Brazzaville and Kinshasa

Source: Google Earth

From the western end of Pool Malebo, the Congo River descends 267 m (876 ft) into a series of 32 rapids, known as the Livingstone Falls, to the port of Matadi. At Matadi, in the Lower Congo River, the Congo estuary narrows to between 0.8-1.6 km (0.5-1 mi), but eventually widens again below Boma, from where it flows freely into the Atlantic Ocean.

The Congo River experienced a period of stable discharges, from the beginning of the twentieth century to the 1960s with two successive phases of low discharge being experienced from 1971 onward. The lowest recorded discharge in the second phase (1980 to present) occurred in 1984 (Figure 5.2-3).

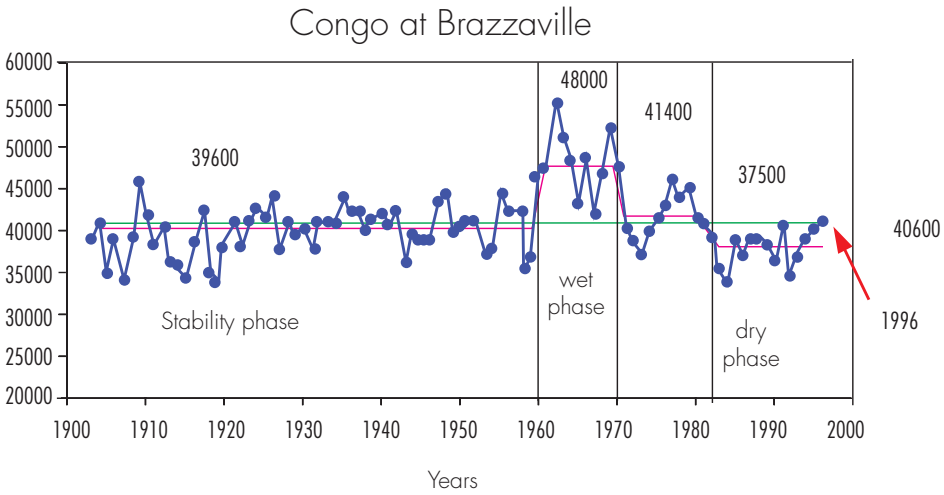

Figure 5.2-3: Congo River flows during 20th century

Source: Laraque et al. 2001, redrawn by UNEP

The spatial configuration of the river network is such that the sum of all the tributaries results in a constant flow of the river. This occurs mainly because the surface area of the Congo Basin is so large (approximately 20 per cent of the African continent), that the weather pattern in one particular region will have little effect on the river's overall water level. Heavy rainfall in the northern areas that contribute to the Ubangi River, for example, may cause flooding in the region itself, but will generally not lead to floods in the southern portion of the Congo Basin. By the time the river waters join together very little effect will be seen because of the vastness of the area, which allows the river flow to be buffered and not change too drastically.

More than 4,000 islands are found in the Congo River, with more than 50 of them being at least 16 km (52 mi) long.

Hydrogeology

The Congo River Basin is hosted by the stable Congo Craton, formed during the Precambrian Era some 570 million years ago. The craton is primarily made up of granitic and metamorphic rocks, with the central part of the basin characterized by a large, shallow, saucer-shaped depression known as the cuvette. The depression contains Quaternary to Recent alluvial deposits of continental origin derived from erosion of uplifted formations around the cuvette. Kabogo (2004) groups these rock types into six main hydrogeologic units:

- Unit I - Ancient and Recent fluvial and lacustrine alluvium; the unit has a high groundwater potential;
- Unit II - Mesozoic fine- to coarse-grained sandstone up to 120 m (394 ft) thick in some places, also with a high groundwater potential;
- Unit III - eighty metre (262 ft) thick sandstone with basal conglomerate, with a low potential;
- Unit IV - heterogonous fine- to coarse-grained sandstone intercalated with shales and limestone; some areas are highly fractured and, therefore, the permeability is mainly secondary;
- Unit V - composed of schist, arkoses, limestone and dolomite, with secondary permeability being dominant;
- Unit VI - crystalline and metamorphic rocks typified by granitoids, migmatites and metasediments, with fracture permeability dominating.

Water availability

The total annual available surface water resources for the DRC alone are 1,283,000 million m^3, of which 900,000 million m^3 is renewable (Kabogo 2004). The annual renewable groundwater is estimated to be 421,000 million m^3. Because the DRC alone occupies more than 60 per cent of the total surface area of the Congo basin, these figures may be extrapolated to represent the entire basin. The total annual discharge at the mouth of the Congo River is 1,269,000 million m^3, with the per capita water availability estimated to be 16,240 m^3.

5.2.2 Socio-economy

Demography

More than 73 million people live in the Congo River Basin, 75 per cent of which are found in the DRC. Considering the 3,690,750 km^2 (1,425,006 mi^2) surface area of the basin, this equates to a relatively low population density of 20 $persons.km^{-2}$ (52 $persons.mi^{-2}$)

Economy

The Congo River is one of Africa's most navigable systems. The DRC alone has more than 14,480 km (8,997 mi) of navigable waterways. Barges carrying loads of 800 to 1,100 tonnes (1.8-2.4 million pounds) are able to navigate at least 1,000 km (621 mi) of the Congo River throughout the year. The commonly-transported goods are timber, minerals and agricultural produce, with logging, agriculture and mining being the principal economic activities in the basin. The Congo River also provides a very important communication and transportation network in central Africa, especially for areas not served by roads. Where navigation is hampered by the presence of waterfalls, the link is complemented by railway systems from the coast to the hinterland.

The Congo River is Africa's largest potential source of hydroelectric power. Efforts by the government have resulted in the completion of the first phase of the Inga Dam Project, located along the Livingstone Falls, the most valuable site for development of hydropower in the Congo River Basin.

Logging is currently one of the most important economic activities in the Congo River Basin, and all riparian countries have issued exploitation licences to loggers of various categories.

Poverty

Significant poverty exists in the Congo River Basin, mainly due to the civil war in the DRC, the Republic of Congo, Rwanda, and Burundi. Other significant contributing factors are malaria and HIV/AIDS killing the economically-active population of the region, and poor governance.

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Artisanal gold miner

Water uses and demands

Water is mainly used for domestic water supply, hydroelectric power generation, agriculture, navigation, fishing, and mining.

Water-related conflicts

The large abundance of surface and groundwater resources in the Congo River Basin has ensured a low level of competition for access to water by individuals and states. Thus, water-related conflicts in the basin are minimal.

5.2.3 Management

More attention has been given to managing the forest resources of the Congo River Basin than to the water resources, probably due to the basin's abundance of surface and groundwater resources. With increasing evidence that climate variability and change are impacting water and associated resources worldwide, however, the countries of the region have found it imperative to jointly manage the resources of the basin. As a result, the International Commission for the Congo-Oubangui-Sangha Basin, (CICOS) was created in 1999 by Cameroon, CAR, DRC, and Republic of Congo (Fonteh 2004). The immediate objective was to improve cooperation amongst the member states, through improved communication using the Congo River and its tributaries. A future objective is to promote IWRM, in order to enhance development and alleviate poverty in the member states.

A separate project that would have facilitated the attainment of these objectives is the Congo-HYCOS. These objectives are undermined, however, by a lack of financial resources and commitment. GTZ (German Technical Cooperation) is taking strides to circumvent these problems through its proposed 'Transboundary Water Management project in the Congo Basin.' The leading executing agency will be the Congo-Oubangui-Sangha Basin International Commission (CICOS), with the principal goal of establishing joint principles and strategies through which riparian countries can manage the Congo River Basin.

5.2.4 Key issues, adaptation and mitigation

Among the key issues identified, the paramount adaptation and mitigation option relates to extensive extension work involving community training and education.

Physiography

Climate vulnerability

The Congo Basin is subject to extreme climatic conditions, ranging from low rainfall to severe floods. The floods tend to affect the sub-catchments, rather than the whole catchment. Droughts also locally affect areas of the basin.

Adaptation and mitigation

There is a need:

- To implement new, or strengthen existing, monitoring systems;
- To develop an early warning system for impending droughts and floods.

Land degradation

- Land degradation is a serious problem, being a threat to food security, ecosystems, and water resources within the river basin.

Adaptation and mitigation

There is a need:

- To develop standardized legislation, policies and guidelines for holistic land management, and cropping patterns suited to various soil types;
- To control anthropogenic activities that result in land degradation (e.g., using remote sensing techniques as a means of monitoring) (e.g., De Grandi et al. 1999);
- To involve communities in ecosystem management efforts, and to develop projects that directly benefits them as an integral part of these efforts.

Socio-economy

Population growth and urbanization

Increased population growth and urbanisation are exerting pressure on water supply in regard to both demands and pollution.

Adaptation and mitigation

There is a need:

- To increase investments in upgrading infrastructure and development in both urban and rural areas;
- To implement measures that curb the negative effects of industrialization.

HIV/AIDS and water related diseases

HIV/AIDS and malaria are pandemics that are exacerbating the poverty in the basin. The young and most productive members of the communities are the group affected most by these diseases, and orphaned households and poverty levels are rising.

Adaptation and mitigation

There is a need:

- To educate and train the community;
- To increase awareness through the media;
- To implement anti-retroviral and malaria prevention programmes;
- To provide adequate domestic water resources to ensure general hygiene, and to minimize disease transmission.

Water availability, uses and demands

Although the river basin is endowed with plentiful water resources, harnessing it for development purposes is lagging behind water demands. The water resources are used for a variety of purposes, including agriculture, hydro-energy, domestic use, transport and recreation.

Adaptation and mitigation

There is a need:

- For all riparian countries to implement IWRM in a coordinated manner, focusing on holistic water use, and with a balance between all land uses;
- To implement pollution monitoring and mitigation measures at the basin level to ensure the maintenance of good water quality.

Management

International protocols

Management of the basin's water resources is weak.

Adaptation and mitigation

There is a need:

- To develop basin protocols among the riparian countries, and establish management structures, with a focus on the basin authority;
- To address land management by developing basin policies;
- To implement and commit to management policies.

Data availability, standardization and monitoring

Monitoring and databases development are fragmented.

Adaptation and mitigation

There is a need:

- To establish monitoring and database development schemes through already-established basin management structures;
- To harmonize monitoring and database development procedures.

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5.3 SANAGA RIVER BASIN

Sanaga is the largest river basin in Cameroon (Figure 5.3-1). The Sanaga River collects waters from the south Adamawa, and from the central plateau through the Djerem, Meng, Vina, and Lom Rivers, swollen by the Pangar River. It converges with the Mbam River and its tributaries (Noun and Kim Rivers) from the west (Morin 1980). The river contains falls and rapids, the last being the Edea Falls. The Sanaga River Basin is predominantly a Cameroonian river basin, with a very small portion of 200 km^2 (77 mi^2) found within the CAR. The basin covers about one third of the total surface area of the country, furnishing about a quarter (65,000 $km^3.yr^{-1}$) of the total surface water resources of Cameroon. The main characteristics of the basin are summarized in Box 5.3-1.

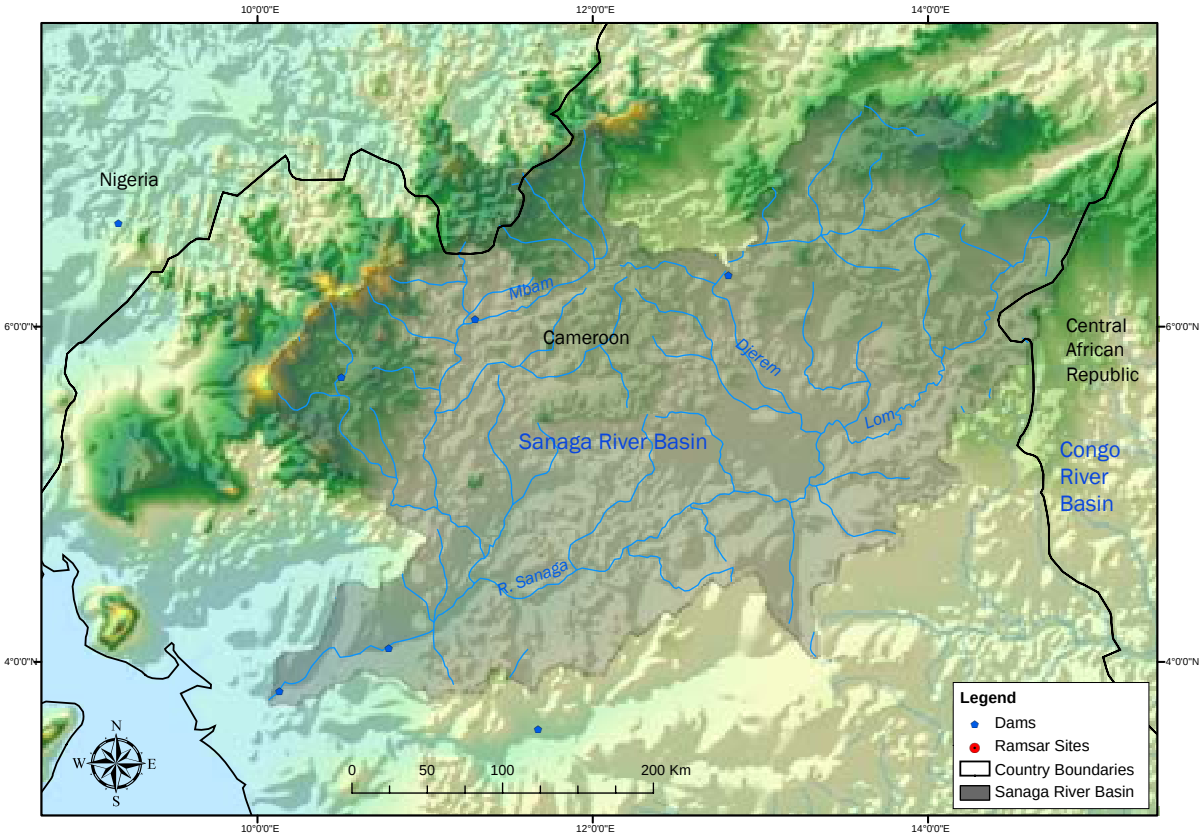

Figure 5.3-1: Sanaga River Basin

5.3.1 Physiography

Climate

Cameroon has a varied climate because of its size and shape (about 1,200 km [746 mi] from south to north), its proximity to the sea and the influence of its altitude. The country can be broadly divided into two climatic zones, including the equatorial climate extending from latitude 2°N to 6°N, and the tropical climate from latitude 6°N to 13°N (Neba 1999). The Sanaga River Basin is typified by a transitional tropical to equatorial climate. Temperature varies monthly, with February and March being the hottest months (32.1 °C [90 °F]), and the lowest temperatures occurring in July and August (19.3 °C [89.8 °F]). The mean annual relative humidity varies inversely with latitude, dropping from 88 per cent in the southwest (Eseka) to 66 per cent in the northeast (Ngaoundere). The rainfall exhibits the same trend, decreasing from 2,730 $mm.yr^{-1}$ (107 $in.yr^{-1}$) in the southwest, to 1,658 $mm.yr^{-1}$ (65 $in.yr^{-1}$) in the northeast. The daily mean evaporation is 6.5 mm (0.26 in) in the northeast, and 3.2 mm (0.13 in) in the southwest.

Box 5.3-1: Main characteristics of Sanaga River Basin

Basin
Surface area: 140,000 km^2 (54,054 mi^2)
MAP: 1,658–2,730 mm.yr-1 (65-107 in.yr^{-1})

Demography
Population: 10 million
Density: 71.4 persons.km^{-2} (185 persons.mi^{-2})

Water Resources
River length: 920 km (572 mi)
MAR: 65,000 Mm^3.yr^{-1}

Major Dams
A: Mbakaou 2.6 Mm^3
B: Bamendjin 1.8 Mm^3
C: Magba 3.2 Mm^3

Total dam storage: 7.6 Mm^3

Water Use
Hydropower
Agriculture
Industry
Mining
Domestic

Vulnerability
Increases to the northeast

Major Aquifers
Crystalline basement

Ecosystems

The vegetation in the equatorial climate zone is dominated by equatorial forests, mangrove forests in the coastal areas, and guinea savannah elsewhere. In the tropical climate zone, the vegetation is mainly Sudan savannah in the south, and Sahel savannah in the extreme north (Fonteh 2004).

Land degradation and desertification

A rapidly increasing population (2.6 per cent per year; BEAC 2004), increasing urbanization and industrialization, a rising demand for farmland, indiscriminate exploitation of timber, and a rapid increase in the consumption of industrial rocks and minerals – against the broad backdrop of climate change – are among the factors primarily responsible for the rapid land degradation in the Sanaga River basin.

Hydrology

Cameroon has a varied landscape with many plains, plateaux and highlands, and a dense network of rivers. Neba (1999) distinguishes five main geomorphological zones in the country: (i) Coastal Lowlands; (ii) Southern Plateau; (iii) Adamawa Plateau; (iv) Western Highlands; and (v) Northern Lowlands. The Adamawa Plateau is situated in the centre of the country, with an average altitude of 1,100 m (3,609 ft), and forms the main watershed. It stretches across the country into the Central African Republic. Cameroon is riparian to the Sanaga, Niger (Benoue), Congo (Kadei-Sangha and Dja-Ngoko) and Lake Chad Basins. The Sanaga Basin, located in the centre of the country, covers 29 per cent of Cameroon's total surface area. There is great variability in stream flows from south to north. Most of the rivers are ephemeral in the north, flowing only for about four months in a year, and reduced to sand beds for the remainder of the year. In contrast, most rivers flow throughout the year in the south, but with greatly reduced flow rates during the dry season. The average flow of the Sanaga River is 2,072 m^3.s^{-1}, with a mean low flow of 473 m^3.s^{-1} in March (minimum flow of 171 m^3.s^{-1}). During flood periods, the flow reaches 7,550 m^3.s^{-1}. The importance of the surface

area and mean monthly flows of the Sanaga River Basin is illustrated in Table 5.3-1. The west and south basins of the Sanaga River represent smaller intra-Cameroonian basins, found to the west and south of Sanaga, respectively.

Table 5.3-1 Major river basins in Cameroon, and relative contribution to national surface water flow (Olivry (1986); Banque Mondiale (1992))

Intra-national basins	Surface area (km²)	Major rivers in basin		Average monthly flow (m³.s-1)		
		River	Station	Median of maximum flow	Median of minimum flow	Mean flow
Sanaga west	44,640	Cross River	Mamfe	-	28	569
		Mungo	Mndame	636	27.5	164
		Wouri	Yabassi	1,425	49.3	311
Sanaga	132,990	Sanaga	Edea	5,700	614	2,070
Sanaga south	55,800	Nyong	Dehane	1,356	74.8	442
		Lokoundje	Lolodorf	1,185	3.3	28.2
		Lobe	Kribi	390	8.35	102
		Kienke	Kribi	177	7.8	49.2
		Ntem	Ngoazik	764	-	276

Near outlet of the basin

Hydrogeology

The Sanaga Basin is dominated by a Precambrian crystalline basement that constitutes about 90 per cent of the geology of Cameroon. Beta (1976) and Djeuda Tchapnga et al. (1987) identified two main aquifers in the crystalline terrains of Cameroon, one being shallow and the other being deep. A thick lateritic weathering blanket, and highly altered and fractured rocks, make up the superficial aquifer. The thickness of this aquifer ranges from 8-20 m (26-66 ft) (Mafany et al. 2007). Underlying the shallow aquifer is a deep aquifer, composed of low permeability, fractured rocks. Migmatites, gneisses and schists, with intrusions of granitoids, typify the lithology of both aquifers. The superficial aquifer is the most exploited. Considered together, the two aquifers comprise about 66 per cent of the total groundwater resources of Cameroon, estimated to be 120.8 km³. The water resources of the country have not been evaluated in a comprehensive manner, however, and the figures on groundwater resources are derived from extrapolation of small-scale studies.

Water availability

Based on the estimated groundwater and surface water resources of Cameroon, Fonteh (2003) calculated the total renewable water resource to be 283.5 km³.yr⁻¹ (Table 5.3-2).

Table 5.3-2: Water balance for Cameroon

Nature of resources	Volume (km³.yr⁻¹)
Total internal renewable water resources	271
Total external renewable water resources	12.5
Total renewable water resources	283.5

Fonteh (2003) used the population estimates of Cameroon for the year 2000 to demonstrate that the per capita internal available water resource is 18,539 $m^3.yr^{-1}$. UNESCO (2003) provided a higher estimate of 19,192 $m^3.yr^{-1}$, based on a lower population figure. Cameroon is ranked 49th out of 182 countries in the world, in terms of abundant water supply. Compared to the global per capita average annual internal renewable water resources of 7,044 m^3 ,and a value of 5,152 m^3 for Africa, (UNDP 2004), Cameroon as a nation has more than sufficient water for its population.

5.3.2 Socio-economy

Demography

The 2003 population of Cameroon was estimated at 16.3 million, with an annual growth rate at 2.6 per cent (BEAC 2004). The urban population is about 50.6 per cent, and the rural population 49.4 per cent, of the total population. For the entire country, UNICEF (2004) estimated the rate of urbanization to be 4.4 per cent, and the population density to be 33 inhabitants.km^{-2} (85 inhabitants.mi^{-2}) About 10 million people live within the Sanaga River Basin. The population density in the basin drops from above 200 persons.km^{-2} (518 persons.mi^{-2}) in the high plateaux of the northeast, to less than 10 persons.km^{-2} (26 persons.mi^{-2}) in the middle of the basin, rising again to above 200 persons.km^{-2} (518 persons.mi^{-2}) in the agro-industrial southwest region. The average population density in the Sanaga River Basin is 71.4 persons.km^{-2} (185 persons.mi^{-2}) (CICERO 2000).

Economy

Agriculture is the most important economic activity in the country, with cocoa, coffee, banana, palm oil, tea, tobacco, sugar cane, pineapple and rubber being the main agricultural cash crops. Food crops include rice, sorghum, maize, peanuts, beans, plantains, cassava, coco yams and potatoes.

Hydroelectric power production is another significant economic activity in the Sanaga Basin. The regulatory dams of Mbakaou on the Djerem River, Magba on the Mape River and Bamendjing on the Noun River, and the production dams of Edea and Song Loulou, provide more than 648 megawatts of energy, representing 90 per cent of the country's energy consumption.

The only aluminium company (ALUCAM) in Central Africa is found in the Sanaga Basin. The use of rocks and minerals for various construction purposes also is common.

Poverty

According to the UNDP (2004), Cameroon is ranked 141 out of 177 countries, based on the UN Human Development Index (HDI). It is ranked last in the group of nations considered to have a medium human development, based on data from the year 2002. The same authors list Cameroon as one of 20 countries where the HDI has dropped. Although the Cameroon economy is growing, human development is worsening.

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Hydroelectric Dam on the Sanaga River at Edea at the downstream end of the basin

Water demands

The most important uses of water in the Sanaga River Basin currently are agriculture, industry, power, fishing and household water supply. Activities in these domains are increasing as a result of a rapidly-increasing population (2.6 per cent per year). Although the pressure on the country's water resources is increasing, the intensity in use of the available water resources has not increased significantly (Alcamo et al. 2003). Some 40-60 per cent of the region's irrigation water is currently lost through seepage and evaporation. This contributes to serious environmental problems, such as soil salinization and water logging (UNEP 2000).

Water-related conflicts

Transboundary water related conflicts in the use of water resources in the Sanaga Basin are non-existent because more than 97 per cent of the basin lies within Cameroon. There have been conflicting interests within Cameroon, however, principally between hydroelectric uses and irrigation needs by small-scale farmers. In addition to climate change effects, small-scale farmers have been accused of reducing the water volume that reaches the Edea and Song Loulou production dams, by the construction of irrigation canals to divert the water from its main course into farmlands. It was even suggested that this contributed in part to the power cuts experienced between 2002 and 2004 in Cameroon.

5.3.3 Management

Institutional and legislative framework

The national policy on water in Cameroon aims at highlighting water not only as a key factor for development, but also as an element for environmental improvement (MINMEE/DE/SDAE 2004). Water management in Cameroon is fragmented and sectoral, with many involved institutions. The role of the various institutions is prescribed by existing laws and decrees governing water in Cameroon. The various actors can be grouped into the following categories: (i) ministry responsible for water management; (ii) other ministries involved in management; (iii) utility companies; (iv) NGOs; and (v) trans-sectoral coordinators. The institutions implicated in management are involved in project planning, policy formulation, pollution control and financing, as well as the execution of water and sanitation projects. They receive tenders, award contracts, control construction works, and represent the state in the reception of complete projects. There are 12 ministries that can be placed under this category (Fonteh 2004).

The government of Cameroon enacted Law N° 96/12, relating to environmental management, in 1996, of which water is a key element. A separate law on water was later enacted in 1998 to complement the initial law. Water is considered a national heritage and, therefore, the state is responsible for protecting and managing this resource. The environmental law calls for the:

- Establishment of national quality standards;
- Elaboration of a national environmental action plan every 5 years;
- Creation of an inter-ministerial committee on the environment;
- Creation of a national consultative commission on the environment and sustainable development;
- Establishment of a national environmental and sustainable development fund.

Twelve years after the enactment of the law on the environment, however, very few of the above-noted items have been implemented. Only the environmental action plan was established in 1996

(MINEF 1996), but has not been revised as required by the law. The text creating the inter-ministerial committee on environment has been signed, but is still inactive. A national standard has not yet been established, nor has the consultative commission and the development fund been created. The management of the biodiversity and environment in Cameroon generally is haphazard, mainly because of a lack of political will to implement the 1996 environment law, manifested by lack of a proper legal and institutional framework for its implementation. Examples include the absence of quality standards and enabling decrees to apply the law of environment, as well as the lack of prescribed coordinating committees (Fonteh 2004).

Monitoring

The Hydrological Research Centre of Cameroon systematically monitored the hydro-climatic changes in the basin up to 1987. Because of the intensification of the economic crises, however, and the consequent lack of funding, activities thereafter were reduced to erratic non-coordinated studies designed to meet particular project needs (e.g., studies for the Lom-Pangar Dam project). Further, the National Electricity Corporation (AES Sonel) monitors streamflows during the dry season to calculate an estimate of its water budget during low flow. Systematic, coordinated monitoring of the hydro-climatic changes in the basin, however, and their consequent impact on the riparian population and ecosystems, is non-existent.

5.3.4 Key Issues, adaptation and mitigation

The key issue relates to competing needs for water between hydroelectric power generation and irrigation.

Physiography

Climate vulnerability

The basin is subject to extreme climatic conditions and, lately, has been receiving below-average rainfall volumes.

Adaptation and mitigation

There is a need:

- To develop an early warning system for impending droughts or below normal rainfall.

Land degradation

Rapid population growth, particularly in the northern and southern parts of the basin, is exacerbating land degradation.

Adaptation and mitigation

There is a need:

- To develop legislation, policies and guidelines for holistic land management and cropping patterns;
- To involve communities in ecosystems management, and projects that directly benefit them should form an integral part of the management process.

Socio-economy

Population growth and urbanization

- Increased population growth, industrialization and urbanization are exerting pressures on water supply, with regard to both water demands and pollution.

Adaptation and mitigation

There is a need

- To increase investments in infrastructure upgrading and development in both urban and rural areas;
- To implement family planning measures to avoid population expansion, which is not matched by economic growth.

Water availability, use and demands

- There is serious competition for water between hydroelectric generation and agricultural irrigation in the basin.

Adaptation and mitigation

There is a need

- To institute IWRM in a coordinated manner, focusing on holistic water use;
- To develop a system of water demand management;
- To reinstitute the systematic monitoring of quantity and quality at the basin level, in order to ensure maintenance of good water quality.

Management

The management of basin resources is weak and erratic.

Adaptation and mitigation

There is a need

- To implement existing legislative and institutional frameworks that encourage effective and efficient management of the basin's resources, including best practices;
- To address land management by developing basin policies;
- To gain commitment from government and water stakeholders

Data availability, standardization and monitoring

Monitoring and development of water databases are fragmented.

Adaptation and mitigation

There is a need

- To establish standardized procedures for monitoring and database development, through established basin management structures;
- To holistically monitor all indicator parameters at the basin level.

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5.4 LAKE CHAD BASIN

Lake Chad is located between latitudes 12° 20′ N and 14° 20′ N and longitudes 13° 0′ E and 15° 20′ E, and lies at an altitude of 280 m (919 ft). The Lake Chad Basin is Africa's largest inland drainage area (endoreic), and can be divided into a conventional and hydrographic basin (Figure 5.4-1). The main characteristics of the basin are summarized in Box 5.4-1.

The conventional Lake Chad Basin extends over the territories of Cameroon, Chad, Niger and Nigeria. Forty-six percent of the lake and its peripheral marshes occur in the Republic of Chad.

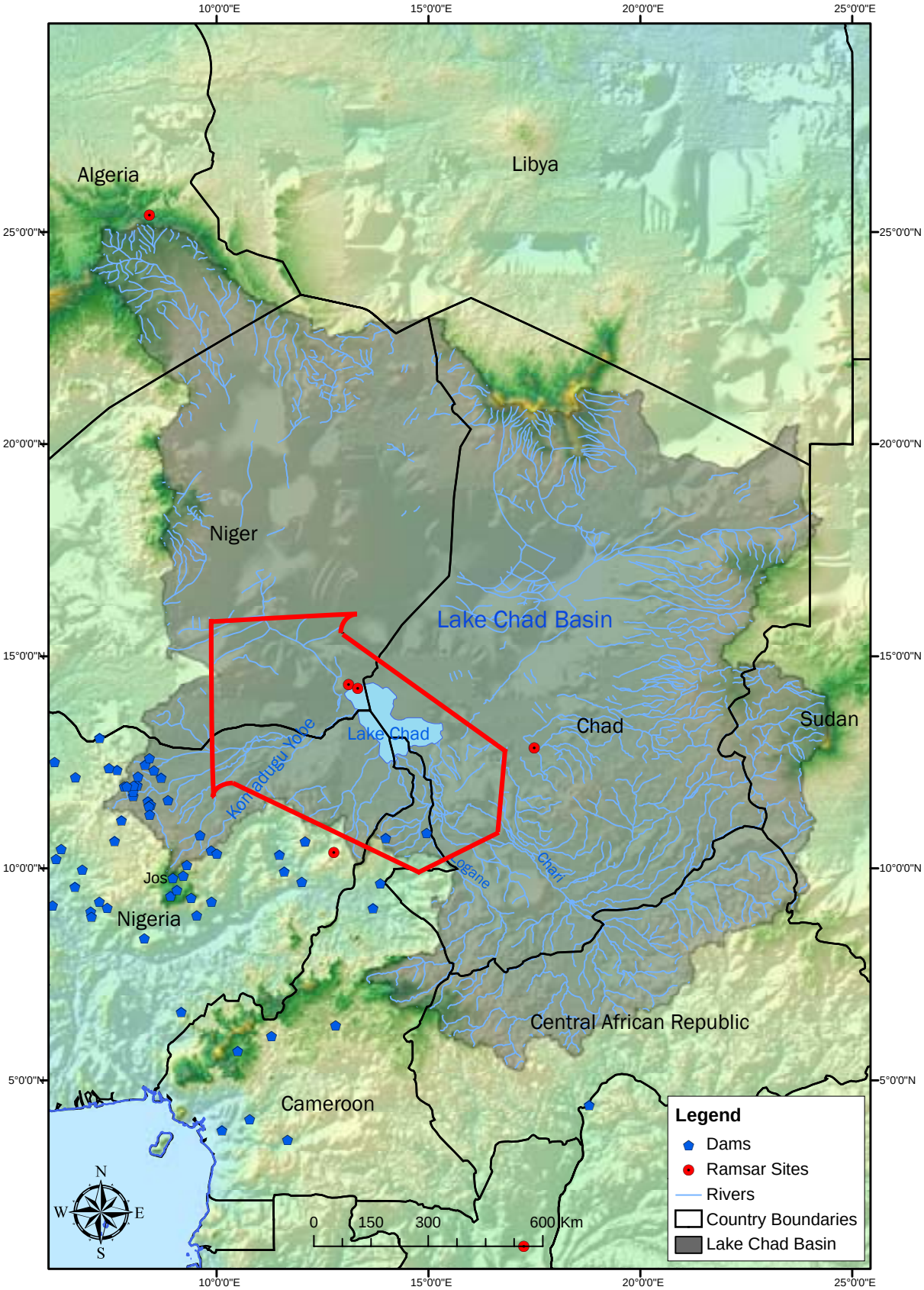

Figure 5.4-1: Lake Chad Basin – Hydrographic and Conventional Basins

Box 5.4-1: Main characteristics of Lake Chad Basin

Basin

Surface area:	
- Hydrographic:	2,434,000 km^2 (9,399,657 mi^2)
- Lake Area:	10,000-25,000 km^2 (3,860-9,650 mi^2; 35 yrs ago)
	1,500-2,500 km^2 (580-965 mi^2; present time)
MAP:	255-560 mm.yr^{-1} (10-22 in.yr^{-1})

Water Use

Agriculture
Domestic
Industry
Mining
Hydropower

Increasing

Demography

Population:	37 million
Density:	7-154 persons.km^{-2} (18-399 persons.km^{-2})

Water Resources

MAR:	38 Mm^3.yr^{-1}

Major Dams

Mbakaou	2.6 Mm^3

Vulnerability

High aridity, over-exploitation, ecosystem damage and reduced groundwater recharge

Major Aquifers (sedimentary)

Groundwater recharge: 3.6 billion m^3.yr^{-1}
- Quaternary phreatic aquifer; exploitation potential ~ 150 billion m^3
- Pliocene aquifer (artesian in some areas); exploitation potential ~ 3 billion m^3.yr^{-1}
- Continental terminal and hamadian aquifers: uncertain

When the Lake Chad Basin Commission was established in 1964 by Cameroon, Chad, Niger and Nigeria, the surface area of the conventional basin was about 20 per cent that of the hydrographic basin area. The area of the conventional basin increased in 1994 and 2000 when the CAR and Sudan were respectively admitted into the Lake Chad Basin Commission.

The hydrographic basin has a surface area of about 2,434,000 km^2 (939,773 mi^2). The catchments draining into Lake Chad include the Tibesti to the north, the Djebel to the east, the Adamaoua and Mandara to the south, the Hoggar to the extreme north, and the Jos plateau to the southwest. Lake Chad is made up of a northern and southern lake linked through the Baga Kawa Depression. Eighty percent of the water supply into the lake comes from the Logone and Chari Rivers to the south. No river has been observed to flow out of the lake. However, some water is said to percolate along the dry bed of the Gazel River to feed the oases of the Bodele Depression, about 40 km (25 mi) to the northeast.

5.4.1 Physiography

Climate

Two strong air masses influence the climate of the Chad Basin, including a dry continental air mass, and a humid maritime air mass. The dry air mass becomes dominant toward the end of the dry season, and with high evaporation rates occurring. The low humidity and strong winds result in a

large water loss in the lake. The average temperatures are 18 °C (64 °F) during the rainy season and 32°C (90 °F) during the dry season. The annual rainfall varies between 1,500 mm (59 in) in the southern parts of the basin, to less than 100 mm (4 in) in the north, resulting in a mean annual rainfall range of 255-560 $mm.yr^{-1}$.(10-22 $in.yr^{-1}$) The potential evapotranspiration exceeds 2 $m.yr^{-1}$ (6.6 $ft.yr^{-1}$) in the centre of the basin.

Aridity

In the 19th century, the surface area of Lake Chad was estimated to be 25,000 km^2 (9,653 mi^2), with a water depth of about 286 m (938 ft). By the mid-twentieth century, however, its surface area had decreased to 15,000 km^2 (5,792 mi^2). At the end of the twentieth century, the depth had decreased by a factor of 10. Its mean depth in 1969 was estimated to be 12 m (39 ft). The decreased water volume isolated northern Lake Chad from southern Lake Chad, with a drastically diminished total surface area of about 2,500 km^2 (965 mi^2; Figure 5.4-2).

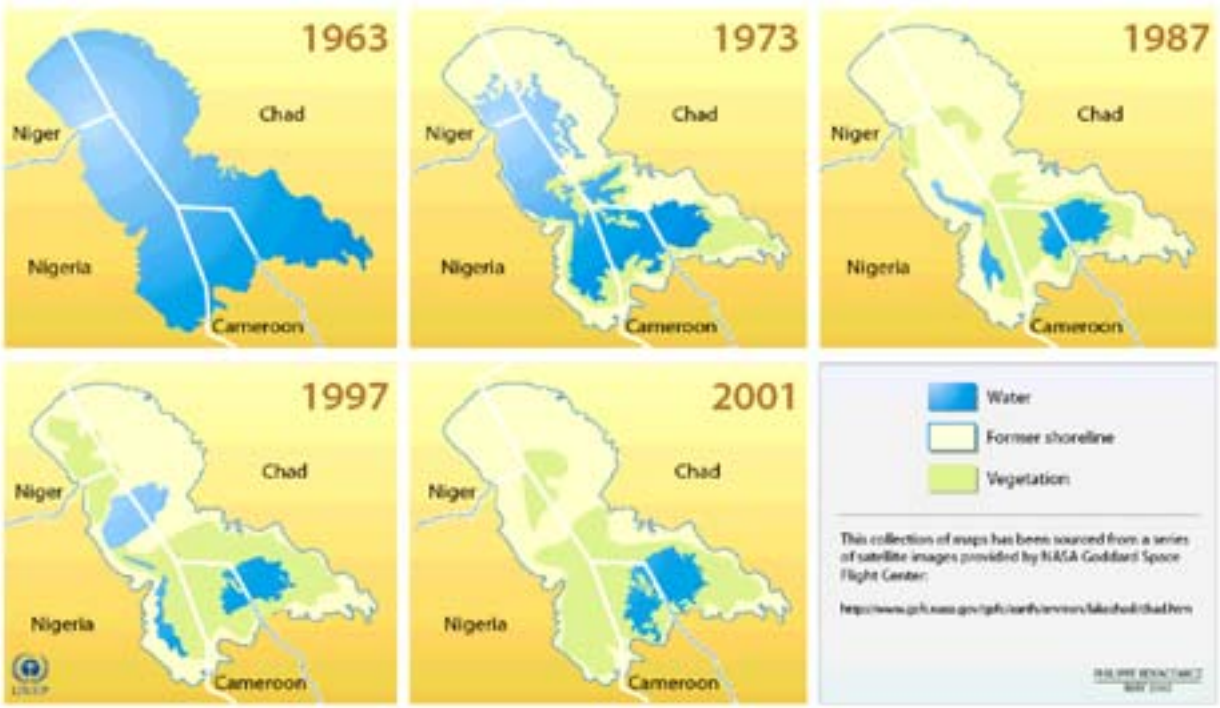

Figure 5.4-2: Diminishing water volume and surface area of Lake Chad

Source: UNEP GRID Arendal 2003

The natural and anthropogenic stresses the lake has been subjected to over the years is depicted in Figure 5.4-2, drawn from a series of satellite images (some of which are shown below in Figure 5.4-3). The reason for this reduction is the drought that has plagued the region for more than three decades, being attributed to climate change and human water demands.

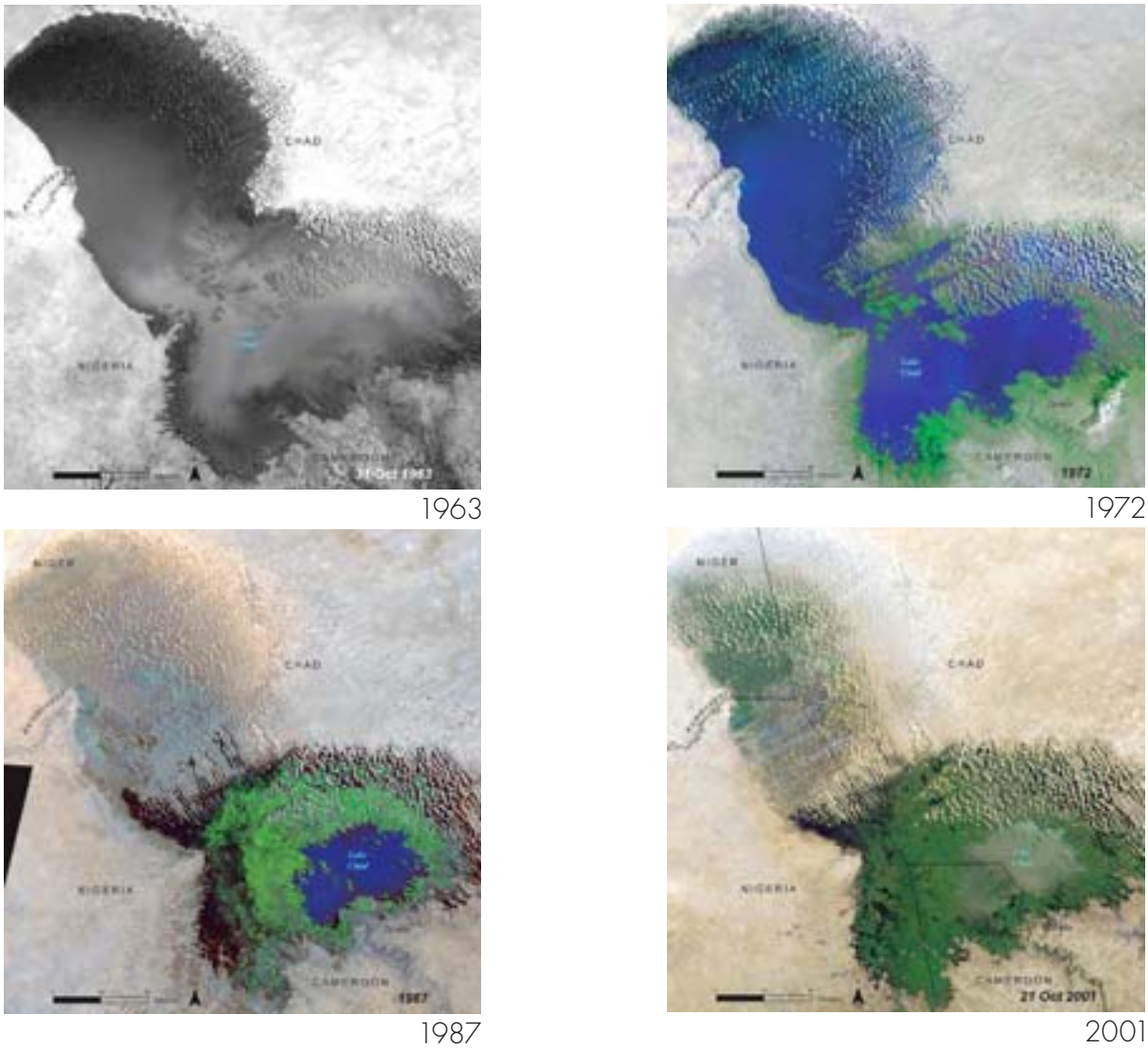

Figure 5.4-3: Satellite images depicting temporal changes of Lake Chad surface area from 1963 to 2001

Source: www.spaceandmotion.com/Images/africa-lake-chad-environment.jpg

Although Lake Chad was once the sixth-largest lake in the world, persistent drought since the 1960s has seen the lake shrink to about one-tenth of its former size (from ~25 000 km^2 [9,653 mi^2] to ~3 000 km^2 [1,158 mi^2]). The most dramatic decrease in the size of the lake occurred in the 15 years between 1973 and 1987. The quantity of water used for irrigation began to increase in 1983. Between 1983 and 1994, the quantity of water diverted for irrigation ultimately quadrupled from the quantity used over the previous 25 years. The red colour in the 1997 satellite image in Figure 5.4-3 denotes vegetation on the lake bed, with the ripples on the western edge of the lake representing sand dunes formed by wind. Other studies indicate that both the Nile and Niger River Basins were connected to Lake Chad in the nineteenth century. Today, however, only the Niger Basin has a poor connection with the Chad Basin through the Komadougou-Yobe and the Yedseram drainage systems.

Ecosystems

Over 100 species of fish have been recorded for the upper Chari system, while over 120 species are recorded for the lake and the lower reaches of the Chari River. Both the lake and the Chari floodplains support a rich terrestrial and aquatic fauna. The region is also notable for Kuri ox, a domesticated breed of *Bos taurus longifrons*, which is now at risk of extinction.

Lake Chad is located on a major migration route for birds moving between Africa and the Palearctic. At least 70 species of bird make stopovers at the lake each year, especially Pintail (*Anas acuta*) (about half a million), Garganey (*Anas querquedula*) (about 400,000) and Ruff (*Philomachus pugnax*) (about 130,000). Other important wildlife in the basin include sitatunga (*Tragelaphus spekii*), African elephant (*Loxodonta Africana*), hippopotamus (*Hippopotamus amphibius*) and crocodile (*Crocodylus sp.*).

The oil exploration now going on in the Chad Basin poses a danger to its ecosystems. The damage that can be inflicted by oil spills when production actually begins is expected to be much more devastating than that currently being experienced in the Niger Delta. The fragile Sahelian ecosystems, especially with respect to water, must be protected against this serious threat.

Land degradation and land subsidence

Land degradation is taking place in the basin, being prevalent toward the south, and exacerbated by the southward advance of the Sahara desert. There is potential for land subsidence because of large-scale groundwater abstractions, especially in the Maiduguri metropolis area.

Hydrology

The hydrologic regime of the lake is greatly influenced by the rivers that drain its basin and by the rainfall pattern (UNESCO/UNDP 1972; FAO 1973). Cameroon and the CAR are the principal sources of rainwater that feed the lake. About 80 per cent of the inflow is via the Logone and Chari Rivers, with the El Beid contributing about 2.5 per cent. The remaining 17 per cent of the water discharged into the lake comes from the Yobe and Yedeseram Rivers in Nigeria.

Lake Chad basin is a closed basin. Studies have shown that the basin previously had an outlet to the east; namely, the dry Bahr el Ghazal riverbed. The last time the lake level was sufficiently high to spill into the riverbed, however, was probably in the 1800s. Unlike most closed systems, Lake Chad's water is surprisingly fresh. The Chari River puts few dissolved solids into the lake, since many of its suspended solids drop out onto its wide floodplain. Once in the lake, some dissolved solids precipitate, and some are absorbed by plants. Further, 5-10 per cent of the lake water seeps away through the ground, carrying dissolved solids with it.

Hydrogeology

The Basement Complex of Pre-Cambrian age constitutes the bedrock on which sedimentary deposits have been laid down in the basin (Figure 5.4-4; Matheis 1976; Schneider 1991). The sedimentary deposits form four major aquifers (Miller et al. 1968). The Quaternary Phreatic Aquifer at shallow depth constitutes a groundwater reserve estimated at about 150 billion m^3, with the quality of its water being suitable for domestic consumption. The next layer is the 60 m (197 ft) thick lower Pliocene Aquifer, found at depths of about 250 m (820 ft). The aquifer is artesian in some parts of the basin. Although the water reserve of the lower Pliocene Aquifer is unknown, its exploitation is estimated to be about 3 million $m^3 \cdot yr^{-1}$. The chemical properties of its waters, however, render it unsuitable for irrigation. The Continental Terminal Aquifer is essentially an alternation of sandstone and clay about 250 m (820 ft) thick (Oteze and Aiyegbusi 2002). The annual recharge from the outcropping sandstones is estimated to be 15-20 million $m^3.yr^{-1}$. The suitability of this water for irrigation is debatable. Finally, the Cretaceous continental Hamadian Aquifer is an important aquifer in western Africa, although very little information about it is available for the conventional basin. These aquifers are recharged by infiltration from tributaries of the lake, with the total annual recharge in the hydrographic basin estimated to be 3.6 billion $m^3.yr^{-1}$.

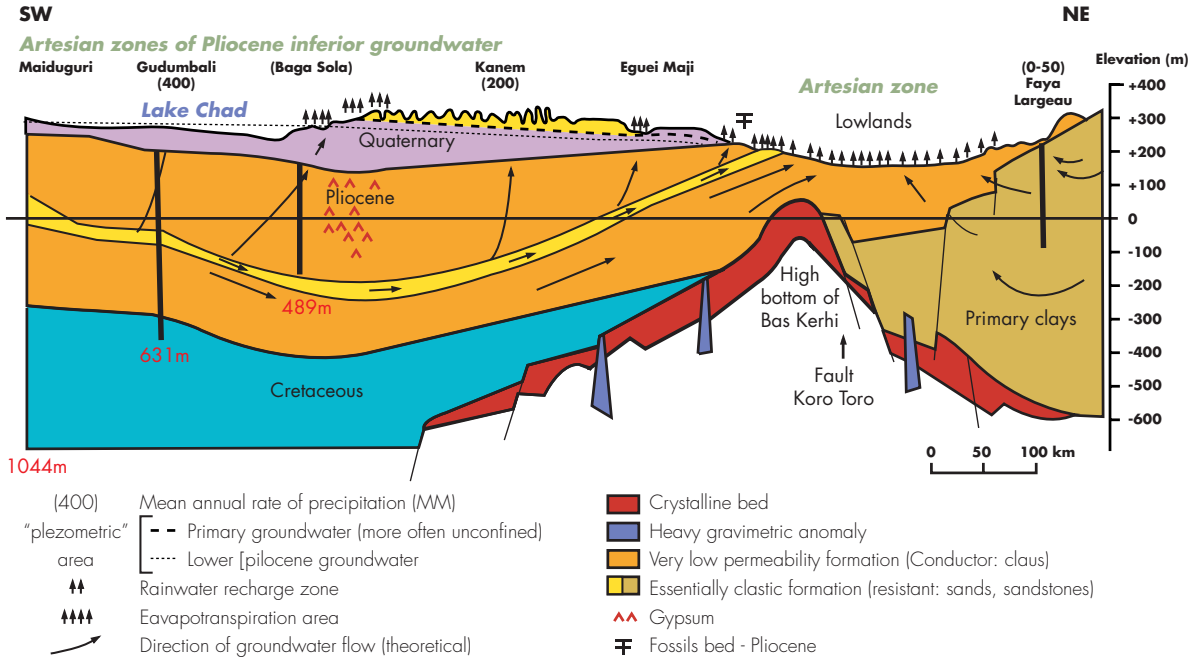

Figure 5.4-4: Hydrogeological cross-section of Lake Chad Basin

Source: redrawn from Schneider 1991, cited in UNEP 2004, redrawn by UNEP

Water availability

The only water entering Lake Chad is from the annual monsoons and from the Chari-Logone Rivers. The Chari-Logone Rivers, with a flow of 38.5 $km^3.yr^{-1}$, contribute about 95 per cent of the total inflow to Lake Chad. The surface area of Lake Chad has varied in recent times between 3,000-25,000 km^2 (1,158-9,653 mi^2), with variations in its level or depth being over 8 m (26 ft), and in its water volume being between 20-100 km^3. The total water inflow has varied between 7 $km^3.yr^{-1}$ in 1984-1985, and 54 $km^3.yr^{-1}$ in 1955-1956. The quantity of water flowing into the lake from the Chari River has decreased by approximately 75 per cent over the last 40 years. The negative effects of climatic change on water availability, against a background of increased water demands, calls for concerted management efforts to avoid Lake Chad becoming a swamp.

5.4.2 Socio-economy

Demography

The population of the conventional basin is about 20 million, including 2.55 million in Cameroon, 1.93 million in Niger, 11.38 million in Nigeria, 5.05 million in Chad, and about 0.63 million in the CAR. In regard to the hydrographic basin, the Nigerian sector covers 152,000 km^2 (58,688 mi^2) and has a population of about 37 million people, resulting in population density of 154 persons. km^{-2} (399 persons.km^{-2}), compared to the average population density for Chad being 7.3 persons. km^{-2} (19 persons.km^{-2}). The annual population growth rate is 2.5-3 per cent in all the riparian countries, with a low life expectancy in all the areas, being 48 years in Chad and Cameroon, and 52 years in Nigeria.

HIV/AIDS and poverty

The HIV/AIDS pandemic affects all the Lake Chad Basin countries. The percentage of the population living with HIV/AIDS is 5.75 per cent in Cameroon, 3 per cent in Nigeria, 5 per cent in Chad, and

4 per cent in Niger. Eighty per cent of Chadians, 60 per cent of Nigerians, and 48 per cent of Cameroonians live below the poverty line

Economy

The principal economic activity and biggest water user in the Lake Chad Basin is agriculture, which provides about 60 per cent of the total employment. Livestock, fishing and general trade account for 14, 3, and 10 per cent of the other major occupations, respectively. Fishing generates about 1.5 billion francs cfa annually.

Water-related conflicts

Recurrent droughts have led to the depletion of surface water and groundwater, and to deterioration of water quality. This has caused a human migration in search of water, with a resultant increase in anthropogenic pressures on wetlands, thereby disrupting ecosystems. Poverty, armed robbery and insecurity prevail. The navigable waters of the lake have become shallow, bringing a halt to the transport of goods and services across the lake. These problems have degenerated to conflict situations among the riparian countries.

Today, over 20 million people struggle to survive in the lake basin. There are conflicts between, and among, fishermen, farmers and cattle herders, and between nationals of the different riparian countries.

5.4.3 Management

In a bid to seek non-violent solutions to water-related conflicts in the Lake Chad Basin, the 4 countries that directly share the lake (Cameroon, Niger, Nigeria, Chad) created the Lake Chad Basin Commission (LCBC) in 1964, with the principal objective of ensuring the most rational use of water, land, and other natural resources in the basin.

An ambitious LCBC project intended to reverse the diminishing trends in the Lake Chad Basin is the Inter Basin Water Transfer from the Congo Basin to the Lake Chad Basin. The project, still in its conceptual stage, plans to transfer about 100 billion m^3 of water annually (3,200 $m^3.s^{-1}$) from the Congo River, to augment the available water resources of the Sahelian areas of the Lake Chad Basin. The transfer route would be a navigable canal, 2,400 km (1,491 mi) long. Further, through the construction of dams in both the donor and recipient basins, about 30 to 35 GWh of electricity is expected to be produced, which can be supplied to the countries in the region. An area of between 5-7 million ha (19,305-27,027 mi^2) could be put under intensive irrigation development in the recipient basin. It is feared however, that the proposed project could create exactly the same kind of problem for the Congo Basin as that afflicting Lake Chad, if not properly planned, implemented and managed.

5.4.4 Key Issues, adaptation and mitigation

Effective management of land and water resources in the Lake Chad Basin is central to sustaining the lives and livelihoods of its people.

Physiography

Climate vulnerability

The Lake Chad Basin is subject to extremely dry conditions for most parts of the year, with the basin also being subject to recurrent droughts.

Adaptation and mitigation

There is a need

- To develop techniques that would fully harvest water resources in the years of good rainfall (e.g., artificial recharge).

Land degradation and land subsidence

Land degradation is a serious problem and a threat to food security, ecosystems, and water resources within the lake basin. Over-abstraction of groundwater from some of the aquifers in the basin may result in land subsidence.

Adaptation and mitigation

There is a need

- For comprehensive conservation measures, including revegetation, soil conservation and efficient use of resources;
- To enforce environmental impact assessments as an integral part of project design and implementation within the basin, to control land degradation and pollution;
- To properly manage the basin's aquifers.

Water availability, use and pollution

There is concern about the capacity of the Lake Chad Basin to provide a sustainable means of livelihood for its inhabitants because of dwindling water resources and a growing population. There also is lack of integrated use and management of water resources by member states at both the national and regional levels. Oil exploration is currently ongoing and, if discovered, its subsequent mining poses a serious danger to the basin's environment and water resources.

Adaptation and mitigation

There is a need

- To carry out groundwater assessment studies to establish potential aquifers; to develop techniques to allow for the full harvest of water resources in years of good rainfall (e.g., artificial recharge);
- To harmonize the exploitation and harnessing of lake basin resources through appropriate legal frameworks;
- To institutionalize IWRM by all riparian countries in a coordinated manner, focusing on holistic water use;
- To institute pollution monitoring and mitigation measures at the basin level.

Socio-economy

Population growth

Population growth and high urbanization rates are exerting severe pressure on available water resources and water supply in regard to water demands and pollution.

Adaptation and mitigation

There is a need

- To invest more in upgrading and developing infrastructure in both urban and rural areas;
- To implement measures that curb the adverse effects of population growth;
- To conduct community awareness and education programmes on conserving the basin's natural resources.

HIV/AIDS and water-related diseases

The prevalence of HIV/AIDS in the basin is relatively low, being about 6 per cent of the basin population. Both HIV/AIDS and malaria are pandemics, and exacerbate poverty, with the young and most-productive members of the communities being the most affected. Orphaned households and poverty are on the increase.

Adaptation and mitigation

There is a need:

- To educate, train and create awareness in the community;
- To implement anti-retroviral and malaria prevention programmes;
- To provide adequate domestic water resources to ensure general hygiene as a means of minimizing disease transmission.

Water-related conflicts

Because of increasing pressure on the dwindling water resources, there is a potential for conflict between communities (farmers and pastoralists), as well as between the various riparian countries.

Adaptation and mitigation

There is a need

- To develop IWRM strategies to ensure equity in water allocation;
- To develop institutional capacity for conflict resolution within the basin.

Management

Institutional and legislative frameworks

No effective institutional and legislative frameworks exist in the basin.

Adaptation and mitigation

There is a need

- To strengthen the Lake Chad Basin Commission (representing all the riparian countries) to effectively manage the basin's water resources;
- To develop and implement appropriate legislative frameworks, including regulations.

Data availability, standardization and monitoring

Reliable data on the quantity and quality of both human and physical resources, as well socio-economic activities, within the Chad Basin is lacking, resulting in poor decision-making and inappropriate water and environmental management practices. There also is inadequate monitoring, especially in regard to groundwater levels and abstractions, as well as ineffective coordination and networking among research institutes.

Adaptation and mitigation

There is a need:

- To establish basin level monitoring networks;
- To collect standardized data within the basin riparian countries;
- For regular data analysis, interpretation, sharing and disseminating results into the IWRM of the basin.

5.4.5 References

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5.5 DOUALA MULTI-AQUIFER SYSTEM

The Douala Sedimentary Basin (DSB) is a 7,000 km^2 (2,703 mi^2) coastal basin in southwest Cameroon, at the flexure of the Gulf of Guinea, between latitudes 3°N and 5°N (Dumort 1968). The DSB is made up of four aquiferous units configured to form a multi-aquifer system, the Douala Multi-Aquifer System (DMAS; Figure 5.5-1). The main characteristics of the DMAS are summarized in Box 5.5-1.

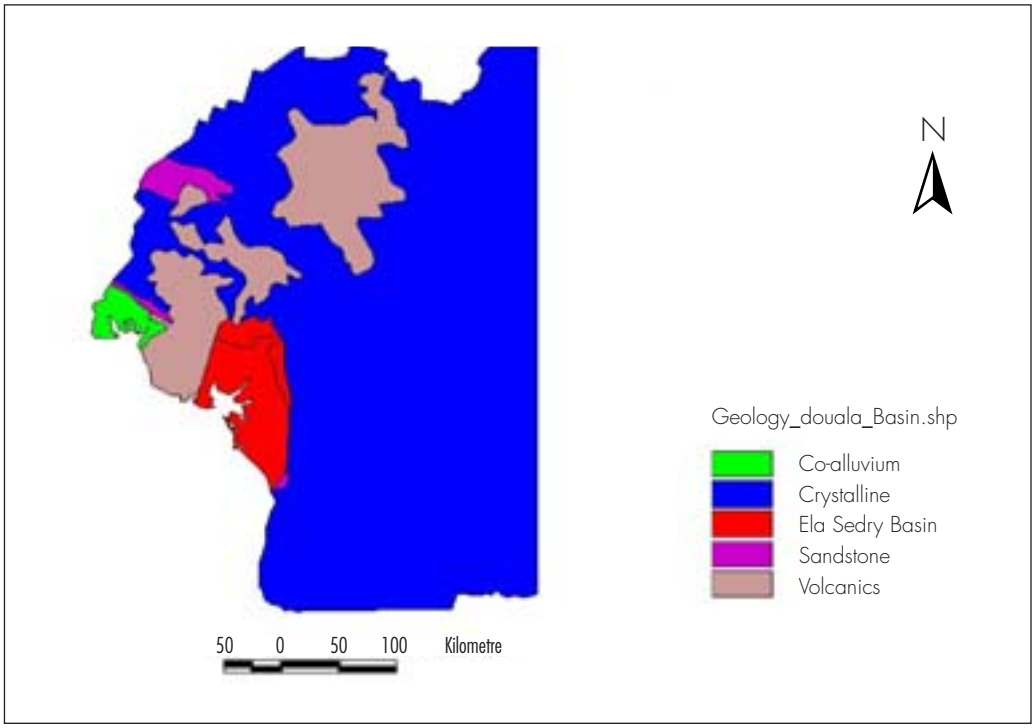

Figure 5.5-1: Geology of the Douala Sedimentary Basin

Source: Mafany 1999

Box 5.5-1: Douala Multi-Aquifer System: Main characteristics

Basin		**Water Use**	
Surface area:	7,000 km^2 (2,703 mi^2)	Industry	Increasing
MAP:	3,000–4,500 mm.yr^{-1} (118-177 in.yr^{-1})	Domestic	
		Agriculture	
Demography			
Population:	4 million	**Vulnerability**	
Density:	571.4 persons.km^{-2} (1,480 persons.km^{-2})	Increasing pollution toward the coast	
Major Aquifers:	Pleistocene alluvium (unconfined); recharge estimated at 990 Mm^3.yr^{-1}		
	Pliocene Sands (unconfined)		
	Palaeocene Sandstone (confined)		
	Cretaceous Basal Sandstone		

Source: Dumort (1968); Regnoult (1986); Mafany (1999).

5.5.1 Physiography

Climate

The DSB is characterized by a wet humid equatorial climate, being under the influence of monsoon circulation for most of the year. The dominant presence of strong, moisture-laden southwest monsoon winds results in one long wet season, and a short dry season. The rainy season runs from March to November, with mean annual rainfall above 4,000 mm (157 in). Temperatures are relatively constant, averaging between 24-27 °C (75-81 °F), with a mean annual humidity of about 83 per cent (CICERO 2000). The abundant rainfall provides for copious surface water and groundwater resources.

Ecosystems

The main estuaries of the DSB are covered with several species of mangroves. The specific diversity, however, is lower than that of the Asiatic mangroves (Folack 1994). The mangroves play an important role in the ecology and biology of fish and shrimps, serving as nursery zones, and providing excellent shelter for shrimps and fish spawning (Folack 1997). The mangroves also constitute a natural protection against coastal erosion. In addition to the mangroves, the DSB also harbours coastal forests containing species of high economic value, as well as endemic species of ecological importance.

Land degradation and desertification

There are three main types of land use in the basin, including agriculture, human occupation and industries. Land dedicated to urban use expanded from 2,750 ha (10.6 mi^2) in 1970, to 10,030 ha (39 mi^2) in 1992 (CICERO 2000), most of which has been used for housing. Development has been most rapid in the low-lying plains, which are known to be highly vulnerable to floods.

Artisanal fishing occurs within two nautical miles of the shore, as well as within the mangrove zone. Mangrove forests are being harvested for fuel wood and construction. Artisanal and semi-industrial sand mining also is taking place, further modifying the mangrove ecosystem. The result is a gradual landward encroachment of the ocean, which is accentuated during the rainy season.

Hydrology

The relief is generally flat, rarely rising above 200 m (656 ft). The low-lying relief, proximity to the Atlantic Ocean, and abundant rainfall, make most of the basin highly vulnerable to floods. A dense network of rivers drains the basin, most being in hydraulic contact with the groundwater system, especially the shallow aquifers.

Hydrogeology

The 4 aquiferous units of the Douala Multi-Aquifer System (DMAS) include: (i) the Lower Cretaceous sandstone; (ii) Palaeocene sandstone; (iii) Pliocene sands; and (iv) Pleistocene alluvium. The basal sandstone outcrops in the northern portion of the basin, being easily exploited by shallow hand-dug wells. Further away from the northern margin towards the coast, however, the dip increases, with exploitation becoming difficult because of the increasing thickness of the overlying beds. The Palaeocene sandstone is the most important aquifer in the basin, in terms of water quantity and quality, but is the least exploited. The most exploited aquifers are those of the Wouri formation, which encompasses the Pliocene sands and Pleistocene alluvium. The Wouri formation, the youngest in the DSB, is typified by an alternating sequence of estuarine mud and silt and marine sands.

Groundwater availability

The DMAS is a renewable water resource system. The high rainfall and high infiltration rate provides for abundant surface and groundwater resources. The estimated recharge is 990 million m3.yr-1 (Mafany 1999). The DSB has about 21.6 km3 of available groundwater (Banque Mondiale et al. 1992).

Groundwater pollution

The shallow groundwater resources of the DMAS are susceptible to pollution because of a combination of anthropogenic activities and geology. The southwest coast of Cameroon, in which the DMAS is located, is characterized by intensive agro-industrial activity. Pesticides and nitrates represent the main sources of aquifer contamination in agricultural zones (Dupuy et al. 1997a; 1997b). The high permeability and porosity of the DSB sediments are expected to facilitate the infiltration of contaminants into the sub-surface. Douala, the main town in the DSB, has the highest concentration of industries in the country. Effluent from these industries is discharged untreated onto the surface, where it flows into rivers (Eneke 2001), or percolates down to the groundwater table (Ketchemen et al. 2001). In spite of this high contamination potential, from a physico-chemical point of view, the groundwater in the DMAS exhibits very little pollution. Shallow groundwater in densely populated areas such as Douala, however, exhibited faecal coliform signatures higher than 300 $CFU.mL^{-1}$. Indiscriminate disposal of domestic, industrial and hospital waste is responsible for this contamination. Cases of waterborne diseases (e.g.., typhoid; cholera; amoebic dysentery) are recurrent in most parts of the DSB. Between 1984 and 1993, for example, 8,000 cases of cholera, 11,500 cases of typhoid fever and 46,400 cases of ameobic dysentery were recorded (Nola 1996), all originating from the consumption of water from unprotected hand-dug wells.

5.5.2 Socio-economy

Population density and growth

Douala is the most populated (>2.5 million people) and most industrialized town in Cameroon. The DSB has the highest population density in the country of 571.4 $persons.km^{-2}$ (1,480 $persons.km^{-2}$). The population growth rate of the town of Douala is about 5 per cent per yea, due mainly to increasing urbanization. As more and more people leave rural areas for the urban centres in search of jobs (with Douala being the most prolific), especially in the private and informal sectors, the pressures on groundwater resources will likely increase. They will impinge further on the quality of the groundwater, which already is exposed to a high level of pollution as the result of indiscriminate disposal of industrial and municipal wastes (Mafany 1999). Development has been most rapid in the low-lying plains, which are known to be highly vulnerable to floods. The total population of these areas in 1990 was estimated at 382,000, and is presently estimated to be three times this number.

Economy

Most of the major economic centres in Cameroon are in the Douala basin. Seventy per cent of national industries, including extensive agro-industrial plantations, are located in the basin. The municipality of Douala lies along the banks of the Wouri River, it alone having a population greater than 2.5 million inhabitants. The total population of the basin is approximately 4 million inhabitants. The main ports of Limbe, Tiko, Douala and Kribi are found in the DSB, being vital to the economies of Cameroon and her landlocked neighbours, such as Chad and the CAR.

The physical infrastructure of the major towns of the basin consists of roads, bridges, buildings and port facilities. CICERO (2000) estimates that Douala alone has 376 km (234 mi) of paved roads, and 560 km (348 mi) of earth roads.

Poverty

Douala, as the main economic centre of the country, has the most affluent individuals enjoying a high standard of living. The majority of the population in the DSB, however, can be characterized as low-income, surviving on less than one US dollar per day.

Water demands and water uses

More than 60 per cent of the basin population depend on groundwater for domestic, municipal and industrial water needs. Groundwater is exploited both through shallow hand-dug wells and deep boreholes. The National Water Corporation (SNEC) estimated a total annual groundwater abstraction of 4.7 million $m^3.yr^{-1}$ in the mid-1980s. The abstraction increased to 13 million $m^3.yr^{-1}$ in 1999, due to increased urbanization, industrialization and population growth (Mafany 1999). The maximum estimated abstraction rate measured against the estimated recharge of 990 million $m^3.yr^{-1}$ (Mafany 1999) is far below the safe yield of the basin aquifers. Thus, the groundwater resources of the basin are currently under-exploited and, even if the exploitation was increased by a factor of ten, it will have little impact, in terms of quantity, on the available groundwater resources.

5.5.3 Management

The low groundwater abstraction rate from the DMAS may be the reason there is no basin-wide groundwater information or education programmes. There also are no institutional structures with activities directed toward groundwater management. Most water-concerned bodies (e.g., Ministry of Water and Energy; Ministry of Scientific Research and Innovation; Ministry of Agriculture and Rural Development; National Water Corporation) broadly consider all water resources, without any focus on groundwater (Mafany *et al.* 2007). There is nevertheless a need for information and data on groundwater in the DSB to appropriately control and manage its use.

5.5.4 Key Issues, adaptation and mitigation

Physiography

Climate vulnerability

Projections by CICERO (2000) indicate that, for the city of Douala, a sea level rise of 50 cm (20 in) in the year 2050 would lead to a total land loss of 12 km^2 (4.6 mi^2), with the land areas lying between 0-2 m (0-6.6 ft) altitude being the most vulnerable. The sea level rise would result in landward encroachment of saline water, and consequent salinization of surface water and shallow (unconfined) groundwater resources.

Adaptation and mitigation

There is a need:

- To protect surface and groundwater resources;
- To use surface water and groundwater resources together, in order to ensure good quality water for water supply.

Ecosystems

Intense human development within mangrove ecosystems, coupled with the rapid urbanization of adjacent towns, and the excessive utilization of trees for fuel wood, construction, and production of charcoal, have led to a gradual degradation of these ecosystems. The destruction of these mangroves is increasing the vulnerability of freshwater resources to seawater encroachment.

Adaptation and mitigation

There is a need:

- To conserve the mangrove ecosystems, within the context of appropriate institutional and legislative frameworks.

Socio-economy

Population growth and urbanization

Increased population growth and urbanization are exerting pressures on water supply in regards to water demands and pollution. Urban populations also are increasing, due to rural-to-urban migration.

Adaptation and mitigation

There is a need

- To invest in upgrading and developing infrastructure in both urban and rural areas;
- To implement measures that curb the adverse effects of high population growth.

HIV/AIDS and water-related diseases

HIV/AIDS and waterborne diseases exacerbate poverty, with the young and most productive members of the communities being most affected. Orphaned households and poverty are on the increase.

Adaptation and mitigation

There is a need:

- To educate, train and create awareness in the community;
- To implement anti-retroviral and malaria prevention programmes;
- To provide adequate domestic water resources to ensure general hygiene and minimize disease transmission.

Water availability, uses and demands

The basin is endowed with bountiful water resources. Increasing water use due to an increasing population, however, is having an effect on the water quality through pollution.

Adaptation and mitigation

There is a need:

- To institute pollution monitoring and mitigation measures at the basin level.

Management

Institutional and legislative frameworks

Most of the institutional and legislative frameworks on water in Cameroon emphasise surface water when considering management options.

Adaptation and mitigation

There is a need:

- For groundwater to be considered an equally important component of the hydrologic cycle requiring effective management;
- For an institutional and legislative framework for managing groundwater resources.

Data availability, standardization and monitoring

The full potential of groundwater in the DSB is unknown because of a lack of data.

Adaptation and mitigation

There is a need:

- For detailed hydrogeological assessments of the DMAS;
- For integrated basin monitoring of the DMAS.

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WESTERN AFRICA

6.1 OVERVIEW

The countries located in western Africa (Figure 6.1-1) constitute a homogenous unit in relation to their geology and physiography, population, culture and history, and the economic and social conditions characterizing them as developing countries.

Several characteristics recur from one country to another, including a strong demographic growth, a young population, rapid and uncontrolled urbanization, a national economy dominated by the agricultural sector, slow human resource development, poor access to drinking water, and insufficient or non-existing sanitation systems. Freshwater demands come mainly from agriculture, followed by domestic, industrial and hydroelectric power demands.

There are 16 countries within the region, including the coastal countries of Benin, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mauritania, Nigeria, Senegal, Sierra Leone, and Togo, and the land-locked countries of Burkina Faso, Mali, Niger, and the island state of Cape Verde.

Western Africa has a large number of river basins, 11 of them being transboundary (Figure 6.1-1). There also are 2 major transboundary groundwater basins. This document deals with the following water systems:

- River Basins: Gambia, Komadugu Yobe, Mano, Niger, Senegal, and Volta;
- Groundwater Basins: Nigerian Coastal Area Aquifer System, and Sokoto Aquifer.

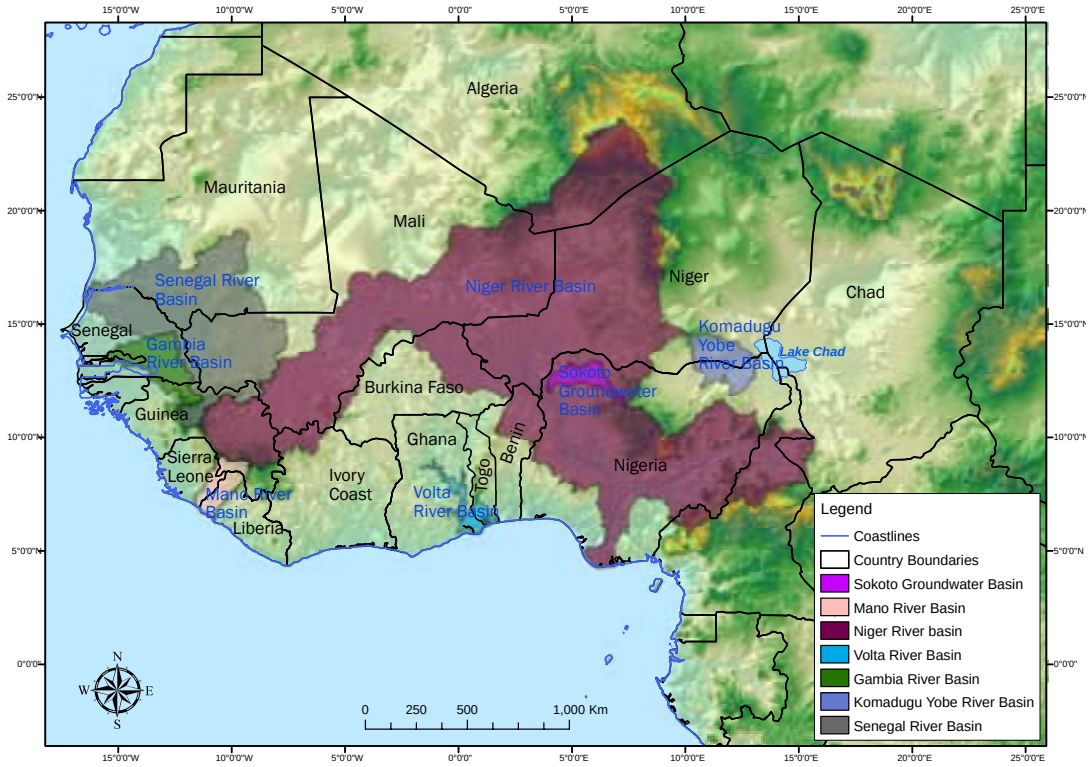

Figure 6.1-1: Major river and groundwater basins of western Africa

Cape Verde Islands

Cape Verde, the only major archipelago in the sub-region, is located approximately 500 km (311 mi) off the coast of Senegal, and consists of two series of islands:

- North islands on the windward side (Barlavento), including Boa Vista, Sal, São Nicolau, Santa Luzia, São Vicente, and Santo Antão; and
- South islands on the leeward side (Sotavento), including Brava, Fogo, Santiago, and Maio.

The population of the islands is half a million, while the respective renewable volumes of surface water and groundwater resources are only 181 million and 124 million $m^3.yr^{-1}$, respectively. Because of the scarcity of freshwater, two desalination plants, with a combined capacity of 1.68 million, were installed on two of the islands in 1997. Seventy four per cent of Cape Verdians have access to drinking water, with more than 90 per cent of the available water resources used for irrigation. About 20 per cent of the GDP is contributed to the domestic economy through home remittances by Cape Verdians in the Diaspora.

6.1.1 Physiography

The climate in the region ranges from humid equatorial at the coast, to arid in the northern Sahelian countries. The precipitation varies from less than 200 $mm.yr^{-1}$ (8 $in.yr^{-1}$) in the arid zone, to more than 1,000 $mm.yr^{-1}$ (79 $in.yr^{-1}$) in the tropical zone, with the inter-annual variation being very high. Decreased precipitation has been observed all over the Sahel over the past 3 decades (1970-2000), being closely linked to a decreased number of rainfall events, except in the extreme south.

The potential evapotranspiration amounts to 1,300 $mm.yr^{-1}$ in the humid regions, increasing to about 2,000 $mm.yr^{-1}$ (79 $in.yr^{-1}$) around latitude 20° N. The actual evaporation is higher in the region of higher rainfall, decreasing to nearly zero in the region of minimum rainfall in the Sahara Desert. The potential and actual evapotranspiration follow the same pattern as the actual evaporation. The annual surplus of water generally decreases northward, turning rapidly into an annual deficit in the region between latitude 10°N and 20°N, and becoming even more acute in the Sahara (lat. 20°N and 30°N).

Ecosystems in western Africa are vulnerable to environmental change for the following reasons:

- Adverse climate changes have further reduced the already low productivity of the arid lands of Sahel;
- Population growth has significantly increased the per capita pressures on natural resources;
- Lack of technological innovation has led to unsustainable land management practices;
- Poverty limits the potential of the populations to efficiently address the degradation; and
- Lack of efficient governance constrains the possibilities for governments and stakeholders to address the relevant issues.

The region's surface water resources include rivers, lakes and wetlands. The major rivers flow over more than one hydro(geo)logical region and are transboundary, making it imperative for the riparian states to cooperate in water resources management. The river runoff decreases northwards, and water is most abundant between August and October, during which 40-70 per cent of the annual runoff occurs. Southward, about 80 per cent of the annual runoff in the sub-humid parts of the tropical zone is accounted for in 5-6 months, whereas there is a more even distribution of runoff during the year in the humid zones, with two peaks being observed (Ayibotele 1993). About 80 per cent of the mean annual runoff occurs within 8-9 months.

The sub-Saharan drought of the early-1970s in western Africa had serious consequences on the region's water resources. Analysis of the monthly rainfall data for the region by Le Barbe and Lebel (1997) shows that the dry period was characterized by a decreased number of rainy events, while the mean storm rainfall varied little. A rainfall deficit of 10-30 per cent generally leads to a 20-60 per cent deficit in river discharge. The Niger River, the largest river in western Africa, dried up for several weeks at Malanville in the Benin Republic in 1985. This was a consequence of a one-year lag of the lowest rainfall and runoff (1984) recorded in the upper basin since the beginning of the century.

The groundwater potential of the western African region is determined by 3 major types of aquifers, including: (i) basement aquifers; (ii) deep coastal sedimentary aquifers; and (iii) superficial aquifers. Groundwater availability depends on the type of substrate, and varies on the basis of the quantities of precipitation and recharge. In the arid and semi-arid zones, large, deep sedimentary aquifers are often present, mostly in the form of fossil aquifers. In humid and sub-humid regions, the groundwater is dominated by Precambrian crystalline formations and large sedimentary formations.

Although large sedimentary aquifers have attracted detailed studies because of their geographical extension and water storage, their exploitation is rarely rigorously controlled. The coastal sedimentary formations consist of some very productive sandstone and limestone layers. Water yields averaging 18 $m^3.h^{-1}$ are obtained from these types of aquifers in Côte d'Ivoire, Togo, Togo-Benin, and Benin. Discontinuous (basement) aquifers have been the object of rapid assessments, and the development of methodologies to increase the success in establishing productive boreholes and wells. Their exploitation is always limited, depending mainly on the means used to abstract the water, and the variation in the piezometric levels. Borehole and well yields are generally low, ranging between 0.3-3 $m^3.h^{-1}$. They can, however, reach 10 $m^3.h^{-1}$, with water yields as high as 45 $m^3.h^{-1}$ having been observed in some areas.

There is a great concern about water quality. Even when perennial surface water is available, its consumption in an untreated state represents a serious risk for human health because it is frequently contaminated by pathogens. The issue of groundwater quality and pollution is not adequately addressed, largely because of insufficient sampling and analyses. It is known, however, that groundwater in some countries (e.g., Senegal; Ghana) contains iron concentrations above the permissible limits for human consumption.

Aridity and water availability

Western Africa's water resources are characterized by extreme variability, both over space and time. Some countries are well-endowed with water resources, while others face serious water-scarcity problems. While drought has been a common feature of the Sahelian zone since the 1970s, floods periodically affect the coastal belt. Generally, the region is characterized on the one hand by a high degree of vulnerability as a result of natural climatic variation, combined with an increased unpredictability of precipitation variability while, on the other hand, by increased water demands from the region's rapidly-growing population.

6.1.2 Socio-economy

The total population of the western Africa region in 1995 was over 227 million people, with an average population density of 32.4 $persons.km^{-2}$ (84 $persons.mi^{-2}$) (GWP/WATAC 2000). Nigeria exhibits the highest population density (109.3 $persons.km^{-2}$ [231 $persons.mi^{-2}$]), while the lowest

density is in Mauritania (2.2 persons.km^{-2} [6 persons.mi^{-2}]). The growth rate is over 3 per cent per year, and the infant mortality varies between 32-149 per 1,000 births, with an average of 102 per 1,000 births. The life expectancy at birth varies between 45-68 years, with an average of 51 years. The total population is expected to exceed 500 million by the year 2025 (Table 6.1-1). For the region as a whole, 41-49 per cent of the population has an average age of less than 15 years.

The rate of urbanization is high in all countries, with urban populations accounting for up to 50 per cent of the total population in some areas, especially along the coast.

The economies are dominated by rain-fed agricultural activities, mainly at the subsistence level. The region produces and exports primary commodities (e.g., cocoa; coffee; minerals; oil; timber). Thus, the export earnings are subject to fluctuations in world commodity prices. The annual income per person ranges from US$ 1,000 in Cape Verde, to US$ 200 in Liberia. Western African countries rank between 123 and 175 on the UN Human Development Index (HDI)

Water demands and use

Water demands have been steadily increasing in all sectors, as a result of population growth, commercial agriculture and industrial expansion. Total water withdrawals for domestic, industrial, and agricultural consumption were estimated to be 11.4 billion m^3 in 2000 (GWP/WATAC 2000). The per capita water demand in rural areas ranged between 15-35 L.d^{-1} in Guinea to 45 L.d^{-1} in Mali, in 1995. For urban supplies, it ranged from 40 L.d^{-1} in Burkina Faso to 100 L.d^{-1} in Senegal. In the capital cities, it ranged from 50 L.d^{-1} in Burkina Faso to 110 L.d^{-1} in Senegal.

Access to water and sanitation

There has been progress since 1990 in the provision of safe drinking water for western Africa, with only a small backlog for achieving the Millennium Development Goals (MDGs) (see Figure 6.1-2). Much effort is required, however, to meet the MDG for sanitation coverage by 2015, especially in rural areas. The socio-economic consequence of low water supply and sanitation coverage is that the health of the majority of the population is affected by waterborne and water-related diseases (guinea worm; cholera; typhoid; bilharzias; etc).

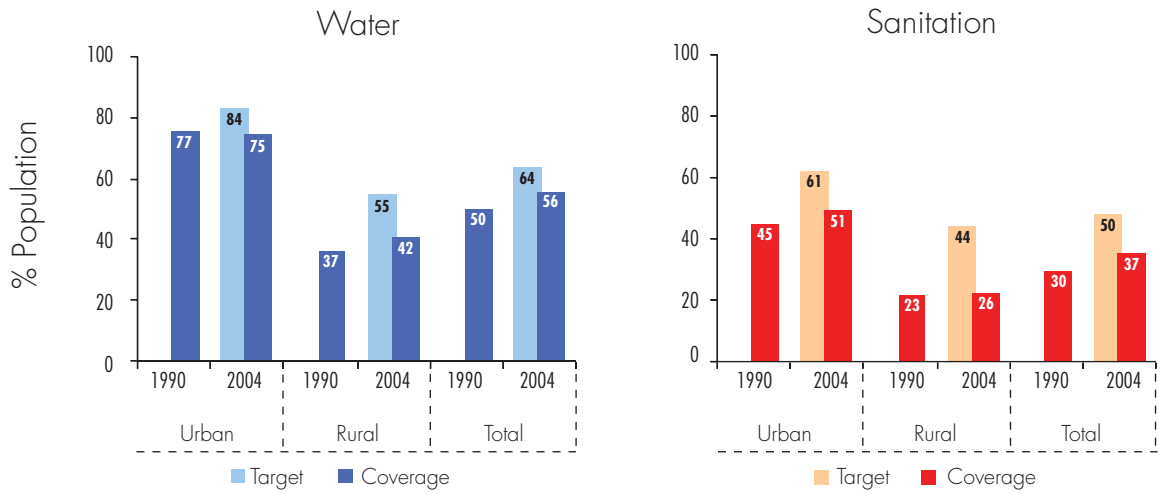

Figure 6.1-2: Water supply and sanitation coverage in rural and urban settings in western Africa between 1990-2004 (Cape Verde, Gambia, Guinea-Bissau and Sierra Leone are excluded due to incomplete data

Source: WHO/UNICEF (2006), redrawn by UNEP

6.1.3 Management

All the river basins in western Africa are managed by an official body or organization.

Crosscutting vulnerabilities

Six western African countries are expected to experience water scarcity by the year 2025; namely, Benin, Burkina Faso, Ghana, Mauritania, Niger and Nigeria. Most of the other countries are now also constrained by inadequate water supply. Climate change scenarios predict reduced rainfall and increased evaporation in most parts of the region. More specifically, an increase in the rate of desertification is predicted for the Sahelian zone (IPCC 2001). Countries in the coastal zone are expected to experience more intense rainfall and increased runoff. If this prediction is combined with the existing high rate of deforestation and ecosystem degradation, it could have serious consequences for soil erosion and, consequently, agricultural production and food self-sufficiency. Table 6.1-1 illustrates the degree of vulnerability of the western African countries.

Table 6.1-1 Water resources and per capita annual water availability

Country	Population (thousand persons)				Animal renewable water (km²) renewable	Per ca[ota water availability (m3, ye-1)			
	1995	2005	2015	2025		1995	2005	2015	2025
Benin	5,421	7,486	10,065	12,587	25.8	4,800	3,400	2,600	2,000
Burkina Faso	10,396	14,080	18,822	23,710	17.5	1,700	1,200	900	700
Cote d'Ivoire	14,535	21,218	30,069	39.344	77	5,300	3,700	2,600	2,000
Cape Verde	438	595	757	922					
Gambia	954	1,271	1,593	1,864	8.0	8,130	6,240	5,020	4,090
Ghana	17,608	23,845	29,884	35,442	53.2	3,020	2,230	1,780	1,500
Guinea	6,700	9,162	12,252	15,273	226.0	3,370	2,470	1,840	1,490
Guinea-Bissau	1,073	1,338	1,649	1,918	27	25,160	20,180	16,370	14,080
Liberia	3,032	4,207	5,689	7,245	232	76,520	55,150	40,780	32,032
Mali	10,799	14,885	19,918	24,774	100	9,260	6,720	5,020	4,040
Mauretania	2,335	3,129	4,129	5,119	11.4	4,880	3,640	2,760	2,230
Niger	9,104	12,694	17,167	21,842	32.5	3,600	2,560	1,840	1,510
Nigeria	127,694	174,307	228,753	280,890	280	2,190	1,610	1,220	1,000
Senegal	8,423	11,172	14,269	16,988	39.4	4,680	3,530	2,760	2,320
Sierra Leone	47,240	6,250	8,161	10,045	160	33,760	25,600	19,610	15,930
Togo	4,138	5,711	7,750	9,842	12	2,900	2,100	1,550	1,220
TOTAL	227,426	311,360	410,942	507,455	1302.5	51,730	4,100	3,130	2,570

Adapted from: West African Water Vision (GWP 2000), and West African Conference on IWRM (Oct 2003)

Although closely linked to low rainfall, water scarcity, streamflow and other vulnerability indicators do not necessarily coincide with the period of rainfall shortage, mainly because of the complexity of the processes that transform precipitation into streamflow, and also because of man-made measures (e.g., flow control; diversion; storage). It is usually assumed that the combination of adverse climatic conditions and human activities in western African is the main cause of the desertification of vulnerable arid, semi-arid and dry, sub-humid areas. In this process, the soil structure and soil fertility are degraded, and bio-productive resources decrease or disappear. The United Nations Convention to Combat Desertification refers to "arid", "semi-arid," and "dry sub-humid" areas being

where the ratio of annual precipitation to potential evapotranspiration falls within the range of 0.05-0.65 (Sehmi and Kunzewicz 1997).

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6.2 GAMBIA RIVER BASIN

The Gambia River Basin (77,054 km^2) (29,751 mi^2) is situated in the West African Atlantic region between latitudes 11° 22′ N and 14° 40′ N, and between longitudes 11° 13′ W and 16° 42′ W (Figure 6.1-1). The basin is shared by Guinea (15.4 per cent), Senegal, (70.9 per cent), Gambia (13.7 per cent) and Guinea Bissau (0.021 per cent). The main characteristics of the basin are summarized in Box 6.2-1.

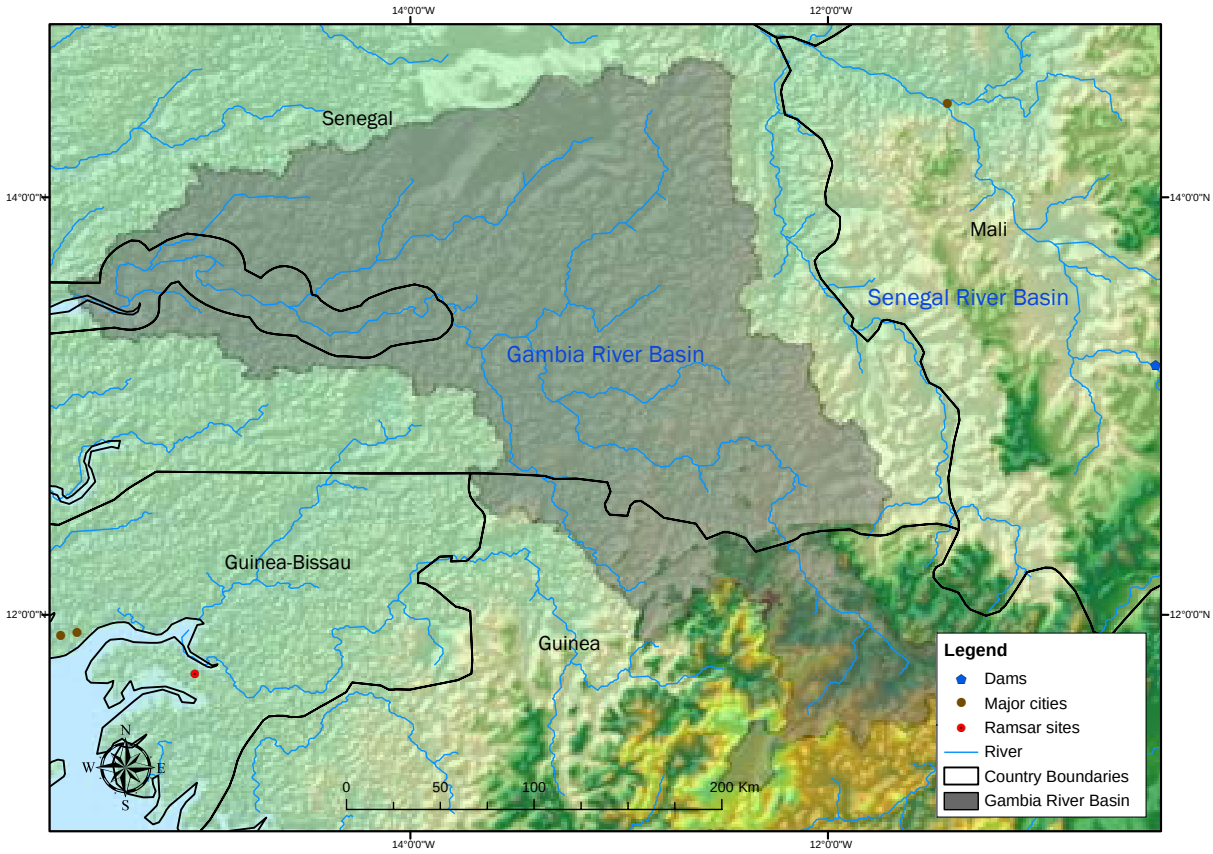

Figure 6.2-1: Gambia River Basin

Box 6.2-1: Main characteristics of Gambia River Basin

Basin

Surface area: 77,054 km^2 (29,751 mi^2)

MAP: 500-2,000 mm.yr-1 (20-79 in.yr^{-1})

Demography

Population: 19.9 million

Density: 49 persons.km^{-2} 127 persons.mi^{-2})

Water Resources

River length: 1,180 km (733 mi)

Rainfall: 92,464 Mm^3.yr^{-1}

River Flow: 2.4 Mm^3.yr^{-1} (at Kedougou)

Major Dams

No dams

Major Aquifer: Continental terminal, Maastrichtien (hard rock)

Water Use

Agriculture

Domestic

Mining (traditional)

Increasing

Vulnerability

Increasing to the west

The Gambia River flows over a distance of 1,180 km (733 mi) from its origin in the mountainous regions of the Fouta-Djalon in the Guinea uplands, to its estuary on the Atlantic Ocean. It comprises 205 km (127 mi) in Guinea, 485 km (301 mi) in Senegal, and 490 km (304 mi) in Gambia.

The basin presents four distinct geographical regions, including: (i) a mountainous zone in Guinea; (ii) a continental basin in Senegal and in the eastern half of Gambia; (iii) a low coastal plain in the western half of Gambia; and (iv) the Gambia River estuary.

6.2.1 Physiography

Climate

The Gambia River Basin is situated in the tropical zone. The climate changes from Sudano-Sahelian type (dry tropical) in Senegal and Gambia, to the tropical Sudanian type (wet tropical) in Guinea. The climate is mainly of Sahelian type in Gambia. The climate is of Sahelian type in Senegal from the north to the centre of the country, becoming tropical in the south. The weather is fresher and wet close to the Atlantic Ocean. A hot and dry wind (the Harmattan) blows inside the country. The rotation of the dry and rainy seasons set the river's hydrological regime; namely, a period of high tides during the wet season, and a period of low tide during the dry season.

The annual rainfall varies considerably in each riparian country: from 1,200 to 4,500 mm (47-177 in) in Guinea; from 1,200 mm (47 in) in the north to 2,400 mm (94 in) in the south in Guinea Bissau; and from 500-1,000 mm (20-39 in) in Senegal and Gambia. The mean monthly rainfall distribution is typically that of the Sudano-Guinean climate. The rainy season begins in May, ending in October. The wettest months are July, August and September, during which the peak of the monthly regime occurs. Figure 6.2-2 compares the annual rainfall for the synoptic stations of Tambacounda and Kedougou.

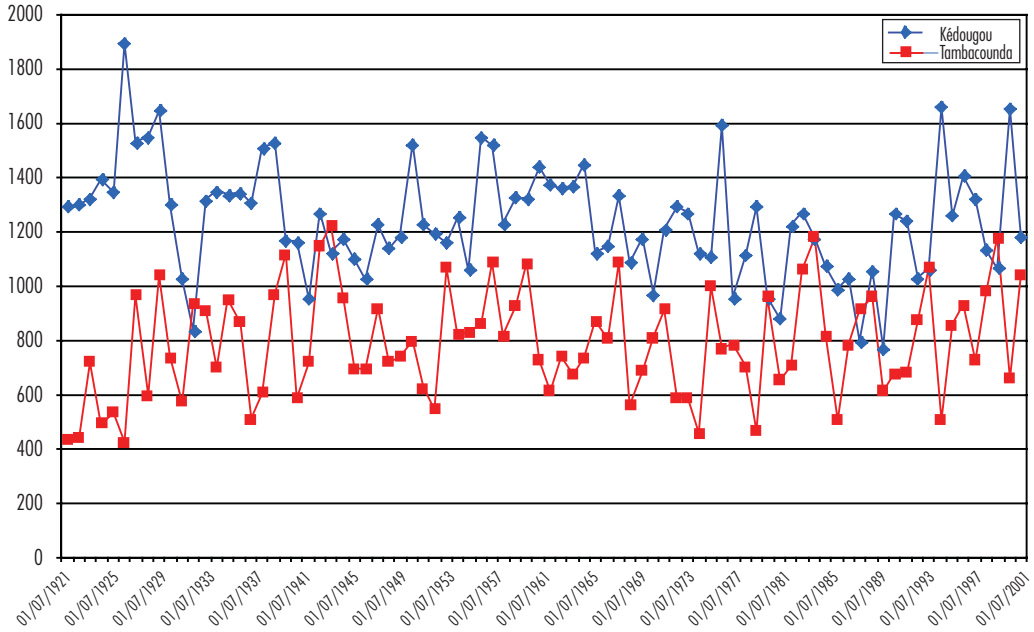

Figure 6.2-2: Inter-annual rainfall for Kedougou and Tambacounda stations, 1950 to 2004

Source: Data from the National Meteorological Services Senegal, redrawn by UNEP

The average temperatures vary between 13-27 °C (55-81 °F). The annual average potential evapotranspiration (PET) is 163 mm (6 in) in Kedougou, and 173 mm (7 in) in Tambacounda. The water balance (rainfall minus PET) is positive in Kedougou during 4 months (June to September), and only 2 months in Tambacounda (August and September).

Soils and vegetation

The topography is the dominant factor of the genesis of soils in the upstream basin of the Gambia River. The climatic and geologic factors also combine to differentiate the soil types, their evolution, and their geographical distribution. The soils of the Gambia River Basin are classified on the basis of several topographic levels, from the valleys and mounds to hillsides and slopes. Particular types of vegetation correspond to these various topographic levels. The dry forest and the woody savanna generally cover the hills, whereas the forest gallery invades riverbanks.

Hydrology

The hydrological regime is of the tropical type of transition, with high tides restricted to 4 months (July to October), and the maximum always occurring in September. Studies of Gambia's hydrological system are based on data from stations controlling the flows at the outlets of the various tributaries. The average flow of the Gambia River at Kedougou station was 76.9 $m^3.s^{-1}$ over the period 1970 to 2004. The Gambia River flow is very seasonal, ranging from 0.308 $m^3.s^{-1}$ in May, to 328 $m^3.s^{-1}$ in September. Saltwater intrusion affects the estuary up to 100 km (62 mi) inland in September and October, and 250 km (155 mi) in May and June. Thus, the monthly and annual variations are very important (Figures 6.2-3 and 6.2-4), with 72 per cent of the flow concentrated during the months of July-October in Kedougou, whereas the figure is 93 per cent in Simenti and Wassadou, upstream and downstream of Kedougou. This figure would be about 97 per cent if the month of November was included.

Hydrogeology

Two aquifers occur in the Gambia Basin, including crystalline rock aquifers and Continental Terminal, occurring on both sides of the Badi – Gamon – Dienoundiala axis. The Continental Terminal aquifer is highly permeable, with a high groundwater potential. The basement rock aquifers contain limited water resources that are not easily exploited.

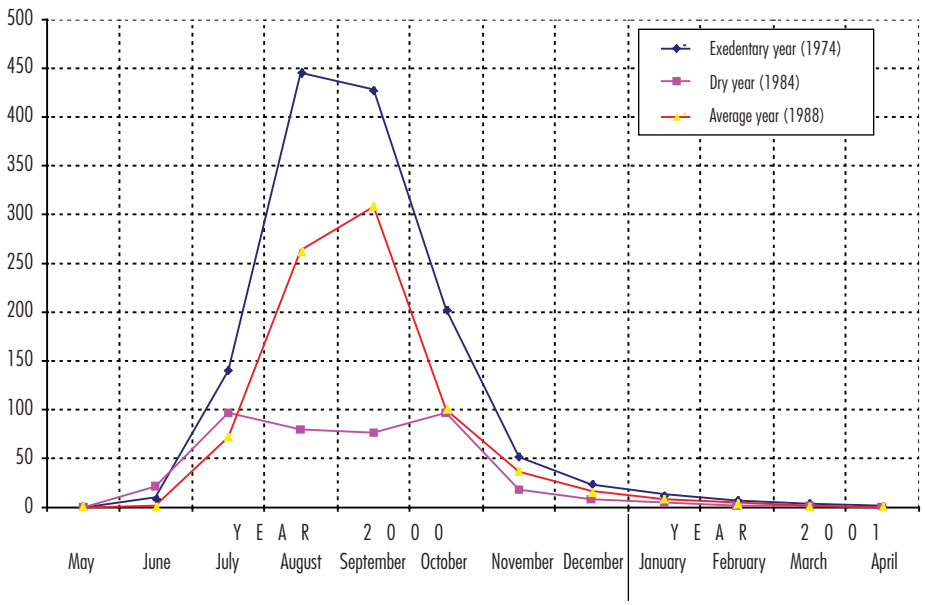

Figure 6.2-3: Monthly average discharge at Kedougou station (1974, 1984 and 1988)

Source: Data from the National Meteorological Services Senegal, redrawn by UNEP

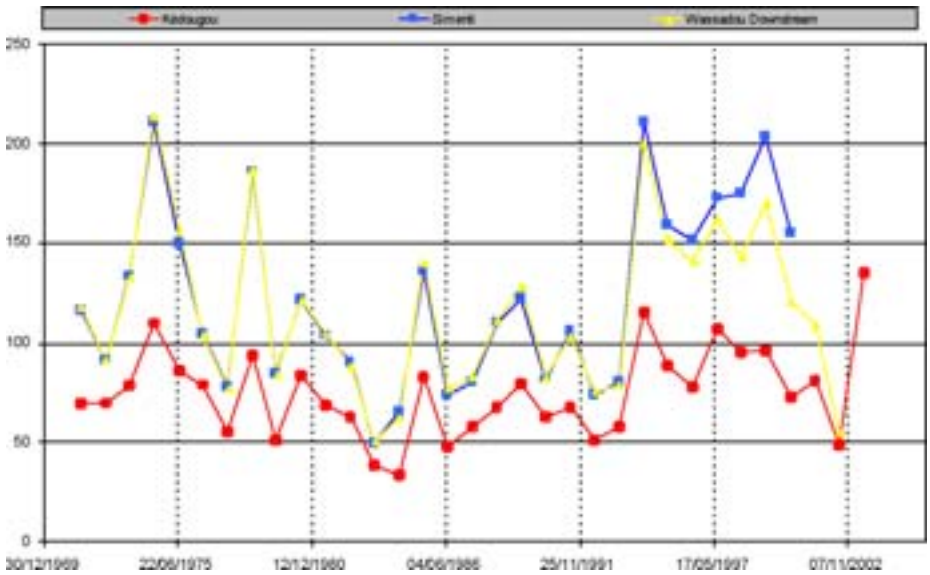

Figure 6.2-4: Inter-annual variation in Gambia River flow (1970-2004)

Source: Data from the National Meteorological Services Senegal, redrawn by UNEP

6.2.2 Socio-economy

Demography

The total basin population was estimated at about 19.9 million inhabitants in 2001, with an annual growth rate of about 2.7 per cent. The population density is about 49 persons.km^{-2} (127 persons.mi^{-2}), varying from 27 persons.km^{-2} (70 persons.mi^{-2}) in Guinea Bissau, to 99 persons.km^{-2} (256 persons.mi^{-2}) in Gambia. In Senegal, the density varies from 2.64 persons.km^{-2} (7 persons.mi^{-2}) in Kedougou, to 19.3 persons.km^{-2} (50 persons.mi^{-2}) in Tambacounda.

Economy

In terms of economic activities, 52 per cent of the basin population is self-employed and unemployed. The unemployment figure is higher, and more significant, for men than for women, although most of the women are classified as housewives, and presumed inactive because their activities are underestimated in the society.

Poverty

The standard of living in the Gambia River Basin reflects the living conditions prevailing in the 4 riparian states. According to the UN HDI, Guinea was classified as 156 out of 177 countries, having an index estimated at 0.425 in 2004, while Senegal was classified as 157 in 2005. About 40.3 per cent of the population in Guinea lives below the poverty line. The percentage of the poor in Senegal decreased between 1994 and 2002 from 67.9 to 57.1 per cent. The severity of poverty varies according to the nature of the settlement – urban or rural. In rural areas, 60 per cent of households and 70 per cent of people live below the basic poverty line.

HIV/AIDS and water-related diseases

The prevalence of AIDS in Senegal was about 1.77 per cent in 1999 (PNLC[7] 2001-2005). The prevalence had decreased to 0.7 per cent of the total population in 2005, due to the effectiveness

[7] Plan National de Lutte Contre le Sida

of preventive programmes. Regarding specific populations (prostitutes; drug addicts; homosexuals), the prevalence rate is 15 per cent according to CNLS[8]. Women are generally more infected than men, having a prevalence of 0.99 per cent, while men have a prevalence of 0.44 per cent. The rates were 2.8, 2.4, and 3.8 per cent for Guinea, Gambia and Guinea Bissau, respectively, according to World Development Indicators (2005).

The most dominant water-related diseases are malaria and onchocercose. Malaria is present in the basin throughout the year, decreasing from north to south due to the rainfall distribution. Malaria claims the lives of 10,000-20,000 people per year in Senegal. Malaria accounts for 36.4 per cent of the causes of morbidity, while diarrhoeal diseases account for 5 per cent in the Tambacounda area.

Access to water and sanitation

Access to water and sanitation evolved positively for a decade, mainly because of implementation of programmes and projects in the rural and urban water sectors. The urban environment is generally is better endowed than the rural environment in regard to infrastructural works. Table 6.2-1 provides some statistics of the 4 riparian countries of the Gambia River Basin, indicating that serious efforts must be made to improve the sanitation facilities in the countries.

Table 6.2-1: Drinking water and sanitation facilities in Gambia River Basin riparian countries in 2004

State	Drinking water			Sanitation facilities		
	Overall access (per cent of total area	Urban area access (per cent)	Rural area access (per cent)	Overall access (per cent of total area)	Urban area access (per cent)	Rural area access (per cent)
Senegal	76	92	60	57	79	34
Guinea	50	78	35	18	31	11
Guinea Bissau	59	79	49	35	57	23
Gambia	82	95	77	53	72	46

Source: WHO/UNICEF (2006)

Water uses

The water resources of the Gambia River are predominantly used for agriculture, although other activities (e.g., fishing) occur in the basin. A hydroelectric generation project is in the study phase (Sambagalou was retained as a site for a future dam).

There are several agricultural products in the basin, the main ones being rice, groundnuts and cotton. The production of cotton, formerly very prosperous, suffered a slight fall, and later stabilized at 18,000 tons (36 million lbs) in 1988. A record production of more than 50,000 tons (100 million lbs) was registered in 2003-2004. The production of the major crops engages the majority of the productive force. Other crops are millet (65,000 tons [130 million lbs] in 1988) and maize (39,000 tons [78 million lbs] in 1988). The potential irrigable land in the basin is estimated to be 93,000 ha (359 mi^2).

[8] Comité National de Lutte contre le Sida

The average annual production of energy at Sambagalou Dam is estimated to be 400 gigawatt hours. The estimated total cost of the hydroelectric development is 228 million Euros, under 2002 economic conditions.

Further, 110 species of fish, belonging to 48 families, were listed in the Gambia River. Mangrove swamps constitute a feeder zone of reproduction for many species.

Water-related conflicts

Conflicts have occurred, especially between farmers and stockbreeders, in connection with the exploitation of low lands and ponds along the Gambia River.

Land tenure

The type of land management varies from one country to another. Land ownership in Senegal, for example, is divided into the three categories of national land, state land, and private land. Although the Constitution guarantees the right of ownership, there can be expropriation for public utility, subject to appropriate compensation. The regulation of state lands in Gambia defines the rules of assignment of the public domain (State Land Regulation) in agriculture. Territorial planning is organized by the Physical Planning and Development Control Act (1990), which envisages national development plans by administrative division and local plans. The land law in Guinea Bissau is in conformity with international standards. Ownership rights on the ground comprise the traditional attributes of the property in Guinea, conferring to its holder the pleasure and use for production of goods and services. Its exercise, however, can be legally limited for public interest reasons.

6.2.3 Management

Institutional and legislative frameworks

The Gambia River Basin Development Organization (OMVG) was created in 1978 by the Republics of Gambia and Senegal. The Republics of Guinea and Guinea Bissau joined the OMVG in 1981 and 1983, respectively. The estimated population of the 4 member states is 19 million. The OMVG, whose mission is to emphasize the Gambia, Kayanga/Géba, Koliba/Corubal and Konkoure River Basins, focuses on the socio-economic integration of member states through achievement of the organization's common programmes and projects. Master plan studies of the hydrological basins carried out within the framework of the OMVG's various programmes have been based on a vision, and a global development approach, that considers the river basin as the planning unit. The OMVG member states are bound by several conventions, including those relating to the statute of the Gambia River, the legal statute of the common works, and the methods of financing of the common works of the OMVG. The OMVG consists of the Conference of the Heads of State and Government; the Council of Ministers, the Executive Secretary, the Standing Committee on Water; and the Consultative Committee.

Data availability, standardization and monitoring

To facilitate and accelerate environmental studies of the basin, it was planned to finalize a project on the creation of a geo-referenced cartographical database, and the OMVG library. The project aims to ensure coordination among the different national policies, and define the criteria that permit harmonization of a data collection network, as well as systems of data processing and dissemination. This project will serve as a vehicle for the exchange of information and experiences among hydrologists and hydrogeologists of different countries, as well as ensuring the training of personnel and hydrologists.

Basic data acquired through the hydrometrical network includes primarily hydrological parameters. A study of the Gambia hydrological system was based on data gathered from the stations controlling flows at outlets of the Gambia River and tributaries.

Only the Gouloumbou station has a long and complete data series, while most stations in the Gambia River Basin have short, incomplete data series. Most of the Gambia stations are logged, enabling assessments of the stations over the period 1970-2000.

6.2.4 Key issues, adaptation and mitigation

Physiography

Climate vulnerability

The basin is prone to climatic variability and change, as its exhibits a wide variation in annual rainfall (500 to 4,500 mm [20-177 in]), and climate changes would result in changes in habitats, ecosystems and food productivity.

Adaptation and mitigation

There is a need:

- For continued, sustained monitoring on climate variability to ensure implementation of appropriate adaptation mechanisms.

Land degradation

Land degradation may become a serious problem because of a high percentage of a young population soon requiring their own agricultural land households.

Adaptation and mitigation

There is a need:

- To involve communities in ecosystem management, with projects directly benefiting them forming an integral part of the management effort.
- To develop guidelines and regulations for better land management.

Socio-economy

Population growth and urbanization

About 60 per cent of the population is below the age of 20 years, posing a great challenge since it increases the pressures on water supply, the need for sanitation facilities, and on land. Urban populations also are bound to increase because of rural-to-urban migration.

Adaptation and mitigation

There is a need:

- To invest more in upgrading and developing infrastructure in both urban and rural areas.
- To implement measures that curb high population growths through community involvement.

HIV/AIDS and water-related diseases

HIV/AIDS, malaria, and onchocercose are potential pandemics that could exacerbate poverty, with the youth and most-productive members of the communities being most at risk.

Adaptation and mitigation

There is a need:

- To increase awareness, community training, and education.
- To implement anti-retroviral and malaria prevention programmes.
- To provide adequate domestic water resources to ensure general hygiene, in order to minimize disease transmission.

Water-related conflicts

There are competing water demands between farmers and stockbreeders, with a potential for possible conflicts.

Adaptation and mitigation

There is a need:

- To institute IWRM by the riparian countries in a coordinated manner, focusing on holistic water use.
- To implement conjunctive water schemes as a way of meeting water demands.

Management

Basin protocols

The OMVG has the responsibility of managing the Gambia River Basin.

Adaptation and mitigation

There is a need:

- To strengthen basin management through capacity-building, including training of staff and provision of necessary equipment.

Data availability, standardization and monitoring

Monitoring and database development, and information sharing, are affected by the frequent breakdown of monitoring equipment.

Adaptation and mitigation

There is a need:

- For a maintenance, repair and replacement programme to ensure continuity in data collection.
- To establish standardized procedures for monitoring and database development, in order to ensure effective information sharing and utilization.

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6.3 KOMADUGU YOBE RIVER BASIN

The Komadugu Yobe Basin (KYB) (Figure 6.3-1), with a total area of approximately 148,000 km^2 (57,143 mi^2) is a transboundary basin. It lies within longitudes 7.63^0 E and 13.57^0 E and latitudes 9.79^0 N and 13.85^0 N. It is shared by Nigeria and Niger Republic, and also is part of the Lake Chad Basin (Section 5.4) which, in turn, is shared with Chad, Cameroon, and Central African Republic. It covers 5 states in the north of Nigeria, including Kano, Jigawa, Bauchi, Yobe, and Borno. The Komadugu Yobe River has its source in the Jos Plateau, and drains these 5 states before running along the Niger and Nigeria Republic boundaries in the Lower Yobe, finally draining into Lake Chad. The main characteristics of the basin are summarized in Box 6.3-1.

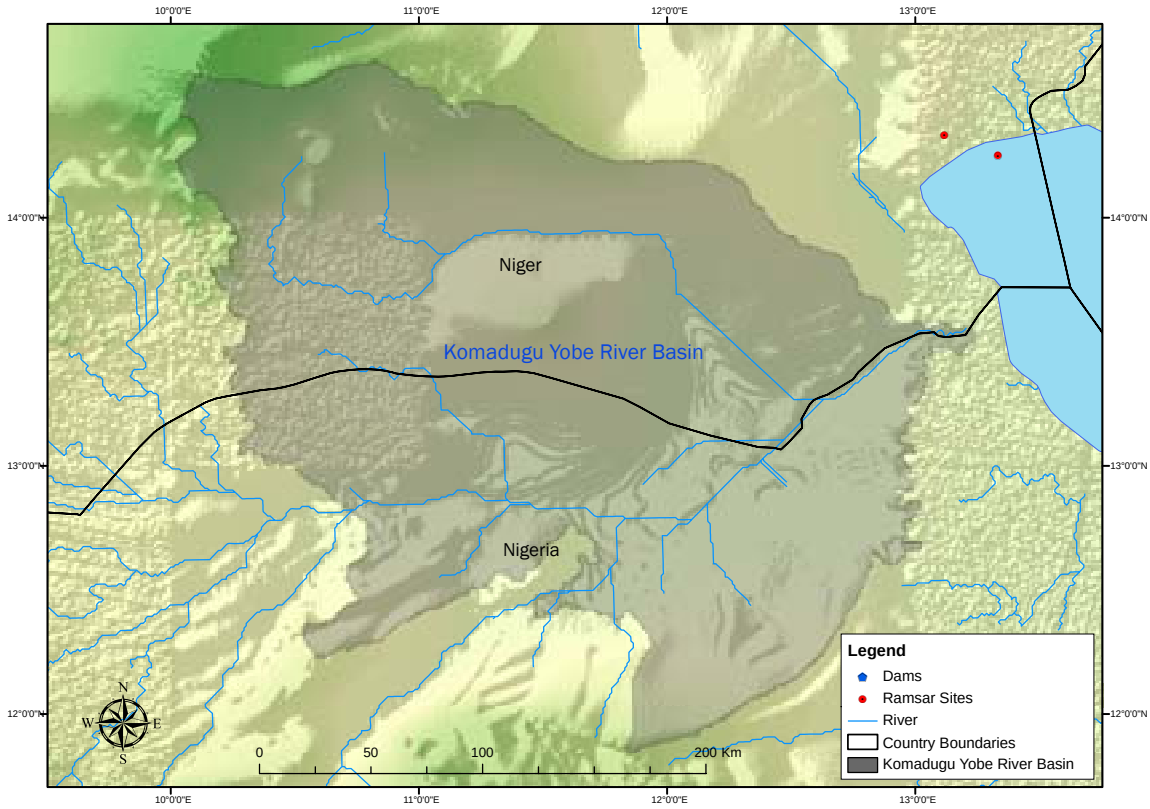

Figure 6.3-1: Komadugu Yobe River Basin

The Komadugu Yobe Basin has strategic national and international importance. It is an area of relatively-dense population in a harsh climatic and edaphic region, where development is increasingly dependent on scarce water resources.

6.3.1 Physiography

Climate

The KYB has a semi-arid climate (Koppen's Aw type), with characteristic wet and dry seasons. Rainfall is the single most important factor controlling the region's hydrology and climate. The region is under the influence of the Inter-Tropical Convergence Zone (ITCZ), which oscillates seasonally between about 15° N and 15° S. North of the ITCZ, the high-pressure belt originating from the Sahara limits the rainfall, except when occasional cold air descends. Rainfall is controlled by the north and south migration of the low-pressure zone formed by the interplay between the moist tropical maritime air mass from the Atlantic, and the dry continental air mass from the Sahara.

Box 6.3-1: Main characteristics of Komadugu Yobe River Basin

Basin

Surface area:	
Hadejia- Jama're:	84,138 km^2 (32,486 mi^2)
Yobe:	146,298 km^2 (56,486 mi^2)
MAP:	300–>1,000 mm.yr^{-1} (12->39 in.yr^{-1})

Water Use

Agriculture
Domestic
Industrial
Forestry
Fisheries

Increasing

Demography

Ecological Uses	
Population:	22 million (UNEP 2004)
Density:	100–5,000 persons.km^{-2} (259-12,950 persons.mi^{-2})

Water Resources

River length:	1,060 km (659 mi)
Rainfall:	1,000 Mm^3.yr^{-1}
Hadejia	1,400 Mm^3.yr^{-1} (at Wudil)
Jama'are	1,881 Mm^3.yr^{-1} (at Bunga)
Yobe	1,147 Mm^3.yr^{-1} (at Gashua)

Vulnerability

Increasing to the north
River flow

Major Dams

Tiga Dam:	1,400,000 Mm^3
Challawa Gorge Dam:	948,000 Mm^3
Hadejia Barrage:	12,000 Mm^3
Total Dam Storage:	2,360,000 Mm^3

Major Aquifer: Alluvial aquifer of the Yobe, with an estimated recharge of 37 million m^3.yr^{-1} along the Yobe River between Gashua and Lake Chad.

The annual rainfall decreases from south to north, in response to the positions of the ITCZ, as well as its duration over the basin. The basin has a prolonged dry season (October–May), corresponding

to the time the ITCZ is to the south of the basin, and a short wet season (June-September), during which the ITCZ is due north of the basin (Griffiths, 1972).

The region also experiences high rainfall variability. The mean annual rainfall occurs from June to October, varying from >1,000 mm (>39 in) in the upstream basement complex area, to about 500 mm (20 in) in the Hadejia-Nguru wetlands, to less than 300 mm (12 in) near Lake Chad (Schultz 1976; Diyam 1987). Figure 6.3-2 illustrates the rainfall regime, and the spatial and temporal variability at 4 representative stations.

Evapotranspiration predominantly accounts for water losses in the Yobe River system, with a small, but significant portion of surface runoff infiltrating and contributing to groundwater replenishment. The evaporation rate for the region is between 20-30 per cent of the available surface water. The mean annual pan evaporation is about 3,000 mm (118 in), decreasing from 432 mm (17 in) in March to about 119 mm (5 in) in the rainy season.

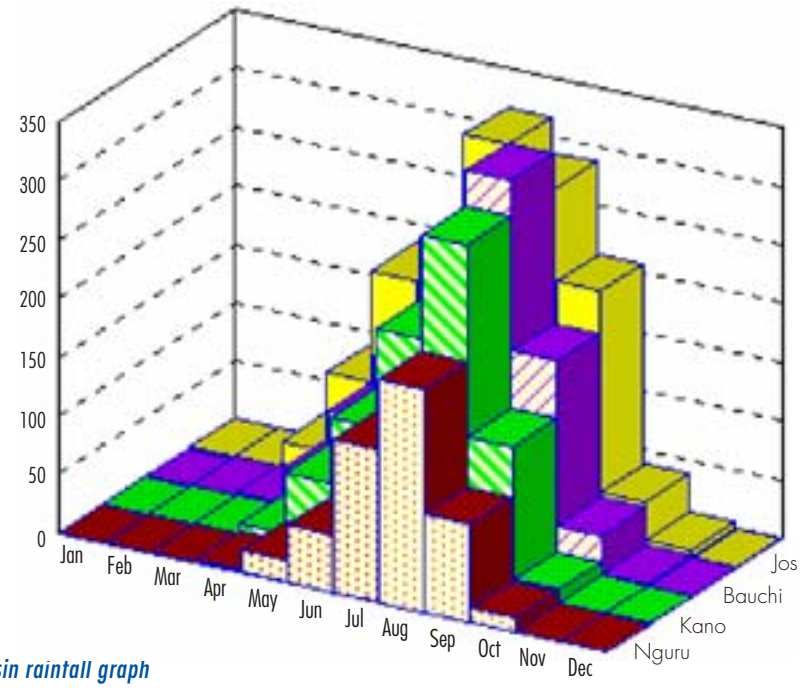

Figure 6.3-2: Yobe Basin raintall graph

Source: Thompson - last updated in 2003

Ecosystems

The wetlands in the centre of the Yobe Basin exhibit a biodiversity of global significance, and are the only Ramsar site in Nigeria. The prolonged drought since the 1970s, coupled with uncoordinated water development, has resulted in a significant reduction of the wetland floods since the 1970s.

Hydrology

The KYB river system contributes less than 2.5 per cent of the total riverine inflow to Lake Chad (UNEP 2004), being its only perennial river system. The Yobe Basin is drained by many rivers (including the Kano, Hadejia and Jama'are/Bunga, and Komadugu Gana), which eventually join to form the Yobe River system that subsequently flows into Lake Chad. The drainage system originates as the Kano and Challawa Rivers, along with their numerous minor tributaries. These two major tributaries meet south of the town of Kano to give rise to the Hadejia, with an annual flow of 1.9 billion m^3 at Wudil. The river cuts the Hadejia valley on a west-east axis. About 24 km (15 mi)

upstream of the town of Gashua, the Hadejia is joined by the Jama'are/Bunga River, which takes its source from the Jos Plateau, a region of relatively high gradient.

6.3.2 Socio-economy

Demography

The current estimated population of the Lake Chad region is approximately 37.2 million people. It has increased by about 11.7 million since 1990. The 1990 population estimate was 25.5 million people (UNEP, 1999), with Nigeria, Africa's most populous country, accounting for 22 million (>86 per cent of the total population living in the region). The population densities are greatest in the areas surrounding Lake Chad, and decrease in the more arid northern provinces.

Economy

The economy of the basin is dominated by subsistence agriculture and livestock, practised mainly by the Hausas and Fulani tribes, respectively. The growing season and number of crops grown per season are dependent on rainfall duration, soil moisture retention, and crop sensitivity to planting dates. Intercropping is practiced, while farm size (including Fadama and other land types) is usually small. The two types of farming practised are: (i) permanent year-round cultivation on the lowland floodplains or Fadama (floodable lands, especially along the edges of the major rivers and their tributaries); and (ii) single-season cultivation on the upland during the wet season, as rain-fed agriculture (locally referred to as 'Tudu').

Poverty

A high proportion of the basin's population falls below the poverty level of US$ 2 per day. The basin's poverty profile has steadily grown worse since the 1980s. The burden of poverty is spread unevenly across regional and socio-economic groups. Single women are among the most vulnerable and impoverished groups, and poverty is more severe in families headed by females than families headed by males.

Access to water and sanitation

Access to safe drinking water in the basin is limited, although the Tiga and Challawa Gorge Dams feed the Kano City Regional Water Supply Project (which supplies the large urban centre of Kano City and the small towns and villages covered by the regional project for domestic and industrial purposes). In the Maiduguri urban centre, however, cases of groundwater abstraction from deep wells for domestic and agricultural purposes have been reported, with a risk of lowering the groundwater level. Alau Dam now serves the needs of the Maiduguri metropolis and its environs. Dadin Kowa Dam caters for the Bauchi urban regional water supply. Nevertheless, Bauchi State has about the lowest access to potable water in Nigeria, with less than 15 per cent being served. Sanitary conditions for rural dwellers are particularly poor, with limited waste disposal facilities. Industrial pollution around Kano industrial city pollutes and deteriorates the water quality, which could result in chronic diseases.

Water use

Water is used for domestic, industrial and agricultural purposes. The domestic water supply is obtained mainly from boreholes and dug wells. Agriculture (flood cropping; recessional farming; large- and small-scale irrigation projects; livestock; fisheries; ecological purposes) is the basin's largest water consumer.

Land tenure and land use

The Hausas, one of the major tribes within the basin, live in relatively small, nucleated settlements, generally concentrated along the rivers, and located on lands usually located above the floodplains. The settlements are normally surrounded by farmlands, linked by a maze of sandy footpaths passable only during the dry season. In contrast, the nomadic Fulanis move from place to place, on the basis of the availability of food and water for their livestock. Trampling by the Fulani herds on Hausa-cultivated agricultural lands has been known to cause ethnic clashes (Udo 1970).

6.3.3 Management

The major water programmes and projects, which involve important basin partners or modify water resources in the KYB, include irrigation and agricultural development, and water supply projects by the 5 states of Nigeria that share the basin, as well as by the 2 river basins and international NGOs. The diverse programmes and projects in the study basin have resulted in fragmented governance and water resources management, with ill-defined and often conflicting responsibilities between government agencies and stakeholders. Lack of coordination between the two Basin Development Authorities in Nigeria (Hadejia-Jama'are River and Lake Chad Basin) illustrates this institutional caveat. The situation is exacerbated by a lack of reliable hydro-meteorological information, since the monitoring network, which used to be effective up to the late-1970s, no longer exists.

Institutional and legislative frameworks

The water resources management legislation in the basin does not enable integrated management of the entire KYB sub-system. However, the Federal Environmental Protection Agency, the National Advisory Council comprising government and non-governmental organizations, as well as the private sector, all contribute to a long-term environmental action plan for the basin.

The poor coordination mechanism, and weakness of the institutional framework, affects the sustainable utilization of the Komadugu-Yobe sub-system water resources. Lack of cooperation between the two river basin development authorities operating in the basin, lack of stakeholder participation, and slow implementation of environmental degradation, are other setbacks to implementation of IWRM efforts in the basin.

Water-related conflicts

One result of uncontrolled water resources development is growing tension between water users and regions, which is already leading to conflicts. Examples are the dogged opposition of the downstream states of Yobe and Borno to the construction of Kafin Zaki Dam, and incessant conflicts between farmers and pastoralists over access to water resources.

Action is underway to address these issues. The Nigerian National Council on Water Resources established a Hadejia-Jama'are-Komadugu Yobe Coordination Committee in 1999. Further, the Lake Chad Basin Commission (LCBC) is implementing a GEF-supported programme for the integrated management of Lake Chad and associated river systems. These activities are complemented by the Komadugu Yobe Integrated Management project that aims to create the institutional environment allowing for participatory and informed decision-making.

Transboundary basin management

At the transboundary level, an agreement between the Federal Republic of Nigeria and the Republic of Niger concerning the equitable sharing in the development, conservation and use of their common water resources was signed in July 1990 at Maiduguri. The purpose was to ensure orderly management of their shared scarce water resources along the common frontier, for the economic and social development of their respective populations living on both sides of the river.

Data availability, standardization and monitoring

A lack of public awareness, poor information sharing, insufficient knowledge of water, and insufficient scientific resources means that monitoring and databases are inadequate for the basin.

6.3.4 Key issues, adaptation and mitigation

Physiography

Climate vulnerability

Rainfall, which constitutes the main water input into the hydrological system in the Sudano-Sahelian Zone (SSZ), is highly seasonal, with its occurrence dictated by the movement of the ITCZ, which is affected by climatic change.

Adaptation and mitigation

There is a need:

- To develop an early warning system for impending droughts.
- To develop and encourage appropriate crops and livestock, and production technologies suitable for drought conditions.

Land degradation

Land degradation is becoming a serious problem and threat to food security in the river basin due to over grazing (mostly from pastoralists), and an increasing population.

Adaptation and mitigation

There is a need:

- To develop legislation, policies and guidelines for holistic land management, and cropping patterns suited for various soil types.
- To involve communities in managing ecosystems, with projects directly benefiting forming an integral part of the management effort.

Socio-economy

Population growth and urbanization

Increased population growth and urbanization, particularly around Kano, are exerting significant pressures on water demands and pollution.

Adaptation and mitigation

There is a need:

- To invest more in upgrading and developing infrastructure in both urban and rural areas.
- To implement measures that curb the adverse effects of high population growth.
- To develop alternative water sources (e.g., groundwater) to meet increasing water demands resulting from population growth.

Water availability, uses and demands

The river basin's water resources are extensively exploited for a variety of uses, including irrigation, livestock and domestic use.

Adaptation and mitigation

There is a need:

- To institute IWRM by the riparian countries in a coordinated manner, focusing on holistic water use, with a balance between all land uses, including efficient irrigation systems, safe drinking-water, water for cattle, and water harvesting.
- For water demand management.
- To develop groundwater resources and implement conjunctive water schemes.
- To institute pollution monitoring and mitigation measures at the basin level, to ensure that no 'precious' water resources are wasted because of pollution

Management

Poor coordination, ineffective use of decision-making tools, inefficient management of existing schemes, and inadequate legislation have been identified as the sources of water management problems in the Komadugo Yobe River Basin.

Adaptation and mitigation

There is a need:

- For a fair, judicious allocation of water resources between competing sectors (irrigation; domestic and industrial; traditional food production systems; ecosystem), and the regions (upstream and downstream states and communities, including south-east Niger).
- To improve communications between the 2 river basin development authorities charged with administration and management of water in the basin (NWRMP 1995).
- To integrate hazard assessment, vulnerability analysis, and enhancement of management capacity.
- To develop integrated management of the land, water and living resources within the basin, in order to promote their sustainable use, conservation and equity of access; IWRM within the basin should involve creation of an enabling institutional environment allowing for participatory and informed decision-making.
- To establish a base for decision-support knowledge so that water management options and other resource management decisions are taken on the basis of up-to-date information.
- To establish a legal, policy-enabling environment for managing vulnerability indicators within the basin, through adoption and implementation of a water charter and supporting basin-level consultation and coordination mechanisms.

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6.4 MANO RIVER BASIN

6.4.1 Physiography

The Mano River Basin is shared by Guinea, Sierra Leone, and Liberia (Figure 6.4-1). Box 6.4-1 summarizes the main characteristics of the Mano River Basin.

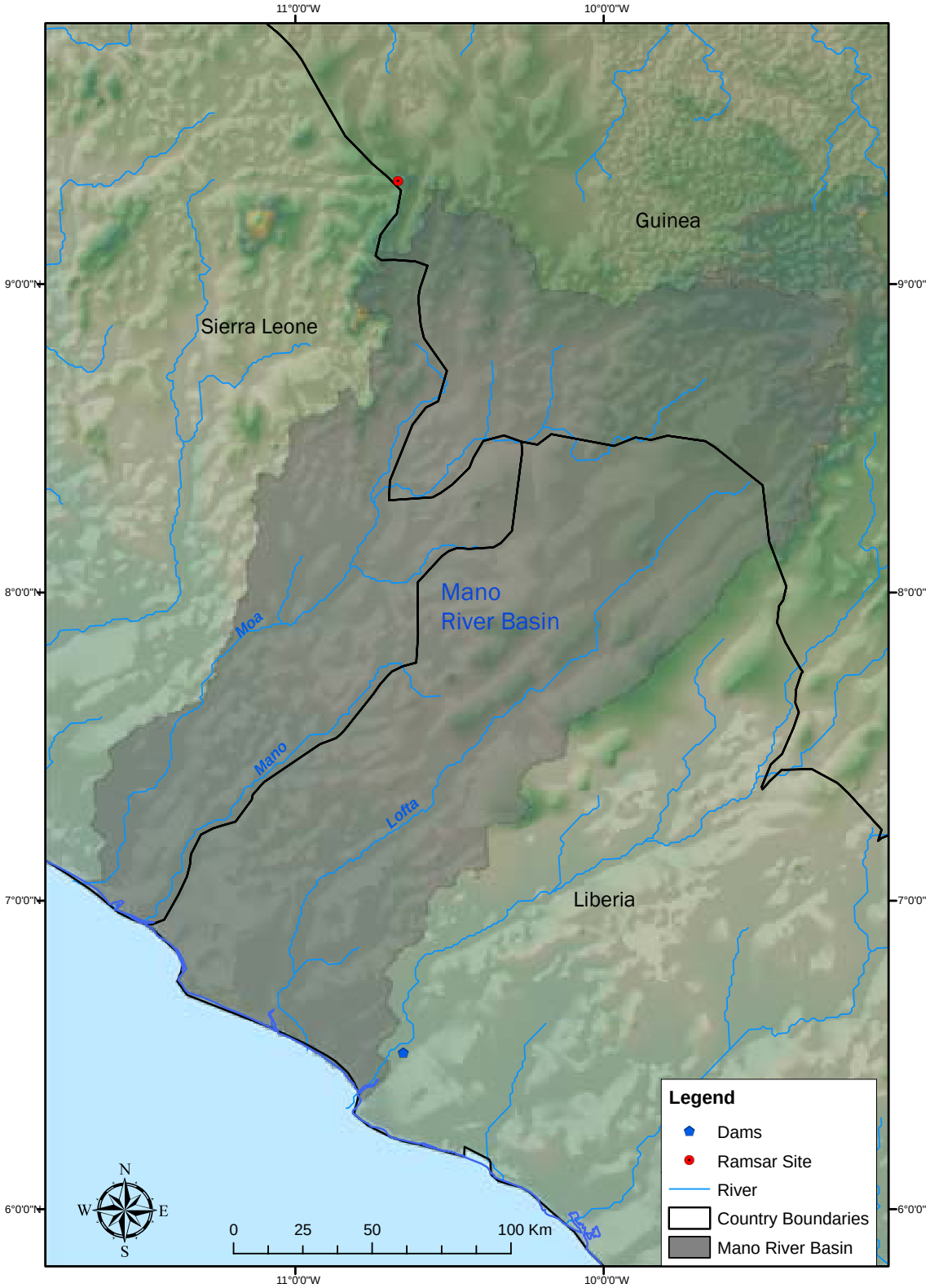

Figure 6.4-1: Mano River Basin

Guinea shares border regions with Guinea Bissau, Senegal, Mali, Ivory Coast, Sierra Leone and Liberia. It is divided into four natural regions as follows:

- Maritime Guinea or Lower Guinea, situated along the Atlantic Ocean;
- Middle Guinea or Fonta-Djalon, of which Mount Loura (1,515 m [941ft] amsl) and Mount Tinka (1,425 m [885 ft] amsl) constitute the highest points;
- Upper guinea savanna region, drained by the Niger River and its tributaries; and
- Forest Guinea, mountainous and largely covered by primary forest that contains precious woods (e.g., mahogany) and ores (e.g., iron).

Box 6.4-1: Main characteristics of Mano River Basin

Basin

Surface area: 8,250 km^2 (3,185 mi^2)

MAP: 1,600 mm.yr^{-1} (63 in.yr^{-1})

Water Use

Mining

Domestic

Agriculture

Demography

Population: Guinée - 9,500,000; Libéria - 3,300,000 ; Sierra Léone - 5,500,000

Density: Guinée 33; Libéria 45; Sierra Léone 37 persons.km^{-2} (85, 117 and 96 persons.mi^{-2}, respectively)

Water Resources

River length: 320 km (199 mi)

Vulnerability

High throughout the basin

Major Dams

No major dams

Sierra Leone and Liberia are situated on the coast of the Atlantic Ocean. Mount Nimba (1,513 m [4,964 ft]) is Liberia's highest point, in a mountain range shared with Guinea.

The Mano River (also called Gbeyar River) has its source in the upper Guinean lands (Upper Guinea). With its tributary (Moro River), the Mano River forms about 145 km (91 mi) of frontier between Liberia and Sierra Leone.

Climate

The Mano River Basin is situated between the Sudanian Zone (Guinea) and Equatorial Zone (Liberia, Sierra Leone). The temperatures are generally high, being about 22 °C (72 °F) for the coldest month (January for Guinea; August for Sierra Leone; October for Liberia). The average annual rainfall in Liberia is about 5,588 mm (18 in).

6.4.2 Socio-economy

Population, urbanization and economic activities

The population of the 3 riparian states of the Mano River Basin is growing rapidly. Figure 6.4-2 illustrates the population growth over the past 5 years, and projections for 2015 and 2025. The population densities of the various states are given in Table 6.4-1.

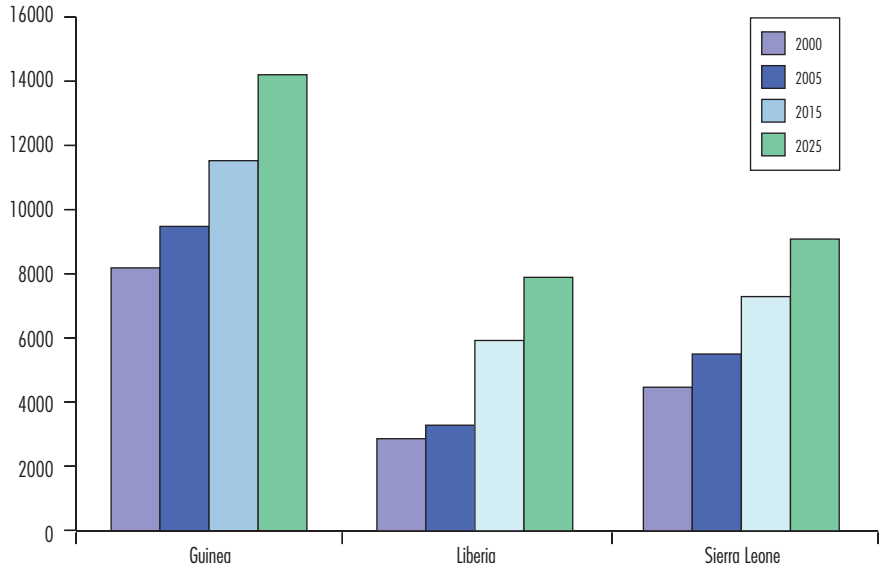

Figure 6.4-2: Population (thousands of people) of Guinea, Liberia and Sierra Leone

Source: Data www.atlas-frncophone.refer.org, redrawn by UNEP

Table 6.4-1: Population density in Mano River Basin

Country	Density (persons.km^{-1}) [persons.mi^{-2}]	Urban population (per cent)
Guinea	33 [85]	38
Liberia	45 [117]	30
Sierra Leone	37 [96]	77

The population is generally young, with more than 40 per cent being in the 0-15 year age range (Table 6.4-2). The diversified ethnic (rather than religious) composition of the river basin population is a source of perpetual conflict.

Table 6.4-2: Population age distribution in Mano River Basin

Country	Population in specific age groups (per cent)		
	0-14	**15-59**	**60+**
Guinea	44.1	51.5	4.4
Liberia	42.7	52.8	4.5
Sierra Leone	44.2	51	4.8

Table 6.4-3 highlights some demographical and socio-economic data for the 3 riparian states of Mano River Basin. The average life expectancy in the 3 states is 43 years for men, and 45 years for women. The average birth and mortality rates are 47 per cent and 21 per cent, respectively, with the average fertility rate being 6 children per woman. The educational level is generally very low, with 36 per cent being registered in Guinea, 44 per cent in Liberia, and 30 per cent in Sierra Leone.

Table 6.4-3: Socio-economic data for riparian states of Mano River Basin (mid-2005 estimation)

Country	Average life expectancy (yrs)		Taux			
	Men	Female	Birth rate (per cent)	Mortality rate (per cent)	Fertility rate (children/ woman)	Level of education (per cent)
Guinea	48	50	43	18	5.9	36
Liberia	41	43	50	22	6.8	44
Sierra Leone	39	42	47	24	6.5	30

Source: http://www.atlas-francophone.refer.org

The economic activities in the Mano River Basin revolve around mining, mainly diamonds, which has been a source of continuous conflict in the region since the late-1980s. Unemployment is very high in the region, giving rise to possibilities of violence.

HIV/AIDS and water-related diseases

The prevalence rate of HIV/AIDS for the adult population in 1997-1998 ranged between 7-85 per cent, based on a world development indicator of the World Bank.

Water-related diseases are those generally encountered in western African, with a high prevalence of malaria.

Access to water and sanitation

The coverage of drinking water in the major part of the basin is about 50 per cent. The exception is Sierra Leone, with an access rate of only 37 per cent. Urban areas generally exhibit better coverage than rural areas. The reverse is true in Guinea, where the urban and rural coverage is 50 and 56 per cent, respectively. The sanitation situation in the urban areas is generally considered satisfactory, while that in the rural areas is very low.

Water-related conflicts

The Mano River Basin lies within a violent conflict zone. According to 'Country Indicators for Foreign Policy' (CIPF 2000), Guinea, Liberia, and Sierra Leone exhibit a high prevalence of violent conflicts and political instability. Efforts are being made to bring peace and stability to the region.

6.4.3 Management

The Union of the Mano River (UFM), established to be responsible for managing the basin, has lately been exclusively in charge of managing the regional conflicts.

Basic data on the Mano River Basin are almost non-existent, primarily because of the violent conflicts in the region.

6.4.4 Key issues, adaptation and mitigation

Physiography

Climate vulnerability
The basin might have abundant rainfall but is prone to climatic change, which could result in habitat and ecosystem changes, impacting on food productivity.

Adaptation and mitigation

There is a need:
- For continued, sustained monitoring on climate variability, in order to ensure implementation of appropriate adaptation mechanisms.

Land degradation
Land degradation may become a serious problem in the basin because of the high percentage of the young population, which will soon require its own agricultural land as this group leads its own households.

Adaptation and mitigation

There is a need:
- To develop standardized legislation, policies and guidelines for holistic land management, and cropping patterns suited to various soil types.
- To involve communities in managing ecosystems, with projects that directly benefit them forming an integral part of the management effort.

Socio-economy

Population growth and urbanization
About 40 per cent of the population is below the age of 15 years, posing a great challenge since it increases the pressures on water supply, and the need for sanitation facilities and land. Urban populations also are certain increase because of a rural-to-urban migration as people look for work. The unemployment rate is currently very high which, when combined with the 40 per cent of the population being young, could worsen the situation.

Adaptation and mitigation

There is a need:
- To invest more in upgrading and developing infrastructure in both urban and rural areas.
- To implement measures curbing high population growth rates through community involvement.
- To invest in education and entrepreneurial skills in order to enhance employment, thereby reducing poverty levels.

HIV/AIDS and water-related diseases
HIV/AIDS and malaria are potential pandemics that could exacerbate the poverty situation. The youth and the most productive community members are most at risk.

Adaptation and mitigation

There is a need:
- To create awareness, community training and education.
- To implement anti-retroviral and malaria prevention programmes.
- To provide adequate domestic water resources to ensure general hygiene and minimize disease transmission.

Water demands
Although there might presently be adequate water resources to meet demands, they must be safeguarded for future generations.

Adaptation and mitigation

There is a need:
- To institute IWRM by all the riparian countries in a coordinated manner that also ensures both water quantity and quality are preserved, as well as the basin's other natural resources.

Management

Basin protocols

The Union of the Mano River (UMF) has the responsibility of managing the Mano River Basin but has been involved in conflict management at the expense of basin management over the last couple of years.

Adaptation and mitigation

There is a need:
- To establish a conflict resolution and management unit, so that UFM can concentrate on basin management.
- To strengthen basin management through capacity-building (e.g., training of staff; provision of necessary equipment), thereby requiring the commitment of all riparian countries.

Data availability, standardization and monitoring
Monitoring and database development, and information sharing, are virtually non-existent because of the perpetual conflicts in the region.

Adaptation and mitigation

There is a need:
- To involve local communities in basic data collection.
- To use remote sensing techniques to bridge data gaps.

6.4.5 References

http://www.atla-francophone.refer.org

6.5 NIGER RIVER BASIN

The Niger River Basin covers 2.27 million km² (876,452 mi²), with the active drainage area comprising less than 50 per cent of the total basin area. The Niger is 4,200 km (2,610 mi) long, being the third longest river in Africa, and the world's ninth-largest river system (Figure 6.5-1). The basin is shared among 10 countries, including Nigeria (27 per cent), Mali (26 per cent), Niger (24 per cent), Algeria (8 per cent), and Benin, Burkina Faso, Cameroon, Chad, Cote d'Ivoire and Guinea (each <5 per cent). The Niger River Basin is generally considered to be one of the two river basins (with the Volta) that are most affected by freshwater shortages. The basin's main characteristics are summarised in Box 6.5-1.

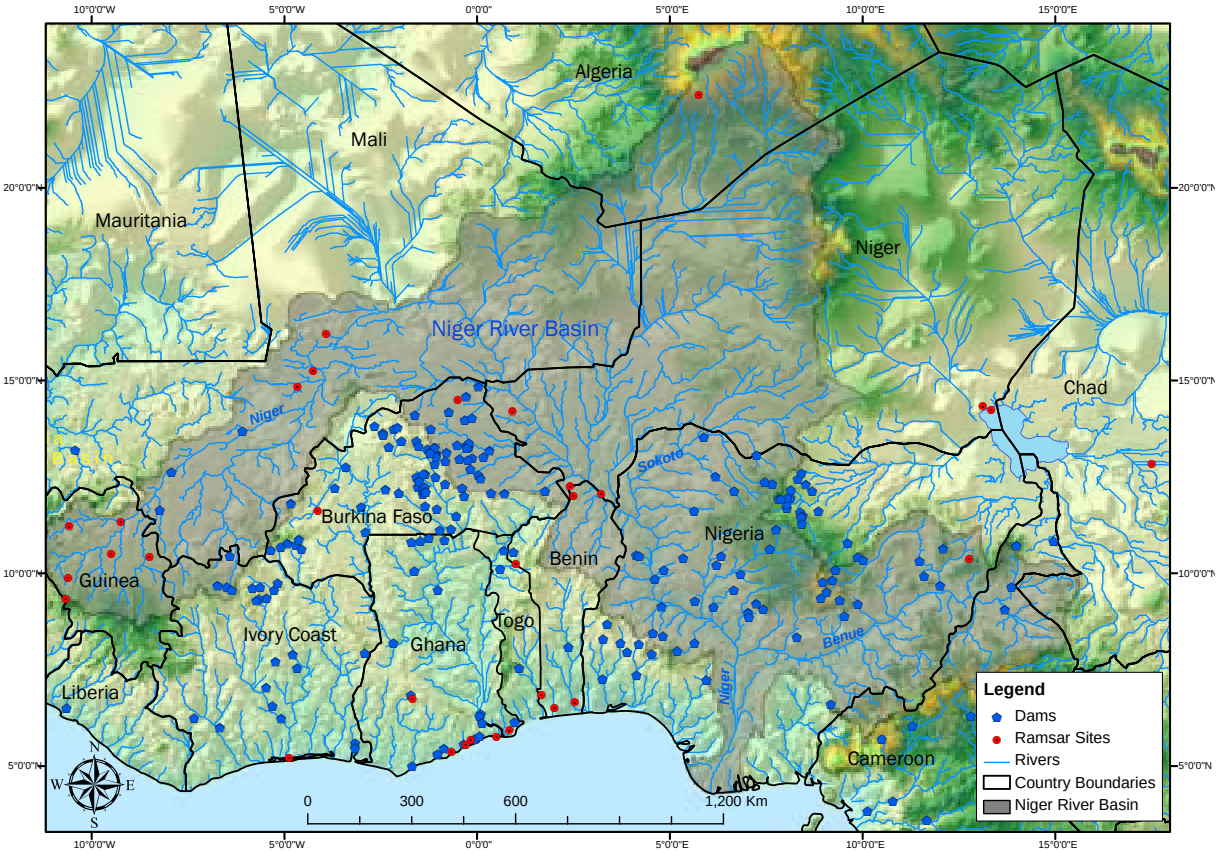

Figure 6.5-1: Niger River Basin

Box 6.5-1: Main characteristics of Niger River Basin

Basin

Surface area:	2,270,000 km^2 (876,452 mi^2)
MAP:	690 mm.yr^{-1} (27 in.yr^{-1})

Demography

Population:	106 million
Density:	31 persons.km^{-2} (80 persons.mi^{-2})

Water Resources

River length:	4,200 km (2,610 mi)
MAR:	221,500 Mm^3.yr^{-1}

Major Aquifers: Sedimentary and basement

Vulnerability: Increasing all over the basin

Water Use

Agriculture
Domestic
Hydropower

Increasing

Major Dams (million m^3)

Dadin Kowa:	2,765
Selingue:	2,200
Kanji:	1,500
Goronyo:	1,100
Jebba:	3,800
Shiroro:	7,000

6.5.1 Physiography

For the past 3 decades, the Sahel area, in which the largest part of the Niger Basin is located, has experienced a persistent drought, resulting in a drastic decline in rainfall, and a southward shift of rainfall zones by ~100 km (62 mi).

The main environmental impacts resulting from the diminishing rainfall and related reduced streamflows are:

- Reduced vegetation cover and changes in riparian habitats;
- Decreased wetlands areas (present coverage is 4.1 per cent);
- Increased soil erosion and siltation;
- Water quality changes, due to reduced dilution capacity; and
- Deterioration of faunal habitats, depletion of fish stocks, and reduced species diversity.

Climate

The Niger River Basin experiences 2 main seasons, a wet and dry season. These seasons are controlled by 2 air masses; namely, the northeast trade winds and southwest trade winds. The northeast trade winds (the Harmattan), which blow from the interior of the continent, are dry. In contrast, the southwest trade winds (the monsoons) are moist, since they blow over the sea. The inter-phase of these two air masses is called the Inter-Tropical Convergence Zone (ITCZ). The ITCZ region is associated with significant convective activity, and the region receives a considerable quantity of rainfall. The ITCZ moves northwards and southwards across the basin from about March to October, when the region receives rainfall. The length of each season varies from place-to-place, depending on the duration of each air mass.

Hydrology

Based on hydrological and ecological diversity, 4 main sub-regions (or drainage areas) can be distinguished, including the Upper Niger, Inner Delta, Middle Niger, and Lower Niger:

The Upper Niger (upstream) extends over 140,000 km^2 (54,054 mi^2) from its source in Guinea, to Ke-Macina in Mali. Its 3 main tributaries are the Tinkisso, Milo, and Niandan Rivers. Before the river enters the Inner Delta in Mali, at the southern edge of the Sahara Desert, its flow averages 45 million km^3.yr^{-1}. The only significant control structure is the Selingue Dam on the Sankarani River, a tributary of the Niger. This single-purpose dam (hydropower) regulates approximately 5 per cent of the upstream flows. A significant decrease in the intensity of high flows has been observed since the 1970s.

The Inner Delta is a vast inland delta in Mali, covering an area of 80,000 km^2 (30,888 mi^2) from Ke-Macina to Timbuktu. It comprises complex and geographically-extensive systems of rivers, lakes and floodplains that have undergone significant development. Some lakes (Debo; Horo) are classified as Ramsar protected sites, being important water bird habitats. The delta size is subject to seasonal and annual variations, depending on inflows from the Upper Niger and Bani Rivers. The inundated area has decreased by 63 per cent, from 35,000 km^2 (13,514 mi^2) in 1967, to 9,500 km^2 (3,668 mi^2) in 1984. This area has an important role in regulating the river flow. Only 50 per cent of the average annual inflow of 70 billion m^3 reaches Timbuktu. The peak discharge of 6 000 m^3.s^{-1} at Koulikoro (Upper Niger) in September has not only been reduced by 75 per cent, to 2,350 m^3.s^{-1}, but has also been delayed by 2-3 months (December-January).

The Middle Niger covers 900,000 km^2 (347,492 mi^2) in Mali, Niger, and Benin, being composed of a series of irrigated terraces. Upstream of the Niger Republic, the river receives inflows from Burkina Faso tributaries. Hydrologic monitoring, dating back to 1923, reveals that water flows in the Middle Niger are significantly affected by water flows from the Inner Delta. The mean annual flow at Niamey between 1971-2000 was one-third less than the flows between 1929-1970, resulting in earlier, shorter floods.

The Lower Niger at the downstream end is located in the humid zones of Nigeria. It has a catchment area of 450,000 km^2 (173,746 mi^2), receiving water from the major tributaries of the Sokoto, Kaduna, and Benue Rivers. Average runoff downstream of the Kainji and Jebba Dams is 1,454 m^3.s^{-1} and 5,590 m^3.s^{-1} after the confluence with the Benue River. Although the Benue contributes 50 per cent of the Niger River flow, the hydrologic significance across the basin is low, since it only flows through one country before joining the Niger River. Between 1929 and 1970, the annual average runoff was 6,055 m^3.s^{-1}, equivalent to almost 200 billion m^3.yr^{-1}, compared to 5,066 m^3.s^{-1} between 1971 and 2000, equivalent to a reduced runoff of almost 20 per cent.

An overview of major developments in the Niger River Basin in terms of hydropower generation and irrigation is presented in Table 6.5-1.

Table 6.5-1: Major developments in Niger River Basin (after Mott MacDonald, 1992)

Development	River	Country	Type	Remarks
Selilingue Dam	Sankarani	Mali	Multi-purpose	2,000 ha (8 mi^2) irrigation/44
Markala Lagdo	Benue	Cameroon	Irrigation	megawatts hydropower
Dam	Sokoto	Nigeria	Irrigation	60,000 ha (232 mi^2)
Goronyo	Sokoto	Nigeria	Irrigation	33,000 ha (127 mi^2)
Bakolori Dam	Niger	Nigeria	Hydropower	450 million m^3 reservoir
Kanji	Niger	Nigeria	Hydropower	760 megawatts
Jebba	Chanchanga	Nigeria	Hydropower	500 megawatts
Shiroro	Gongola	Nigeria	Irrigation	300 megawatts
Kiri	Gongola	Nigeria	Irrigation	325 million m^3 reservoir
Dadin Kowa	Niger	Nigeria	Irrigation	2,765 million m^3 reservoir
Tungan Kawo				22 million m^3 reservoir/ 800 ha (3 mi^2)
Under construction: Omi	Kampe	Nigeria	Irrigation	6,000 ha (23 mi^2)
Under Investigation:	Niandan	Guinea	Multi-purpose	Hydropower
Fomi	Niger	Niger /	Multi-purpose	83,000 ha (23 mi^2) irrigation, >2.5
Tossaye		Mali /		km^3 reservoir, 30-40 megawatts
	Niger	Burkina	Multi-purpose	Irrigation / hydropower
Kandaji	Kaduna	Faso	Hydropower	950 megawatts
Zunguru	Benue	Niger	Hydropower	600 megawatts
Makurdi	Niger	Nigeria	Hydropower	1,950 megawatts
Lokoja	Niger	Nigeria	Hydropower	750 megawatts
Onitsha		Nigeria		
		Nigeria		

The basin has experienced a continued reduction in renewable water resources, due to both natural (drought) and human-induced changes. The latter includes over-exploitation of water resources (including inefficient water storage in large reservoirs with high evaporative losses and over-abstraction of groundwater resources) and land-use changes (including deforestation). The predominance of dry years with persistent droughts over the past 3 decades has led to:

- A 40 per cent decrease in the average annual flows of the Niger River between 1907-1973 and 1974-1994 (NBA-HydroNiger);
- Decreased groundwater levels in alluvial aquifers, resulting in lower base flows, reduced groundwater recharge, and decreased aquifer storage; and
- Reduced river sediment transport capability, degradation and erosion of slopes and riverbanks, and increased siltation, this situation being further aggravated by increasing pressures from people and animals.

A major issue in the coastal area is modification of streamflows (increased or decreased stream and river discharges) as a result of human interventions on a local- or regional-scale. Modification of stream flows through damming, for example, has changed the occurrence of exceptional discharges and, to a lesser extent, the inter-annual salinity of estuaries or coastal lagoons, and the position of the estuarine mixing zone.

While Nigeria benefits from being a major oil-producing nation, with an average crude oil production of two million barrels per day, a major concern is the environmental damage caused by frequent oil spills during the production and distribution processes. Between 1976 to 1998, 5,724 spillage incidents led to 2.57 million barrels of oil being spilled in the Niger Delta (Nwilo and Badejo, 2003). These spills destroyed aquatic life and biodiversity, degraded fertile soils, and polluted drinking water, as well as fermenting political unrest.

6.5.2 Socio-economy

Population, urbanization and economic activities

The total population of the Niger River Basin was over 106 million in 2000, with an average density of 31 people.km^{-2} (80 persons.mi^{-2}) The degree of urbanization in western Africa is expected to reach 65 per cent by 2025, and individuals living in rural areas will have to produce sufficient food to meet their own needs, as well as the needs of the growing urban population. Thus, crop yields will have to increase through intensified farming, and expansion of irrigated areas, both situations placing further pressures on freshwater resources. The Global Water Partnership (GWP 2000) estimates that per capita water consumption will be 100 L.d^{-1} in cities, and 50 L.d^{-1} in rural areas, by 2025.

- From a socio-economic perspective, the combined effects of increased water shortages, water stresses, and urbanization are expected to result in:
- Reduced future land-use options (loss of land for agriculture), and reduced agricultural productivity;
- Losses of hydroelectric power production, and increased costs of alternative water supplies;
- Increased losses relating to water supply and, consequently, greater health risks; and
- Increased costs for protecting the health of human and animal populations.

Poverty

Excepting Nigeria, the Niger Basin countries are some of the poorest in the world, and have underdeveloped economies with GNP per capita of US$ 855 or less. The average annual growth rates are in the range of –0.3 to 3 per cent of GNP.capita^{-1}, highlighting the low performance of the region's economies. Mali has the highest proportion of population below the poverty line (estimated to be 64 per cent in 2001), followed by Burkina Faso (44.5 per cent). The average GNP.capita^{-1} is US$ 500. The per capita GDP growth rates are lower in all countries than the GDP growth rates, reflecting the effects of a rapidly-growing population. Nigeria is a promising economy, with landmark achievements in various sectors. Unemployment is very high in the region, creating discontent, with a strong inclination to violence and violent conflicts especially in the oil-rich region of the Niger Delta in Nigeria.

Water-related conflicts

Freshwater shortages have also begun to trigger major human migrations, with far-reaching transboundary implications. Future freshwater shortages also may trigger upstream-downstream water-related conflicts between different user groups.

6.5.3 Management

The Niger River Basin has a poor legal framework at both regional and national levels. It also is characterized by inadequate implementation of available regulatory instruments. A basin institution,

Autorité du Bassin du Fleuve Niger (ABN), has been established by the riparian countries to manage the basin's water resources. The institutional framework for the water sector in each country is created by the ministry in charge of water resources.

There is a pressing need to modify environmental laws and regulations in Nigeria to address oil spillage problems in the Niger Delta, consistent with the 'polluter-pays' principle.

6.5.4 Key issues, adaptation and mitigation

Physiography

Climate vulnerability

The Niger River Basin is experiencing periodic and sustained droughts related to climatic change and vulnerability, resulting in water scarcity for agriculture, hydroelectric power generation, and domestic purposes. Climate change and variability predictions suggest an aggravation of this situation, with decreased rainfall, runoff and recharge, especially in large parts of the river basin.

Adaptation and mitigation

There is a need:

- To develop mechanisms or systems to provide information on the season's rainfall patterns and quantities, and to advise water users to adapt appropriately.
- To develop and encourage appropriate crops and livestock, and production technologies suitable for drought and reduced water conditions.
- To record and evaluate indigenous knowledge in regard to adaptation to climate variability, and to develop appropriate adaptation mechanisms.

Land degradation

Land degradation is a serious problem, since forests are being cleared to make way for agricultural land. Deforestation also is causing erosion and siltation.

Adaptation and mitigation

There is a need:

- To develop standardized legislation, policies and guidelines for holistic land management, and cropping patterns suited to various soil types.
- To involve communities in managing ecosystems, with projects that directly benefit them forming an integral part of management efforts.

Socio-economy

Population growth and urbanization

Increased population growth and urbanization are exerting significant pressures on water supply, in regard to water demands and pollution. A greater proportion of the population is under the age of 15 years, and will eventually need land, water supplies, and employment to make a living. Urban populations are increasing because of rural-to-urban migration, with emigration also resulting in the loss of skilled manpower.

Adaptation and mitigation

There is a need:

- To invest more in upgrading and developing infrastructure in both urban and rural areas.
- To implement measures to curb high population growths.
- To invest in education and entrepreneurial skills to enhance employment opportunities, thereby reducing poverty levels.

Water availability, uses and demands

Although there is an acute water shortage in the basin, water demands are increasing. The water is used for agricultural (corn, rice, millet, sorghum) and domestic water supply, and hydroelectric power generation.

Adaptation and mitigation

There is a need:

- To institute IWRM by all riparian countries in a coordinated manner, focusing on holistic water use, with a balance between all land uses, including plantations, efficient irrigation systems, safe drinking-water, water for cattle, and water harvesting.
- For water demand management.
- For coordinated development of groundwater resources and conjunctive water schemes.
- To institute pollution monitoring and mitigation measures at the basin level to ensure no 'precious' water resources are wasted because of pollution, and utilizing the 'polluter pay' principle.

Management

Institutional and legal frameworks

The basin's institutional management is very weak. The ABN is charged with managing the basin's water resources, although individual countries have their own mechanisms for managing water resources in their own parts of the basin through government departments and ministries. There is no appropriate legislation for effectively managing the basin's water resources.

Adaptation and mitigation

There is a need:

- To strengthen and broaden the mandate of the ABN in managing basin's natural resources.
- To address land management by developing basin policies.
- To develop and adopt appropriate legislation to ensure effective development and management of the basin's natural resources.

Data availability, standardization and monitoring

Monitoring and databases are country-specific. Information sharing is non-existent.

Adaptation and mitigation

There is a need:

- To establish standardized procedures for monitoring and for database development, in order to ensure effective information-sharing and utilization, which should be done through the ABN.

6.5.5 References

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6.6 SENEGAL RIVER BASIN

The Senegal River, with a length of 1,800 km (1,118 mi), originates in the Fouta-Djalon Mountains in Guinea, and provides water to the semi-arid parts of Mali, Senegal and Mauritania. The Senegal River Basin (Figure 6.6-1) has a total area of 300,000 km^2 (115,831 mi^2). Mali has the largest area of the basin (53 per cent) followed by Mauritania (26 per cent), Guinea (11 per cent), and Senegal (10 per cent). The basin can be divided into 3 distinct parts, including: (i) upper basin (a mountainous area between Fouta Djallon and Bakel); (ii) valley (with a flood plain varying in width between 10-20 km [6-12 mi] between Bakel and Dagana); and (iii) delta, between Dagana and the sea. The topographical, hydrographical and climatic conditions are very different in these 3 regions. Box 6.6-1 summarizes the main basin characteristics.

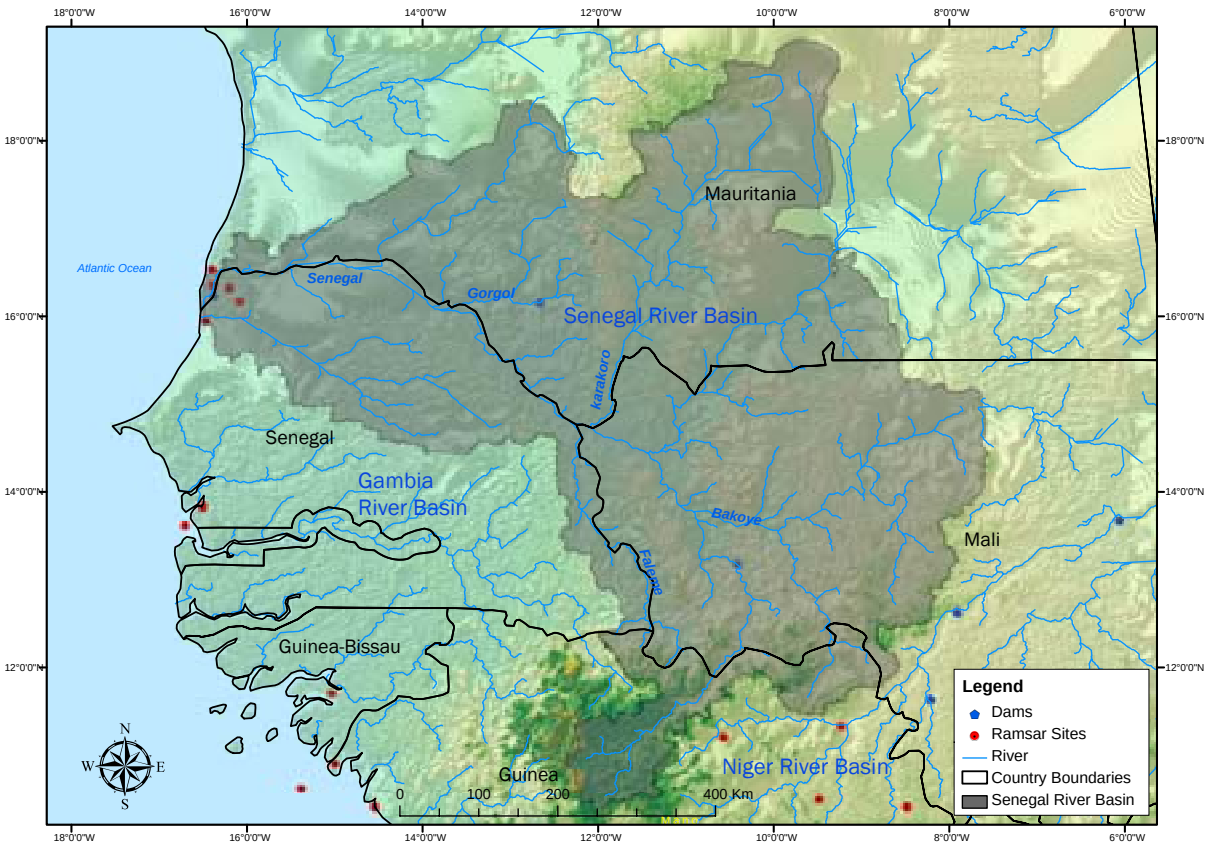

Figure 6.6-1: Senegal River Basin

Box 6.6-1: Main characteristics of Senegal River Basin

Basin		**Water Use**	Increasing
Surface area:	300,000 km^2 (115,831 mi^2)	Agriculture	
MAP:	660 mm.yr^{-1} (26 in.yr^{-1})	Domestic	
		Industry	
Demography		Hydropower	
Population:	3.5 million		
Density:	40 persons.km^{-2} (104 persons.mi^{-2})		
Water Resources		**Major Dams**	
River length:	1,800 km (1,118 mi)	Diama (limits seawater intrusion)	
MAR:	21,760 Mm^3.yr^{-1} (Bakel Station)	Manatali: hydroelectric – 12,000 Mm^3	
Major Aquifers:	Sedimentary	**Vulnerability**: Increasing to the north	

6.6.1 Physiography

Climate

The climatic regime in the basin can be divided into three seasons, including a rainy season (June-September), a cold, dry off-season (October-February), and a hot, dry off-season (March-June). This pattern creates a high-water period or flood stage in the river between July-October, and a low-water period between November-May to June.

The river's flow regime, for the most part, depends on precipitation in the upper basin in Guinea (~2 000 mm.yr^{-1} [79 in.yr^{-1}]). Precipitation is generally low in the valley and delta, rarely being more than 500 mm.yr^{-1} (20 in.yr^{-1}). Since the 1970s, the 400 mm (16 in) isohyets shifted southward over a distance of ~100 km (62 mi), thereby jeopardizing rainfed agriculture (see Figure 6.6-2). The evaporation ranges between 7-8 mm.d^{-1} (0.28-0.31 in.d^{-1}) whereas the annual average evaporation is about 3,000 mm (118 in).

Figure 6.6-2: Southward shift of isohyets in Senegal River Basin

Source: LeBorgne-IRD-Cartographie: www.bondy.ird.fr/carto/SenegalFIG/secheresse.htm

Ecosystems

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The environment of the river basin continues to exhibit critical ecological importance, as illustrated by the existence of a large number of ecological sites of national and regional interest. The National Park of the Birds of Djoudj belongs to the 830 sites of the cultural and natural inheritance of the world with a universal value. The basin also has two Reserves of Biosphere - Reserve of the Loop of Baoulé and the Transboundary Reserve of Senegal Delta (between Senegal and Mauritania). They form part of the 480 reserves identified in the world within the framework of UNESCO's Man and Biosphere (MAB) Programme. The Senegal River Basin contains 5 Ramsar sites, all concentrated in the delta of the Djoudj, Ndiael, and Gueubeul Rivers, on the left bank (Senegal), and Diawling and Chat Tboul on the right bank (Mauritania).

Hydrology

The 3 main tributaries of the Senegal River produce over 80 per cent of its flow. The Bafing River alone contributes about half of the river's flow at Bakel. The 2 largest tributaries on the right bank above Bakel, the Gorgol and Oued Gharfa Rivers, supply only 3 per cent of the water in the Senegal River flowing into the Atlantic Ocean at Saint Louis. For the reference station on the Senegal River at Bakel, the average annual discharge is about 690 $m^3.s^{-1}$, corresponding to an annual discharge of about 22 billion m^3. It ranges from a minimum of 6.9 billion m^3, to a maximum of 41.5 billion m^3. Table 6.6.1 illustrates Senegal River discharge data for different periods. The table highlights the benefit of the Manantali Dam in regulating flows, with the discharge having never fallen below 200 $m^3.s^{-1}$ since the construction of the dam in 1991.

Table 6.6.1: Seasonal changes in Senegal River discharge since 1951

Period	Rainy season ($m^3.s^{-1}$)	Dry season ($m^3.s^{-1}$)
1951–1999	1, 538	138
1951–1971	2, 247	172
1972–1990	993	71
1991–1999	1, 036	201

Source: OMVS

The total capacity of the Manantali Dam on the Bafing River (the largest in the basin) is 11.5 billion m^3, of which about 8 billion m^3 can be easily accessed. Its purpose is to attenuate extreme floods, generate electric power, and store water during the wet season to augment dry-season flows for the benefit of irrigation and navigation. The Diama Dam, located 23 km (14 mi) from Saint Louis, near the mouth of the Senegal River in the delta, sits astride the territories of Mauritania and Senegal. Its threefold purpose is to: (i) block seawater intrusion, thereby protecting existing or future water, and irrigation wells; (ii) raise the level of the upstream waterbody, creating reserves to enable irrigation and double-cropping of approximately 42,000 ha (162 mi^2), and (iii) facilitate the filling of Guiers Lake in Senegal, and Lake Rkiz and the Aftout-es-Saheli depression in Mauritania.

Hydrogeology

The alluvial aquifer is the principal shallow aquifer. It is present in the whole floodplain at various depths, generally less than 2 m (6.6 ft), with an average thickness of about 25 m (82 ft). This aquifer is in hydraulic continuity in some places with a discontinuous network of lenticular aquifers in the permeable strata, interceded in the alluvium. These aquifers are recharged by the river and tributaries, distributaries, ponds and lakes in the flood plain. Deep aquifers are represented by the Maestrichian fossil formation, and Continental Terminal formation.

Aridity and water availability

The Senegal River Basin has been experiencing a long-lasting drought for the past 30 years. The decreased precipitation has led to a corresponding decreased river flow. A 20 per cent decrease in rainfall, for example, resulted in a 40 per cent decrease in available water resources. The drought has reduced rainfed agriculture, decreased seasonal flooding of wetlands, limited economic development, and increased overall poverty. The key hydrological changes occurring in the basin are closely linked to displacement of the isohyets to the south, and to increased evapotranspiration.

6.6.2 Socio-economy

Demography

The Senegal River basin has a total population of around 3.5 million inhabitants, 85 per cent of whom live near the river. The basin population is increasing at an annual rate of about 3 per cent, which is slightly higher than the individual averages for the 3 riparian states. The basin population also is characterized by a large ethnic diversity, including, among others, the Peuls, Toucouleurs, Soninkes, Malinkes, Bambaras, Wolofs, and Moors tribes. There is massive emigration among the young, however, toward the major cities, and to Europe. The financial support received from these emigrants is very important for the livelihood of families remaining in the villages, especially during drought and flood periods. Some of these emigrants return to their villages during the rainy period for seasonal work.

Economy

Colonialists identified the enormous socio-economic potential of the Senegal River Basin long ago, with some resources already being developed long before the countries gained their independence in the 1960s. Table 6.6-2 summarizes the socio-economicdata in the OMVS (Organisation pour la Mise en Valeur du Fleuve Sénégal; see Management 6.6.3) member states. Irrigated agriculture, especially rice growing, has expanded rapidly, mainly because of water from constructed dams. Planned exploitation of the basin's irrigation potential of 375,000 ha (1,448 mi^2) for irrigation, including 240,000 ha (927 mi^2) in Senegal, 120,000 ha (463 mi^2) in Mauritania, and 9,000 ha (35 mi^2) in Mali. Agricultural productivity is relatively low, with total production satisfying only a small portion of the national requirements (e.g., 30 per cent for Mauritania; 15 per cent for Senegal).

Table 6.6-2: Summary of socio-economic data in OMVS member states

	Senegal River Basin	Mali	Mauritania	Senegal
Population (million inhabitants)	3.5	11	3	10
Annual growth rate (per cent)	3	2.97	2.9	2.8
Urbanization rate (per cent)	NA	41	53	51
Farmland (ha) [mi^2]	923,000 [3,564 mi^2]	NA	NA	NA
Irrigated area – national part in basin	NA	78,630 4,000	49,200 44,449	71,400 67,830
Cattle (x1,000 units)	2,700	6,427	1,394	2,927
Sheep and goats (x1,000 units)	4,500	15,986	10,850	8,330
Fish catch (t.yr^{-1}) [lbs. yr^{-1}]	26,000-47,000 [58.2 million-105 million lbs)	100,000 [224 million lbs]	620,000 [1.4 billion]	395,000 [874 million lbs]

Source: OMVS

Livestock breeding is also a major economic activity in the basin. The border, and more remote, populations practise transhumance. The OMVS estimates the livestock concentration in the basin to be more tan 2.7 million bovines and 4.8 million sheep. Concerted efforts are being made to promote intensive livestock breeding.

Fishing is a significant economic activity for the populations living near the riverbanks in the valley and the delta, near the storage lake of Diama Dam, and especially Manantali Dam. There has been a continuous decline of the tonnage of fish catches in the basin for some years. According to the OMVS, the level of catch varies between 26,000-47,000 $t.yr^{-1}$ (58.2-105 million $lbs.yr^{-1}$).

Other important economic activities include the sugar company, which exploits more than 8,000 ha (31 mi^2) of sugar canes. The hydroelectric power plant at Manantali Dam has been in operation since September 2001. The initial objectives of the project were to produce 200 megawatts of electricity, and furnishing an average of 800 $GW.h^{-1}.yr^{-1}$ to electricity companies in the 3 OMVS member states.

Water demands and water use for food production

Flood-recession agricultural yields may be limited by water, availability of plant nutrients, plant diseases, and pests (e.g., insects; birds). Limited water supply or nutrient availability result in a low plant density. Nutrient availability may have been influenced by changing inundation patterns, and the reduced deposition of mud on the floodplain following construction of the Manatali Dam. The inundated area has been considerably reduced since the early-1970s and, in combination with a considerable increase in the valley's population, has meant that flood-recession agriculture can no longer ensure sustainable food production for local markets. In regard to irrigated agriculture, rice cultivation is based on large mineral fertilizer inputs, with reduced inputs leading immediately to decreasing crop yields.

The study by Rasmussen et al (1999) has clearly demonstrated the importance of hydrological information for assessing agricultural development options in the Senegal River Valley. The peak river flow has a direct impact on the potential for flood-recession agriculture, whereas river discharge has a much smaller impact on irrigated agriculture. Economic and management factors appear to be more critical.

6.6.3 Management

Institutional framework

Proper river basin management requires a hierarchy of institutions at different levels. In the case of the Senegal River Basin, these include institutions at the village, national and transboundary levels. The interests of institutions at different levels are likely to be in conflict with each other (Rasmussen et al, 1999). Managing the water resources of the Senegal River has caused controversy between the involved countries, and between various stakeholder groups. Conflicts of interests have been associated with hydroelectric power production, allocation of, and access to, water for irrigation and domestic supplies, modern and traditional agricultural water requirements, and conservation of wetland ecosystems and the wider environment.

To overcome these conflicting interests, OMVS (a supra-national authority) was established to decide waters allocation and dam management principles within the river basin. Mali, Mauritania

and Senegal, and recently Guinea, are OMVS members. The organization has created a flexible, functional legal framework that enables collaboration and co-management of the basin. The OMVS functions with the following management bodies:

- Permanent bodies
  - Conference of Heads of State and Government;
  - Council of Ministers;
  - High Commission (executive body);
  - Permanent Water Commission (representatives of member states) that defines principles of, and procedures for, allotment of Senegal River water between member states and use sectors; it also advises the Council of Ministers.
- Non-permanent bodies
  - An OMVS national coordination committee in each member state.

Data availability, standardization and monitoring

Because of a discharge-monitoring network established in 1904, OMVS has abundant quantitative data, with updated records stored in a database of the OMVS High Commission. The Technical Department of the High Commission also publishes a monthly hydrological bulletin as a technical service for the member states and other actors (producers, development partners, NGOs, industrial projects) carrying out activities in the basin. The High Commission established an Observatory of the Environment in November 2000, to create a network of producers and possessors of thematic data, linking them to a general database managed by the Observatory's Coordination Bureau. Agreement protocols will soon be prepared by these organizations, and the OMVS, to formally define the roles and responsibilities of each actor in data collection, processing, storage, and dissemination.

6.6.4 Key issues, adaptation and mitigation

Physiography

Climate vulnerability

The Senegal River Basin experiences periodic droughts, due to climate change and vulnerability, which has resulted in reduced rainfed agriculture.

Adaptation and mitigation

There is a need:

- To develop an early warning system to provide information on the seasonal precipitation patterns and quantities, and to advise water users to adapt accordingly.
- To develop and encourage appropriate crops and livestock, and production technologies suitable for drought and reduced water conditions.

Land degradation

Land degradation is linked to a growing population, and the need for more agricultural land, being a potential problem and threat to food security in the river basin.

Adaptation and mitigation

There is a need:

- To develop standardized legislation, policies and guidelines for holistic land management, and cropping patterns suited for various soil types.
- To involve communities in managing ecosystem projects, with those directly benefiting them forming an integral part of the management efforts.

Degradation of ecosystems

The flood plain ecosystems have been most affected by dam construction. In less than 10 years, environmental degradation, and its consequences on the health of the local population, has been spectacular. The OMVS began to collaborate with the World Bank in 1997 to develop a GEF project for the Senegal River Basin, focused on establishing a viable integrated resources management strategy for water, biodiversity and environment. The transboundary diagnostic analysis completed in 2006 provided some recommendations to mitigate environmental degradation.

Adaptation and mitigation

There is a need:

- To act on the mode of the river, while trying to recreate a system with characteristics similar to natural conditions as much as possible, in addition to the mechanical methods used to address aquatic weeds in the delta by national authorities, and with the support of local populations.
- To have a reliable system of water quality control (e.g., through a network of suitably-equipped laboratories); it is planned to use appropriate legal instruments to implement suitable measures to more effectively combat water pollution.

Socio-economy

Population growth and urbanization

Increased population growth and urbanization is exerting pressures on water supply, in regard to both water demands and pollution. The construction of dams created unexpected environmental, social and economical problems, partly resulting in violent conflicts.

Adaptation and mitigation

There is a need:

- To invest more in upgrading and developing infrastructure in urban and rural areas.
- To implement measures that curb high population growth.
- To invest in education and entrepreneurial skills to enhance employment opportunities, thereby reducing poverty levels.

Water availability, use and demand

There is a high demand for water for domestic water supplies, irrigation and hydropower generation, against a backdrop of dwindling water supplies. The OMVS is presently attempting to re-define medium- and long-term development strategies for the entire basin, linking development with integrated, sustainable management. The Senegal River Water Charter, and the initiation of environmental monitoring by the Observatory, represent golden opportunities to increase the involvement of representatives of various stakeholders in the management decision-making process.

Adaptation and mitigation

There is a need:

- To reinforce a participatory approach, by launching a master plan in the near future.
- For coordinated development of groundwater resources and conjunctive water schemes.
- To institute pollution monitoring and mitigation measures at the basin level to ensure that no 'precious' water resources are wasted because of pollution.

Management

Institutional framework

OMVS is mandated with managing the river basin.

Adaptation and mitigation

There is a need:

- To strengthen the OMVS, through capacity-building
- To cover land management through developing basin policies.

Data availability, standardization and monitoring

Monitoring methodology and databases have been, and are being established.

Adaptation and mitigation

There is a need:

- To establish standardized procedures for monitoring and database development, in order to ensure effective information-sharing and utilization.

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6.7 VOLTA RIVER BASIN

6.7.1 Physiography

The Volta River Basin covers an estimated area of more than 400,000 km^2 (154,441 mi^2). It stretches from approximately latitude 5° 30′ N in Ghana, to 14° 30′ N in Mali. The widest stretch is from approximately longitude 5° 30′ W to 2° 00′ E, although the basin becomes narrower towards the Gulf of Guinea coast. The Volta Basin spreads over 6 western African countries, with 43 per cent being in Burkina Faso, 42 per cent in Ghana, and 15 per cent each in Togo, Benin, Cote d'Ivoire and Mali; Figure 6.7-1). The main characteristics of the basin are summarized in Box 6.7-1.

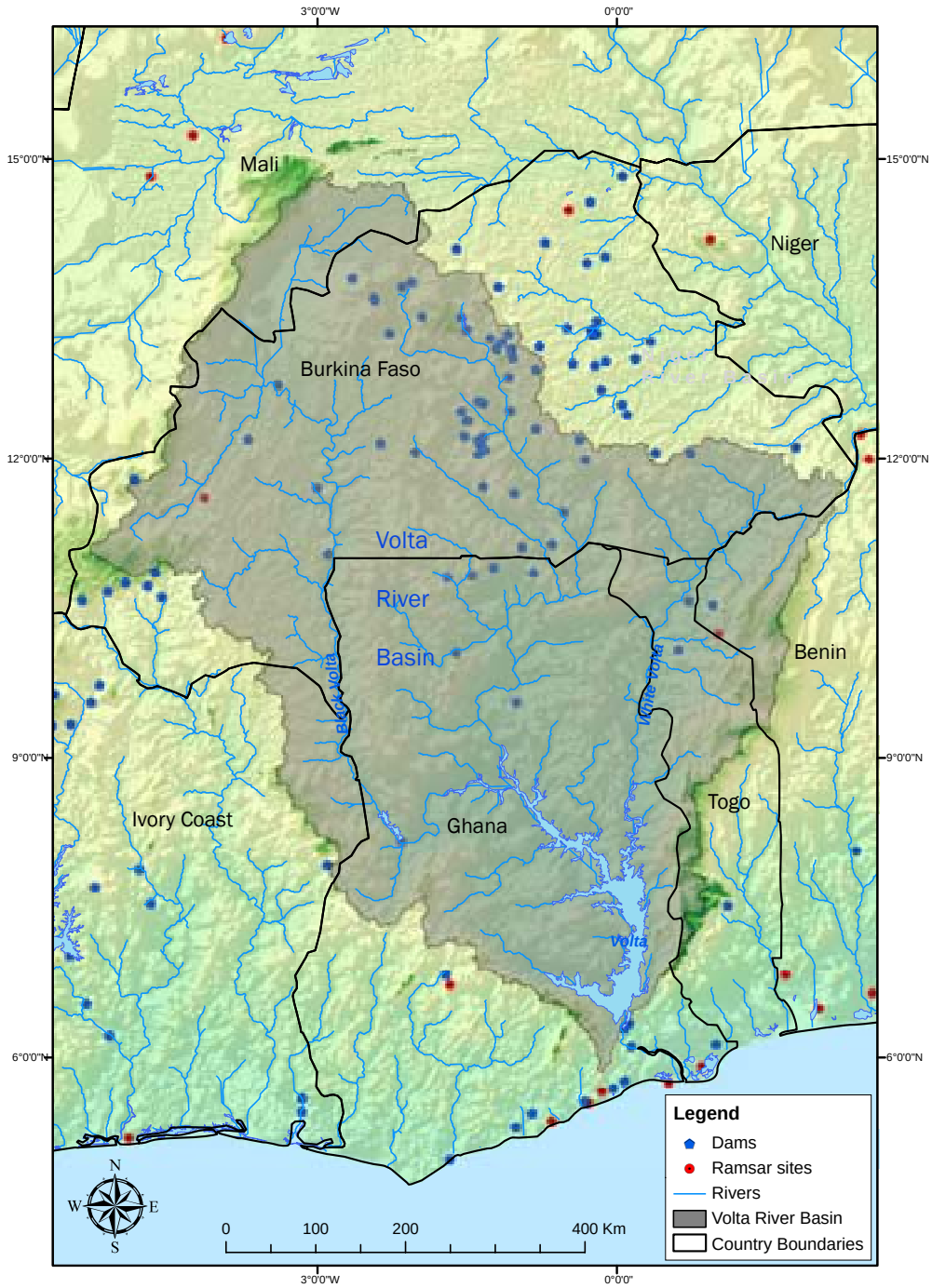

Figure 6.7-1: Volta River Basin

Box 6.7-1: Main Characteristics of Volta River Basin

Basin Volta

Surface area:	417,382 km^2 (161,152 mi^2)
MAP:	360-1,600 mm.yr-1 (14-63 in.yr^{-1})
Relief:	up to 972 m (3,189 ft) amsl
Evaporation:	1,400-3,015 mm.yr^{-1} (55-119 in.yr^{-1})

Water Use

Agriculture
Domestic
Hydropower
Industrial
Mining
Tourism

Increasing

Demography

Population:	18.64 million (2000)
Density:	8–104 persons.km^{-2} (21-269 persons.mi^{-2})
Average Density:	48.5 persons.km^{-2} (126 persons.mi^{-2})
Average Growth Rate:	2.54 per cent per annum

Water Resources:

River length:	8,242.8 km (5,122 mi)
Average Total Rainfall Volume:	500 km^3
Average Flow:	38,295 million m^3.s^{-1}
Tributaries/Sub Basin:	White Volta, Black Volta and Oti

Vulnerability: (Increasing to north) Increasing temperature, decreasing precipitation. (Increasing to south) deforestation and desertification

Major Dams:

600-1,400 dams and lakes

Akosombo:	512 megawatts
Kpong Dam:	548 megawatts
Benin Republic:	350 Mm^3 (15 megawatts)

As shown in Table 6.7-1, the relative proportion of the basin area found within a specific country does not necessarily reflect its relative importance in that country. While a country may contain only a small percentage of the total basin area within its borders, as in the case of Togo, this area might comprise a significant proportion of the entire country. Further, the area of a country within the basin might hold an abundance of natural resources, relative to the entire country, as is the case with Mali, Burkina Faso, Ghana and Togo.

Table 6.7-1: Distribution of Volta River Basin in its six riparian countries.

Country	Area of Volta River Basin (km^2)[mi^2]	Per cent of basin	Per cent of country in the basin
Benin	17,098 [6,602]	4.10	15.2
Burkina Faso	178,000 [68,726]	42.65	63.0
Côte d'Ivoire	12,500 [4,826]	2.99	3.9
Mali	15,392 [5,943]	3.69	1.2
Togo	26,700 [10,309]	6.40	47.3
Ghana	167,692 [64,746]	40.18	70.0
Total	417,382 [161,152]	**100.00**	

Source: Figures from respective national reports; (Andreini et al. 2000; UNEP 2001)

The basin generally exhibits a low relief, with altitudes ranging between 1-920 m (3.3-3,018 ft). The average mean altitude is approximately 257 m (843 ft), with more than half the basin in the range of 200–300 m (656-984 ft). The global slope index is between 25-50 $cm.km^{-2}$ (25-51 $in.mi^{-2}$). The basin is flanked by a mountain chain on its western section; and the Akwapim Ranges rise from the sea and the northeast, followed by the Togo Mountain, Fazao Mountain, and the Atakora ranges in Benin, and the Kwahu plateau which branches northwest after the Akosombo Gorge. The only other significant relief on the western part of the basin is the plateau of Banfora.

Climate

The climate of the region is controlled by 2 air masses, including the northeast and southwest trade winds. The northeast trade winds (the Harmattan), blowing from the interior of the continent, are dry. In contrast, the southwest trade winds (the monsoons) are moist since they blow over the seas. The interphase of these 2 air masses is called the Inter-Tropical Convergence Zone (ITCZ). This zone is associated with significant convective activity and, therefore, the region receives a considerable quantity of precipitation. The ITCZ moves northwards and southwards across the basin from March to October, when the region receives precipitation.

The average annual rainfall varies across the basin, ranging from approximately 1,600 mm (63 in) in the southeast in Ghana, to about 360 mm (14 in) in the northern part of Burkina Faso. The contribution of each riparian country to the total basin rainfall (Figure 6.7-2) highlights another aspect of this spatial variability. Further, as noted by Opoku-Ankomah (2000), some sub-catchments in the basin have undergone a number of changes in their precipitation patterns and distribution, as reduced rainfall and runoff has become evident since the 1970s. Some areas that used to have a bimodal precipitation pattern now exhibit only one mode, with the second minor season having become very weak or nonexistent. Thus, rainfed agriculture can only be carried out once, instead of twice, a year, except where water has been stored in dams.

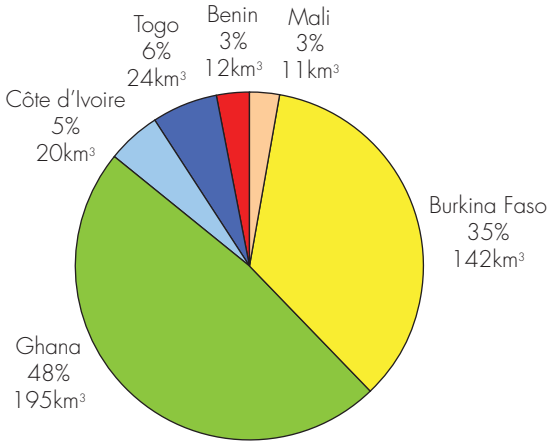

Figure 6.7-2: Volta Basin Rainfall

Source: Barry et al. 2000, redrawn by UNEP

Hydrology

The Volta Basin is drained by several major rivers, including the Black Volta, White Volta with the Red Volta as its tributary, Oti and Lower Volta River. The mean annual flows of the Black Volta, White Volta, and Oti River are 7.673 million, 19.565 million, and 11.215 million m^3, respectively Ministry of Works & Housing, 1998).

Because of its regularization by the Kompienga Dam in Burkina Faso, the Oti River is perennial, with an annual average flow ranging between 100-300 $m.s^{-1}$, with the ability to reach 500 $m^3.s^{-1}$. All virtually all the tributaries stop flowing during the dry season; their annual average flows are around 5 $m^3.s^{-1}$. In Ghana, the Black Volta, White Volta and Oti Rivers join the main Volta River at Volta Lake, which was created by the Akosombo Dam (Barry et al. 2000). The damming of the Volta River at Akosombo has created one of the largest man-made lakes in the world, covering an area of approximately 8,500 km^2 (3,282 mi^2).

6.7.2 Socio-economy

Population density and growth

The population in the Volta River Basin is generally rural (64-88 per cent), with the people largely dependent for their livelihoods on the exploitation of the natural resources, which may not be environmentally-sustainable in the future. The total basin population is expected to grow significantly, from an estimated 18.6 million in 2000, to 33.9 million in 2025, an expected 80 per cent increase over a 25-year period. This high growth rate is due to the high average population growth rate (2.54 per cent) in the basin. The geographic distribution of the population within the basin is highly variable, with a density ranging between 8-104 $persons.km^{-2}$ (21-269 $persons.mi^{-2}$). High population densities (e.g., Ghana's upper east regions) result in great pressures on land and water resources in some areas. Areas with low population densities generally are either national parks (e.g., Comoe, in Cote d'Ivoire, one of the largest western African national parks), or regions where *onchocerciasis* or river blindness is prevalent (e.g., valleys of the Black Volta River).

Economy

Economic activities in the basin are very similar in all the countries, including crop production, livestock breeding, fishing, logging, agro-industry, transportation, and tourism. These activities can be grouped under agriculture, industry, manufacturing, and services.

The riparian countries of the Volta River Basin are some of the poorest in the world, with underdeveloped economies having a per capita GNP of US$ 755 or less (WARM 1997). The average annual growth rates range between 0.3-2.7 per cent of GNP.capita^{-1} also illustrate the low performance of the region's economies. Mali has the highest percentage of the population below the poverty line of 64 per cent in 2001, being 44.5 per cent in Burkina Faso in 1997, and Ghana recording the least in 1992 (34.1 per cent). Côte d'Ivoire has the highest GNP in the region, being US$ 710 per capita, while Mali is ranked lowest at only US$ 190. The average GNP.capita^{-1} is US$ 372, making the region one of the poorest in the world. The per capita GDP growth rates are lower than GDP growth rates in all countries, reflecting the effects of a fast-growing population, the difference being widest in Togo with the fastest growing population.

Water demands and water uses

Projections for water demands are based on population growth, and the activities envisaged to be carried out under the country's development plans. Table 6.7-2 summarizes the water demands for the Volta River Basin.

Table 6.7-2: Water demands of Volta River Basin (million m^3)

Country	1990			2000			2010			2020		
	D/I	I	L	D/I	I	L	D/I	I	L	D/I	I	L
Benin	56	152	40	196	548	94	336	1,225	133	448	1,225	133
Burkina Faso	67	43	37	85	203	46	106	384	61	132	384	61
Côte d'Ivoire	-	19	1	4	57	2	5	166	3	12	166	3
Ghana	82	75	18	138	565	26	192	1,871	41	272	1,871	41
Mali	5	126	4	9	180	37	13	219	74	16	219	74
Togo	51	43	15	68	50	19	92	91	22	123	91	22
Total	261	458	115	500	1,603	224	744	3,956	334	1,003	3,956	334

D/I= Domestic/Industrial; I = Irrigation L= Livestock

Source: Compiled from country reports; WARM 1997; UNEP 2001

Land tenure and land use

Because agriculture and animal husbandry are the primary economic activities in the basin, land resources are critical to the basin inhabitants. Although the available resources currently meet these needs, the growing population will require additional land, combined with the anthropogenic and climatic threats to land resources, which suggests this situation might not always be the case.

6.7.3 Management

Institutional and legislative frameworks

Institutional structures and legal frameworks have been established to some degree in the riparian countries for environmental management. A summary of the various national institutional structures and legal frameworks is given in Table 6.7-3.

Table 6.7-3: Ministries for managing water and land resources in Volta River Basin riparian countries

Ministries/ Authorities	Responsibilities	Riparian countires					
		Benin	Burkina Faso	Cote d'ivoire	Ghana	Mali	Togo
Ministry of Environment, etc.	Environmental management	•	•	•	•		
	Control of water withdrawals from water courses, aquifers, lagoons, and the sea for industry and agriculture						•
	Protection of water and forests, and ensuring sustainable development			•	•		
	Assessment of surface and groundwater resources in quantity and quality				•		
Ministry of Agriculture, etc.	Rural development			•		•	•
	Forest and natural resources	•					
	Agriculture, fishing and livestock						
	Irrigation		•		•	•	
	Water and soil management	•					•
Ministry of Mines, Energy, and Hydraulics	Management and distribution of water resources	•				•	
	Hydropower production		•	•	•		
	Utilization of mineral and water resources		•				
Ministry of Public Health	Implementation of national policies: hygiene and health	•			•		•
	Protection against water-associated diseases			•			
	Water analysis						•
	Public health		•				
Ministry of Transport	Collection of climatological data	•	•				
	River and marine transportation			•			
River Basin & Valleys Authority	Valley and basin management		•				
Ministry of Construction and Urban Development	Sanitation	•		•			
	Control of urban land management						
Ministry of Work, Water and Housing	Planning and regulation of development and use of freshwater resources	•				•	
	Provision of potable water					•	

(Compiled from country reports, Ministry of Works & Housing 1998; Water Resources Commission 1999; UNEP 2001; Andreini et al. 2002).

Many institutions in the riparian countries are charged with responsibility of managing water and soil resources, resulting in overlapping responsibilities and coordination difficulties. Coordination of activities among the institutions is generally weak and, in some cases, is only on an *ad hoc* basis for crisis situations.

The effectiveness of the laws governing resources poses another problem, since the laws and regulations established for managing water and soil resources appear to be weak and ineffective. The laws are adequate in some instances, but are not adhered to, or enforced, due either to lack of institutional capacity or political commitment. The knowledge base of the state of natural resources, rate of depletion, and consequent future impacts is poor, probably contributing to the weak political commitment on the part of governments and general apathy on the part of the populace.

Regional institutions

Regional institutions, such as the Economic Community of West African States (ECOWAS), and the Economic and Monetary Union of West Africa (UEMOA), all have promotion of integrated management of region's natural resources for social and economic development within their purview. A coordinated framework for holistic management of the natural resources (water and land resources), and the ecosystem of the Volta Basin for sustainable development, does not currently exist.

Data availability and accessibility

The countries sharing the Volta River Basin presently have no common database for common analysis, with monitoring being carried out by individual countries.

6.7.4 Key issues, adaptation and mitigation

Physiography

Climate vulnerability

The Volta River Basin is experiencing the effects of climate change and vulnerability, resulting in rainfed agriculture being carried out only once a year, instead of the previous 2 times per year.

Adaptation and mitigation

There is a need:

- To develop an early warning system to provide information on the season's precipitation patterns and quantities, and advise water users accordingly.
- To develop and encourage appropriate crops and livestock, and production technologies suitable for drought and reduced-water conditions.

Land degradation

Land degradation is becoming a serious problem, and a threat to food security in the Volta River Basin because of over-grazing and deforestation.

Adaptation and mitigation

There is a need:

- To develop standardized legislation, policies and guidelines for holistic land management, and cropping patterns suited to various soil types.
- To involve communities in managing ecosystems, with projects directly benefiting them forming an integral part of management efforts.

Socio-economy

Population growth and urbanization

Increased population growth and urbanization are exerting significant pressures on water demands and pollution. Urban populations also are increasing because of rural to urban migration. Emigration from countries, such as Burkina Faso, is resulting in the loss of skilled manpower.

Adaptation and mitigation

There is a need:

- To invest more in upgrading and developing infrastructure in both urban and rural areas.
- To implement measures that curb high population growths.
- To invest in education and entrepreneurial skills to enhance employment opportunities, thereby reducing poverty levels.

HIV/AIDS and water-related diseases

HIV/AIDS, malaria and river blindness are exacerbating poverty. The young and most-productive members of the communities are most vulnerable to HIV/AIDS.

Adaptation and mitigation

There is a need:

- For community training and education.
- To increase awareness through all the media.
- To implement anti-retroviral, and malaria and river blindness prevention programmes.
- To provide adequate domestic water resources to ensure general hygiene and minimize disease transmission.

Water availability, uses and demands

There is a high water demand for domestic water supplies, irrigation and hydropower generation, all against a backdrop of dwindling water supplies. Groundwater resources are being overexploited and, in certain areas, are being misused.

Adaptation and mitigation

There is a need:

- To strengthen IWRM by all riparian countries in a coordinated manner, focusing on holistic water use, with a balance between all land uses, including plantations, efficient irrigation systems, safe drinking-water, water for cattle, and water harvesting.
- For water demand management.
- For a coordinated development of groundwater resources, and implementation of conjunctive water schemes.
- To institute pollution monitoring and mitigation measures at the basin level to ensure no 'precious' water resources are wasted because of pollution.

Management

Institutional framework

There is no authority tasked with management of the basin. Each riparian country is carrying out management in its own partition, through government departments and ministries.

Adaptation and mitigation

There is a need:

- To establish a basin authority or organization representing all the riparian countries, with the mandate of ensuring the sustainable development, utilization and management of the basin's natural resources.
- To cover land management through developing basin policies.

Data availability, standardization and monitoring

Monitoring and databases are country specific and information-sharing is non-existent.

Adaptation and mitigation

There is a need:

- To establish standardized procedures for monitoring and database development, in order to ensure effective information sharing and utilization through the basin authority.

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6.8 NIGERIAN COASTAL AREAS AQUIFER SYSTEM

The Nigerian coastline has two sedimentary basins, the Dahomey Embayment and the Niger Delta Basin (see Figure 6.8-1). The two basins merge geologically across the Benin Hinge Line, which are areas of heavy population densities. Lagos, for example, has the highest population density in Nigeria. The nomenclature used for the geological units changes across the Benin Hinge Line, except for that of the Benin Formation. The area is plagued by diverse problems. More than 70 per cent of the industries in Nigeria are concentrated in this area, along the coast. Although the report emphasizes the Nigerian Coastal Areas Aquifer System, ample references are made to formations that occur in the Dahomey Embayment. The main characteristics of the Nigerian Coastal Areas Aquifer System are summarized in Box 6.8-1.

Box 6.8-1: Main characteristics of Nigerian Coastal Areas Aquifer System.

Basin
Surface area: 70,000 km^2 (27,027 mi^2)

Water Use
Agriculture and Fishing
Domestic
Industrial (especially oil)
Mining (petroleum)

Increasing

Demography
Population: 20 million
Population Density: 286 persons.km^{-2}

Vulnerability
High salinity & saline intrusion
Overexploitation (highly variable)
(741 persons.mi^{-2})
Decreased water table & artesian heads
Air and water pollution
Ecosystem damage
Land subsidence
Pollution & high iron content

Geological formations:
Quaternary Deposits (40-150 m [131-492 ft] thick) sand, clay and silt (Alluvium)
Meander belts & saltwater mangrove swamps (5-50 m [16-164 ft] thick) black to gray organic silt

Benin Formation: 13,000 km (8,078 mi) stretch
Volume unconfined and confined: 4.875 billion m^3
Imo Shale/Ewekoro Formation
Ameki - Oshosun – Ilaro Formation

6.8.1 Physiography

Hydrogeology

The Niger Delta has been described as a large arcuate delta of the destructive wave-dominated type (Short and Stauble 1967). Its areal extent is about 70,000 km^2 (27,027 mi^2), and it lies within the Gulf of Guinea on the western coast of central Africa (Figure 6.8-1). The Cenozoic Niger Delta is situated at the intersection of the Benue Trough and South Atlantic Ocean. At one time it was a triple junction developed during the separation of South America from Africa. The Pro-delta developed in the northern part of the basin during, or with, the Paleocene transgression.

Formation of the modern delta began during the Eocene, and consists of a sedimentary prism of 12 km (7 mi) thickness, covering a total area of 140,000 km^2 (54,054 mi^2) initially deposited on continental crust, and later on oceanic crust. The overall succession reproduced a gross coarsening upward sequence of a major regressive cycle known as 'escalator' regression. Well information and outcrop studies have indicated that, during the lower Tertiary time, the sea transgressed the whole of southern Nigeria, terminating the advance of the Cretaceous Niger delta.

Most of the coastline areas experience saltwater intrusion (Figure 6.8-1), which occurs in recent sediments and aquifers in the Dahomey Basin, and in both confined and unconfined aquifers in the Niger Delta. This phenomenon usually results from over-development of coastal aquifers. In addition to saline intrusion, boreholes drilled near the coast may encounter connate water tapped in rapidly-deposited sequences. Below 60 m (197 ft) in the Benin Formation aquifers, however, the impermeable silt, clays and shales tend to 'screen off' the saltwater, so that freshwater becomes available, usually in artesian aquifers (e.g., Escravos, Brass, and Bonny Opobor, where freshwater aquifers have been encountered between 80-120 m (262-394 ft) from the surface.

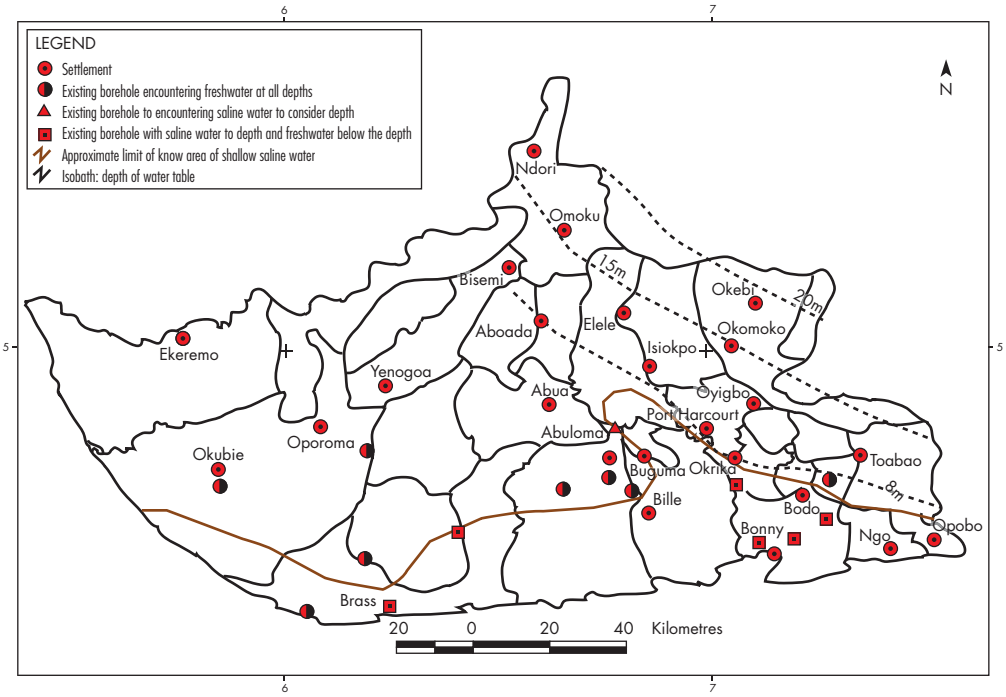

Figure 6.8-1: Areas of high groundwater salinity in Niger Delta

Source: Redrawn from Abibio 1988, redrawn by UNEP

About 70 per cent of Nigeria's industrial activity is in the coast area. When the effects of oil exploitation activities in the Niger Delta are superimposed on its saltwater intrusion problems, it is obvious the Niger Delta environment is being subjected to very severe stresses.

About 4 per cent of gas is flared at oil-producing sites on a worldwide basis. In Nigeria, 70 per cent is flared, resulting in massive air pollution. About 76,455 m^3 of the gas released each day during oil production is burned in Nigeria, accounting for 20 per cent of the total daily global flares. There are about 100 gas-flaring sites, some of which have been burning continuously for 40 years. According to Wenfel Li (2002), Nigeria is becoming one of the biggest victims of climatic change worldwide, with the Niger Delta being most vulnerable to the effects of global warming, since it releases 35 mm t.yr^{-1} of carbon dioxide, and 120 mm t.yr^{-1} of methane, into the sky.

Oil spills have rendered farmlands and rivers unusable, and also have affected shallow groundwater. The large number of steel gasoline storage tanks buried in the geometrically-multiplying petrol stations in the country, from which leakages occur frequently, and refinery wastes and spills (e.g. Kaduna), are a big threat to groundwater resources, especially where the water table is located near the surface. Some 2.4 million barrels of crude oil released into the environment from 4,647 spills in Nigeria from 1976 to 1996 (Department of Petroleum Resources, 2001) have taken a considerable toll on farmlands and fishery resources. Further, Abibo (1988) reported the prevalence of iron in groundwater in parts of the Niger Delta.

SOUTHWESTERN NIGERIA BASIN

The Maastrichtian Sandstones

The Maastrichtian sandstones underlie a belt from Agenebode, Fugar through Auchi, Afuze, Uzebba, Imushin, Aiyetoro, and Ijebu-Ode, among others. The strata are composed of alternating layers of fine and coarse sandstones with subordinate clays. The white sandstones are false bedded.

Westward beyond the Okitipupa Ridge, the Abeokuta formation contains prolific aquifers under water table and artesian conditions. Idowu et al. (1999) report that even the thin outcrops near the basement contain good aquifers (e.g., Aiyetoro (5.9 m [19 ft]); Ishaga (7.9 m [26 ft]); Ijesha-Ijebu (7.2 m [24 ft]), with an average yield of 36 $m^3.h^{-1}$.

Imo Shale/Ewekoro Formation

The Palaeocene marine sediments immediately overlie the Maastrichtian sandstones in southwest Nigeria. The Imo shale aquiclude extends from across the River Niger westwards, where it consists of dark grey and blue-black shales with sandstone lenses. It confines the aquifer of the Cretaceous sandstones, and may render them artesian in several localities. The 60-70 m (197-230 ft) thickness of the Imo Shale at Sabongidda-Ora, for example, affects the artesian sandstone aquifers.

Ameki - Oshosun - Ilaro

The Ameki Formation stretches westwards from across the River Niger. The Ameki and Ogwashi-Asaba Formations are hydrogeologically similar. They have identical characteristics, with formations west of the Niger, and are tapped in Asaba, Agbor, Ogwashi-Uku and Ibusa, among others, where the aquifer is prolific.

The water quality is generally good, with moderate total dissolved solids of 200-500 ppm, although pyrite-derived iron, usually associated with lignite seams or carbonaceous horizons in the rock, is a common problem (Figure 6.8-2). Thus, treatment for iron in the aquifer water is necessary, such as at Ekiadolor, Ilaro, and Irrua, where the iron content usually is greater than 0.3 ppm.

6.8.2 Socio-economy

Even though the census figures indicate the Niger Delta contained 12.6 million people in 1991, with a population density of 180 $persons.km^{-2}$ (466 $persons.mi^{-2}$), current figures are about 20 million over an area of 70,000 km^2 (27,027 mi^2), equivalent to a population density of about 285 $persons.km^{-2}$ (738 $persons.mi^{-2}$). The Niger Delta is an area experiencing major oil exploration and exploitation activities, a commodity that contributes over 90 per cent of the national economy. It

is a very socially-restless area in which traditional social structures appear to have broken down, with youths and armed groups leading the restlessness.

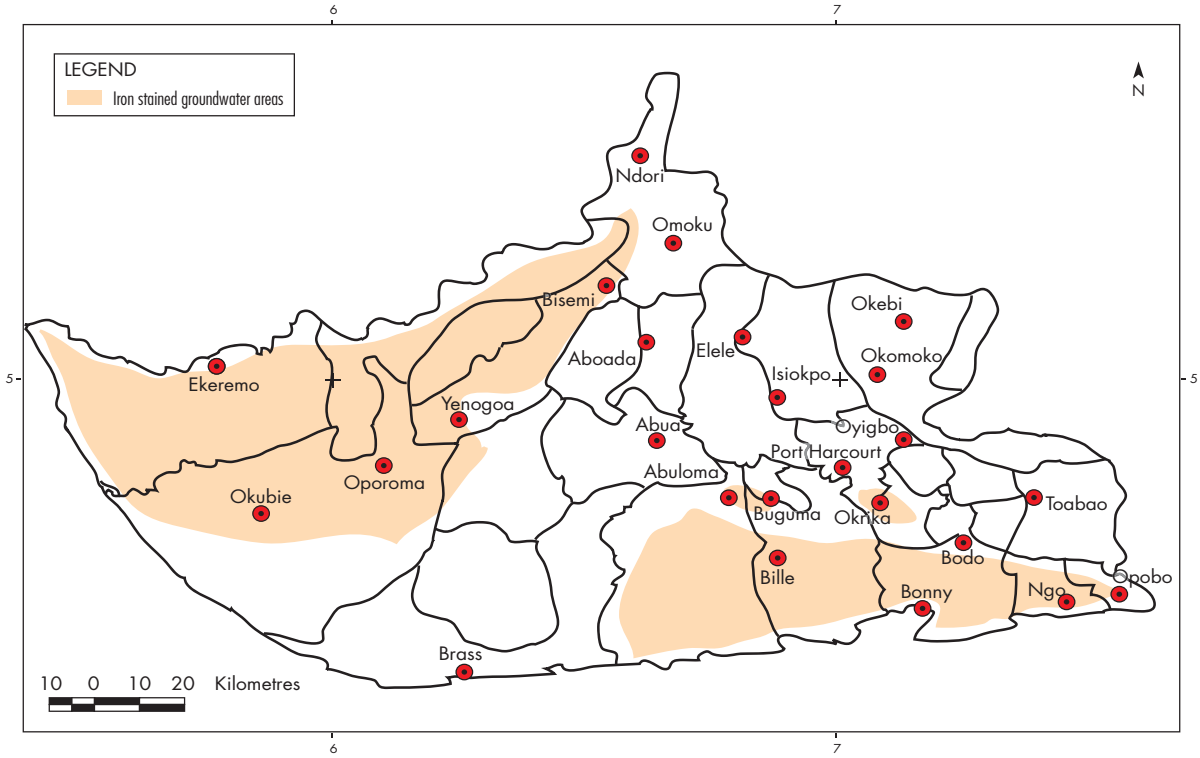

Figure 6.8-2: Iron-stained groundwater areas of Niger Delta

Source: Redrawn from Abibo 1988, redrawn by UNEP

This situation may be attributed to poor development of the area in the midst of foreign oil exploitation facilities and personnel. The degradation caused to the environment, and surface and groundwater resources, by the oil industry, including drilling, oil spills, oil waste disposal and gas flaring, has rendered much of the land unsuitable for agriculture, and also depleted the fish populations of the waters.

Conflicts frequently arise between the delta communities and the authorities, and sometimes between the communities themselves.

Lack of basic infrastructure (e.g., electricity, roads water) represents a paradox in the area that is supposed to produce high incomes for Nigeria. Formation of the Niger Delta Development Commission (NDDC), and the extra budget of 13 per cent derivation funds from the federal budget to the state governments in the area, do not appear to have improved the living standards of the population.

The water supply situation is low, being about 40 per cent of demands, with most families having hand-dug wells.

The crime rate, including criminal vandalism of oil and other industrial structures and facilities, is high. The incidence of HIV/AIDS also is high. Although the main cities are industrialized, the unemployment rate is so high that it tends to fuel social discontent, leading to criminal activities.

6.8.3 Management

The major management issues in the Niger Delta are associated with weak institutional management infrastructure, coupled with peculiar and special problems, calling for proper, efficient, and systematic management. The coastal people are faced with the ironic situation of being surrounded by water, yet not having any potable water. The River Basin Development Authorities (RBDAs) are supposed to streamline basin-wide integrated water resources development and management for the Niger-Delta area. The concerned RBDAs are the Niger-Delta Basin Development Authority, Benin-Owena River Basin Development Authority, and Cross River Basin Development Authority. Unfortunately, however, their areas of jurisdiction are not clearly defined hydrologically. In addition, the Dahomey Embayment is the responsibility of the Ogun-Osun River Basin Development Authority. Emphasis on short-term development projects leaves little room for acquisition of proper water resources data to enable them to quantify and control water allocations and uses. Thus, efficient, equitable allocation and use are lacking.

The State Water Agencies, local government authorities, and federal and state parastatals supply water. Their efforts, however, can only meet about 40 per cent of water demands. In Benin City (Edo State), for example, the State Water Board can supply only 23 per cent of the demand. Private agencies and individuals fend for themselves, by means of boreholes in urban areas, and rain harvesting in rural areas.

6.8.4 Key issues, adaptation and mitigation

The Nigeria Coastal Aquifer System is the main groundwater source for about 20 million people, providing water for domestic, agricultural and industrial purposes. The basin exhibits a rapid population growth, but a limited water supply. The aquifers are being over-exploited in an attempt to meet growing demands for potable water; and aquifer management is poor.

Physiography

Water availability, distribution and pollution

Groundwater occurrence throughout the basin is not fully known or understood. There are areas within the basin where groundwater overdrafts have resulted in observed groundwater level declines. An example is Lagos, where water levels are dropping at a rate of 2 $m.yr^{1}$ (6.6 $ft.yr^{1}$). Sea water intrusion (such as in Burutu, Forcados and Buguma) has resulted in abandonment of wells. Oil mining and gas flaring are causing huge groundwater, farming land, and air pollution.

Adaptation and mitigation

There is a need:

- To carry out groundwater assessment studies to establish additional potential aquifers.
- To develop techniques to fully harvest water resources in years of good rainfall (e.g., artificial recharge).
- To effect sound groundwater management practices.
- To map potential areas of pollution, and develop appropriate control mechanisms.

Socio-economy

Population growth and urbanization

High urbanization and population growth are putting severe pressures on available water and other natural resources. The current water supply is meeting only 40 per cent of the water demand, and poverty levels are high.

Adaptation and mitigation

There is a need:

- To invest more in upgrading and developing infrastructure in both urban and rural areas.
- To implement measures to curb high population growths.
- To conduct community awareness and education programmes for conserving the basin's natural resources.

HIV/AIDS

HIV/AIDS prevalence in the basin is high, due to high poverty levels and population.

Adaptation and mitigation

There is a need:
For community training and education.

- To increase awareness through the media.
- To implement anti-retroviral prevention programmes.
- To provide adequate domestic water resources to ensure general hygiene, and minimize disease transmission.

Water-related conflicts

Conflicts occur between communities, since they compete for the basin's limited water resources.

Adaptation and mitigation

There is a need:

- To enhance development of IWRM strategies to ensure equity in water allocations.

Management

Institutional and legislative frameworks

The institutional and legislative frameworks in the basin are very weak. Management of the Niger Delta is the responsibility of 3 River Basin Development Authorities, each with its own area of jurisdiction within the basin. This is a poor arrangement, since there are no clearly-defined roles. The Dahomey Embayment also has no clearly-defined basin authority.

Adaptation and mitigation

There is a need:

- To establish and strengthen existing basin management authorities fully mandated with effective basin management; it is preferable to have a single basin management authority for the entire basin.
- To carry out capacity-building of basin authorities to enable them to effectively operate.
- To develop and implement appropriate legislative frameworks, including regulations.

Data availability, standardization and monitoring

Monitoring and data collection on a basin level are very weak, and comprehensive data collection networks do not exist.

Adaptation and mitigation

There is a need:

- To establish basin-level monitoring networks
- To analyse data, interpret results, and utilize them in IWRM of the basin, in order to improve basin management.

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6.9 SOKOTO GROUNDWATER BASIN

The Sokoto Basin covers Sokoto and Kebbi States, and parts of Zamfara and Kwara States in Nigeria. It lies between longitudes 3° 30′ E and 6° 58′ E and latitudes 10° 20′ E and 14° N. The surface area is drained by the Sokoto River System. The groundwater system, however, is more complex, comprising different aquifers, and it being possible to encounter more than six in one vertical section.

What is regarded as the Sokoto Basin in Nigeria actually constitutes the southeastern tip of the Iullemeden Basin, which extends westward into the Republics of Benin and Niger, and northward into Niger Republic (Figure 6.9-1). The folded metamorphic rocks of the Hoggar, Adrar des Iforas and Air form the northern boundary of the basin, while the metamorphics of northern Nigeria, Benin Republic and Togo form the southern boundary. The Nigerian sector, covering 59,570 km^2 (23,000 mi^2), constitutes only about one-tenth of the area of the entire basin. Box 6.9-1 summarizes the main characteristics of the basin.

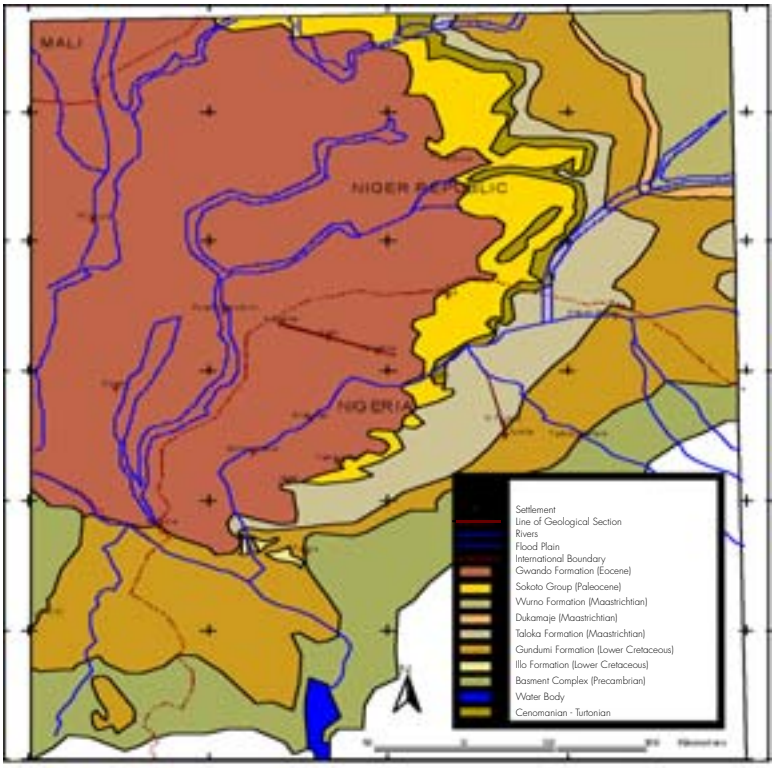

Figure 6.9-1: Geological map of Sokoto Basin and adjoining areas

Source: Redrawn from Oteze 1979

Box 6.9-1: Main characteristics of Sokoto Groundwater Basin (Nigerian)

Basin		**Water Use**
Surface area:	525,000 km² (202,704 mi²)	Agriculture
Mali	31,000 km² (11,969 mi²)	Domestic
Niger	434,000 km² (167,568 mi²)	Industrial
Nigeria	59,570 km² (23,000 mi²)	Mining
Others	430 km² (166 mi²)	
Demography		**Vulnerability**
Population:	13,364,620	High aridity
Density:	25.45 persons.km^{-2}	Overexploitation
	(66 persons.mi^{-2})	Drop in water table
		Drop in artesian heads
Major Aquifers:		Pollution in some areas
Gwandu Formations		Ecosystem damage
Storage volume unconfined and confined:	500 billion m³	
Kalambaina Formation		
Unconfined storage volume:	Unknown	
Down flow:	441 million m³	
Rima Aquifers		
Confined and unconfined storage volume:	277.5 billion m³	

Increasing

6.9.1 Physiography

Climate

According to UNESCO's (1978) World Water Balance and Water Resources of the Earth, the average annual moisture content of the Sokoto Basin from 0-7 km (0-4 mi) is about 25 mm (1 in). A large part of the advected water vapour is carried beyond the basin, without contributing to precipitation within it. Evapotranspiration accounts for over 80 per cent of the precipitation. The annual precipitation in the basin area varies between 1,100 mm (43 in) in the south, to less than 550 mm (22 in) at Illela in the north (Figure 6.9-2). The potential annual evapotranspiration is ~2100 mm (83 in), and the actual evapotranspiration is ~900 mm (35 in) in the south, and 500 mm (20 in) in the north.

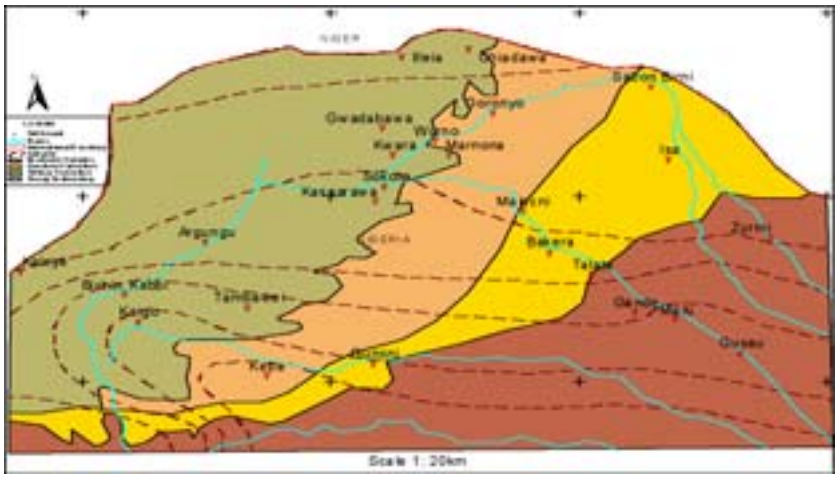

Figure 6.9-2: Isohyets and geological formations of Sokoto Basin in Nigeria

Source: Redrawn from Oteze 1989

Hydrogeology

Springs

There are many seasonal springs, mostly from the laterites (e.g., Tudun Wada-Sokoto town; Wurno). The Tungar Basu spring in Wamako is perennial, flowing from the Kalambaina limestones at an average discharge rate of 6,000 $m^3.d^{-1}$. It supports a population of 30,000, and feeds the Sokoto State government's fish ponds (Umar 2000). The sedimentary succession is rather thin in Nigeria, the thickest part being only about 1,110 m (3,609 ft).

Aquifers

Groundwater is found in the sedimentary succession illustrated in Table 6.9-1.

Table 6.9-1: Sedimentary succession of Sokoto Basin in Nigeria

Age group	Formation	Lithology	Hydrological significance
Recent	Alluvium	Sands & clay	Good aquifer
	Laterites	Lateritic sands	Poor aquifer
Eocene	Gwandu	Sands & clay	Prolific aquifer
Palaeocene Sokoto	Gamba	Clays	Aquiclude
	Kalambaina	Limestone	Aquifer (part)
	Dange	Clay/shale	Aquiclude
Maastrichtian Rima	Wurno	Silty sand/clay	Good aquifer
	Dukamaje	Shales	Aquiclude
	Taloka	Fine-coarse sand/clay	Moderate aquifer
Turonian	Gundumi III (Continental)	Sand & clay	Moderate aquifer

The water quality varies greatly. The pH, for example, varies between 3.7- 8.7, and high iron contents (about 32 ppm) have been encountered about 42 km (26 mi) southeast of Sokoto.

Aquifer vulnerability

This issue is very relevant for the Sokoto Basin in Nigeria, and is very noticeable because of the interplay between surface and groundwater, and the intensive exploitation of the aquifers. Issues relevant in this context include:

- The effect of waste disposal on, or near, the surface is very evident in the shallow aquifers in the alluvium, laterites, and Kalambaina limestones. Domestic sewage disposal facilities (e.g., soakaways; pit latrines), penetrate the aquiferous rocks at a shallow depth. While the laterites and alluvium allow for direct contact at some time of the year, and leachates from surface waste dumps also percolate down in them, the fracture pores in the limestones allow these contaminants to travel down to the aquifer. As far back as 1973, the laterite aquifer that contained many hand-dug wells in the Rijia Dorowa quarters of Sokoto town, contained water with heavy bacterial (E. Coli) loads, and nitrate contents above 50 ppm;
- The importance of the Kalambaina limestones in maintaining the lakes in the basin has been noted. The stresses affecting this aquifer have been demonstrated by the disappearance of the Bodinga Lakes. In the outcrop areas of the Kalambaina Formation, about 300 boreholes were sunk by 2001. The importance of the Kware Lake, the sole source of the Rima River in the Sokoto area during the dry seasons, has been diminished due to construction of the Goronyo Dam;

- This same limestone suffers from Karst development, with land subsidence along with the clayey surface (alternate swelling and shrinking), evidenced by the large number of buildings with cracked walls in Sokoto and environs;
- Mining of these limestones further stresses the Kalambaina aquifer, since the groundwater level has been exposed as a result of stripping the limestone for the cement industry. Springs and lakes have been developed because of the mining activities, and the water is contaminated, thereby being wasted;
- Intensive groundwater exploitation is taking place in the basin, which is bound to affect the groundwater reserves with consequent declines in the water table and piezometric levels. Eleven boreholes drilled into this aquifer suffered a decline in head of 4.2 m (14 ft) over an average of 4 years (1994-1998). Unfortunately, the monitoring network, which was established in the 1960s by U.S. Agency for International Development for the Geological Survey, was maintained for a while and subsequently neglected. There are presently more than 1,000 boreholes in the basin and, by 2001, the distribution of recorded boreholes was as follows:

Formation	number of recorded boreholes (2001)
Gwandu	296
Rima Group	149
Kalambaina	302

- The use of fertilizers, especially in the fadamas, is a problem for the alluvial aquifer, which is in contact with the main aquifers in the basin. This is a potential source of pollution.

A monitoring network for the basin should be established to avoid a catastrophe in the near future, mainly because groundwater development is continuing unabated.

6.9.2 Socio-economy

The total land area covered by the Iullemeden Basin is 525,000 km^2 (202,704 mi^2). Mali covers 31,000 km^2 (11,969 mi^2; 5.9 per cent), Niger covers 434,000 km^2 (167,568 mi^2; 82.7 per cent), while Nigeria covers 59,570 km^2 (23,000 mi^2; 11.3 per cent). However, the Nigerian sector has the greatest population density, holding 9.18 million people, or 64.6 per cent of the total population of the area. Niger, with 3,892 000 people, contains 29 per cent of the population, while Mali, with 298,840 people, contains only 2.2 per cent of the population.

The area is marked by harsh environmental problems, exhibiting recurrent droughts. Niger is currently facing starvation on a large scale, following a devastating drought, accompanied by locust invasion (although aid is on the way).

Estimates of the water reserves are possible for only a part of the Nigerian sector. The Gwandu aquifer holds about 500 billion m^3, while the Rima aquifer has about 277.5 billion m^3, of which 21.2 million m^3 is under compression storage. Estimates have not been done for the other aquifers, although Alagbe (2004) estimated the daily flow across the maximum cross section of the Kalambaina limestone to be is 441 million m^3.

6.9.3 Management

The main issue in the Sokoto Basin is the rising water demand, resulting in overexploitation of the aquifers. The effects on the Kalambaina Aquifer are already obvious, with the disappearance of Bodinga Lake. The pristine aquifers of the Rima Group now have low recharge rates. Thus,

exploitation of these aquifers in many localities amounts to water mining, especially in the western parts of Kebbi State.

The International Niger Basin Authority, headquartered in Niamey, has 9 member countries. It is supposed to harmonize use of the waters of the Niger River Basin, which covers these aquifers. UNESCO initiated a project in 1999 to harmonize studies on the Iullemeden Basin within the region, but it has not yet been finalized. The authorities presently exploit the aquifers within their territories without any control or management.

In Nigeria, the Sokoto-Rima River Basin Development Authority (RBDA) is supposed to access, monitor and regulate water use in the basin through a master plan. With emphasis on development, the assessment and monitoring aspects are not being given prominence. The result is that the RBDA itself, the state water agencies (e.g., Sokoto and Kebbi State Water Boards) local governments, parastatals (e.g., Agriculture Development Project), are directly involved in groundwater exploitation in an area of limited groundwater recharge.

Borehole drilling programmes are being carried out in aquifers whose overall potentials have not yet been assessed. Despite this effort, only about 48 per cent of the population has access to potable water. To strengthen the institutional capacity of the state water agencies (Water Boards), streamlining the activities of the RBDAs, and implementing serious manpower training for the agencies, would be very useful first steps.

6.9.4 Key issues, adaptation and mitigation

The Sokoto Groundwater Basin extends over 9 countries. The population is poor, and water supply coverage very low, being about 48 per cent in the Nigerian section of the basin. The basin exhibits rapid population growth, but has a limited water supply. Thus, the aquifers are being over-exploited in an attempt to meet growing demands for potable water; with aquifer management being very poor. Droughts and locust invasion are recurrent features, and seriously affect the basin.

Physiography

Water availability, distribution and pollution

Groundwater occurrence throughout the basin is not fully known or understood. Some hydrogeological data is available only for the Nigerian section of the basin. There are areas within the basin where groundwater abstractions have resulted in observed groundwater level declines. In Sokoto, for example, groundwater levels dropped 4.2 m (14 ft) between 1994 and 1998.

Adaptation and mitigation

There is a need:

- To carry out groundwater assessment studies to establish potential aquifers within the whole basin.
- To develop techniques to fully harvest water resources in years of good precipitation (e.g., artificial recharge).
- To effect sound groundwater management practices.
- To map potential areas of pollution, and develop appropriate control mechanisms, since some aquifers are unconfined.

Socio-Economy

Population growth and urbanization

High population growth is putting severe pressures on the available water and other natural resources. Water supply coverage is only 48 per cent in the Nigerian section of the basin, and poverty levels are high throughout the basin.

Adaptation and mitigation

There is a need:

- To invest more in upgrading and developing infrastructure in both urban and rural areas.
- To implement measures to curb high population growths.
- To conduct community awareness and education programmes on conserving the basin's natural resources.

Management

Institutional and legislative frameworks

The institutional and legislative frameworks are very weak. Although the International Niger Basin Authority is responsible for managing the basin, it is ineffective, especially in regard to managing groundwater resources. Each country is developing groundwater resources within its own section of the basin, without considering the implications to the overall basin.

Adaptation and mitigation

There is a need:

- To build capacity in the International Niger Basin Authority to enable it to operate effectively.
- To develop and implement appropriate legislative frameworks, including regulations and guidelines.

Data availability, standardization and monitoring

Monitoring and data collection on a basin level are very weak. Comprehensive data collection networks have been neglected, and are non functional.

Adaptation and mitigation

There is a need:

- To establish or revive basin level monitoring network
- To analyze and interpret data, and utilize the results in IWRM efforts in order to improve basin management.

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NORTHERN AFRICA

7.1 OVERVIEW

Northern Africa embraces the Maghreb countries (Morocco, Algeria, Tunisia, Libya) and the Nile River Basin countries (Egypt, Sudan) (Figure 7.1-1), and is one of the most water-scarce regions in the world. The water demands from all sectors in northern Africa have increased tremendously because of rapid economic and population growth, with an immediate result being an acute water scarcity in some of the countries.

Northern Africa also is one of Africa's most distinctive regions, in which arid climatic conditions express the physical constraints on water availability. Desert conditions prevail throughout, except for the narrow coastal strip along the Mediterranean shoreline, and the upper stretches of the Nile in Sudan. The harsh conditions in the Sahara Desert have compelled approximately 70-90 per cent of the population in most northern African countries to live along the Mediterranean coast and the Nile River.

Although there are few river basins, there are many groundwater basins in northern Africa. Of the existing river basins, the Nile River Basin is the most important. The Nile River, the longest river in the world crossing various climatic zones, is the major water supply for one of the most arid zones in Africa. It is inhabited by more than 160 million people from 10 countries, including Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda. Other river basins are found in the Maghreb countries.

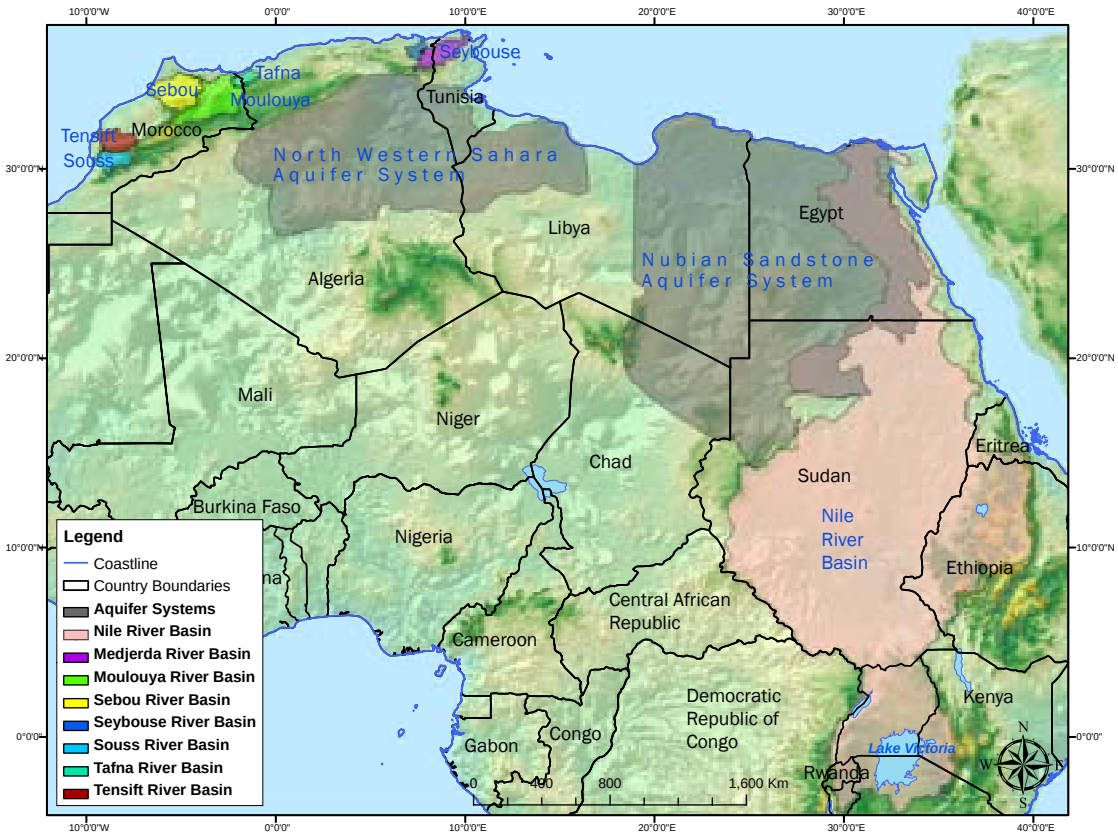

Figure 7.1-1: Major river and groundwater basins in northern Africa

7.1.1 Physiography

Except for a narrow strip in the north along the Mediterranean Sea and southern Sudan, the region is located in arid to semi-arid climatic zones, with dry conditions prevailing. The annual precipitation is high along the northern coast, decreasing as one moves southward. In the Sudan, the rainfall increases from the desert parts to the subequatorial regions, ranging from less than 50 $mm.yr^{-1}$ 2 $in.yr^{-1}$) in the southern parts (deserts), occasionally increasing to as much as 1,000 $mm.yr^{-1}$ (39 $in.yr^{-1}$) in some parts of the extreme northwest of Maghreb, and to more than 1,500 $mm.yr^{-1}$ (59 $in.yr^{-1}$) in southern Sudan (Figure 7.1-2).

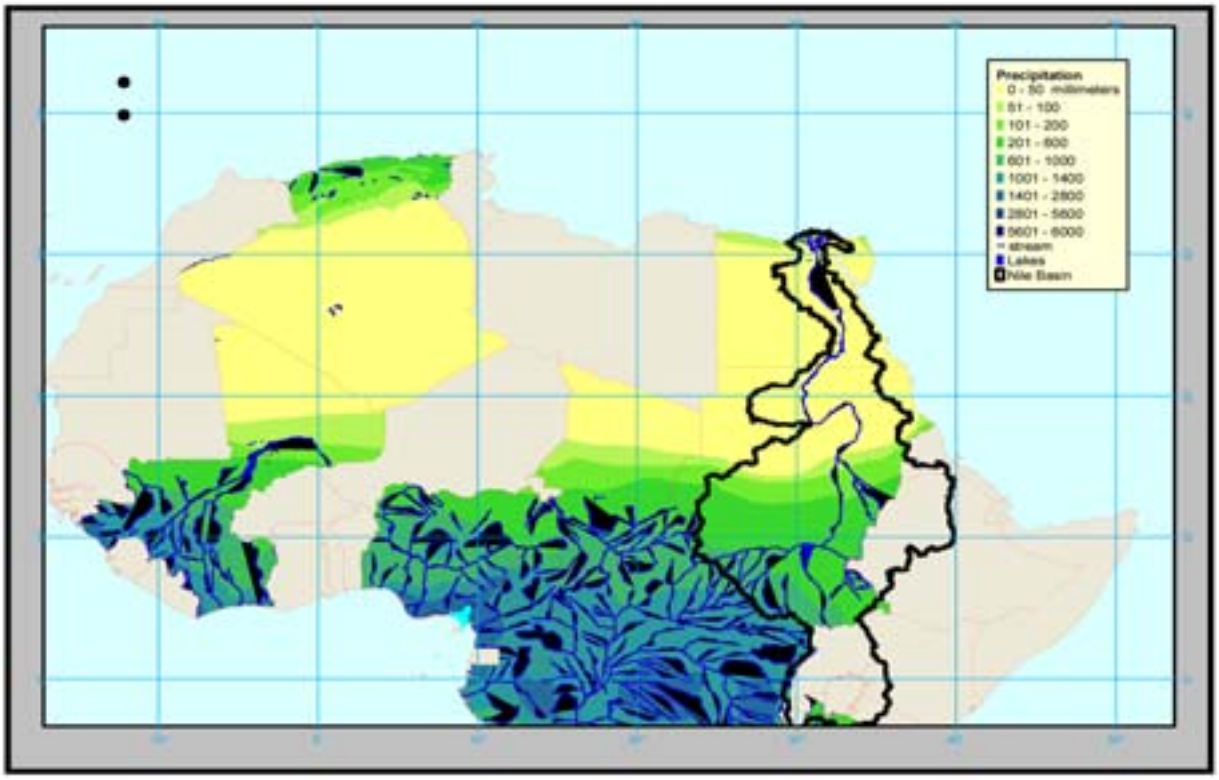

Figure 7.1-2: Northern Africa – Precipitation, rivers and Nile River Basin

Source: Rainfall: ESRI (1998); Rivers and Dams: ESRI (1992)

The land cover in northern Africa largely mirrors its climate, with more than 90 per cent characterized by desert and semi-desert vegetation (Figure 7.1-3).

Surface water is limited in the region. In the east, the Nile River Basin is shared by 10 countries, stretching from the Great Lakes region to Sudan and Egypt. The discharge mainly originates from outside the region. In the Maghreb countries in the west, there are several relatively small rivers, some being shared by more than one country (e.g., the Mejerda between Algeria and Tunisia; the Tafna between Algeria and Morocco). These rivers and tributaries form mostly local, small- to medium-sized basins. A dense network of ephemeral wadis and streams also exists. In these countries, many dams have been built to mitigate the highly-variable precipitation.

Groundwater plays a vital role in meeting basic water requirements in many parts of northern Africa. The aquifers are mostly non-renewable, however, with some being transboundary by nature. There are two major shared aquifer systems in northern Africa (Figure 7.1-1): (i) the Nubian Sandstone

Aquifer System (NSAS); and (ii) the North Western Sahara Aquifer System (NWSAS). The Nubian Sandstone Aquifer System is located in northeast Africa, being shared by Egypt, Libya, Sudan and Chad. Libya, Tunisia and Algeria share the North Western Sahara Aquifer System. Other aquifers, although non-transboundary, support populations located away from the Nile, as exemplified by the Umm Ruwaba Aquifer in western Sudan.

There is great concern in regard to the water quality of both surface water and groundwater. Intensive nitrate and pesticide use for agriculture are major threats to the quality of surface water in the Maghreb countries, as well as the quality of the Nile River water, which is used and reused along its course. Because of inefficient irrigation practices, and poor drainage management practices, groundwater salinity is increasing. Salinization also occurs in coastal aquifers because of over-exploitation, often resulting in seawater intrusion.

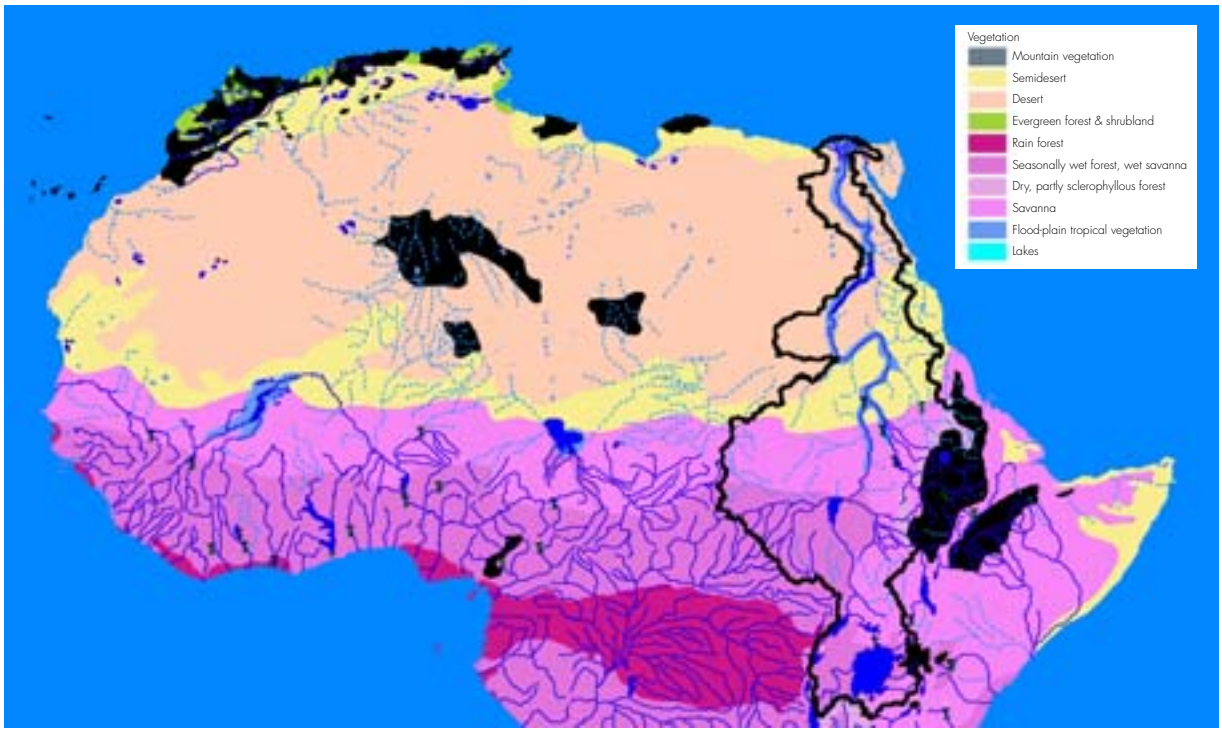

Figure 7.1-3: Northern Africa land cover

Source: Vegetation: ArcAtlas ESRI (1998)

Aridity and water availability

Due to high aridity and recurrent droughts, the region's water resources are highly vulnerable. The average annual renewable water resources in northern Africa was about 950 $m^3.capita^{-1}.yr^{-1}$ in 2000, which is below the 1,000 $m^3.capita^{-1}.yr^{-1}$ threshold of water scarcity, and the trend continues to decrease.

7.1.2 Socio-economy

After the deep recession the region faced in the 1980s, wide-ranging economic reforms were implemented in the 1990s, aimed at tightening demand, liberalizing trade, and improving the regulatory framework in which the development process was being implemented. These reforms provided a significant boost to economic growth, with an average annual GDP growth of around 4 per cent over the period of 1992–2002 www.earthtrends.wri.org 2007), and started laying the foundations of a market-based economy in which the private sector is called upon to play a more prominent role.

Water demands and water uses

Northern Africa is one of the most water-scarce regions in the world; with a regional annual average of 1,200 $m^3.capita^{-1}.yr^{-1}$ (world average is close to 7,000). Because of population increases, the regional average water availability is projected to be just over 500 $m^3.capita^{-1}.yr^{-1}$ by 2025. The region is characterized by high population growth rates, large and rapidly-increasing food deficits, highly-variable income levels, both within and between countries, and limited natural resources, particularly arable land and water. Most of the region falls within the arid and semi-arid rainfall zones in which 60 per cent of the total population lives (Shetty 2006).

The challenge of meeting northern Africa's water demand is determined mainly by the limited quantity of renewable water resources. The important economic activities of the countries are highly dependent on water resources. Agriculture has been practised for centuries in many regions of North Africa, consuming more than 80 per cent of the available water resources. The present water resources are insufficient, and future projections of increasing water demands and uses are expected to aggravate the situation, in that there will be increasingly smaller quantities of water available per person.

Most northern African countries, except Sudan, suffer from a substantial lack of precipitation and surface water resources and, therefore, are heavily reliant on groundwater resources, which are non-renewable in some cases. Egypt depends mainly on the surface water of the Nile River. Utilization of non-renewable groundwater, and protection of groundwater quality for future generations, has become a complex issue, particularly in regard to its sustainability. There appears to be no other choice in a number of cases than to rationalize utilization of water resources, increase recycling and reuse, and preventing water pollution.

Other water uses include domestic water supply, industry, hydropower production, and recreation. The contributions of agriculture to the GDP, as well as the employment involved in the agricultural sector in the region, are summarized in table 7.1-1.

Table 7.1-1: Water use and GDP contribution of agriculture and industry in some North African Countries

Country	Agriculture share			Industry share		
	Water use (per cent)	GDP (per cent)	Contribution of 1 per cent of water to GDP (per cent)	Water use (per cent)	GDP (per cent)	Contribution of 1 per cent of water to GDP (per cent)
Algeria	69	12	0.17	15	60	4.00
Egypt	88	14	0.16	8	34	4.25
Morocco	93	16	0.17	4	22	5.50
Tunisia	87	12	0.14	3	29	9.67
Sudan*	95	45	0.47	1	25	25.00

Source: Water use share: AQUASTAT, FAO; GDP Contribution: World Development Indicators (FAO: 2002. FAOSTAT. http://apps.fao.org/default.htm)

** Ministry of Finance and Economic Development (2006).*

While agriculture and the rural economy are important elements in the region, the relative contribution of agriculture to the overall GDP is low, and has been declining. However, agriculture is by far the dominant water user (Shobha Shetty 2006).

Nevertheless, it is important from a broader development perspective to note that agriculture claims the largest share of the work force in the region, with a high proportion of the poor dependent on it for their livelihoods. Regionally, 88 per cent of the economically-active population works in the agriculture sector. In some countries (e.g., Egypt, Morocco), more than 90 per cent of the economically-active population is agricultural workers (Table 7.1-2.). Thus, despite the small contribution to GDP, agriculture is still the key to development in the region.

Table 7.1-2: Share of agriculture in total economically-active population

Country	Total economically active (1000)	Agriculture (1000)	Share of agriculture (per cent)
Algeria	10,458	7,257	69.39
Egypt	25,790	24,871	96.44
Morocco	11,780	10,909	92.61
Tunisia	3,826	2,329	60.87

Source: FAO (2002). FAOSTAT; http://apps.fao.org/default.htm

Water supply is unequally distributed in space and time, both at the regional level, and within each country. The per capita water availability in Northern Africa is among the lowest in the world. It is estimated that 7 per cent of the entire Mediterranean population (28 million people) has less than 500 $m^3.capita^{-1}.yr^{-1}$of water availability, and another 29 per cent (115 million people) are below the threshold of 1,000 $m^3.capita^{-1}.yr^{-1}$.

The intensive extraction and use of water for domestic, agricultural and industrial purposes is leading towards substantial reduction in water quantities. On the other hand, the absence of proper provisions for protecting the resource has led to serious water pollution of surface and groundwater resources.

Access to water and sanitation

Despite the progress made since 1990, northern Africa slightly lags behind on the Millennium Development Goal (MDG) for safe drinking water (see Figure 7.1-4). The situation is more serious for the MDG sanitation target in rural areas, although if Sudan is excluded from analysis, the region is well on target for meeting both the water and sanitation coverage.

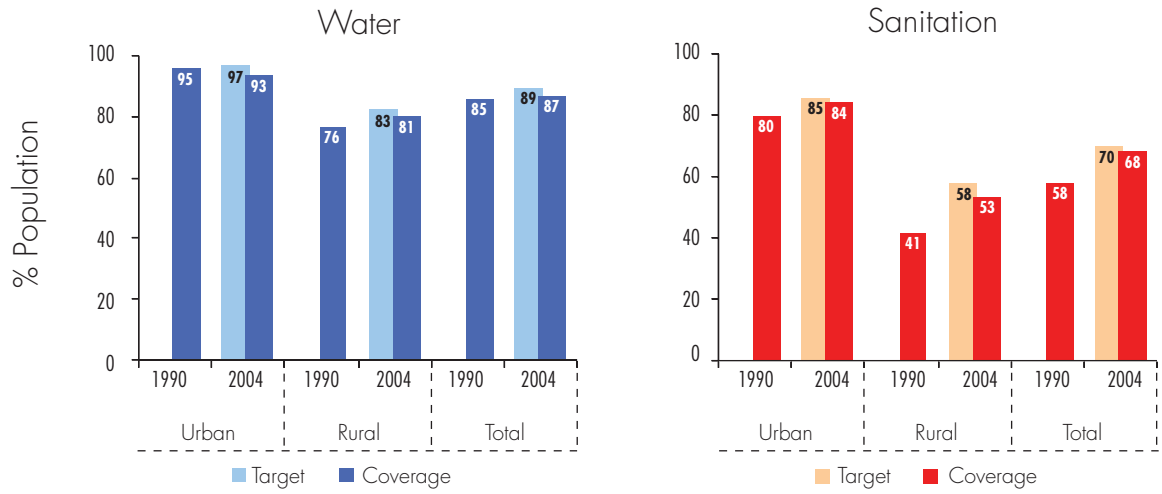

Figure 7.1-4: Water supply and sanitation coverage in rural and urban settings during 1990-2004 for northern Africa (Western Sahara is excluded due to incomplete data)

Source: WHO/UNICEF (2006), redrawn by UNEP

Population growth

The main population centres in northern Africa are concentrated along the north coast and the Nile River, with annual population growth rates varying between 1.8-3 per cent%. Increased water demands, and the potential for pollution hazards, illustrate the human-induced stresses on water resources associated with these population centres.

The total population of the region is estimated to be about 198 million, with nearly 40 per cent being in Egypt, compared to less than 3 per cent in Libya (Table 7.1-3). The projected population increase to more than 250 million by 2050 (Fig. 7.1-5) is expected to significantly increase the need for water supply and sanitation services.

Table 7.1-3: Total population of northern Africa

Country	Population (inhabitants)	Per cent of total population
Morocco	33,241,259	17
Algeria	32,930,091	17
Tunisia	10,175,014	5
Libya	5,670,688	3
Egypt	78,887,007	40
Sudan	37,000,000	18
Total	**197,904,059**	**100**

Source: Wikipedia, July 2006; Estimation of the United Nations, 2006, redrawn by UNEP

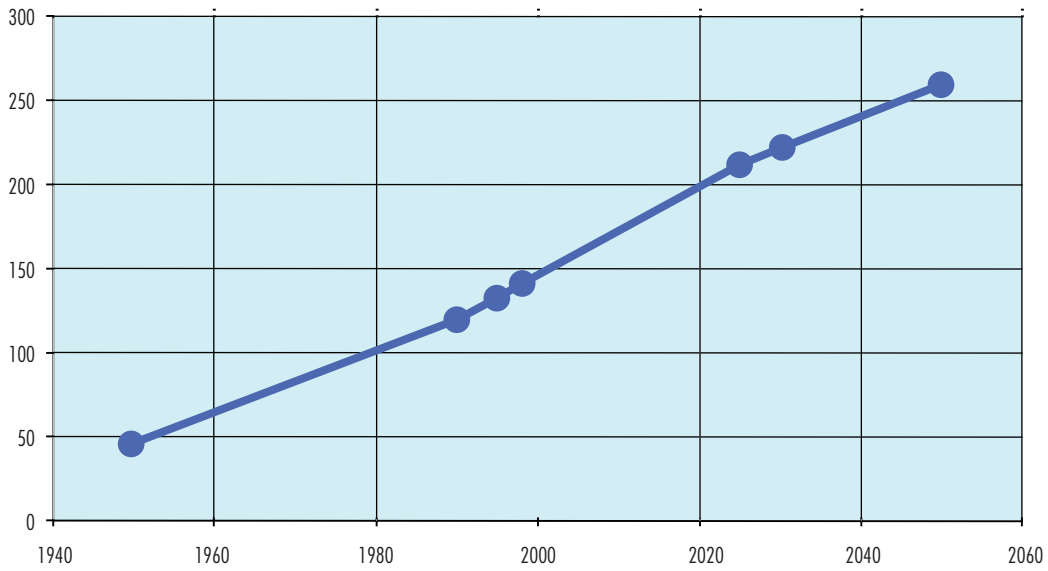

Figure 7.1-5: Present and projected population growth for northern Africa

Source: WRI (2002), redrawn by UNEP

Water-related conflicts

The average per capita renewable water resources in northern Africa has decreased from 3,430 m^3 in 1960, to less than 1,000 m^3 in 2005. It is expected to be further reduced to about 670 m^3 by 2025. Thus, renewable freshwater in several countries will barely meet basic human needs in about 20 years. This will likely increase competition for water resources between different water-use communities within the countries, with some restless incidences already having happened in western Sudan between the nomadic tribes and the sedentary agro-pastoralists. Water-related conflicts also may arise because of increased competition between riparian countries over shared and non-renewable water resources, especially in the absence of a comprehensive assessment of actual water uses, and the true potential of available water resources in many of these shared water basins.

7.1.3 Management

Water sector reform

Most countries in the region realized in the 1900s that a 'business as usual' scenario for dealing with water management and water security issues is no longer suitable to cope with future challenges. A gradual shift to Integrated Water Resources Management (IWRM) is being initiated throughout the region, exhibiting variable levels of implementation. There is an actual need for: (i) reinforcement of institutional frameworks as a means of strengthening national and local institutions in the water sector; (ii) better management of shared river basins and aquifers; (iii) building the institutional capacities for the implementation of IWRM; and (iv) good water governance.

Participatory approaches are increasingly being introduced at various levels for water resources management. Examples including establishment of Water User Associations in Egypt, the National Water Council in Morocco, and a framework for consultations between Algeria, Libya and Tunisia in regard to the NWSAS.

Vulnerability studies in northern Africa

Few studies have addressed the vulnerability of water resources to climate change and human-induced effects. Within the UNFCCC (UN Framework Convention on Climate Change), the countries of the region have completed the first National Communication on Climate Change Studies, emphasizing aspects and issues of the vulnerability of water resources to climate change. The process of producing the second National Communication is now underway in the countries of the region, and these studies will provide a basis for establishing strategies needed to face the vulnerability of water resources to climate change, and to suggest measures for mitigation and adaptation.

Available studies include:

- National Communication on Climate Change Studies. Reports of the North African sub-region countries;
- Vulnerability of northern African Countries to Climatic Changes http://www.cckn.net/compendium/north_africa.asp
- Water and Climatic Changes in North Africa, a 1998 publication within the framework of the UNEP-GEF Project RAB94G31; and
- Climate and Health in North Africa, a 2002 publication within the framework of the UNEP-GEF Project RAB94G31.

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7.2 MOULOUYA RIVER BASIN

7.2.1 Physiography

With a surface area of 76,664 km² (29,600 mi²), the Moulouya River Basin is the largest river basin of Morocco, and of the non-Saharan river systems of the Maghreb region (Figure 7.2-1). It originates in the Atlas Mountains at an altitude of 1,770 m (5,807 ft), flowing into the Mediterranean Sea. In regard to topography, about 3 per cent of the drainage basin is mountainous (altitude >2,500 m [8,202 ft]), 15 per cent is hilly (1,500 m [4,921 ft] < altitude <2,500 m [8,202 ft]), 71 per cent is foothills and a plateau region (500 m [1,640 ft] < altitude <1,500 m [4,921 ft]), and 11 per cent is plains and valleys. The slopes of the streams gradually decrease from about 0.56 per cent in the upper part of the basin, to 0.19 per cent in the lower Moulouya. The upper basin is separated from the lower floodplain by the large Mohammed V Reservoir, which traps most of the sediment delivered from the upstream region. The bedrock consists predominantly (97 per cent) of sedimentary rocks (calcareous rocks, marls, sandstone, conglomerate, etc.), with crystalline and metamorphic rocks outcrops forming only 3 per cent of the basin area (Conseil Supérieur de l'Eau 1990).

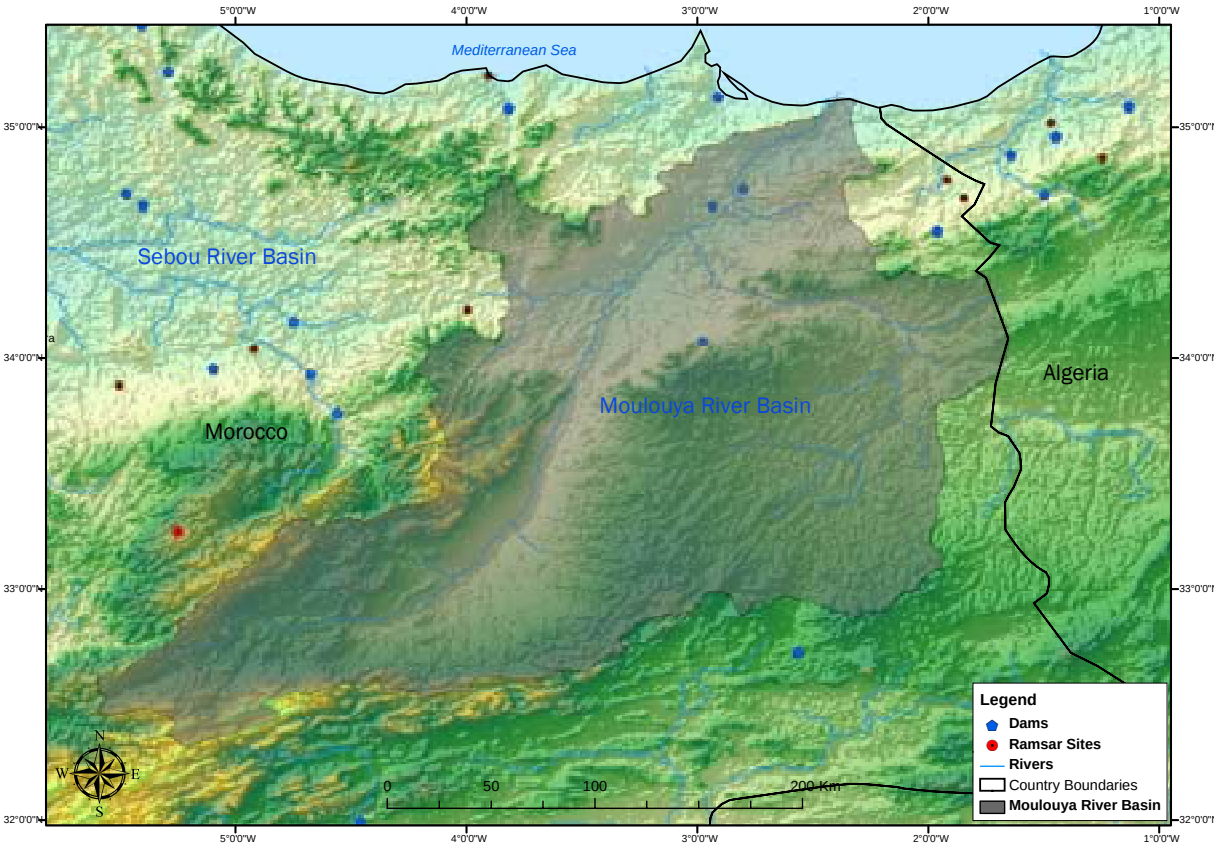

Figure 7.2-1: Moulouya River Basin

Climate

The climate is Mediterranean, from arid to semi-arid, with 80 per cent of the catchment exhibiting high aridity. The average precipitation ranges from 200-600 mm.yr^{-1}, (7.9-24 in.yr^{-1}), with most of the precipitation occurring in only a few days. The runoff is estimated to be 16 mm (0.6 in), for an average precipitation of 300 mm.yr^{-1} (12 in.yr^{-1}). The mean annual temperature ranges between 9-20 °C (48-68 °F).

Box 7.2-1: Main characteristics of Moulouya River Basin

Basin

Surface area:	76,664 km^2 (29,600 mi^2)
MAP:	300 mm.yr^{-1} (12 in.yr^{-1})

Demography

Population:	2.2 million
Density:	33 persons.km^{-2} (85 persons.mi^{-2})

Water Resources

River length:	≈ 600 km (373 mi)
MAR:	2,122 Mm^3.yr^{-1}

Major Dams

Mohamed V	530
Mechra Homadi	82
Hassan II	3
Total storage:	700

Water Use

Agriculture
Domestic
Industry
Hydropower

Increasing

Vulnerability

Increases down the valley

Source: Agence du Bassin Hydraulique de la Moulouya (2006) www.water.gov.ma/

Ecosystems

Among the most valued natural resources in the basin is the coastal wetland of the Moulouya River, which constitutes one of the most important coastal wetlands of the Mediterranean coast. It represents a Site of Biological and Ecological Interest (SBEI), with an area of about 3,000 ha (12 mi^2).

www.wikimedia.com

The wetland is a refuge for many birds of global or national interest, and a national-protected habitat for diversified wildlife and rare plants. In fact, among the 67 globally-threatened taxa present on Morocco's Mediterranean coast, 18 are present on the SBEI of the Moulouya.

The basin also includes the Beni Snassen Forest, which also is classified as a SBEI because of its rich, diverse vegetation about a 6,000 m (1,969 ft) altitude, the Nador Lagoon, the most important lagoon in Morocco, the cliffs of the Moulouya Cap des Trois Fourches, and the Jbel Gourougou. The principal objective of the project "MedWetCoast-Morocco" (2003), which includes all these ecological sites, is protecting and conserving these ecosystems.

Land and water degradation

According to the Administration des Eaux et Forêts et de la Conservation des Sols (1994), the catchment erosion is estimated at about 250 t.km^{-2}.yr^{-1} (1.45 million lbs.mi^{-2}.yr^{-1}). This degradation is directly linked not only to the geological and morphological nature of the land, but also to the deforestation and vegetation clearing. The areas of erosion cover approximately one-fifth of the Basin (Dakki et al. 2003).

In terms of water quality, domestic and industrial effluents are discharged directly into the Moulouya River without any pre-treatment. Most of the aquifers are contaminated, and also are becoming increasingly saline because of poor agricultural practices.

Hydrology

There currently are 21 hydrometric stations in the Moulouya Basin. The recorded flow at the Melg El Ouidane station, representing the total flow of the upstream basin controlled by the dam, with an area of 49,920 km^2 (19,274 mi^2), was estimated to be approximately 316 m^3.s^{-1} from 1963-1995. Like all Mediterranean rivers, however, the flows are very irregular on both an annual and inter-annual basis. The mean annual surface water resources are approximately 1,610 Mm^3. The Agence du Bassin Hydraulique de la Moulouya estimates the supply to the Mohamed V. Dam to be approximately 940 Mm^3.yr^{-1}.

In terms of infrastructural development, the basin encompasses three large dams (Mohamed V; Mechra Homadi; Hassan II), and more than 40 small reservoirs, with a total storage capacity of 21,830 Mm^3. The Mohamed V Dam assures irrigation of the plains of the lower Moulouya, through the waters released and diverted to the setting-off Mechra Homadi Dam. Two canals run from the dam, including the canal of the Triffa on the right bank, and the canal supplying the perimeters of the Zebra, Garet and Bou Areg on the left bank (Figure 7.2-2). The Mohamed V Dam also is equipped with a hydropower station that supplies the irrigation waters, and part of the overflow.

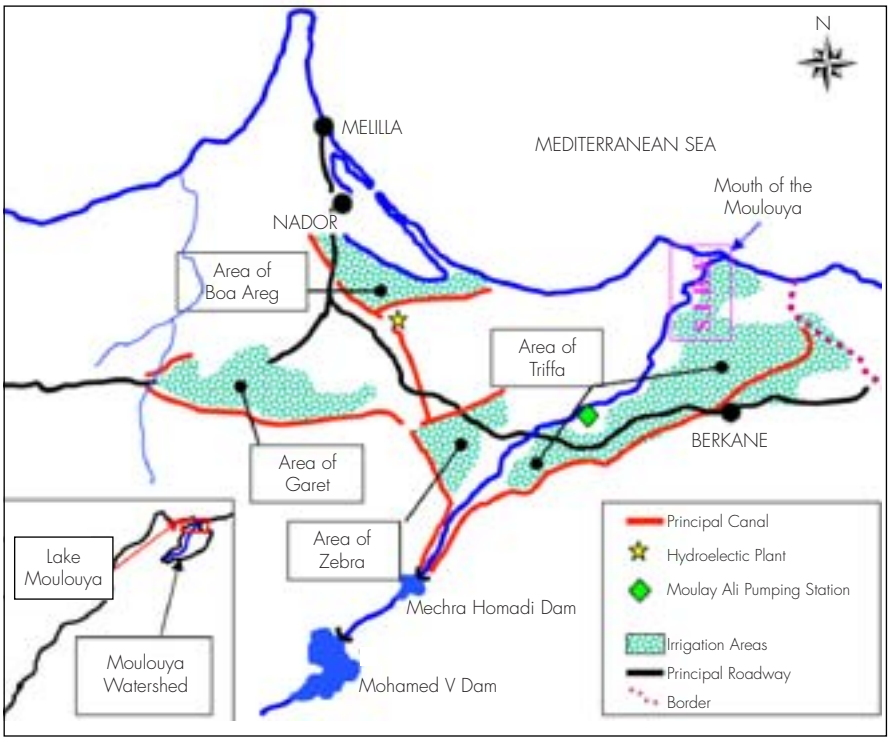

Figure 7.2-2: Infrastructural development in lower portion of Moulouya Basin

Source: Snoussi M. (2003)

Hydrogeology

The Moulouya River Basin encompasses nearly 30 groundwater units. The importance of these units depends on the geological structures, the lithology of the basement, and the precipitation.

The groundwater potential is estimated at 512 $Mm^3.yr^{-1}$. According to current information, the total volume of exploitable groundwater is nearly 450 $Mm^3.yr^{-1}$, of which about 80 $Mm^3.yr^{-1}$ has a salinity of more than 2 $g.L^{-1}$ (Plains of Triffa and Garet-Bouareg).

In regard to the Lower Moulouya, the hydro-geological basin comprises:

- The Triffa water table, a shallow aquifer in which 3,000 wells are currently used to complement the surface water for irrigation; only one-third of the area is suitable for irrigation, however, due to the high salinity of the groundwater.
- The Béni Snassen water table, a deep aquifer that occurs in the dolomitic limestone of Lias, which constitutes an important aquifer where springs are used for irrigation, and wells for potable water supply.
- The Garet and Bou Areg water tables are fed by precipitation, and runoff from irrigation; the total groundwater volume from the different aquifers currently in use is estimated to be about 230 Mm^3, of which two-thirds is used for irrigation.

7.2.2 Socio-economy

Demography

The population of the Moulouya Basin was approximately 2.2 million inhabitants in 1994. It is predominantly rural, but with an increased rural-to-urban migratory flux because of rural poverty and low employment opportunities. Major cities in the basin include Oujda, Nador, Taourirt, and Midelt. According to official estimates, the growth rate of the urban population was 4.31 per cent during 1971-1982, and 4.41 per cent during 1982-1985. It is expected to decrease to 1.99 per cent during 2010 to 2020. The growth rate for the rural population is expected to decrease to 0.49 per cent during 2000-2010, and to zero for the period 2010-2020.

Economy

The socioeconomic activities are dominated by the agro-pastoral sector (138,000 km^2 (53,282 mi^2) of irrigated lands). Agriculture is developed mainly in the lower Moulouya, which has fertile soils and adequate water supply. The main crops are cereals, horticulture, and sugar beets. In the more arid zones, the land is used mainly for livestock grazing. Industrial activities (ferrous metallurgy; sugar refinery; cement factories) are concentrated mainly in the northern regions of the basin.

Water uses and water demands

Water demands and competition in the basin are very high. Agriculture consumes more than 95 per cent of the available water, with domestic and industrial sectors utilizing the remaining 5 per cent. Of the groundwater, two-thirds is used for irrigation, and one-third for potable and industrial use. The situation is anticipated to worsen (Table 7.2-1).

Based on these projects, it appears the available water resources in 2020 will not be able to fully meet water demands. Further, the obtained deficit of 176 $Mm^3.yr^{-1}$ is an underestimate, since it does not consider the reduced water resources attributed to global warming, which is estimated for Morocco to be approximately 15 per cent by 2020 (MATUHE 2001).

Table 7.2-1: Projections of available water resources and water demands by 2020

Resources/demand by 2020	Volume ($Mm^3.yr^{-1}$)
Surface water	930
Groundwater	500
Total water resources	1,430
Demand for drinking and industrial water	148
Demand for irrigation water	1,458
Total water demand	1,606
Balance	**- 176**

Source: Ministère des Travaux Publics (1997)

7.2.3 Management

Institutional and legislative frameworks

Several administrations are involved in water issues of the Moulouya River Basin, specific ones being (i) Agence du Bassin Hydraulique de la Moulouya (AHBM); (ii) Office Régional de la Mise en Valeur Agricole de la Moulouya (ORMVAM); (iii) Office National de l'Eau Potable (ONEP); (iv) State Secretariat for Water Affairs; (v) Water and Forests Administration; and (vi) State Secretariat for the Environment. On an inter-sectoral level, the Water and Climate High Council devises the general orientation of national water policy, whereas the AHBM organizes and manages water at basin level.

In regard to legislation, the Water Law (10-95) assures a more efficient, decentralized management of water resources, jointly established at all levels by the administration, water users, and elected politicians. It is because of this law that the Moulouya Basin Agency, as well as the other basin agencies, was created to manage water more coherently, considering the entirety of the watershed.

7.2.4 Key Issues, adaptation and mitigation

Physiography

Climate vulnerability

The Moulouya River Basin is highly vulnerable to climate variability and change. Several floods and droughts have been reported over the last few decades. Floods in May 1963 reached a flow of 7,200 $m^3.s^{-1}$, causing serious damage. Similar events occurred in April 1975 and November 1993. The drought periods in the Moulouya Basin, lasting from 2-5 years on average, also have had severe impacts on agriculture, livestock breeding, potable water supply, and hydroelectric production.

Adaptation and mitigation

There is a need:

- To develop an early warning system for floods and droughts.
- To adapt agriculture to drought conditions, by growing appropriate crops and implementing water conservation techniques.

Land and water degradation

Land degradation is becoming a serious problem in the Moulouya River Basin, and is the main cause for the silting-up of Mohamed V Reservoir. This reservoir is predicted to fill with sediment within 59 years, having already lost 35 per cent of its water storage capacity during 1967-1991 (Snoussi et al. 2000). It is estimated that 70,000 ha (270 mi^2), and 300 megawatts of electricity, will be lost by 2030 as a consequence of the high rate of dam siltation.

Adaptation and mitigation

There is a need:

- To reforest and stabilize the landscape.
- To strengthen regulations for enforcing land management and land use.
- To protect water resources from pollution.

Socio-economy

Population growth and urbanization

Increased urbanization and tourism development, particularly around Berkane and Nador areas, are exerting significant pressures on water supply, especially in summer, when the water supply is lowest.


ONEP

Adaptation and mitigation

There is a need:

- To develop policies and legislation to control urbanization.
- To develop further infrastructure, including upgrading water supply and sewage systems.

Water availability, uses and demands

The river basin's water resources are extensively exploited, and the projections indicate that, despite the construction of new dams, the water resources will not be able to fully meet water demands by 2020.

Adaptation and mitigation

There is a need:

- For further groundwater resources assessment and development.
- To develop alternatives water sources (e.g., recycling, desalinization, hydrothermal, etc.).
- For effective pollution control management.
- For water demand management and creation of awareness.

Management

Institutional and legislative frameworks

Despite the existence of many institutions involved in administering water issues in the Moulouya River Basin, there is no coordination, and no appropriate tools for the effective management the basin's water resources.

Adaptation and mitigation

There is a need:

- To improve communication and coordination between different institutions.
- To strengthen the mandate of the Moulouya Basin Agency.

7.2.5 References

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7.3 NILE RIVER BASIN

The Nile River Basin covers a large area of ~3 million km^2 (1,158,306 mi^2), comprising approximately 10 per cent of the African continent, and containing the longest river in the world, with a total length of approximately 6,700 km (4,163 mi) (Figure 7.3-1; Box 7.3-1). The basin is shared among 10 countries, and extends from latitude 4° S to 31° N, and longitude 21° E to 40° E. Because of its size, and variety of climates and topographies, it is one of the most complex major river basins in the world. Box 7.3-1 summarizes the main characteristics of the Nile River Basin.

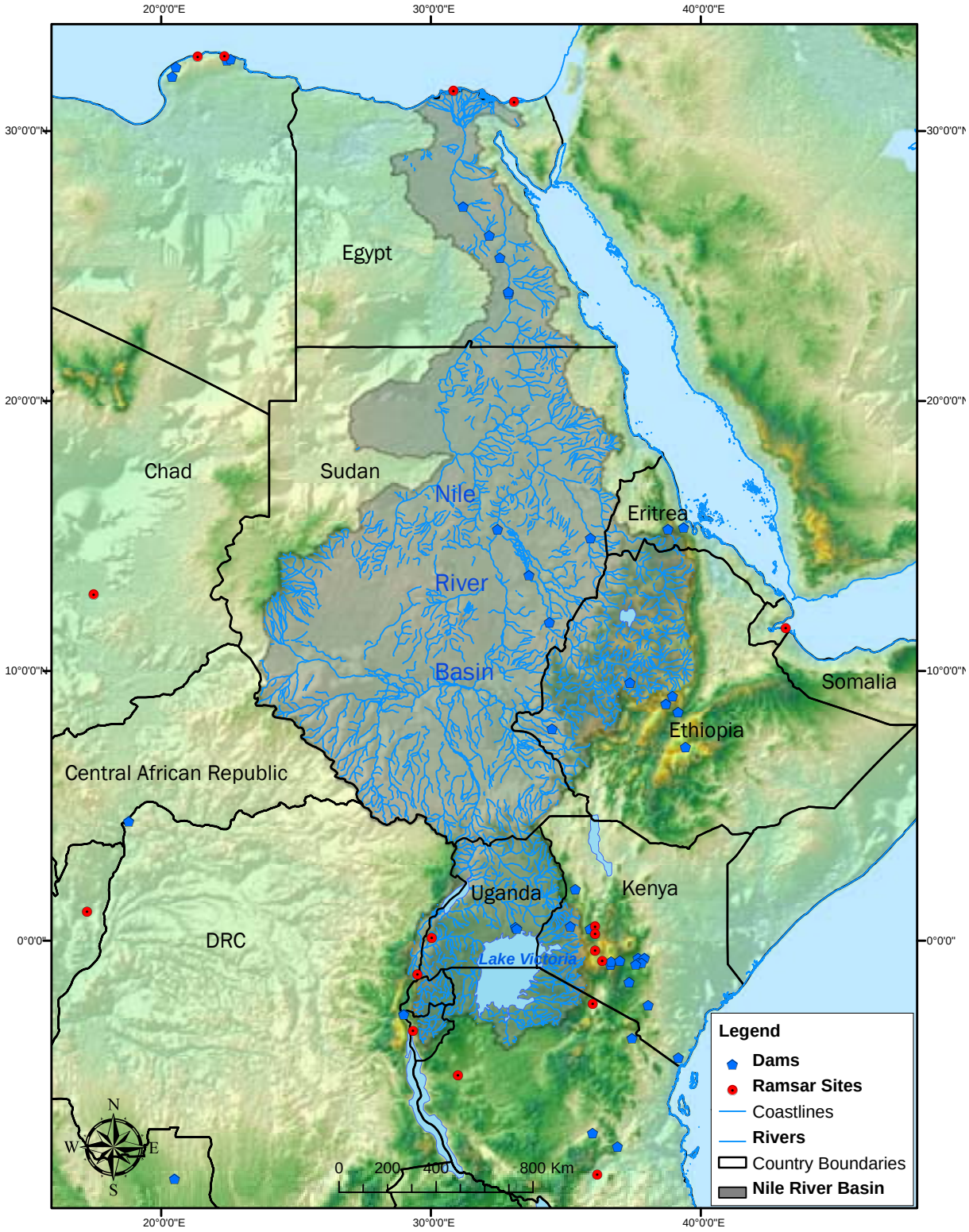

Figure 7.3-1: Nile River Basin

Box 7.3-1: Main characteristics of Nile River Basin

Basin

Surface area:	2,900,000 km^2 (1,119,696 mi^2)
MAP:	0–2,100 mm.yr^{-1} (83 in.yr^{-1})

Demography

Population:	160 million
Density:	55 persons.km^{-2} (142 persons.mi^{-2})

Water Resources

River length:	6,700 km (6,700 mi)
Rainfall:	1,660,000 Mm^3.yr^{-1}
River Flow:	84,000 Mm^3.yr^{-1} (at Aswan)

Major Dams

Owen Falls Dam:	2,750,000 Mm^3 (350 megawatts)
High Aswan:	162,000 Mm^3 (2,100 megawatts)
Aswan Dam:	5,000 Mm^3 (345 megawatts)
Roseires:	3,350 Mm^3 (210 megawatts)
Gebel Aulia:	3,000 Mm^3
Khashm Elgirba:	1,300 Mm^3 (13 megawatts)
Sennar Dam:	930 Mm^3 (15 megawatts)

Total dam storage: 2,924,730 Mm^3

Major Aquifer: Nubian Sandstone

Water Use

Agriculture
Domestic
Industry
Mining
Hydropower

Vulnerability

Increasing to the north

Source: World Resources Institute (WRI 2002); Nile Water Sector, Egypt

The Nile has 3 sources: (i) the basin of the Equatorial Lakes plateau; (ii) Ethiopian highland plateau; and (iii) Bahr el Ghazal Basin. Almost 85 per cent of the annual river flow at Aswan in Egypt originates from precipitation on the Ethiopian Highlands, through the Sobat, Blue Nile and Atbara Rivers. The remaining 15 per cent originates from the Equatorial Lakes, through the White Nile. The Lake Victoria Basin, the major sub-basin of the Equatorial Lakes, is described in detail in the eastern Africa section (section 4.9).

7.3.1 Physiography

Rainfall in the Nile River Basin ranges from nil in most of Egypt and northern Sudan, to almost 1,600 mm.yr^{-1} (63 inch.yr^{-1}) on the southeast borders of the Sudan, and almost 2,100 mm.yr^{-1} in the Equatorial lakes and Ethiopian Highlands. The average total rainfall volume over the Nile River Basin is ~1,660,000 million m^3.yr^{-1}. Less than 4 per cent (55,500 Mm^3.yr^{-1}) of this volume reaches northern Africa through the Nile at the Aswan High Dam in Egypt, where a great proportion is utilized within the country, before the river drains into the Mediterranean Sea. The average annual discharge of the Nile River, upstream of Egypt (84,000 Mm^3.yr^{-1}), is less than 6 per cent of the average total rainfall over the basin. The remaining 94 per cent is kept upstream, where it is used, lost to groundwater seepage and evaporation, or stored in surface waterbodies.

Cropland coverage within the Nile River Basin varies significantly between countries, ranging from about 47 per cent in Burundi and Rwanda, to just 3 per cent in Egypt. The same holds true for pastureland coverage, being 0 per cent in Egypt, and up to 30 per cent in Burundi and Rwanda. In regard to forest and woodland coverage, Egypt has the lowest, while the Democratic Republic of Congo has the highest coverage, comprising nearly 75 per cent of its total land area.

Groundwater resources within the Nile River Basin are highly variable, both in terms of their renewability and their spatial extent. In the northern part of the basin, the main aquifers are the Nile Valley System and the Nubian Sandstone Aquifer System. The Nubian Sandstone Aquifer is fossil (i.e., non-renewable). There are other water-bearing formations in the Nile River Basin, including the Late Tertiary-Pleistocene fluvial sediments, referred to as the Umm Rawaba Formation. It is an important aquifer system in the Sudan, supporting many non-Nilotic people, livestock and vegetation. This aquifer, which occupies 20 per cent of the countries' area, lies under semi-confining conditions, being separated from the overlying sand dunes by a clay-rich layer that varies in thickness and clay content. The mean aquifer thickness is 150 m (492 ft). The groundwater generally flows from the northwest to the southeast, with the groundwater level varying from a few metres to around 328 m (1,076 ft). The groundwater storage capacity is estimated to be approximately 4,000 km^3 while the annual recharge rate is estimated to be only about 600 km^3 (O. Ali, pers. com.).

The per capita annual 'potential renewable water resources' (PRWR) and 'forests, vegetation and cultivated land' for each of the riparian countries is given in Figure 7.3-2. These data clearly demonstrate the decreasing availability of renewable water resources, forests and cultivated land from south to north and, therefore, an increasing vulnerability in the same direction.

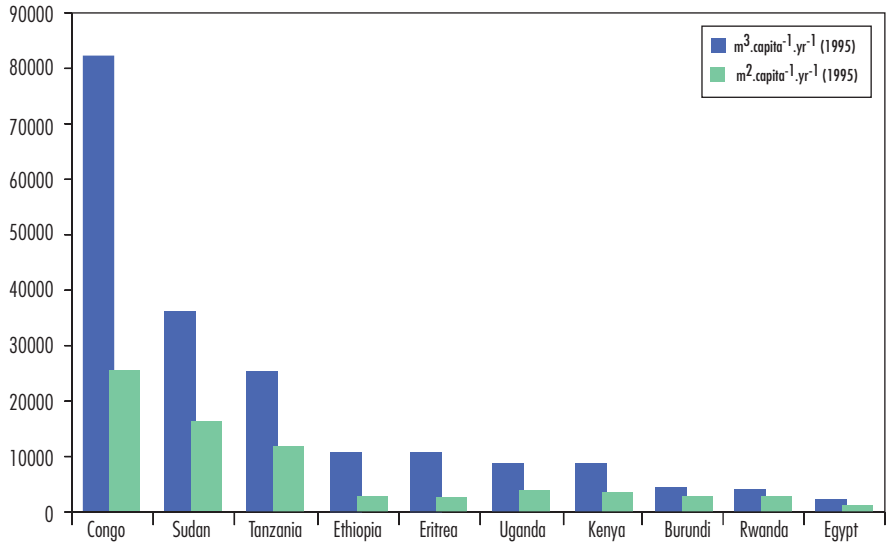

Figure 7.3-2: Per capita potential renewable water resources ($m^3.capita^{-1}.yr^{-1}$) and forests, vegetation and cultivated land ($m^2.capita^{-1}.yr^{-1}$)

Source: Abu Zeid 1996, redrawn by UNEP

It should be noted that the above data are preliminary estimates, and that further investigations and detailed assessments are required for verification, particularly regarding Nile River Basin groundwater resources.

The impact of climate change and variability on the water resources of the Nile River Basin is illustrated in Figure 7.3-3, highlighting a stream hydrograph for one of the gauging stations along the Nile River (Atbara Station), which was established early in the twentieth-century. The hydrograph covers a 90-year period of monitoring from 1907-1997. Three distinct periods of water level increases and decreases are illustrated in the graph, the first period being between 1907-1961 with a slightly rising water level, the second between 1962-1984 with a steep decline, and the third between 1987-1997 with a water-level rise as steep as the decline in the previous period.

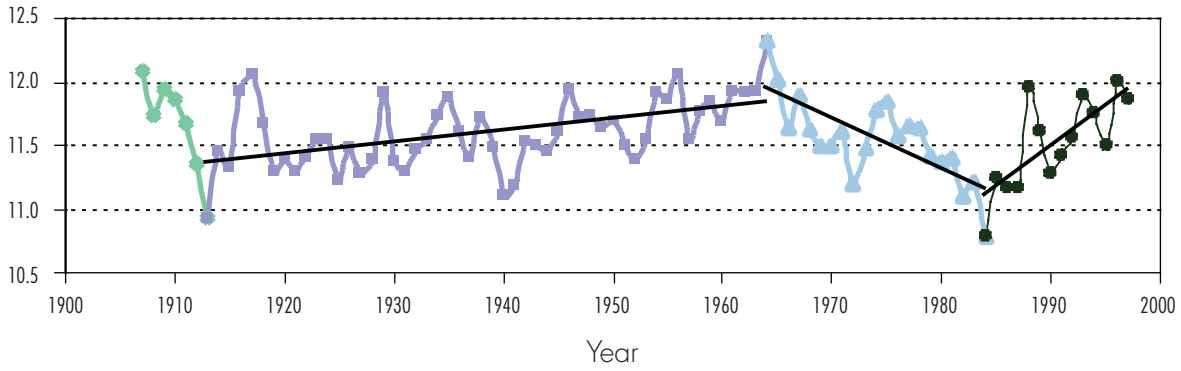

Figure 7.3-3: Annual average stream levels of Nile River at Atbara

Source: Nile Water Sector 2003, redrawn by UNEP

7.3.2 Socio-economy

Population figures for 1997 (WRI 2002) indicate there were just over 160 million people living in the Nile River Basin, which translates to an average population density of about 55 persons.km^{-2} (142 persons.mi^{-2})

Agriculture is the main economic activity in most Nile River Basin countries, contributing 35-50 per cent of the overall GDP, and providing employment to 60-90 per cent of the population. Only Egypt has a smaller agricultural sector, contributing 17 per cent to the country's GDP and providing employment to about 30 per cent of its population.

The Nile River Basin is shared by 10 countries with varying dependencies on, and needs for, freshwater. While the upstream countries depend more directly on precipitation to sustain forests, wildlife, lake ecosystems, rain-fed agriculture, fishing and groundwater recharge, the Nile River is the only renewable water resource available to sustain irrigated agriculture and drinking water supplies for the downstream country of Egypt.

There is sufficient water overall in the Nile River Basin to sustain its population. If precipitation was evenly distributed over the basin, the per capita water share of the basin population would be more than 10,000 m^3.capita^{-1}.yr^{-1}, or about 10 times the water scarcity threshold value of 1,000 m^3.capita^{-1}.yr^{-1}. The per capita water share downstream, however, is less than 1,000 m^3.capita^{-1}.yr^{-1}. Upstream water problems are more related to drainage, flood protection, occasional droughts and drinking water infrastructure, while the downstream problems are more related to water scarcity. Once these problems are clearly identified and understood, there is a great potential for transboundary cooperation, rather than conflict. Upstream countries could use surface waterways to generate power for groundwater development in remote areas, in order to

supply drinking water and supplement irrigation during drought periods. Meanwhile, projects for decreasing evaporation losses and preventing flood hazards upstream could be developed to make additional riverflows available for the downstream countries downstream.

Consistent with this perspective, negotiations have recently begun between the Nile River Basin countries under the Nile Basin Initiative (see Section 7.3.3). This is expected to result in joint projects, and possibly a treaty, representing a common understanding among the basin countries.

7.3.3 Management

Sharing and utilization of the waters of the Nile River Basin have long been governed by bilateral treaties (1929 - Egypt and Britain; 1959-Egypt and Sudan). Further, a number of basin countries have been collaborating on technical issues since 1967. The first regional Nile River Basin project was the Hydromet (Hydrometeorological Survey of the Catchments of Lakes Victoria, Kyoga and Albert), which involved Burundi, Egypt, Kenya, Rwanda, Sudan, Tanzania, Uganda and Zaire, with Ethiopia participating as an observer.

The Ministers of Water Affairs of 6 Nile River Basin countries established the Technical Cooperation Committee for the Promotion of the Development and Environmental Protection of the Nile River Basin (TECCONILE) in 1992. The TECCONILE members were Egypt, Rwanda, Sudan, Tanzania, Uganda and Zaire. Burundi, Ethiopia and Kenya participated as observers.

The Nile Basin Initiative (NBI) was launched in February 1999. It is a regional partnership, through which the 10 basin countries have united in common pursuit of the long-term development and management of the waters of the Nile River Basin. It is developing an agreed basin-wide framework, being guided by a shared vision "to achieve sustainable socio-economic development through the equitable utilization of, and benefit from, the common Nile Basin water resources." Thus, the 10 basin countries have now begun to speak openly about the challenges they face.

7.3.4 Key issues, adaptation and mitigation

The main key issue relates to water scarcity, variability, pollution and land degradation.

Physiography

Climate vulnerability

The impact of climate change and variability on the water resources of the Nile River Basin is illustrated in Figure 7.3-3.

Adaptation and mitigation

There is a need:

- To develop an early warning system for managing floods and droughts.

Socio-economy

Population growth and urbanization

Population growth and urbanization in the Nile River Basin countries increases wastewater disposal, most likely resulting in deteriorated river water quality. Upstream pollution in the basin also will affect downstream water quality. Increased urbanization in upstream countries also may result in increased flooding in downstream countries, since urbanization decreases soil infiltration and natural evapotranspiration and more runoff will contribute to river flows to downstream countries.

Adaptation and mitigation

There is a need:

- To invest more in upgrading and developing infrastructure, in both urban and rural areas
- To implement measures curbing high population growths.

Water availability, use, demand and pollution

The basin is experiencing severe water shortages, worsened by water pollution (Nile River and tributaries) because of inadequate disposal and treatment of waste (water) originating from municipal waste, industrial effluent and agricultural drainage. Sedimentation (in the dams' reservoirs) and bank erosion are severe problems that particularly affect the stretches of the Nile River in Sudan. Table 7.3-1 shows the severity of siltation within the reservoirs in Sudan.

Table 7.3-1: Current storage capacities of dams in Sudan

Dam	Design water storage capacity (km^3)	Current water storage capacity (km^3)	Water loss (per cent)
Sennar	0.93	0.37	60
Roseiris	3.35	2.2	34
Jebel Aulia	3.0	3.0	0
Khasm el Girba	1.3	0.6	54
Total	8.58	6.17	28

Source: Ali (2007)

Adaptation and mitigation

There is a need:

- To strengthen IWRM efforts in all the riparian countries in a co-ordinated manner, focusing on holistic water use.
- For proper management of water demands.
- For watershed management projects that emphasize increasing and reinstating natural plant cover.
- To institute pollution monitoring and mitigation measures at the basin level, to ensure that good water quality is maintained
- To consider desalination methods as a freshwater source.

Water-related conflicts

The Nile River Basin is shared by 10 countries with varying dependencies on, and needs for, freshwater resources. The individual approaches of each country to the development and management of the basin's water resources will definitely affect downstream countries, particularly Egypt, inevitably leading to tensions or conflicts between the countries. Intra-country water conflicts also could arise among different water users in areas suffering from water scarcity and variability (e.g., the Sudan).

Adaptation and mitigation

There is a need:

- For an integrated approach in developing and managing the basin's natural resources (see Management adaptation and mitigation below)

Management

International protocols

The Nile River Basin Initiative (NBI), launched in February 1999 by the 10 riparian countries, is an initial important step in addressing the sustainable development of the basin's water resources.

Adaptation and mitigation

There is a need:

- To formulate the institutional and legislative framework of the NBI.
- To strengthen the NBI through capacity-building (e.g., human resources training; equipment and material).
- To implement IWRM in all basin countries.
- To incorporate other natural resources (e.g., land) in holistic basin management.
- To ensure equity in allocating water resources amongst the riparian countries, since this will act as an incentive for the countries to effectively participate in managing the basin's natural resources.

7.3.5 References

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7.4 SEBOU RIVER BASIN

The Sebou River Basin, with a total area of about 40,000 km² (15,444 mi²) is one of the largest basins in Morocco. It is located between 33° N and 35° N, and between 4° W and 7° W (Figure 7.4-1). It stretches for about 600 km (373 mi) from its source in the Middle Atlas Mountains to the Atlantic Ocean, draining the Rif Mountains in the north, and the Middle Atlas in the south. Box 7.4-1 summarizes the main characteristics of the Sebou River Basin.

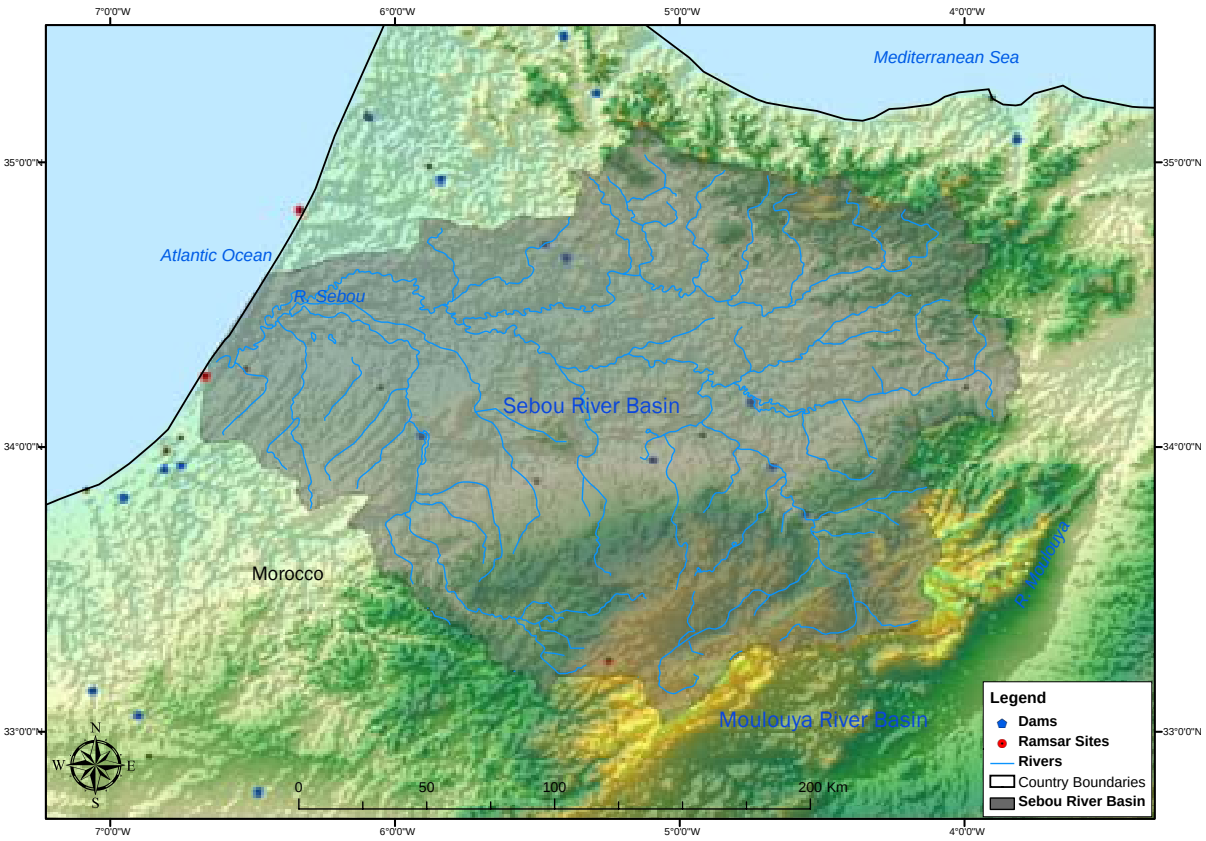

Figure 7.4-1: Sebou River Basin

7.4.1 Physiography

The physiography of the watershed is strongly influenced by the altitude variation between the north and the south. The Sebou Basin can be divided into three distinct geomorphic regions, including the upper, middle, and lower Sebou. The upper Sebou rises over 2,800 m (9,186 ft) in altitude in the Middle Atlas Mountains, being underlain mainly by calcareous rocks. The middle-Sebou Basin is located at the Rif and the Prerif Mountains, which are characterized by an average altitude of 2,000 m (6,562 ft), very steep slopes, and a substratum composed of shale, marls and sandstone. The Ouerrha and the Inaouene Rivers are the major tributaries of the Sebou Rivers, draining the Rif and the Prerif Mountains. The upper Sebou River is characterized by the perennial flow of some tributaries to the Sebou River, while other tributaries such as the Ouergha and Inaouène Rivers, have temporary flow regimes, depending on the quantity of precipitation. Flash floods sometimes occur. At the lower end of the basin, the Sebou River opens into a wide valley, the Gharb, where it meanders through the flood plain.

Box 7.4-1: Main characteristics of Sebou River Basin

Basin

Surface area:	40,000 km² (15,444 mi²)
MAP:	600 mm.yr⁻¹ (24 in.yr⁻¹)

Demography

Population:	6.2 million
Density:	50–200 persons.km⁻² (130-518 persons.yr⁻¹)

Water Use

Agriculture
Domestic
Industry
Hydropower

Increasing

Water Resources Vulnerability

River length:	≈ 600 km (373 mi)
MAR:	5,500 Mm³.yr⁻¹

Climate variability and change
Industrial and agricultural pollution
Land erosion & siltation of dam

Major Dams (Mm³)

Al Wahda	3,714
Allal El Fassi	64
Idriss 1er	1,152
El Kansera	230
Asfalou	317
Sidi Ecchahed	170
Sahla	62
Bab Louta	35

Total dam storage ≈ 5,836 Mm³

Major Aquifers: Gharb, Mamora , Middle Atlas, Fès-Meknès and Couloir Fès-Taza

Source: Agence du Bassin Hydraulique du Sebou website: http://www.abhsebou.ma/

Climate

The climate prevailing in the basin is a Mediterranean type, ranging from sub-humid to semi-arid, being controlled by the Atlantic, Mediterranean and Saharan airflow influences. The basin's mean annual precipitation is about 600 mm (24 in). High rainfall, totalling more than 1,000 mm.yr⁻¹ (39 in.yr⁻¹), occurs in the Rif Mountains, while low rainfall (less than 300 mm.yr⁻¹ [12 in.yr⁻¹]) occurs in the Gharb Plain (Figure 7.4-2). The mean annual temperature is 13 °C (55 °F) in winter and 27 °C (81 °F) in summer. The evaporation varies between 340 mm.yr⁻¹ (13 in.yr⁻¹) in summer, and 80 mm.yr⁻¹ (3 in.yr⁻¹) in winter in Fes.

Ecosystems

The Sebou River Basin is characterized by the presence of many important wetlands (Gharb Plain wetlands, Sebou estuary, Merja El Halloufa, Merja Bekka, Idriss 1st reservoir, etc.). This includes two Ramsar sites: (i) Sidi Bou Ghaba Lake (800 ha [3 mi²]), which is considered the main stopover for many bird species; and (ii) Aguelmane Sidi Ali wetlands (600 ha [2.3 mi²]), which are among the most southernmost representatives of the lacustrian mountain ecosystems of the temperate paleo-arctic bioregion. In addition to the wetlands, the Mamora Forest is an important ecosystem, covering an area of about 390 km² (151 mi²), and encompassing native species, is largely dominated by the cork oak. Eucalyptus, pine and acacia are among the main introduced species in this forest.

There are also two protected areas; namely, the Tazzeka National Park (13,737 ha [53 mi^2]) and Ifrane National Park (125,000 ha [483 mi^2]). Some of these sites, however, exhibit environmental problems, such as pollution (sometimes due to the incineration of solid waste) and over-exploitation of natural resources.

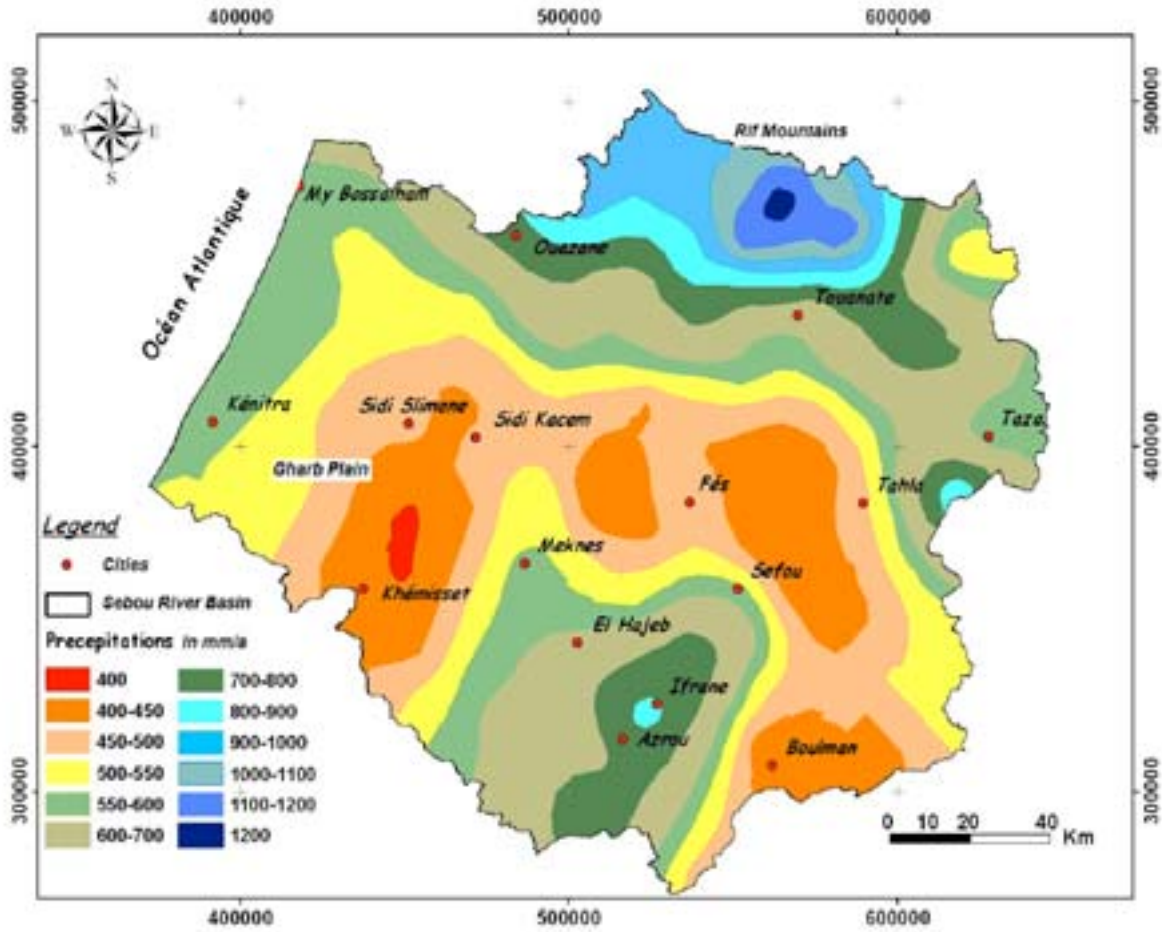

Figure 7.4-2: Distribution of precipitation in Sebou River Basin

Source: Agence Hydraulique du Bassin du Sebou, 2006

Land and water degradation

While land erosion in the Sebou River Basin is caused by physical factors (e.g., young mountains; extensive sedimentary rocks; irregular and often stormy precipitation; scarce vegetation), human activities (deforestation; overgrazing) also are exacerbating land degradation. The mean rates of erosion have been estimated to be between 1,000-2,000 t.km^{-2}.yr^{-1} (5.8-11.6 million lbs.mi^{-2}.yr^{-1}) in the Prerif, reaching 6,000 t.km^{-2}.yr^{-1} (34.8 million lbs.mi^{-2}.yr^{-1}) in some parts of the Rif Mountains. This high rate of erosion is responsible for rapid silting up of the reservoirs. According to Lahlou (1994), the annual sedimentation rate in Moroccan reservoirs has reached 50 million m^3.yr^{-1}. This siltation has serious environmental and socio-economic impacts, since it reduces the reservoirs' capacity and life spans, and affects the morphological equilibrium of the coastline (Snoussi et al. 2002).

Hydrology

The hydrology of the Sebou River system is influenced by its numerous tributaries. The High Sebou (12.5 per cent of the overall supply of the Sebou) is relatively uniform because of reliable water sources (e.g., melting snow). The Sebou system grows progressively irregular as it receives tributaries

from pluvial regimes, such as the Ouerrha, which represents only 15 per cent of the basin's total area, but is responsible for an average of 5,600 $Mm^3.yr^{-1}$, which is approximately half of the whole Sebou supply. These inflows occur mainly as flash-floods, which often resulting in disastrous inundations in the Gharb Plain. The maximum observed flow reached 8,000 $m^3.s^{-1}$ at Mjara in December 1950, with the corresponding volume increasing to 1 billion m^3. The floods of 1962-1963, which affected almost all the tributaries, were more devastating in the Gharb Plain, flooding an area of about 18,000 hectares (69 mi^2).

Runoff extremes have been recorded for the Sebou River System, ranging from 500 million $m^3.yr^{-1}$ to 15,000 million $m^3.yr^{-1}$, because of climatic variations.

The seasonal flow distribution reaches a maximum in December, January and February (40 per cent, in the case of Ouerrha). For the High Sebou River and the other tributaries, the maximum flows take place in February and March, and sometimes in April.

Hydrogeology

The main aquifers of the Sebou River Basin (Gharb; Mamora; Saïs) are essentially composed of Liasic and Plio-Quaternary deposits, displaying several lithologies, including sandstone, sand, and limestone (Table 7.4-1). The Gharb and Mamora aquifers are underlain by Mio-Pliocene marls (Zouhri *et al.* 2003). The aquifers, which are recharged mainly by rainfall, constitute the most important water source in the basin. In the Middle Atlas Mountains, the well-developed karstic system also constitutes an important aquifer system.

Table 7.4-1: Main characteristics of aquifers in Sebou River Basin

Groundwater units	Nature of basement	Surface (km^2)	Geoundwater volume (Mm^3)		
			Recharge	Potential	Exploited
Tabular Middle Atlas	Liasic Calcareous	4,461	460	260	271
Folded Middle Atlas		4,200	230	80	80
Fes-Taza Corridor		1,560	100	56	56
Fes-Meknes	Plioquaternary and Liasic Calcareous	2,100	220	200	300
Gharb	Sand and sandstone	4,000	330	270	270
Mamora	Sand	2,200	180	128	128
Drader-Souiere	Sand	600	72	22	22
Bouagba	Sandy sandstone	65	3	3	4
My Driss Zerhoun	Sandstone	250	16	16	16
TOTAL		19,436	1,611	1,035	1,147

Source: Agence du Bassin Hydraulique du Sebou, 2005

Groundwater use in the basin largely serves agricultural demands and municipal water supplies, while rural communities rely on wells and boreholes for their water supply. Many of the shallow aquifers, however, are vulnerable to pollution. The Mamora coastal aquifer is becoming increasingly vulnerable to seawater intrusion because of its over-exploitation (Ben Kabbour et al. 2005).

Water availability

The Sebou River Basin holds 30 per cent of the country's surface water resources, and 20 per cent of its groundwater resources. The basin's surface water represents nearly one-third of the country's surface water. The surface water resources may reach to 5,561 million $m^3.yr^{-1}$ (average of the period 1939-2002), of which 2,877 million $m.yr^{-1}$ (51 per cent) are drained by the Ouergha River; 615 million $m^3 \cdot yr^{-1}$ (11 per cent) by the upper Sebou River; and 363 million m^3.yr-1 (7 per cent) by the Beht River.

There are nine major aquifers within the basin, with groundwater resources constituting a significant part of its water resources.

7.4.2 Socio-economy

Demography

The Sebou Basin is one of the most populated regions in Morocco. Based on the 2004 National Census, the Sebou River Basin hosts a population of about 6.2 million inhabitants, with 49 per cent living urban areas and the remaining 51 per cent in rural areas. The annual population growth rate is between 1.6-2.3 per cent for urban areas, and between 0.6-0.8 per cent for the rural population. It is anticipated that the population in the Sebou River Basin will reach 7.5 million people by 2020, posing major challenges in the areas of food security, health, social and economic needs, and the rational and sustainable management of natural resources.

Economy

The main economic activities within the Sebou River Basin are industry, agriculture, livestock farming, forestry, and tourism. Agriculture is the most important economic activity, and also the main water-consuming sector. Agricultural land constitutes 1,880,000 ha (7,259 mi^2; 20 per cent of the national potential). The irrigable land covers 375,000 ha (1,448 mi^2), of which 268,800 ha (1,038 mi^2) is currently under irrigation (116,800 ha [451 mi^2] in large irrigation schemes, and 152,000 ha [587 mi^2] in small and medium irrigation schemes).

The basin hosts several industrial units (both artisanal and modern), including a sugar refinery, cooperative dairy, oil refinery, paper mills, flour mills, and ceramic works. The main industries developed in the Gharb Plain are: (i) paper (209,000 tons [468 million lbs]); (ii) olive oil (65 per cent of national production); (iii) leather (60 per cent); (iv) sugar (50 per cent); and (v) refined oil (3,300 tons; [7.4 million lbs]). The tourist activity is limited to the imperial cities (Fez; Meknes), and the thermal springs.

Water uses and water demands

The Sebou River Basin surface water resources are almost fully developed. In fact, satisfying the water needs for domestic water supply and the large irrigation areas of the Gharb Plain, and provide hydroelectric power, a large-scale programme for dam construction has been carried out in the basin. The basin encompasses 10 large reservoirs, and more than 44 small ones, constructed over a period of 70 years. The Al Wahda Dam on the Ouerrha River is the second most important dam in Africa (after the Aswan Dam). It was completed in 1996, with a storage capacity of 3.8×10^3 km^3, and a height of 88 m (289 ft). These dams control river flows, and mitigate the occurrence of floods and the effects of droughts. The storage capacity of the existing dams is estimated to be more than 3,000 $Mm^3.yr^{-1}$.

Irrigation

This is the largest water-consuming sector in the Sebou River Basin, with an annual water supply of 1,500 Mm^3, including 970 Mm^3 from freshwater (97 per cent of all mobilized freshwaters), and 530 Mm^3 from groundwater.

Domestic and industrial water

The water demands of the main conurbations of the Sebou River Basin (e.g., Fez; Meknes; Kenitra; Taza) have long been met from groundwater resources. The rapid population growth and economic development these towns are experiencing means groundwater resources are no longer adequate to meet the increasing domestic and industrial water demands. Efforts are now being focused on complementing groundwater resources, with surface water from the Sebou River. The volume of water used by the domestic and industrial water sectors in 2005 reached 230 Mm^3, of which 200 Mm^3 was from groundwater, and 30 Mm^3 from surface water.

Hydropower production

The hydropower stations corresponding to the Idriss 1st, El Kansera, Al Wahda and Allal El Fassi Dams produce an average energy output of 814 $Gigawatts.hr^{-1}.yr^{-1}$.

The water demand projections for 2020, as forecast by the Ministry of Public Works (1997) for the Sebou River Basin, are 4,060 $Mm^3.yr^{-1}$ (Table 7.4-2). To meet this demand, and also protect the Gharb Plain against flooding, a development programme for 13 new dams is planned in the next 25-30 years.

Table 7.4-2 Projections of population and water demands by 2020.

Population (million inhabitants)	7.5
Domestic and industrial water (Mm^3)	660
Allocation of water for irrigation (Mm^3)	3,400
Area irrigated (ha) [mi^2]	378,780 [1,462]
Total demand (Mm^3)	4,060

Source: Ministère des Travaux Publics (1997)

7.4.3 Management

Institutional and legislative frameworks

The 'Office Régional de Mise en Valeur Agricole du Gharb' (ORMVAG), created in 1966, was the first public institution in charge of managing the water resources of the Sebou River Basin. Operating under the supervision of the Ministry of Agriculture, and Rural Development and Fishing, the ORMVAG missions include: (i) assessment and planning of agricultural projects; (ii) developing agricultural lands; (iii) managing hydro-agricultural infrastructures; (iv) capacity building; and (v) strengthening farmer awareness.

As a result of the 1995 Water Law, new institutions were established in 2002 to effectively manage water resources in Morocco. One was the Sebou River Basin Organization (Agence du Bassin Hydraulique du Sebou: AHBS, 2006), whose major challenges include the following:

- Waste water treatment;
- Efficient use of resources;
- Rationalization of aquifer exploitation (whose depletion is due to both drought and intensified abstraction, mostly for agricultural use);
- Soil erosion; and
- Water allocation conflicts between different users (e.g., domestic water and industrial needs on the one hand, and agricultural needs on the other).

The AHBS aims to amalgamate the various stakeholders by involving all of them in water resources planning and management processes.

Data availability, standardization and monitoring

There are several established monitoring networks for both surface water and groundwater. A considerable quantity of information on water resources (meteorological; hydrological; hydrogeological) is available, with most being accessible from the AHBS web site. GIS and statistical databases have been developed, but currently exhibit limited online access. AHBS also is in charge of maintaining river flow gauging stations and groundwater monitoring stations (piezometers) in the basin. The ORMVAG also carries out hydro(geo)logical assessments, including monitoring in the Gharb Plain.

7.4.4 Key Issues, adaptation and mitigation

Physiography

Climate vulnerability

The Sebou River Basin is highly vulnerable to climate variability and change, and rainfall throughout the basin is highly variable in both time and space. This has resulted in water scarcity for agriculture, hydroelectric power and domestic purposes. Climate change, with increased frequencies of extreme events, is expected to exacerbate the rainfall variability. The recurrent droughts, combined with over-pumping of aquifers, have resulted in a dramatic decline in the water levels of many aquifers (e.g. Fes-Meknes aquifer, Figure 7.4-3).

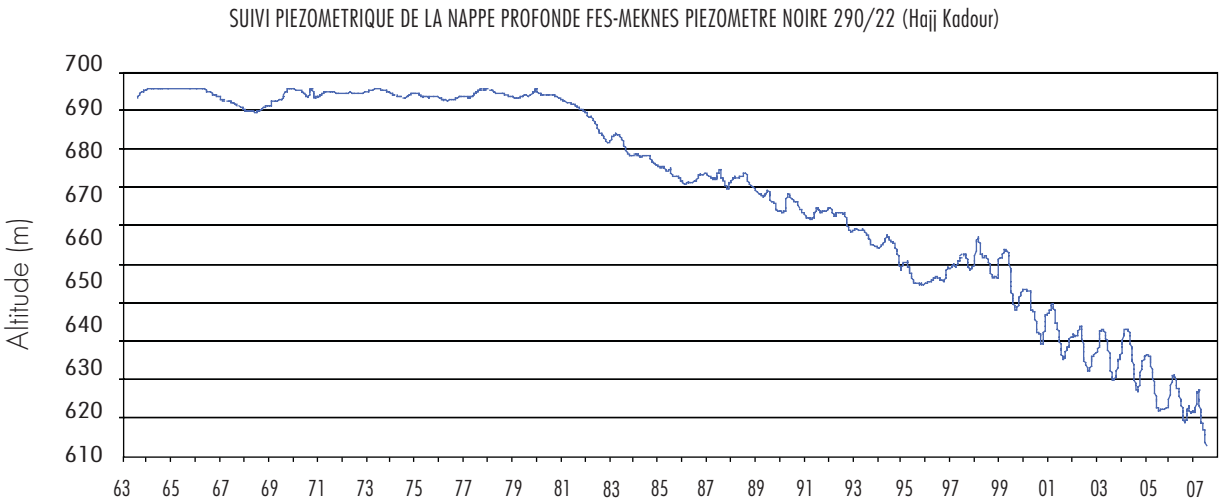

Figure 7.4-3: Water level changes of Fes-Meknes deep aquifer

Source: http://www.abhsebou.ma/, redrawn by UNEP

Adaptation and mitigation

There is a need:

- To develop an early warning systems for drought, including the Drought Observatory (Observatoire de la Sécheresse) developing more pro-active strategies./
- To strengthen the existing flood early warning system.
- To pursue scientific research on appropriate drought-resistant crops.
- To control ground exploitation, since its depletion is due both to drought and excessive exploitation for agricultural use.

Land and water degradation

Vegetation clearance and deforestation, overgrazing, and bad cultural practices all contribute to soil erosion, resulting in desertification, siltation of dams, and degradation of the ecological functioning of the river system and coastal zone.

Adaptation and mitigation

There is a need:

- To reforest and stabilize the landscapes.
- To strengthen regulations and enforce land management and land use.
- To build capacity, strengthen awareness, and involve rural communities in all projects dealing with ecosystems and land management.

Socio-economy

Population growth and urbanization

The recurrent droughts have led to many farmers migrating to urban areas causing expansion of slums and exerting pressure on the water supply and demand and pollution.

Adaptation and mitigation

There is a need:

- To invest more in infrastructure development in rural areas (e.g., ecotourism; agriculture; fishing) as a means of combating rural-to-rural migration.
- For further urban infrastructure development (e.g., upgrading water supply and sewage systems).

Water availability, uses and demands

Water demands, as forecast by the Guiding Plan of the Sebou River Basin, will double by 2020. The basin's surface water resources are almost fully developed now, and additional water demands will be difficult to meet.

Adaptation and mitigation

There is a need:

- To strengthen water demand management.
- To develop alternative water sources (e.g., water recycling; desalinization; etc.).
- For further assessment and development of groundwater resources.
- For effective pollution control management.

Management

Institutional and legislative frameworks

Since the creation of the Sebou River Basin Organization in 2002, which complemented the mission of the ORMVAG, the institutional and legislative frameworks have been strengthened. The full operation of this organization, however, should be accelerated.

Adaptation and mitigation

There is a need:

- To improve communication and coordination between different departments and agencies, in order enhance effective decision-making and efficient management of existing schemes.
- To strengthen capacities of these institutions in regard to water resources development and management, and to effectively adapt to the basin's changing climatic and environmental conditions.

Data availability, standardization and monitoring

A significant quantity of data and information on the surface and groundwater of the Sebou River Basin are available, but not easily accessible.

Adaptation and mitigation

There is a need:

- To improve online access to data.
- To expand monitoring analysis, including physical, chemical and pollutants parameters.

7.4.5 References

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7.5 SEYBOUSE RIVER BASIN

The Seybouse River Basin is located in Algeria, covering an area of about 6,500 km² (2,510 mi²). It lies within the territories of the Wilayas of Guelma, El-Tarf (by Drean) and Annaba. It is bordered in the north by the Mediterranean Sea, in the south by the Wilaya of Souk-Ahras, in the west by the Edough massif, Lake Fetzara, and Ain Berda, and in the east by Oued Mafragh (Figure 7.5-1). The main characteristics of the Seybouse River Basin are summarized in Box 7.5-1.

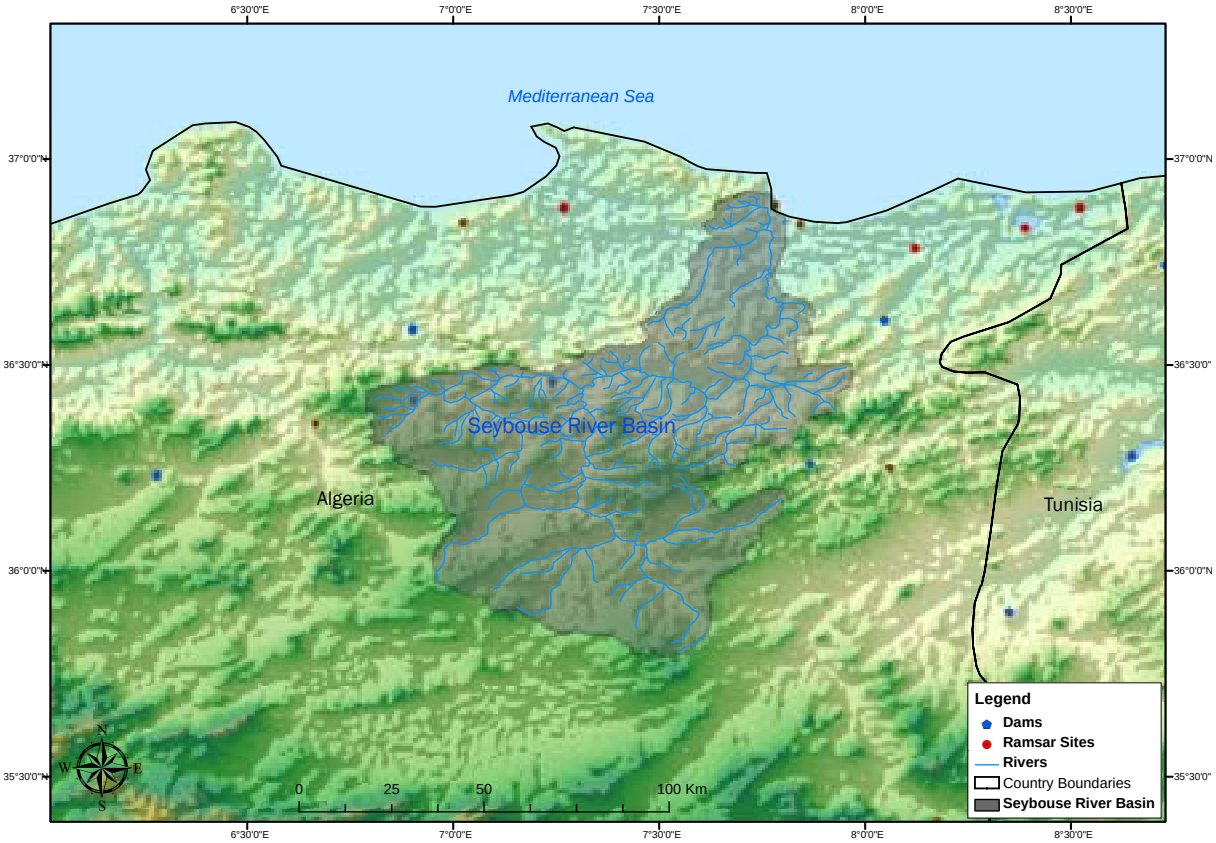


Figure.7.5-1: Seybouse River Basin

7.5.1 Physiography

The Seybouse River flows through depressions containing unconfined alluvial aquifers, which allows the regulation of a great quantity of winter precipitation received by the mountain range. When the river reaches the plain of Annaba, it loses its energy, leaving behind a great load of sediments. The geomorphologic characteristics of the plain, including gentle slopes, a sand dune barrier, and areas prone to inundation, allow the river to flow easily into the sea. The geology of the area is characterized by a metamorphic core complex of Precambrian to Palaeozoic age (the Edough massif), overlain by a sedimentary cover of mainly Mesozoic to Cenozoic formations. The Edough massif constitutes the most eastern metamorphic complex of the Algerian coast, being characterized by high relief (up to 1,008 m [3,307 ft] amsl) and very complex structures.

Climate

The mean annual precipitation in the Seybouse River Basin varies between 400-700 mm (16-28 in), with a monthly maximum between 90-120 mm (4-5 in) in December-January. The minimum

temperature (less than 10 °C [50 °F]) is observed in December-January and the maximum (between 25-30 °C [77-86 °F]) in July or August.

Box 7.5-1: Main characteristics of Seybouse River Basin.

Basin
Surface area: 6,500 km² (2,510 mi²)
450-1,000 mm.yr⁻¹ (18-39in.yr⁻¹)

Demography
Population: 1.3 million
Density: 50 persons.km⁻² (130 persons.mi⁻²)

Water Resources
River length: ≈160 km (99 mi)
MAR: 4.9 Mm³.yr⁻¹

Major Dams (Mm³)

Hammam Debagh	220
Foum El Khanga	157
Tifech	5.8
Medjez El B'gare	2.9
Total storage	**385.7 Mm³**

Minor Dams (Mm³)
Number: 76, Total Flow: **12 Mm³**

Major Aquifers: Annaba, Bouchegouf, Guelma

Water Use
Agriculture
Industry

Vulnerability
Climate variability and change
Industrial and agricultural pollution
Land erosion & siltation of dams
Soils and groundwater salinization

Source: ABHCSM & ANRH (2001)

Ecosystems

Lake Fedzara is the only Ramsar site in the Seybouse River Basin. The lake dimensions are 17 km (11 mi) from west to east, and 13 km (8 mi) from north to south. The lake water is characterized by high salinity (Debieche, 2002).

Land degradation and desertification

The sedimentation rate in Algeria's dams is estimated at 1.5 Mm³.yr⁻¹ (Remini 2005). The sediment load is generated by land erosion in the catchments. This degradation is directly linked to the geological and morphological nature of the land, and also to deforestation and vegetation clearing.

Hydrology

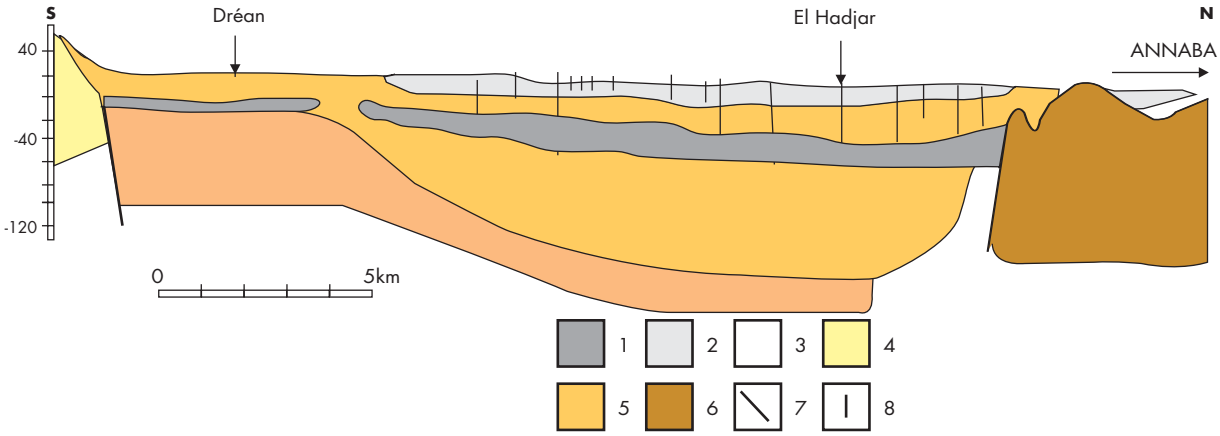
The basin is equipped with 33 meteorological stations. The basin's main hydrological characteristics are summarized in Table 7.5-1.

Table 7.5-Hydrological characteristics of Seybouse River basin

Regional/ characteristics	Relief (m)	Type of Climate	Precipitation (mm.y⁻¹)	Infiltration (mm)	Runoff (mm)
Seybouse (Annaba)	1000 – 5	Mediterranean to semi-arid	1,000 – 450	162	79

Hydrogeology

The Seybouse River flows through some depressions containing alluvial aquifers. The disposition of these formations highlights two aquifers, including the superficial aquifer of Annaba and Alluvial aquifer of the high terraces (Figure 7.5-2) which exhibit hydraulic continuity (Djabri et al. 2003; Hani 2003). The aquifers are alluvial and calcareous in the Guelma region.



(1) Pebbles and gravels; (2) sand; (3) Numidian clay; (4) Cenomanian marl and marly limestone; (5) Plio-Quaternary detrital clays; (6) metamorphic formations; (7) fault; (8) drilling.

Figure 7.5-2: Cross-section through Annaba Plain

Source: Djabriet et al 2003; Hani 2003, redrawn by UNEP

7.5.2 Socio-economy

Demography

The total population of the Seybouse River Basin is estimated to be over 1,300,000 people. Two major periods of population distribution in Algeria are obvious, the first being 1962, in which there was a large migration of the rural population into urban areas after independence was obtained. The second influx occurred between 1990-2000 (25.6 million to 31.8 million) because of the creation of new towns (e.g., Sidi Amar (100,000); El Hadjar (120,000); El Bouni (130,000); Annaba (600,000)). The population of these cities has tripled in a time space of only 10 years, resulting in sub-standard construction works for social infrastructure.

Economy

The industrial sector (with 112 industrial units) plays a very important economic role in the Seybouse River Basin. The main industries include: fertilizer factory (ASMIDAL with 3,000 workers); iron factory (El-Hadjar with 15,000 workers); milk factory (ORELAIT with 1,400 workers); bicycle factory (1,200 workers); SN Metal (1,300 workers); ceramic (3,000 workers); sugar (1,000 workers). Seasonal industrial units (12,000 workers) exert further pressures on water demands because of the large migration labour force (Djabri 1996).

Water uses and water demands

The demands and competition for water in the basin is very high. Agriculture consumes more than 95 per cent of the available water resources, with domestic and industrial sectors utilizing the remaining 5 per cent. In regard to groundwater, two-thirds is used for irrigation, and one- third for potable and industrial use. Table 7.5-2 summarizes the basin's water distribution and its water resources deficits.

Table 7.5-2: Water resources distribution in Seybouse River Basin

Resources/demands by 2020	Volume ($Mm^3.yr^{-1}$)
Surface water (regulated)	118
Groundwater	94.6
Total water resources	***212.6***
Drinking and industrial water demands	138.4
Irrigation water demands	75.8
Total water demands	***241.2***
Water Balance	***-30.2***

Source: Rhumel-Seybouse and Medjerda Basin Agency (2000)

7.5.3 Management

Institutional and legislative frameworks

Several administrations are involved in Seybouse River Basin water issues. The most important are: (i) General Directorate of Hydraulic (DHW); (ii) Algerians des Eaux (ADE); (iii) Agence de Basin Rhumel, Seybouse and Medjerda (ABH CSM); (iv) Agence National des Barrages; and (v) Direction of Agricultural Office. These various institutions do not coordinate well, however, in managing the basin's water resources.

7.5.4 Key Issues, adaptation and mitigation

Physiography

Climate vulnerability

The Seybouse River Basin is highly vulnerable to climate variability and change. Several floods and droughts have been reported in the last few decades (Figure 7.5-3), particularly the droughts observed during 1990-2000. The maximum precipitation during this period did not exceed 600 $mm.yr^{-1}$ (24 $in.yr^{-1}$).

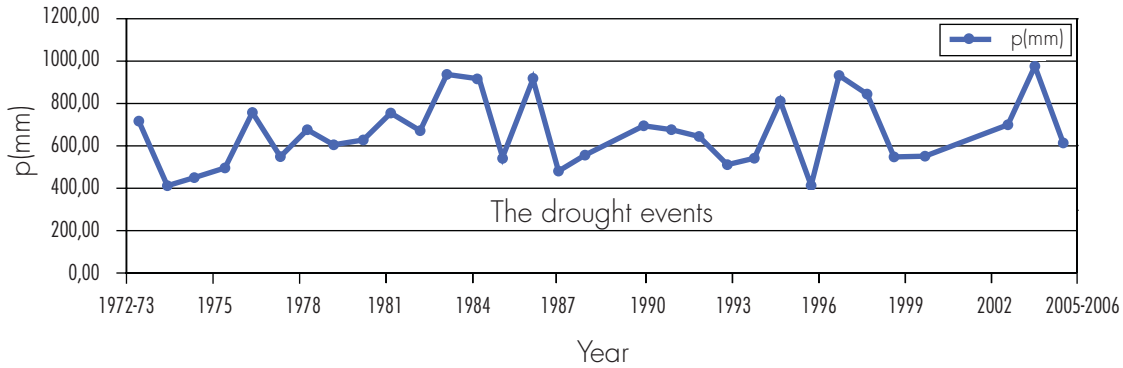


Figure 7.5-3: Annual variation of precipitation in Seybouse River Basin

Source: Djabri L, Hani A, Laouar R, Mania J, Mudry J, Louhi A (2003), redrawn by UNEP

Adaptation and mitigation

There is a need:

- To develop an early warning system for flood and drought management.
- To adapt agriculture to drought conditions (e.g., growing appropriate crops; implementing water conservation techniques).

Land and water degradation

Land degradation is a serious problem in the Seybouse River Basin, being the main cause of silting build-up in reservoirs. The river deposits vary between 10-15 per cent of the total load (Remini 2005). In regard to water degradation, the Seybouse River receives heavily-polluted wastewaters from many towns (Berriche, Guelma, Bouchegouf, Drean,) and several factories. Organic pollution from domestic sewage and food industries pollutes downstream river water to the extent that it can hardly be used for irrigation and drinking water supply (Figure 7.5-4).

Adaptation and mitigation

There is a need:

- To reforest and stabilize landscapes.
- To strengthen regulations and their enforcement for land management and land use.

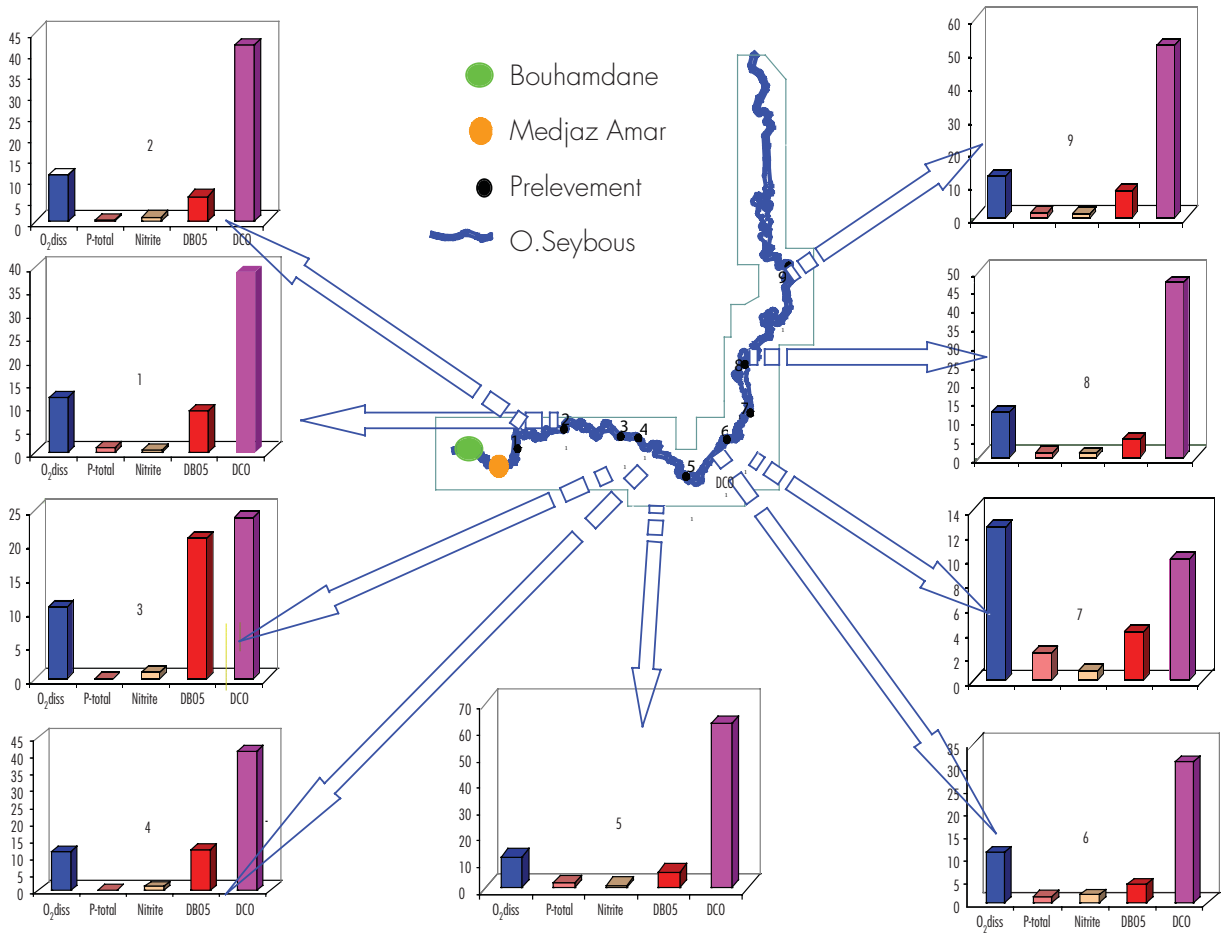


Figure 7.5-4: Water pollution in Seybouse River

Source: Remini 2005 adapted by UNEP

Socio-economy

Population growth and urbanization

Increased urbanization and development, particularly in the Annaba, Guelma and Bouchegouf areas, is exerting significant pressures on water supply and demands, and wastewater disposal, mainly in the summer, when the water supply is lowest.

Adaptation and mitigation

There is a need:
- To develop policies and legislation to control urbanization.
- For further infrastructure development (e.g., upgrading of water supply and sewage systems).

Water availability, uses and demands

The basin's water resources are extensively exploited, resulting in a large deficit in the water balance. Climate change and variability exert further pressures on the availability of these resources. To mitigate the effects of climate change and risks of water shortages, and to meet the needs of an increasing population, it is imperative to build new dams and explore new aquifers. The most important measure, however, is the rational use of water resources through Integrated Water Resources Management (IWRM).

Adaptation and mitigation

There is a need:
- For further assessment and development of groundwater resources.
- To develop alternatives water sources (e.g., water recycling, desalinization, etc.).
- For effective management of pollution control.

Management

Institutional and legislative frameworks

Despite the existence of many institutions involved in administration of the waters of the Seybouse River Basin, there is no coordination, and no appropriate tools, for effective management of the basin's water resources in the basin.

Adaptation and mitigation

There is a need:
- To improve communication and coordination between different institutions.
- To strengthen the mandate of the Rhumel-Seybouse and Medjerda Basin Agency.

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7.6 SOUSS RIVER BASIN

The Souss River Basin covers an area of about 16,200 km^2 (6,255 mi^2), being surrounded by the High Atlas Mountains to the north, and the Anti Atlas Mountains to the south. The main river stretches for about 200 km (124 mi) from its source in the High Atlas Range to the Atlantic Ocean (Figure 7.6-1). The Souss Plain has an areal extent of 4150 km^2 (1,602 mi^2). The main characteristics of the basin are summarized in Box 7.6-1.

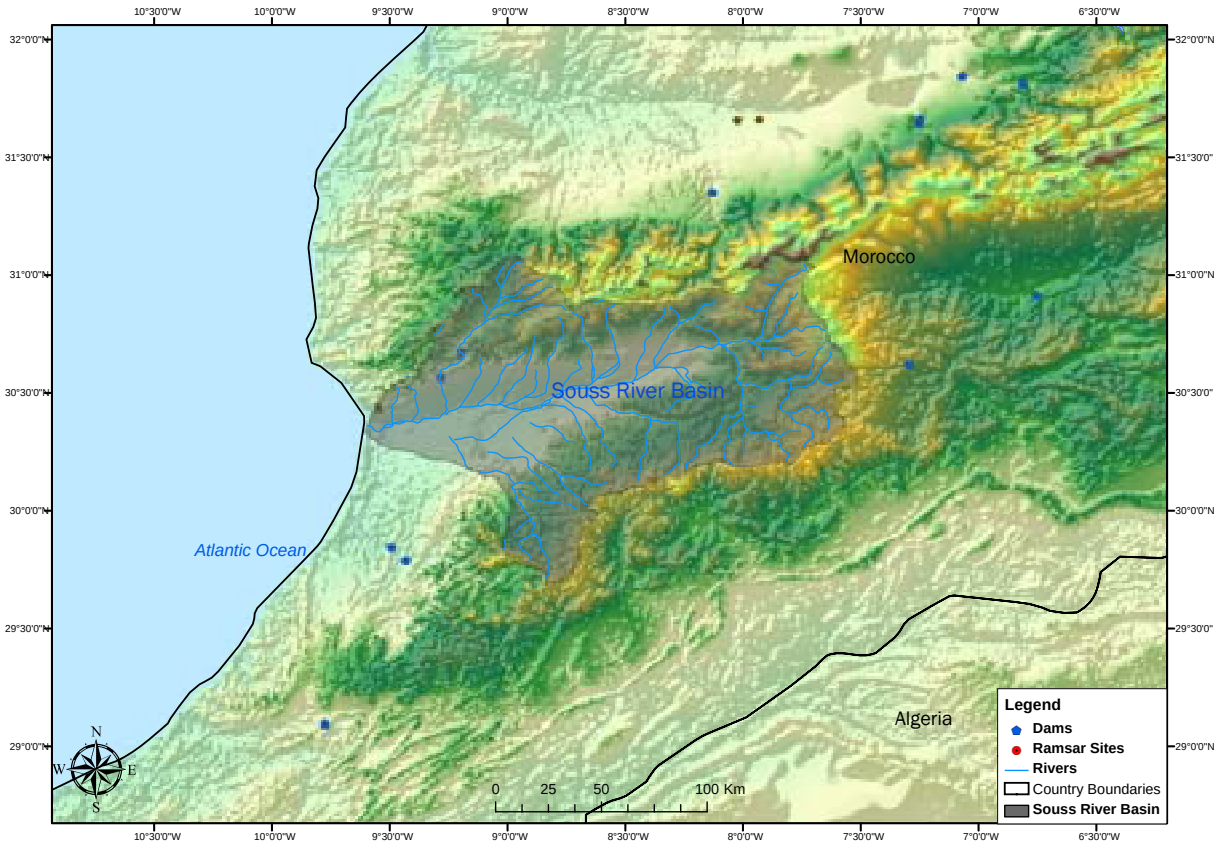

Figure 7.6-1: Souss River Basin

7.6.1 Physiography

Climate

The prevailing climate in the basin is mostly arid, varying from humid in the west of the High-Atlas Mountains, to Saharan in the plains. The aridity conditions are reduced to the west by the closeness of the ocean, the influence of the Canary Islands Current, and the High Atlas Mountains. The latter protect the Souss Plain from the Saharan winds, thereby giving the area a semi-humid climate. The basin receives an average annual rainfall of 280 mm (11 in), ranging from about 600 mm (24 in) in the highlands, to less than 150 mm (6 in) in the southern part of the basin (Agence du Bassin Hydraulique du Souss-Massa, 2006). About 95 per cent of the rainfall occurs between November-April.

Mean annual temperatures range from 14 °C (57 °F) in the High Atlas Range, to 20 °C (68 °F) in the Anti Atlas, with the range between the daily minimum and maximum temperatures reaching 49 °C (120 °F). The potential evaporation varies between 1,400-2,000 mm.yr^{-1} (55-79 in.yr^{-1}).

Box 7.6-1: Main characteristics of Souss River Basin

Basin

Surface area:	16,200 km^{-2} (6,255 mi^{-2})
MAP:	280 mm.yr^{-1} (11 in.yr^{-1})

Demography

Population:	3.11 million
Density:	54 persons.km^{-2} (140 persons.mi^{-2})

Water Resources

Souss River length:	≈ 200 km (124 mi)
MAR:	394 Mm^3.yr^{-1}

Water Use

Agriculture
Domestic
Industry
Recharge

Vulnerability

Climate variability and change
Industrial and agricultural pollution
Land erosion & siltation of dams

Major Dams (Mm^3)

Abdelmoumen:	75
Aoulouz:	165
Mokhtar Soussi	45
Total dam capacity	≈ **285 Mm^3**

Major Aquifers: Souss aquifer

Source: Agence du Bassin Hydraulique du Souss-Massa (2006) www.water.gov.ma/

Ecosystems

There is a diversified variety of fauna and flora species within the basin, especially at the mouth of the Souss River, and in the National Park of Souss-Massa, which covers an area of 33,800 ha (131 mi^2) south of the Souss Basin. This park, which lies between Agadir to the north, and Sidi Ifni to the south, was created in 1991, and includes a variety of habitats, including *Argania spinosa* woodlands, cultivated fields, *Retama* and *Euphorbia* steppes, dunes, cliffs, sandy beaches, and wetlands. It encompasses estuaries of the Souss River (the northern limit of the park) and Massa River. An area of 30,000 ha (116 mi^2), south of the park, also has been included because it is used periodically as a feeding area by *Geronticus eremite.*

Land degradation and desertification

Except for the low lands of the plains, the basin soils are experiencing severe degradation. Specific erosion was estimated to range between 340-660 t.km^{-2}.yr^{-1} (2-3.8 million lbs.mi^{-2}.yr^{-1}). Areas with a high erosion rate represent nearly 40 per cent of the total basin area, and are responsible for the rapid siltation of the Abdelmoumen Dam, which has already lost about 25Mm^3 of its total capacity.

An extensive desertification consultation programme was conducted in 2003 to determine an urgent means of combating land degradation and desertification, and to ensure the actions undertaken are effective; mainly stabilization of the sand dunes (Figure 7.6-2).

Hydrology

Given the varied and low rainfall, only the tributaries draining the High Atlas Mountains are perennial. The mean annual runoff is estimated at 394 Mm^3, although it is very irregular, both

annually and monthly. Most precipitation originates from short and heavy storms, with the flood events contributing extensively to the river water flows. During the floods of December 1963, which affected almost all the tributaries, the peak flood discharge rates increased to nearly 1,200 $m3.s^{-1}$. The basin is experiencing a continued reduction in renewable water resources due to both natural (droughts) and human-induced changes (over-exploitation).


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Figure 7.6-2: Stabilization of sand dunes in Souss-Massa

There are 3 large reservoirs in the river basin (Aoulouz; Abdel Moumen; Youssef Ben Tachfine; Figure 7.6-1), which are used for flow regulation and groundwater recharge.

Hydrogeology

A variety of sedimentary rocks of predominantly calcareous nature were laid down during the Tertiary period. In some areas of the valley (e.g., Admine Forest), this limestone, together with conglomerates, forms important aquifers (Geanah et al. 1988), facilitating the development of intensive agriculture by providing a perennial source of irrigation water (Popp 1989). A large groundwater aquifer of 50 billion m^3 accumulated during the geologic era.

The Souss River Basin comprises 3 main groundwater units Souss aquifer, Chtouka aquifer, and Tiznit aquifer. The water budget of these aquifers is given in Table 7.6-1.

Table 7.6-1: Water balance of Souss-Massa Aquifers

Aquifer	Potential renewable inputs (Mm^3)	Outputs (Mm^3)	Balance (Mm^3)
Souss	323	553	-230
Chtouka	35	93	-58
Tiznit	17	17,6	-0,6

Source: Agence du Bassin Hydraulique du Souss-Massa (2006)

7.6.2 Socio-economy

Demography

Based on the 2004 census, the population of the entire Souss-Massa region was about 3.11 million inhabitants, with about 59 per cent being in rural areas. The basin encompasses the major part of the Wilaya of Agadir, with 500,000 inhabitants, and a part of the province of Taroudant with 780,000 inhabitants. According to future projections, the population of the Souss River Basin will increase to 2.64 million by 2020.

Economy

The regional economy depends mainly on agriculture, tourism, and maritime fishing. Agriculture provides an important source of foreign currency, via the exportation of citrus produce and horticultural products, including flowers.

Agriculture

This sector constitutes by far the major economic activity in the basin. The irrigated area, located mainly within the Souss Plain, covers about 134,300 ha (519 mi^2), representing nearly 54 per cent of the potential soil resources for irrigation. In term of production, market gardening represents 34 per cent, citrus fruits 25 per cent, cereals 10 per cent, and livestock 28 per cent.

Tourism

This constitutes the second most important economic activity in the region, with a total accommodation capacity of nearly 30 per cent of the national capacity.

Poverty

Poverty has been observed in rural areas, being manifested by low incomes because of infertile soils and limited, or lacking, agricultural production. The poor rural population often migrates to the city of Agadir to seek alternative employment.

Water uses and water demands

The total annual volume of water used in the Souss-Massa River Basin averages 394 Mm^3, of which 82 per cent is from groundwater. Irrigation consumes more than 95 per cent of the water resources of the basin. Development of large hydrologic infrastructures allows for: (i) mobilization of about 180 $Mm^3.yr^{-1}$ of water for irrigating 34,000 ha (131 mi^2) of land; (ii) provision of 36 Mm^3 of industrial and potable water for the agglomerations of the Grand Agadir and Tiznit-Sidi Ifni; and (iii) the use of about 294 $Mm^3.yr^{-1}$ for artificial recharge of the Souss aquifer.

Water-related conflicts

The Souss River Basin is currently experiencing water shortages as a result of droughts, and over-exploitation of surface and groundwater. Analysis of water flows into the dams indicates that water inputs decreased globally by 32 per cent during 1945-2000. The groundwater level of the Souss aquifer dropped between 10-30 m (33-98 ft), due to over-pumping (Figure 7.6-3). In fact, more than 15,000 pumping wells have been recorded, although the groundwater level generally has decreased by 1-3 $m.yr^{-1}$. This situation generates conflicts, mainly between the tourism and agriculture sectors.

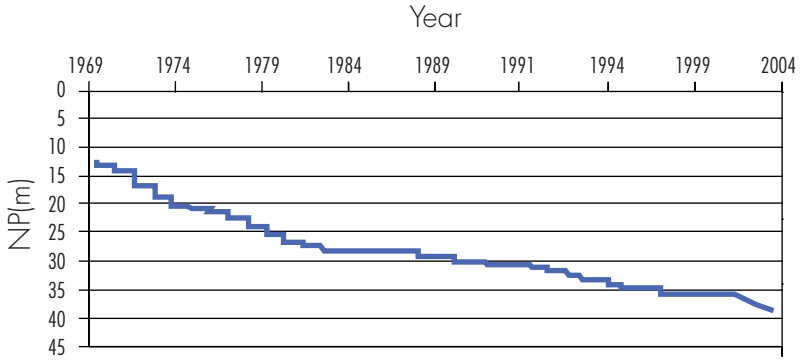

Figure 7.6-3: Groundwater level decline in Souss aquifer (1960 – 2004)

Source: Agence du Bassin Hydraulique du Souss-Massa (2006), redrawn by UNEP

7.6.3 Management

Institutional and legislative frameworks

The Souss-Massa Basin Agency, created in 2000, is the leading institution in charge of managing the basin water resources. This organization, however, must be strengthened. The Souss-Massa Integrated Water Management (SIWM) Project is designed to support existing and new institutions in developing and implementing sustainable practices in integrated water resources planning and management (USAID 2001).

Data availability, standardization and monitoring

Monitoring and database development are fragmented within different regional departments of different ministries, agencies, and cooperatives of water users and farmers.

7.6.4 Key issues, adaptation and mitigation

Physiography

Climate vulnerability

The Souss River Basin is highly vulnerable to climate variability and change. The region has experienced severe and frequent droughts, the most severe droughts having occurred during 1920-1935, 1970-1985, 1990-1995, and 1998-2000 (Figure 7.6-4). Flooding also is a problem, with Figure 7.6-5 illustrating the devastating effects of the last decade.

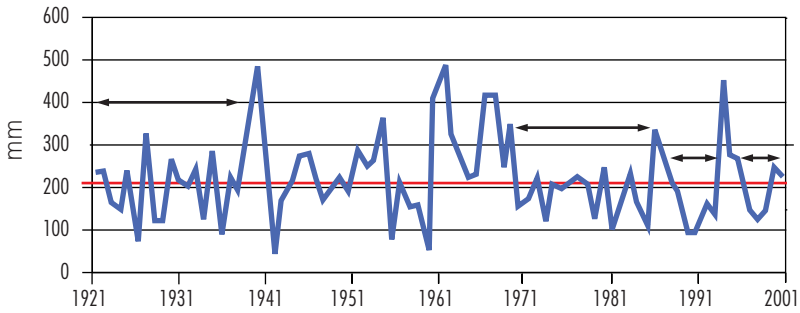

Figure 7.6-4: Annual variation of precipitation at Taoudant (Souss River Basin), illustrating main droughts

Source: Agence du Bassin Hydraulique du Souss-Massa, 2006, redrawn by UNEP

Figure 7.6-5: Floods in Souss River Basin

Source: Agence du Bassin Hydraulique du Souss-Massa (2006)

Adaptation and mitigation

There is a need:

- To develop an early warning system for floods and droughts.
- To develop appropriate crops, and ameliorated species resistant to recurrent droughts.
- To assess indigenous knowledge with regard to adaptation of water resources to climate change.

Land and soil degradation

Land degradation is a serious problem in the Souss River Basin, with forests having been extensively cleared for agriculture. Overgrazing, and bad cultural and cultivation practices, also contribute towards soil erosion, thereby enhancing desertification, siltation of dams, and wetlands degradation.

Adaptation and mitigation

There is a need:

- To strengthen reforesting and stabilization of the landscape.
- To strengthen and enforce regulations for land management and land use.
- To involve communities in ecosystem management.

Socio-economy

Population growth and urbanization

The population of the basin is expected to almost double by 2020, compared to 1994. Further, domestic per capita water use is expected to increase from 75 to over 120 $L.d^{-1}$ by 2020. This projected population increase will increase pressures on water supplies, mainly in the summer, when the water supply is lowest.

Adaptation and mitigation

There is a need:
- For further urban infrastructure development (e.g., upgrading of water supply and sewage systems).
- To build the capacity of community groups, in partnership with local governmental agencies, NGOs and the private sector.

Water availability, uses and demands

Although there is an acute water shortage in the basin, water demands continue to increase. The basin's surface water resources are almost fully developed, and yet the water demands are expected to double in 2020. There is already a groundwater deficit, ranging from 250-300 Mm^3, meaning additional water demands will be difficult to meet.

Adaptation and mitigation

There is a need:
- For further groundwater resources assessment and development.
- To develop alternative water resources (e.g., water recycling; desalinisation) and innovative technologies for economical water use.
- For effective pollution control management.

Management

Institutional and legislative frameworks

The Souss-Massa Basin Agency needs strengthening, both in terms of human resources, capacity building, and equipment.

Adaptation and mitigation

There is a need:
- To improve communication and coordination between different institutions.
- To strengthen the mandate of the Souss-Massa Basin Agency

Data availability, standardization and monitoring

Monitoring and database development are fragmented among different ministries, agencies and cooperatives of water users and farmers.

Adaptation and mitigation

There is a need:
- To establish standardized procedures for monitoring and data collection.
- To establish a web site for the Souss-Massa Basin Agency, and allow online data access.

7.6.5 References

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7.7 TAFNA RIVER BASIN

The Tafna River Basin is a transboundary basin between Morocco and Algeria (Figure 7.7-1) with a third of its basin being in Morocco. The basin covers an area of 7,245 km² (2,797 mi²), being bounded to the south by the Tlemcen Mountains, to the north by the Mediterranean Sea, and to the east by the Daïa Mountains. The basin is located in a sub-humid to semi-arid region, with many of its tributaries being intermittent streams (Dakiche 2005). The main characteristics of the basin are summarized in Box 7.7-1.

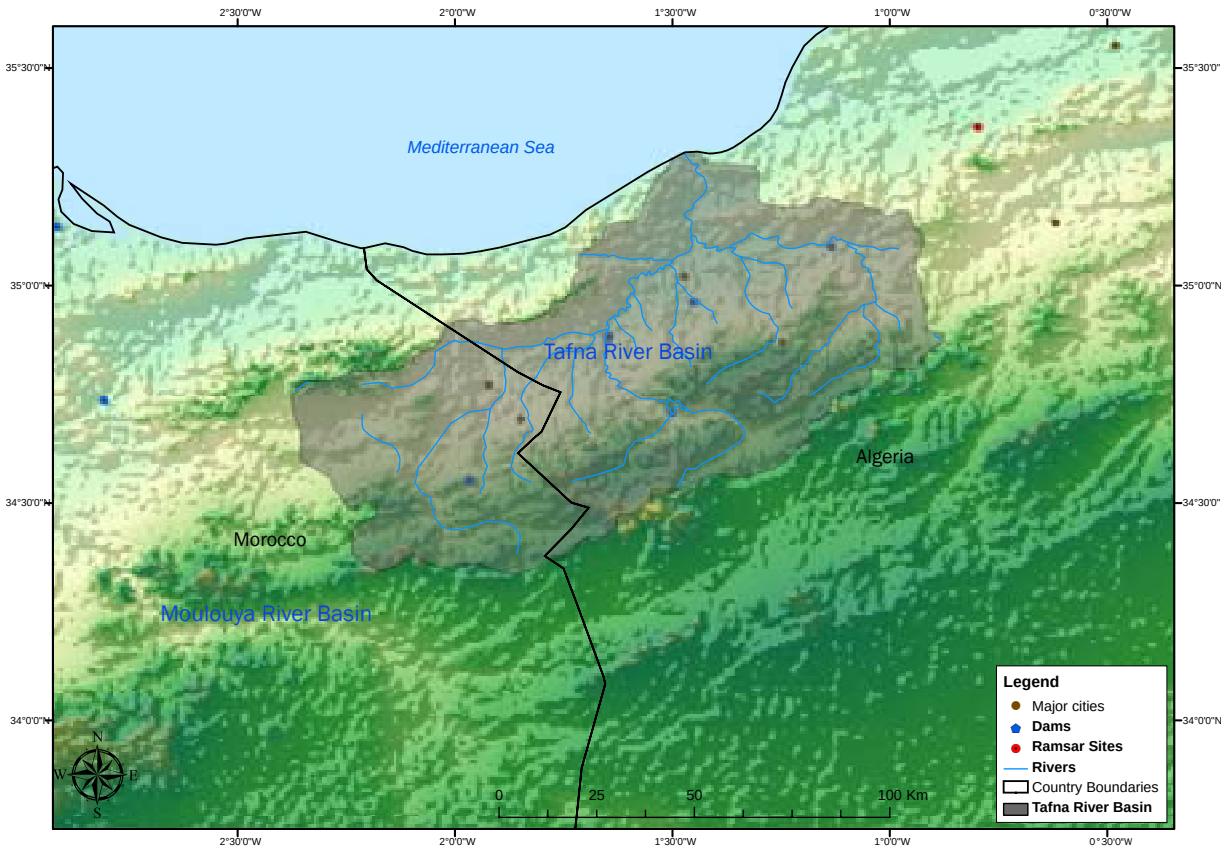

Figure 7.7-1: Tafna River Basin

7.7.1 Physiography

The morphology of the Tafna River Basin is characterized by 2 transversal mountainous belts, including the Tellian Mountains and Atlas Mountains, which control the region's climate. These mountains surround the Chellif and Sidi Belabbes plains in the west, the Mitidja plain in the centre, and the Annaba plain in the east. In the desert region of the High Plateaux in the south, many salt lakes (Chotts) collect surface water. Some have a very low topography (e.g., -40 m (-131 ft) in the Chott Melrhir), which explains why almost all the southern water basins are endoreic.

Climate

The prevailing basin climate is of a Mediterranean type, ranging from sub-humid to semi-arid. The mean annual precipitation in the whole Tafna River Basin is 394 mm (16 in), with a monthly maximum of 45 mm (1.8 in) during November-December, and 54 mm (2 in) during February-March, and a monthly minimum of between 1-2 mm (0.4-0.8 in) in July.

Box 7.7-1: Main characteristics of Tafna River Basin

Basin

Surface area:	7,245 km^2 (2.797 mi^2)
MAP:	250-600 mm.yr^{-1} (10-24 in.yr^{-1})

Demography

Population:	842,054
Density:	50 persons.km^{-2} (127 persons.mi^{-2})

Water Resources

Major rivers: ≈	**170 km** (106 mi)
MAR:	2.9 Mm^3.yr^{-1}

Major Dams (Mm^3)

Ben-bahdel:	66
Mefrouch:	15
Sidi Abdelli:	110
Hammam Boughrara:	177
Sikkak:	176

Total dam capacity ≈ 395 Mm^3

Major Aquifers: Maghnia and Tlemcen aquifers

Water Use

Agriculture
Domestic
Industry

Vulnerability

Climate variability and change
Industrial and agricultural pollution
Land erosion & siltation of dams
Soils and groundwater salinization

Source: Agence nationale des barrages

The annual rainfall is characterized by a high north-south gradient. and weak east-west gradient. The mean precipitation in the north is about 600 mm (24 in). Drought episodes since 1974 have been observed in many regions of Algeria, including the Tafna River Basin. Regarding prevailing temperatures, the minimum temperature (lower than 10 °C [50 °F]) occurs in January or February, and the maximum (between 25-30 °C [77-86 °F]) in July or August. The annual mean evapotranspiration varies between 1,000-2,000 mm (39-79 in).

Ecosystems

The only wetland in the basin is the Chat Cherub, a lake characterized by high water salinity.

Land and water degradation

The runoff in the Tafna River Basin is torrential, mainly because of the basin's steep slopes, which generate a large quantity of suspended sediments (estimated at 286,000 tons [641 million lbs]). The estimated mean erosion rate is 1,120 $t.km^{-2}.yr^{-1}$ (6.5 million $lbs.mi^{-2}.yr^{-1}$), varying between 4,283 $t.km^{-2}.yr^{-1}$ (24.9 million $lbs.mi^{-2}.yr^{-1}$) in 1990-1991, and 24 $t.km^{-2}.yr^{-1}$ (139,000 $lbs.mi^{-2}.yr^{-1}$) in 1992-1993 (Megnounif et al. 2003). The estimated erosion from the sediment rate in Beni Bahdel Reservoir is about 1 million $m^3.yr^{-1}$ (Remini, 2003). This degradation is directly linked to the geological and morphological nature of the land, and also to deforestation and vegetation clearing.

Water pollution has industrial, agricultural and urban sources. The Tafna River collects heavily-polluted wastewater from the town of Maghnia and several factories. Domestic sewage and food industries are a source of organic pollution. Ore treatment industries discharge very acidic wastewater. Table 7.7-1 highlights the average concentrations of some physico-chemical parameters, nutrients, and some heavy metals in the Tafna River.

Table 7.7-1: Selected physico-chemical parameters in Tafna River

Parameter	T (°C)	O_2	pH (standard units)	BOD_5	COD	NH_4	NO_3	PO_4	Pb	Cu	Cr
Average value	18	1.1	7.9	1.225.5	290	71.2	8	29	20.38	0.8	3.25

(T, temperature; O_2, dissolved oxygen; BOD_5, biochemical oxygen demand; COD, chemical oxygen demand; NH_4, ammonia nitrogen; NO_3, nitrate nitrogen; PO_4, phosphate; Pb, lead; Cu, copper; Cr, chromium; all units are $mg.L^{-1}$, unless otherwise noted).

Other sources of pollution include quarries, cemeteries, waste disposals, wells and boreholes distributed throughout the region. Organic pollution exhibits the highest impacts, becoming more acute in the summer, when the water supply is lowest. Figure 7.7-2 highlights the monthly concentrations of nutrients at the Mouillah Station (Tafna River).

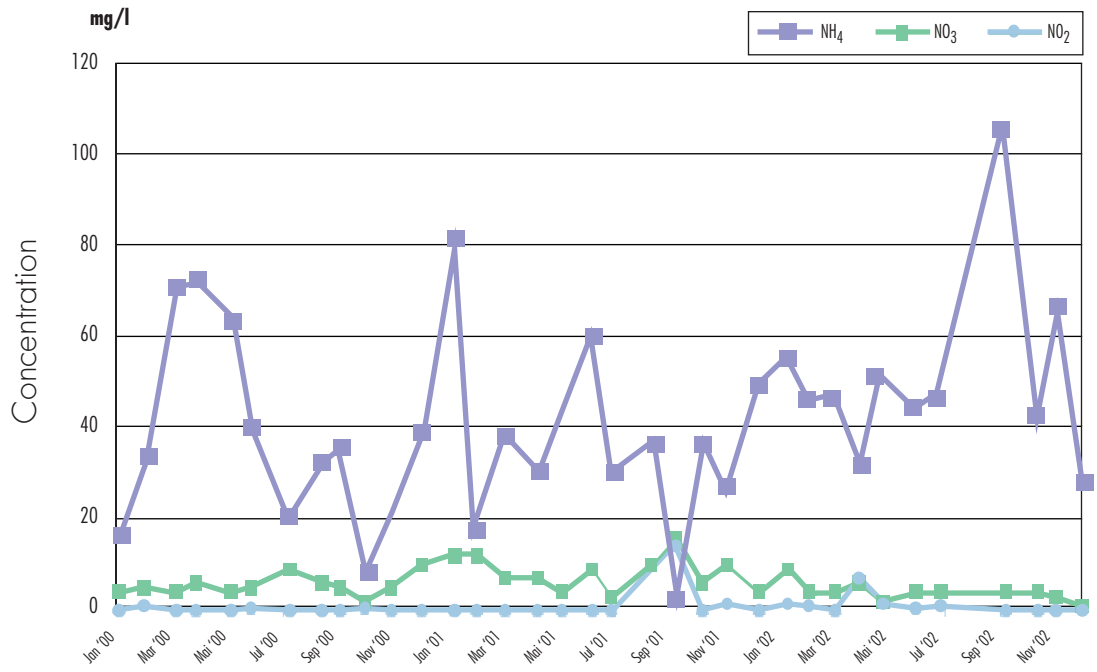

Figure 7.7-2: Changes in nutrient concentrations at Mouillah Station (Tafna River)

Source: Data from Mouillah Station, redrawn by UNEP

Hydrology

There are currently 26 hydrometric stations in the Tafna Basin (Bouanani 2002). The largest flows for the medium and low Tafna River are observed during the winter and spring. The flows are low during the rest of the year, and more often fed by discharges from urban and industrial wastewater. This is the case for Mouillah Oued, where sewage effluent represents the bulk of the low streamflow.

The streamflows are estimated to be 1.72 $m^3.s^{-1}$ for the wadi Mouillah in Sidi Belkheir Station (drainage area of 2,650 km^2 [1,023 mi^2]), 1.35 $m^3.s^{-1}$ for the wadi Isser in Sidi Aissa Station (drainage area of 114 km^2 [44 mi^2]), 1.46 $m^3.s^{-1}$ for the wadi Sebdou Bahdel (drainage area of 255 km^2 [98 mi^2]), and 0.65 $m^3.s^{-1}$ for the Sikkak wadi (drainage area of 218 km^2 [84 mi^2]). Table 7.7-2 shows the main hydrologic characteristics of the Tafna River Basin.

Table 7.7-2: Main hydrologic characteristics of Tafna River Basin (Remini 2005)

Parameter	Water basins	
	Oranie-Chott Chergui	Cheliff-Zahras
Surface (km^2)[mi^2]	76,000 [29,344]	56,200 [21,699]
Rainfall (million $m^3.yr^{-1}$)	24.5	23.5
Annual flow (million $m^3.yr^{-1}$)	958	1 974

Like all Mediterranean rivers, the Tafna River flow is very irregular from one year to the next. The variations of the water supply to Maffrouch Dam (Figure 7.7-3) illustrate an important decrease since 1974, suggesting the possible impacts of climate variability and change.

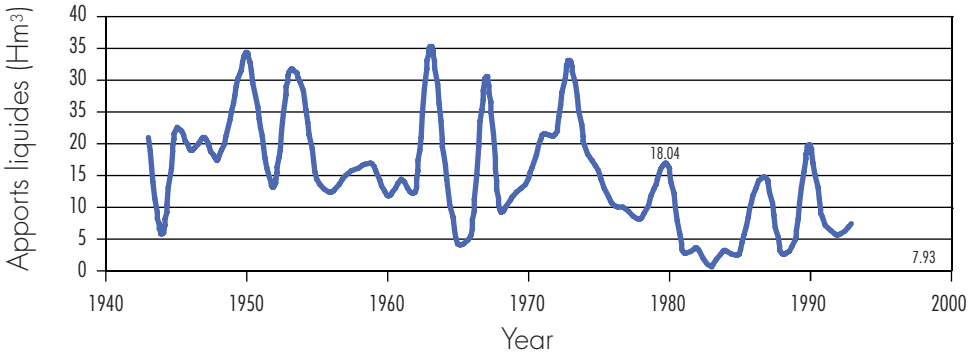

Figure 7.7-3: Water supply variations to Maffrouch Dam (1943-1993)

Source: Dakiche 2005; Bouanani 2002, redrawn by UNEP

Hydrogeology

Aquifers in the Tafna River Basin are few and of limited areal extent. The most important, the Maghnia Plain, Tlemcen and High Plains aquifers, are almost fully exploited. Table 7.7-3 illustrates their water yields.

Table 7.7-3: Main aquifers of Tafna River Basin

Aquifers	Potential (million $m^3.yr^{-1}$)	Exploited volume (million $m^3.yr^{-1}$)
Maghnia Plain	15	15
Tlemcen Highlands	45	40
High Plains of Tlemcen	60	60

Water availability

The annual water availability in Algeria is estimated to be about 16 km^3. The water resources comprise groundwater (12.8 km^3) and surface water (2.8 km^3), being mainly used for agriculture, industry, and human consumption. There is an evident chronic deficit of water resources, which accentuates water pollution, the latter attributed mainly to industrial discharges and urban wastewater, as well as agricultural runoff.

7.7.2 Socio-economy

Demography

There is no specific population data for the Tafna River Basin, with the only available data being at the national level. Based on the 1998 national census, the estimated population was 29.27 million inhabitants. The previous census (1987) provided a population estimate of 22.71 million people, which translates into an annual growth rate of 2.28 per cent. The annual growth rate has steadily increased over the years (1977-1987 = 3.06 per cent; 1966-1977 = 3.21 per cent). More than 90 per cent of the Algerian population lives in the northern part of the country, which includes a coastal band along the plains, mountains, and highlands of the Mediterranean.

Economy

The main socio-economic activity of this region during the colonial period was agriculture. It has since shifted to industry, causing an important migration from rural to urban areas. This migration

necessitates the clearing of vegetation and building on agricultural lands. The Algerian economy is based mainly on oil, which accounts for 90 per cent of its foreign financial resources. A rigorous policy is underway for agricultural sufficiency. With a surface area of 2.4 million km^2 (926,645 mi^2), Algeria is the largest country in northern Africa, with most of its land area occupied by the Sahara desert, which is unfit for agriculture. Currently, agriculture is mainly developed in the lower Tlemcen, where the soils are fertile and the water supply adequate. The main agricultural activity is horticulture. In the more arid zones, the land is used primarily for livestock ranching. The principal industrial activities in the basin are the clothing industry (Soitex, Ecotex), ceramics, earthenware, canning factories, and marble aggregates.

Water uses and water demands

The demand and competition for water is high in the basin. Agriculture consumes more than 95 per cent of the available water, with domestic and industrial sectors using the remaining 5 per cent. Two-thirds of the groundwater is used for irrigation, and one-third for potable and industrial use. The demand for drinking water in the Tafna River Basin is 46.1 $Mm^3.yr^{-1}$, while the supply is only 30.08 $Mm^3.yr^{-1}$. The industrial water demand is 4.53 $Mm^3.yr^{-1}$, whereas the supply does not exceed 3.63 $Mm^3.yr^{-1}$. (www.abhoranie.dz/bdd/besoin.htm). There are five dams for addressing the water needs for agriculture, industry and drinking water supply, including Beni Bahdel (66 Mm^3), Mefrouch (15 Mm^3), Sidi Abdelli (110 Mm^3), Hammam Boughrara (177 Mm^3), and one under construction (Sikkak; 176 Mm^3). These dams, however, will not be able to meet the basin's future water demands and, as of late, some desalination plants are augmenting the water supply from the dams.

Water-related conflicts

There is a high potential for water-related conflicts in the basin, given that it already is experiencing a shortage of water resources. Conflict may only be averted if the water resources are managed efficiently and effectively.

7.7.3 Management

Institutional and legislative frameworks

Several administrations are involved in water issues involving the Tafna River Basin. The most important are: (i) General Directorate of Hydraulic (DHW); (ii) Algérienne des Eaux (ADE); (iii) Agence de Basin Chott Chergui Zahez; (iv) Agence Nationale des Barrages; and (v) Directorate of the Agricultural Office. The Algérienne des Eaux is the leading institution in charge of water production and trade.

7.7.4 Key issues, adaptation and mitigation

Physiography

Climate vulnerability

The Tafna River Basin is highly vulnerable to climate variability and change. Several floods and droughts have been reported over the few last decades, examples being the droughts recorded between 1990 and 2000.

Adaptation and mitigation

There is a need:

- To develop an early warning system for flood and drought management.
- To adapt agriculture to drought conditions (e.g., growing appropriate crops; implementing water conservation techniques).

Land and soil degradation

Land degradation is a serious problem in the Tafna River Basin, and also the main cause of reservoir silting. The capacity of the Beni Behdel Dam, for example, has been reduced to only 11.95 Mm^3, corresponding to only 21.98 per cent of its total water capacity.

Adaptation and mitigation

There is a need:

- To reforest and stabilize the landscape.
- To strengthen and enforce regulations for land management and land use.

Socio-economy

Population growth and urbanization

Increased urbanization and development, particularly around Tlemcen and Maghnia areas, is exerting significant pressures on water supply, mainly in the summer, when the water supply is lowest.

Adaptation and mitigation

There is a need:

- To develop policies and legislation to control urbanization.
- For further infrastructure development (e.g., upgrading water supply and sewage systems).

Water availability, uses and demands

The basin's water resources are already being extensively exploited. Further, the projections indicate that, despite the construction of new dams, the available water resources will not be able to fully meet the water demand by 2025.

Adaptation and mitigation

There is a need:

- For further groundwater resources assessment and development.
- For effective pollution control management.
- To develop alternative water sources (e.g., water recycling; desalinisation).
- To promote rational water use.

Management

Institutional and legislative frameworks

Although many institutions are involved in the administration of water issues for the Tafna River Basin, there is no coordination and no appropriate tools for effectively managing the basin's water resources.

Adaptation and mitigation

There is a need:

- To improve communication and coordination between different institutions.
- To strengthen the mandate of the Oranie Basin Agency.

7.7.5 References

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www.abhoranie.dz/

7.8 TENSIFT RIVER BASIN

The Tensift River Basin is located in the western centre of Morocco, covering an area of 20,450 km^2 (7,896 mi^2; Figure 7.8-1). The main characteristics of the basin are summarized in Box 7.8-1.

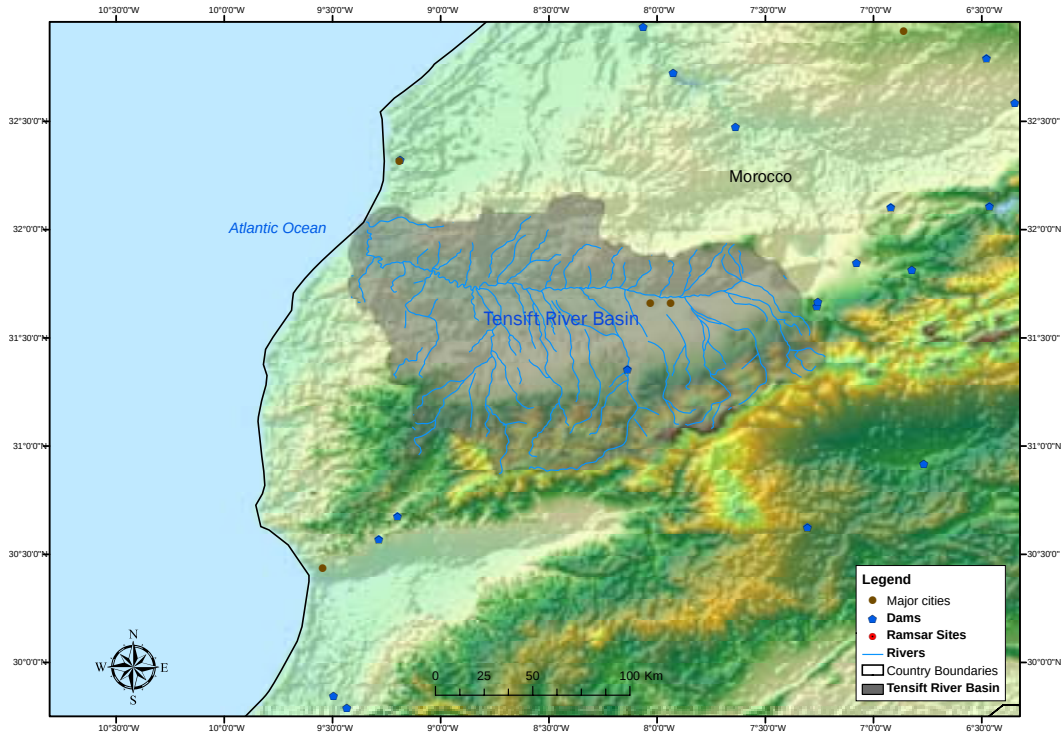

Figure 7.8-1: Tensift River Basin

Box 7.8-1: Main characteristics of Tensift River Basin

Basin		**Water Use**
Surface area:	20,450 km^2 (7,896 mi^2)	Agriculture
MAP:	250-700 $mm.yr^{-1}$ (10-28 $in.yr^{-1}$)	Domestic
		Industry
Demography		
Population:	2.7 million	
Density:	110 $persons.km^{-2}$ (285 $persons.mi^{-2}$)	
Water Resources	**Vulnerability**	
River length:	≈ 600 km (373 mi)	Climate variability and change
MAR:	816 $Mm^3.yr^{-1}$	Industrial and agricultural pollution
	Land erosion & siltation of dams	
Major Dams		
Lalla Takerkoust :	85 Mm^3	
Total dam storage	≈ 73 Mm^3	
Major Aquifers:	Haouz-Mejjate and Bahira aquifers	

7.8.1 Physiography

The Tensift River Basin can be subdivided into three geographical sub-basins:

- In the south, the High Atlas constitutes a zone of mountains with the highest altitudes of the country (4,167 m (13,671 ft); Jbel Toubkal).
- In the centre, the Haouz plain and the Mejjate basin represent a depression of 6,000 km^2 (2,317 mi^2) that receives most of the tributaries draining the High Atlas Mountains.
- In the north, the Jbilet is a mountainous area of low altitude, surrounding the Haouz plain.

Climate

The climate prevailing in the basin ranges from sub-humid in the High Atlas. to arid in the Haouz plain. The precipitation is generally low, being characterized by a high seasonal and inter-annual variability. Like all Mediterranean climates, there are two contrasting seasons, including a wet season from October-April, representing 85-95 per cent of the annual rainfall, and a dry season from May-September with only 5-15 per cent of the annual rainfall. The annual average rainfall is about 250 mm (10 in) in Marrakech, and can reach 700 mm (28 in) in the High Atlas. The average monthly temperatures vary between 18.5-20.5 °C (65-69 °F), and the annual average evaporation varies from 1,830 mm (72 in) in the High Atlas, to 2,640 mm (88 in) in the plain of Haouz.

Land and water degradation

Deforestation, and bad cultural and cultivation practices, contributed to an accelerated soil erosion, thereby enhancing desertification within the basin, and siltation of the Lalla Takerkoust Dam at an average rate of 0.8 $Mm^3.yr^{-1}$ (Figure 7.8-2). The erosion rate could reach more than 3,000 $t.km^{-2}.yr^{-1}$ (17.4 million $lbs.mi^{-2}.yr^{-1}$) in certain areas (Agence du Bassin Hydraulique du Tensift 2006).

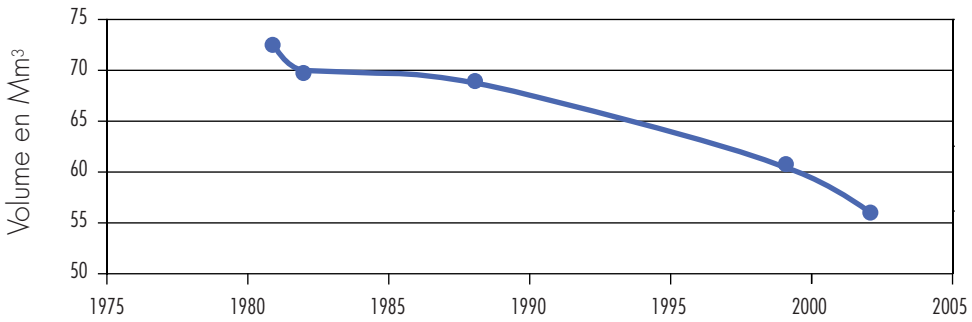

Figure 7.8-2: Volume reduction of Lalla Takerkoust Dam due to siltation

Source: Agence du Bassin Hydraulique du Tensift 2006, redrawn by UNEP

This situation has worsened due to successive years of drought over the past few decades, resulting in the extinction of a number of important plant species with high nutritional value, and which constituted a principal source of fodder for livestock (Alkama and Chakib 2004).

Hydrology

The main tributaries of the Tensift River originate in the High Atlas Mountains, where the runoff is torrential. The estimated mean annual runoff of the Tensift River between 1970-2002 was about 816 $Mm^3.yr^{-1}$, varying between a maximum of 2,690 $Mm^3.yr^{-1}$ and a minimum of 76 $Mm^3.yr^{-1}$ (Figure 7.8-3). Further, the basin benefits from the transfer of 300 Mm^3 of water from the adjacent OumerRbia Basin.

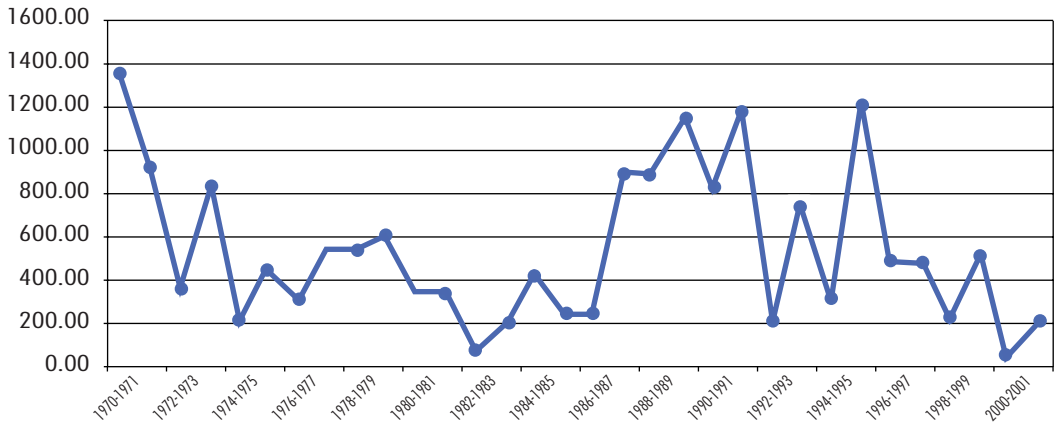

Figure 7.8-3: Tensift River discharge ($Mm^3.yr^{-1}$) during 1970-2001

Source: Agence du Bassin Hydraulique du Tensift 2006, redrawn by UNEP

Hydrogeology

The Tensift River Basin comprises three main groundwater units, including the Haouz aquifer, Mejjate aquifer, and Bahira aquifer. The groundwater balance of these aquifers (Table 7.8-1) indicates a huge deficit, particularly for the Haouz Aquifer. The water table of this aquifer has decreased by 20 m (66 ft) since 1970, mainly in the highly-exploited areas.

Table 7.8-1: Water balance of Tensift aquifers

Aquifer	Potential renewable inputs (Mm^3)	Outputs (Mm^3)	Water balance (Mm^3)
Haouz	238	411	-173
Mejjate	92.5	93.5	-1
Bahira	56	63.5	-7.5
Total	386.5	568	-181.5

Source: Agence du Bassin Hydraulique du Tensift (2006)

Water availability

The estimated surface water resources regulated within the basin in an average year are about 520 $Mm^3.yr^{-1}$, with 85 $Mm^3.yr^{-1}$ being from the Lalla Takerkoust Dam, 2 $Mm^3.yr^{-1}$ from small dams, and 433 $Mm^3.yr^{-1}$ from traditional withdrawals (séguias).

7.8.2 Socio-economy

Demography

According to the 2004 national census, the basin population was 2,723,097 (nearly 9.11 per cent of the country's population), of which 1,071,022 inhabitants (39.3 per cent) live in urban areas, and 1,652,075 (60.7 per cent) live in rural areas.

Economy

The main economic activities within the Tensift River Basin are agriculture, industry, livestock farming, forestry, and tourism.

Poverty

Due to the recurrent drought over the last few decades, and the low agriculture income, poverty is mainly seen in the rural areas of the river basin. The basin development strategy aims to achieve decentralization, integration and participation of the poor population in management of the natural resources by 2020.

Water uses and water demands

Water demand is increasing in the basin. The agricultural sector is the primary user of water resources in the basin, consuming more than 80 per cent of the total water resources, compared to the domestic and industrial sectors, which consume 13 and 7 per cent, respectively. The total irrigated area within the basin is about 226,466 ha (874 mi^2), using more than 1,245 Mm^3 of water per year. Terrace agriculture is practised in some parts of the basin. Domestic and industrial sectors use an estimated 80 Mm^3 of water, of which 60 per cent is from groundwater. This volume is expected to reach 130.2 Mm^3 in the future, including 84.7 Mm^3 for urban centres and 10.5 Mm^3 for industry.

© Biosphoto / Ruoso Cyril / Still Pictures

The inhabitants of the Haouz plain have irrigated their lands by traditional means for several centuries, as evidenced by the *rhettaras* (the type of underground galleries that conveyed groundwater to the surface) which they developed. More than 650 *rhettaras* were developed in various parts of the Haouz plain, producing a continuous flow of 3.2 $m^3.s^{-1}$ for domestic use and irrigation of 20,000 ha (77 mi^2). These works are currently dry because of lowered groundwater levels as a result of intensive pumping and persistent dryness in the area. In fact, the works have been completely destroyed in some areas due to lack of maintenance.

Water-related conflicts

Many users have regular conflicts in regard to equitable sharing of the scarce water resources of the Tensift River Basin. These users mainly comprise farmers and agro-industrial entities. The emergence of sectors parallel to agriculture (e.g., urbanization; tourism; industry; mining) has evidenced a sharp increase in water demands, being a recipe for further conflict if the available water resources are not efficiently and effectively managed.

7.8.3 Management

Institutional and legislative framework

The regional agency of the Tensift River Basin is officially in charge of coordinating all the institutions involved in managing the basin's water resources. Because of limited financial and human resources, however, its role is still limited and must be strengthened.

7.8.4 Key Issues, adaptation and mitigation

Physiography

Climate vulnerability

The Tensift River Basin is highly vulnerable to climate variability and change. Precipitation is already highly variable, in both time and space, throughout the basin. Analysis of the climate data (Figure 7.8-4) highlights a decreased rainfall at all the sampling stations, being more pronounced since 1998. Climate change, with the expected increased frequency of droughts and floods, will exacerbate rainfall variability (UNDP/GEF 2002). The decreased rainfall has been accompanied by an increased use of groundwater resources, particularly in the agricultural sector since this sector has a pivotal role in the region's socio-economic development (Abourida et al. 2004).

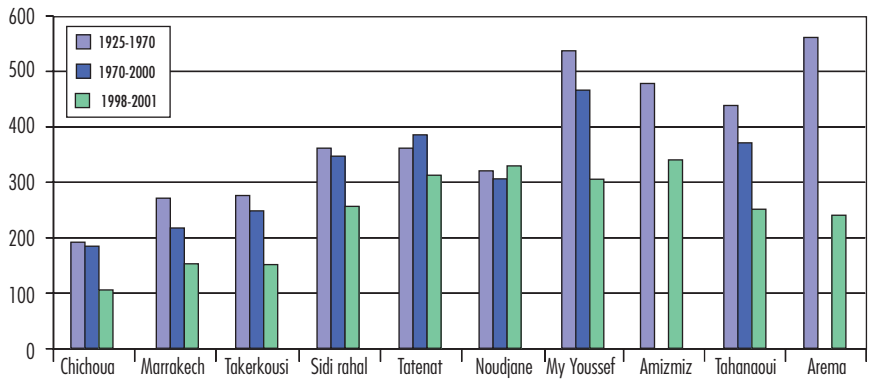

Figure 7.8-4: Mean annual precipitation at different meteorological stations in Tensift River Basin

Source: UNDP/GEF 2002, redrawn by UNEP

Adaptation and mitigation

There is a need:

- To develop an early warning system for drought, including the development of more proactive strategies by the Drought Observatory (Observatoire de la Sécheresse).
- To strengthen the existing flood early warning system.
- To develop scientific research on appropriate drought-resistant crops.
- To control aquifer exploitation, as part of an effective, efficient water resources management programme, in which the groundwater depletion is due to both reduced recharge because of recurrent droughts, and intensified abstraction for agricultural water use.

Land and water degradation

Land degradation is becoming a serious problem in the basin, as forests are being cleared and replaced by agricultural lands. Regarding water degradation, domestic wastewater from urban centres, which total more than 85,000 $m^3.d^{-1}$, is disposed of without preliminary treatment. Moreover, most of the rubbish dumps are uncontrolled, generating lixiviates that contribute to the pollution of freshwater resources. (RADEEMA 1999).

Adaptation and mitigation

There is a need:

- To reforest and stabilize slopes.
- To strengthen and enforce regulations for land management and land use.
- To upgrade water supply and sewage systems.
- To build capacity, increase awareness, and involve rural communities in all projects dealing with water and land management.

Socio-economy

Population growth and urbanization

Increased population growth and urbanization, particularly around the Marrakech metropolitan area, which attracts increasing numbers of people migrating from rural areas, are exerting significant pressures on water supply, demands and pollution.

Adaptation and mitigation

There is a need:

- To invest more in infrastructure development in rural areas (e.g., ecotourism) to combat the rural-to-urban migration.
- To develop policies and legislation to control urbanization and curb high population growth.

Water availability, uses and demands

The water demand projections for the Tensift River Basin foresee a sharp increase (Agence du Bassin Hydraulique du Tensift 2006). Because the basin's water resources are almost fully developed, additional water demands will be difficult to meet. Groundwater levels have sharply declined in the Bahira and Haouz Aquifers since the last decade (Figure 7.8-5).

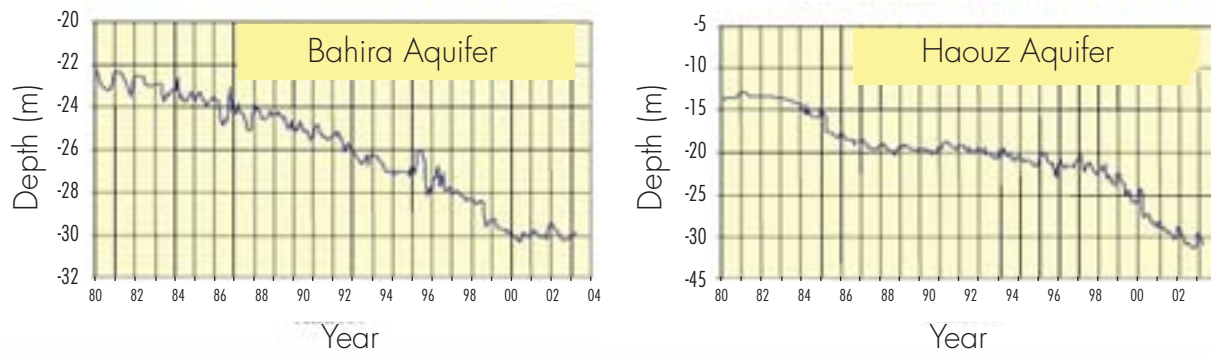

Figure 7.8-5: Groundwater level declines in the main Bahira and Haouz Aquifers

Source: Agence du Bassin Hydraulique du Tensift 2006

Adaptation and mitigation

There is a need:

- To strengthen water demand management.
- To strengthen and enforce regulations for water management and use.
- To develop IWRM to ensure sustainable development.
- To establish alternative water sources (e.g., recycling; desalinization).
- For further assessment and development of groundwater resources.
- For effective pollution control management.

Management

Institutional and legislative frameworks

The Tensift River Basin Agency is supposed to coordinate all activities dealing with basin water resources. The organization needs to be strengthened, however, for it to be fully operational and effective.

Adaptation and mitigation

There is a need:

- To improve communication and coordination between different departments and administrations for effective decision-making, and efficient management of existing schemes.
- To strengthen the capacities of these institutions on water resources development and management, in order to ensure effective adaptation to changing climatic and environmental conditions in the basin.

Data availability, standardization and monitoring

While much data and information on groundwater of the Tensift River Basin is available, (even if not easily accessible), accurate data on surface water resources are lacking.

Adaptation and mitigation

There is a need:

- To expand the monitoring network.
- To improve access to data.

7.8.5 References

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7.9 NORTH WESTERN SAHARA AQUIFER SYSTEM

The North Western Sahara Aquifer System (NWSAS) is a transboundary, multi-layered aquifer system shared by Algeria, Tunisia, and Libya. The whole system covers an area of more than 1 million km^2 (386,102 mi^2), with 700,000 km^2 (270,272 mi^2) in Algeria, 250,000 km^2 (96,526 mi^2) in Libya, and 80,000 km^2 (30,888 mi^2) in Tunisia (Figure 7.9-1). The NWSAS encompasses 2 major water bearing formations, including the Continental Intercalaire (CI) and Complexe Terminal (CT). The main characteristics of the aquifer system are summarized in Box 7.9-1.

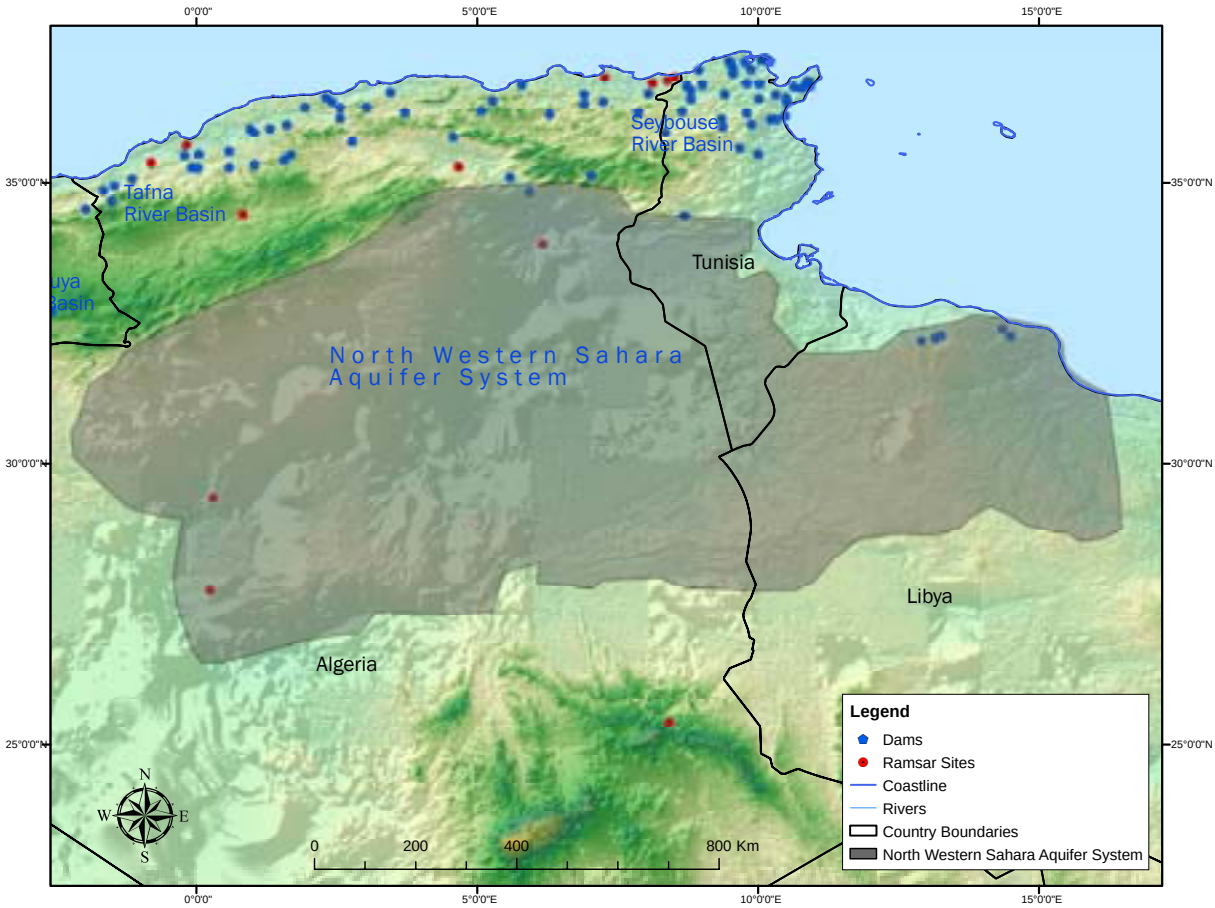

Figure 7.9-1: North Western Sahara Aquifer System

Box 7.9-1: Main characteristics of North Western Sahara Aquifer System

Basin

Surface area:	~1,000,000 km^2 (386,102 mi^2)
MAP:	60 mm.yr^{-1} (2.4 in.yr^{-1})

Demography

Population:	5 million
Density:	~5 persons.km^{-2} (13 persons.mi^{-2})

Water Resources

Major Aquifers	
Continental intercalaire	
Volume	20,000 km^3
MAP:	400 Mm^3.yr^{-1}
Complexe terminal	
Volume	11,000 km^3
MAP:	650 Mm^3.yr^{-1}

Water Use

Agriculture
Domestic
Industry

Increasing

Vulnerability

Over abstraction
Salinization
Piezometric decline
Land degradation

Source: OSS (2003, 2007)

7.9.1 Physiography

Climate

The aquifer system lies within the Sahara Desert, with its climate being characterized by an extremely high aridity, with prolonged rainless periods and generally very low precipitation. The most important rainfall occurs on the Saharan Atlas Mountains in the north, where the mean annual precipitation is estimated to be between 200-250 mm (8-10 in). The mean annual precipitation is between 80-150 mm (3-6 in) in the Dahar region. On the Jebel Nefusa, and along the Libyan coastline, the mean annual precipitation is between 80-250 mm (3-10 in). These regions are the principal NWSAS aquifer recharge areas. The southern parts of the system experiences low precipitation, and desert conditions prevail. Although there are few precise measurements, the evaporation is known to be largely greater than the precipitation, estimated to be between 1,500-2,500 mm.yr^{-1} (59-98 in.yr^{-1}) from north to south, respectively.

Ecosystems

Groundwater constitutes the main water resource within the NWSAS area. Many wetlands, from oases to salt lakes (e.g., Sebkhas; Schotts), are connected to the aquifers. These sources of life in the arid and xeric Sahara Desert constitute unique habitats for many fauna and flora species, such as migrant birds from the Mediterranean region to the Sahara), particularly in the winter season, among which certain species are threatened with extinction (e.g., 'pink floyds'; tadome casarca) and fennec. The flora is highly diversified, and depends on the water salinity and level. Chotts are propitious for endemic species (e.g., Chott Melghir in Algeria), where 14 endemic species have been identified. In this respect, the wetlands of the NWSAS are rich in species and varieties of cultivated plants adapted to resist water stresses and climate variability.

Land degradation and desertification

The desert prevails already on more than 90 per cent of the North Western Sahara Basin. Nevertheless, development of irrigation systems around the oases has allowed Saharan farmers to grow crops on increasing large areas. Irrigated land surfaces now reach more than 250,000 ha (965 mi^2) in the area. Poor irrigation management practices have caused serious land degradation, mainly through soil salinization. Nearly 75 per cent of the irrigated land in Algeria, and 42 per cent in Tunisia, is now salinized to various degrees. In addition to the damage to the ecological quality of the land, the severity of salinization in the region is evident through the net loss of soils, evaluated to be more than 4,000 ha (15 mi^2) per year in Algeria on an irrigated land surface of 170,000 ha (656 mi^2), to 300 ha (1.2 mi^2) per year in Tunisia for 40,000 ha (154 mi^2) of land surface; and to 3,000 ha (12 mi^2) per year in Libya for 40,000 ha (154 mi^2). The now-abandoned oasian cultural systems, and the traditional techniques of integrated fertility management, have contributed to land degradation and soil fertility. Over-grazing on rangelands is exacerbating desertification.

Hydrology

More than 30 watersheds located in the Saharan Atlas range (Aurès, Dorsale du Mzab or Dahar Mountains), and covering a total area of 250,000 km2 (965 mi2), act as water collectors during flash floods. Exhibiting a very high intra- and inter-annual variability, the global mean inter-annual discharge flowing into these seasonal rivers (called Oueds) is estimated to be about 1 billion m^3, with half this quantity coming from the Saharan Atlas basins.

Hydrogeology

The Saharan Basin is a large, multi-layer sedimentary entity. A precise geological and hydrogeological assessment of the basin has resulted in the modelling of an aquifer system. Further, a mathematical model of the water exchanges and flows within the system has been developed. The multi-layer NWSAS can be simplified into 3 superimposed aquifers, separated by, or communicating through, semi-permeable formations. These formations include: (i) the Continental Intercalaire Aquifer (CI); (ii) the more-localised Turonian Aquifer; and (iii) the Complexe Terminal Aquifer (CT). The hydrogeology of the area has been well-established through a series of investigations spanning 1950-2000.

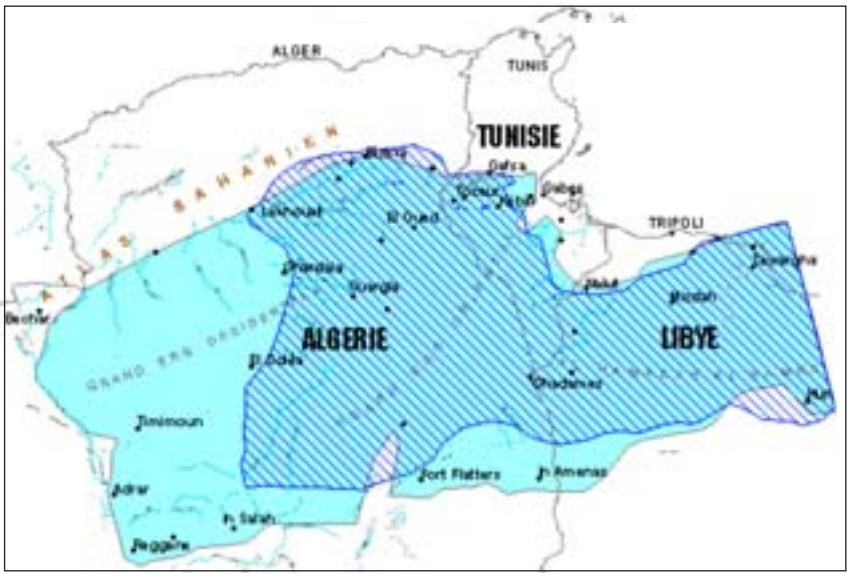

Figure 7.9-2: NWSAS aquifers extensions

Source: Sahara and Sahel Observatory

Groundwater recharge is very low due to the arid Saharan climate conditions. Recharge of the NWSAS is globally estimated to be about 1 billion m^3.yr-1, mostly infiltrated at the piedmonts of the Saharan Atlas in Algeria, and on the Dahar in Tunisia and the Djebel Nefoussa in Libya. The large areal extent of the system, however, and the massive thicknesses of its layers, have allowed important reserves to accumulate over the past centuries, estimated to be about 30,000 billion m^3.

These important resources are currently being threatened with over-exploitation. The estimated water withdrawals were about 2.5 billion m^3 in 2003 (cf. water uses and demands). This exploitation causes significant risks to water resources at the local level, examples being: (i) disappearance of artesian conditions; (ii) drying up of the Foggaras (traditional irrigation systems) in Algeria; (iii) drying up of the Tunisian outlet of the CT (which supplies the coastal Tuniso-Libyan Djeffara Aquifer, the principal water resources of this highly-populated area); (iv) the decline of the piezometric heads, leading to deeper pumping levels and, consequently, higher energy costs; and, more critically, (v) the risk of salt water inversion from the saline wetlands, particularly in the Algiero-Tunisian Chotts area, and the region of Biskra.

Nevertheless, the large groundwater reserves provide good potential for further development, particularly in the Grand Erg Occidental basin in Algeria, where the CI is unconfined and, consequently, easily accessible. It is estimated that water abstractions on a large scale could be increased from 2.5 billion to nearly 8 billion m^3 by 2030, taking into account the risks described above. Groundwater development is currently focused on inhabited areas and, in order to increase water abstractions, groundwater development should be carried out in the remote uninhabited areas. Algeria is now following this route.

7.9.2 Socio-economy

Demography

The census carried out for Algeria in 1998, for Tunisia in 1994, and for Libya in 1995, coupled with other national demographic statistics, enabled development of demographic models that provided projections of population dynamics in the NWSAS area through the year 2030. As shown in Table 7.9-1, the total NWSAS population is expected to double over the 2000-2030 period, the increase being most obvious in Algeria and Libya. In the case of Algeria, the population increase will be accompanied by high urban development, with the urban index reaching 63 per cent of the population in 2015, and 73 per cent in 2030.

Table 7.9-1: Demographic projections NWSAS (inhabitants of NWSAS area per country)

Country	Year 2000	Year 2020	Year 2030
Algeria	2,600,000	3,700,000	4,800,000
Tunisia	1,200,000	1,500,000	1,700,000
Libya	1,000,000	1,800,000	2,300,000
Total NWSAS	4,800,000	7,000,000	8,800,000

Economy

The agricultural sector represents by far the major activity of this region. Most agriculture is irrigated, with more than 250,000 ha (965 mi^2) of irrigated land within the NWSAS Basin, with 170,000 ha

(656 mi^2) being in Algeria, and 40,000 ha (154 mi^2) being in each of the other 2 countries. The land is prioritized for tree cultivation (palm and fruit trees). A typology of oases culture has allowed for understanding of the complexity and diversity of the farming systems in Algeria and Tunisia. The agricultural sector is characterized by many small-sized farms. In Algeria, for example, nearly 600,000 people are working on 170,000 ha (656 mi^2) of agricultural land. Thus, the systems are very labour-intensive. In Tunisia, a few large private farms cultivate palm trees on tens of hectares, with the harvested dates principally destined for markets.

The oases cultural systems in the 2 countries are organised around palm trees, which can be combined with other crops within the traditional 3 floor system, or with cattle ranching, which is also an important activity in the region. In Tunisia, about 3 million ha (11,583 mi^2) was being used for cattle farming by 1995. In the Libyan portion of the basin, agricultural development took place in the 1970s and 1980s. It is currently estimated that 40,000 ha (154 mi^2) of agricultural land is under irrigation. The principal agricultural activities in the Libyan part of the basin are cultivation of palm trees and olive trees, cereals, fodder, fruit trees and vegetables.

Oil and phosphate mining have an important role in the economy of Algeria. Further, tourism is a very important economic sector, particularly in Tunisia.

Water uses and water demands

The NWSAS is exploited by nearly 8,800 water points, in the form of wells and boreholes. About 3,500 are located in the Continental Intercalaire, and 5,300 in the Complexe Terminal. The distribution of the water points on a country basis is as follows: 6,500 in Algeria; 1,200 in Tunisia; and 1,100 in Libya. The water abstraction has increased over the past 20 years, to a current rate of 2.5 billion $m^3.yr^{-1}$ (with 1.50 billion $m^3.yr^{-1}$ in Algeria; 0.55 billion $m^3.yr^{-1}$ in Tunisia; 0.45 billion $m^3.yr^{-1}$ in Libya). This water abstraction volume represents more than double the natural recharge of the system.

Irrigated agriculture is the principal groundwater consumer, accounting for more than 90 per cent of groundwater abstractions. Domestic water consumption is estimated to be 120 million $m^3.yr^{-1}$ in Algeria, 40 million $m^3.yr^{-1}$ in Tunisia, and 55 million $m^3.yr^{-1}$ in Libya. Industrial water demand is estimated to be 180 million $m^3.yr^{-1}$, mostly for the oil sector in Algeria, and the industrial sector of Gafsa and Gabes in Tunisia.

Effective and efficient groundwater management mechanisms are needed to ensure the aquifers are developed in a sustainable manner for the benefit of all sectors (domestic, industrial and agricultural). Increased population growth will certainly result in increased domestic water demands which must be met from the limited, and already overstretched, groundwater resources.

7.9.3 Management

Institutional and legislative frameworks

The NWSAS project, led by the 3 countries, and facilitated by the Sahara and Sahel Observatory (OSS) since 1999, is now entering its third phase. Building on shared knowledge, and on creating common management tools, this project has resulted in establishment of an institutional consultation mechanism between the 3 countries sharing the NWSAS water resources. Its secretariat (the Coordination Unit) formally took place at the OSS in November 2007.

The key missions of the Coordination Unit consist of:

- Assisting the countries to implement the main technical activities aimed at facilitating dialogue. This refers mainly to data collection through common monitoring networks that have been developed, updating of the common database, and the hydrological models;
- Sustaining the dynamics of the institutional process through proper identification of the main transboundary hydraulic issues, formulation of solutions, and formalization of consensus; and
- Ensuring information diffusion and organizing debates between decision-makers concerning programmes and options for basin development, and supporting participative management with a strong communication axis.

Data availability, standardization and monitoring

The building of a common database, coupled with a GIS, of a hydrodynamic model covering the whole transboundary aquifer system, and definition of common monitoring networks for the NWSAS water resource quantity and quality, has allowed the 3 countries to obtain a global view of the entire NWSAS system. Further, the consultation mechanism has been defined, with the aim of updating and sustaining data exchanges to supply the database on a sustainable basis.

7.9.4 Key issues, adaptation and mitigation

Physiography

Land degradation

Land degradation is increasing because of inefficient irrigation and over-grazing.

Adaptation and mitigation

There is a need:

- For strong action to restore degraded lands, through developing and implementing effective land management policies.
- To monitor and evaluate the exploitation of natural resources and the resultant environmental impacts.

Socio-economy

Water availability, uses and demands

NWSAS water resources are currently threatened by over-exploitation significantly higher than the annual natural recharge, with irrigated agriculture being the main groundwater consumer. The aquifer system is under potential threat from salinization from the salted waters of the Chotts.

Adaptation and mitigation

There is a need:

- To improve irrigation efficiency.
- To explore the concept of virtual water as a means of augmenting groundwater resources.
- To carry out cost-benefit studies of all available options (e.g., water transfer).
- To diversify from water-intensive agricultural production, in order to lessen the burden on groundwater resources.

Management

Data availability, standardization and monitoring

Socio-economic and environmental data are lacking. Water uses are not well-monitored, particularly in Libya.

Adaptation and mitigation

There is a need:

- To improve knowledge on socio-economic and environmental issues, by collecting the requisite information.

7.9.5 References

OSS 2003: Système Aquifère du Sahara Septentrional, gestion commune d'un basin transfrontière, rapport de synthése.

OSS 2007: Système Aquifère du Sahara Septentrional, gestion commune d'un basin transfrontière, rapport de synthése II.

7.10 NUBIAN SANDSTONE AQUIFER SYSTEM

The Nubian Sandstone Aquifer System (NSAS) is a large fossil groundwater basin (Figure 7.10-1), considered to be one of the world's most important aquifers. The NSAS extends across the borders of 4 African countries (Egypt, Libya, Sudan, Chad). It covers a total area of 2,200,000 km^2 (849,425 mi^2), encompassing a major part of Egypt (37 per cent), the eastern part of Libya (35 per cent), the northwestern part of Sudan (17 per cent), and the extreme northeast of Chad (11 per cent). Thick layers of highly porous continental sediments form an enormous water storage system. The main characteristics of the NSAS are summarized in Box 7.10-1.

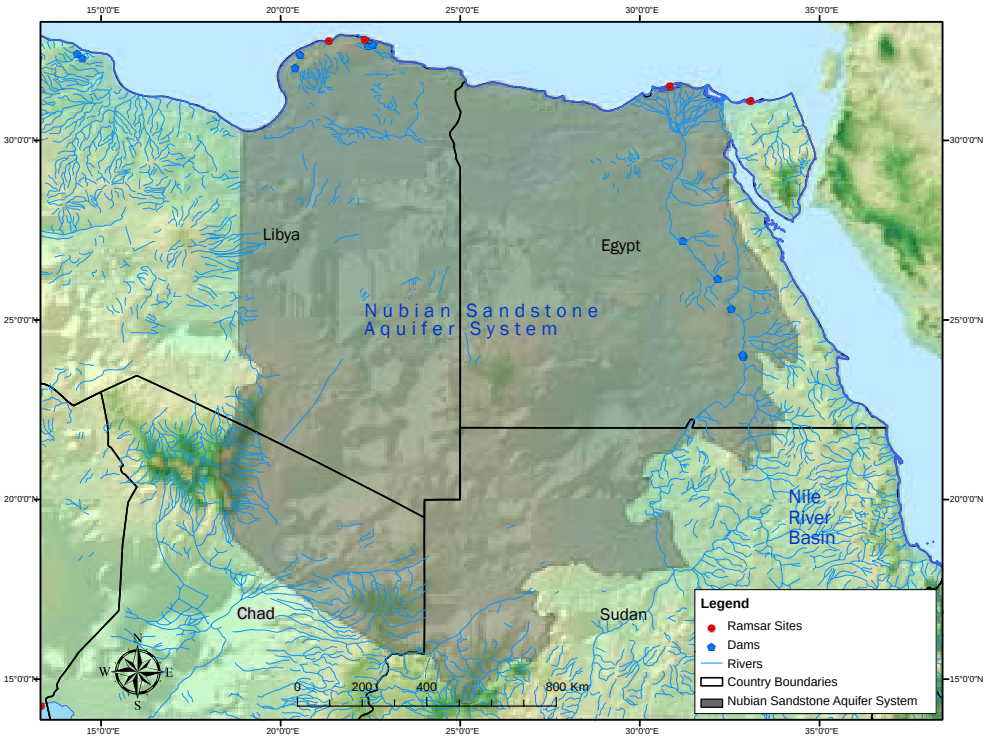

Figure 7.10-1: Nubian Sandstone Aquifer System

Box 7.10-1: Main characteristics of Nubian Sandstone Aquifer System

Basin		**Water Use**
Surface area:	2,200,000 km^2 (849,425 mi^2)	Agriculture
		Domestic
Demography		Mining
Population:	0.76 million	Industry
Density:	0.35 persons.km^{-2} (1 person.mi^{-2})	
Major Aquifers		**Vulnerability**
Nubian Sub-System		Increasing aridity to the north
Unconfined recoverable volume:	8,800 km^3	
Confined recoverable volume:	9 km^3	
Post-Nubian Sub-System		
Unconfined recoverable volume:	6,000 km^3	

Source: CEDARE (2001); AbuZeid (2004)

The regional geological structure of the NSAS was established in late-Paleozoic times, and sedimentation continued into the Tertiary period (CEDARE 2001). To the south and west, the borders are formed by the basement outcrops of the Kordofan block, the Tibesti Mountains, and the eastern slopes of Jabal Haruj (Figure 7.10-2). To the north, the border is formed by the Mediterranean Sea, while the borders are formed to the east by the basement outcrops of the Nubian plate. The crystalline basement complex is considered impervious.

7.10.1 Physiography

The Nubian Sandstone Aquifer System occurs mainly in the Arid Zone Belt of northern Africa, where the average annual precipitation is very low, rarely exceeding 25 mm.yr^{1} (1 in.yr^{1}; Figure 7.10-3). In the northern part of the area, Mediterranean temperate climatic conditions prevail, with the annual precipitation slightly exceeding 100 mm (4 in). Tropical rains occur locally in the south, with the annual rainfall reaching 1,000 mm (39 in). The precipitation quantities within the NSAS and adjacent areas have not changed over the past 120 years, generally being erratic and exhibiting periodicity. In some areas (e.g., Gebel Oweinat), heavy rainfall was recorded in 1921, 1927 and 1960.

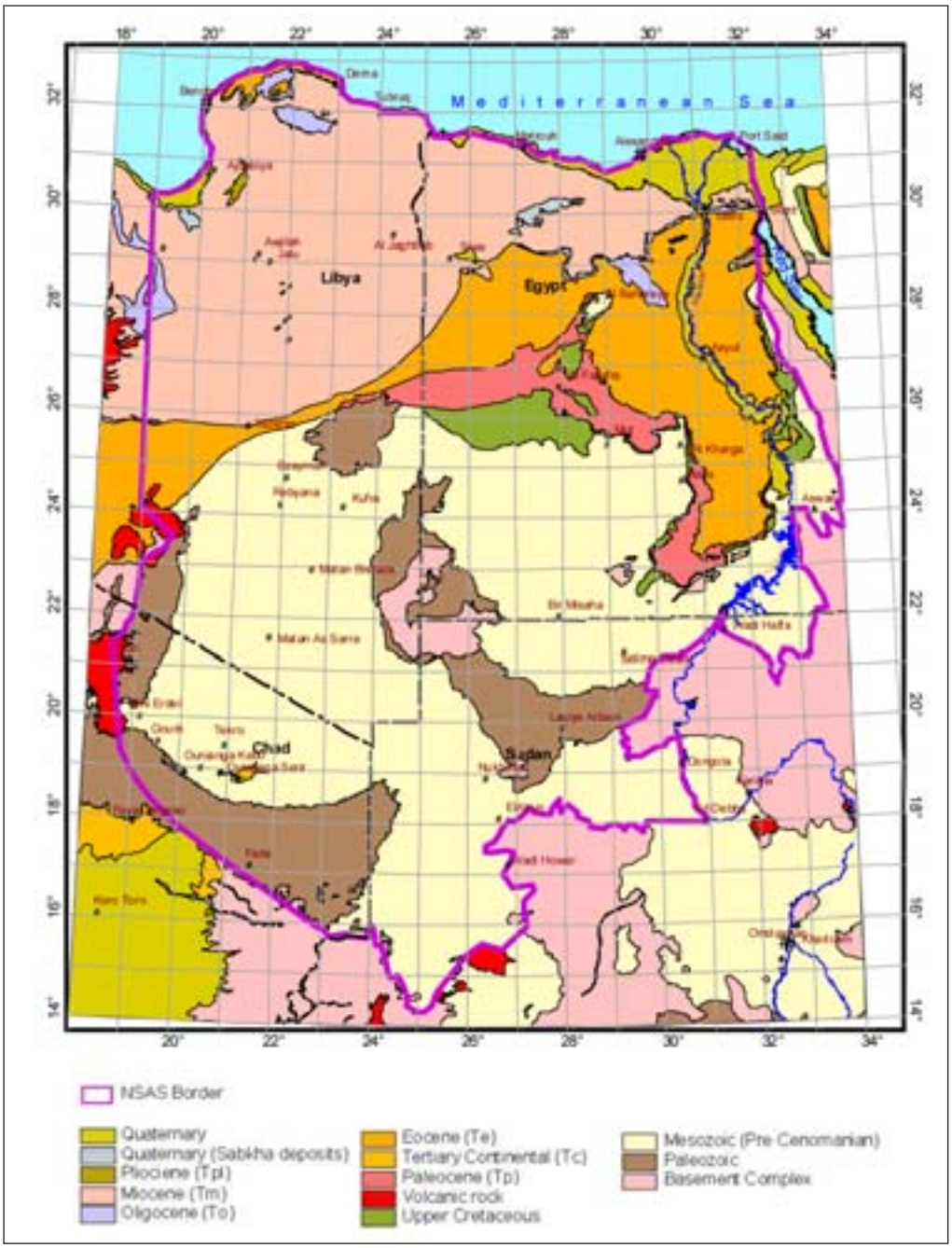

Figure 7.10-2: Geology of Nubian Sandstone Aquifer System (CEDARE 2001)

Source: ESRI (1998), ArcAtlas

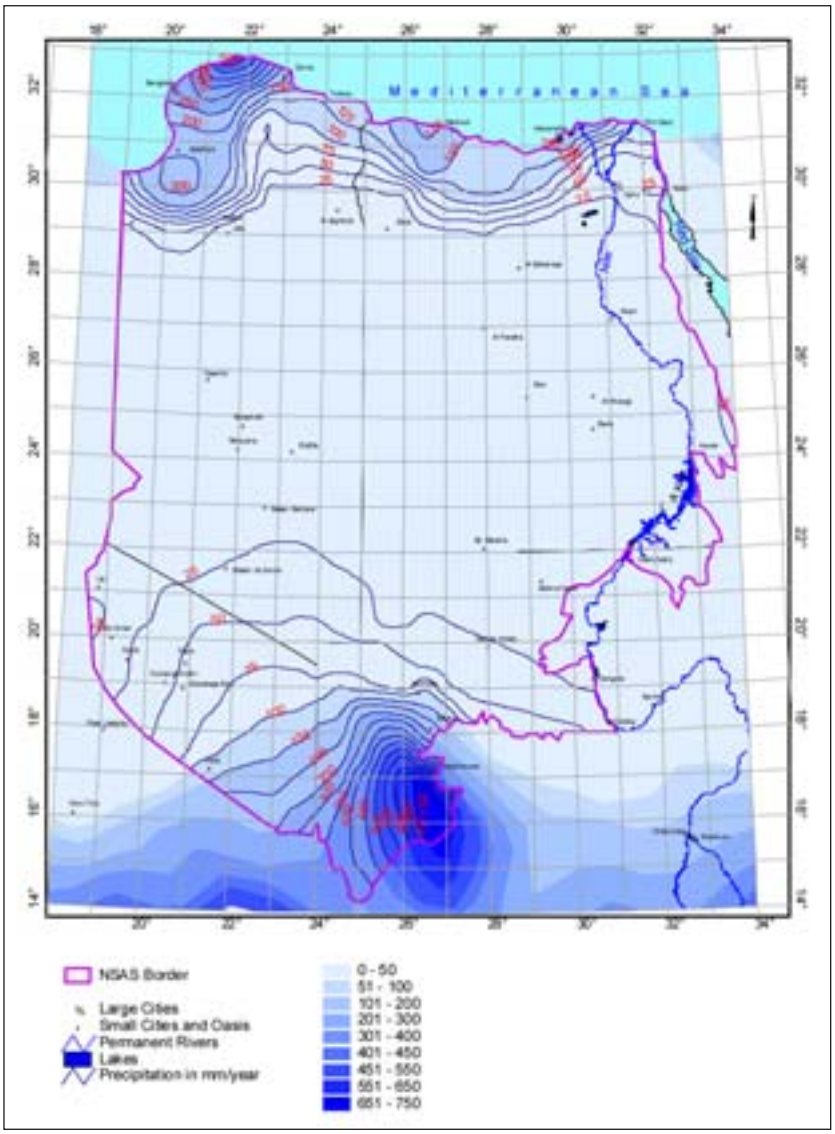

Figure 7.10-3: Precipitation distribution on fringes of Nubian Sandstone Aquifer System.

Source: ESIR 1995; ArcAtlas

Climate

The climate in the area is characterized by: (i) low and irregular rainfall; (ii) high daily and seasonal temperature variations; (iii) low relative humidity and high evaporation intensities; (iv) strong, dry winds; and (v) intensive solar radiation

The major issues regarding water resources management in the area are mining of fossil groundwater and potential groundwater pollution.

Water availability

The Nubian Sandstone Aquifer System is a non-renewable water resource, meaning the population it sustains is very vulnerable to future water availability risks. Although current aquifer water use (about 1.7 $km^3.yr^{-1}$) is still within permissible regional limits (which could sustain the existing population for many years to come), the decline in groundwater levels has already reached 30 m (98 ft) at some locations in the aquifer. This indicates that vulnerability to water availability risks is already occurring at a local level, and may become more widespread if the effects are propagated on a regional scale.

7.10.2 Socio-economy

The estimated total population in the area encompassing the NSAS is about 762,000, including 284,960 in Sudan (37 per cent), 219,090 in Libya (29 per cent), 184,770 in Egypt (24 per cent), and 73,180 in Chad (10 per cent). The NSAS area in Libya is generally a desert area, where communities are only resident adjacent to oases.

The area's socio-economic situation is characterized by: (i) low income levels: (ii) relatively large household sizes; (iii) relatively high mortality rates in some areas; (iv) different ethnic groups; (v) high unemployment rates; and (vi) high illiteracy rates

Economic activities are primarily focused on agriculture, animal husbandry and mining.

7.10.3 Management

Each of the 4 countries within the NSAS area has its own national development plan for groundwater utilization. The transboundary and non-renewable nature of the resource, however, underpins the urgent need for regional cooperation to develop and implement a shared vision for sustainable management of the aquifer system as a whole.

Within this context, the 4 countries have established the Joint Authority for the Study and Development of the Nubian Sandstone Aquifer. The Centre for Environment and Development of the Arab Region and Europe (CEDARE) was tasked in 2001 to devise a regional programme to develop a strategy for utilizing the NSAS (CEDARE 2001). Within this programme, data and information available on the aquifer system in the 4 countries were collated and harmonized to develop a comprehensive regional information system. Regional GIS maps were produced, and a mathematical groundwater model constructed, to predict the aquifer's response to various water development scenarios. The model, which tests the regional behaviour of the aquifer, and the influence of water development scenarios in existing and future well fields, is an important tool for predicting and reducing future vulnerability to water availability. Capacity building of national institutions also formed an integral part of the programme.

7.10.4 Key issues, adaptation and mitigation

The key issue relates to water scarcity.

Physiography

Water availability

Although current water use from the aquifer is still within permissible regional limits, there are locations where groundwater levels have declined by more than 30 m (98 ft). This indicates that vulnerability to water availability risks is already occurring at the local level, and could become more widespread if the effects are propagated on a regional scale. Future generations of people in the basin could be seriously affected by reduced water availability.

Adaptation and mitigation

There is a need:
Adaptation and mitigation

- There is a need: To develop effective monitoring systems, to ensure the effects of groundwater resources development are appropriately managed.
- To look at alternative sources of water (e.g., sea water desalinization; blending of brackish water and freshwater to produce reasonable water quality for other uses).

Socio-economy
High rates of unemployment, illiteracy and mortality rates in some areas, and relatively large household sizes, coupled with low-income levels, are some of the characteristics of the economic situation within the groundwater basin. Economic activities focus primarily on agriculture and animal husbandry, which are dependent on the availability of good quality water.

Adaptation and mitigation

There is a need:
- To invest more in upgrading and developing infrastructure in both urban and rural areas, to raise living standards.
- To implement measures curbing high population growths.

Management

International protocols
Each of the 4 countries within the NSAS area has its own national development plan for utilizing groundwater. A Joint Authority for the Study and Development of the Nubian Sandstone Aquifer was established to devise a regional programme to develop a strategy for utilizing the NSAS.

Adaptation and mitigation

There is a need:
- To strengthen joint authority through capacity-building of human resources and equipment, in order to effectively exercise its mandate on developing and managing the groundwater basin.

Data availability, standardization and monitoring
Monitoring and database development are not well developed.

Adaptation and mitigation

There is a need:
- To establish standardized procedures for monitoring and database development.
- For effective data processing and sharing among the riparian countries.

7.10.5 References

Abu-Zeid, K. 2004: *Framework for the Implementation of the Regional Strategy for the Utilisation of the Nubian Sandstone Aquifer System*. GEF/UNDP/IAEA Workshop.

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There is an intimate relationship between climate change and freshwater since climate affects hydrological cycles at all geographical scales from global to local. According to available scientific knowledge, climate change is leading to substantial changes in precipitation over time and space. Africa's high dependence on natural resources makes its people vulnerable to these climatic changes. This vulnerability relates to natural and human phenomena, inter alia, climate change and variability, pollution, population growth, competition for water, data availability and quality, and knowledge gaps. Many ecosystems are already at high risk, thereby threatening the livelihoods of the many poor who are least capable of adapting to environmental change.

Regional groups of researchers addressed vulnerability issues for their respective regions (southern, eastern, central, western, and northern Africa and the Western Indian Ocean Island States) by assessing major river/lake/groundwater basins on the basis of natural (physiographic), anthropogenic (socio-economic) and management criteria.

This publication documents the findings of the "Vulnerability of Water Resources to Environmental Change in Africa" study and clearly illustrate that Africa's water resources are already facing serious risks, with the situation expected to get worse. It thus marks a starting point for undertaking comprehensive vulnerability assessments of Africa's water resources, informing the management of vulnerability risks at various levels while accomplishing a wider continental, coverage of river/lake/groundwater basins and expanding the network of researchers.

Contact

Division of Early Warning Assessment
United Nations Environment Programme
P.O. Box 30552, Nairobi 00100, Kenya
Tel: (+254) 20 7622015
Fax: (+254) 20 7622798
E-mail: dewainfo@unep.org
Web: www.unep.org

Water Research Commission
Private Bag X03, Gezina, 0031 South Africa
Tel: +27 12 3300340
Fax: +27 12 3312565

www.unep.org
United Nations Environment Programme
P.O. Box 30552, Nairobi 00100, Kenya
Tel: (+254) 20 7621234
Fax: (+254) 20 7623927
E-mail: uneppub@unep.org
Web: www.unep.org

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