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Original Research Article

Assessment of Physicochemical and Bacteriological Quality of Underground (Well) Waters in a Rural Settlement South-South Nigeria

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Abstract

Underground wells are widely used as source of water for household needs and other purposes in rural communities. Water quality and quantity are necessary requirements for use of water for various purposes, and ground water quality problems have been created anthropogenically and have become a menace to the users. This study therefore focused on the physiochemical and microbiological quality of hand dug well waters in a rural settlement in Rivers State. Sampling points (wells) were randomly chosen from wells operational in the sampling communities of Akabuka, Obagi and Obuburu. Physicochemical parameters were analysed using standard analytical procedures and aerobic plate count (APC) as well as most probable number (MPN) techniques were used for microbiological analysis of water samples. Results revealed that pH of the sampled wells were acidic compared to the permissible range. Other physicochemical parameters were lower than the permissible ranges for drinking water quality. Sampled well waters had high load of total aerobic heterotrophic bacteria (THB), total coliform bacteria (TCB), and faecal coliform bacteria (FCB)/thermotolerant coliform bacteria (TtCB) far above the permissible limits for potable water. Occurrence of faecal coliform bacteria/thermotolerant coliform bacteria in all the sampled wells indicated faecal contamination, and high load of aerobic heterotrophic bacteria revealed organic contamination of the water sources. Some pathogenic bacteria such as *Salmonella species* isolated during the study further confirmed organic contamination of the sampled well waters. In conclusion, high numbers of faecal coliform bacteria and high aerobic bacterial counts of the sampled well waters showed exposure to external contamination and unsafe condition of the well waters for drinking and other domestic uses. Hence, the sampled well waters should be subjected to boil water treatment order before use by the inhabitants of the communities.

Keywords: Water quality, anthropogenically, physicochemical, microbiological, rural-settlement.

INTRODUCTION

Underground water is water under the ground where the soil is completely filled or saturated with water known as "aquifer". Ground water moves underground from areas where the elevation is high to places that are low land areas [1-3]. Underground water moves slowly from less than a millimetre up to a mile in a day [2, 3]. A spring is any natural opening/point where water flows out of the ground to the surface of the earth (Wikipedia.org; britanica.com); the water flows into a lake, stream, woodland or the ocean. Well is an artificial opening cut down from the surface into the zone of saturation; a well is successfully drilled only if it penetrates into permeable material below the water table. Water is a chemical substance made up of hydrogen and oxygen atoms. A living being needs water to be healthy, plan and participate actively in the development of a \community and country at large. Water ought to be not only adequate but wholesome in supply [4]. Water is said to be potable if it is free of industrial waste such as crude oil, halogenated hydrocarbons and also free from pathogenic microorganisms and aesthetically appealing; potable water should also be physically pure not having sediments [5].

Majority of the population in developing countries is not adequately supplied with potable water and is thus compelled to use water from sources like shallow wells, boreholes, springs and streams that render the water unsafe for domestic and drinking purposes due to high possibilities of contamination [6, 7]. In order to ensure a safe public health, water supply for human consumption must be free from pathogens, free from chemical toxins and must be physically clear and appealing to taste [8]. It is also important that water for domestic, agricultural or industrial uses should not be acidic or alkaline than is required by standards for the purpose.

Nigeria as a developing country is suffering from lack of access to safe drinking water from improved sources and to adequate sanitation services. As a result, people are still dependent on unprotected water sources such as rivers, lakes, ponds, streams, springs and hand dug wells. These water sources are constantly exposed to contamination from animal origin, oil spillage, and oil from marine vessels, runoff from agricultural lands and sewage from industrial and domestic sources; thus exposing the inhabitants to gastrointestinal infections. Ground water is water found in space between soil particles and rocks, and within cracks of bedrocks. Ground water found beneath the ground surface are harnessed as well and borehole waters, and are the common sources of water in most communities, rural and urban alike for household needs and other purposes [9]. Many types of industrial activities have influenced ground water qualities which range from mining activities, nuclear activities to sewage disposal, agricultural runoffs to military dumps' activities [5, 10]. Ground water quality problems are more or less created anthropogenically except for too few natural sources. The effect of urbanization such as industrial wastes on drinking water quality including ground water is a well-known phenomenon [10]. Forth [11] investigated the effects of acid precipitates as source of soil acidity, and reported that acid rains enter the soil through seepage to contaminate ground water. Also carbon IV oxide released from the decay of solid wastes can be dissolved in soil water to alter soil acidity. Water from permeable layer is grossly contaminated and quite unwholesome for human consumption [1-3].

Water supply method in the study communities is not wholesome. Households' individual activities tend to affect the quality of water storage underground, and dirty habits of handling water are also a problem. To compound the problem the more, the presence of oil prospecting activities around the communities tends to contaminate underground water through seepage from oil wells and oil vapour washed down into the wells during rains. Most peasant dwellers in the study area use hand dug well waters for their domestic purposes.

This study therefore was aimed at evaluating the physicochemical properties and bacteriological quality of underground (well) waters in a rural settlement and to determine the potential health hazards that could be associated with use of the well waters among the rural dwellers of the study area.

MATERIALS AND METHODS

Study Area

The study area was Egi clan, a rural settlement in Ogba/Egbema/Ndoni Local Government Area of Rivers State, South-South, Nigeria. The area is a plain land made up of tropical rainforest vegetation of Niger Delta region. The study area plays host to one of the leading oil prospecting and production companies, Total Fina Elf Plc, for over 60 years. The company carry out oil production activities around the area and owns several oil wells scattered around the communities. Egi clan is made up of rural dwellers whose occupation is predominantly farming and fishing. The clan consists of many villages which share the same cultural heritage. Since their settlement in the area, their sources of water has been hand dug well, rivers and streams, and in recent times, private boreholes. Till date, inhabitants that cannot afford the cost of sinking private boreholes still rely on hand dug wells as source of their drinking water. Due to the high water table level, the wells in this area are mainly shallow wells dug by the rural inhabitants.

Collection of Water Samples

For the purpose of collection of well water samples, three stations were chosen from the study area which represent three major villages of Akabuka, Obagi and Obuburu, designated as stations A, B and C respectively. Three wells (Well1, Well2 and Well3) were randomly chosen from each station to represent 3 sampling points, 1, 2 and 3, respectively. Water samples were collected from the sampling stations weekly for three (3) weeks. Two/replicate samples each were collected from the 3 wells of each sampling stations at weekly intervals for to give a total of fifty four (54) samples used for microbiological investigation. Water samples were also used for physicochemical analysis. Sterile sample bottles were used for collection of microbiological samples while clean sample bottles were used to collect samples for physicochemical analysis. The wells used in this study are hand dug.

Method of Collection of Water Samples

A sterile sample bottle was tied onto a weighted length of clean rope; a heavy piece of clean metal (ethanol sterilized) was used as the weight and the bottle was tied just above the weight. The cap was aseptically removed from the bottle and the bottle was lowered into the well to a depth of about 1 meter. When no air bubbles rose to the surface, the bottle was raised out of the well and the cap was carefully replaced. The sample bottle was then labelled with the sample code number. The containers were labelled accordingly and the samples were transported to the laboratory in an ice-cooled container. All the water samples were analysed immediately on arrivalto the Laboratory.

Physicochemistry of Water Samples

Physicochemistry of the water samples analysed in this study were pH, electrical conductivity, total alkalinity, total hardness, biochemical oxygen demand and total hydrocarbon content according to the methods of APHA [12]. The pH was determined in situ at each sampling site using pH indicator paper and confirmed in the laboratory by the use of Cole-Parmer

digital pH meter. Electrical conductivity was determined using a Jenway 4020 conductivity meter. Total alkalinity was measured titrimetrically using methyl red indicator. Total hardness was determined by the Erichrome Black I method [12]. Biochemical oxygen demand (BOD) was measured by Winkler's method [12]. The toluene extraction method was used to measure total hydrocarbon content of well waters [13, 12].

Microbiological Analysis of Well Waters

Determination of total aerobic heterotrophic bacteria in well waters was done by enumerating the microbial densities, and by isolation of discrete bacterial colonies. Serial ten-fold dilution method was used to dilute water samples in order to obtain required dilutions [14, 15]. Aliquots (0.1ml) of appropriate dilutions of the samples were spread plated, using a sterile bent glass rod, onto the surface of freshly prepared sterile nutrient agar plates. The inoculated plates were incubated at 37^0C for 24 hours. Colonies that developed were counted and recorded as total heterotrophic counts of aerobic bacteria in colony forming units per millimetre (CFU ML^{-1}) of water.

Representative discrete colonies of bacteria were aseptically collected and inoculated onto fresh sterile nutrient agar plates and incubated at 37^0C for 24 hours. The pure cultures were put in the Bijou bottles containing 2ml each of 20% glycerol, stored in the refrigerator at -4^0C and used for further characterization tests.

Estimation of total coliform bacteria and faecal coliform bacteria/thermotolerant coliform bacteria were carried out by multiple Tube method using Most Potable Number (MPN) technique [16, 17, 15, 2]. Fifteen test tubes (15) were employed for the MPN containing double strength and single strength sterile MacConkey broth of 5 tubes and ten tubes respectively. Appropriate volumes of well water samples were inoculated in 10ml, for 5 tubes double strength, 1ml for 5 tubes of single strength, and 0.1ml for another 5 tubes of single strength. The test tubes contained inverted Durham tubes. The inoculated test tubes were incubated at 37^0C (for TCB) and 44.5^0C (for FCB/TtCB) for 24 – 48 hours. After incubation, positive tubes (colour change from purple to yellow and gas collection in the Durham tubes) were counted and recorded. Coliform bacteria were estimated statistically using MPN statistical table. Presumptive, confirmatory and completed tests were performed on the water samples to confirm the presence of coliform bacteria [5, 18].

Characterization and Identification of Bacterial Isolates

The bacterial isolates were characterized by their colonial/morphological characteristics, and biochemical reactions. Standard characterization tests performed on the bacterial isolates were Gram stain, motility, oxidase, catalase, coagulase, nitrate and citrate utilization, urease test, starch hydrolysis, methyl red, Voges Proskauer, indole and sugar fermentation tests. The characterized isolates were identified by reference to Buchanan and Gibbons [19]; Cowan and Steel [20] and Winn *et al*., [21]. Bacterial species were confirmed using ABIS Online Laboratory Software tool based on morphological and biochemical characters.

RESULTS

Data for physicochemical parameters are presented in Table-1. Mean densities of aerobic heterotrophic bacteria, total coliform bacteria and faecal coliform bacteria are shown in Fig 1-3. Table-2 shows the bacterial species isolated during the study period. Physicochemical parameters of 3 wells for stations A, B and C respectively ranged as follows: pH 5.1 to 5.4, 5.6 to 5.9 and 6.2 to 6.6; EC (µ$/$cm^{-1}$) 180 to 207, 26 to 30 and 21 to 25; Total Alkalinity (mg/l) 31 to 40, 12 to 16 and 24 to 28; Total Hardness (mg/l) 23.0 to 29.2, 3.3 to 4.1 and 3.1 to 3.8; BOD (mg/l) 1.4 to 2.0, 2.2 to 2.6 and 1.6 to 2.1; THC (mg/l) <0.02 in all well water samples from all the stations. Ranges of weekly counts of aerobic heterotrophic bacteria ($X10^4$cfu/ml water) in 3 wells at the sampling stations were: 2.08 to 2.96 (Station A), 1.75 to 2.94 (Station B) and 1.10 to 2.00 (Station C). Number of coliform bacteria (MPN index/100ml) in the 3 wells ranged as follows: Total coliforms - 30 to 300 (Station A), 34 to 220 (Station B) and 21 to 47 (Station C); faecal coliforms - 20 to 80 (Station A), 16 to 120 (Station B) and 11 to 29 (Station C).

The bacterial species isolated from the water samples include: *Bacillus lequilensis*, *Bacillus* species, *Buttiauxella ictalium*, *Cedecea neteri*, *Citrobacter rodentium*, *Citrobacter* species, *Edwardsiella ictaluri*, *Enterobacter amnigenus*, *Enterobacter nimipressuralis*, *Enterococcus* species, *Escherichia coli*, *Klebsiella singaporensis*, *Providencia rustigianii*, *Proteus myxofaciens*, *Pseudomonas fuscovaginae*, *Pseudomonas* species, *Salmonella enterica*, *Salmonella paratyphi*, *Serratia plymuthica*, *Serratia* species, *Staphylococcus* species, and *Streptococcus* species.

Table-1: Data for Physicochemical Parameters of Well Water Samples of the Sampling Stations

Parameter	Values in 3 wells of Sampling Stations									Maximum Permitted Levels
	A1	A2	A3	B1	B2	B3	C1	C2	C3	
pH	5.3	5.1	5.4	5.9	5.8	5.6	6.4	6.2	6.3	6.5 – 8.5
EC (µ$/cm^{-1})	180	199	201	29	26	30	21	24	25	1000µ$/cm^{-1}
Total Alkalinity	40	34	31	16	12	14	26	24	28	250mg/l
Total Hardness	25.1	23.0	29.2	3.3	3.8	4.1	3.1	3.8	3.5	150mg/l
BOD (mg/l)	1.4	1.6	2.0	2.8	2.4	2.2	1.8	1.6	2.1	NA
THC (mg/l)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	NA

Key: A, B, C, represent the study wells

Of the 16 bacterial genera isolated, *Edwardsiella* species and *Escherichia coli* had the highest prevalent rate of 11.4%, *Enterobacter, Pseudomonas* and *Staphylococcus* species had prevalent rate of 8.6%, *Bacillus, Citrobacter, Providencia, Proteus, Salmonella, Serratia* and *Streptococcus* species had prevalent rate of 5.7% while *Buttiauxella, Cedecea, Enterococcus* and *Klebsiella* species had the least prevalent rate of 2.9%. More bacteria occurred in Station A with percentage of 46% followed by station B with percentage of 37% and Station C had less number of bacteria with percentage of 17%.

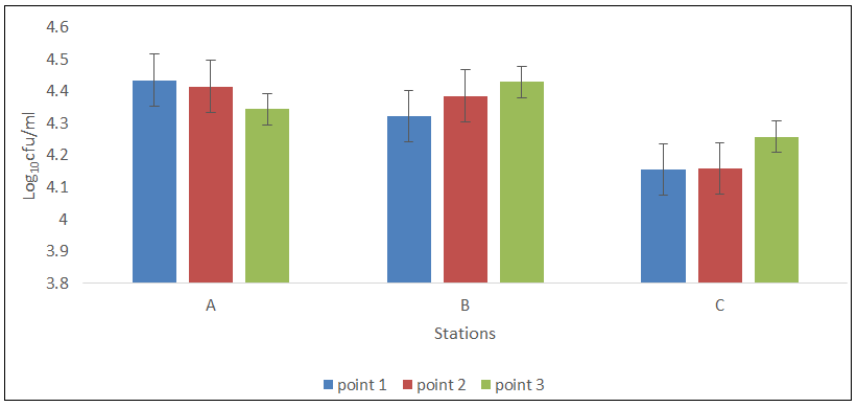

Fig-1: Mean densities of heterotrophic bacteria of 3 wells at the sampling stations
Allowable/permissible: <100cfu/ml

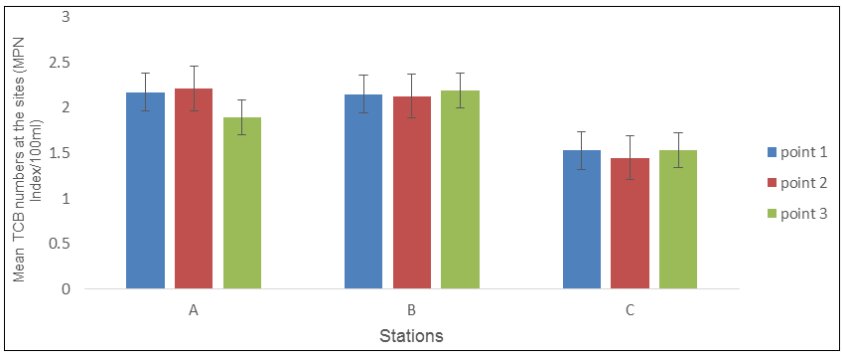

Fig-2: Mean numbers of Total Coliform Bacteria of 3 wells at the sampling stations
Allowable/permissible limits: 0-2coliforms/100ml

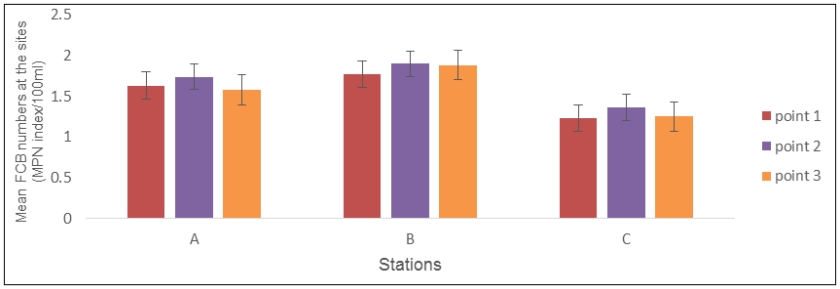

Fig-3: Mean number of Faecal Coliform Bacteria of 3 wells at the sampling stations
Allowable/permissible limits: 0 coliforms/100ml

Table-2: Number of bacterial species isolated from each station

Bacterial species	Percentage occurrence at the stations		
	A	B	C
Bacillus species	+	+	+
Buttiauxella ictalium	+	+	-
Cedecea neteri	+	+	+
Citrobacter species	+	+	+
Edwardsiella ictaluri	+	+	+
Enterobacter species	+	+	+
Enterococcus species	-	+	-
Escherichia. coli	+	+	+
Klebsiella singaporensis	+	-	-
Providencia rustigianii	+	+	-
Proteus myxofaciens	+	+	+
Pseudomonas species	+	+	+
Salmonella species	+	+	-
Serratia species	+	+	+
Staphylococcus species	+	+	+
Streptococcus species	+	+	-

DISCUSSION

Water quality analysis of hand dug wells in study communities was the focus of this work throughout the period of study. Some physical parameters were determined, total aerobic heterotrophic bacteria were enumerated and coliform bacteria were estimated in the well water samples.

Data obtained during the study showed that physicochemical parameters had various levels of concentrations. Values for pH of the sampled well waters were all within acidic range outside the maximum permitted range. This showed that the well waters of the study wells are acidic. The wells at station A had the lowest pH values followed by station B which had pH values higher than those of station C which are less acidic. Wells at station C had the highest pH values close to the minimum permissible range. Total alkalinity values were highest in station A followed by station C while station B had the lowest values; all the values were far lower than the maximum permissible limit. BOD values were generally lower in all the wells sampled. Station B had the highest BOD values and station C had the lowest values. Station A had BOD values between the other two stations. THC values were equal in all the wells and less than 0.02mg/l, which revealed absence of underground contamination by crude oil. The study area is crude oil-producing area however THC data showed little or no contamination of the underground water by hydrocarbon.

The well-to-well variations of physicochemical parameters showed that pH was highest in well 1 at station C and lowest in well 2 at station A. EC value was highest in well 3 at station A and lowest at station C in well 1. Highest value for total alkalinity was recorded in well 1 at station A and lowest value was recorded at station B in well 2. Total hardness was highest at station A in well 3 and lowest at station C in well 1. BOD value was highest at station B in well 1 and lowest at station A in well 1. Value of total hydrocarbon content was very low in all the wells studied. The physicochemical parameters were all lower than the maximum permissible levels. Results of statistical analysis showed significant difference ($P>0.05$) in the values of physicochemical parameters between the study wells and between the weekly samples; values for total hydrocarbon content showed no significant difference.

Counts of aerobic heterotrophic bacteria were generally higher than the permissible limits of 100cfu ml^{-1} for drinking water [22, 23, 7, 24]. All the wells sampled had different levels of heterotrophic bacterial densities; wells 1 and 2 at station A had the highest densities of heterotrophic bacteria when compared to the other stations except in well 3 at station B where the highest population of aerobic heterotrophic bacteria were recorded. The lowest bacterial counts were recorded in all wells at station C. Generally speaking, the high counts of aerobic heterotrophic bacteria could be attributed to the nature of construction of the wells which exposes them to external contamination from surrounding environments. Furthermore, no treatment process was applied to the well waters. This study revealed that wells at station A were most contaminated because they had highest counts of bacteria, followed by those of station B, while wells in station C had the lowest counts and probably less prone to contamination. Statistical analysis showed significant difference ($P<0.05$) in the counts of heterotrophic bacteria between the wells sampled and between the weekly samples.

The numbers of coliform bacteria recorded in all sampled wells at the three stations were higher than the permissible limits for a good drinking water. WHO [22, 23, 7, 24] standards recommended that total

coliform bacteria in potable water should be 0 - 2 coliforms per 100ml of water and faecal coliform bacteria should be 0 coliforms per 100ml. None of the water samples met these standards. Numbers of coliform bacteria were highest in wells 1 and 2 at station A and well 3 at station B but lowest in all wells at station C. The coliform group of bacteria particularly faecal coliform bacteria are used as indicators of faecal contamination and their presence in water indicates likely presence of intestinal pathogenic microorganisms of human or animal origin [8, 23, 7, 24]. Drinking of such water means ingestion of microbial organisms of public health significance. Hence, drinking well waters in this study area should be of public health concern. Statistical analysis showed significant difference ($P < 0.05$) in the numbers of coliform bacteria between the wells sampled and between the weekly samples.

Of the sixteen (16) bacterial genera isolated, *Edwardsiella* species and *Escherichia coli* were more prevalent followed by *Enterobacter*, *Pseudomonas* and *Staphylococcus* species. *Bacillus, Citrobacter, Providencia, Proteus, Salmonella, Serratia* and *Streptococcus* species were less prevalent while *Buttiauxella, Cedecea, Enterococcus* and *Klebsiella* species had the least prevalent rate. Most of the isolates occurred in Station A and Station B except *Enterococcus* species which did not occur in Station A and *Klebsiella* species which did not occur in station B. Less numbers of bacteria were isolated in Station C than the other stations during the study.

It should be noted that high counts of aerobic heterotrophic bacteria in the well waters revealed exposure of the wells to external contamination and absence of any known water treatment process. Many of the bacteria isolated during this study have been associated with diseases of public health concern such as bacillary dysentery, shigellosis, enteric fever, cholera, urinary tract infection, ulcers, skin infections, boils, burns, pulmonary infection and salmonellosis [25, 5]. The research also showed that hundred percent (100%) of the wells sampled were positive for both total and faecal coliform bacteria far above the permissible levels. High contamination of public water supplies with coliform bacteria indicates contamination by faecal matter which poses health risk to the users. The reason being that presence of coliform bacteria in any water source indicated likely presence of pathogenic microbes of enteric origin [22, 23, 7, 24]. The coliform group is an indicator bacteria used to evaluate the quality of drinking water and their presence indicates contact of water with sewage containing faecal matter [25, 5]. Results of this research showed that there was lesser microbial contamination at station C (Obuburu well waters) than at station A (Akabuka well waters) and station B (Obagi well waters) which had high microbial contamination. The high microbial contamination of the hand dug wells could be due to runoffs carrying leachates, faecal matters and other contaminants from nearby waste dumps, open vegetation and surrounding environments that find their way into the wells. This confirms the assertion made by previous researchers that high coliform population in well water samples are an indication of poor sanitary conditions which results from inadequate and unhygienic handling of solid wastes in the area leading to generation of high concentration of microbial organisms [2].

Concentrations of physicochemical parameters above the maximum permitted levels have been shown to have certain health impact [26]. However, the physicochemical parameters determined during this study were lower than the permissible limits and may have little or no associated health impact; even the low acidic pH observed in this study could be adjusted by addition of appropriate chemicals to the water.

In conclusion, the quality analysis of the well waters sampled showed that the greatest threat posed to the well waters could arise from microbiological contamination on the health of the inhabitants who use the waters as sources of drinking water. The well waters generally had high aerobic heterotrophic bacteria which showed exposure to external contamination and lack of proper treatment; high numbers of coliform bacteria particularly faecal coliform bacteria and other enteric pathogens such as *Salmonella* species revealed contacts of the water sources with faecal matter. The study revealed that the quality of the water samples was affected by the conditions of the immediate environment. All the well water samples in the vicinities contained faecal and total coliforms above the WHO stipulated limits for potable water. On the other hand, the physicochemical parameters analysed were below WHO guideline values for potable water. The well waters sampled failed to meet the WHO standards for potable water.

Hence, the hand dug wells without standard treatment are unfit for drinking and domestic uses. It is recommended that these wells be treated before use in order to eliminate pathogenic microbes as well as harmful chemicals and provide safe water for the inhabitants of the area. Also, wells in the study area should be constructed high above ground (at least 1 m) and sited at least 30 m away from any source of pollution to prevent runoffs and other contaminants from contaminating the wells. Intensification of education and implementation of regulations on safe drinking water by the agencies concerned will go a long way to reduce incidences of water-borne diseases. If the well waters must be used for drinking, they should be subjected to “boil water treatment order” before use by the inhabitants of the communities.

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