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BACTERIOLOGICAL PROPERTIES OF GROUNDWATER IN PARTS OF NIGER STATE, NIGERIA

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Bacteriological analysis of groundwater from newly drilled boreholes in hospital environments in towns and villages in central Nigeria, has revealed that groundwater can be contaminated by microorganisms, even in a seemingly well-designed and constructed water well, particularly if the wells are located in urban areas or in public sanitary places such as hospitals or health centers. Microorganisms can gain access to boreholes through one of the following mechanisms; surface runoff, leachate migration, use of contaminated water for drilling, and improper handling of well construction materials and water supply fittings. It is not a normal practice for microbiological analysis of soils to be carried out in groundwater exploration program. However, the findings in this study suggest that buried feces or damaged sewers could be potential sources of contamination to the groundwater system, if wells are inadvertently sited in such areas. It is suggested that in developing countries, microbiological analysis of soil deposits be included in the exploration program for selection of a suitable drilling site, and in the general quality assessment for potability of water, particularly in urban areas that may be suspected to host potential contaminant sources.

INTRODUCTION

In the past, most groundwater was of such high quality that disinfection, although often required by law, was probably unnecessary. Today, the presence of microbes in groundwater is becoming more widespread, and more rigorous treatment of groundwater is required. Identification of specific types of pathogenic bacteria is quite difficult and laborious and laboratories only attempt to determine the presence or absence of coliform organisms. Coliforms originate primarily in the intestinal tract of warm-blooded animals, including humans. Although coliform bacteria are normally non-pathogenic, their presence suggests that conditions are appropriate for pathogenic organisms and that fecal contamination is possible. The maximum contamination level for coliform bacteria in a water system is 1 coliform bacteria per 100 ml of water. Many serious diseases are related to microbiological contamination of water, most of them due to pathogenic bacteria excreted by people suffering from or carrying the disease. While it is possible to examine water for the presence of a specific pathogen, a more sensitive test employs an indicator organism, Escherichia Coli, which is a normal inhabitant of the human intestine and is excreted in large numbers.

RESEARCH STUDY

This paper is an outcome of a project undertaken for Consortium Voest Alpine Austro-plan, a consulting firm for the Niger State Ministry of Health, aimed at determining the biological quality of groundwater in newly drilled boreholes for Niger State Government hospitals. This project was the first of its kind in Niger State. The lapses in the process of borehole drilling, design and construction are illustrated in this study.

Pumped water samples from ten boreholes located at various parts of Niger State, Figure 1, were collected for microbiological analysis. Samples were analyzed within six hours of collection, using the standard methods recommended by the World Health Organization on the examination of water for pollution control. The following tests were performed:

1. MPN Fecal Coliform bacteria per 100 ml of sample.

2. MPN Escherichia Coli per 100 ml of sample.

3. Plate count of fecal streptococci on selective media.

4. Heterotrophic microbial counts at 20^{o}C and 37^{o}C to determine the presence of easily degradable organic matter in water.

5. MPN Clostridium Welchi per 100 ml of sample.

Because of their small size, observation of microorganisms with the naked eye is impossible and in the case of the simpler microorganisms their physical features do not provide identification. Nutrient agar medium was used to obtain plate counts of living bacteria (viable cell count). The procedure involves mixing 1 ml of water sample with liquefied agar at 40^{o}C in a petri dish. The agar sets to a jelly, thus fixing the bacterial cells in position. The plate is then incubated under appropriate conditions (72 hr at 22^{o} C for natural water bacteria, 24 hr at 37^{o} C for bacteria originating from animals or man, Tebbut, 1983). At the end of incubation the individual bacteria will have produced colonies visible to the naked eye and the number of colonies is assumed to be a function of the viable cells in the original sample. Detection of coliforms was achieved using a lactose medium (MacConkey Broth) inoculated with serial dilution of the sample. The appearance of acid and gas after 24 hours at 37^{o} C was taken as positive indication of the presence of coliform bacteria, results were expressed with the aid of statistical tables as most probable number (MPN) per 100 ml. As a confirmatory test for Escherichia Coli, positive tubes were subcultured in fresh medium for 24 hr at 44^{o} C under which conditions only E. Coli will grow to give acid and gas.

The boreholes from which the samples were taken were drilled primarily to provide potable water to the hospital community in which they were located. The hydrogeological investigation was undertaken to determine the nature of the aquifers, as well as the type of borehole design and construction, in order to relate these to the results of microbiological analysis.

STUDY AREA.

Niger State is located within the middle belt of Nigeria, Figure 1, stretching between longitudes 4^{o} 40' to 7^{o} 30' and latitudes 7^{o} 51' to 11^{o}. It is drained by the River Niger and its tributaries, of which the major ones are Rivers Kaduna, Gurara, Chanchaga and Kontagora. The climate of Niger State is like much of West Africa. The daylight temperatures vary from about 24^{o}C at the middle of the wet season to above 35^{o}C at the peak of dry season. The seasonal rainfall regime gives rise to a longer wet season of about seven months with average rainfall of 250 mm, and a dry season of about five months with little or no rains at all.

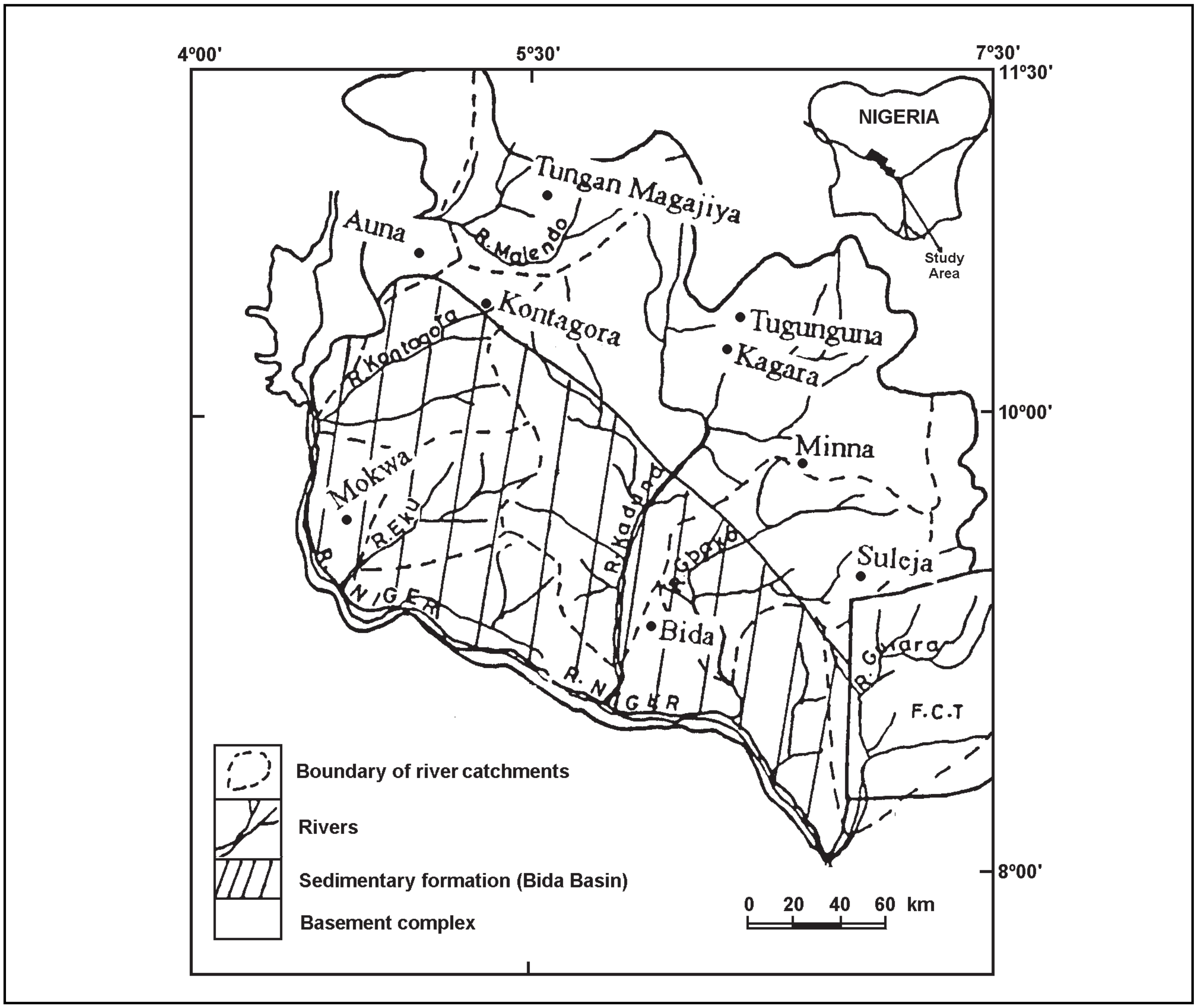

Figure 1. Map of study area showing sampling sites.

GEOLOGY AND HYDROGEOLOGY

About one half of the land mass of Niger State is underlain by Basement Complex rocks, while the remainder is Cretaceous sedimentary rocks of the Bida basin. The boundary between these rocks runs in a northwest to southeast direction, with the Basement rocks to the north and the sedimentary formations to the south. Six out of the nine locations from which samples were collected for this project are situated within the Basement Complex terrain, while the other three lie in the Cretaceous sedimentary formations.

The Basement rocks consist of a suite of Precambrian granites, gneisses, migmatites and schists (Oyawoye, 1972 and McCurry, 1976). The gneisses and schists which constitute the host rocks are found mostly as flat-lying outcrops, often poorly exposed except along river channels and road cuttings. The sedimentary formations on the other hand consist of loosely cemented sandstones of varying grain sizes, siltstones, clays and shale, and they are often capped by lateritic and/or ironstone concretions, particularly in upland areas (Shekwolo, 1992).

Aquifers in the sedimentary formations are either confined or semi-confined. In the Gbako and Kaduna catchments, the aquifers are mostly semi-confined, with confined and perched conditions occurring only locally. The aquifer in Eku catchment is unconfined and has generally a deeper water table than the semi-confined areas (Shekwolo, 1992).

In the Basement Complex rocks, two aquifer types exist. These are the weathered zone aquifer and the fracture zone aquifer. The fracture zone aquifer underlies the weathered zone.

A typical weathered profile of the Basement rocks consists of two main zones, firstly, the surficial zone, which is usually about on or two meters thick, and secondly, the fractured or fissured rock zone, which may range from a few meters to over 20 m in places. Products of weathered granites and gneisses are usually loose aggregates of medium to coarse sand, while the weathered products of schist are generally made up of clayey sand.

RESULTS OF LABORATORY ANALYSIS

The results of bacteriological analysis are presented in Table 1.

Table 1. Result of Bacteriological Analysis of Water Samples

S/No.	Name of Locality	Type of Test (Determinants)	Plate Count (ml)	pH
1	Kagara	Faecal Coliform (E. Coli) Faecal Streptotococci Heterotrophic Micro-Organism (Non-Faecal) Clostridium Welchi (Perfringens) Clostridium Sphenoides Clostridium Vulgatus	Nil Nil TNTC Nil Isolated " "	6.5
2	Kontagora	Faecal Coliform (E. Coli) Faecal Streptotococci Heterotrophic micro-organism (Non-Faecal) Clostridium Welchi (Perfringens) C. Sphenoides B. Silvatus	Nil Nil TNTC Nil Isolated " "	7.8

Table 1. Result of Bacteriological Analysis of Water Samples (continued)

3	Auna	Faecal Coliform (E. Coli) Aerobacter aerogenes Heterotrophic micro-organisms (non-faecal) Faecal Streptotococci Clostridium Welchi (perfringens) B. Subtilis	4 Isolated 120 Nil Nil Isolated	6.8
4	Tungan-Magajiya	Faecal Streptotococci Faecal Coliform (E. Coli) Heterotrophic micro-organisms (non-faecal) Clostridium Welchi (perfringens) C. Centrosporogenes C. Histolytrcum	Nil 6 TNTC Nil Isolated "	8.2
5	Mokwa	Faecal Streptotococci Faecal Coliform (E. Coli) Heterotrophic micro-organisms (non-faecal) Clostridium Welchi (perfringens) C. Sphenoides	Nil Nil TNTC Nil Isolated "	7.0
6	Tugunguna	Faecal Streptotococci Faecal Coliform (E. Coli) Heterotrophic micro-organisms (non-faecal) Clostridium Welchi (Perfringens) Clostridium Sphenoides	Nil Nil TNTC Nil Isolated	7.5
7	Suleja	Faecal Streptotococci Faecal Coliform (E. Coli) Heterotrophic micro-organisms (non-faecal) Clostridium Welchi (perfringens) C. Centrosporogenes	Nil Nil TNTC Nil Nil	7.4
8	Minna	Faecal Streptotococci Faecal Coliform (E. Coli) Salmonella Typhosa Salmonella Enteritidis Salmonella Typhumurum Aerobacter aerogenes Heterotrophic micro-organisms (non-faecal) Clostridium Welchi (perfringens) C. Tertium C. Sphenoides	Nil 46 Isolated Isolated " " 125 Nil Isolated "	7.6
9	Bida	Faecal Streptotococci Faecal Coliform (E. Coli) Heterotrophic micro-organisms (non-faecal) Clostridium Welchi (perfringens) C. Centrosporogenes C. Butyricum	Nil Nil 180 Nil Nil Isolated "	7.5
		TNTC = Too numerous to count		

DISCUSSION OF RESULTS

Fecal Coliform.

Results presented in Table 1 show that fecal coliforms of the Escherichia Coli species and others were found in three of the nine samples examined. The localities in which these were found are Minna, with an E. Coli colony of 46 bacteria per 100 ml of water sample, Tungan-Magajiya, with a colony of 6 bacteria per 100 ml, and Auna with a colony of 4 bacteria per 100 ml of water. Aerobacter aerogenes were also found in these three samples. The sample from Tungan-Magajiya contained Candida albicans in addition to the two mentioned above, while the sample from Minna had in addition Salmonella typhosa, Salmonella enteritidis and Salmonella typhumurum.

As earlier mentioned, the presence of E. Coli is an indication of contamination. The presence of Salmonella typhosa in water sample from Minna, which incidentally has the highest number of E. Coli colonies, is not unexpected. This species of Salmonella is known to be responsible for typhoid fever (Tebbut, 1983).

About one year after this study was conducted, an epidemic outbreak of typhoid was reported in Minna and other parts of Niger State. Minna is the capital of Niger State, and the general hospital in Minna is the biggest in terms of size and population. The effluent discharges from sanitary facilities such as soak-aways and septic tanks are relatively higher than other localities in the study area. This partly accounts for the presence of the relatively large number of coliform bacteria in this borehole.

Non-Fecal Bacteria

Heterotrophic bacteria are known to be consumers of organic matter. They are non-fecal microorganisms. These were found in numbers too numerous to count (TNTC) in most of the samples, with the lowest number of counts occurred in the sample from Bida with a plate count of 120 bacteria/ml. Their presence is an indication of a large amount of organic matter in water, probably originating from the top soil, or the aquifer material. The Clostridia and Bacillus species, which are not of fecal origin, were isolated in virtually all the samples.

Hydrogeological Implications - Well Design and Mechanisms of Contaminant Migration

The well designs of the localities in which fecal coliform were found are shown in Figure 2. The borehole log of Minna shows a thin layer, about 1.5 m of top surficial soil, followed by a 5.0 m thick highly weathered zone of granitic rock. The highly weathered zone is underlain by another 6.0 m of slightly weathered zone of the same rock. The remaining depth is fresh granite which has been fractured in places.

Figure 2 shows the position of the screen at the bottom of the hole, between depths of 34 to 40 m, which indicates the presence of fracture aquifer at that point. The remaining upper part of the borehole is lined with a PVC casing, which protrudes about 0.5 m above the ground surface. The borehole is also grouted with cement to a depth of about 1.0 m. It can be concluded that the borehole was properly designed and constructed. Other factors therefore must have been responsible for the presence of biological contamination in the well.

There are five possible ways through which the fecal coliform bacteria found in the water sample might have gained access into the well.

(a) Through surface runoff of contaminated water from the surrounding area into the well during drilling. The borehole in this locality is situated on sloping ground, and if care was not properly taken

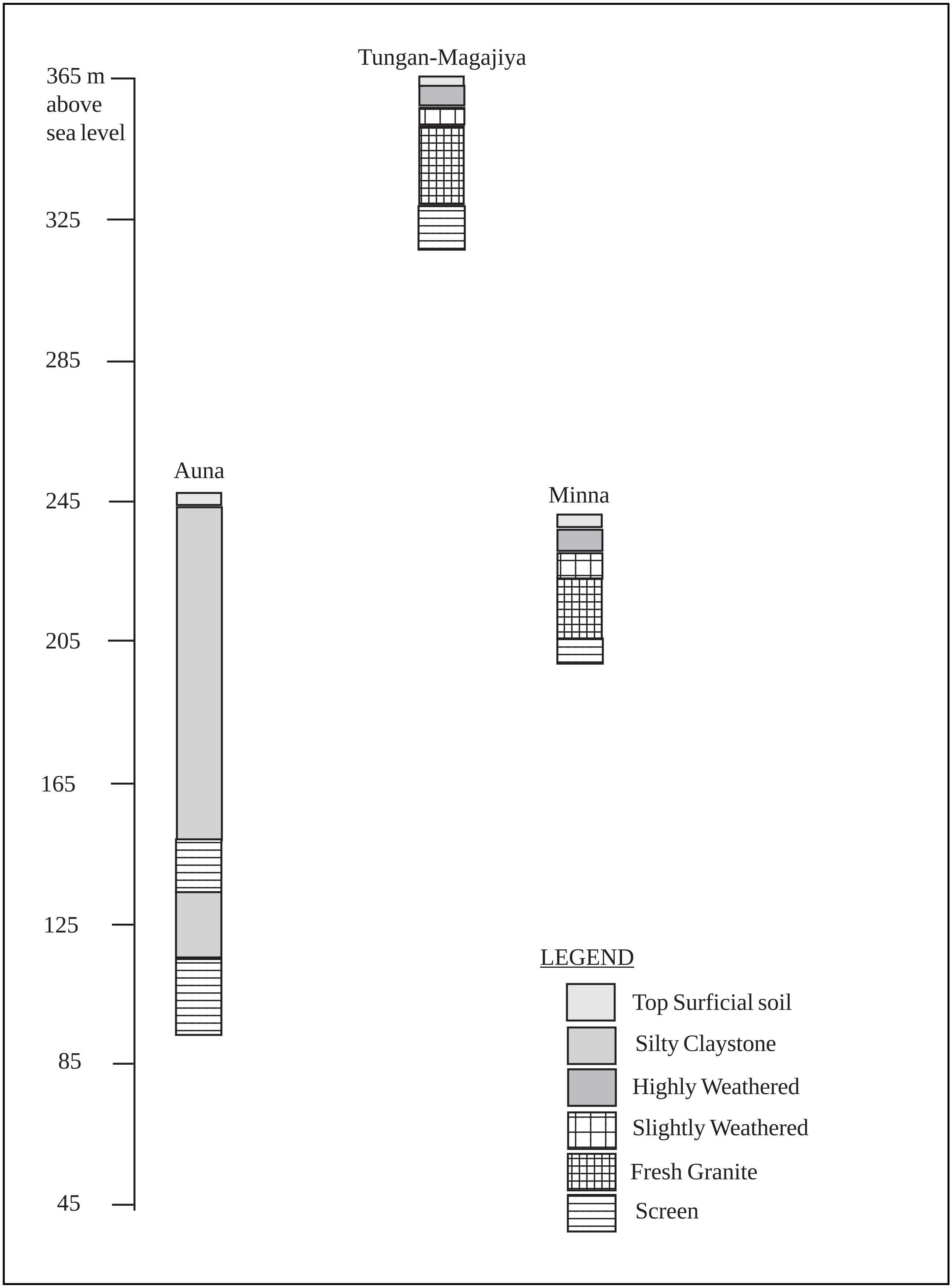

Figure 2. Well design and borehole logs at Minna, T/Magajiya and Auna, central Nigeria.

by the drillers during the drilling process the possibility of runoff from the upslope into the well cannot be ruled out.

(b) It is also possible that fecal deposits might have been buried at a certain depth where the borehole was sited.

(c) Another possibility is that of leachates from nearby soak-aways or damaged septic tank, being transported in suspension. Since the soil was not examined for possible occurrence of contaminants before drilling at the site commenced, this factor and that of (b) may not be ruled out.

(d) The water used for the preparation of drilling fluid and for drilling might be a source of contamination, particularly if it was taken raw from the stream.

(e) Contamination might also have come from the unhygenic handling of casings and screens used for the construction of the well, or from the rising mains used in the installation of water supply pump.

The borehole at Tungan-Magajiya, which was also affected by contamination, is in a similar geological setting as that of Minna. In fact the lithological log and the borehole design are similar to that of Minna, except that the weathered zone at Tungan-Magajiya is thinner than that of Minna. The mechanisms of contaminant transport and possibilities of contamination outlined above are basically the same at these sites.

Auna, on the other hand, lies in the Cretaceous sedimentary formations. The borehole was drilled to a total depth of 115 m. The first 2 m consist of lateritic soil, followed by a 78 m thick layer of silty clay which can be considered an aquiclude. The first aquifer occurs at depths ranging from 80 to 91 m and is underlain by a stratum of clay from 91 to 105 m. The second aquifer extends from 105 to 115 m at which point the borehole terminates. The first and the second aquifers were installed with screens, while the remaining portions of the borehole were lined with PVC casings. The borehole was also artificially gravel packed. The design of this well can be considered as appropriately done. The question that arises is how the contaminants got into the well.

According to Domenico and Schwartz (1990), particles such as bacteria and viruses which are in suspension can be mobile in sand and gravel not containing a fine grained fraction. Because of their small size, such particles have relatively large surface areas, which makes them efficient contaminant collectors. In cases where these contaminants have a low mobility in solution, facilitated transport on particles such as clay minerals, can create unexpectedly high fluxes. This may be applicable in a limited way to the contaminant transport in the weathered zone of Basement rocks, such as in Minna and Tungan-Magajiya localities. Transport in this way is controlled by the physical and chemical character of the particle rather than the chemical characteristics of the contaminant itself.

In a situation where the geological materials are composed of a fine grained fraction (silt and clay), as is the case with the borehole at Auna, contaminant particles of bacteria size might be stopped from moving as a result of physical filtration that limits their migration. According to McDowell-Boyer et al. (1990), filter cakes or surface mats form when particles of the same size or larger than the pore openings simply cannot penetrate into the medium. Straining occurs as particles small enough to enter the porous medium are caught in smaller pore spaces. A third mechanism for filtration is the sorption of particles on to the porous medium. This narrows down the cause of contamination in Auna borehole to mechanisms a, d, and e, with greater weight given to a.

CONCLUSIONS

This study of the bacteriological content of groundwater, which is the first in the area, has revealed that groundwater can be contaminated by microorganisms, even in a seemingly well-designed and constructed water well, particularly if the wells are located in urban areas or in public sanitary places such as hospitals or health centers. This calls for the necessity to include bacteriological examination in groundwater quality assessment, particularly in urban areas. It is concluded that microbiological organisms can gain access into boreholes through one of the following mechanisms.

(a) Surface runoff of contaminated water from the surrounding into the well during the process of drilling.

(b) Decomposition of fecal deposits that might have been buried where the borehole was sited.

(c) Leachates from nearby soak-aways or damaged septic tanks, being transported in suspension.

(d) The use of contaminated water from surface streams for the preparation of drilling fluid and for drilling.

(e) Unhygenic handling of casings and screens used for the construction of the well, or from the rising mains used in the installation of the water supply pump.

It is suggested that microbiological analysis of soil deposits be included in the exploration program for selection of suitable drilling sites, particularly in urban areas that are suspected to host potential contaminant sources, and especially in developing countries.

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