GROUNDWATER QUALITY IN RURAL AREAS OF WESTERN AFRICA

O. Langenegger, Regional Project Officer
Regional Water and Sanitation Group
World Bank, 01 BP. 1850
Abidjan 01 - Cote d'Ivoire 1/

ABSTRACT

The physico-chemical composition of groundwater plays an important role not only because of its health impact but also in terms of user acceptance, and affects technical aspects, (e.g., corrosion), as well as industrial and agricultural applications.

This paper gives a general overview of groundwater quality with regard to its physico-chemical composition. The results originate mainly from the West African field trials of the World Bank-executed UNDP-INT/81/026 Handpumps Project 2/ comprising the following countries: Burkina Faso, Côte d'Ivoire, Ghana, Mali, and Niger, as well as from the 3000 Well Drilling Programme in Ghana (GWSC, IDC) and the Helvetas Project in Mali (Mathys, 1983).

Based on the water quality parameters taken into consideration in this paper and the WHO guideline values (WHO, 1984), the groundwater occurring in the Handpumps Project areas is, in general, of good quality with a low level of dissolved minerals, which is typical for non-carbonate rock formations which underlie much of the investigated areas. On the other hand, the predominance of "acidic" rocks is the major cause of aggressive groundwater. Organic wastes in and around the settlements are the single most important source of groundwater pollution in the rural environment.

INTRODUCTION

General

The main reasons for considering aspects of water quality during the first phase of the Handpumps Project (1981-1986) were to investigate the relationship between water quality and user acceptance, the problem of handpump corrosion, and groundwater pollution in the rural environment.

1/ The views and interpretations in this paper are those of the author and should not be attributed to the World Bank, the UNDP, their affiliated organizations, or any institution, enterprise, etc. referred to in the paper.

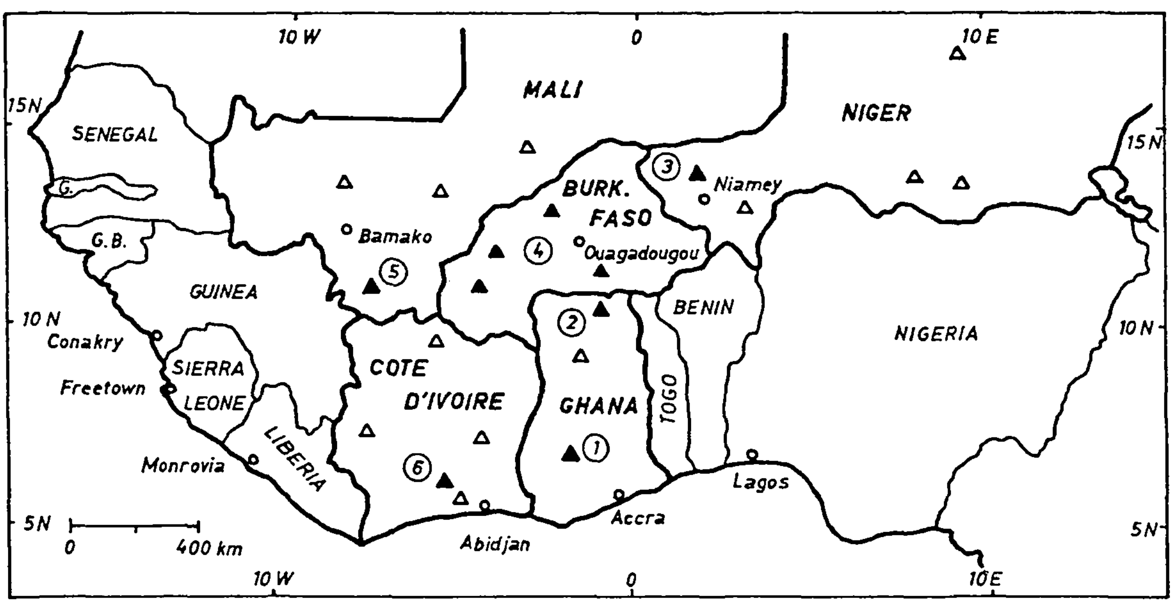
2/ World Bank executed UNDP-Project INT/81/026 - Laboratory and Field Testing and Technological Development of Community Water Supply Handpumps

The purpose of this paper is therefore to present the results of groundwater quality testing and monitoring within the Handpumps Project in West Africa. Since the Handpumps Project in West Africa was spread over a large area (see Figure 1), the presented results give a general overview of the water quality situation in the West African Sub-region, and may be useful for rural water supply project planning and implementation, as well as for resolving water quality problems.

The project area

The geographical situation of the Handpumps Project areas is shown in Figure 1. It stretches from the coast of the Atlantic (Gulf of Guinea), with an average yearly rainfall of up to 2300 mm to the Sahelian zone, with a yearly precipitation of less than 700 mm. The mean annual air temperatures are around 26 °C in the south along the coast and 30 °C in the north.

The landscape is relatively monotonous, mainly consisting of flat to undulating plains with plateaus, and some hilly to mountainous zones. The vegetation changes gradually from the forest belt in the south through the savanna to the steppe (Sahelian Zone) in the north.



▲ Field trial areas   △ Other areas considered in this paper

Figure 1. Map of the Handpumps Project in West Africa (project areas).

The underlying rock in the project areas south of 18° northern latitude is composed of an average of about 23% igneous rocks (granite, migmatite, etc.), 14% metamorphic rocks (phyllite, schist, gneiss, etc.), and 63% of sedimentary rocks (sandstone, sand, alluvials, etc.). Table 1 lists details on the geology (cartes geologiques).

The majority of the water samples considered in this paper originate from drilled wells equipped with handpumps. The average depths of the wells in the different field trials are between 30 and 55 m with mean static water levels in the range of 8 to 40 m, and yields usually between 0.5 and 10 m3/h. The main aquifers tapped by such wells are the weathered and fractured zones of the various rock formations.

Table 1: Percentages of igneous, metamorphic, and sedimentary rocks.

Rock Type	Burkina Faso (%)	Côte d' Ivoire (%)	Ghana (%)	Mali (%)	Niger (%)	Total (%)
Igneous	60.0	62.1	22.0	10.9	4.4	23.4
Metamorphic	21.9	34.9	36.5	6.5	0.9	13.9
Sedimentary	18.1	3.0	41.5	82.6	94.7	62.7

RESULTS

Physical parameters

Temperature

The mean annual groundwater temperatures in the project areas are between 25 and 30 °C, which corresponds with the mean annual air temperatures. The mean seasonal variations are in the range of 0.5 to 1.5 °C.

pH

The pH range measured in the project areas is 4.5 to 8.5, with an average of about 6.5 (Figure 2). Out of more than 800 samples 76% showed a pH of less than 7, and 45% were below 6.5. The pH is the only parameter considered in this paper which largely deviates from WHO guideline values (6.5 to 8.5).

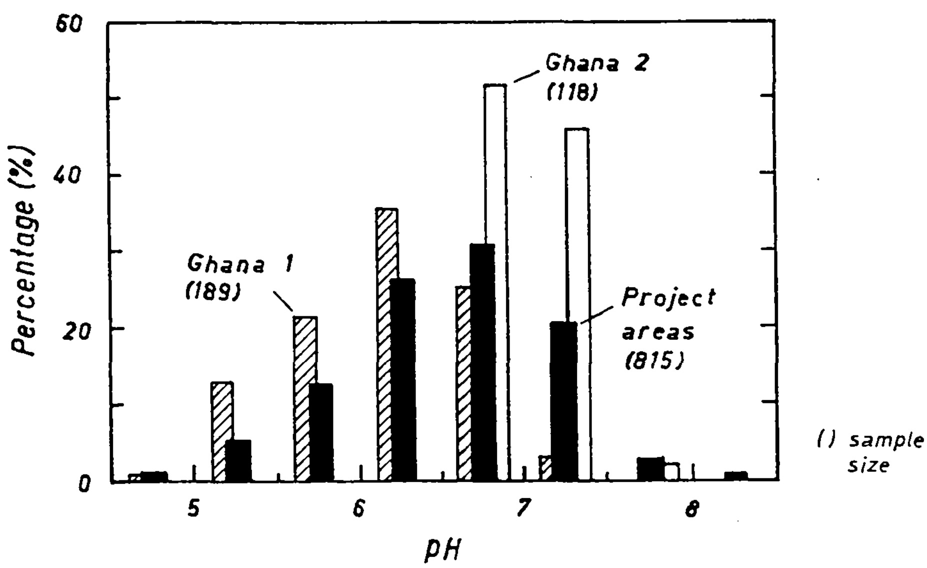


Figure 2. Frequency distribution of pH. 1/

Electrical conductivity

The electrical conductivity (EC) range measured in the investigated areas is between 20 and 3000 µS/cm. However, approximately 90% of the water samples considered showed an EC of less than 500 µS/cm, and about 98% less than 1000 µS/cm (see Figure 3).

1/ The figures in parentheses indicate the sample size. The project areas comprise field trials plus other areas as indicated in Figure 1.

With regard to rural water supply, the importance of the EC is its measure of salinity, which greatly affects the taste, and thus has a significant impact on user acceptance. The single most important class of consumer complaints with regard to water supplies are related to taste and odor problems (Mallevialle and Suffet, 1987). This statement is true not only for the developed countries, but also for rural areas in developing countries.
In the forest areas, where surface water is usually available within short distances from most villages, water with an EC of 300 to 500 µS/cm is already considered salty. The threshold of salinity in taste in the savanna and steppe, where people depend much more on the more mineralized groundwater than in the wetter forest zones, is in the proximity of 1000 µS/cm.

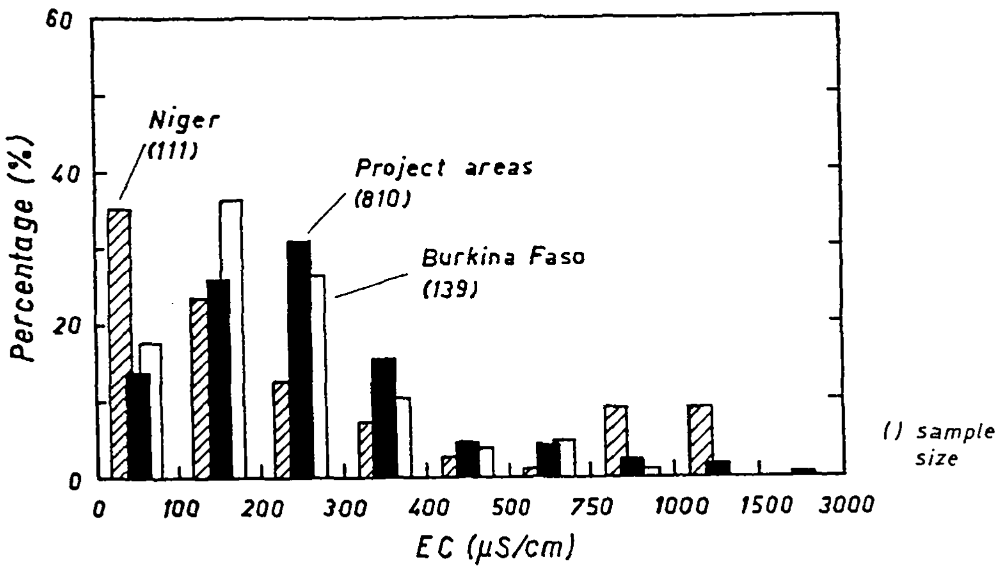


Figure 3. Frequency distribution of EC.

WHO has set a guideline value for TDS at 1000 mg/l, which is about equal to an EC of 1400 µS/cm. This value is based on taste considerations.

Turbidity

The turbidity of water is caused by suspended material and is an excellent indicator of water quality, particularly with regard to well pollution. Turbidity does not necessarily have a direct effect on health. However, from the aesthetic point of view, turbid water is badly accepted by consumers. According to WHO, the threshold at which turbidity of water may be detected by the naked eye is 5 NTU (nephelometric turbidity units). The WHO guideline value for turbidity is 5 NTU, but preferably less than 1 NTU, when the water is disinfected. Groundwater in the investigated areas usually has turbidity levels below 1 NTU. Typical ranges of measured turbidities in the project areas are presented in Table 2.

Table 2: Typical turbidity ranges in NTU of different types of wells.

Type of Well	Turbidity Range (NTU)
Drilled wells with handpumps	0.2 - 1
Drilled wells with corrosion affected handpumps	1 - 100
Open dug wells with apron	1 - 10

Chemical parameters

Iron, manganese

Iron (Fe) and manganese (Mn) generally only occur in small concentrations in groundwater in the investigated areas. The levels of total iron (ferrous plus ferric) measured under natural conditions are usually less than 1 mg/l and those of manganese below 0.3 mg/l. The results of iron and manganese measurements in the project areas are shown in Figure 4. The samples considered originate from wells with corrosion-resistant handpumps.

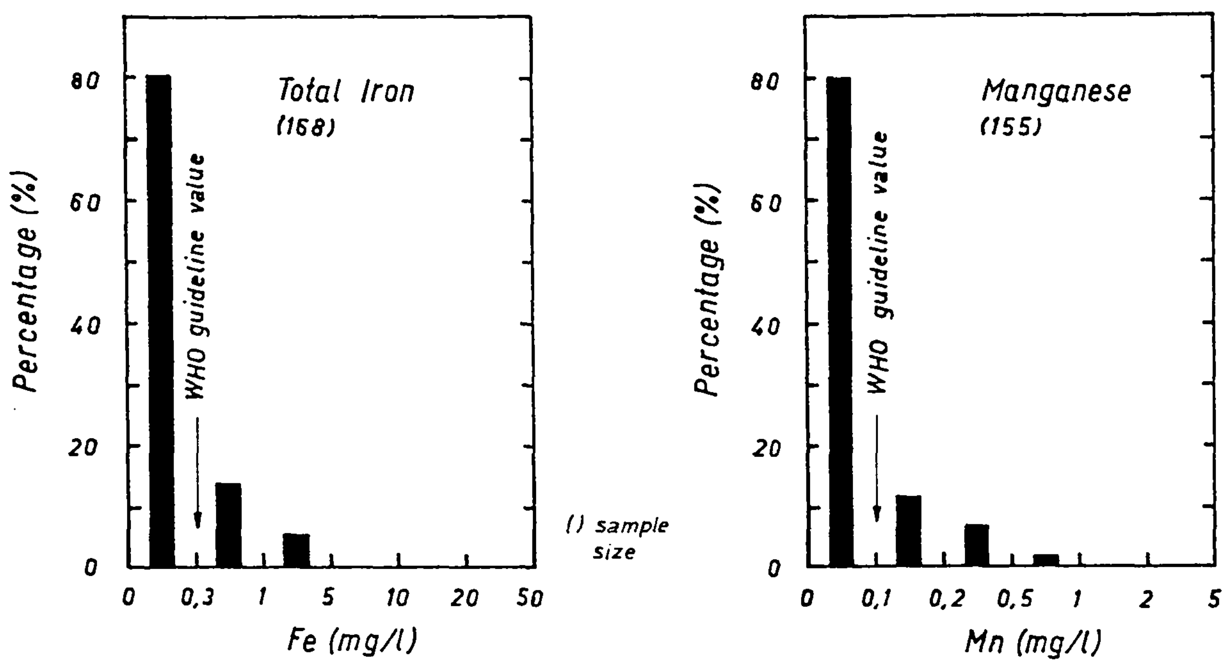


Figure 4. Frequency distribution of total iron (Fe) and manganese (Mn) in the project areas.

The WHO guideline values for iron and manganese are 0.3 mg/l and 0.1 mg/l respectively. These values are based on aesthetic and organoleptic considerations and not on health hazards.

High iron concentrations of groundwater from wells with handpumps are very common all over the investigated areas. Many villagers know the problem of red water early in the morning when they start pumping water after the pump has not been used for a couple of hours, for example at night. This particular problem is due to handpump corrosion (Langenegger, 1987).

Oxygen, carbon dioxide

The range of oxygen concentrations in groundwater from handpump-equipped wells in the project areas is generally between 0.7 and 4.5 mg/l in oxidizing milieus, which corresponds to oxygen saturations of about 10% and 60%. The oxidizing environment is predominant, but wells with handpumps which are heavily affected by corrosion and very little used, reducing milieus, that is with no or only very little dissolved oxygen, are quite common. Field observations suggest that the oxygen content of water from large-diameter (dug) wells is higher than from boreholes. The reason for this is obviously the effect of aeration through the contact with the air.

The average free carbon dioxide (CO_2) concentration measured in the savanna was about 70 mg/l and in the forest area around 120 mg/l. The difference in free carbon dioxide concentrations between the groundwater in the north (savanna, steppe) and the south (forest) of the investigated areas obviously results from the different environmental conditions in the two zones, mainly in terms of vegetation and climate.

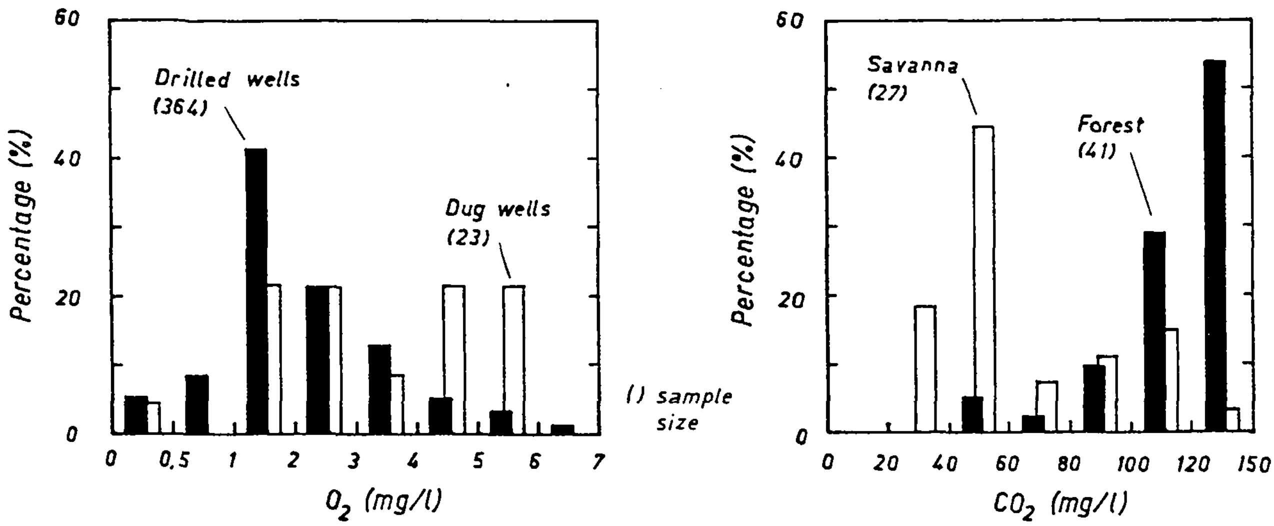


Figure 5. Frequency distribution of dissolved oxygen (O_2) and free carbon dioxide (CO_2) of water from wells with handpumps in the project areas.

Ammonium, nitrite, nitrate

Ammonium (NH4), nitrite (NO2), and nitrate (NO3) are considered to be classic indicators of pollution by organic matter. Nitrate, however, is only valid as a pollution indicator under oxidizing conditions. In other words, where no or very little oxygen is available in groundwater, nitrate is decomposed through denitrification.

Ammonium and nitrite are generally only found in concentrations of less than 0.1 mg/l and 0.01 mg/l respectively in groundwater in the project areas. There are, however, two exceptions. First of all, excessive levels of these two constituents are contained in groundwater from wells equipped with corrosion-affected handpumps. Ammonium is predominant under reducing conditions, where as much as 1 mg/l were measured, while nitrite prevails under oxidizing conditions, with observed levels as high as 0.5 mg/l. Secondly, high concentrations of ammonium and nitrite are common where well or groundwater pollution occurs.

The WHO guideline value for nitrate is 10 mg/l nitrogen (N), which corresponds to 45 mg/l nitrate (NO_3). The reasons for setting this guideline value are that excessive levels of nitrate can cause methaemoglobinaemia in bottle-fed infants (blue babies) and that certain forms of cancer might result from very high nitrate concentrations (WHO, 1984). The percentage of wells in the project areas with nitrate concentrations exceeding the 45 mg/l WHO guideline value is about 15%. However, there are remarkable variations between different areas (see Figure 6).

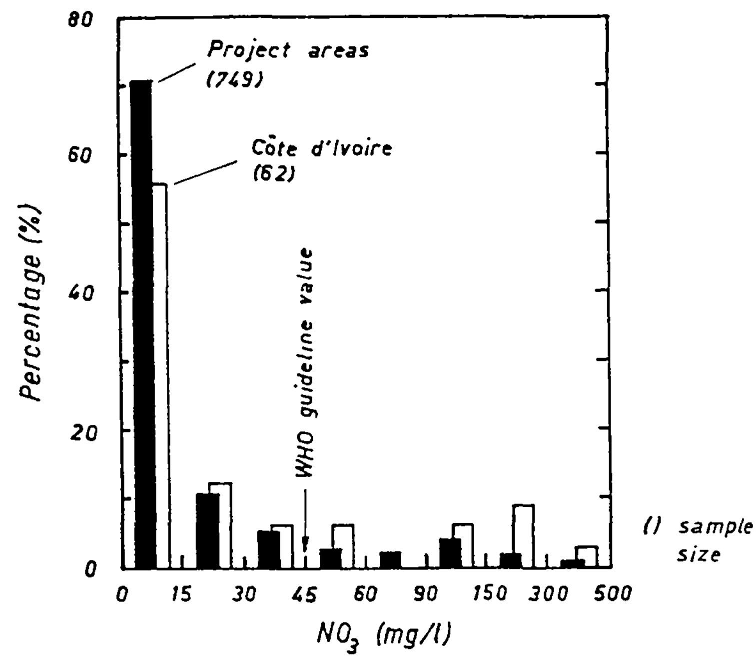


Figure 6. Frequency distribution of nitrate (NO3).

Other parameters

In addition to the parameters described and presented in the preceding pages, the components shown in Table 3 were also part of the water quality investigations within the Handpumps Project. The relationship between some rock types, the pH, and the EC, based on data from the 3000 Well Drilling Programme, is shown in Figure 7 (GWSG, IDC).

Groundwater from the deep aquifers, that is, from the weathered and fractured bedrock, showed little seasonal fluctuations in physico-chemical composition. However, great variations in water quality, even during short pump- operating times, were observed in situations where groundwater from different aquifers was tapped.

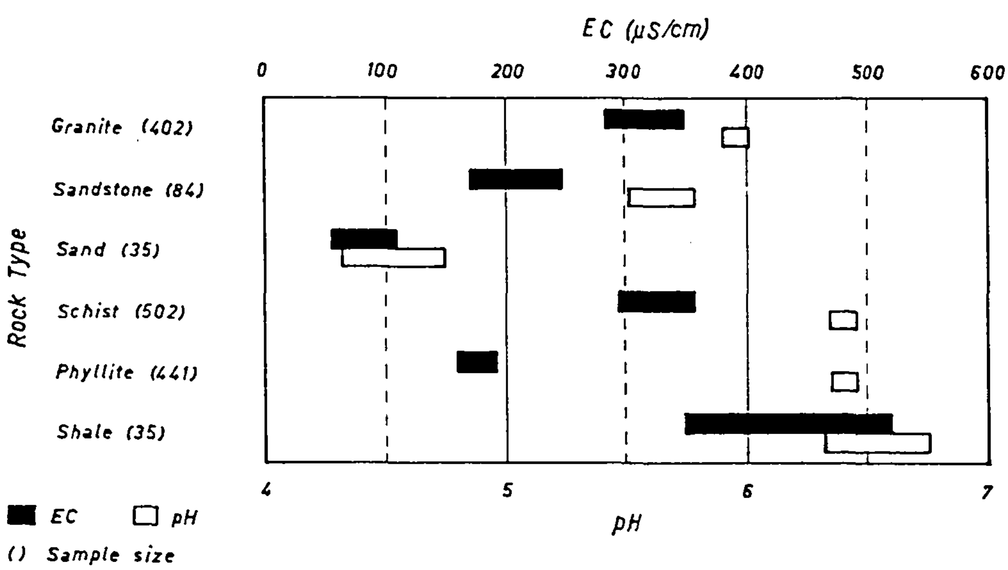


Figure 7. Relationship between rock type, pH, and EC
(95% confidence intervals of mean values).

Table 3: Mean values of investigated constituents in the project areas (field trials & other areas, see Figure 1).

Constituents	WHO a.	Burkina Faso	Côte d'Ivoire	Ghana 1	Ghana 2	Mali	Niger
Temp. (°C)	-	30.4 (231)	27.1 (43)	25.4 (139)	31.0 (157)	29.6 (219) d.	28.7 (40)
pH	6.5-8.5	6.5 (137)	6.2 (58)	6.1 (195)	6.9 (120)	6.7 (219) d.	6.4 (122)
EC (µS/cm)	1400 b.	225 (137)	429 (58)	252 (245)	354 (118)	233 (235)	334 (127)
TH (mg/l) c.	500	105 (40)	120 (52)	55.4 (56)	145 (29)	60.0 (23)	69.3 (63)
Ca (mg/l) c.	-	68.5 (32)	79.9 (52)	35.7 (53)	86.4 (29)	34.3 (23)	40.5 (63)
A (mg/l) c.	-	112 (40)	96.1 (56)	64.2 (53)	157 (29)	73.6 (22)	96.8 (42)
Na (mg/l)	200	-	36.5 (23)	14.1 (6)	23.4 (5)	17.6 (181) d.	13.3 (34)
K (mg/l)	-	3.1 (16)	7.0 (52)	5.5 (31)	4.4 (37)	6.1 (23)	2.7 (53)
Cl (mg/l)	250	2.1 (32)	37.9 (48)	10.9 (26)	44.5 (29)	5.5 (23)	13.5 (45)
SO_4 (mg/l)	400	3.0 (11)	11.5 (51)	4.6 (26)	15.1 (29)	8.4 (23)	30.9 (31)
SiO_2 (mg/l	-	45.5 (19)	56.5 (51)	51.9 (31)	59.0 (37)	44.9 (23)	43.1 (25)
NO_3 (mg/l)	45	17.9 (39)	42.4 (57)	12.3 (130)	17.3 (33)	10.9 (22)	33.0 (39)
O_2 (mg/l)	-	3.1 (15)	2.6 (34)	0.9 (169)	1.5 (68)	2.4 (8)	2.4 (31)
CO_2 (mg/l)	-	67.0 (2)	118 (27)	121 (15)	67.3 (7)	84.5 (7)	40.4 (10)

Legend:
- a. WHO guideline values (WHO, 1984)
- b. Derived from TDS guideline value set at 1000 mg/l
- c. mg/l as $CaCo_3$
- d. Including values from the Helvetas Project (Mathys, 1983)
- ( ) Values in parentheses indicate the sample size
- A Total alkalinity
- EC Electrical conductivity
- TH Total hardness

Groundwater and well pollution

The main causes of groundwater pollution observed in the rural environment are: (1) organic wastes (domestic refuse and excrements), (2) livestock concentrations around water points, and (3) dirtiness and inadequate drainage of water points. Furthermore, indications of the effect of the application of fertilizers and pesticides on the groundwater quality have been detected, for example in the field trial areas in the Côte d'Ivoire and in northern Ghana (Akiti, 1982).

The single most important groundwater pollution observed within the Handpumps Project areas is from organic wastes and excrements of settlements. An example of such a situation is shown in Figure 8. It compares the quality of groundwater from shallow dug wells with water levels between 3 to 6 meters in Bolgatanga, a regional town in northern Ghana, and from handpump-equipped shallow drilled wells with static water levels between 1 to 20 meters in the field trial Ghana 2 near Bolgatanga representing a rural area with a negligible degree of groundwater pollution. The hydrogeological situation is basically the same in both areas, that is, the groundwater tapped by both wells is from the same type of shallow aquifer.

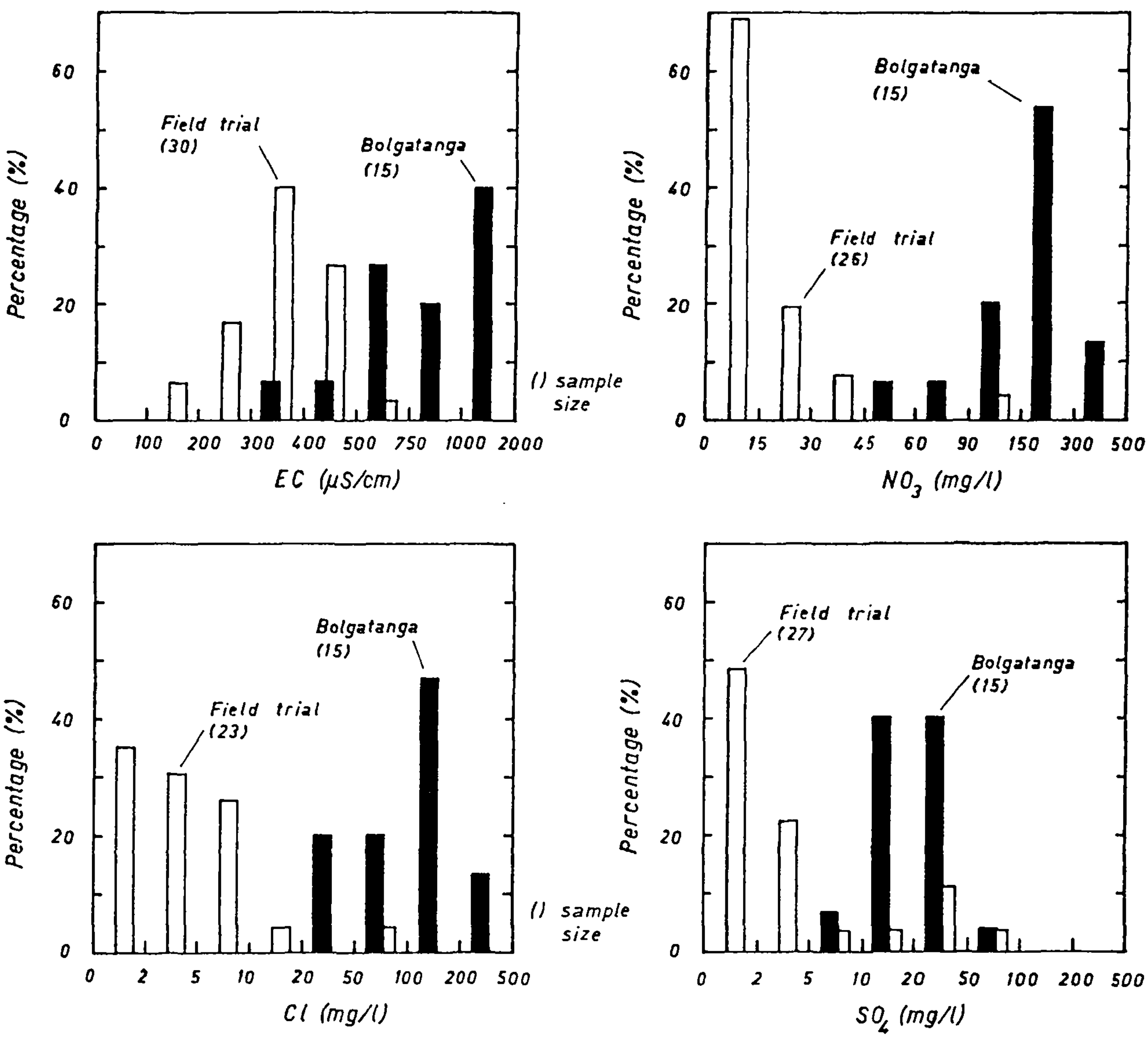


Figure 8. Comparison of the quality of shallow groundwater in Bolgatanga and its nearby rural area.

High nitrate concentrations in groundwater in and around settlements, as well as a relationship between the nitrate level and the density and size of settlements has also been reported by Groen and Schuchmann, and by Langenegger (1981) respectively.

Bolgatanga has a town water supply. But, as indicated above, there also exist quite a number of public and private dug wells, which are concrete lined and even partially covered, and which are used by parts of the population for domestic applications and, in certain cases, also for drinking. The purpose of presenting the Bolgatanga case, which is typical for large settlements, is to illustrate the high degree of physico-chemical pollution of shallow groundwater in this particular environment by means of some classic pollution indicators (nitrate, chloride, sulfate), and to indicate that this kind of groundwater pollution is not limited to dug wells. The latter point is supported by the fact that a handpump-equipped drilled well in the investigated Bolgatanga area showed a similar degree of pollution as the dug wells with nitrate and chloride concentrations of 140 mg/l and 190 mg/l respectively, and an electrical conductivity of 1250 µS/cm.

As to well pollution, the major categories observed are: (1) inadequate well construction or defective wells, (2) poorly installed or defective handpumps, and (3) inadequately designed handpumps and handpump corrosion.

REFERENCES

Akiti, T.T. (1982). Nitrate levels in some granitic aquifers from Ghana. International Symposium IAH, Impact of Agricultural Activities on Groundwater, Prague.

Carte Géologique de la Côte d'Ivoire, 1:1.000.000. Direction des Mines et de la Géologie du Gouvernement de la Côte d'Ivoire, Abidjan (1965).

Géological Map of Ghana, 1:2.000.000. Survey of Ghana, Accra (1969).

Carte Géologique de la République Haute-Volta, 1:1.000.000. Direction de la Géologie et des Mines (1976).

Carte Géologique de la République du Mali, 1:1.500.000. Direction nationale de la géologie et des mines (1980).

Carte Géologique de la République du Niger, 1:2.000.000. Bureau de Recherches Géologiques et Minières (1966).

Ghana Water and Sewerage Corporation (GWSC), International Drilling Consultants (IDC). 3000 Drilling Programme in Southern and Central Ghana. Final Report, Accra.

Groen K. and Schuchmann J.B. Nitrate Pollution of Groundwater in Villages in Northwestern Burkina Faso.

Langenegger, O. (1981). High Nitrate Concentrations in Shallow Aquifers in a Rural Area of Central Nigeria caused by Random Deposits of Domestic Refuse and Excrement. Quality of Groundwater. Studies in Environmental Science. Volume 17, Elsevier Scientific Publishing Company.

Langenegger, O. (1987). Groundwater Quality - An Important Factor for Selecting Handpumps.

Mallevialle, I. and Suffet, O.H. (1987). Identification and Treatment of Tastes and Odors in Drinking Water. American Water Works Association Research Foundation, Lyonnaise des Eaux, Denver.

Mathys, A. (1983). Analyses physico-chimiques des eaux souterraines des cercles de Bougouni, Yanfolia et Kolondieba (République du Mali), résultats et commentaires. Projet de Forages Hydrauliques Zone Mali-Sud, Helvetas/DNHE, Bougouni (Mali).

World Health Organization (1984). Guidelines for Drinking-Water Quality, Vol. 1, Recommendations, WHO, Geneva.