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The occurrence of high nitrate concentration in groundwater in villages in Northwestern Burkina Faso

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Abstract- In the «Volta Noire» rural water supply project 168 boreholes have been drilled and equipped with handpumps in north-western Burkina Faso in the period 1984 - 1986. In 15% of these drilled wells nitrate concentrations exceeded the World Health Organization recommended limit of 45 mg/l. This was also the case in 36% of dug wells sampled during reconnaissance surveys. A review of the field data showed that high nitrate concentrations were more pronounced in villages of certain ethnic groups characterized by a high housing density. Nitrate contamination is caused by the dumping of organic waste in and around the villages. When villages or village-quarters are spread out over larger areas, the contamination is more diffuse and the crops grown between the houses are presumed to take up a substancial part of the nitrogen charge. Groundwater with a high electrical conductivity is positively related to high nitrate concentrations. Near villages with high housing density, conductive groundwater bodies have been detected by routine geo-electrical profiling. It was observed that in boreholes downstream of the village with regard to the direction of groundwater flow, a higher incidence of nitrate contamination is present.

It is therefore recommended to site boreholes in villages with a close grouping of houses upstream from the village and to observe a minimum distance from the village center of at least 200m. Siting of boreholes can be improved by applying electrical or electro-magnetic methods.

INTRODUCTION

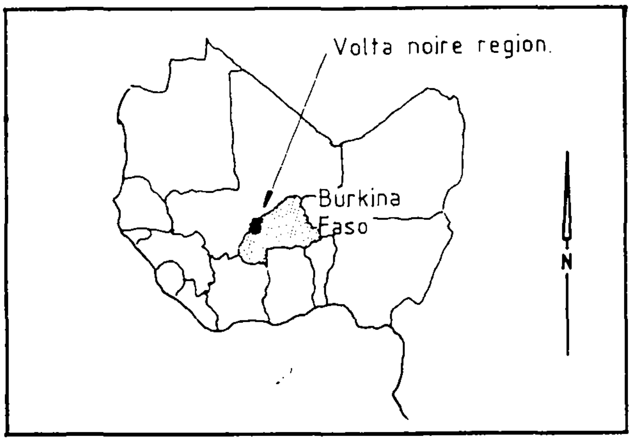
In the framework of the United Nations Water Decade, many rural water supply projects are being carried out in the Sahel region. Due to the climate, characterized by a short rainy season and high evapotranspiration, surface water is an unreliable source for rural water supply projects, which therefore rely mainly on groundwater. Moreover, the development of groundwater is generally cheaper as storage reservoirs and purification installations are not needed. Groundwater in Burkina Faso is normally of sufficient quality for direct use, although in some areas high arsenic concentrations have been reported (de Jong and Kikietta, 1980).

In a rural water supply project, in progress in the Volta Noire region of northwestern Burkina Faso (Fig. 1), mainly financed by the Dutch Government, high nitrate concentrations were encountered locally which exceed the World Health Organization recommended limit of 45 mg/l for drinking water. In this project 168 boreholes have been successfully drilled and equipped with a handpump in the period 1984 - 1986 (Schuchmann, 1986).

A high consumption of nitrate is thought to cause infantile methemoglobinemia, a blood poisoning which reduces the oxygen transport capacity of the blood of young infants and may cause death. High consumption of nitrate has also been related to an increased risk of stomach cancer (Int. Standing Committee on Water Quality and Treatment, 1974; Fraser and Chilvers, 1981; Fritsch and De Saint Blanquat, 1985; Hegesh and Shiloah, 1982).

Although the link between nitrate rich water and the mentioned diseases is still a matter of debate and no such cases have been reported from Burkina Faso, the desirability of low nitrate in drinking water is evident.

The occurrence of a high nitrate content in groundwater in the Volta Noire region will be discussed here in relation to the physical and social environment.



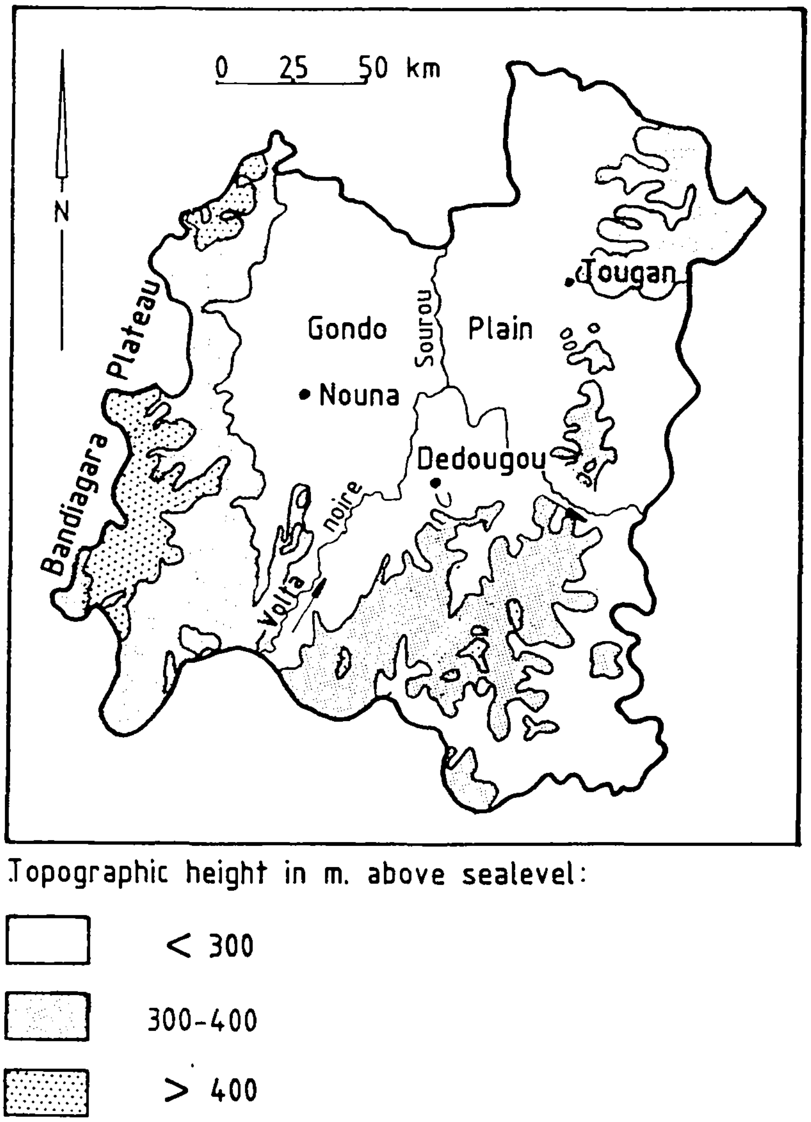
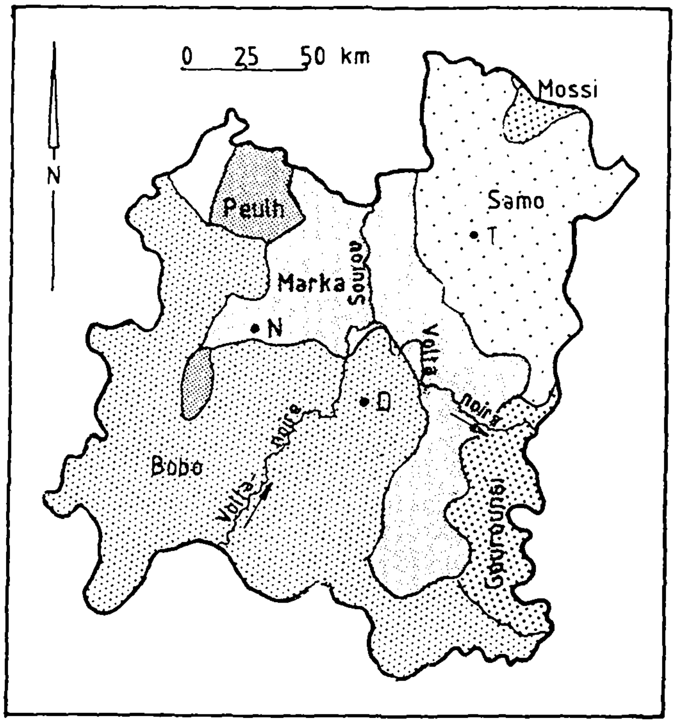


Fig. 1 Location of the Volta Noire region.

Fig. 2 Topography of the Volta Noire region.



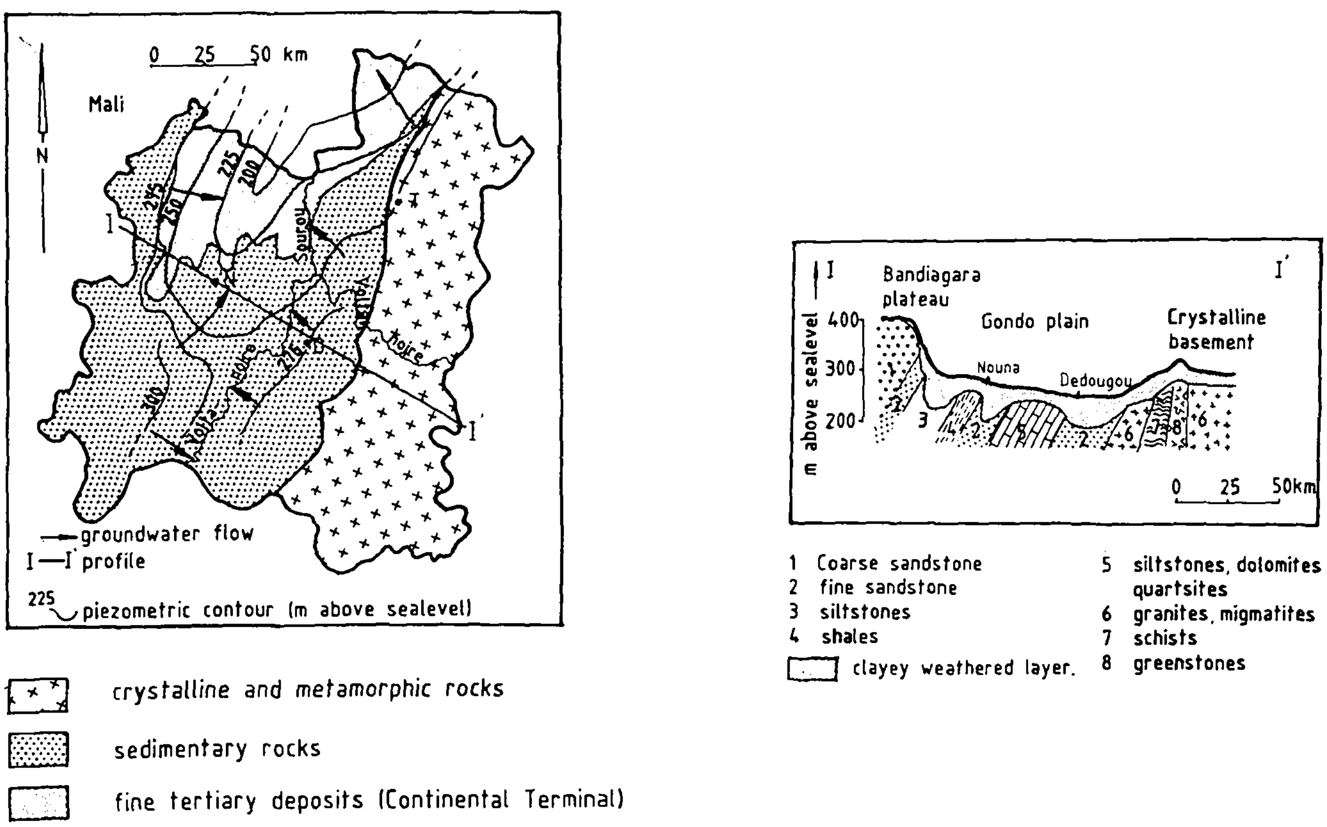


Fig. 3 Hydrogeological map of the Volta Noire region.

Fig. 4 Ethnic groups.

PHYSICAL SETTING

The Volta Noire region, named after the only perennial river in Burkina Faso, comprises three provinces, viz. the Kossi, Sourou and Mouhoun, and covers a total area of 35.000 km² (Fig. 2). The region forms part of the vast West African peneplain where weathering and erosion resulted in flat monotonous plains which support a savannah vegetation. In the east the Volta Noire region forms part of the crystalline basement, composed of metamorphic and igneous rocks. The major part of the region is underlain by Precambrian sandstones and shales (Fig. 3). A weathered zone of 20 to 100m thickness composed of clayey alterite often capped by laterite, covers the bedrock.

An interesting morphological feature is the Gondo Plain, which extends from the center of the Volta Noire region around Nouna and Dedougou to the north across the Mali border. This area forms a flat basin characterized by the absence of a coherent draining system. The northern part is a relatively low lying area, the Gondo Plain, which is characterized by the absence of a coherent drainage system. Only in the north is the plain covered by fine textured unconsolidated Tertiary sediments often featuring sand dunes. About 60% of boreholes were made in the Gondo plain, where drinking water problems are urgent.

To the west and the east the Gondo plain is bordered by respectively the sandstone outcrops of the Bandiagara plateau and the crystalline basement plateau. Average annual precipitation ranges from 600 mm in the north to 1000 mm in the south of the region. Rainfall is restricted to the rainy season which lasts from June to October. Potential evapotranspiration probably exceeds 2000 mm/year.

SOCIAL GEOGRAPHY

The population of the Volta Noire region totals 850.000 and is growing at a rate of 3.4 % per year; the mean population density in the region is 27 persons per km². Most people live in villages with 100 to 1500 inhabitants. Six ethnic groups live in the area, viz. the Marka, Samo, Bobo, Mossi, Gourounsi and Peulh. Their geographical distribution is shown in Fig. 4. Boundaries between different tribal areas are not very clear and the Mossi and Peulh villages in particular are found throughout the region. Agriculture is the most important economic activity for all but the semi-nomadic Peulh, who rely chiefly on cattle breeding. The traditional sources of drinking water are hand-dug wells and ponds used in the rainy season. Wells are usually located inside the village perimeter and are shared by the whole community. In rural water supply projects presently in progress large diameter dug wells with concrete lining are made, and small diameter boreholes equipped with handpumps. These are generally sited outside the village perimeter.

HYDROGEOLOGY

The Precambrian sedimentary sequence discordantly overlies the crystalline basement, composed of granites and schists of Birrimien and Antebirrimien age (fig. 5.). The lithology of the sedimentary rocks varies in the Volta Noire area from pure sandstones in the east and west to clayey sandstones and shales in the center. The dip of the strata is only about 2° to 5°, so that over large areas the same geological unit can be expected although facies changes may give minor variations in lithology.

Althouth the crystalline basement has undergone various phases of intense deformation, this is not the case for the overlying sedimentary rocks; boundaries of the different units can be followed over hundreds of kilometers on satellite images and lineaments on aerial photographs are scanty.

Three types of aquifers occur:

- the fractured zones in the basement rocks;
- the jointed sandstone layers in the sedimentary sequence, and
- the weathered mantle aquifer, which are present in both units. Continuous aquifers of regional extent do not occur in the crystalline basement; the fracture zones are local phenomena and are often poorly interconnected. The weathered zone of the crystalline rock is also generally clayey except for the granular alterite lying directly above the hardrock. The sub-horizontally layered sedimentary rocks form a regional aquifer: individual sandstone layers are well jointed and the weathering products are also generally sandy.

Boreholes usually draw water from the fractured or jointed bedrock while dug wells are restricted to the weathered mantle. Both aquifers are considered to be in hydraulic contact, since piezometric levels of both dug wells and boreholes are generally the same. Pumping tests carried out in boreholes give transmissivitiy values, which range from 2 to 135 m²/day, with a mean of 30 m²/day.

Static groundwater levels are found at depths of 10 to 60 m below the surface, with deepest levels occurring in the northern part of the area. The water table shows a seasonal variation of 1 to 2 m all over the Volta Noire region. The fluctuating water levels demonstrate that everywhere local recharge takes place by infiltrating rainfall and temporarily stored surface water during the rainy season, followed by evapotranspiration during the dry season. Water balance and isotope studies

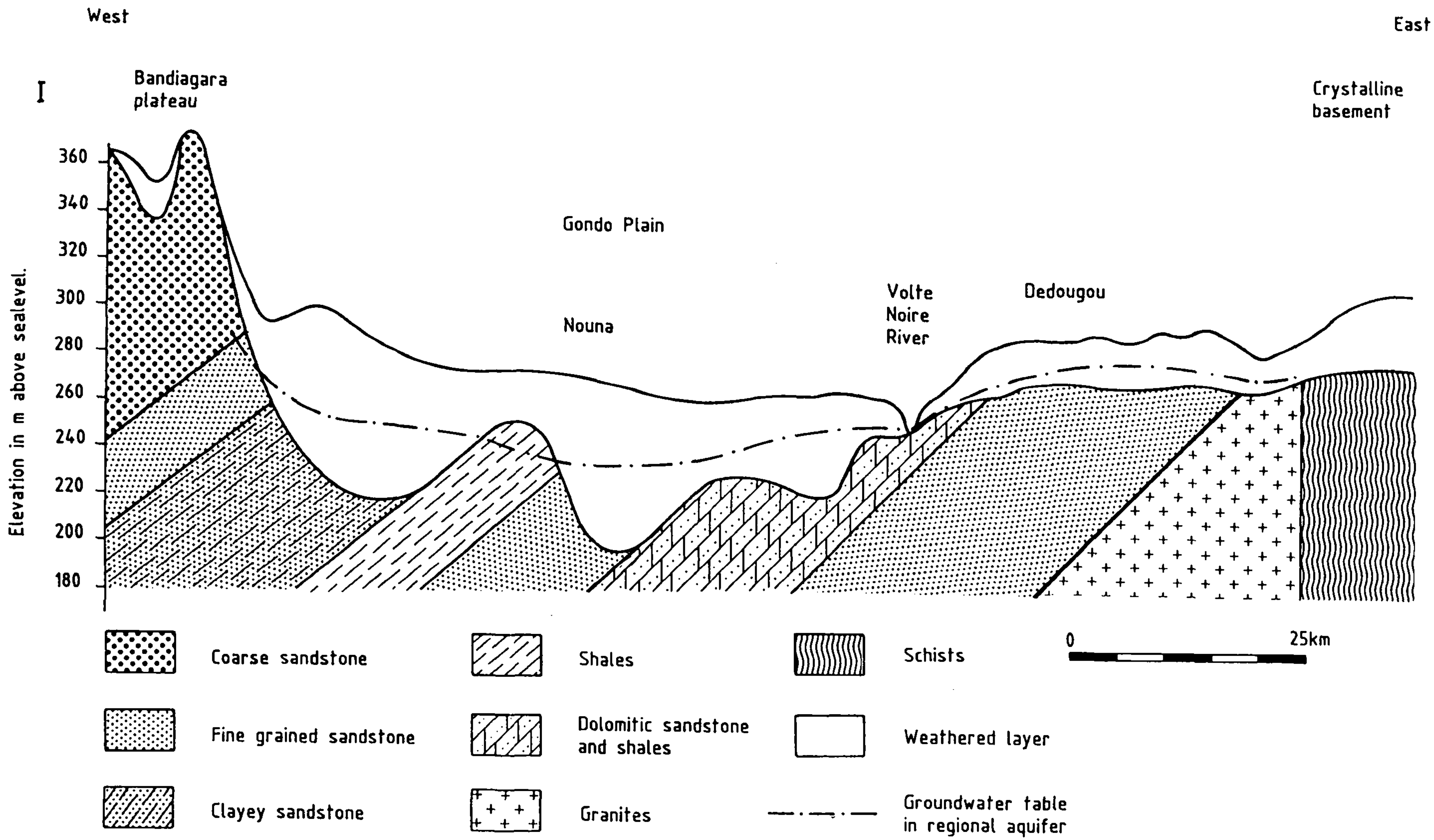
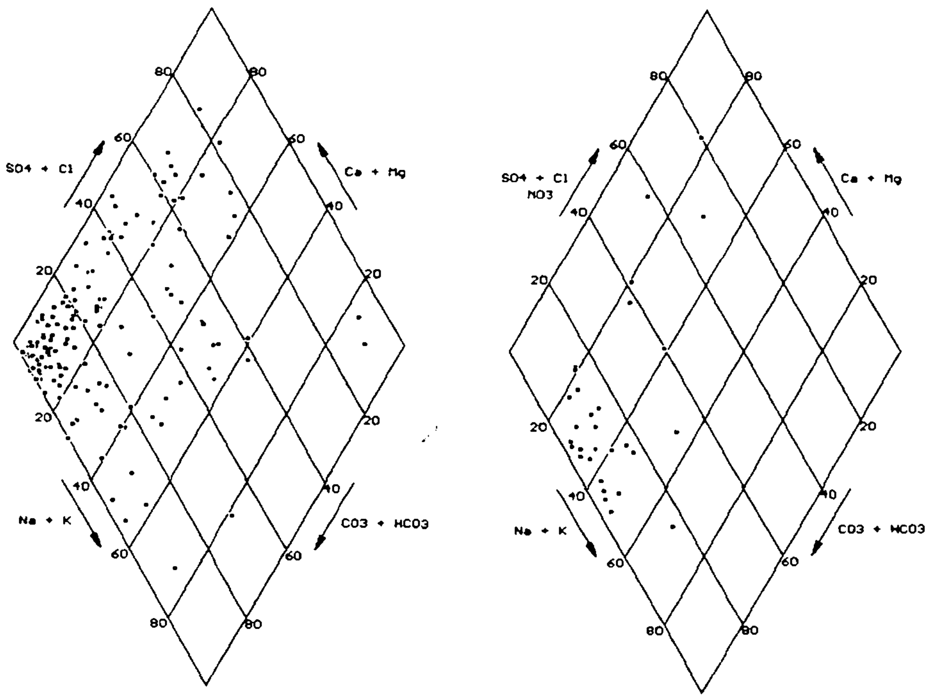


Fig. 5 Hydrogeological section across the Volta Noire region (For location see figure 3.).



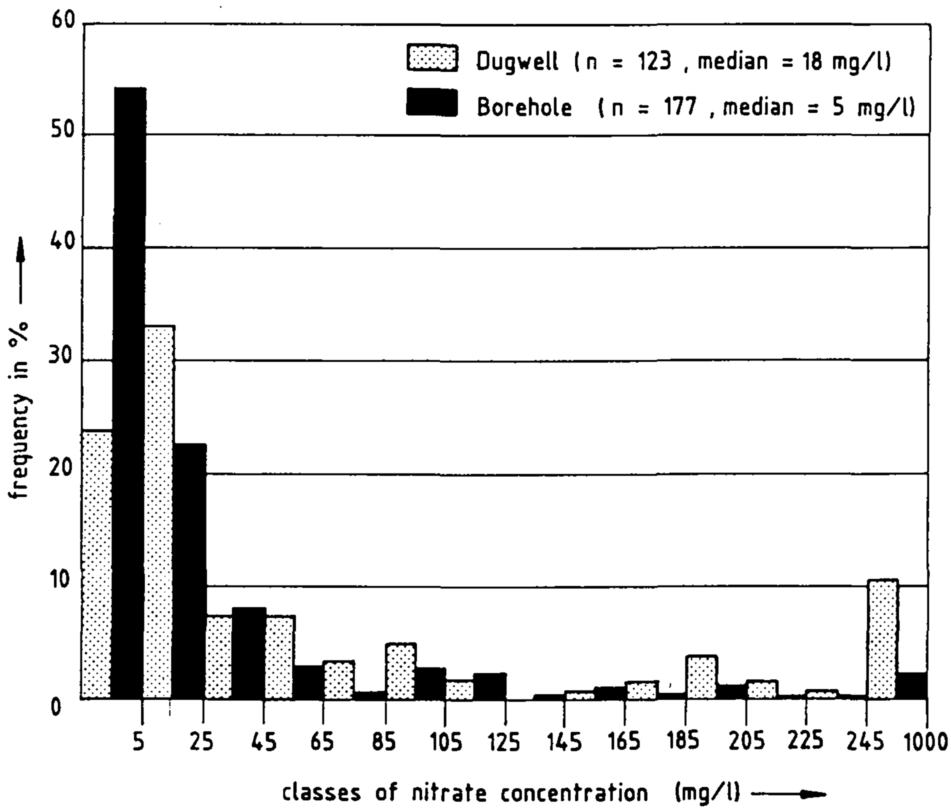
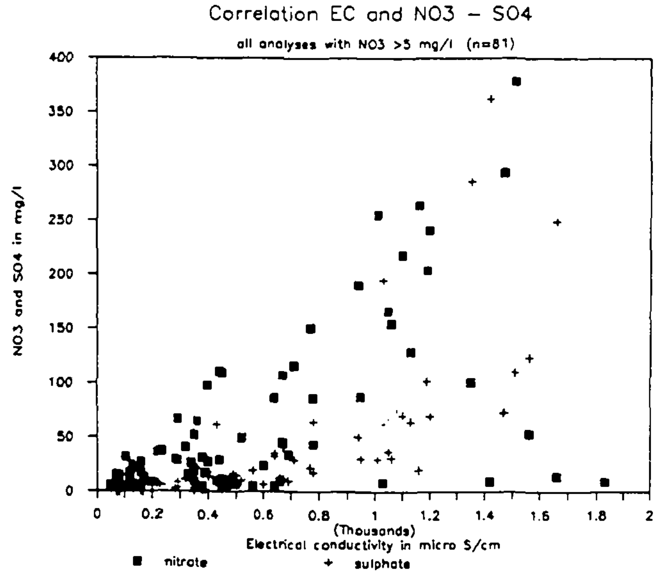


Fig. 6 Piper diagramms of water samples from crystalline rocks (right) and sedimentary rocks (left).

Fig. 7 Distribution on nitrate concentration in dug wells and boreholes.



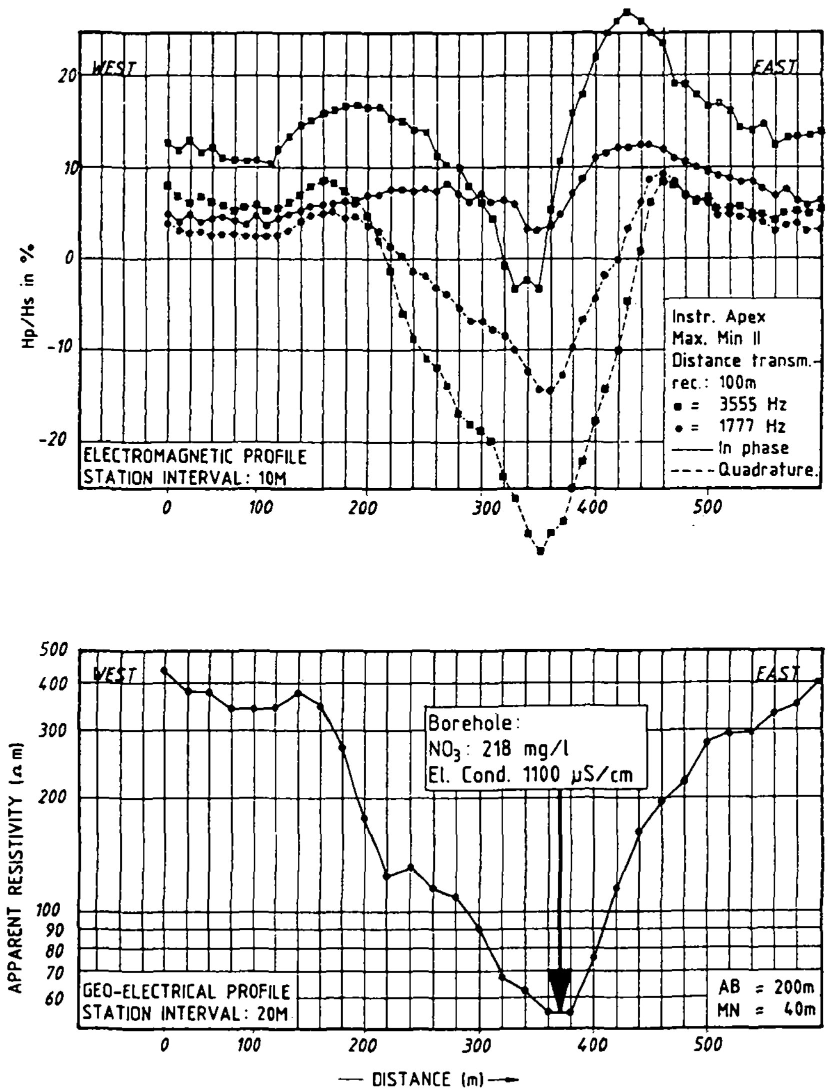


Fig. 8 Relation between electrical conductivities and nitrate and sulphate concentrations

Fig. 9 Geo-electrical and electro-magnetic profile over a village with groundwater pollution (Tougourou 3-7-84).

carried out elsewhere in Burkina Faso suggest recharge values in the order of 60 to 160 mm/year (Engalenc, 1979; BRGM/Aqater, 1986; Brussel, van *et al* 1988).

In the sedimentary aquifers groundwater table indicate a groundwater flow from the plateaux to the center of the plain in the north near the Mali border (Fig. 3.).

Along the borders of the plain direct infiltration of surface water is thought to be the dominating recharge process. Most of the intermittant rivers coming from the plateaus disappear on the plain. Several explanations have been proposed for the discharge process in the center of the plain, such as a non-stead groundwater flow situation, discharge through deep karstified strata and evapotranspiration (Archambault, 1986, Defossez, 1962, Palausi, 1958). An analytical groundwater model shows that a net evapotranspiration surplus for the observed piezometric pattern in the plain (IWACO, 1986).

HYDROCHEMISTRY

In total 177 chemical analyses, comprising all major anorgainic constituents, were carried out on water samples from boreholes in 159 different villages.

Dug wells were investigated during geological reconnaissance surveys; 123 colorimetric analyses were carried out to determine the nitrate content of the well water in 49 villages. The borehole samples were taken from both the sedimentary rocks and the crystalline basement rocks.

The electrical conductivities vary between 50 and 2700 µS/cm. with medians of 270 and 370 µS/cm for dug wells and boreholes respectively. For both the sedimentary and the crystalline rocks bicarbonate is the dominant anion for non-contaminated samples (Fig. 6.). The cation composition of water from both rock types is distinct: in sedimentary rocks Ca and Mg are dominant with a Mg/Ca ratio of about 0.4, while in crystalline rocks the molecular fractions of Ca, Mg and Na are about equal.

In 15% of the analyses of water from boreholes and in 36% of the dug well samples, nitrate concentrations were above the WHO limit of 45 mg/1. Figure 7 depicts the freqency distribution of nitrate concentrations both in boreholes and dug-wells.

A reasonable correlation between electrical conductivity and groundwater nitrate concentration is shown in Figure 8. This figure also shows that the conductivities about 1200 µS/cm are from boreholes in the shales where groundwater circulation is slow and solution of pyrite is taking place.

The routine geophysical measurements for borehole siting often indicated large conductive anomalies under villages, which could not be interpreted as structural or lithological features (Fig. 9.). The presence of conductive groundwater is a probable explanation and suggests the occurrence of large bodies of nitrate rich groundwater under the villages. The example of Fig. 9 shows a geoelectrical profile in a village 30 km west of Tougan on deeply weathered sandstone; the borehole in the center of the anomaly produces nitrate rich groundwater, which has an electrical conductivity 3 times as high as the average value in the region.

ORIGIN OF THE NITRATE CONTAMINATION

A geological origin of the nitrate present in the groundwater is considered unlikely since high nitrate contents occur in most of the identified lithologies (Table 1). An anthropogenetic source of the nitrates seems therefore more likely, a conclusion also made by Langenegger (1982) in Nigeria and Gould and Healy (1981) in Senegal. Gould and Healy attributed high nitrate to organic matter falling into the open wells.

In the Volta Noire region we believe there is a relationship with the type of village. A data review showed that high nitrate concentrations occur mostly in villages of the Marka, Samo and Bobo tribes (Table 2). Although the Mossi villages are not well represented in this region, other drilling programs and studies in the east, where Mossi tribes dominate, do not report the occurrence of high nitrate concentrations (Van der Sommen, 1984).

The 67% of dug wells sampled inside the village perimeter of the Marka, Samo and Bobo villages a nitrate concentration higher than 45 mg/1 was ovserved. This was the case in only 17% of dugwells sampled outside the perimeter. Dug wells in these villages consistently show higher nitrate concentrations than samples from boreholes. It was also observed that boreholes located downstream from the village with regard to the regional direction of ground water flow showed a higher incidence of nitrate contamination.

The main difference between villages of the Marka, Samo and Bobo on the one hand and those of the Mossi, Peulh and Gourounsi on the other is housing density. Villages of the first group are characterized by a close grouping of houses, devoid of any vegetation, with a village size of no more than a few hundred meters. The second group has more dispersed settlements, individual houses are mostly more than 100 m apart, resulting in village sizes, which often exceed 1000 m. Furthermore, sorghum and millet are grown seasonally on the fields between the houses.

In the concentrated villages the age-long dumping of organic waste is likely to have drastically

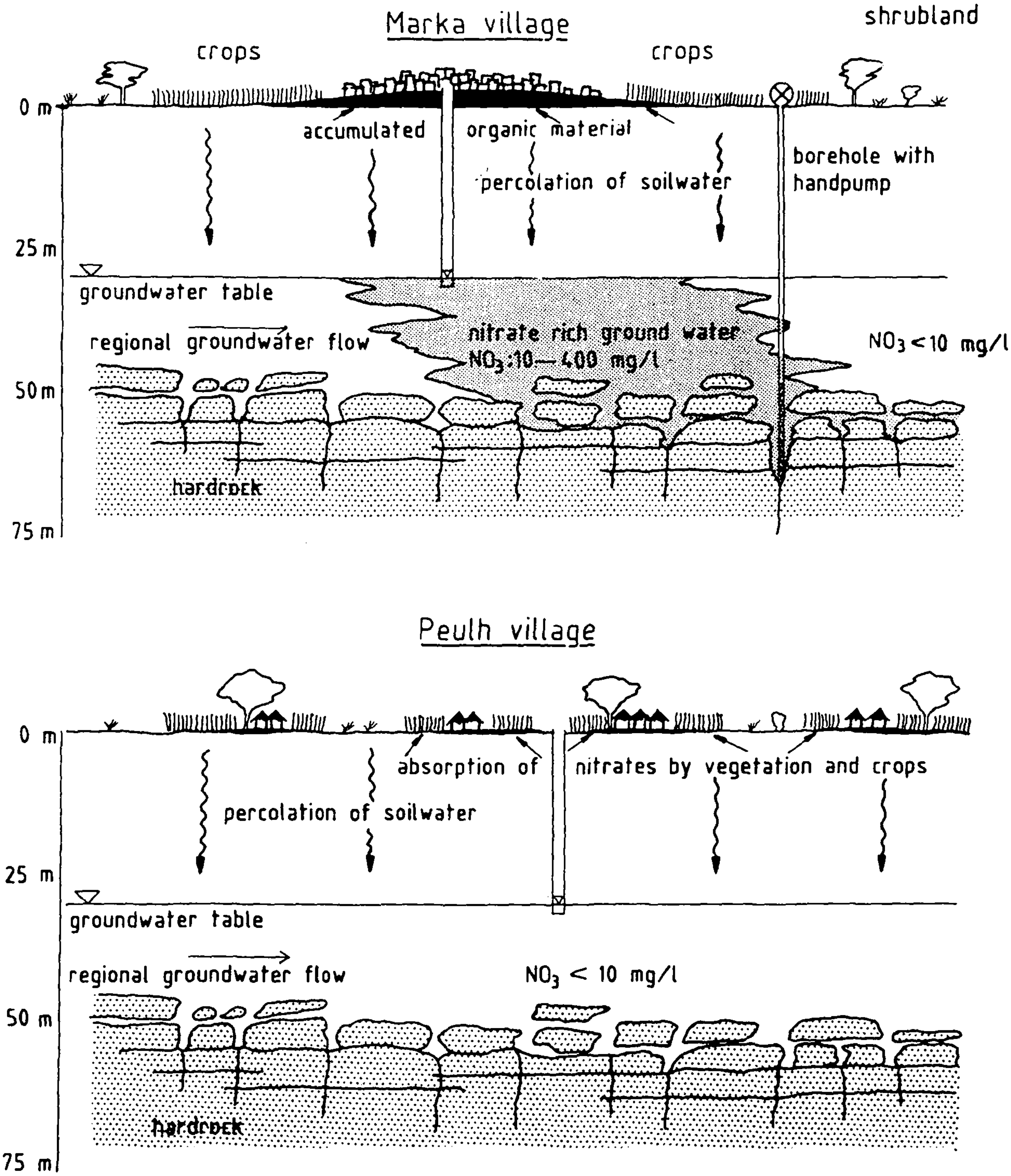


Fig. 10 Schematic hydrogeological sections of villages with and without a concentrated housing pattern.

	Nr. of analyses	Nitrate >45 mg/l	%
Granitic rocks	14	3	21
Basic and metam. rocks	21	2	10
Coarse sandstone	6	1	17
Fine grained sandstone	31	3	10
Clayey sandstone	23	0	0
Shales	5	1	20
Soliceous and dolom. sandst.	15	5	33
Wathering layer	63	13	21

Table 1: Nitrate rich groundwater in boreholes in different lithological units

	Dug wells			Boreholes		
Ethnic group	Nr. of villages	Nitrate >45 mg/l	%	Nr. of villages	Nitrate >45 mg/l	%
Marka	15	11	73	30	8	27
Bobo	21	13	62	44	7	16
Samo	1	0		57	12	21
Mossi	1	0		7	0	0
Peulh	11	1	9	21	1	5

Table 2: Nitrate rich groundwater in villages of different ethnic groups

enriched the subsoil with nitrogen compounds, which are slowly percolating towards the groundwater with the infiltrating rainwater. During this process, complete oxidation takes place, since ammonium concentrations are comparitively low (<2 mg/l). In 2 dug-wells and 1 borehole nitrate concentrations higher than 1 mg/l have been found.

It is interesting to note that Marka villages are often placed on somewhat elevated ground due to the build-up of refuse (Keyzer, 1986). Since dug wells penetrate the aquifer only a few meters under the phreatic water table, contamination is more pronounced than in drilled wells, which reach 10 to 30m below the water table. In the dispersed villages refuse is also dumped in the vicinity of the houses, but there it constitutes a more diffuse source of contamination. Moreover, the crops grown between the houses will largely take up the nitrate charge. Schematic hydrogeological sections of both village types are presented in Figure 10.

CONCLUSIONS

Nitrate contamination of groundwater in villages of certain ethnic groups with a high housing density is caused by a relatively concentrated disposal of refuse. This process has been taking place for ages and is not the result of some modern development. As water from drilled wells with screens set between 10 and 30 m below the water table also shows high nitrate levels, a large volume of polluted water must be present beneath a number of these villages.

It has been shown that lateral groundwater flow has displaced the zone of contamination beyond the village perimeter. This flow is a slow process and a decrease of nitrate in the waterpoints is not expected in the foreseeable future.

New boreholes in villages with concentrated housing should therefore be sited, with regard to the direction of groundwater flow, upstream from the village and at least 200m away from the village center. If the regional flow cannot be established, then routinely applied geophysical methods can be used to map the extent of the polluted water.

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REFERENCES

Archambault, J., 1986 - Réflexions sur l'alimentation et l'évaporation des nappes phréatiques en Afrique subsaharienne. Contribution au colloque international sur la révision des normes hydrogeologiques suite aux incidences de la sécheresse, Ouagadougou, Burkina Faso.

BRGM/Aquater, 1986. - La récharge naturelle des aquifères de socle sous climats Sahélien et Soudanien. BRGM, Orleans, France.

Brussel, J. van, Geirnaert, W., Simmers, I. and Sommen,J.J. van der, 1988. - An investigation of groundwater recharge mechanisms in Burkina Faso. Proc. of the Sahel Forum on the state of the art of hydrology and hydrogeology in the arid and semi-arid areas of Africa, Ouagadougou, Burkina Faso.

Défossez, M., 1962. - Contribution à l'étude géologique et hydrogéologique de la boucle de Niger. *Mémoire du Bureau de Récherches Géologiques et Minières* n° **13**.

De Jong, S.J. and A. Kikietta, 1980. Une particularité heureusement bien localisée; la présence d'arsenic en concentration toxique dans un village pres de Mogtedo (Haute Volta). *Bull. CIEH* n° **42-43.**

Engalenc, M., 1979. - Méthode d'étude et de récherche de l'eau souterraine des roches cristallines de l'Afrique de l'ouest. Volume 1 et 2. Comité Interafricain d'Etudes Hydrauliques (CIEH), Ouagadougou, Burkina Faso.

Fraser, P. and Chilvers, C., 1981. - Health aspects of nitrate in drinking water. *Science Total Environment*, Vol. **18**, pp. 103-116.

Fritsch, P. and De Saint Blanquart, G., 1985. - La pollution par les nitrates. *La Récherche* Vol. 16, n° **169**, pp. 1106-1115.

Gould, M.S. and M.J. Healey, 1981. - Nitrate in rural wells of the Senegal River basin. *Water Res. Bull.* Vol. 17, n°. **2**., pp. 244-247

Gould, M.S. and M.J. Healey, 1981. Nitrate in rural wells of the Senegal River Basin. *Water Res. Bull.* Vol. **17**, n° 2.

Hegesh, E. and Shiloah, J., 1982 - Blood nitrates and Methemoglobinemia. *Clinica Chimica Acta* Vol. **125**, pp. 107-115.

International Standing Committee on Water Quality and Treatment, 1974. - Nitrates in Water Supplies. *Aqua* Vol. **1**, pp. 5-24.

Iwaco, 1984. Etude du bilan d'eau au Burkina Faso. Rapport général de la phase préparatoire,. Tome III. Ministère de l'Eau. Ouagadougou.

Iwaco, 1986. Projet hydraulique villageoise Volta Noire. Programme des forages. Rapport final des travaux de forages, Ministère de l'Eau, Ouagadougou.

Jong, S.J. de and Kikietta, A., 1980. - Une particularité heureusement bien localisée; la présence d'arsenic en concentration toxique dans un village preès de Mogtedo (Haute Volta). *Bull. CIEH* **42**.

Keyzer, M. 1986. Etude hydrogéologique de l'origine de nitrate dans l'eau potable dans la région du projet Volta Noire, rapport préléminaire. Projet Volta Noire, Dedougou.

Kikietta, A., 1986. - Contribution a l'étude hydrogéologique des massifs granitiques et cristallins basiques en Afrique intertropicale: l'hydrogéologie du bassin versant de la Bougouriba (Haute Volta). Thèse, Institut National Polytechnique de Lorraine, France.

Langenegger, O. 1982. High nitrate concentrations in shallow aquifers in a rural area of central Nigeria, caused by random deposits of domestic refuse and excrement. *Proc.* Int. Sym. Noordwijkerhout, The Netherlands. *Studies in environmental science.* Vol. **17**. Elseviers. Publ. Comp.

Palausi, G., 1958. - Contribution à l'étude géologique et hydrogéologique des formations primaires au Soudan Méridional et en Haute Volta, Thèse, *Bulletin de Service de Géologie et de Prospection Minière*, n°**33**, Haute Commissariat Général à Dakar.

Schuchmann, J.B., 1986. Dorpwatervoorzienings project Volta Noire - Eindrapport projectphase 1 en 2, DGIS, Den Haag.

Sommen, J.J. van der, 1984. - Hydrochimie des eaux souterraines du socle cristallin en Haute-Volta. Institute of Earth Sciences, Free University, Amsterdam, The Netherlands.