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Effectiveness of Different Hand-Dug Well Treatment Methods in a Typical Basement Complex Environment

Konwea, C.I. and Ajayi, O.
Department of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria.
Correspondence E-mail: onyekonwea@oauife.edu.ng

Abstract
The effectiveness of different treatment methods in the eradication of bacteria from contaminated hand-dug well within the crystalline rocks of Ile-Ife, Southwestern Nigeria was evaluated. Hydrogeological and geophysical investigations revealed that groundwater around the hand-dug well flowed from southeast to northwest. The area is underlain by four subsurface layers of topsoil, lateritic layer, clayey weathered layer, and fresh basement rock, with thicknesses of 3.2 m, 5.0 m and 35.7 m, respectively. Mechanical treatment of the hand-dug well was not effective as the most probable number (MPN) of bacteria count went from 150 cells/100 ml before treatment to 270 cells/100 ml after two weeks of treatment. Single and multiple chemical dosage treatment methods using chlorine of 0.5 mg/L were employed. Single dosage method reduced the MPN of bacteria count to 75 cells/100 ml, but did not eradicate the bacteria. The multiple chemical dosage method completely eradicated the bacteria, giving a MPN of bacteria count of 0 cells/100 ml. The multiple chemical dosage method was the most effective in the treatment of the contaminated hand-dug well.

Keywords: *Hand-dug well, groundwater contamination, water treatment, chlorination, bacteria count, crystalline rock*

Introduction

There has been, in recent times, an increase in the demand for potable water supply. Surface water supply is easily prone to contamination from surface processes. These surface processes include agricultural, mining and industrial activities, as well as indiscriminate waste disposal. These activities have deteriorated the quality of surface water (Fatoki and Ogunfowokan, 1993; Ogunkoya and Aboyeji, 2014). Due to the fact that surface water occur in restricted locations along river course, its availability is therefore subject to proximity.

The quality of surface water bodies in Nigeria has deteriorated greatly in its physical, chemical and biological properties (Isikwue *et al.*, 2011). This is greatly due to surface processes arising from human activities (Fatoki and Ogunfowokan, 1993, Tirima *et al.*, 2016; Hassan *et al.*, 2015).

With population growth and urbanization especially in Southwestern Nigeria, more water is required to meet the growing demand. In Ile-Ife area of Osun State, Southwestern Nigeria, for example, studies have shown that between 1996 and 2006, there has been a 200 % increase in land use area and a corresponding increase in population from 186,856 in 1991 to 355,818 in 2006 (National Population Commission, 2010). The population growth and urbanization have led to the physical, chemical and biological degradation of River Opa in Ile-Ife (Fatoki and Ogunfowokan, 1993; Ogunkoya and Aboyeji, 2014).

The shortfall in the quantity and quality of surface water around the Ile-Ife area is augmented by pipe borne water supply. The pipe borne water supply to Ile-Ife is from the Ede water works. There has, however, been a growing challenge in the pipe borne water supply to Ile-Ife community. Most homes have now resorted to groundwater exploitation through boreholes and hand-dug wells to meet up with their water need (Adekunle, 2008, Adelekan, 2010). Boreholes require high level skill to construct and are more expensive to develop and maintain than hand-dug wells (Sonou, 1997; Danert *et al.*, 2009; Oyebode *et al.*, 2015), hence hand-dug wells are common sights in the homes of middle and low income earners in Ile-Ife.

Even with groundwater exploitation, the problem of water quality still persists (Cobbina *et al.*, 2014). Groundwater contamination occurs when there is an artificially induced degradation of the natural groundwater quality. Sources of groundwater contamination can be grouped into municipal, industrial, agricultural, and miscellaneous sources (Todd and May, 2005).

Over 1.1 billion people across the world have no access to potable water supply (Mintz *et al.,* 2001). Lack of potable water supply has led to several water borne diseases such as diarrhoea, cholera, syphilis, and typhoid. Records have it that an estimated 500 million cases of diarrhoea occur annually among children below the age of 5 in Africa, Asia and Latin America, while over 40 % deaths in developing countries are attributed to infections from water related diseases (Adejuwon and

Mbuk, 2011). In the light of these, there is a dire need to maintain the quality of water accessible to man. This study therefore aims to assess the effectiveness of different treatment methods in the treatment of contaminated hand-dug well.

Study Area

The site is located off Hezekiah Oluwasanmi Road (Road 7), Eleyele, Ile-Ife, Ife Central Local Government Area of Osun State, Southwestern Nigeria. The site falls on latitude 07° 30' 493" N and longitude 04° 32' 856" E (Fig. 1). Ile-Ife community is largely occupied by staff and students of the Obafemi Awolowo University, as well as the local inhabitants. The ancient city of Ile-Ife is underlain by crystalline Basement Complex rocks of Southwestern Nigeria. These crystalline rocks are relatively impermeable hence can only accommodate groundwater in fissures or in the superficial weathered zones. The site is underlain by mica schist (Fig. 1), composed basically of quarts, feldspar, biotite and muscovite. The site is accessible through Road 7, west of the Obafemi Awolowo University gate linking the Opa and Sabo areas of Ile-Ife (Fig. 2).

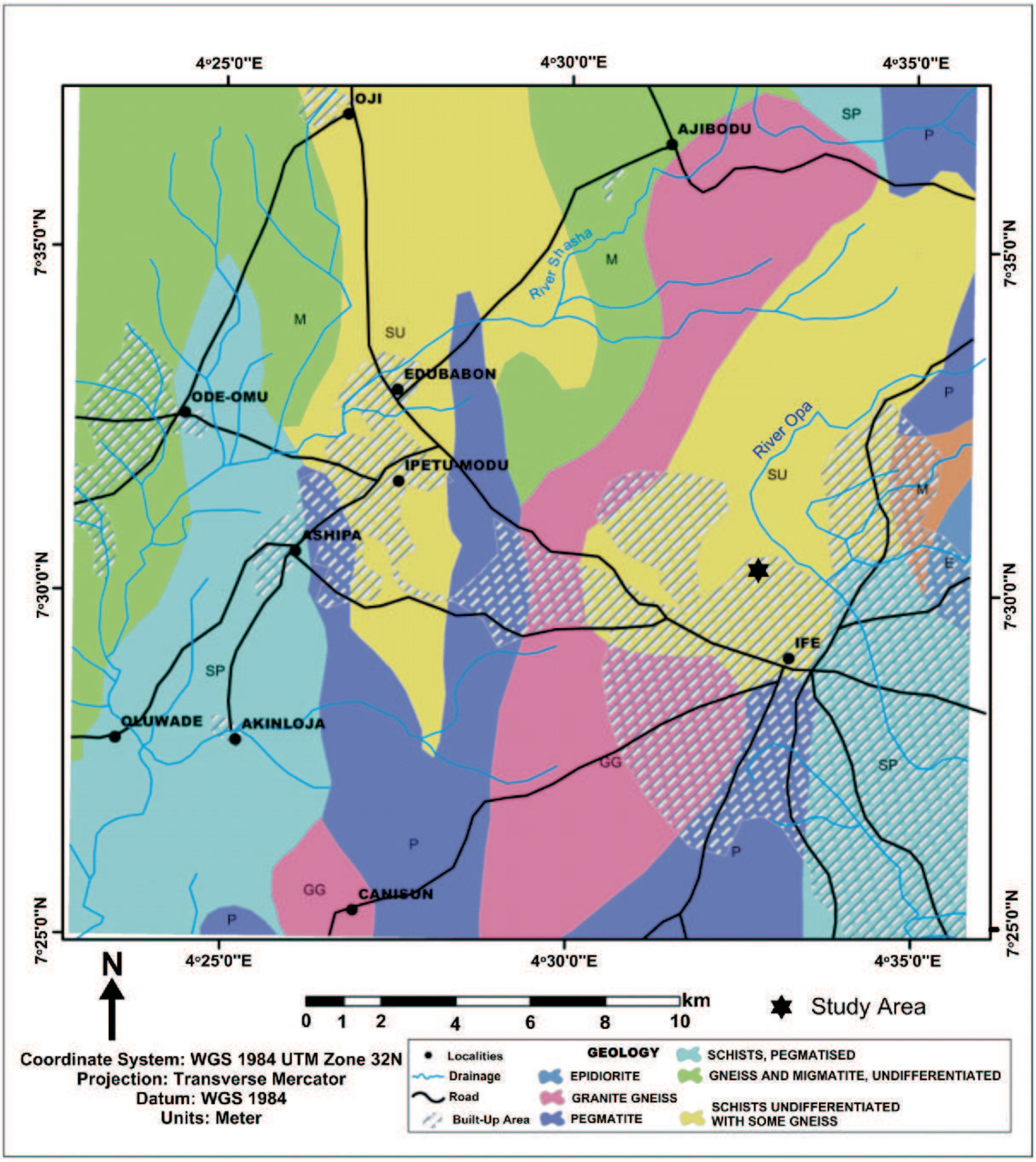

Fig. 1: Geological Map of Ile-Ife and Environs (Modified after NGSA, 1966)

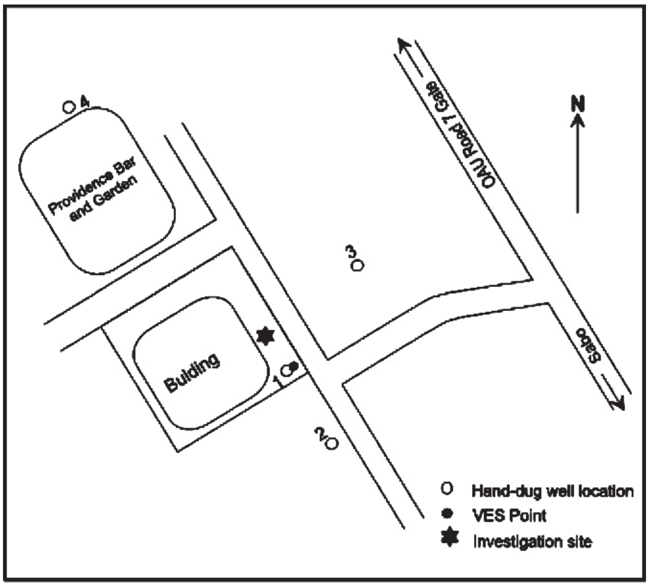

Fig. 2: Sketch of Study Area Showing Hand-Dug Well Locations

Materials and Methods

Hydrogeological and geophysical investigations of the study area were carried out to determine the groundwater occurrence and flow system around the study location. Hydrogeological investigation involved inventory and inspection of hand-dug wells around the site. Depth to static water level and total dug depths of hand-dug wells were obtained using a steel tape. Vertical Electrical Sounding (VES) technique of the Electrical Resistivity method of geophysical investigation was employed to probe the subsurface. The VES data obtained were analysed and the result was used to model the subsurface layers. Mechanical and chemical treatment of the hand-dug well was carried out. Groundwater samples were collected after each treatment using 750 ml plastic bottle. Microbial analysis was carried out on the groundwater samples, and the most suitable hand-dug well treatment method was established.

Results and Discussions

Hydrogeological Setting

The study location is a typical Basement Complex environment underlain by mica schist (Fig. 1). The basement rock is overlain by weathered regolith. Four (4) hand-dug wells were investigated around the study location (Fig. 2). The data obtained is as shown in Table 1. Analysis of the depths to static water level from the four (4) hand-dug wells revealed that groundwater flow from southeast to northwest direction around the study location (Fig. 3). The VES survey was carried out at the location of the hand-dug well under investigation (Fig. 2). The VES data were acquired using the ABEM 300 terrameter, with a spread of 150 m. The data obtained from the VES survey were interpreted manually and iterated using the WINRESIST software (Fig. 4). The interpretation of the VES data revealed that the area is underlain by four subsurface layers: the topsoil with layer resistivity of 54 Ωm – 89 Ωm and thickness of 3.2 m; lateritic layer with resistivity of 233 Ωm and thickness of 5.0 m; clayey weathered layer with resistivity of 53 Ωm and thickness of 35.7 m, and the fresh basement with resistivity of > 1000 Ωm. The clayey weathered layer constitutes the aquifer unit. The hand-dug well under investigation was constructed within a residential area to supply water to a one storey building for domestic purposes. The hand-dug well was completed on the 28th of March, 2019. The hand-dug well was dug manually to a depth of 11.6 m. The hole was cased top to bottom with cylindrical concrete rings of 1.2 m and 0.8 m external and internal diameters, respectively. The concrete rings extend above the ground level, giving the hand-dug well an elevation of 0.8 m above the ground level. A circular concrete slab with square opening at the centre was used to seal the top of the hand-dug well. The 0.3 m square opening provided access to the hand-dug well for groundwater extraction. The opening was fitted with metallic cover which could be locked to protect the hand-dug well. The well was fitted with submersible pump of 1.0 hp connected to a 3,000 L overhead tank. The pump was installed at a depth of 10.5 m. The pump supplied groundwater at the rate of 0.5 Ls^{-1}, hence it took about 100 minutes to fill the overhead tank.

Table 1: Hand-Dug Well Data

Hand-Dug Well	Location	Elevation (m)	Total Dug Depth (m)	Static Water Level (m)
1	07° 30' 493" N 04° 32' 856" E	257	11.6	7.6
2	07° 30' 491" N 04° 32' 857" E	257	10.2	6.7
3	07° 30' 494" N 04° 32' 858" E	257	13.5	7.5
4	07° 30' 495" N 04° 32' 853" E	257	11.4	8.4

Microbial Analysis

The hand-dug well was the only source of water supply to the residential building. Since the plumbing work for the building was not completed, the artisans involved in the building construction work collect water manually from the well using a plastic bucket tied to a rope. Arising from the verbal report that the bucket used to collect water from the hand-dug well had previously

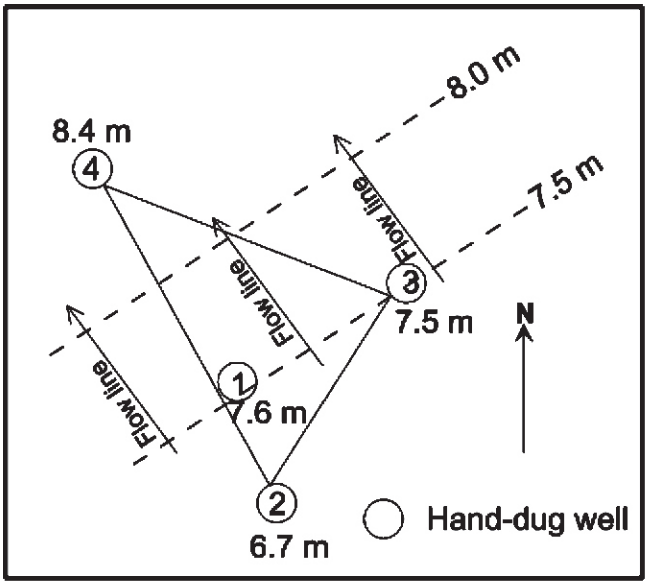

Fig. 3: Groundwater Flow Direction

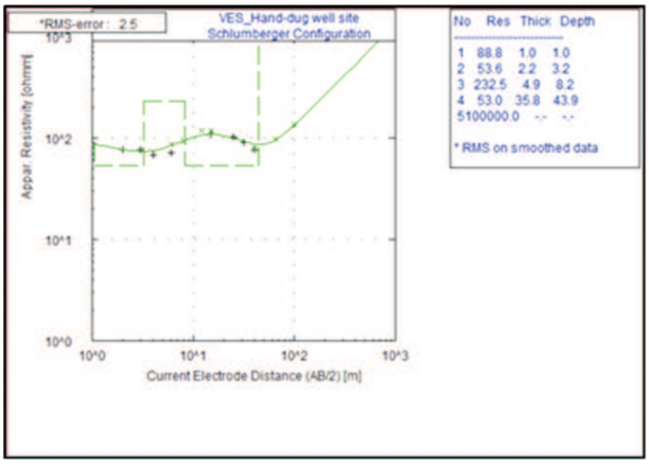

Fig. 4: VES Model of Study Area

been used to empty a sewage pond, the hand-dug well was suspected to have been contaminated and the groundwater within it polluted. Groundwater sample from the hand-dug well was subjected to microbial analysis in the Department of Microbiology, Obafemi Awolowo University, Ile-Ife, Nigeria.

The microbial analysis was aimed at determining the most probable number (MPN) of coliform in the groundwater sample. The result of the microbial analysis revealed that the hand-dug well has been contaminated with bacteria with concentration of 150 cells/100 ml. Microbial contamination of water causes chronic diseases such as diarrheal, cholera, typhoid, headache and nausea, and, in some cases, can lead to death. The WHO (2008) and USEPA (2009) standards for potable water recommended that total coliform bacteria must not be detected in any 100 ml water, hence the groundwater from the hand-dug well is not suitable for drinking.

Source of Hand-Dug Well Contamination

The hand-dug well in this study was constructed within a residential area devoid of agricultural and industrial activities. There were no municipal wastes (Septic tank and sanitary landfill) within a 20 m radius of the hand-dug well in this study. However, since the hand-dug well was constructed within mica schist, any municipal waste system will be located within the clayey weathered material with low permeability. The clayey material above the aquifer unit provides good attenuation effect on any contaminant percolating through the topsoil. The processes involved in attenuation of contaminant include filtration, sorption, chemical processes to break down contaminant, microbiological decomposition, and dilution (Todd and May, 2005). The hand-dug well in this study is insulated from municipal waste contamination. Since the site is a residential area, industrial and agricultural sources of contamination of the hand-dug well were also ruled out. The possibility of the hand-dug well being contaminated via backflow from carbon filters and leaking well caps (Nkansah *et al.,* 2010) were equally ruled out since the plumbing work was on-going as at the time of contamination. The hand-dug well has an elevation of 0.8 m above the ground level, hence contamination of the hand-dug well through surface runoff was not likely, although, the area is neither threatened by flooding nor erosion. Unsecured and open hand-dug wells are prone to contamination through injection of materials. Having eliminated other likely sources of contamination of this properly covered and secured hand-dug well, the most probable source of contamination is through material injection.

Hand-Dug Well Treatment Plans

Most microorganisms such as viruses and bacteria do not flourish outside a host. The host of microorganisms are higher organisms and media where they could get nutrient and thrive. Outside their host, microorganisms are destroyed. The rate of survival of bacteria outside a host vary from one specie to another (Todd and May, 2005), although their survival in different environments have not been well understood due to difficulty in monitoring specific species in complex mixed population (Banning *et al.,* 2002). Bacteria float on water bodies and are easily filtered out of the water especially when the water flows through soil. Clayey and silty materials are more effective filters than sandy and gravelly materials (Todd and May, 2005).

Treatment of hand-dug well contaminated with bacteria obtained via the injection of contaminated material can be carried out through mechanical or chemical methods. Mechanical treatment involves the complete extraction of the water within the hand-dug well. Chemical treatment of the hand-dug well involves the use of disinfectants such as chlorine (Melvin *et al*., 1967), iodine or passing the water through germicidal ultraviolet (UV) light under a low pressure lamp (Hijnen *et al.,* 2006; Bergmann *et al*., 2002). An adequate dosage of chemical is essential as excess dosage will give a bad taste to the water, while lesser dosage will not completely disinfect the water (Snoeyink and Jenkins, 1980).

Mechanical Treatment

The mechanical treatment of the hand-dug well was carried out by evacuating the entire volume of groundwater in the hand-dug well. The total volume of water in the hand-dug well was estimated using Equation 1.

$$\textit{Volume of water} = \Pi r^2 h \text{ ....(1)}$$

where,
r = radius of the hand-dug well
h = total depth of hand-dug well – static water level

With an internal diameter of 0.8 m, total dug depth of 11.6 m and static water level of 7.5 m; the volume of water in the hand-dug well was estimated at 2.1 m^3 (2100 L). At a flow rate of 0.5 L (5.0×10^{-4} m^3/s), it would take 4,200 s (70 min) to evacuate the 2.1 m^3 of water in the hand-dug well. The hand-dug well was therefore pumped for 140 min to evacuate twice the volume of the water in the hand-dug well. Twice the volume of water in the hand-dug well was evacuated to account for processes of replication of the bacteria and dilution effect during the pumping.

Groundwater sampling and analysis were carried out after two weeks of treatment. The time lapse was to allow for considerable replication of any bacteria still present in the hand-dug well. Microbial analysis revealed that the hand-dug well was still contaminated with bacteria. The MPN of coliform in the groundwater sample was 290 cells/100 ml.

Chemical Treatment

Chlorine was used as the disinfectant because it is relatively cheaper and readily available. Chlorination of 0.2 – 0.5 mg/L is required for water treatment. The upper limit of the concentration is used for surface water treatment or groundwater with sudden pollution with microorganism (Brandt *et al*., 2017). Water with chlorine concentration of less than 0.2 mg/L is prone to microorganism infection (WHO, 2017). Excess chlorine in water impacts taste and odour. Substantial contact or residence time is required for the chlorine to kill the microorganisms and thus disinfect the water body.

Single dosage of the hand-dug well was carried out. At a static water level of 7.5 m, the volume of water in the hand-dug well was estimated at 2.10 m^3 (2100 L). Chlorination of 0.5 mg/L was carried out by first dissolving 1050 mg of chlorine powder in some quantity of water using a 750 ml plastic bottle before pouring into the hand-dug well.

The contact time of the chlorine was estimated using Equation 2.

$$\textit{Contact time} = \frac{\textit{Volume of water in storage}}{\textit{Consumption rate}} \text{ ....(2)}$$

where,
Volume of water in storage = 2.10 m^3 (2100 L).
Consumption rate = Number of daily users (5) x per capita daily water need (0.085 m^3day^{-1}) = 0.425 m^3day^{-1}

$$\textit{Contact time} = \frac{2.10\ \mathbf{m^3}}{0.425\ \mathbf{m^3 day^{-1}}} = 4.94\ \textit{days} \text{ ...(3)}$$

At the time of dosage, there were 5 persons using the hand-dug well. At per capita daily usage of 0.085 m^3day^{-1} (NDHS, 2003), the consumption rate of the groundwater in the hand-dug well was 0.425 m^3day^{-1}. The chlorination of 0.5 mg/L in the hand-dug well had a contact period of 4.94 days. With a contact time of 5 days, groundwater sampling and analysis were carried out after 5 days.

The results of the microbial analysis of the groundwater sample after single chlorination dosage of 0.5 mg/L revealed that the hand-dug well was still contaminated with bacteria. The MPN of coliform in the groundwater samples was 75 cells/100 ml.

The hand-dug well was again sampled after 14 days to confirm if the concentration of bacteria in the groundwater will continue to decrease, increase or remain static. The result of the microbial analysis revealed that the MPN of coliform in the groundwater sample was 290 cells/100 ml. The concentration of the bacteria in the groundwater sample increased from 75 cells/100 ml to 290 cells/100 ml. This indicates that as long as traces of the bacteria are still remaining in the hand-dug well, the concentration will continue to increase as the contact time lapses.

Multiple chlorination dosage of the hand-dug well was carried out since the single chlorination dosage did not completely eradicate the bacteria. Three (3) successive chlorination dosages were carried out in the hand-dug well, using 0.5 mg/L of chlorine (Table 2). The average contact time of the chlorination was 4 days, hence the chlorination was carried out at intervals of four days.

At the lapse of the contact time of the third chlorination dosage, groundwater sampling and analysis were carried out. The result of the microbial analysis revealed that the MPN of coliform in the groundwater sample was 0 cells/100 ml.

Table 2: Multiple Chlorination Parameters

S/N	SWL (m)	Volume of groundwater (m^3)	Mass of Cl (mg)	Concentration of Cl (mg/L)	Contact time (days)
1	7.9	1.86	930	0.5	4.4
2	8.1	1.76	880	0.5	4.1
3	8.3	1.66	830	0.5	3.9

Conclusions

Mechanical and chemical treatments of the hand-dug well contaminated with bacteria were carried out within the crystalline Basement Complex rock of Ile-Ife, Southwestern Nigeria. Mechanical treatment involving the evacuation of the groundwater in storage within the hand-dug well was not effective in the treatment of the hand-dug well. Single dose chemical treatment with 0.5 mg/L of chlorine proved effective in reducing the concentration of the bacteria from 290 cells/100 ml to 75 cells/100 ml, but did not completely eradicate the bacteria. Multiple dosage treatment involving three successive chlorination dosages with 0.5 mg/L of chlorine proved effective in eradicating the bacteria to a concentration of 0 cells/100 ml. The result of this investigation is only applicable for hand-dug well contaminated via direct injection of contaminant. It may not apply for hand-dug well tapping from a contaminated aquifer.

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