Some physico-chemical properties of water from hand-dug wells in the basement complex of south-western Nigeria

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ABSTRACT

Analysis of physico-chemical properties of water from hand-dug wells in south-western Nigeria was carried out in three different geological environments between November and February 1997/98. The laboratory investigation revealed that 100% of the water samples are acceptable for drinking using World Health Organization (WHO) guidelines. The quality of the water samples meets the recommended limits of the American Water Works Association (AWWA) for industrial uses and US Department of Agriculture for irrigation purposes. There is very little or no pollution in groundwater as a result of human activities. The possible future sources of contamination are discussed. Recommendations are made for protection against the speculated and potential pollution by emphasizing the use of low cost technology based on local materials and the financial resources of the people.

Key words | basement complex, hand-dug wells, physico-chemical properties, water

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INTRODUCTION

Hand-dug wells are wells that terminate at minimal depth (within the vadose layer), because digging deep into aquifers may be difficult due to the low level of technology, and the digger may be at risk of drowning. The digging of the well is usually done with simple implements such as hoes, diggers, shovels, spades and cutlasses. This type of well is usually found in weathered zones, joints, cracks and veins of non-homogeneity of crystalline rocks. The wells may be lined with bricks or thin cement, and may be covered with iron or wooden slabs, though some are unlined and unprotected. Water is taken from the wells by a bucket and rope-pulley system.

These wells have been exploited for human and economic activities since the earliest time, but little attention has been paid to quality analysis in relation to the nature of the well water, its occurrence and importance in the groundwater system.

In Nigeria, particularly in the study area, the importance of well water is increasing because the quality of surface water has decreased in recent times. The reasons for this are environmental degradation as a result of effluent discharge from industrial and domestic activities, heavily fertilized agricultural land, and urbanization. Water companies cannot afford the cost of water treatment to ensure a supply of safe water. The increase in demand for water is due to improved socio-economic conditions of the people. Little capital is required for well construction in comparison with dams, and wells in this area are relatively free from suspended solids. Hence little or no treatment is needed for potable and other water uses.

Some examples of groundwater quality investigations include: analysis for acceptable use (Everett 1980); spatial and vertical variation in quality (Canter *et al*. 1970; Foster *et al*. 1986; Geake *et al*. 1986); risk assessment (Foster & Hirata 1988; Guerra de Macedo 1993) and sampling and monitoring (Mossion 1983; Foster & Gomes 1989). In Nigeria hydrogeological literature concerning water quality is scarce, although there are notable exceptions, such as Iwugo (1986) Osibanjo (1979), and Owolabi &

Adegoke-Anthony (1983). From the audit of the literature, extensive studies have been carried out in developed countries, and but little in developing countries, and therefore a worldwide investigation is desirable since the conditions of the two geographical regions need not be related. Also, shortage of equipment and necessary capital inhibit research in this part of the world. Therefore this paper will be an advancement in the understanding of physico-chemical properties of wells in the basement complex which have not been given deserved attention elsewhere.

This study has the following objectives:

1. To augment the water resources in this area by investigating groundwater quality of water from hand-dug wells as a preliminary study for bore-hole drilling.
2. To determine the suitability of the water for drinking, economic and agricultural purposes.
3. To suggest possible ways of improving and protecting hand-dug wells.

This study will be particularly useful by providing better information to hydrologists, hydrogeologists and water engineers from developed countries who are mainly used as experts in Nigeria.

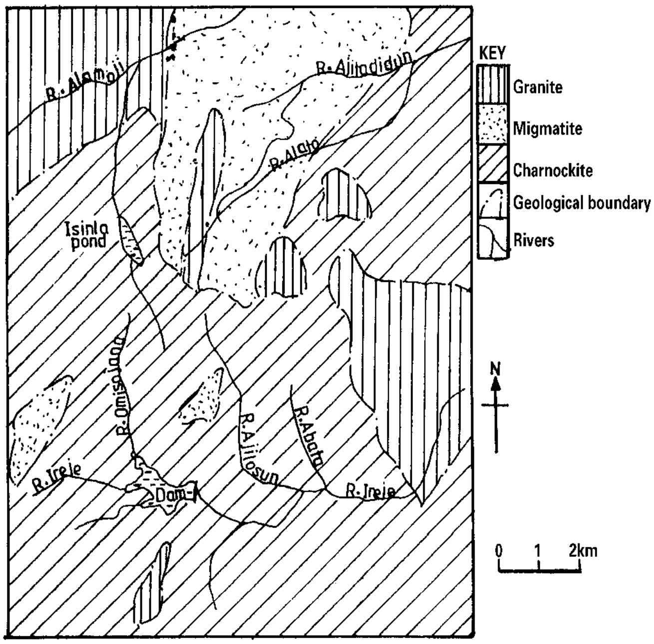

Figure 1 | Geological map of Ado Ekiti, south-western Nigeria.

THE STUDY AREA

Ado-Ekiti (Long. 5°12′ E, Lat. 7°38′ N), is the capital of Ekiti State. It has an estimated population of about 400,000 people with many small-scale industries, a Polytechnic and a University. A geological map of the area is shown in Figure 1.

The study area is underlain by coarse porphyritic older granite of Nigeria's basement complex rocks, which has experienced weathering due to the humid climate. There are other rocks like migmatite, and charnockites. The geological sequence shows increasing age from granite through migmatite to charnockites. The granite belongs to older granites of the basement complex of south-western Nigeria. It consists of fine-grained biotite, a medium to coarse-grained non-porphyritic hornblende. Migmatite is formed under regional metamorphism. It is very extensive and covers the northern part of the area. Charnockites in the study area are oval in shape. In many places they are smooth, rounded and in the form of isolated hills.

The dominant structural feature is foliation, as a result of metamorphism. There are lineations that produce major and minor faults. Lithologies are disaggregated crystalline rocks causing secondary porosity. Groundwater occurs within fissures and inter-granular spaces. The rocks contain an appreciable amount of quartz and aluminium-silicate minerals such as feldspar and micas. These minerals are unstable and tend to dissolve when in contact with water. Weathering produces profiles with secondary features such as fractures, fault and joints, with a depth range between 2 and 15 m.

METHODOLOGY

Samples of water were collected in 2.5 l plastic bottles sealed with cellophane paper. Four samples were collected in each of the three geological environments namely: granite, migmatite and charnockites. The wells were randomly selected because of similar terrain and water sources in the study area.

Cations and anions were determined in each of the samples. The physical parameters measured were conductivity, temperature, pH and depth of the wells. The tritrimetric method was used in the laboratory analysis of magnesium, calcium, sulphate, nitrate, bicarbonate and chloride. A flame photometer was used for sodium and potassium, and an atomic spectroscopic method was used for total iron. An Extech digital conductivity meter was used to measure the temperature and electrical conductivity. pH values were determined as a qualitative expression for acidity and alkalinity of water measured with a Philip Haris pH meter. Depths of wells were measured with a tape meter. The samples were collected from November 1997 to February 1998 during the dry season to avoid interruption by rain.

The author is aware of other water quality parameters that can be determined from physical, biological and radio-nuclides of groundwater, but low technology and lack of chemicals makes this impossible. Water quality variables like colour, turbidity, odour and taste were observed. It was found that the wells were free of sediments or suspended solids.

DATA ANALYSIS AND RESULTS

For ease of explanation the parameters were analysed using some descriptive statistics (Table 1).

Electrical conductivity

The mean value of electrical conductivity varies from 4.24 μs/cm to 19.80 μs/cm. Charnockites have the highest value of 19.80 μs/cm. The coefficient of variation is very low for granite (22.3%) but very high for migmatite (107.16%). The high electrical conductivity of charnockites indicates a higher concentration of dissolved constituents than other rocks. The salt concentrations for all the samples are generally low. A high coefficient of variation in migmatite is an indication of a heterogeneous environment.

Temperature

Variations are very small. The temperature ranges from a low value of 25.68°C in migmatite to 26.40°C in charnockite, while granite has a medium value of 25.8°C. The coefficient of variation is very low and ranges from 0.98% in charnockite to 1.90% migmatite with 1.40% for granite. The reason for the low temperature variation is because the wells are shallow (4.60 to 7.63 m deep), and it is a reflection of constant surface air temperature.

pH

The mean pH value ranged from 7.34 for charnockite to 7.68 for granite and 8.15 for migmatite. The coefficient of variation is very low in all the geological environments: 2.29% for granites, 3.00% for charnockite, and 4.50% for migmatite. This implies the pH is close to neutrality. The high value for migmatite may be as a result of sodium carbonate and bicarbonate in the migmatic environment.

Calcium

The mean value ranges from 26.93 mg/l for charnockite to 49.05 mg/l for granite, while migmatite has a value of 37.75mg/l. The coefficient of variation is low for charnockite at 30.01%, high for granite at 64.83%, and higher still for migmatite at 76.80%.

Sodium

The mean value ranges from 85.00 mg/l for charnockite to 141.00 mg/l for granite and 247.50 mg/l for migmatite, which is the highest. The coefficients of variation for all the samples are very high at 112.20%, 138.53% and 169.84% for migmatite, charnockite and granite respectively.

Table 1 | Descriptive statistics of parameters determined from rock type

Rock type	EC µs/cm	Temp. (°C)	pH	Depth (m)	Calcium (mg/l)	Magnesium (mg/l)	Sodium (mg/l)	Potassium (mg/l)	Iron (mg/l)	Hydrogen carbonate (mg/l)	Sulphate (mg/l)	Chloride (mg/l)	Nitrate (mg/l)
Charnokites	25.40	26.20	7.60	9.00	40.00	8.16	250	53	0.09	114	25.00	60	0.40
	12.30	26.40	7.45	8.70	36.70	5.23	30	56	0.06	80	11.50	18	0.38
	25.40	26.70	7.10	4.20	18.40	6.18	17	40	0.08	40	3.00	7	0.11
	16.12	26.30	7.20	8.60	12.60	5.88	43	45	0.03	30	5.50	8	0.20
Mean	19.80	26.40	7.34	7.63	36.93	6.36	85	48.50	0.07	66.00	11.25	23.25	0.27
Standard deviation	6.65	0.26	0.22	2.29	13.47	1.26	110.51	7.33	0.03	38.61	9.84	25.00	0.14
Coefficient of variation	33.57	0.98	3.00	30.01	50.19	19.81	138.53	15.11	42.86	58.50	86.40	107.53	51.90
Granite	3.40	25.70	7.80	5.10	85.60	22.08	500.00	215.00	0.25	300.00	80.00	112.00	0.84
	5.16	26.30	7.85	2.90	40.40	1.40	30.00	11.40	0.06	200.00	15.00	10.20	0.96
	3.20	25.70	7.60	5.00	10.20	0.34	24.00	7.00	0.04	125.00	5.00	15.10	0.80
	4.20	25.50	7.45	9.80	6.00	1.40	10.00	3.00	0.02	20.00	4.00	11.30	0.48
Mean	4.00	25.80	7.68	5.70	49.05	6.31	141.00	59.10	0.09	161.25	26.00	37.15	0.77
Standard deviation	0.90	0.35	0.19	2.92	31.85	10.53	239.48	104.00	0.11	118.35	34.67	49.93	0.62
Coefficient of variation	22.30	1.40	2.29	51.23	64.83	167.96	169.80	176.00	122.20	73.40	133.38	134.42	80.52
Migmatite	4.80	25.80	7.80	4.30	12.40	5.32	36.00	6.00	0.12	68.00	7.00	24.00	0.18
	3.60	25.50	8.10	2.10	15.50	3.76	24.00	3.00	0.18	41.00	7.80	21.20	0.20
	18.00	26.00	8.20	8.40	72.40	25.85	610.00	227.00	0.16	290.00	80.00	120.00	1.20
	1.50	25.40	8.50	3.60	50.70	33.40	320.00	61.00	0.14	220.00	35.00	68.10	0.95
Mean	6.98	25.68	0.15	4.60	37.75	17.08	247.50	74.45	0.15	154.75	32.45	58.33	0.63
Standard deviation	7.48	0.28	0.29	2.69	29.00	14.68	227.70	105.08	0.03	119.69	34.27	46.39	0.52
Coefficient of variation	107.16	1.90	4.52	58.80	76.80	85.99	122.20	142.00	13.33	77.43	112.57	79.83	82.71

Potassium

The mean value ranges from 48.50 mg/l for charnockites to 59.10 mg/l for granite and 74.45 mg/l for migmatite. The coefficient of variation is very low for charnockite at 15.11%, and very high for migmatite and granite with values of 142.00% and 176.0% respectively.

Iron (total)

The average value ranges from 0.07 mg/l for charnockite to 0.09 mg/l for granite and 0.15 mg/l for migmatite. The coefficient of variation is low for migmatite with a value of 13.33%, while charnockite has a value of 42.86% and granite has a high value of 122.20%.

Bicarbonate

A low average value of 66.00 mg/l is recorded for charnockite, 154.7 mg/l is recorded for migmatite, and the highest value of 161.25 mg/l is recorded for granite. The coefficient of variation ranges from 58.50% for charnockite to high values for granite and migmatite of 73.40% and 77.34% respectively.

Sulphate

The mean value ranges from 11.25 mg/l for charnockite to 26 mg/l for granite and 32.45 mg/l for migmatite. The spatial variation is very high in all the geological formations with values of 86.40%, 112.57% and 138.8% for charnockite, migmatite and granite respectively.

Chloride

The mean value ranges from 23.25 mg/l for charnockite to 37.15 mg/l for granite and 58.33 mg/l for migmatite. The coefficient of variation is very high for all samples with values of 79.53% for migmatite and 107.53% for charnockite.

Nitrate

The mean value ranges from 0.27 mg/l for charnockite to 0.63 mg/l for migmatite and 0.77 mg/l for granite. The coefficient of variation is moderate for charnockite with a value of 51.90% and high for granite and migmatite with values of 80.52% and 82.71%.

INTERPRETATION OF RESULTS FOR GROUNDWATER RESOURCES DEVELOPMENT

The geological setting of the study area is the basement complex of Precambrian origin which is generally characterized as a poor aquifer because of its discrete nature, confinement and shallowness of water-bearing formations. However, economic exploitation of groundwater within the basement complex is feasible because the rocks and weathered derivatives constitute a large reservoir of groundwater due to high annual rainfall of 1500 mm resulting in high recharge, developments of deep weathered profiles, and the presence of fractured zones and non-homogeneity which result in contact zones with attendant permeability contrast which favours the occurrence of groundwater.

There is a high yield of water in the study area. The quality of the well water is satisfactory when compared with the recommended limits of WHO for drinking water, AWWA for industrial water use, and the US Department for Agriculture for irrigation purposes, as shown in Tables 2, 3 and 4.

The hand-dug wells can be upgraded to boreholes to meet the increase in demand for water use. This is very promising because the yields are sufficient for economic utilization. The average water yield of boreholes in the basement complex (study area inclusive), is about 29,000 imperial gallons per day (130,500 litres per day). This can serve approximately 500 people at about 60 imperial gallons (270 litres) per capita per day. Figures of water consumption used in planning circles in Nigeria range from 10 to 100 imperial gallons (45 to 450 litres) per capita per day from rural to urban settings (Osibanjo 1979). Even exceptional yields of over 240,000 imperial gallons

Table 2 | Allowable maximum concentration of selected water variables (World Health Organisation (WHO) 1993)

Parameter	Allowable maximum concentration
pH	6.5–8.0
Hardness (bicarbonate)	500 mg/l
Chloride	250 mg/l
Sulphate	400 mg/l
Sodium	200 mg/l
Iron	0.30 mg/l
Nitrate as N	100 mg/l

(1,080,000 litres) per day have been reported for the Ikere artesian borehole (Ekiti State, Nigeria) drilled in the basement complex (Ako *et al.* 1986).

In the study area water demand is increasing with an increasing standard of living and there is a need to develop groundwater to supplement other sources. The groundwater resources development in this area will be utilized for domestic, industrial and agricultural purposes.

Domestic uses

The increasing population of both urban and suburban areas has necessitated the development of groundwater to complement other water resources, and the standard of living can be judged by the daily per capita consumption of water in homes. Hospitals, schools and homes need a large amount of water for maintenance, modern cleanliness and sanitation. Waters in the study area have been found to be satisfactory when compared with WHO guidelines (Tables 1 and 2). Although microbiological analysis is not within the scope of this study, the water is relatively safe for drinking since the incidence of water borne diseases is not common in the study area. Arsenic and fluoride are associated with deposits of marine origin and recent orogeny. The study area is made up of an ancient African basement complex of Precambrian age in which such elements are rare.

Industrial uses

The development of any country depends on the establishment of industries. These increase the wealth of the nation, reduce imports and increase employment. The results of the water analysis are compared with AWWA recommendations for industrial uses (Tables 1 and 3). It is found that industries such as baking, brewing, carbonate beverages, food canning, ice manufacturing, laundering and textiles can be established without water quality problems.

Agricultural purposes

Many people are suffering from malnutrition as a result of food shortages. The study area is blessed with abundant rainfall, however seasonality and variability are a threat to agriculture. There is a need to combat scarcity of food and boost exports, thereby increasing the earnings of farmers, by irrigation which will make year-round agriculture possible. Compared with the US Department of Agriculture standards (Tables 1 and 4), salt concentrations expressed in terms of specific electrical conductivity are low. This is an indication that the water can be used for irrigation for crops such as lemons, grapefruit, oranges, pears, onions, carrots and potatoes, taking into consideration the climatic condition of the study area.

SPECULATED CAUSES OF WATER QUALITY DETERIORATION AND REMEDIAL MEASURES

Deterioration in water quality may be caused by natural and human activities. Natural causes can be leaching, weathering, dissolution and cation exchanges. However, the pollution due to human activities is of serious concern. Pollution from buckets, ropes, surface runoff from washing headwalls, and modern farming practices of intensive

Table 3 | Recommended concentration for industries (American Water Works Assocation (AWWA) 1971) (units are in mg/l)

	Hardness (bicarbonate)	Alkanity (bicarbonate $CaCo_3$)	pH unit	Chloride	Sulphate	Iron
Textile	—	—	—	100	100	0.1 to 1.0
Brewing	75 to 80	—	6.5 to 7.0	60 to 100	—	0.1
Baking	—	—	—	—	—	0.2
Bicarbonate beverage	200 to 250	50 to 130	—	250	250	0.1 to 0.2
Drinking	—	—	—	250	250	0.3
Food processing	1 to 250	30 to 250	—	—	—	0.2
Ice manufacturing	—	—	—	—	—	0.2
Laundering	0.50	60	6.00 to 6.8	—	0.2 to 1.0	—

usage of agro-chemicals will possibly induce quick seepage into groundwater from domestic sewage, industrial wastewater and heavily fertilized farmland. Therefore there is need for preventive measures. The following remedies are suggested:

1. Health education concerning water quality and water-related diseases.
2. Lining of wells with bricks or concrete plus installation of hand pumps. The lining will prevent seepage of contaminated wastewater from the surface, and hand pumps will reduce the incidence of contamination from buckets and ropes.
3. Deepen the wells and encase with concrete rings in the period of the year when the groundwater table is at its lowest.
4. Discourage personal buckets by introducing one bucket and one rope to reduce the incidence of contamination from different buckets.
5. A concrete slab on top should be installed to cover and protect the well.

Table 4 | Relative tolerance of crops to salt concentrations expressed in terms of specific electrical conductivity (US Dept. of Agriculture (Ayers 1975))

Crops	Salt tolerance
Fruit:	0–300 µs/cm (low)
Lemon	
Grapefruit	
Orange	
Pear	
Vegetables:	4,000 μs/cm (median)
Onion	
Carrot	
Potato	
Tomato	

CONCLUSIONS

The results of the analysis of all the water samples are within the recommended limits of WHO for drinking water, AWWA for industrial water, and the US Department of Agriculture for irrigation purposes–hence little or no treatment is required. It appears that sufficient groundwater can be obtained by drilling boreholes. Presently, the quality of the water is satisfactory, but contamination is envisaged and treatment may be needed in future. This can be prevented by protecting the wells and lining them with concrete or bricks, intensive health education and the introduction of hand pumps. It is believed that this study will provide useful information for water engineers, hydrologists and hydrogeologists who are involved in the prospecting and drilling of boreholes in the basement complex.

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