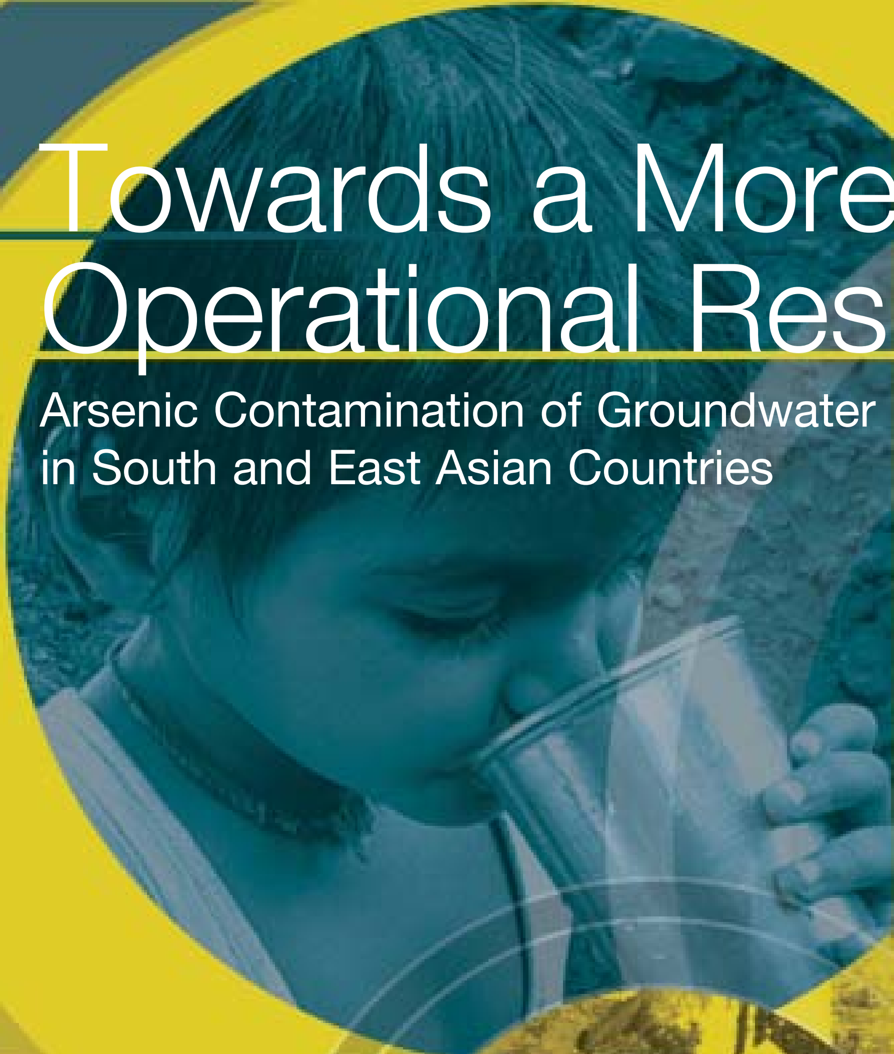
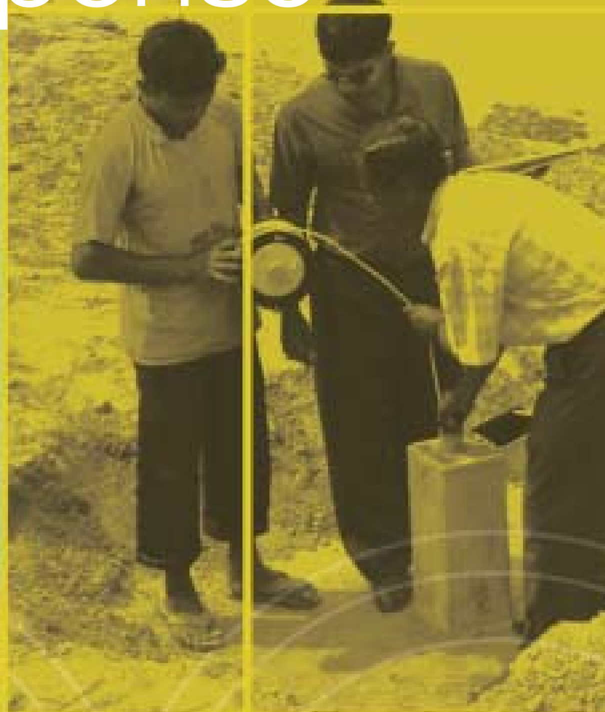
Towards a More Effective Operational Response

Arsenic Contamination of Groundwater in South and East Asian Countries





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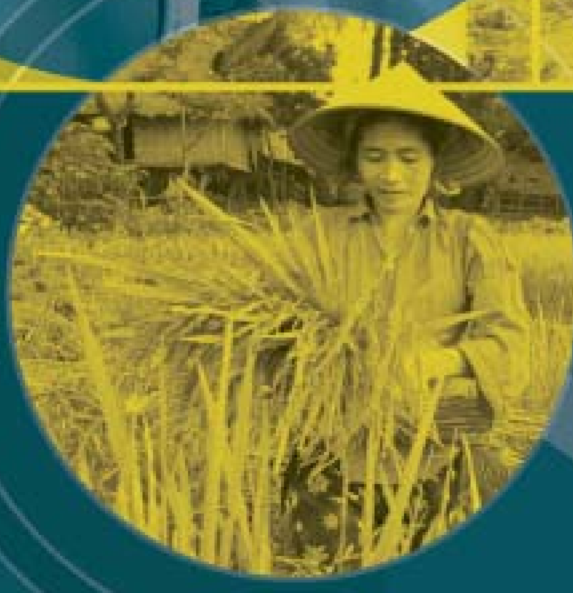

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VOL I POLICY REPORT

Report No. 31303

Towards a More Effective Operational Response

Arsenic Contamination of Groundwater in South and East Asian Countries

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The World Bank
Environment and Social Unit - South Asia Region
Water and Sanitation Program (WSP) - South and East Asia

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Foreword

Access to safe water is one of the key Millennium Development Goals. It is an important foundation for sustainable poverty reduction. The natural occurrence of arsenic in groundwater constitutes a setback in the provision of safe drinking water to millions of citizens in Asia. Since arsenic was first detected in groundwater in the early 1990s in Bangladesh and West Bengal in India, following tightly on the United Nations Water Decade and major investment in apparently safe groundwater resources, it has now also been identified in Cambodia, several provinces of China, Lao People's Democratic Republic, Myanmar, Nepal, Pakistan, Vietnam, and in further states of India. At least 60 million people live in arsenic-affected areas and many drink arsenic-contaminated water on a daily basis.

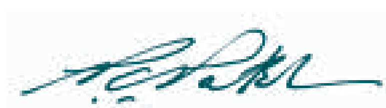
The present study focuses on the operational responses that have been undertaken by country governments, development agencies, nongovernmental organizations, and academia to address the arsenic issue. The outcome is encouraging on the one hand because much work has been carried out in the past years and far more is now known about arsenic and how to deal with it than when it was first identified. At the same time the study highlights the significant gaps that still exist, both in terms of geohydrological, hydrochemical, and epidemiological knowledge and in terms of technological, social, and institutional options to address the issue.

The key recommendations of the study therefore are to take a more strategic approach to arsenic in South and East Asian countries, at project, national, and global levels. This includes the targeted integration of arsenic as a risk factor in water supply and irrigation investments undertaken in the region, rather than treating it as a special issue to be dealt with by special authorities or agencies. This will involve the active institutional integration of water supply with water (especially groundwater) management concerns, the sequencing of concrete actions when arsenic is detected in a certain area, overcoming the political economy constraints that may impede awareness raising and mitigation activities, a strategic research agenda that will provide urgently needed answers to such issues as the dose-response relationships for arsenic (that is, how many people in exposed areas can actually be expected to become ill at what levels of arsenic concentration), study of arsenic in the food chain, and geohydrological and hydrochemical research.

The study outlines concrete operational responses that have been and can be undertaken at the local and country levels, even in the absence of full certainty about the arsenic issue. At the global level, a concerted effort by governments, development agencies, nongovernmental organizations, and academia is needed to make arsenic research more strategic and effective.

The World Bank has a commitment to support developing countries in achieving the Millennium Development Goals and can assist this process by supporting effective approaches in dealing with arsenic. Arsenic is an issue cutting across many sectors and countries. It must also be seen in the context of the overall water supply sector because too many people die yearly of waterborne diseases, often through contaminated surface water sources. This is an immediate health threat which is interlinked with the long-term arsenic threat and which does not offer simple solutions.

It is hoped that in bringing together and analyzing the past experience of many stakeholders, this study will contribute to the development of a more strategic and operational response to the arsenic issue so that the millions of people living in arsenic-affected areas in Asia will be able to reap the benefits of investments already made and still to be made not only in water supply and irrigation infrastructure but also in such institutions as schools and hospitals, all of which provide water to burgeoning populations.



Praful Patel
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Acknowledgments

This study was conducted by the World Bank and the Water and Sanitation Programs of South and East Asia, with additional financing from the Bank Netherlands Water Partnership Program and the UK Department for International Development (DFID). It was prepared by a team composed of Karin Kemper and Khawaja Minnatullah (co-task leaders); Amal Talbi, Ede Ijjasz-Vasquez, and Carla Vale (World Bank); Stephen Foster and Albert Tuinhof (World Bank Groundwater Management Advisory Team - GWMATE); and Jan-Willem Rosenboom (WSP-East Asia). The background papers were prepared by Pauline Smedley (British Geological Survey), Amal Talbi (World Bank), Feroze Ahmed (Bangladesh University of Engineering and Technology) and Phoebe Koundouri (Reading University/University College London and GWMATE). Valuable comments were provided by Caroline van den Berg, John Briscoe, and Nadim Khouri (peer reviewers); and Junaid Ahmad, Guy Alaerts, Ejaz Ghani, Rachel Kaufmann, Smita Misra, Rick Pollard, Jamal Saghir and Luiz Tavares. In addition, the study benefited from numerous comments from participants at the session held at the World Bank Water Week in Washington, D.C. in February 2004 and at the Regional Operational Responses to Arsenic Workshop held in Kathmandu, Nepal, in April 2004. The team would like to express their gratitude to Jeffrey Racki (Acting Director, South Asia Social and Environment Unit), Alastair McKechnie (Country and Regional director, South Asia Region) and Shantayanan Devarajan (Chief Economist, South Asia Region) for their guidance during the study. The team would also like to thank Shyam Ranjitkar (World Bank, Nepal Office) and Dibya Ratna Kansakar from the Department of Irrigation in Nepal for hosting the workshop in Kathmandu, the respondents of the study survey and the many colleagues in the World Bank, WSP and numerous organizations who provided information for this study. The study documentation was edited by John Dawson. Vandana Mehra (WSP) managed design and publication arrangements.

Abbreviations and Acronyms

The following list includes all abbreviations and acronyms used throughout Volumes I and II of the report.

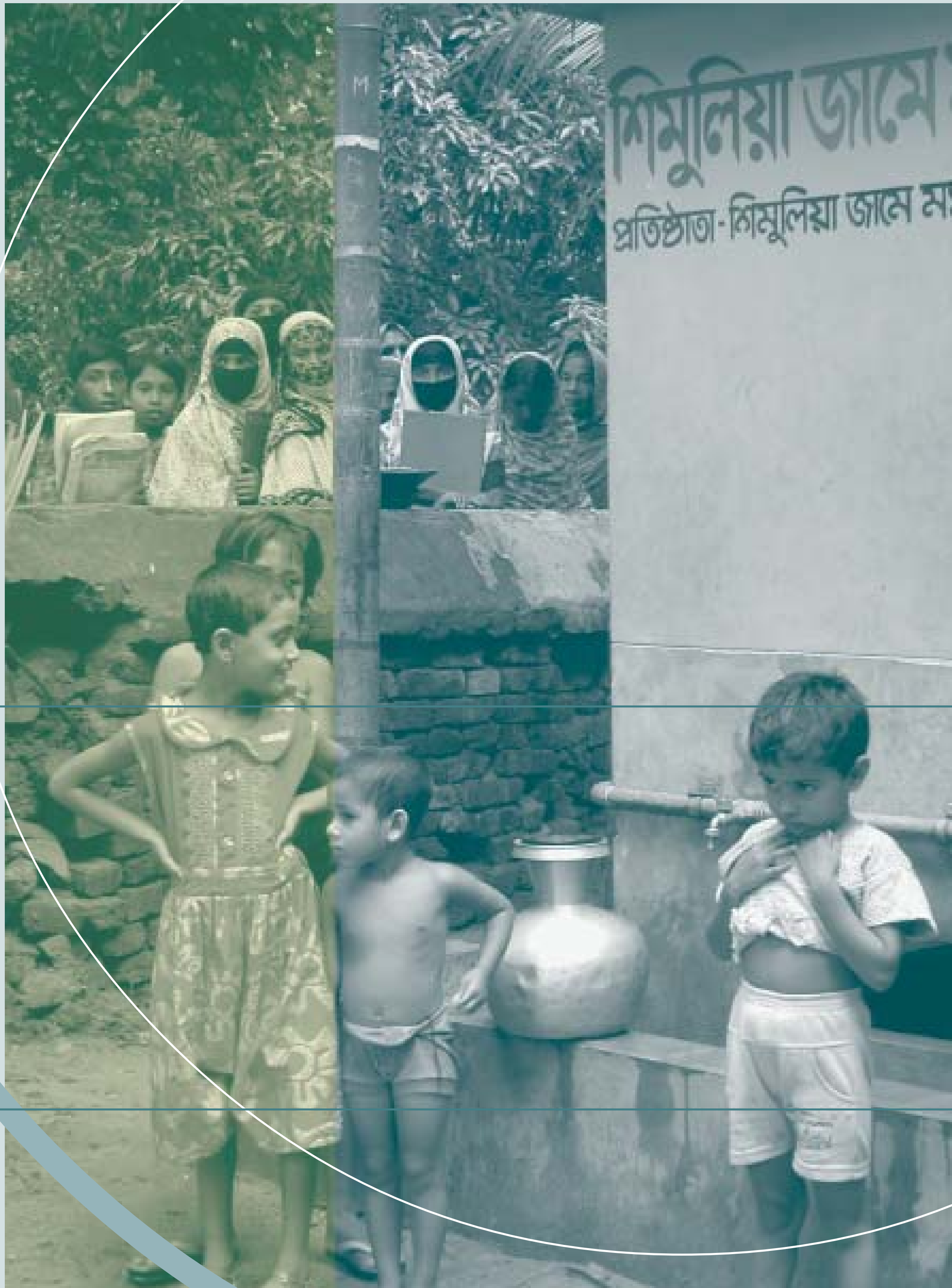
AAN	Asian Arsenic Network
AAS	atomic absorption spectrometer/spectrometry
AES	atomic emission spectrometry
AIIH&PH	All India Institute of Hygiene and Public Health
APSU	Arsenic Policy Support Unit (Bangladesh)
As	arsenic
ASV	anodic stripping voltammetry
AusAID	Australian Agency for International Development
AWWA	American Water Works Association
BAMWSP	Bangladesh Arsenic Mitigation Water Supply Project
BGS	British Geological Survey
BUET	Bangladesh University of Engineering and Technology
CBA	cost-benefit analysis
CCA	chromated copper arsenate
CEPIS	Pan American Center for Sanitary Engineering and Environmental Sciences (Peru)
CGIAR	Consultative Group on International Agricultural Research
Danida	Danish Agency for International Development
DF	discount factor
DOC	dissolved organic carbon
DPHE	Department of Public Health Engineering (Bangladesh)
DWSS	Department of Water Supply and Sewerage (Nepal)
EAWAG	Swiss Federal Institute for Environmental Science and Technology
EPA	Environmental Protection Agency (United States)
GDP	gross domestic product
GF-AAS	graphite furnace-atomic absorption spectrometry
GPL	General Pharmaceutical Ltd.
GPS	global positioning system
GWMATE	World Bank Groundwater Management Advisory Team
HG-AAS	hydride generation-atomic absorption spectrometry
HG-AFS	hydride generation-atomic fluorescence spectrometry
ICP	inductively coupled plasma
ICP-MS	inductively coupled plasma-mass spectrometry
IRC	International Water and Sanitation Center (formerly International Reference Center for Community Water Supply)
JICA	Japan International Cooperation Agency
Lao PDR	Lao People's Democratic Republic
MDG	Millennium Development Goal
MS	mass spectrometry
NAMIC	National Arsenic Mitigation Information Center (Bangladesh)
NASC	National Arsenic Steering Committee (Nepal)
NGO	nongovernmental organization
NPV	net present value
NRC	National Research Council (United States)
NRCS	Nepal Red Cross Society
NTU	nephelometric turbidity unit
PAHO	Pan American Health Organization
PV	present value
SDDC	silver diethyldithiocarbamate
SORAS	solar oxidation and removal of arsenic
TCLP	toxic characteristic leaching procedure
UNCHS	United Nations Centre for Human Settlements
UNDP	United Nations Development Program
UNICEF	United Nations Children's Fund
WHO	World Health Organization
WRUD	Water Resources Utilization Department (Myanmar)

Units of Measurement

µg	microgram
mg	milligram
kg	kilogram
L	liter
$\mu g\ L^{-1}$	micrograms per liter
$mg\ L^{-1}$	milligrams per liter
cm	centimeter
m	meter
km	kilometer

Units of Currency (January 2004)

1 US$ = 58 taka (Tk) (Bangladesh)
1 US$ = 48 rupees (Rs) (India)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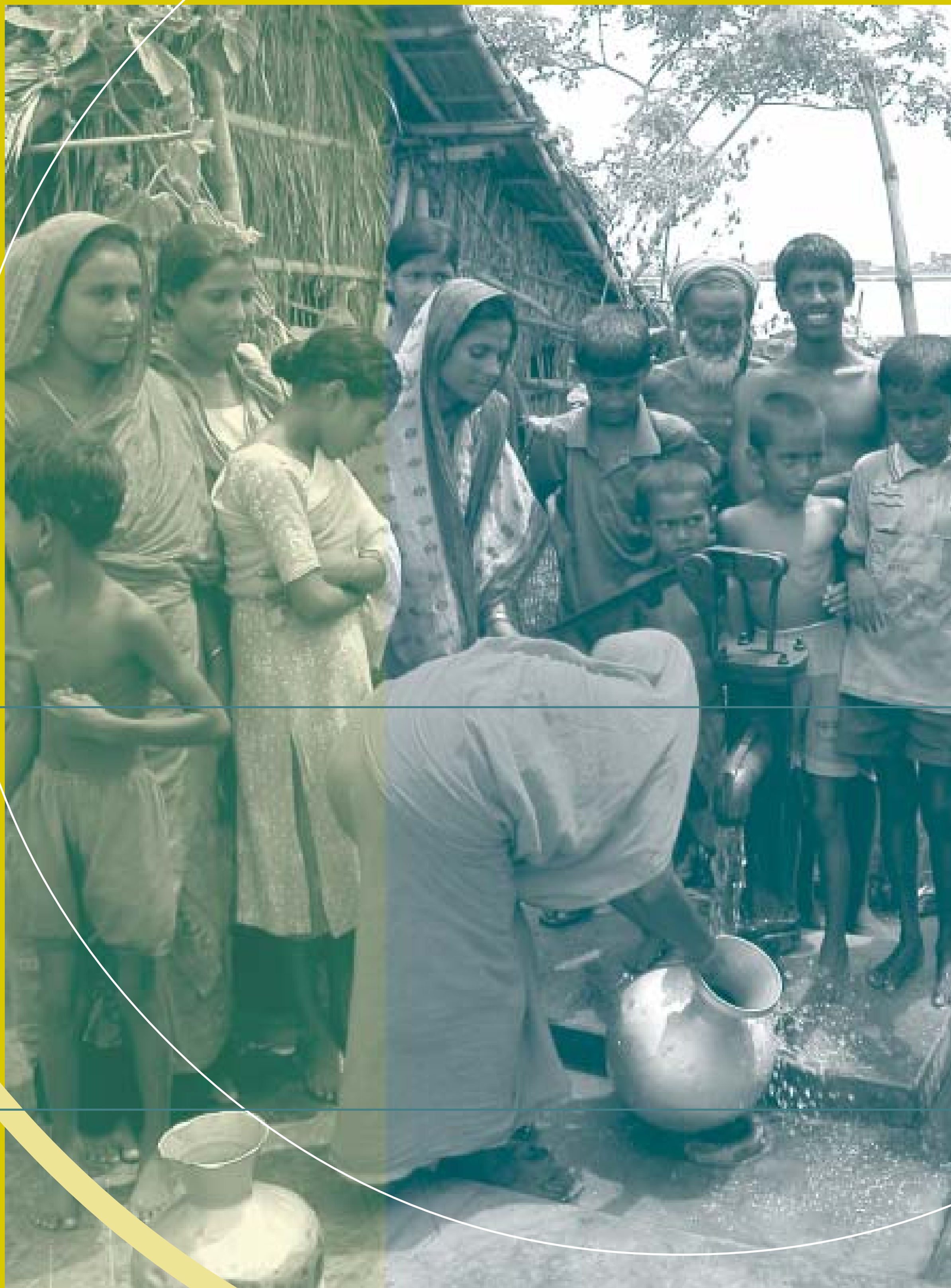
Key Points of this Study

The following are the key points to emerge from this study of operational responses to arsenic contamination of groundwater in South and East Asia:

- Millions of people throughout South and East Asia inhabit areas where certain hydrogeological processes mean that groundwater may be contaminated naturally with levels of arsenic that constitute a danger to human health.
- A considerable amount of research has been carried out into the causes and effects of this contamination and possible mitigation measures, but significant uncertainties remain which have to be factored in when attempting to define a balanced policy response.
- A number of operational responses have already been implemented. This study reviews the current status of both research and operational responses.
- Unfortunately, the responses to arsenic contamination have so far lacked cohesion, and the problem needs to be addressed in a much more integrated and strategic manner in future, primarily within the water supply sector. For example, arsenic mitigation needs to be a primary consideration in any new water supply or irrigation interventions in the identified areas.
- The same consideration needs to be applied to institutional approaches to developing arsenic mitigation strategies, which need to take account of the importance of building capacity and providing incentives for different actors to respond to the arsenic problem.
- Arsenic is not the only problem relating to drinking water supply. Not only may other inorganic constituents (such as iron and manganese) be present, but another major problem is poor bacteriological water quality, which in fact claims many more lives annually and over time than arsenic contamination. These problems occur at scales whose resolution is beyond current available resources; it will therefore be necessary to consider trade-offs that take into account the costs and benefits of a range of mitigation measures.
- This study suggests a methodology by which a cost-benefit analysis can help resolve this difficult issue.
- The complexity of the arsenic problem is such that mitigation measures cannot wait for definitive answers to the issues. Mitigation activities will, in many cases, have to proceed against a background of uncertainty.
- This report outlines what can be done at project, national, and global levels. At all levels it is important that governments overcome the constraints related to such a politically sensitive issue and drive forward measures that can mitigate the effects of arsenic contamination.



VOL I POLICY REPORT

Executive Summary

Background and Introduction

i. The detrimental health effects of environmental exposure to arsenic have become increasingly clear in the last few years. High concentrations detected in groundwater from a number of aquifers across the world, including South and East Asia, have been found responsible for health problems ranging from skin disorders to cardiovascular disease and cancer.

ii. The problem has increased greatly in recent years with the growing use of tubewells to tap groundwater for water supply and irrigation. The water delivered by these tubewells has been found in many cases to be contaminated with higher than recommended levels of arsenic. In the study region, countries affected include Bangladesh (the worst affected), India, Myanmar, Nepal, and Pakistan (South Asia); and Cambodia, China (including Taiwan), Lao People's Democratic Republic, and Vietnam (East Asia).

iii. This study concentrates on operational responses to arsenic contamination that may be of practical use to actors who invest in water infrastructure in the affected countries, including governments, donors, development banks, and nongovernmental organizations (NGOs).

Objectives and Audience of the Study

iv. The objectives of this study are (a) to take stock of current knowledge regarding the arsenic issue; and (b) to provide options for specific and balanced operational responses to the occurrence of arsenic in excess of permissible drinking water limits in groundwater in Asian countries, while taking into account the work that has already been carried out by many different stakeholders.

v. The study provides information on (a) occurrence of arsenic in groundwater; (b) health impacts of arsenic; (c) policy responses by governments and the international community; (d) technological options for and costs of arsenic mitigation; and (e) economic aspects of the assessment and development of arsenic mitigation strategies. The focus of the study is on rural rather than urban areas, due to the particular difficulties associated with applying mitigation measures in scattered rural communities.

vi. The study is structured as follows:

Volume I: Policy Report. This report summarizes the main messages of Volume II, and highlights the policy implications of arsenic mitigation.

Volume II comprises four specialist papers:

- Paper 1. Arsenic Occurrence in Groundwater in South and East Asia: Scale, Causes, and Mitigation
- Paper 2. An Overview of Current Operational Responses to the Arsenic Issue in South and East Asia
- Paper 3. Arsenic Mitigation Technologies in South and East Asia
- Paper 4. The Economics of Arsenic Mitigation

The Scale of the Arsenic Threat

vii. In South and East Asia an estimated 60 million people are at risk from high levels of naturally-occurring arsenic in groundwater, and current data show that at least 700,000 people in the region have thus far been affected by arsenicosis. However, although the negative health effects of arsenic ingestion in general, and the specific impact of ingestion of arsenic-contaminated groundwater, have both been widely studied, there is still no clear picture of the epidemiology of arsenic in South and East Asia, and uncertainty surrounds such issues as the spatial distribution of contamination; the symptoms and health effects of arsenic-related diseases, and the timeframe over which they develop; and the impact of arsenic compared to other waterborne diseases whose effects may be more immediate.

viii. While arsenic is clearly an important public health threat, it needs to be noted that morbidity and mortality due to other waterborne diseases are also a serious health issue. Therefore, mitigation measures to combat arsenic contamination in South and East Asia need to be considered within the wider context of the supply of safe water.

ix. Due to the carcinogenic nature of arsenic, the World Health Organization (WHO) recommends a maximum permissible concentration for arsenic in drinking water of 10 µg L^{-1} (micrograms per liter), which has been adopted by most industrial countries. Most developing countries still use the former WHO-recommended concentration of 50 µg L^{-1} as their national standard, due to economic considerations and the lack of tools and techniques to measure accurately at lower concentrations. Further studies are needed to assess the relationship between levels of arsenic and health risks in order to quantify the inevitable trade-offs at different standards between such considerations as health risks, the ability of people to pay for safe water, and the availability of water treatment technology.

Distribution of Arsenic Contamination

x. The concentration of arsenic in natural waters, including groundwater, is usually below the WHO guideline value of 10 µg L^{-1}. However, arsenic mobilization is favored under some specific hydrogeochemical conditions, especially highly reducing (anaerobic) conditions, which can bring about the dissolution of iron oxides and the associated desorption of arsenic. In South and East Asia such conditions tend to occur in the shallower parts of Quaternary aquifers underlying the region's large alluvial and deltaic plains (Bengal basin, Irrawaddy delta, Mekong valley, Red River delta, Indus plain, Yellow River plain). (Some localized groundwater arsenic problems relate to ore mineralization and mining activity, which are not the focus of this study). Recent hydrogeochemical investigations have improved our knowledge of the occurrence and distribution of arsenic in groundwater, although some uncertainty remains regarding the source, mobilization, and transport of the element in aquifers.

xi. One of the important findings of recent detailed aquifer surveys has been the large degree of spatial variability in arsenic concentrations, both with depth and even laterally at the same depth over distances of a few hundred meters. Temporal variability also occurs, though insufficient monitoring has been carried out to establish a clear picture of variations in arsenic levels over different timescales.

Arsenic Mitigation Measures

xii. Arsenic mitigation requires a sequence of practical steps involving enquiry and associated action. Assessing the scale of the problem (now and over time) involves field testing, laboratory testing, and monitoring; identifying appropriate mitigation strategies involves technological, economic, and sociocultural analysis of possible responses; and implementation involves awareness raising and direct action by governments, donors, NGOs, and other stakeholders at local, national, and regional levels. Sustainability in the long run remains a major challenge.

xiii. The two main technological options for arsenic mitigation are to (a) switch to alternative, arsenic-free water sources; or (b) remove arsenic from the groundwater source. Alternatives in the first category include development of arsenic-free aquifers, use of surface water and rainwater harvesting; alternatives in the second category involve household-level or community-level arsenic removal technologies. For each option there will be a wide range of design specifications and associated costs.

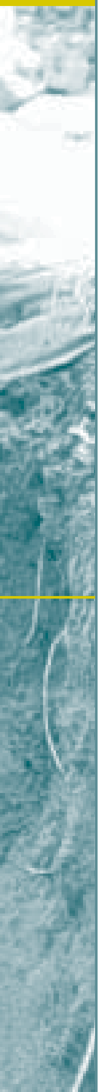
xiv. Despite continuing uncertainty regarding arsenic occurrence and epidemiology, the lethal nature and now well-established effects of arsenic exposure in South and East Asia make it necessary that informed choices and trade-off decisions are made to address arsenic contamination of drinking water sources and the scope and extent of mitigation measures, within the context of the development of the water sector and the wider economy.

xv. Accordingly, a simple cost-benefit methodology has been developed that takes into account data limitations and provides decisionmakers with an approach for rapid assessment of the socioeconomic desirability of different mitigation policies under various scenarios. In particular, the methodology permits an analysis of options in order to choose between different approaches in dealing with (a) the risk that arsenic might be found in an area where a project is planned; and (b) the risk mitigation options where a project's goal is arsenic mitigation per se.

xvi. Demand-side perspectives are an important consideration for designing arsenic mitigation measures that meet the requirements of households and communities. For example, are users willing to pay for an alternative such as piped water? Demand preferences can be assessed through contingent valuation or willingness to pay studies and can provide important guidance to decisionmakers. There is a need to strengthen institutional capacities in the countries to carry out such assessments.

The Political Environment of Arsenic Mitigation

xvii. Arsenic has become a highly politicized topic in the international development community and within some affected countries due to its carcinogenic characteristics and due to the earlier failure to consider it as a possible natural contaminant in groundwater sources. This factor makes rational analysis of the issue difficult and highlights the fact that application of mitigation measures needs to consider the political as well as the social and economic climate. The scattered rural communities most affected by arsenic contamination often have limited political presence and are in particular need of support.



xviii. Governments that want to address the arsenic issue will therefore have to take a stronger lead role in their countries and on the international plane. This goes both for more strategic research and knowledge acquisition regarding arsenic in their countries, as well as for the choice and scope of arsenic mitigation activities.

The Importance of an Effective Operational and Strategic Approach

xix. Significant strides have been made since arsenic was first detected in drinking water tubewells in Eastern India and Bangladesh in the early 1980s and 1990s, respectively. However, a range of factors — including projected population growth in the region, continuing private investment in shallow tubewells, and the drive towards achievement of the Millennium Development Goal related to safe water supply — add to the urgency of adopting a more strategic approach for effective action at project, national, and international levels.

xx. At project level, any interventions that consider using groundwater as a source must involve an assessment of whether occurrence of arsenic would affect the outcome of the project. Such an assessment would include consideration of technical factors (such as screening and possible mitigation technologies), social and cultural factors, and economic factors (including a cost-benefit or least-cost analysis).

xxi. Some countries have taken arsenic to the national level of attention, including Bangladesh, Nepal, and Cambodia. Others, such as India, Pakistan, and China, have only started to address the issue, while in others, international organizations such as UNICEF and local NGOs and universities are the focal points for arsenic-related activities. Although the characteristics of arsenic contamination are unique to each affected country, study results suggest that three simple steps would help governments more effectively address the problem now and in the future:
(a) encourage further research in potentially arsenic-affected areas in order to better

determine the extent of the problem; (b) ensure that arsenic is included as a potential risk factor in decision-making about water-related issues; and (c) develop options for populations in known arsenic-affected areas.

xxii. At the global level, focused research on the chemistry of arsenic mobilization and the dose-response relationships for arsenic are of vital importance in formulating a more effective approach. If governments and the international community are to achieve the MDGs in water supply and sanitation then the knowledge gaps regarding arsenic need to be filled, notably by (a) further epidemiological research directly benefiting arsenic-affected countries; (b) socioeconomic research on the effects of arsenicosis, understanding behavior and designing demand-based packages for the various arsenic mitigation techniques; and (c) hydrogeological and hydrochemical research.

xxiii. It also needs to be made clear that, due to the nature of arsenic itself, in the not-so-distant future there will be diminishing returns on investments in scientific arsenic research to reduce uncertainty. The important challenge will be to identify those areas where improved research-level data collection is likely to provide a major return. For other areas the main question will be how to manage in the face of unavoidable and continuing uncertainty.

xxiv. Accordingly, the international dialogue should shift towards targeted research priorities that address these issues. This would also include the pursuit of the research agenda regarding arsenic in the food chain. Both the World Bank and a number of development partners are contributors to the Consultative Group on International Agricultural Research (CGIAR) and this organization would lend itself to building up a coherent and focused research agenda on this topic in order to provide decisionmakers with guidance regarding arsenic-contaminated groundwater.

Background and Introduction

The detrimental health effects of environmental exposure to arsenic have become increasingly clear in the last few years. Drinking water constitutes one of the principal pathways of environmental arsenic exposure in humans. High concentrations detected in groundwater from a number of aquifers across the world, and specifically in South and East Asia, have been found responsible for health problems ranging from skin disorders to cardiovascular disease and cancer. Food represents a further potential exposure pathway to arsenic in instances where crops are irrigated with high-arsenic groundwater, or where food is cooked using arsenic-contaminated water. However, the relative impact on human health is not as yet quantified and is in need of further study.

With groundwater-based water supply and irrigation projects being implemented across the arsenic-affected regions of Asia, there is a serious need to address this issue not only for a single country like Bangladesh — the most well-known and dramatic case — but also in a regional context, as more countries in the region have been reported to have higher than the permissible standards of arsenic in groundwater. In South Asia, other countries affected by arsenic include India, Myanmar, Nepal, and Pakistan. In East Asia Cambodia, China (including Taiwan), Lao People's Democratic Republic, and Vietnam are affected. The increasing recognition of the wide geographic spread of the problem has provided the motivation to carry out this study at a cross-regional scale.

Current literature available on arsenic tends to be conceptual, analytical, or prescriptive in terms of standard setting, with little coverage of concrete operational responses for those actors who invest in water infrastructure in these countries, such as governments, development banks, nongovernmental organizations (NGOs), and donors. Since the potential health hazards of arsenic are now known, it is necessary to frame and implement responses in operational terms, outlining steps that minimize the health risks presented by water supply projects whose intended benefits may be negated by the harmful medium or long-term effects of arsenic exposure.

Objectives and Audience of the Study

The objectives of this study are to (a) take stock of current knowledge regarding the arsenic issue; and (b) provide options for specific and balanced operational responses to the occurrence of arsenic in excess of permissible limits in groundwater in Asian countries. It also aims to provide stakeholders with tools and guidance to analyze the extent of the arsenic contamination in their respective countries and regions and help them to develop appropriate responses while taking into account the work that has already been carried out by many different stakeholders.

The study thus provides information on (a) state-of-the-art knowledge about natural occurrence of arsenic in groundwater, including spatial distribution and hydrogeochemical aspects; (b) current state of knowledge regarding known and potential health impacts of arsenic; (c) previous policy responses by governments and the international community (development partners, civil society, and academia); (d) technological options for and costs of arsenic mitigation; and (e) economic aspects of the assessment and development of arsenic mitigation strategies. The study also indicates steps to be taken by decisionmakers regarding investment projects that use groundwater, both in terms of specific considerations during project design and implementation and in terms of relevant upstream sector analysis.

Thus, the principal target audiences of this study are governments and their development partners, including international development banks, bilateral donors, and development NGOs who are active in water-related issues in the region. Within these groups, it is expected that decisionmakers and managers will primarily focus on the Policy Report (Volume I of this study), which provides a synthesis of the comprehensive review and an analysis of the subject matter, and distils the policy implications.

Technical staff and water sector professionals will also have an interest in Volume II, the Technical Report, which comprises the detailed study background papers providing a wealth of state-of-the-art information and references to specialized literature. Volume II includes four papers, namely:

- Paper 1. Arsenic Occurrence in Groundwater in South and East Asia: Scale, Causes, and Mitigation

- Paper 2. An Overview of Current Operational Responses to the Arsenic Issue in South and East Asia
- Paper 3. Arsenic Mitigation Technologies in South and East Asia
- Paper 4. The Economics of Arsenic Mitigation

While the papers are complementary, they have been prepared as stand-alone products in order to serve as reference literature for readers who require more detail about each of these topics.

It is expected that academics and a wider civil society audience who are involved in water resources development issues, and specifically water supply and sanitation, will also benefit from the study.

Methodology

Comprehensive literature reviews were undertaken for all background papers. Papers 1 and 3 largely draw on the body of internationally available existing analysis, and provide state-of-the-art overviews. Paper 4 also draws on available information, but in addition develops a simple and pragmatic methodology for decisionmakers to deal with the economics of interventions regarding arsenic and to make rational choices between potential (different) strategies.

Paper 2 is based on an extensive literature review and on a survey administered to government officials, international organizations, NGOs, and researchers. All papers draw on the feedback received at the session organized during the World Bank Water Week in Washington, D.C. in February 2004, and on the results of the Regional Operational Responses to Arsenic Workshop subsequently held in Kathmandu, Nepal, during 26 and 27 April 2004.

The study thus links these strings of information more closely with one another, and draws out the broader policy and institutional implications for issues currently under discussion. The study also evaluates in-depth experience from one country, Bangladesh, the most affected and active in this regard, and compares its findings with that of other countries where appropriate, to understand the impact of past and current interventions on arsenic mitigation and knowledge generation, and to provide policy recommendations for future interventions in this area.

VOL I POLICY REPORT

Key Findings

Continued Uncertainty about Epidemiology: How Big Is the Arsenic Threat?

Over the years, a number of studies have been conducted to assess and quantify the impact of ingesting arsenic-contaminated groundwater.[1] However, a surprising finding of the present study has been that — in spite of more than a decade of research, studies, and other interventions regarding arsenic in South and East Asia — no clear picture has yet emerged of the epidemiology of arsenic in the region. Estimates of the (future) health impacts of arsenic ingestion are mostly based on and extrapolated from data for the United States of America and Taiwan (China), and their validity for interpretation at a wider scale is therefore frequently questioned.

Globally, the only large-scale screening, carried out in Bangladesh through the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) and other Government of Bangladesh funding sources and donors, which included patient identification, indicated that far fewer people show signs of arsenicosis than could be expected from extrapolation of the United States and Taiwan epidemiological data.

The negative health effects of arsenic ingestion have been documented for the last 200 years. In spite of the uncertainty regarding exact numbers it is clear that there are major effects, but it is not yet clear how widespread or serious these are or what the relationship of disease to exposure is in different settings. It is, however, obvious that millions of people are at risk from arsenic-induced diseases. Table 1 summarizes, for the currently affected countries for which data are available, the estimated area and population at risk, and the levels of arsenic in groundwater.

Table 1 shows that the estimated population at risk from natural arsenic contamination in groundwater in Asian countries is at least 60 million. What is not clear is (a) how many people in these risk areas will be affected by arsenic-related disease and within which timeframe (especially compared with other waterborne diseases where effects may be more immediate, such as diarrhoea in under-five-year-olds, which is often fatal); and (b) what exactly the health effects are going to be; there is still uncertainty whether skin lesions, typically the most visible expression of arsenicosis, are the first symptom or if internal cancers and other ailments can also be present in the absence of skin lesions.

[1] See Papers 1 and 2 in Volume II for more detailed information.

Table 1. Scale of Arsenic Contamination: Selected Countries in South and East Asia

Location	Areal extent (km^2)	Population at risk[a]	Arsenic range ($\mu g\ L^{-1}$)
Alluvial/deltaic/ lacustrine plains			
Bangladesh	150,000	35,000,000	<1-2,300
China (Inner Mongolia, Xinjiang, Shanxi)	68,000	5,600,000	40-4,400
India (West Bengal)	23,000	5,000,000	<10-3,200
Nepal	30,000	550,000	<10-200
Taiwan (China)	6,000	(?) 10,000[b]	10-1,800
Vietnam	1,000	10,000,000[c]	1-3,100
Myanmar	(?) 3,000	3,400,000	-
Cambodia	(?) <1,000	320,000[d]	-

- Not available. [a.] Estimated to be drinking water with arsenic >50 $\mu g\ L^{-1}$. From Smedley 2003 and data sources therein. [b.] Before mitigation. [c.] United Nations Children's Fund (UNICEF) estimate. [d.] Maximum.
Source: Regional Operational Responses to Arsenic Workshop in Nepal, 26-27 April 2004.

Generally, it can be said that far more rural than urban populations are at risk. This is due to the fact that it is easier and more affordable to implement arsenic removal technologies in urban areas. For rural domestic water supply the situation is completely different; the distinctive feature of arsenic contamination of groundwater in South and East Asia is the very large number of scattered small communities affected, constituting a major financial and management challenge. Accordingly, this report primarily addresses the rural dimension of the arsenic issue.

Current Estimates and Projections of Number of Arsenicosis Patients in Asia

The estimates of the current number of patients with arsenicosis for countries of East and South Asia are summarized in table 2.

Table 2 shows that there are approximately 700,000 people who have been affected by arsenicosis. For Bangladesh in particular, with regard to projected future cases, an estimate of the arsenic-related health burden, provided in Ahmed (2003) and adjusting data from the United

Table 2. Current Population Identified with Arsenicosis in East and South Asian Countries

Region/country	Number of arsenicosis patients identified so far	Year of first discovery
East Asia		
Cambodia	-	2000
China provinces: Inner Mongolia XinjiangJilin, Shanxi, Ningxia, Qinghai, Anhui, Beijing	522,566	 1990s 1983 2001-2002
Taiwan	-	1960s
Lao PDR	-	-
Myanmar	-	1999
Vietnam	-	1998
South Asia		
Bangladesh	10,000 (partial results)	1993
India (West Bengal)	200,000	1978
Nepal	8,600	1999
Pakistan	242 cases per 100,000 people based on the results of 10 districts	2000

- Not available.

States Environmental Protection Agency (EPA) to Bangladesh conditions, concluded that skin cancer would affect 375,000 people. Using data from a more detailed survey of the data currently available in the literature, Maddison, Luque, and Pearce (2004) estimated the annual impact on health of arsenic in Bangladesh as indicated in table 3.

The estimates suggest that in Bangladesh 6,500 people will die from cancer every year, a total of 326,000 people in a period of 50 years, while 2.5 million people will develop some kind of arsenicosis over that period. So far, these two figures are the only quantification of the potential arsenic-related health burden. They depend heavily on epidemiological assumptions and demonstrate how the lack of reliable epidemiology information adds uncertainties to the projected number of people at risk.

Table 3. Bangladesh: Estimated Health Impact of Arsenic Contamination of Tubewells

Impact on health/ type of illness	**Males**	**Females**	**Combined**
Cancer cases:			
Fatal cancers/year	3,809	2,718	6,528
Nonfatal cancers/year	1,071	1,024	2,095
Total cancer fatalities accumulated over 50 years	**190,450**	**135,900**	**326,400**
Arsenicosis cases[a]:			
Keratoses	277,759	74,473	352,233
Hyperpigmentation	654,718	316,511	971,230
Cough	21,823	68,887	90,712
Chest sounds	144,831	67,025	211,858
Breathlessness	93,247	176,874	270,122
Weakness	132,927	240,176	373,104
Glucosuria	67,887	63,551	131,439
High blood pressure	94,396	88,366	182,762
Total arsenicosis cases in each year	**1,487,588**	**1,095,863**	**2,583,460**

[a.] *Figures indicate average number of cases occurring in each year (not number of* new cases).
Source: Maddison, Luque, and Pearce 2004, p. 32.

When comparing morbidity and mortality due to arsenic with that of other waterborne diseases, bacteriological contamination is a much more serious issue. A study conducted by the World Health Organization (WHO) and UNICEF in 2000 indicated that approximately 4 billion cases of diarrhoea are reported globally every year, causing 2.2 million deaths, mostly among children under five, and intestinal worms infect about 10% of the population in the developing world (WHO-UNICEF 2000). Diarrhoea and worm infestation are two major waterborne public health threats in South Asia. A 2000 survey in Bangladesh by the Bureau of Statistics and UNICEF indicated that about 110,000 children under five die due to diarrhoea every year (Bureau of Statistics-UNICEF 2002). The situation is similar or even worse in Nepal, India, and Pakistan.

Table 4 shows the estimated annual deaths of children under five due to diarrheal disease in the countries under study. Estimated deaths vary from 650,000 to 1.3 million per year, depending on whether the assumption is made that 15% or 30% of total deaths are due to diarrheal disease. The figures cannot be directly compared to arsenicosis or arsenic-induced fatalities because they are estimates for the entire areal extent of the countries, not just for those areas that are arsenic affected. Nevertheless, they show the magnitude of the burden due to diarrheal disease, as an indicator of the impact of inadequate water supply.

Table 4. Estimated Annual Deaths from Diarrheal Disease of Children under Five

Country	Region	Annual total mortality of children under the age of five[a]	Low estimate (15% of child mortality under 5 years due to diarrhoea)	High estimate (30% of child mortality under 5 years due to diarrhoea)
Bangladesh	South Asia	323,000	48,450	96,900
Cambodia	East Asia	65,000	9,750	19,500
China	East Asia	735,000	110,250	220,500
India	South Asia	2,346,000	351,900	703,800
Lao PDR	East Asia	20,000	3,000	6,000
Myanmar	South Asia	129,000	19,350	38,700
Nepal	South Asia	74,000	11,100	22,200
Pakistan	South Asia	579,000	86,850	173,700
Vietnam	East Asia	64,000	9,600	19,200
South Asia total		3,451,000	517,650	1,035,300
East Asia total		884,000	132,600	265,200
Total		4,335,000	650,250	1,300,500

[a] *Data from UNICEF website.*

Two conclusions can be drawn here. First, the public health effects of arsenic are a reality and they need to be taken seriously. As the effects of arsenic are long term it is likely that arsenic-related disease, with and without fatal outcomes, is going to increase over the coming decades, affecting hundreds of thousands of people. Second, with waterborne disease claiming so many lives annually, it is important to integrate arsenic considerations into a rational approach within the overall context of waterborne public health threats. Further investment in safe water supply is a necessity and arsenic is but one of the considerations in this regard.

Standards for Arsenic Concentrations in Water

Due to the carcinogenic nature of arsenic, the WHO has issued a provisional guideline for maximum permissible concentration of arsenic in drinking water of 10 µg L^{-1} (microgram per liter). WHO guidelines are intended as a basis for setting national standards to ensure the safety of public water supplies and the guideline values recommended are not mandatory limits. Such limits are meant to be set by national authorities, considering local environmental, social, economic, and cultural conditions.

The WHO-recommended maximum permissible value is usually related to acceptable health risk, defined as that occurring when the excess lifetime risk for cancer equals 10-5 (that is, 1 person in 100,000). However, in the case of arsenic, the United States EPA estimates that this risk would mean a standard as low as 0.17 µg L^{-1}, which is considered far too expensive to achieve, even for industrial countries such as the United States. The EPA thus conducted an economic study with concentrations of 3, 5, 10, and 20 µg L^{-1} and concluded that for the United States a standard of 10 µg L^{-1} represents the best trade-off among health risks, the ability of people to pay for safe water, and the availability of water treatment technology. Thus, even this stricter standard, which has been adopted by most industrial countries, is a compromise.

Most developing countries still use the former WHO-recommended concentration of 50 µg L^{-1} as their national standard for arsenic in drinking water, partially due to economic considerations and the lack of tools and techniques to measure accurately at such low concentrations (table 5). Here, it is important to note that even though the exact health effects of an arsenic concentration of 50 µg L^{-1} have not been quantified, many correlations between internal cancer and lower concentration of arsenic have also been found. Therefore, while the respective current national standards are valid and followed by international agencies such as the World Bank, epidemiological studies at these lower concentrations are of utmost importance in providing a better basis for decisionmakers in developing countries to understand the risks they are taking by adhering to their higher national standards and the trade-offs involved in investing in arsenic mitigation compared to other development needs.

Table 5. Current National Standards of Selected Countries for Arsenic in Drinking Water

Country/region	Standard: μg L^{-1}	Country	Standard: μg L^{-1}
Australia (1997)	7	Bangladesh (1997)	50
European Union (1998)	10	Cambodia	50
Japan (1993)	10	China	50
USA (2002)	10	India	50
Vietnam	10	Lao PDR (1999)	50
Canada	25	Myanmar	50
		Nepal	50
		Pakistan	50

Regarding arsenic concentration in irrigation water, neither international agencies nor individual countries propose any recommended maximum permissible values and further research is needed to come to conclusive recommendations in this regard in the next chapter.

What is the Global and Regional Distribution of Arsenic Contamination?

The concentration of arsenic in natural waters, including groundwater, is typically below the WHO provisional guideline value for arsenic in drinking water of 10 μg L^{-1}. However, arsenic mobilization in water is favored under some specific geochemical and hydrogeological conditions and concentrations can reach two orders of magnitude higher than this in the worst cases. Most of the extensive occurrences of high-arsenic groundwater are undoubtedly of natural origin, that is to say they involve the mobilization of arsenic naturally present in the ground and not the discharge of pollutants at the land surface, although the extent to which mobilization can be accelerated by groundwater pumping is still open to question.

Figure 1 shows the distribution of documented cases of arsenic contamination in groundwater and the environment worldwide. Many of these cases are related to areas of mineralization and mining activity and a few are associated with geothermal sources. While these cases can be severe, with high concentrations of arsenic in waters, sediments, and soils, their lateral scale is

Figure 1. World Distribution of Arsenic in Groundwater and the Environment

Source: Modified after Smedley and Kinniburgh 2002.
Note: In China, arsenic has further been identified in the provinces of Jilin, Qinghai, Anhui, Beijing, and Ningxia (reported at Regional Operational Responses to Arsenic Workshop in Nepal, 26-27 April 2004).
In India, further affected states are Assam, Arunachal Pradesh, Bihar, Manipur, Meghalaya, Nagaland, Uttar Pradesh and Tripura.

usually limited. Other areas with recognized high-arsenic groundwater are not associated with obvious mineralization and mining or geothermal activity. Some of these occur in major aquifers and may be potentially much more serious because they occupy large areas and can provide drinking water to large populations. This study deals with these areas rather than those where arsenic release is due to mining or geothermal activities.

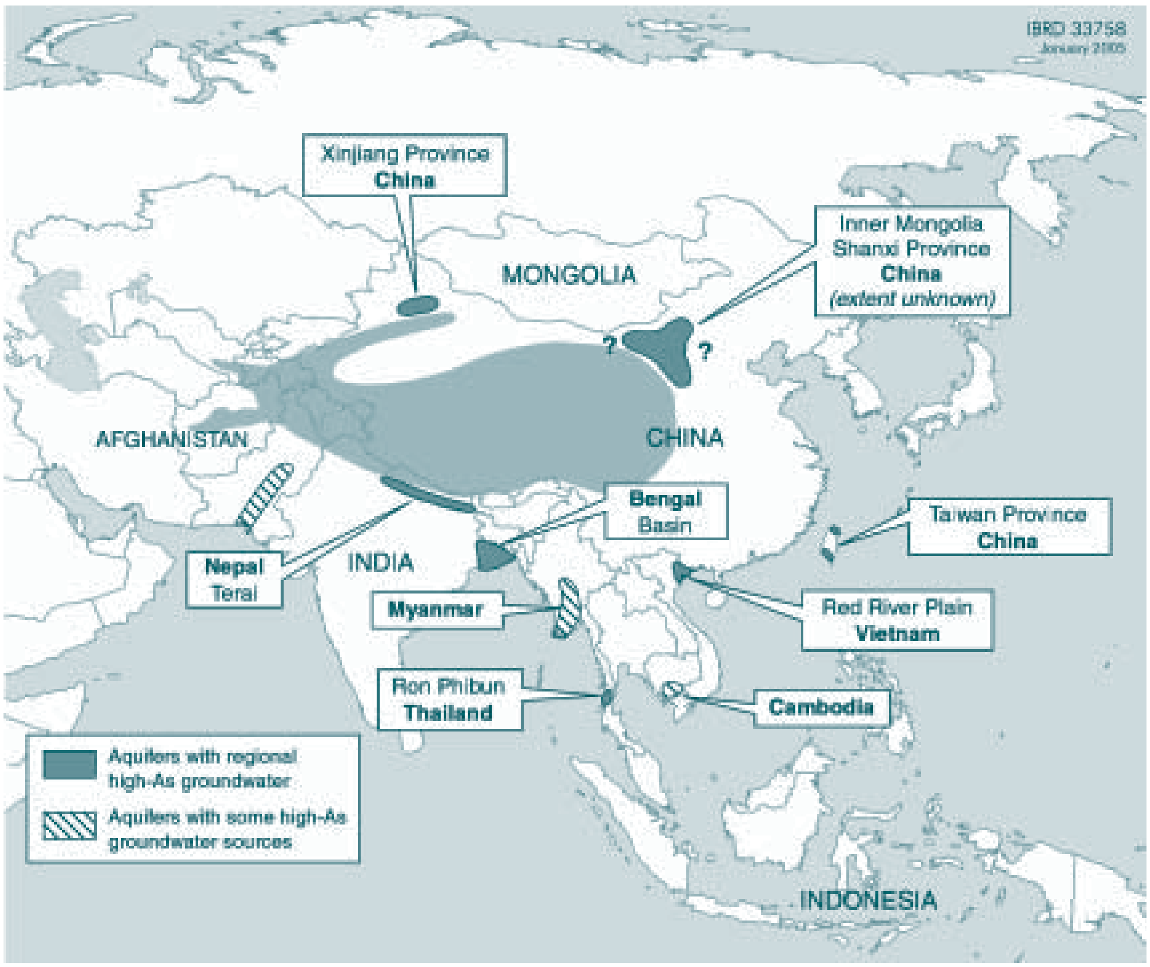
Major alluvial plains, deltas and some inland basins composed of young sediments are particularly prone to developing groundwater arsenic problems. Several of these aquifers around the world have now been identified as having unacceptably high concentrations of arsenic. These include not only the alluvial and deltaic aquifers in parts of Asia, but also inland basins in Argentina, Chile, Mexico, the southwestern United States, Hungary, and Romania. Important differences exist between these regions, but some similarities are also apparent. The majority of the high-arsenic groundwater provinces are in young unconsolidated sediments, usually of Quaternary age, and often of Holocene deposition of less than 12,000 years in age. These aquifers do not appear to contain abnormally high concentrations of arsenic-bearing minerals but do have geochemical and hydrogeological conditions favoring mobilization of arsenic and its retention in solution.

Many of the world's aquifers with high arsenic levels are located in those areas of Asia where large alluvial and deltaic plains occur, particularly around the perimeter of the Himalayan mountain range. In South Asia, naturally occurring arsenic in groundwater was initially identified in West Bengal, India, and in Bangladesh in the early 1980s and 1990s respectively. Since then governments, donors, international organizations, NGOs, and research institutions have increased testing of groundwater sources. As a result, naturally occurring arsenic has now been identified in the groundwater of the countries in South and East Asia that are the subject of this study. Figure 2 shows (see page 34) the locations of high-arsenic groundwater provinces in the countries of South and East Asia. There may be other Quaternary aquifers with high groundwater arsenic concentrations that have not yet been identified, but since awareness of the arsenic problem has grown substantially over the last few years, these are likely to be on a smaller scale than those already identified

Many of the health consequences resulting from contaminated groundwater have emerged in relatively recent years as a result of the increased use of groundwater from tubewells for drinking and irrigation. In terms of numbers of groundwater sources affected and populations at risk problems are greatest in Bangladesh, but have also been identified in India (West Bengal, and more recently Assam, Arunachal Pradesh, Bihar, Manipur, Meghalaya, Nagaland, Tripura and Uttar Pradesh), China, including Taiwan, Vietnam, Thailand, Cambodia, Myanmar, and Nepal. Occasional high-arsenic groundwaters have also been found in Pakistan, although the occurrences there appear to be less widespread.

Hence, much of the distribution is linked to the occurrence of young (Quaternary) sediments in the region's large alluvial and deltaic plains (Bengal basin, Irrawaddy delta, Mekong valley, Red River delta, Indus plain, Yellow River plain). Although groundwater arsenic problems have been detected in some middle sections of the Indus and Mekong valleys, such problems have

Figure 2. Locations of High-Arsenic Groundwater Provinces in South and East Asia



Source: Modified after Smedley 2003

apparently not emerged in the lower reaches (deltaic areas). Whether this represents lack of testing or whether arsenic problems do not occur there is as yet uncertain. However, the young Quaternary aquifers most susceptible to developing groundwater arsenic problems appear to be less used in these areas as a result of poor well yields or high groundwater salinity.

Other Quaternary sedimentary aquifers in Asia have not been investigated and so their arsenic status is unknown. Some localized groundwater arsenic problems in South and East Asia relate to ore mineralization and mining activity (for example in peninsular Thailand and Madhya Pradesh, India).

Mechanisms of Arsenic Mobilization: How does It Get into the Groundwater?

One of the key hydrogeochemical advances of the last few years has been in the better understanding of the diverse mechanisms of arsenic mobilization in groundwater, as well as its derivation from different mineral sources. The most important mineral sources in aquifers are metal oxides (especially iron oxides) and sulfide minerals (especially pyrite). Release of arsenic from sediments to groundwater can be initiated as a result of the development of highly reducing (anaerobic) conditions, leading to the desorption of arsenic from iron oxides with the breakdown of the oxides themselves. Such reducing conditions are usually found in recently-deposited fine-grained deltaic and alluvial (and some lacustrine) sediments.

Release of arsenic can also occur in acidic groundwaters under oxidizing (aerobic) conditions. This tends to occur in arid and semiarid settings resulting from extensive mineral reaction and evaporation. High-arsenic groundwaters with this type of association have not been reported in Quaternary aquifers in South and East Asia but are found in some arid inland basins in the Americas (western United States, Mexico, Argentina). Analogous conditions could occur in some arid parts of the region, such as northern China or western Pakistan, but there is as yet no evidence for this.

Despite the improved understanding of the occurrences and distribution of arsenic in groundwater, there remains some uncertainty as to the precise nature of the source, mobilization, and transport of the element in aquifers. It is only in the last few years that detailed hydrogeochemical investigations have been carried out in some of the affected regions.

Earlier responses to water-related arsenic problems typically involved engineering solutions or finding alternative water sources, with little emphasis on research. It is worthy of note that, despite the major epidemiological investigations that have been carried out in Taiwan since the discovery of arsenic-related problems there in the 1960s, there has been little hydrogeochemical research carried out in the region. Even today, the aquifers of Taiwan are poorly documented and the arsenic occurrence little understood.

One of the important findings of recent detailed aquifer surveys has been the large degree of spatial variability in arsenic concentrations in the affected parts of aquifers, even over lateral distances of a few hundred meters. This means that predictability of arsenic concentrations on a local scale is poor (and probably will always be so). Hence, blanket testing of individual wells in affected areas is necessary. This can be a major task in countries like Bangladesh where the contamination is extensive and the number of wells is very large.

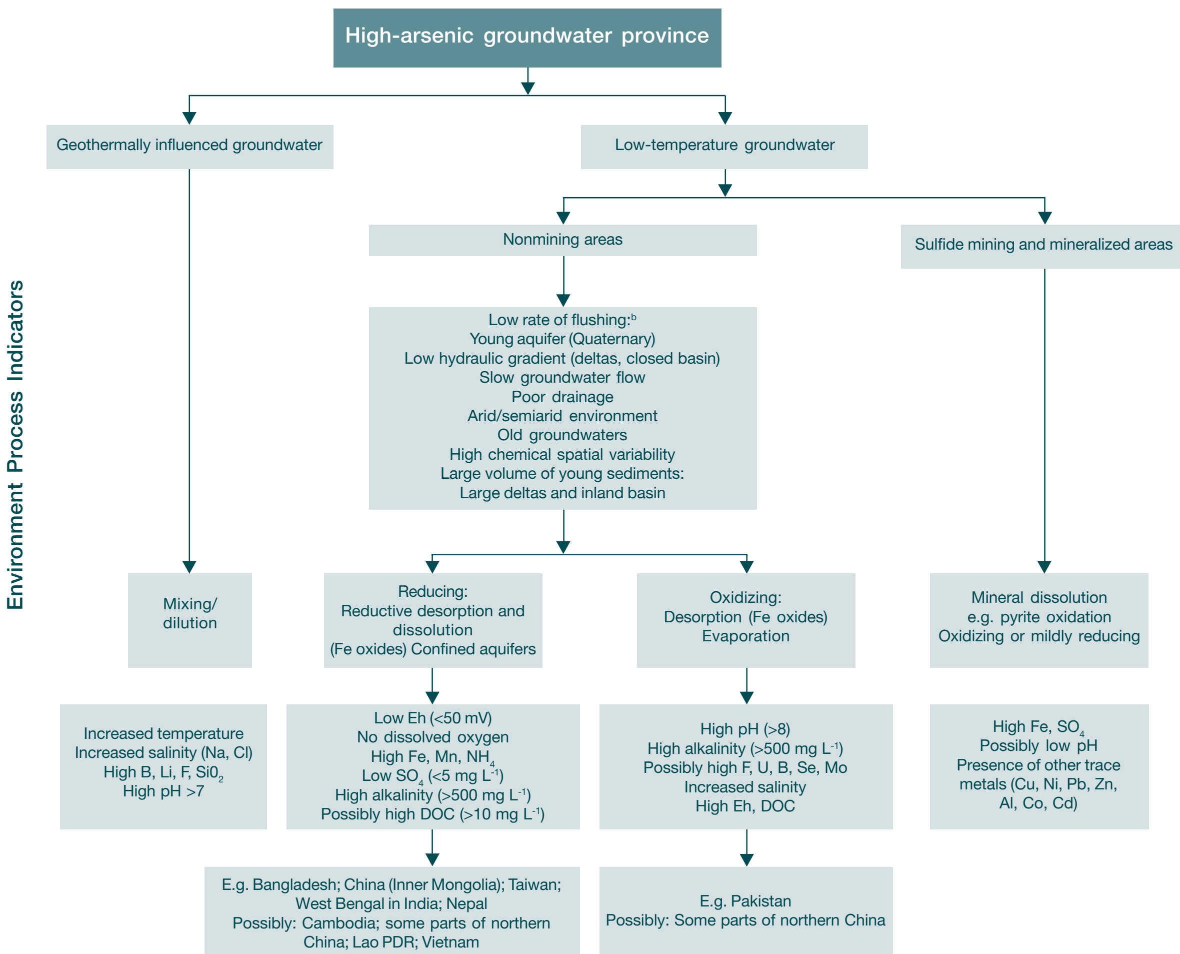
There is also uncertainty regarding the temporal variability of arsenic concentrations in groundwater as very little groundwater monitoring has been carried out. Some studies have noted unexpectedly large temporal variations over various timescales but the supporting data are often sparse and inaccessible and so these reports cannot be relied upon. More controlled monitoring of affected groundwaters is required to determine their variability in the short term (daily), in the medium term (seasonally), and in the long term (years, decades).

How Is Groundwater Quantity Related to Groundwater Quality?

The emerging arsenic problem has revealed the dangers of groundwater development without consideration of water quality in tandem with water quantity. Improved understanding of the risk factors involved in development of groundwaters has enabled targeting of those aquifers perceived to be most susceptible to developing arsenic problems in recent years. However, the toxicity of arsenic is such that it should also be afforded greater attention in other aquifers used for drinking water supply. There is an argument for routine testing for arsenic in all new wells provided in major groundwater development projects, regardless of aquifer type. Randomized reconnaissance-scale sampling for arsenic is also recommended for existing public supply wells in all aquifer types where no arsenic data currently exist in order to obtain basic statistics on the distribution of arsenic concentrations. Groundwater development in previously unexploited but potentially susceptible sedimentary aquifers needs to be preceded by detailed hydrogeological and hydrochemical investigations to ensure that groundwater will be of sufficiently high and sustainable quality. The scale of investigations should be commensurate with the scale of proposed development.

Figure 3 illustrates a tool for an initial risk assessment of the susceptibility of an aquifer to arsenic contamination. The shaded boxes indicate the most susceptible pathway. The figure also indicates that significant knowledge about the geography of arsenic has been created in past years, which permits a strategic response to arsenic contamination.

Figure 3. Classification of Groundwater Environments Susceptible to Arsenic Contamination[a]



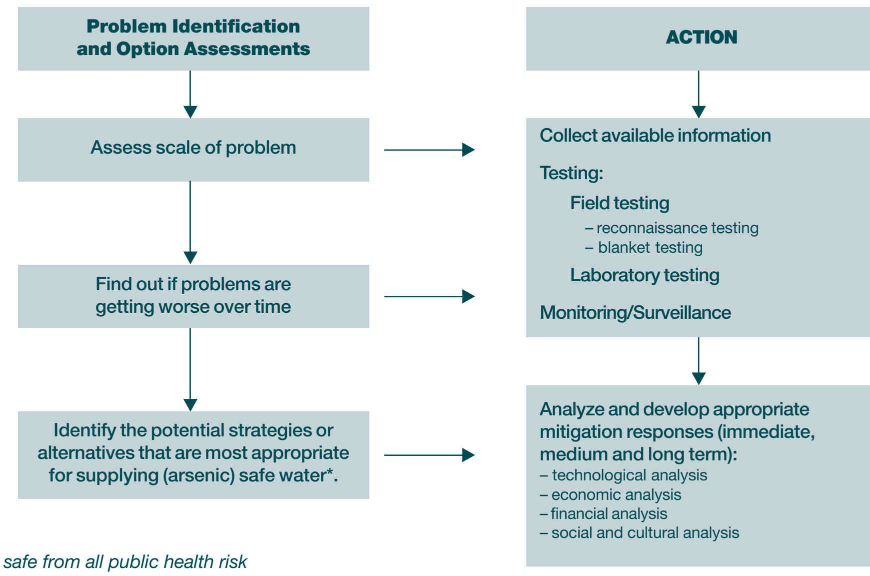
[a] For further details see Paper 1, Volume II. [b] Not all indicators of low flushing rates necessarily apply to all environments.
Source: Smedley and Kinniburgh 2002.

Technical Options and Social Considerations: What Can and Should be Done?

Sequencing

On the technical side, there would appear to be a logical sequencing for dealing with arsenic. As shown in figure 4, concrete steps can be identified in coping with arsenic at the project level,

Figure 4. Practical Steps for Project-Level Responses to Arsenic Contamination in Groundwater



** Implies water safe from all public health risk*

ranging from screening for arsenic (localized, countrywide, and regional) to awareness raising and implementation of arsenic mitigation measures (usually implying a switch to other available water sources, followed by provision of additional safe sources through NGOs, governments, donors, and other stakeholders).

Although our ability to precisely predict arsenic concentrations in groundwater from a given area or aquifer is still rather limited, knowledge of its occurrence and distribution has improved greatly over the last few years. We therefore generally know enough about where high concentrations tend to occur to make reasonable estimates of likely at-risk aquifers on a regional scale, with young sediments in alluvial and deltaic plains and inland basins, and areas of mining activity and mineralization, as obvious target areas for further evaluation.

The guidelines for improving understanding of the arsenic problem and how to go about dealing with it are broadly the same in any region at increased risk from arsenic contamination. Firstly, the scale of the problem needs to be assessed. Secondly, where problems exist, it is necessary to find out whether or not the situation is becoming worse with time. Thirdly, where problems exist, it is necessary to identify the potential strategies or alternatives that are most appropriate for supplying safe (low-arsenic) water.

Central to these issues is arsenic testing. In any testing program, it is important to distinguish between reconnaissance testing, which is necessary for establishing the scale of a groundwater arsenic problem, and blanket testing, which is required for compliance and health protection. Blanket testing involves the analysis of a sample of water from every well used for drinking water. For reconnaissance testing, the numbers of samples need not be large; they should however be collected on a systematic basis. Some monitoring (repeat sampling of a given water source in order to assess temporal changes over a given timescale – (as distinct from repeat testing to cross-check analytical results) may also be required.

Regardless of the scale of arsenic contamination in water, there are two ways to measure it. The first method is to use a field test kit, and the second is to conduct laboratory chemical analysis. The field test measures are more qualitative than quantitative, thus the choice of one method versus the other depends on several parameters, including the precision of measurement required.

The quality of analytical results is also paramount; analysis of arsenic in water is by no means a trivial task, yet reliable analytical data are key to understanding the nature and scale of groundwater arsenic problems as well as dealing with them. Instigation of any new arsenic testing or monitoring program requires consideration of the analytical capability of the local laboratories. In some cases, development of laboratory capability (for example quality assurance procedures, training, equipment upgrades, increased throughput) may be required and should be built into the testing program.

Appropriate mitigation responses for arsenic-affected regions will necessarily vary according to local hydrogeological conditions, climate, population affected, and infrastructural factors. Surface water may or may not be available as an alternative. Other groundwater aquifers at different depths or in different locations may be available for use and need additional assessment. Decisions about what action to take in respect of the arsenic-affected aquifer depend on factors such as percentage of wells of unacceptable quality and range in concentrations (degree by which standards, for example 50 $\mu g\ L^{-1}$ or 10 $\mu g\ L^{-1}$, are exceeded).

Technology Options

The two main technological options are (a) to switch to alternative, arsenic-free water sources; or (b) to remove arsenic from the groundwater source.

Table 6 illustrates that there is a range of technological options that can be used to mitigate arsenic exposure. They vary in terms of cost (total and per capita), need for operation and maintenance, and expected sustainability. The cost figures provided in the table have been collected from those countries where these options are implemented (mainly from Bangladesh) in order to provide an approximate idea of costs, but they will vary between countries. The financial and sociocultural sustainability of any options chosen will depend on the same factors as other typical water supply interventions, again highlighting that arsenic mitigation needs to be integrated in the sector.

Regarding arsenic removal specifically, a number of treatment technologies have been successfully deployed in many industrial, and also some developing countries. These technologies are also very expensive and therefore lend themselves to economies of scale, making them more suitable to high-population urban centers than to lower population density rural areas. Small-scale arsenic removal technologies, especially handpump-mounted ones, are being developed, field-tested, and validated in various countries. Bangladesh has been the front runner for such an extensive technology validation, and demonstrates the complex nature of the process and duration. After about three years of field testing a few technologies were provisionally validated by the government, with recommendations for further testing for a similar duration before final certification. Paper 3 provides a detailed presentation of available technologies for arsenic screening and arsenic removal and their approximate costs and management requirements at household and community levels.

As in the water supply sector in general, the main challenge is sustainability. While it would conceivably be possible to install community arsenic removal plants in small urban areas and in villages with piped community water supply (keeping in mind the economy of scale), these units would have to be maintained in order to be effective in the long run. This is also true for small community and household-level units. Thus, the equation does not only include financing, but also social and cultural factors. The extreme long-term toxic nature of arsenic, combined with the

Table 6. Water Supply Options for Arsenic Mitigation

Technology	Tech life	Annualized capital recovery (US$)	Operation & maintenance cost/year (US$)	Water production (m^3)	Unit cost (US$/$m^3$)
Water Supply Technologies:					
Rainwater harvesting	15	30	5	16.4	2.134
Deep hand tubewell	20	120	4	820 4,500	0.151 0.028[a]
Pond sand filter	15	117	15	820 2,000	0.161 0.066[a]
Dug/ring well	25	102	3	410 1,456	0.256 0.072[a]
Conventional treatment	20	2,008	3,000	16,400	0.305
Piped distribution	20	5,872	800	16,400 73,000	0.375 0.084[a]
Arsenic treatment (households) based on:					
Coagulation-filtration	3	3	25	16.4	1.70
Iron coated sand/brick	6	0.9	11	16.4	0.73
Dust	5	3	1	16.4	0.24
Iron fillings	5	1.2	29	16.4	184
Synthetic media/ activated alumina	4	3.2	36	16.4	2.39
Arsenic treatment (community) based on:					
Coagulation-filtration	10	44	250	246	1.21
Granulated ferric hydroxide/oxide	10-15	500-600	450-500	820-900	1.20
Activated alumina	10-15	30-125	500-520	164-200	3.20
Ion exchange	10	50	35	25	3.40
Reverse osmosis	10	440	780	328	3.72
As-Fe removal (air oxidation-filtration)	20	32,000	7,500	730,000	0.054

[a] Development of full potential of the system.
Source: Paper 3, Volume II.

fact that it has essentially no physical parameters for detection (colorless, tasteless, and odorless), and is very difficult to analyze in the field at concentrations twice the WHO guideline value (10 µg L^{-1}), mean that arsenic treatment units require very sensitive monitoring and maintenance arrangements.

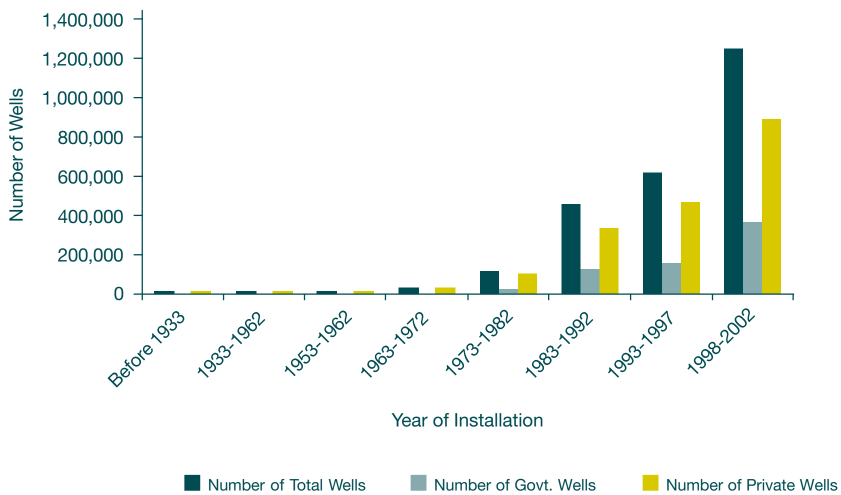
This nature of arsenic thus calls for carefully sequenced and highly effective mitigation measures, such as screening of sources for arsenic (local, countrywide, and regional levels), awareness raising about the nature of arsenic poisoning, and implementation of arsenic mitigation measures, from the immediate (switching to safe sources for drinking and cooking water supply) to the ultimate provision of a long-term viable arsenic-safe water supply.

Social and Cultural Considerations

A number of social, cultural, economic, and political factors come into play in deciding the sequencing and implementation strategy for effective mitigation. As in any other context these factors vary by country, and even within countries. Issues include suggestions for sharing of arsenic-safe wells (opinions vary as to whether households who have their own handpumps are really amenable to long-term sharing of their water source with neighbors whose source is contaminated). In the case of Bangladesh, it seems that households interpret the shift to shared communal systems (installation of pond sand filters and maintenance-intensive rainwater harvesting) as a step backwards, compared to the convenience of the shallow handpumps they have grown accustomed to (and invested in) over the past 30 years. Data collected by the BAMWSP show that increased investment in shallow tubewells has taken place over the past 30 years, including in the five years preceding the BAMWSP screening program, which ended in 2003 (figure 5). This happened in spite of the widely known hazards of arsenic contamination and stands in contrast to Cambodia, where rainwater harvesting has been part of rural culture, even in recent decades. Contingent valuation studies can be useful in identifying people's preferences and in designing an appropriate menu of arsenic mitigation options for individuals and communities, but this also involves an institutional change in attitude towards listening to communities.

Stigmatization of arsenicosis victims is prevalent in a number of countries. Anecdotally, it is considered a serious social side effect of arsenic contamination. It affects entire families and has

Figure 5. Private/Public Investments in Tubewells in Bangladesh in the Last 70 Years



Source: BAMWSP-NAMIC Database, 2004.

an adverse impact on, for example, marriage prospects for young people and on income-earning opportunities. Interestingly, little research has been carried out on the social aspects of arsenic mitigation, and only a few scientific papers provide sufficient rigor and depth to prepare any guidance on the matter.

Operational Responses Undertaken by Countries So Far

The results of this study have shown that most countries in the region have carried out some of the concrete operational steps described above. Table 7 (see page 45) summarizes the operational responses that the countries have undertaken so far. Bangladesh and West Bengal, India, have been the most dynamic, primarily because they were the first ones to detect arsenic in their groundwater. Only Bangladesh and West Bengal have implemented these measures at a larger scale, while other countries have started to become active in more limited areas and regions. In addition, especially in the smaller East Asian countries, NGOs and international organizations seem to have been the main drivers, rather than government entities. An interesting point is that virtually no country has taken major steps towards active and strategic monitoring of arsenic in groundwater, and much of the action has focused on provision of technological options to address the arsenic issue. Paper 2 provides a detailed account of these activities in each country.

The Economics of Arsenic: Investment Choices – What and When?

Using Cost-Benefit Analysis (CBA) to Inform Arsenic Decision-making

In spite of the uncertainty regarding arsenic epidemiology, the lethal nature and now well-established effects of arsenic exposure in South and East Asia compel governments, international financing institutions, donors, and NGOs in the water field to make informed choices and trade-off decisions to address arsenic contamination of drinking water sources and the scope and extent of mitigation measures.

At the same time, investments in arsenic screening and mitigation need to be assessed from a wider development perspective. Given the huge investment needs that countries are facing in areas such as basic health care, education, transport, and agriculture, are arsenic-related investments justified? And how can this question be rationally answered, taking into consideration the host of uncertainties mentioned earlier?

Accordingly, a simple cost-benefit methodology has been developed that explicitly takes into account data limitations and provides decisionmakers with an efficient and readily applicable methodology for rapid assessment of the socioeconomic desirability of different mitigation policies under various scenarios. Paper 4 provides a general introduction to the way of thinking about costs and benefits of mitigating (natural) pollutants, including considerations of trade-offs in decision-making with respect to the allocation of financial resources in a budget-constrained environment.

In particular, the methodology permits an analysis of options, enabling a choice to be made between different approaches in dealing with (a) the risk that arsenic might be found in an area where a project is planned; and (b) the risk mitigation options when a project's goal is arsenic mitigation per se.

Table 7. Operational Responses Undertaken by East and South Asian Countries

Activities (✔ indicates presence of activity)	East Asia						South Asia			
	Cambodia	China	Lao PDR	Myanmar	Taiwan (China)	Vietnam	Bangladesh	India	Nepal	Pakistan
Assessment of the arsenic situation										
Screening (field test)	✔	✔	✔	✔		✔	✔	✔	✔	✔
Screening (laboratory)						✔	✔	✔	✔	✔
Mitigation activities										
Water sharing	✔						✔		✔	
Dug well				✔			✔	✔	✔	✔
Rainwater harvesting	✔			✔	✔	✔	✔			
Pond sand filter							✔			
Deep tubewell				✔		✔	✔	✔	✔	
Household water treatment	✔			✔		✔	✔	✔	✔	✔
Community water treatment	✔[a]	✔			✔	✔	✔		✔	
Long-term collection and dissemination of information										
Arsenic monitoring program	✔[b]					✔[b]	✔[c]			
Database	✔						✔	✔	✔	✔
Dealing with arsenic at the national or state policy level										
Arsenic policy						✔	✔			
Arsenic committees/ programs	✔	✔					✔	✔[d]	✔	

[a] The water treatment is based on blend of safe and potentially contaminated water. [b] Only for piped water supply. [c] Incipient. [d] The Joint Program of Action (JPOA) with UNICEF.

The suggested approach estimates benefits of mitigation activities as the sum of saved output productivity and foregone medical costs achieved through the reduction of arsenic exposure. The present value of these benefits is then compared with the present value of costs of various mitigation measures in order to determine when and which mitigation policies pass a CBA (that is, produce a positive change in social welfare).

As an illustration, the model was then applied to the case of Bangladesh and clearly confirmed the value of arsenic mitigation measures that are being undertaken in the country (box 1).

The model results also show that not all mitigation technologies pass the CBA unless they are assumed to be 100% effective. Moreover, rainwater harvesting (combined with dug wells or deep hand tubewells during the dry season) is not welfare increasing, even at 100% level of effectiveness. This result points to the need for careful evaluation of the mitigation measures to be implemented, and indicates that it is not true that any mitigation technology can be applied. In addition, the results indicate that at the project level a least-cost analysis needs to be carried out.

The results of this simple model were also compared with those of a paper by Maddison, Luque, and Pearce (2004), which used more sophisticated data, drawing on the growing body of Bangladesh-specific data and on the best available epidemiological estimates. The results of the comparison between the simple model and the Maddison, Luque, and Pearce applications are very similar, clearly indicating the applicability of the model in countries where available data are even more limited than in Bangladesh.

Demand-Side Management

Different mitigation technologies may be effective, but a key question is whether people find these desirable and are willing to adopt and sustain them (for example, moving from 50% to 90% of successful implementation). Therefore demand-side perspectives are an important consideration for designing appropriate arsenic mitigation measures. No matter what the solution is in terms of technology, if it does not meet the preferences of households and communities the adoption, usage, or scaling up of the technology will not occur. Indeed, results of studies carried out by the Water and Sanitation Program in Bangladesh suggest that communities are not only

Box 1. Results of the Economic CBA in the Case of Bangladesh

Ten different arsenic mitigation technologies were analyzed, ranging from dug wells to pond sand filters and piped village water supply systems. The surprising result of the analysis was that the net present value ranged from US$8.2-1.1 billion, to US$22.3-11.1 billion, to US$71.8-87.9 billion as the discount rate ranged from 15%, to 10%, and to 5% respectively. The variation under the same discount rate reflects the varying costs of different technology options. The net present value arising from these calculations can be as large as 11% of current Bangladesh gross domestic product (GDP).

A sensitivity analysis was undertaken, assuming more realistic scenarios under which only 70% and 50% of mitigation activities would be effective. Under scenario 1, the relevant net present value (discounted at 10%) amounted to approximately US$9.5 billion, which constitutes around 4% of current Bangladesh GDP. Under scenario 2 the relevant net present value (discounted at 10%) amounted to approximately US$5 billion, still constituting around 2% of Bangladesh GDP.

It is important to note that in the calculation (a) the environmental benefits of mitigation strategies were not taken into account (mainly due to lack of precise data); and (b) the calculated health expenditures represent lower bounds of the relevant magnitudes. Thus, while the latter are the current actual expenditures made, they may not be really sufficient for the treatment of arsenic-related illnesses in Bangladesh. The calculated net benefits from arsenic mitigation are therefore underestimates of the true benefits and should be used as a very conservative measure of the welfare increases to be derived from implementing the various mitigation policies.

With the exception of the option of rainwater harvesting (supplemented by a dug well for the dry season) when discounted at a 10% rate, all other considered mitigation technologies are welfare increasing (that is, they pass a CBA) under all three levels of effectiveness at both 5% and 10% discount rates. However, when discounted at a 15% rate many of the mitigation technologies do not pass a CBA at lower than 100% level of effectiveness. Moreover, rainwater harvesting (+ dug well) and rainwater harvesting (+deep tubewell) are not welfare increasing even at 100% level of effectiveness. Thus, proposed mitigation measures need to be carefully evaluated and it does make a difference which mitigation technology can be applied in a specific context. Moreover, these results indicate that at the project level one may want to carry out a least-cost analysis.

The use of pond sand filters (30 households/pond sand filter), taking account of the level of service, turns out to be superior to other technologies. However, even though the analysis concludes that pond sand filters are the economically most efficient option, two real-life caveats make this option

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less attractive. First, pond sand filters are often very polluted. To take this into account in a CBA a risk-weighting factor should be included in the methodology to indicate the increase in child morbidity and mortality due to water source contamination. The second caveat is the lack of space in Bangladesh for accommodating so many ponds. In earlier years space was not an issue, but increasing population density has reduced available land in any given village, or people use the ponds for fish farming, a significant source of income in rural Bangladesh. This situation makes the shadow price involved in using the pond very high, as it should include the price of the land where the pond will be situated. It can even be the case that the corresponding land has to be purchased through an actual money transaction, which makes the relevant price an explicit one.

Overall, no significant discrepancies among technologies are documented. The more dramatic effects on the desirability of different mitigation technologies emerge by the changes in the choice of discount rate of the future flow of cost and benefits. This exercise highlights the significance of the choice of the discount rate, as well as the importance of the ability to predict the degree of effectiveness of a proposed policy, which in turn is related to the need to listen to communities and find out their true demand for the respective arsenic mitigation options.

seeking arsenic-free water sources but are also prepared to pay for alternatives that are as convenient as the traditional tubewell, for instance piped water (Ahmad and others 2003). Demand preferences can be assessed through contingent valuation or willingness to pay studies and can provide important guidance to decisionmakers. These studies for instance, have provided the background for preparation of the Bangladesh Water Supply Program Project, which started implementation in 2005, with financing from the World Bank.

The Economics of Arsenic Mitigation

The results of the economic analysis powerfully illustrate four points. First, from an economic point of view, arsenic mitigation interventions in Bangladesh are very well justified. Second, even in a situation of limited data, economic analysis can and should be carried out. As mentioned above, the results of the purposefully simple model developed here are very similar to those based on a far more detailed analysis, providing confidence that in countries with much less available information than Bangladesh relatively simple calculations can provide decision-making support. This is a clearly needed contribution to the politicized arsenic debate addressed in the next section.

Third, the findings make an economic case for up-front investment in scientific data (aquifer investigation and screening programs). The logic behind this necessity is the following. The long-run nature of project-specific developments means that initial screening costs will be discounted over a long-run horizon; hence, these costs will be relatively small in net present value terms irrespective of their absolute initial value. On the contrary, the effects of arsenic contamination could be detrimental to both the economy and health of the inhabitants of an area over a much shorter horizon. Moreover, one should keep in mind that the decision to develop a particular area is irreversible in practical terms. This characteristic of irreversibility necessitates great caution about the decision to develop or not, hence such decisions should be taken under minimum risk conditions. The combined result of these three effects increases the net potential benefit to society that can be achieved through gathering information regarding the extent and existence of arsenic contamination prior to any other project-related appraisal.

Fourth, not only should the demand-side perspective be incorporated, but well-established methodologies exist for such assessments. To increase effectiveness of arsenic mitigation measures, it is important to strategically employ them up-front.

Thus these methodologies, when applied on a case-by-case basis for the different countries, may provide guidance as to the trade-offs between (a) a variety of arsenic-related investments (for example, screening versus implementation of different mitigation options); and (b) arsenic-related investments compared to other investments in water supply and sanitation, which would also save lives from other waterborne diseases. There is a clear need to strengthen institutional capacities in the countries to carry out such assessments. Of course, economic analysis can only contribute one building block to the development of an operational response to arsenic contamination; ethical, social, and political considerations will also play a role in such deliberations.

The Political Economy of Arsenic: What Are the Prospects for Action?

Arsenic has become a highly politicized topic in the international development community and within some affected countries due to its carcinogenic characteristics and, more importantly, due to the earlier complete failure to consider it as a possible natural contaminant in groundwater sources. The slow nature of arsenic poisoning, accompanied by eventual very visible marks of arsenicosis, including gangrene and skin keratoses, is very striking for the media, and such cases are highly publicized in countries of high arsenic occurrence. It was not possible in the course of the present study to get deeper into this area and there are very few hard data about this issue – which, however, is at the core of effectively dealing with arsenic. A case in point is the fact that a number of knowledgeable people in the different countries who were approached by the study team to fill out the study survey (Paper 2, annex 1) were not willing to respond because they felt that the topic was too sensitive. On the one hand, this has made the survey instrument less useful than anticipated, but on the other it underlined the fact that arsenic is a very sensitive issue with deep political significance and, therefore, technocratic solutions alone are not likely to be successful. Politicization of the arsenic issue induced a strong bias in reporting of data and studies, with activists making claims that are often weakly substantiated and sensational, while skeptics are being intimidated into not reporting their data and findings.

Table 8 shows an incentive matrix, developed in an attempt to analyze the incentives that different stakeholders — notably governments, donors, international agencies, and NGOs — face in dealing with arsenic.

It is obvious that on the government side, urgency regarding arsenic comes about only when it is shown to be a really crucial issue, when compared with the many other development issues affecting a country. This may explain why some governments have not been as active as some actors might have expected.

However, a further issue is related to the fact that in most of the countries — including Bangladesh and Nepal — groundwater was rightly promoted by governments and development partners as a safe water source compared to surface water, due to the very high public health risk of waterborne disease caused by pathogens. While this policy helped to reduce the disease burden due to bacteriological contamination, it was, however, detrimental to the health of a part of the population due to ignorance regarding arsenic contamination, and official acknowledgment of this constitutes not only a loss of face, but also highlights an issue that is difficult to resolve as there are no clear alternatives. As mentioned earlier, technologies for arsenic removal exist but — especially in rural contexts — they are often too expensive or too difficult to maintain to be

Table 8. Conceptualized Incentive Matrix: Stakeholder Incentives for Action on Arsenic Issues

Incentive factors	Government	Donors/international agencies	NGOs
Number of people at risk	Low incentive	Low incentive	Low incentive
Number of arsenicosis patients	Great incentive	Great incentive	Great incentive
Rural areas	Low incentive	Medium incentive	Medium incentive
Urban areas	Great incentive	Medium incentive	Medium incentive
National media coverage	Great incentive	Medium incentive	Low incentive
International media coverage	Great incentive	Great incentive	Low incentive
Water pricing and accountability	Medium incentive	Great incentive	Low incentive
Transparency in choice of mitigation measures	Medium incentive	Great incentive	Medium incentive
Availability of short-term solutions	Great incentive	Medium incentive	Great incentive
Availability of long-term solutions	Medium incentive	Medium incentive	Low incentive
Perception of reputational risk	Great incentive	Great incentive	Low incentive

Low incentive   Medium incentive   Great incentive

considered as effective alternatives. The other options — using other sources, such as deep groundwater in some countries or a return to surface water or rainwater harvesting — are fraught with other health-related problems. Thus, governments may prefer to avoid dealing with the arsenic issue. Clearly, this presents a difficulty because awareness raising is an important way to give affected people the tools to protect themselves, even though it is not a complete solution. At the same time, politicians are in a dilemma as they fear promoting another solution that, in the long run, might be detected to be inappropriate or detrimental.

This is highlighted by the ongoing debate about the use of the deep (old) aquifers in Bangladesh and Nepal. These aquifers — for a number of hydrogeochemical reasons not yet entirely understood — are not susceptible to arsenic contamination. They clearly constitute an alternative as a safe water supply source in rural areas where the overlying shallow aquifers are contaminated, and where surface waters are suboptimal due to the associated microbial pollution risks. Yet there is a risk (the assessment of the extent of this risk varies significantly depending on the interlocutor) that these deep aquifers might also become locally polluted if the wells tapping them were inadequately constructed or if there was a sudden surge in irrigation abstraction from these aquifers. Not surprisingly, in Bangladesh, politicians have been reluctant to promote this alternative and instead prefer to promote other noncontroversial options in spite of their short-term health risks, lack of effectiveness, and low social acceptability among the arsenic-affected populations. This stalemate situation is now showing signs of resolution as a more structured approach to the investigation is available and controlled use of the deep aquifers is being developed.

On the other hand another stakeholder group, donors and international finance institutions, have quite a strong incentive to deal with arsenic, as they have been under close and serious scrutiny for the quality and effectiveness of their water supply investments in the region. This has become all the more clear since the lawsuit against the British Geological Survey by some affected patients from Bangladesh. Especially during the Water Decade (1981-1990) international aid agencies strongly promoted groundwater as a safe source, particularly in rural areas, and financed and promoted water supply projects wholly reliant on groundwater. The detection of naturally occurring arsenic in large parts of Bangladesh and in West Bengal came as a very unwelcome surprise, and there were no clear-cut strategies for quickly and effectively addressing the situation. It is therefore not surprising that the development partners play a very active role in financing arsenic-related interventions, including research, support to policy formulation, and mitigation. However, most partners are at present focusing on detection of arsenic, awareness building, mitigation measures, and action research. Arsenic considerations are still not fully integrated into water supply sector decision-making. According to the study team's knowledge, only the Australian Agency for International Development (AusAID) has taken the initiative to develop specific guidelines to address the issue of arsenic in its funded projects.

Clearly, though, while these international institutions, public sector agencies, and NGOs have an incentive to act, they also need not worry about reelection in their constituencies, and thus they are less risk averse than the elected governments.

A further group of stakeholders consists of a variety of research institutions. As a sensitive and relatively new topic, arsenic is attracting researchers from all over the world. In line with the above, however, most research has been financed from outside the region, though Asian researchers have been involved on the teams. The only major study financed within a country, conceptualized and carried out by national researchers, is probably the one in China.

It is also notable, as mentioned earlier, that most research has focused on hydrogeology rather than on epidemiology and social aspects, although a variety of international conferences have pointed out those glaring gaps (Ahmed 2003). This again highlights the lack of government leadership and direction in dealing with the issue. It may also reflect the desire of donors and international finance institutions to cover a serious lapse through ostensive action, rather than taking a more comprehensive operational view of the issue.

Finally, it must be said that the arsenic crisis has opened a new market, not only for NGOs, but also for investors in the water sector. The crisis mode and labels such as "the greatest mass poisoning in history", which has often been repeated in the literature, permits a growing number of actors to lobby for certain types of investments, notably those involving a return to various types of surface water resources with treatment (thus taking investments out of households' private hands) in both water and irrigation supply, or promotion of arsenic removal technologies of various kinds.

In summary, the political economy is such that many actors continue pursuing their own interests, not necessarily in a cost-effective manner conducive to solving the issue or to the benefit of those affected by arsenic. This latter stakeholder group suffers from the well-known problem faced by large groups with many free riders, in that a large amount of mainly rural people are potentially affected, but due to a lack of knowledge, social standing, and resources they are not developing the political clout to demand or implement effective solutions. Poverty certainly plays a role, given that wealthier households - even rural ones - do have the means to look for alternative sources.

Governments that want to address the arsenic issue will therefore need to overcome their own hesitancy and take a stronger lead role in their countries and on the international plane in order to address the issue. This includes more strategic research and knowledge acquisition regarding arsenic in their countries, appropriate choice and scope of arsenic mitigation activities, and internal capacity building of the relevant water supply and water resource agencies. Such action can be supported by the knowledge accumulated in the past decade regarding arsenic, arsenic mitigation, and tools for options analysis that can be used by decisionmakers to analyze local and national options.

What Should Governments, Development Partners, and the World Bank Do?

Significant strides have been made since arsenic was first detected in drinking water tubewells in Eastern India and Bangladesh in the late 1980s and early 1990s. However, more needs to be done and it needs to be done in a more strategic manner, at project, national, and international levels. This section summarizes the remaining action and knowledge gaps and what could be done by different stakeholders in order to enhance the operational responses to the arsenic issue in Asian countries.

It is clear that arsenic consideration needs to be embedded in overall water supply investments and cannot be seen as an isolated issue. In fact, similar considerations apply to other toxic trace elements (such as fluoride, manganese, and boron) that are found in groundwater. The recommendations put forward here can also be applied to those elements. The differences lie primarily in geographic occurrence, scale, and politicization of the topic.

Arsenic contamination is a long-term issue and, with extended screening, more affected areas are likely to be found in the future, if not at the same scale as those so far located. Interventions and action by governments and their development partners should therefore take place at three different levels simultaneously: (a) project and local level; (b) national level; and (c) global level.

Project-Level Action

The findings of this study make it clear that the occurrence of arsenic in groundwater sources must henceforth be taken as a strong possibility in the countries of the region. Therefore, in any project interventions that consider using groundwater as a source, decisionmakers need to make a judgment if occurrence of arsenic would affect the outcome of the project and make provisions accordingly. In general, this would be the case for all water supply projects, but would also include education and health projects that use groundwater as sources for schools and hospitals, and irrigation projects (where wells are often also used for domestic water supply).

As pointed out earlier, there are currently no guidelines for arsenic in irrigation water. International study results are not conclusive as to the impacts of irrigating crops with arsenic-contaminated water. For this reason, arsenic in irrigation wells should be tested for and documented in order to have information available for possible future use (see in this section on global-level action).

Sequencing and integration are important. Following the simple sequence of steps outlined in figure 4 would ensure that investments adequately internalize arsenic as another factor that has to be taken into account in interventions in water supply and irrigation. Obviously, possibilities for this will be conditioned by a number of factors, including the political economy involved. This has to be considered in making investment commitments.

National-Level Action

Some countries have taken arsenic to the national level of attention, including Bangladesh, Nepal, and Cambodia. Others, such as India, Pakistan, and China, have only started to address the issue, and in others, international organizations such as UNICEF and local NGOs and universities are the focal points for arsenic-related activities (see table 7 and Paper 2). Since each country has a unique situation in terms of knowledge, scale, and scope of the problem, generalized and sweeping recommendations on what to do will not be useful.

Study results suggest, however, that the countries would benefit from (a) encouraging further research in potentially arsenic-affected areas in order to better determine the extent of the problem; (b) ensuring that arsenic is included as a potential risk factor in decision-making about water-related issues (see section above on project-level action); and (c) developing viable options and coping mechanisms for populations in known arsenic-affected areas. With these three steps, governments — whether at national or at provincial and state level — would be able to address problems currently affecting populations and prevent future investments having negative impacts on their citizens.

The arsenic issue has shown that there has been an underinvestment in groundwater monitoring. While arsenic is now identified and is being tested for, there are other elements that also need attention. Governments and development partners should actively work to link water supply and water resources management investments in order to address the issue of groundwater quality monitoring up-front and build the requisite capacity.

At the national level, governments thus need to take more assertive action in defining their countries' needs and developing strategic actions to deal with arsenic in groundwater.

Global-Level Action

Focused research on the chemistry of arsenic mobilization and the dose-response relationships for arsenic are of vital importance in formulating a more sensible approach. If the Millennium Development Goals (MDGs) in water supply and sanitation are to be achieved, then the glaring knowledge gaps regarding arsenic need to be filled, notably by (a) further epidemiological research in directly arsenic-affected countries; (b) socioeconomic research on the effects of arsenicosis, understanding behavior and designing demand-based packages for the various arsenic mitigation techniques; and (c) hydrogeological and hydrochemical research.

In addition, it is likely that in the near future there will be diminishing returns on investments in scientific arsenic research to reduce uncertainty. The important challenge will be to identify those areas where improved research-level data collection is likely to provide a major return and for other areas the main question will be how to manage in the face of unavoidable and continuing uncertainty.

Accordingly, the international dialogue should shift towards targeted research priorities addressing these issues. This would also include the pursuit of the research agenda regarding arsenic in the food chain. Both the World Bank and a number of other development partners are contributors to the Consultative Group on International Agricultural Research (CGIAR), and this organization would lend itself to building up a coherent and focused research agenda on this topic in order to provide decisionmakers with guidance on arsenic-contaminated groundwater in irrigation.

These suggested operational responses and their expected outcomes are summarized in annex 1.

Conclusions and Recommendations

The present study has shown that naturally occurring arsenic in groundwater is more widespread in South and East Asian countries than is generally recognized and that, with continuous testing, more contaminated groundwater aquifers are bound to be identified, if not at the same scale as previously. At least 60 million people are currently estimated to live in arsenic risk-prone areas. This, along with projected population growth in the region, continuing private investments in shallow tubewells, and consideration of the MDGs related to safe water supply, will have considerable impact on government and development community engagement in water supply and possibly also in irrigation.

Although our ability to predict arsenic concentrations in groundwater from a given area or aquifer is still rather limited, knowledge of its occurrence and distribution has improved greatly over the last few years. Enough is therefore probably known about where high concentrations tend to occur to make reasonable estimates of likely at-risk aquifers on a regional scale. Young sediments in alluvial and deltaic plains and inland basins and areas of mining activity and mineralization are obvious target areas for further evaluation.

There are still considerable knowledge gaps regarding arsenic, notably on the epidemiological side. While microbial contamination is undoubtedly of a larger scale and has more immediate impacts, notably on children, the scope of the public health threat that arsenic poses in the medium and long terms is not yet clear. This is especially true when compared with other development challenges faced by the countries in the region. The issue itself, and the political economy that has developed around it, is such that clear and easy answers are not likely to be available in the near future.

Nevertheless public health effects of arsenic are a reality and they need to be taken seriously. As the effects of arsenic are long term it is likely that arsenic-related disease, with and without fatal outcomes, is going to increase over the coming decades, affecting hundreds of thousands of people. At the same time, with other waterborne diseases, notably diarrhoea, still claiming so many lives annually, it is important to integrate arsenic considerations into a rational approach to reflect the overall context of waterborne public health threats. Further investment in safe water supply is a necessity and arsenic is but one of the considerations in this regard.

It is thus recommended that governments and development partners make use of the information and experience generated over the past two decades and actively include arsenic into assessments when investing in projects that use groundwater as a source (such as water supply, irrigation, and education infrastructure) and support institutional strengthening at various levels in order to deal with arsenic and other groundwater pollutants.

At national as well as provincial and state levels, governments would benefit from (a) supporting and originating further research on arsenic occurrence in their territories; (b) making sure that arsenic is taken into account when water-related investments are made and that trade-offs are adequately analyzed; and (c) making their voices heard in developing a cross-regional and international research agenda that would strategically address the remaining knowledge gaps. To make these actions effective, the institutional arrangements within countries, provinces, and states will need to be reviewed and, if necessary, improved and strengthened.

Annex 1

Policy Matrix: Operational Responses to Arsenic Contamination in South and East Asian Countries

Level	Activity	Expected outcome	Responsibility
Project level	Disseminate information on arsenic to national and international project staff	Technical staff are well informed and can incorporate arsenic issues appropriately in investment projects and studies	Governments; development organizations, including development banks, donors, and NGOs
	Incorporate arsenic considerations in all projects using groundwater as a (potential) drinking water source (including water supply, education, irrigation projects, health projects) in South and East Asia	Arsenic is effectively incorporated into upstream decision-making and design regarding investment projects and studies ensuring benefits from interventions are achieved	Governments; development organizations, including development banks, donors, and NGOs
	If arsenic is a factor in the proposed project, develop appropriate activities to be incorporated into the project, such as reconnaissance testing, blanket testing, monitoring, arsenic mitigation investments, social and economic assessments, willingness-to-pay studies (see Volume II)	Arsenic issues are effectively incorporated into investment projects and studies, ensuring benefits from interventions are achieved	Technical staff in governments, development organizations, and NGOs
National level	Encourage further research in potentially arsenic-affected areas in order to better determine the extent of the problem and ensure that data are publicly	Knowledge base increases and provides input to decision-making at different levels	Governments

Level	Activity	Expected outcome	Responsibility
	available as soon as possible		
	Ensure that arsenic is included as a potential risk factor in decision-making about water-related issues, for example by issuing guidelines	Investments in water supply will take into account arsenic as a risk factor so that any occurrence can be mitigated up-front	Government authorities
	Develop and implement options for and with populations in known arsenic-affected areas (including awareness raising and training programs, alternative water supply options)	Affected people will receive (and participate in) effective mitigation measures and reduce their exposure, leading to positive health benefits	Government authorities with, if requested, support from development partners; NGOs
	Develop and implement integrated groundwater management programs, including aquifer mapping, testing, monitoring, and publicly accessible databases in order to support the water-using sectors and institution building	Increased knowledge of groundwater resources and aquifers to permit more effective decision-making regarding water supply investments and necessary arsenic mitigation measures Capacity to effectively address arsenic and other pollutants is strengthened within the country at local, regional, and national levels	Government authorities with, if requested, support from development partners; NGOs
	Integrate arsenic as one factor in national policies regarding water supply-related activities, including research and investments	Arsenic issues become integrated into sector policies and will be more effectively addressed by drawing on existing institutions and knowledge	Governments

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Level	Activity	Expected outcome	Responsibility
Global level	Develop and implement a more strategic global research agenda to the benefit of arsenic-affected countries, including: • Targeted epidemiological research • Social research on the effects of arsenicosis, understanding behavior and designing demand-based packages for the various arsenic mitigation techniques • Geohydrological and hydrochemical research in countries and in the region • Research on arsenic in the food chain, for example through CGIAR network	Knowledge gaps are diminished and arsenic -inherent uncertainties are more strategically addressed Feedback loop into projects and national-level activities improves project and policy outcomes	Governments, development partners, NGOs
	Ensure that data and analyses carried out by external research organizations and universities are made available to the respective countries as soon as possible	Research results are disseminated effectively and in a timely manner and can be put to use as soon as possible	Governments; research institutions and universities

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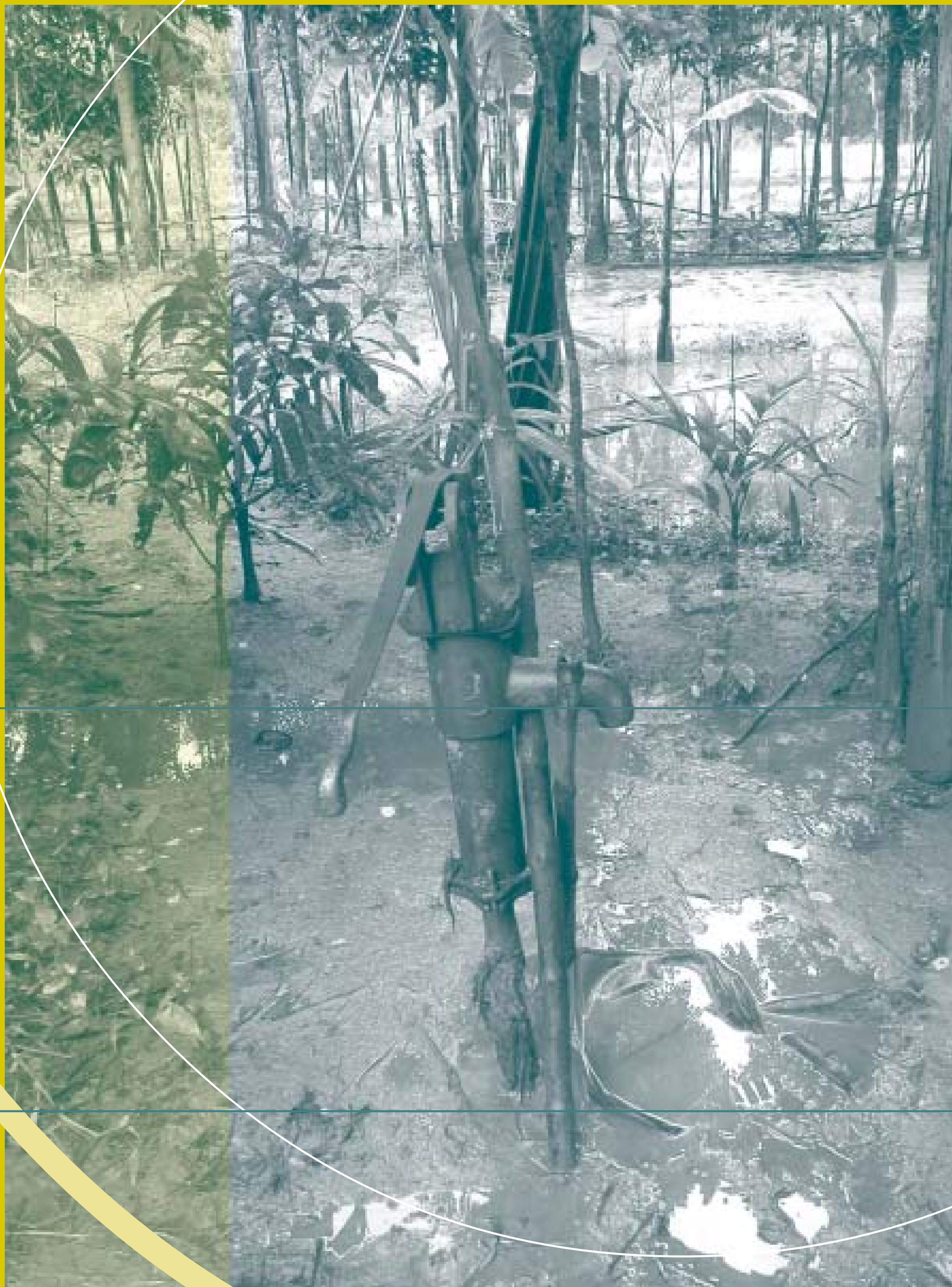

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March, 2005
Volume I, Policy Report, No 31303

Designed and printed by: Roots Advertising Services Pvt. Ltd.