Pollution, 4(3): 429-438, Summer 2018
DOI: 10.22059/poll.2017.243578.331
Print ISSN: 2383-451X Online ISSN: 2383-4501
Web Page: https://jpoll.ut.ac.ir, Email: jpoll@ut.ac.ir

Assessment of Heavy Metals and Microbial Load of Groundwater Samples from Ibadan Metropolis Nigeria

Salaudeen, I. A. [1*], Ogunbamowo, P. O. [2], Rasheed-Adeleke, A. A.[1], Olaniyi, A. A.[1]

1. The Polytechnic, Ibadan, P.M.B 22, UI Post Office, Ibadan Oyo State Nigeria

2. Forestry Research Institute of Nigeria, PMB 5054, Jericho hill Ibadan, Oyo State Nigeria

Received: 13.10.2017 Accepted: 29.11.2017

ABSTRACT: The present study investigates groundwater quality in terms of heavy metals level and microbial contamination as well as the impact of bleaching powder on microbial load of groundwater samples in close proximity to a surface water body inside selected areas of Ibadan Nigeria. To do so, it collects nine water samples from three boreholes and six hand-dug wells from six locations, namely Eleyele, Wofun-Olodo, Oluyole Industrial Estate, Ogunpa, Olorunsogo, and Ojoo, keeping them in 750 mL plastic bottles. The samples are then divided by two, giving a total amount of 18 samples, with 3 and 6 duplicates apiece being treated with bleaching powder and the rest remaining untreated. Both sample sets have been analysed for water quality parameters such as pH, biochemical oxygen demand, and chemical oxygen demand, assessed using standard methods. The coliform count has been determined, using the pour plate method while heavy metal has been set by means of Atomic Absorption Spectrophotometer (AAS) after nitric acid digestion. Results show that the pH ranges within 6.0-6.5, BOD within 1.67-4.33mg of O_2/L, and COD within 2.93-9.43, while heavy metal concentration is from 0.013 to 0.047 mg/L for lead, ND to 0.023 mg/L for chromium, and ND to 0.010 for cadmium. What is more, the coliform count in the samples is between 0.00 and 913.33 CFU/mL. Most of the samples exceed the WHO limits for heavy metals in drinking water, having significant levels of microbial contamination. Bleaching powder treatment alleviated the level of pollution to varying degrees; therefore, constant monitoring of groundwater source and treatment before drinking is of utmost importance.

Keywords: Groundwater, Heavy metals, Bleaching powder, Microbial load, Ibadan.

INTRODUCTION

Over 70% of the surface of the Earth is covered by water, the importance of which for life cannot be overemphasized. Being an essential resource necessary to sustain both life and the environment, water is also a vital component of healthy function of any ecosystem (Pimentel et al., 2004; Selvam et al., 2017), and having access to safe drinking water is essential for health, being considered a basic human right (Hunter et al., 2010; WHO, 2011; Bain et al., 2014).

In many places in the world, groundwater serves as a major source of water both for drinking and other uses (Egbinola & Amanambu, 2014). Globally, between 25% and 40% of world's drinking water comes from boreholes and dug wells. Groundwater is a term, used to describe the water present

* Corresponding Author, Email: salaudeenibra@yahoo.com, timilolo@yahoo.co.uk

below the ground surface, saturating the pore spaces in the subsurface.

As a result of governments' inability to meet the ever-increasing water demand, a large percentage of people in developing countries resort to groundwater sources such as boreholes and dug wells as an alternative source of water for their various uses; therefore, humans can pump groundwater through a borehole, drilled into the aquifer for domestic, industrial, and agricultural uses (Momodu and Anyakora, 2010; Palamuleni and Akoth, 2015). In terms of access to sources of water in Nigeria, it has been shown that 48% of the total population (about 67 million Nigerians) depend on surface water for domestic use, with 57% (79 million) using hand-dug wells; 20% (27.8 million), harvest rain. About 14% (19.5 million) have access to pipe-borne water, and 14% to borehole water sources (FGN, 2007). However, groundwater sources especially hand-dug wells are widely observed to be vulnerable to pollution, which may degrade their quality. Furthermore, anthropogenic activities can change the natural composition of groundwater through disposal or dissemination of microbial matter and chemicals on the land surface and into soils, or through injection of wastes directly into groundwater. Additionally, pesticides and fertilizers, applied to lawns and crops, can get accumulated and flow into water tables, thus affecting physical, chemical, and microbial quality of water (Palamuleni and Akoth, 2015). Current practices like spills from industrial operations, infiltration from urban runoff, uncontrolled and improper waste disposal, leaking from landfills, dumpsites, and abattoir wastes could also contribute to the pollution of groundwater sources. Contamination of groundwater with heavy metal, originating either from natural sources, which are leached from rocks and soils according to their geological mobility, or from anthropogenic sources as a result of human land occupation and industrial operation is a matter of utmost concern to public health (Hashim et al, 2011; Ocheri et al., 2014). Waterborne diseases like cholera and typhoid have killed millions of people, especially the children, in the past, still causing many problems in less developed countries (Manahan, 2000; Hunter et al., 2010).

In rural Africa, the microbial quality of groundwater is threatened due to the use of pit latrines as well as citing of wells and boreholes in close proximity to septic tanks, solid wastes dumpsite, and other diverse source of organic pollution (Palamuleni and Akoth, 2015). Dumping sites, particularly for municipal wastes, are known to produce leachates that move to adjacdent areas, resulting in gross pollution of soil, surface water, and ultimately groundwater (Awajiogak, 2013).

Consequently, water-related diseases continue to be one of the major health challenges all over Africa. According to Macler and Merkle, (2000), a significant fraction of all waterborne disease outbreaks is associated with groundwater. Controlling these pathogens starts with source-water protection activities to prevent fecal contamination of aquifers and wells, which includes assessment of wellhead vulnerability to fecal contamination and correction of identified deficiencies. Amendment may include controlling sources or rehabilitation of the well, itself. Disinfection has been noted to serve as a useful barrier, recommended as a prudent public-health policy for all groundwater systems (Macler and Merkle, 2000). Chlorination is a disinfection method, generally employed to reduce the level of microorganisms that can cause diseases, existing in the water, by means of a concentrated liquid chlorine solution. Improving the quality of groundwater resources offers an important economic opportunity for gradual improvement of life quality in rural dryland communities. In order to develop strategies to diminish or eliminate microbiological contamination in groundwater wells, it is primarily necessary to assess the variability of its concentrations along with the relative importance of different factors, affecting pollution (Valenzuela et al., 2009).

Thus, it is tremendously important to monitor and test groundwater quality, focusing on research activities both in the developed and developing world in order to find effective solutions to purify drinking water. It is against this background that the present study has been conducted to access some ground water quality parameters, heavy metal pollution, and microbial load, not to mention the impact of bleaching powder treatment on groundwater quality within selected areas in Ibadan, purposely chosen to reflect the influence of the major activity, observed within the areas.

MATERIALS AND METHODS

In total 9 groundwater samples from 3 boreholes and 6 hand dug wells were collected from the following 6 locations: Eleyele, Wofun-Olodo, Oluyole Industrial Estate, Ogunpa, Olorunsogo, and Ojoo. The samples were divided into two, giving 18 samples, which were collected purposely within an area, almost 20 metres in radius from the known surface water body which were inside the locations. Water samples were collected from the selected hand-dug wells and boreholes into 750 mL plastic bottles. Out of the 3 boreholes and 6 hand-dug well samples, 3 and 6 duplicates apiece were treated, using bleaching powder, while the rest remained untreated. Both samples were then analysed for some water quality parameters as well as microbial, and heavy metal contamination.

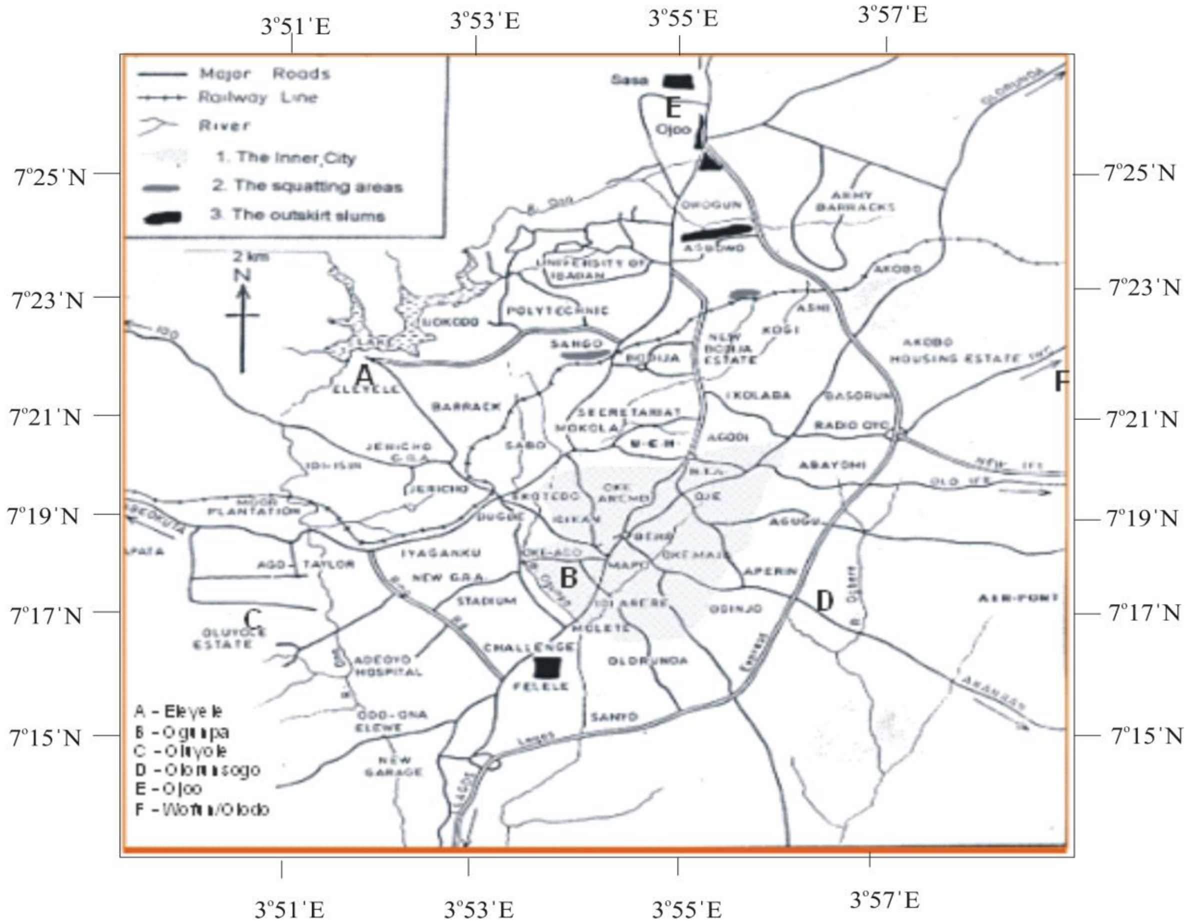

Fig. 1. Map of the Study Area and the sampling point.

The dose of the bleaching powder was estimated by means of a solution of the bleaching powder (in which 40g of chlorinated lime in 1L of distilled water was needed to prepare an 1% solution), after which the amount required to disinfect 1L of sample water sample was determined, using standard titrimetric method with sodium thiosulphate solution. The chlorine demand was thus calculated as chlorine consumption (obtained from titration) + desired residual chlorine. This value was used to treat the water, prior to further analysis.

The pH of the samples was analysed, using a Jenway 205 pH-meter. The degree of oxygen consumption by microbial-mediated oxidation of contaminants in water is called Biochemical Oxygen Demand (BOD) which is commonly measured through determining the amount of oxygen, utilized by suitable aquatic microorganisms within a five-day period. Despite the somewhat arbitrary five-day period, this test remained a respectable measure of the short-term oxygen demand, exerted by a pollutant. BOD was determined by adding a microbial "seed" to the diluted sample, which is in turn saturated with air and incubated for five days, and by determining the remaining oxygen. The results were calculated to show BOD as mg/L of O_2 (Manahan, 2000).

Chemical Oxygen Demand (COD) did not differentiate between biologically-available and inert organic matter, being a measure of the total quantity of oxygen, required to oxidize all organic material into carbon dioxide and water.

Both untreated and treated water samples were analysed immediately after collection for the sake of coliform count by plate count, using pour plate method in accordance with the standard method described by Clesceri et al. (1998) as well as the results, expressed in Colony Forming Units (CFU) per 100mL. One mL of the water samples was dispensed into a sterile petri dish through a sterile pipette, followed by 15-20mL of sterile nutrient agar to get thoroughly mixed via gentle swirling. The dish was then incubated at 37°C for 18-24hours. The number of colonies, growing in the agar plates, was then counted. The isolates were identified after examining their cultural, morphological, biochemical, and physiological characteristics, including their microscopic and macroscopic examination.

For heavy metal analysis, samples were digested, using concentrated nitric acid. Afterwards, the digested water samples were analysed, using Atomic Absorption Spectrophotometer Varians 730-ES model, the detection limit of which was 0.001ppm for toxic metals such as lead, cadmium, and chromium (Momodu and Anyakora, 2010).

All samples were analysed in triplicates, and results were subjected to statistical analysis (student's t test, ANOVA), using SPSS v. 17, where necessary.

RESULTS AND DISCUSSION

The pH of all untreated hand-dug well samples ranged from 6.0 to 8.5, while that of boreholes was between 6.0 and 8.0. Figure 2 presents the results of Biochemical Oxygen Demand and Chemical Oxygen Demand for both treated and untreated water samples from different locations. BOD of untreated hand-dug well samples was between 1.67 and 4.33mg of O_2/L, while for boreholes it ranged from 2.10 to 3.57 mg of O_2/L. As for treated samples, the BOD of the hand-dug wells ranged from 1.13 to 3.40 mg of O_2/L and from 1.47 to 2.23 mg of O_2/L for boreholes ones. The COD of untreated well water samples was between 2.93 and 9.43 mg of O_2/L and between 4.47 and 6.73 mg of O_2/L for untreated boreholes, while the COD for treated well water and borehole samples ranged from 2.03 to 5.77 mg of O_2/L and 2.37 to 4.20 mg of O_2/L, respectively.

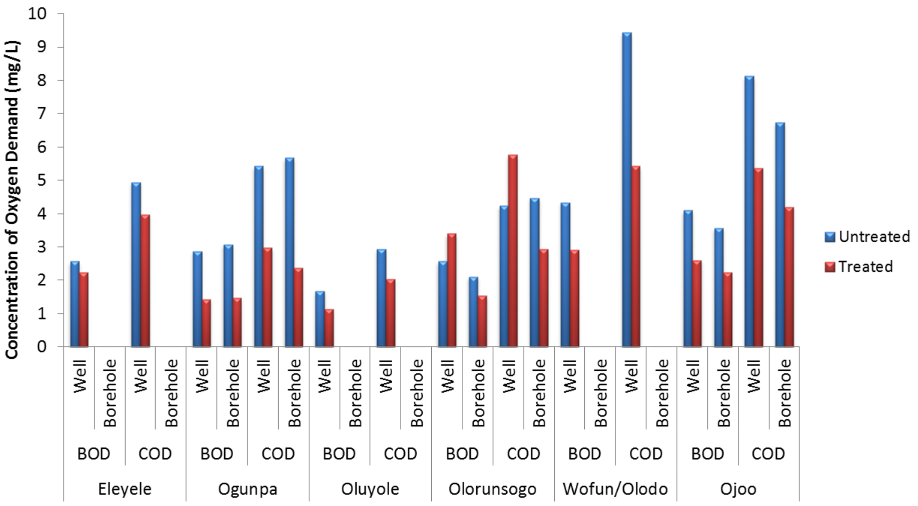

Fig. 2. Comparative BOD and COD of treated and untreated groundwater samples from different locations in ibadan metropolis

Figure 3 gives the results of heavy metal analysis for all water samples. Concentration of lead in the untreated well water samples ranged within 0.013-0.047 mg/L and 0.020-0.033 mg/L in untreated well and borehole samples, respectively, whereas in treated ones, it was changed to 0.010-0.023 mg/L and 0.013-0.020 mg/L. The concentration of chromium in untreated well water and borehole samples was within Not Detected (ND)-0.023 mg/L and ND-0.010 mg/L, respectively, while this became ND-0.013 mg/L and ND-0.010 mg/L in the treated ones. The concentration of cadmium ranged between ND and 0.010 in both untreated well and borehole water samples, while it was not detected in treated borehole samples.

Table 1 shows the results of microbial analysis. The coliform count in untreated well water samples turned out to be from 0.00 to 913.33 CFU/mL, and from 0.00 to 273.33 CFU/mL for untreated well water and borehole samples, respectively; while for the treated water samples it ranged within 0.00-590.00 CFU/mL and 0.00-173.33 CFU/mL. Organisms, isolated from some of the samples, included *Aeromonas sp* (majorly present in Eleyele, Ogunpa, Ojoo, and Oluyole Samples), *Proteus sp*, and *enterobacter sp*.

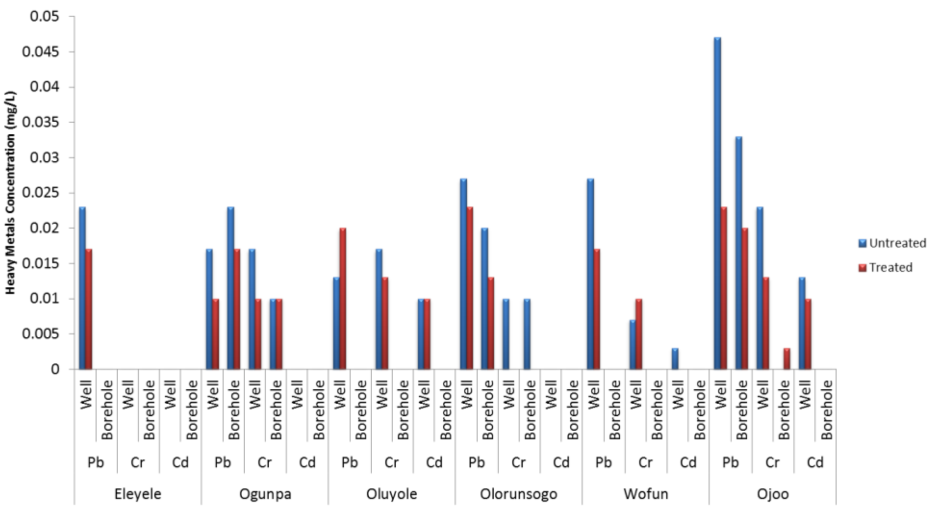

Fig. 3. Comparative heavy metal concentration in treated and untreated groundwater samples

Table 1. Results of microbial analysis

Sampling Point	Treatment	Source	Coliform Count(CFUs/mL)
Eleyele	Untreated	Well	286.67±37.86
	Treated		176.67±25.17
Ogunpa	Untreated	Well	830.00±137.48
		Borehole	350.00±62.45
	Treated	Well	590.00±121.24
		Borehole	113.33±100.17
Oluyole	Untreated	Well	913.33±41.63
	Treated		500.00±168.23
Olorunsogo	Untreated	Well	0.00
		Borehole	0.00
	Treated	Well	0.00
		Borehole	0.00
Wofun/Olodo	Untreated	Well	0.00
	Treated		0.00
Ojoo	Untreated	Well	763.33±75.06
		Borehole	273.33±191.40
	Treated	Well	343.33±60.28
		Borehole	173.33±60.28
WHO			Nil

Contaminated drinking groundwater can have serious health effects, thus causing a public health concern for many governments, especially in developing countries. It is, therefore, essential to carry out constant surveillance of drinking water in other to ensure good water quality, prompt detection of water contamination, and potential sources of contamination. Nearly all bodies of surface-water (streams, lakes, reservoirs, wetlands, and estuaries) interact with groundwater, which may take many forms. In many situations, surface water bodies obtain both water and solutes from ground-water systems, while in others the surface-water body, itself, is a source of ground-water recharge, causing some changes in ground-water quality. This study highlighted the potential impact of surface water pollution on groundwater quality as well as the impact of bleaching powder treatment on the samples. The pH is a measure of acidity or alkalinity of water sample, being a very important parameter as it can not only enhance the toxicity of certain heavy metals at certain pH but also its control is one of the factors, considered in the biological treatment of water, (Lokhande et al. 2011). The pH of all groundwater samples were within the recommended range of 6.5-8.5, specified by the World Health Organization (2004) and Nigerian Standard for drinking water (NSDQW, 2007), except for well and borehole samples from Olorunsogo which was 6.0.

Biochemical Oxygen Demand (BOD) is an index of organic pollution, measuring the amount of dissolved oxygen needed by aerobic biological organisms to break down organic materials present in a given water sample at a certain temperature and over a specific period of time. Thus, BOD was measured in this study as an index of organic pollutants and its degrading microbes seeping either through nearby river or surrounding pollution. Thus, higher BOD may suggest more microorganisms, which in turn means the presence of more organic wastes in the water (Prajapati and Dwived, 2016), whereas lower concentration of BOD indicates good quality water. BOD of the untreated groundwater samples in the study locations ranged between 1.67 and 4.33 mg of O_2/L, comparable to the range reported by Alabi et al,, (2013) for groundwater samples in Sagamu, Ogun State Nigeria along with the one in the study by Ramaiah et al., (2014) on leachate characterization and assessment of groundwater pollution near municipal solid waste in Bangalore, India. The range of BOD concentration in this study was also very low, compared to the one reported by Adewoyin et al., (2013) for groundwater in auto-mechanic village, thus highlighting the potential impact of pollutants seeping into groundwater sources. For the treated samples, BOD of groundwater samples was from 1.13 to 3.40 mg of O_2/L, showing a slight reduction that is likely due to the impact of bleaching powder solution, used in treatment of ground water samples with oxidizing organic pollutants on potential microbes using up the oxygen to degrade organic contaminants in the water samples. No drinking water standard for BOD has been established so far; however, the value in this study fell well below the limit of 20 mg/L, stipulated for BOD in river water. BOD in both dug-well and borehole samples did not differ statistically from one another, suggesting a similar rate of organic pollution (Figure 2)

Chemical oxygen demand is an important water quality parameter because, similar to BOD, it provides an index to assess the influence of discharged wastewater on the receiving environment, where higher COD levels mean a greater amount of oxidizable organic material in the water sample, which will reduce dissolved oxygen levels. This test is often used as an alternate to BOD thanks to its shortened length of testing time, usually measured for effluent wastewater streams releaed into the environment. However, this parameter is measured in order to assess the effect of surface water bodies, receiving potentially organic polluted waste water, on groundwaters within 20m off the nearby surface water bodies. The COD levels in this study stayed within a range of 2.93-9.43 mg of O_2/L for untreated groundwater samples, in close proximity to a major surface water body in Ibadan metropolis, which is within the range, reported by Alabi et al., (2013) in their assessment of groundwater quality in Sagamu, Ogun state Nigeria. However, this range was lower than the findings of Adewoyin et al., (2013) who reported a higher range of 14.7-205.86 mg/L COD in groundwater, present in auto-mechanic workshops; a reflection of the effect of higher chemical contamination in and around mechanic workshop.

The data for treated samples suggested a slight reduction in the contaminant with a COD range of 2.03-5.77 mg of O_2/L for groundwater samples within the selected study locations. There has been no recent standard for BOD and COD in drinking water; however, the value of COD in this study was well below the value, generally quoted as maximum permissible limit in river (100 mg/L) by WHO (Alabi et al., 2013). The groundwater source was found to have minimal effect on the level of COD. Lower levels of COD were observed in the borehole samples, compared to hand-dug wells; however, this was not significant at $p < 0.05$, indicating that chemical contamination of groundwater samples occurred in a similar trend (Figure 2).

Heavy metals are naturally-occurring substances, present at low concentrations in the environment; however, anthropogenic activities have increased their concentration (Ocheri et al., 2014). Generally, humans are exposed to toxic metals like lead, chromium, and cadmium through ingestion as either food or drinking water, capable of affecting human health. The concentration of lead in the untreated groundwater samples ranged between 0.013 and 0.047 mg/L for both dug well and boreholes, which exceeded the WHO permissible limit for lead in drinking water (0.01 mg/L) in all of the samples. This value was also lower than the one from a similar study, involving groundwater in Ibadan (Adewoyin et al., 2013), though similar in trend to the lead concentration, reported by Alabi et al., (2013) for groundwater in Sagamu, Ogun State. This shows that in the former's study, auto-mechanic activities inside the studied area greatly affected the groundwater in the vicinity. Groundwater samples from Ojoo had the highest level of lead, compared to other sampling points; with comparatively lower levels, observed at Eleyele, Ogunpa, Olorunsogo, and Wofun (Figure 3). A significant effect of bleaching powder treatment was observed on the concentration of lead in the treated samples, as the value obtained for both treated and untreated differed significantly from each other at $p < 0.05$. This suggests that bleaching powder may precipitate lead out of solution; however, this known disinfection treatment is not enough to bring the level below the WHO limit for lead in drinking water.

Chromium concentration in groundwater samples from all the location ranged between ND and 0.023 mg/L, showing that groundwater samples from all sampled locations fell within the WHO permissible limit of 0.05 mg/L for chromium in drinking water, thus posing no potential public health issue with respect to chromium in these areas. Bleaching powder treatment had no significant effect on chromium levels as no significant difference was observed in both treated and untreated samples. Cadmium was not detected in most of the samples and where it was detected in Oluyole and Ojoo samples, it exceeded the WHO recommended limit of 0.003 mg/L for cadmium in drinking water (Figure 3), making it unsuitable for human consumption. The complex nature of some treatment plans like biosorption, iron based techniques, biological sulphate reduction, etc. reviewed extensively by Hashim *et al.*, (2011) for heavy metal removal in groundwater calls for the attention of governments and public health stakeholders in order to prevent potential public health issues that arise from heavy metal pollution.

Coliform bacteria may not cause any disease, but can be indicators of pathogenic organisms that cause diseases. The latter can cause intestinal infections, dysentery, hepatitis, typhoid fever, cholera, and other illnesses. It is easy and inexpensive to test for coliform bacteria. If testing does detect coliform bacteria in a water sample, water systems search for the source of contamination and restore safe drinking water. The presence of bacteria and pathogenic (disease-causing) organisms is a major concern, when considering the safety of drinking water. According to common water quality standards, drinking water must be completely free from any colony (Abdulbaki et al., 2014). In this study the coliform count in the untreated groundwater samples from all the locations ranged between 0.00 and 913.33 CFU/mL, with the dug well samples exhibiting significantly higher coliform counts than the borehole ones. This may be due to the difference in depth, wherein dug wells are shallow and more exposed to surface than the boreholes which are usually deep and protected. Similar observation was found in a similar study in Chile (Valenzuela et al., 2009), Northern Malawi (Kanyerere et al., 2012), and South Coast of Tamil Nadu, India (Selvam et al., 2017). Samples from Eleyelye, Ogunpa, Oluyole, and Ojoo are notably contaminated due to their high coliform count; however, bleaching powder treatment was able to improve the water quality in terms of coliform count significantly. Human and animal wastes are a primary source of bacteria in water. These sources of bacterial contamination include runoff from feedlots, pastures, and other land areas, where animal wastes are deposited. Additional sources include seepage or discharge from septic tanks, sewage treatment facilities, and natural soil/plant bacteria. Bacteria from these sources may enter wells, either open at the land surface or without any water-tight casings or caps.

Another way for bacteria to enter a water supply is through inundation or infiltration by flood waters or by surface runoff. Flood waters commonly contain high levels of bacteria. Small depressions filled with flood water provide an excellent breeding ground for bacteria, thus whenever a well is inundated by flood waters or surface runoff, bacterial contamination is likely. Shallow wells and wells without any water-tight casings can be contaminated by bacteria infiltrating with the water through the soil near the well, especially in coarse-textured soils which are common observations in some of the sampled location. The same result has been similarly reported in the groundwater samples of flood affected areas in Pakistan (Sarfraz et al., 2016).

CONCLUSION

The results, obtained from this study, confirm the necessity for continuous monitoring of groundwater within the study areas, which is due to the fact that most groundwater sources may have been polluted by seepages from the nearby surface water bodies. BOD and COD are two parameters, basically measured for waste waters and effluents and their presence in drinking water of this study indicates organic pollution, the point source of which may have been from the nearby surface water, commonly used to discharge assorted municipal solid wastes and industrial wastes. Heavy metals and microbial contamination was also detected in majority of the samples. Bleaching powder treatment was found to alleviate the pollutants especially coliform and BOD, where the microbial load was reduced by the disinfectant, thus getting the right treatment dosage would go a long way in its use as a cheap water treatment material. Consequently, it is recommended to encourage continuous monitoring of groundwater sources within the study area and awareness should be created on the dangers of drinking for polluted groundwater sources. Finally, as a cheap and easily accessible disinfectant, proper and controlled use of bleaching powder ought to be encouraged.

REFERENCES

Abdulbaki, U. D., Ahmad, H. I. and Maina, M. M. (2014). Quality Assessment of Groundwater around Open dumpsites in Kano Metropolis, North-Western Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology, 8* (9), 139-145.

Adewoyin, O. A., Hassan, A. T. and Aladesida, A. A. (2013). The impacts of auto-mechanic workshops on soil and groundwater in Ibadan metropolis. *African Journal of Environmental Science and Technology, 7*(9), 891- 898.

Alabi, Mutiu A. Idowu, G., Oyefuga, Olalekan H., Sunday, Rita M., Olowookere, Temitope., Osanaiye, Folake B. and Odiaka, Stella. (2013). Assessing the Ground Water Quality in Sagamu Town, Ogun State, South West Nigeria. *IOSR Journal Of Environmental Science, Toxicology And Food Technology, 6* (3), 57-63.

Awajiogak, A. U. (2013). Evaluating Groundwater Contamination Processes and Developing Framework For Qualitative Management in Parts of Nigeria. *International Journal of Innovative Research in Science, Engineering and Technology , 2* (8), 3890-3900.

Bain, R., Cronk, R., Wright, J., Yang, H., Slaymaker, T., & Bartram, J. (2014). Fecal Contamination of Drinking-Water in Low- and Middle-Income Countries: A Systematic Review and Meta-Analysis. *PLoS Medicine, 11*(5), e1001644. https://doi.org/10.1371/journal.pmed.1001644

Clesceri, L.S., Greenberg, A.E., and A.D. Eaton. (1998). *Standard methods for the examination of water and wastewater.* Washington DC, USA: American Public Health Association (APHA).

Egbinola, C. N., & Amanambu, A. C. (2014). Groundwater contamination in Ibadan , South-West, *3*(1), 1–6. https://doi.org/10.1186/2193-1801-3-448

FGN. (2007). Legal Notice on Publication of the 2006 Census Report. *Federal Government of Nigeria official Gazette , 4* (94), 1-8.

Hashim, M. A., Mukhopadhyaya, S., Sahu, J. N. & Sengupta, B. (2011). Remediation technologies for heavy metal contaminated groundwater. *Journal of Environmental Management*, *92*(10), 2355–2388.

Hunter, P. R., MacDonald, A. M., & Carter, R. C. (2010). Water Supply and Health. *PLoS Medicine*, *7*(11), e1000361. https://doi.org/10.1371/journal.pmed.1000361

Kanyerere, T., Levy, J., Xu, Y., & Saka, J. (2012). Assessment of microbial contamination of groundwater in upper Limphasa River catchment , located in a rural area of northern Malawi. *Water SA*, *38*(4), 581–596.

Lokhande, R. S., Singare, P. U., & Pimple, D. S. (2011). Pollution in Water of Kasardi River Flowing along Taloja Industrial Area of Mumbai , India. *World Environment*, *1*(1), 6–13. https://doi.org/DOI: 10. 5923/j.env.20110101.02

Macler, Bruce A. and Merkle, Jon C. (2000). Current knowledge on groundwater microbial pathogens and their control. *Hydrogeology Journal* , *8* (1), 29-40

Manahan, S. E. (2000). *Environmental Chemistry* (7th ed.). Boca Raton London New York Washington D.C.: Lewis Publishers.

Momodu, M.A. and Anyakora, C.A. (2010). Heavy Metal Contamination of Ground Water: The Surulere Case Study. *Research Journal Environmental and Earth Sciences* , *2*(1), 39-43.

Nigerian Standard for Drinking Water Quality (NSDWQ), (2007). Nigerian drinking water quality. Nigerian industrial standard NIS standard organization of Nigeria, pp:30

Ocheri, M.I, L.A.Odoma & Umar.N.D. (2014). Groundwater Quality in Nigerian Urban Areas: A Review. *Global Journal of Science Frontier Research: H* , *14* (3), 35-45.

Palamuleni, L. and Akoth, M. (2015). Physico-Chemical and Microbial Analysis of Selected BoreholeWater in Mahikeng, South Africa. *International Journal of Environmental Research and Public Health* , *12*, 8619-8630.

Pimentel, D., Berger, B., Filiberto, D., Newton, M., Wolfe, B., Karabinakis, E., Clark, S., Poon, E., Abbett, E., and Nandagopal, S. (2004). Water Resources: Agricultural and Environmental Issues. *BioScience*, *54*(10), 909–918.

Prajapati, U. B. and Dwived, A. K. (2016). Free Oxygen Budget of a Polluted Tropical River. *Hydrology Current Research*, *7*(2), 5–8.

Ramaiah, G. V., Krishnaiah, S., & Naik, M. (2014). Leachate Characterization and Assessment of Ground Water Pollution near MSW Dumpsite of Mavallipura , Bangalore, *4*(1), 267–271.

Sarfraz, M. D., Sultana, N., Jamil, M. D. & Ashraf, R. (2016). Investigation of Portable Groundwater Quality and Health Risk Assessment of Selected Trace Metals in Flood Affected Areas of District Rajanpur, Pakistan. *Journal of Environmental Analytical Chemistry*, *3*(2), 1000183. https://doi.org/10.4172/2380-2391.1000183

Selvam, S., Antony Ravindran, A., Venkatramanan, S., & Singaraja, C. (2017). Assessment of heavy metal and bacterial pollution in coastal aquifers from SIPCOT industrial zones, Gulf of Mannar, South Coast of Tamil Nadu, India. *Applied Water Science*, *7*(2), 897–913. https://doi.org/10.1007/s13201-015-0301-3

Valenzuela, M., Lagos, B., Claret, M., Mondaca, M. A., Pérez, C., & Parra, O. (2009). Fecal Contamination of Groundwater in a Small Rural Dryland Watershed in Central Chile. *Chilean Journal of Agricultural Research*, *69*(2), 235–243. https://doi.org/10.4067/S0718-58392009000200013

WHO. (2011). *Guidelines for Drinking Water Quality, 4th edn.* Geneva: World Health Organization.

WHO. (2007). *Water for Pharmaceutical Use. In. Quality Assurance of Pharmaceuticals: A Compendium of Guidelines and Related Materials.* Genever: World Health Organization.