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GROUNDWATER: QUALITY LEVELS AND HUMAN EXPOSURE, SW NIGERIA

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Abstract

Groundwater serves as a source of freshwater for agricultural, industrial and domestic purposes and it accounts for about 42%, 27% and 36% respectively. As it remains the only source of all-year-round supply of freshwater globally, it is of vital importance as regards water security, human survival and sustainable agriculture. The main goal of this study is to identify the main cause-effect relationship between human activities and the state of groundwater quality using a communication tool (the DPSIR Model; Drivers, Pressures, State, Impact and Response). A total of twenty-one samples were collected from ten peri-urban communities scattered across three conterminous Local Government Areas in Southwestern Nigeria. Each of the groundwater samples was tested for twelve parameters - total dissolved solids, pH, bicarbonate, chloride, lead, electrical conductivity, dissolved oxygen, nitrate, sulphate, magnesium and total suspended solids. The study revealed that the concentrations of DO and Pb were above threshold limits, while pH and N were just below the threshold and others elements were within acceptable limits based on Guidelines for Drinking Water Quality and Nigeria Standard for Drinking Water Quality. The study revealed that groundwater quality levels from the sampled wells are under pressure leading to reduction in the amount of freshwater availability. This is a first-order setback in achieving access to freshwater as a sustainable development goal across Less Developed Communities (LDCs) globally. To combat this threat, there is the need for an integrated approach in response towards groundwater conservation and sustainability by all stakeholders.

Keywords: groundwater, DPSIR, cause-effect, peri-urban, communication tool

INTRODUCTION

Clean, safe and adequate availability of freshwater is vital to the survival of all living organisms and the smooth functioning of ecosystems, communities and economies (Ibeh and Mbah, 2007; Akoteyon, 2013). Availability and access to freshwater is also a global concern and a major unit of the sustainable development goals (SDGs). In terms of availability, two major sources of freshwater are surface water and groundwater. Groundwater provides a valued fresh water resource to human population and constitutes about two-third of the fresh water reserves presently occupying various spaces across the world. Groundwater is used for agricultural, industrial and domestic purposes. It accounts for about 50% of livestock and irrigation usage and just under 40% of water supplies, whilst in peri-urban areas, 98% of domestic water use is from groundwater (Todd, 1980; Stigter et al., 2006). Groundwater can be put into different uses such as domestic, agricultural and industrial activities. These activities put a demand on groundwater thereby attenuating the remaining portion of available groundwater reserves (Sangodoyin and Agbawhe, 1992). Activities such as these not only put pressure on global groundwater reserves but also affect the quality of groundwater (Oluwande, 1983; MacDonald et al., 2005; Stigter et al., 2006; Akoteyeon, 2013). Groundwater quality comprises the physical, chemical and biological qualities (Phillips et al., 2013). It becomes polluted when its quality is disturbed, whether the physico-chemical or the biological property.

Groundwater pollution can also be described as water contamination. It occurs when pollutants are released to the ground and make their way down into groundwater. It can also occur naturally due to the presence of minor and unwanted constituents, contaminants or impurity in the groundwater, in which case it is more likely referred to as contamination rather than pollution (Phillips et al., 2013). In most tropical climes such as Nigeria, increase in the rate of population, a corollary effect of increase in the level of urbanization, industrial and agricultural activities are perceived to pose serious pollution threats with all its concomitant health hazards on groundwater quality especially in urban and peri-urban areas (Kehinde et al., 1989; Adelana et al., 2008). Groundwater in some climes contain specific ions (such as fluoride) and toxic elements (such as arsenic, lead and selenium) in quantities that are harmful to health, while others contain elements or compounds that cause other types of problems (such as the staining of sanitary fixtures by iron and manganese).

Most peri-urban towns in tropical countries such as Nigeria are heavily populated due to rapid urbanization because of urban renewal processes; a growing planning process in urban planning, closeness to major urban centres, etc. It is based on this background that this research seeks to assess groundwater quality levels across three conterminous Local Government Areas (LGAs) in Osun State. These three LGAs (Boluwaduro, Ifelodun and Boripe) are close to Osogbo, the Osun State Capital and they have been enjoying influx of people from Osogbo who are settling down in these areas. These three LGAs have been experiencing population growth (NPC, 2006) and are fast becoming urbanized with unchecked physical planning process coupled with observed sanitary issues and difficulties in the use of freshwater especially for drinking purpose; the area becomes ideal for this kind of study. These factors (urbanization, unchecked physical development and sanitation issues, offshoot of population growth) are impacting on freshwater availability within the study area and thereby reducing its quality. With the present global challenge on freshwater, there is the need for developing countries such as Nigeria to drive policies that will protect her freshwater reserves and ensure sustainability. One of the channels through which the nations of the world can achieve protection and sustainability is encouraging more research into groundwater reserves using human-environmental models that can be used to understand interactions between nature and man in order to drive policies that are long sustainable and achievable. The aim of this study is to assess the spatial variation in groundwater quality across three conterminous LGAs in Osun State and present a sustainable water management approach. To achieve this aim, this study employed the use of DPSIR (Driving force, Pressure, State, Impact and Response) Model in understanding the importance and functions of groundwater quality in Boluwaduro, Boripe and Ifelodun LGAs in Osun State. The main goal of this model is to identify the main cause-effect relationship between human activities and the state of water quality and present a response approach geared towards sustainable freshwater availability. Borja et al. (2005) used the model together with other methodologies to identify the relevant pressures and impacts of water quality changes in estuarine and coastal areas. Danielopol et al. (2003) reviewed the changes in the status of groundwater ecosystems and the important driving forces, resulting from the direct or indirect impacts of human activities. Their discussion divided the environmental pressures which are largely produced by human activities in two major classes, namely; groundwater quantity problems and the critical depletion of aquifers in many parts of the world and groundwater quality problems, where the systems are overloaded with contaminants. An application of the DPSIR model based on the uniqueness of the study area and its peculiarities (being a tropical community, peri-urban zone, its absolute dependence on freshwater through groundwater abstraction and increasing emergence of light industries) becomes very relevant and sets to add more to growing body of knowledge on integrated water quality studies especially in tropical climes and offers a unique solution for similar Less Developed Communities (LDCs) across the world. Also, given globally recognized water scarcity, using the worlds accessible freshwater in a sustainable manner becomes critically important.

STUDY AREA

Three LGAs were investigated in this research – Ifelodun, Boluwaduro and Boripre (Fig. 1, 7055’N, 4040’E; 7◦57’N, 4◦48’E; 7◦57’N, 4◦48’E). Ifelodun has an area of 114km^2 with a population of 96, 444 with its headquarters located at Ikirun, Boluwaduro has an area of 144km^2 and a population of 70,954, with its headquarters located at Atan-Ayegbaju while Boripe with an area of 132km^2 and a population of 138,742 as at 2006 census has its headquarters at Iragbiji.

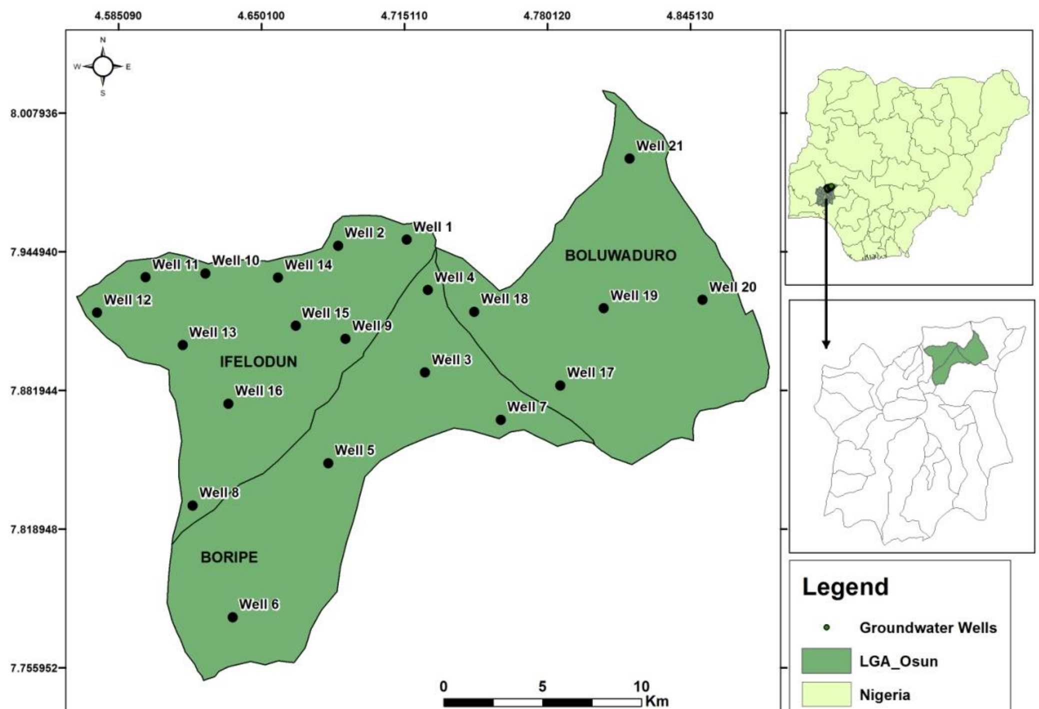

Fig. 1 Map showing study area and groundwater sampling points

The study area (Fig. 1) receives an average rainfall of 1,150 mm a year; it lasts from April to late October or early November (South-westerly winds prevail), though it eases off in July or August (August Break). The dry season lasts from November to March which is the period of intense harmattan when the North-easterly dusty wind prevails, mixed with occasional intense heat. Osun State is an inland state, lying mainly in the tropical rainforest, in the deciduous forest area which spreads towards the grassland belt of the study areas. Climate here is less humid and hot than the greater part of South-Western Nigeria although the effect of the harmattan wind is strongly felt in the dry season. The towns are situated on a raised land which is well over 500 meters above the sea level and is drained by the tributaries of River Osun.

Various economic activities are being carried out within the study areas. Sizeable numbers of the populace within the zone are civil servants who also are into one form of petty trading. Market structures within the zone are mostly periodic with few ones being patronized on a daily basis. The area boasts of various industries from local craft ones to light industries (food crops processing plants, auto-mechanic workshops, etc.) and few heavy industries (Iron smelting, metal fabrication, etc.). Due to large expanse of available arable land, the area is intensively cultivated for various crops while some are already being converted into industrial sites.

METHODOLOGY

Field survey was carried out before sample collection. This was necessary in order to examine the general characteristics of the area, determine the most feasible routes for sample collection and identify wells and their characteristics. Communities where samples were taken are Iree, Obagun, Otan-Ayegbaju, Ada, Oba, Erinpa, Ikirun, Eko-Ajala, Iragbiji located within the Local Government Areas Boripe, Boluwaduro and Ifelodun (Table 1). These areas were identified during the course of the reconnaissance and it was gathered that their source of groundwater which is mostly from wells is not too safe for drinking.

DPSIR model

DPSIR model is a chain of causal links starting with ‘driving forces’ (economic sectors, human activities) through ‘pressures’ (emissions, waste) to ‘states’ (physical, chemical and biological) and ‘impacts’ on ecosystems, human health and functions, eventually leading to political ‘responses’ (prioritization, target setting, indicators). Describing the causal chain from driving forces to impacts and responses is a complex task, and tends to be broken down into sub-tasks, e.g. by considering the pressure-state relationship. A ‘driving force’ is a need. Examples of primary driving forces for an individual are the need for shelter, food and water, while examples of secondary driving forces are the need for mobility, entertainment and culture (Kristensen, 2004). Driving forces lead to human activities such as transportation or food production, i.e. result in meeting a need. These human activities exert 'pressures' on the environment, as a result of production or consumption processes.

Table 1 Location of sampled groundwater wells

ID	Geographic coordinates		Depth (m)	Flow
	Nothing	Easting		
Well 1	07°55' 46.221"	04°40' 30.370"	7	Perennial
Well 2	07°55' 44.207"	04°40' 20.006"	2	Seasonal
Well 3	07°56' 08.450"	04°43' 41.446"	2	Perennial
Well 4	07°56' 11.886"	04°43' 46.192"	8	Seasonal
Well 5	07°56' 13.011"	04°43' 30.199"	12	Seasonal
Well 6	07°53' 27.352"	04°42' 47.338"	12	Seasonal
Well 7	07°53' 32.399"	04°42' 46.743"	12	Seasonal
Well 8	07°54' 22.510"	04°41' 12.610"	2	Seasonal
Well 9	07°54' 20.596"	04°41' 15.500"	2	Perennial
Well 10	07°56' 33.035"	04°37' 34.008"	6	Perennial
Well 11	07°55' 02.547"	04°34' 31.910"	2	Seasonal
Well 12	07°55' 03.512"	04°34' 28.859"	6	Perennial
Well 13	07°54' 31.711"	04°34' 41.251"	14	Seasonal
Well 14	07°55' 37.113"	04°39' 13.297"	7	Perennial
Well 15	07°55' 13.326"	04°40' 08.198"	14	Seasonal
Well 16	07°55' 07.601"	04°40' 09.509"	2	Seasonal
Well 17	07°56' 22.387"	04°44' 39.922"	14	Seasonal
Well 18	07°56' 19.271"	04°44' 40.429"	2	Seasonal
Well 19	07°56' 19.115"	04°44' 38.494"	2	Seasonal
Well 20	07°56' 50.558"	04°47' 24.027"	12	Seasonal
Well 21	07°56' 51.940"	04°47' 24.439"	12	Seasonal

As a result of pressures, the ‘state’ of the environment is affected; that is, the quality of the various environmental compartments (air, water, soil etc.) in relation to the functions that these compartments fulfil. The ‘state of the environment’ is thus the combination of the physical, chemical and biological conditions. The changes in the physical, chemical or biological state of the environment determine the quality of ecosystems and the welfare of human beings. In other words, changes in the state may have environmental or economic ‘impacts’ on the functioning of ecosystems and human lives (Kristensen, 2004). A ‘response’ by society or policy makers is the result of an undesired impact and can affect any part of the chain between driving forces and impacts. DSPIR was applied as a guiding model for a well-developed water quality study in the light of sustainable freshwater management.

Driving forces and Pressures

The need for shelter, healthy living and improved financial status were identified as the driving forces acting upon the sustainable use of freshwater supply within the zone. A corollary effect of these forces is increased population growth which in turn affects urbanization and industrialization. As a basic pressure, population growth was analysed using existing records between 2006 and 2011 (NPC, 2006) and possible contamination sources that predispose groundwater to pollution were identified on the field.

State and Impact

The state of the groundwater in terms of its quality was determined from the Laboratory using standard protocols and measures (APHA et al., 2008) at the University of Ibadan, Department of Agronomy. A total of twenty-one (21) samples were collected from ten (10) peri-urban communities scattered across the three Local Government Areas (Boripe, Boluwaduro and Ifelodun). The water samples were collected with the aid of Polyethylene bottles (APHA et al. 1998) and each location was determined using a Global Positioning System. Also, the state of each of the wells was determined in terms of depth and volume of water was qualitatively described using seasonality. At the time of sampling, bottles were thoroughly rinsed two to three times with the well water. The samples were taken immediately to the laboratory to determine their physico-chemical properties. Each of the groundwater samples was analyzed for 12 parameters: Total Dissolved Solids (TDS), pH, Bicarbonate, Chloride, Lead, Electrical Conductivity, Dissolved Oxygen, Nitrate, Sulphate, Magnesium and Total Suspended Solids using standard laboratory procedure (APHA et al., 1998).

The spatial variation of the physico-chemical properties was determined using charts across the 21 communities. Based on WHO and Nigeria standards, average values of each of the parameters were compared against the WHO standard to ascertain the level of exposure to risks being posed by the consumption of freshwater within the study area. Risk map for threatening parameters was produced using ArcGIS 10.1 in form of dot map using proportional circles.

Response

The present capacities of major stakeholders were evaluated to understand how to cope with the impact of polluted groundwater and finally presenting a required management intervention that is both long-term and short-term.

RESULTS

Driving Forces and Pressures

The driving forces identified within the study area are population growth and urbanization. These activities arise as a result of human needs for food, water, shelter and health. Due to population increase (NPC, 2011) across the area, there is increase in the rate of urbanization and agricultural practices. On the average, across the three LGAs, population increased by over 14%. By 2050, it is expected that global water demand will increase by 55 percent (Cap-net, 2016) mainly due to growing demands from manufacturing, thermal electricity generation and domestic use. As population increases across the study area (Fig. 2) so does production of wastewater and other products that predisposes groundwater to being polluted. By 2020 the proportion of urban population in LDCs is predicted to surpass 50% and it is expected that 57% of the world's population will live in cities (UN Report, 1997). Going by the trend, peri-urban communities are likely to have greater influx of urban dwellers of which a large proportion will be poor. This in itself implies increase in pressure on domestic and drinking water supply, sanitation and food supply (Danielopol et al., 1997).

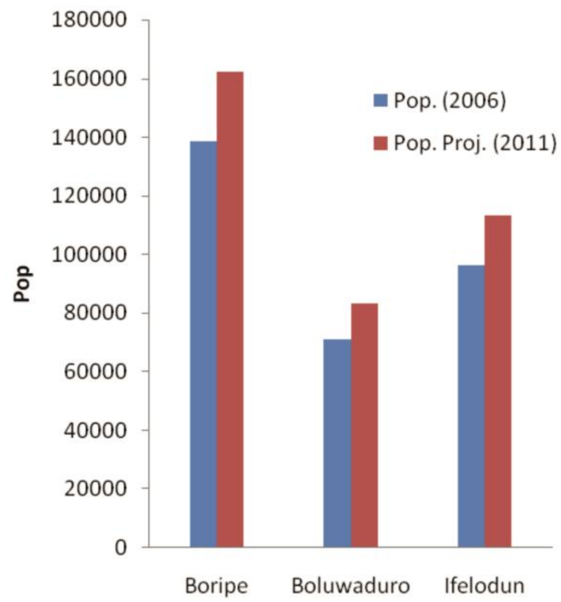

Fig. 2 Graphical representation of population growth across the study area

Agricultural practice exerts pressure on the environment and it is a major source of high concentration of nitrate in groundwater in wells, through the application of chemical manure. Fertilizers and pesticides applied to crops eventually reach underlying aquifers particularly if the aquifer is shallow and not protected by an overlying layer of low permeability materials.

State and Impact

The values in Table 2 shows that well 13 has the highest pH value followed by well 6. pH is a measure of the acidic or basic nature of a solution pH average (6.5) value for groundwater is within the permissible level (Table 3). It has been noted in the Nigeria Standard for Drinking Water Quality (NSDWQ, 2007) that pH usually does not have a direct bearing on consumers of water. DO is a measure of the amount of oxygen level in a body of water. It is affected by pressure, temperature and salinity. Average value for DO across the studied wells is 10.6. The average value for DO here is above the threshold limit (NSDWQ, 2007). Excess dissolved oxygen in water bodies can cause external bubbles (emphysema), a rare occurrence that affects the skin and other tissues (Kumar et al., 2007).

Table 2 Physico-chemical result of groundwater analyses across the twenty-one communities

ID	pH	EC (μS/cm)	TDS mg/l	TSS mg/l	Cl mg/l	NO_3 mg/l	SO_4 mg/l	HCO_3 mg/l	Ca mg/l	Mg mg/l	Pb mg/l	DO mg/l
Well 1	6.71	542	20.5	1.4	17.8	0.8	1.2	0.07	20.5	3.1	0.34	11
Well 2	5.66	432	18	0.5	35.5	0.6	1.1	0.19	19.1	3.8	0.35	9
Well 3	6.83	512	21.8	1	22.5	0.9	1	0.1	18.5	2.9	0.43	10
Well 4	6.71	842	22.4	1.5	27	1.3	1	0.12	17.35	2.2	0.32	12
Well 5	6.83	422	20.6	1.19	25.6	1.1	1.5	0.16	19.8	1.7	0.2	13
Well 6	6.24	362	33.2	0.8	24.5	1.2	0.9	0.08	17.3	1.8	0.19	11
Well 7	6.31	392	30.4	0.65	21.5	1	1.6	0.07	21.5	1.9	0.17	12
Well 8	6.55	545	26.8	1.11	20.6	1.4	1.1	0.06	22.8	2.15	0.22	9
Well 9	6.53	792	20	0.92	17.3	1.7	1.2	0.05	26.1	2.35	0.3	8
Well 10	6.71	382	25.5	0.85	35.5	1.8	0.8	0.16	25.3	2	0.26	8
Well 11	6.75	372	24.2	0.7	18	0.4	1	0.2	18.75	4.19	0.4	8
Well 12	6.82	322	23.2	1.1	21	1.1	1.1	0.02	22.8	2.6	0.28	9
Well 13	9.92	682	17.9	0.6	18.5	0.9	0.7	0.16	27.33	2.8	0.49	12
Well 14	6.36	332	16.5	0.9	13.8	1.1	1.7	0.14	35.1	3.3	0.31	13
Well 15	6.23	352	14	0.3	12.9	0.7	0.9	0.1	29.2	4.8	0.33	11
Well 16	6.54	662	13.6	0.45	18	0.9	1.6	0.09	18.7	2.9	0.21	12
Well 17	6.26	352	20.3	0.25	19.2	0.7	1.4	0.11	16.5	3.15	0.26	12
Well 18	6.55	342	18.6	0.4	21	1.1	1.6	0.16	17.1	2.9	0.18	11
Well 19	6.52	342	19.1	0.3	16	1.3	0.8	0.12	19.3	1.6	0.14	11
Well 20	6.85	602	12.7	0.22	13	0.8	1	0.1	18.6	1.45	0.1	10
Well 21	6.8	852	14.8	0.18	20	1.1	1.7	0.08	17.8	2.15	0.11	11
Average	6.70	496.90	20.67	0.73	20.91	1.04	1.19	0.11	21.40	2.65	0.27	10.62

For calcium, well 14 appeared with the highest value and well 6 for TDS. Well 2 and 10 has the highest value for Cl. Calcium concentration, Cl and TDS appears with an average of 21.40mg/l, 20.9 mg/l and 20.6mg/l respectively and they are well within acceptable standard (Table 3). The palatability of drinking water rated by panels of tasters in relation to its TDS level is as follows: excellent, less than 300 mg/l; good, between 300 and 600 mg/l; fair, between 600 and 900 mg/l; poor, between 900 and 1,200 mg/l; and unacceptable, greater than 1,200 mg/l (WHO, 1996a, b). TDS concentrations across sampled wells are quite low and there is the tendency for the water to become flat and insipid in taste (Kumar et al., 2007).

Table 3 Nigeria Standard for Water Quality (NSDWQ, 2007)

Physico-chemical parameters	NSDWQ
pH	6.5 -8.5
EC (μS/cm)	1000
TDS (mg/l)	500
TSS (mg/l)	500
Chloride (mg/l)	250
Nitrate (mg/l)	50
Sulphate (mg/l)	100
Bicarbonate (mg/l)	-
Calcium (mg/l)	75
Magnesium (mg/l)	0.20
Lead (mg/l)	0.01
Dissolved oxygen (mg/l)	5.0

Magnesium (Mg) concentration as observed in the study is higher than the sulphate (SO_4) level. Well 15 has the highest concentration level of Mg exceeding the permitted level without any known effect on human health. As for sulphate, well 14 and 21 has the highest concentration level. SO_4 has an average concentration of 1.13mg/l lower than the permitted class given by NSDWQ (2007). It has been noted that low SO_4 concentration has no effect on human health.

Well 10 has the highest level of nitrate concentration. Across the studied wells, NO_3- has an average value of 1.04mg/l which is well within the permitted standard globally. For lead, the highest concentration was observed in well 13 (0.49mg/l). Lead across the study wells presents an average value of 0.266mg/l exceeding the permitted threshold level of 0.01 mg/l. From the study, Lead has been found to be highly concentrated in most wells across Obagun, ObaOke, Oba – Oke and Iree. Most wells across the study area are shallow and particularly these wells are sited close to auto-repair workshops, such as; auto mechanic, auto welding and auto painting. Wastes disposal from these workshops found their way into the soil profile and contaminate the aquifer level resulting in groundwater pollution due to their shallowness. Pb is quite deadly and it results in several diseases which are harmful to the human health especially children. The presence of Pb above the normal threshold (WHO, 1996a; NSDWQ, 2007) results in carcinogenic diseases,

Table 4 Groundwater Quality Matrix (Red: High Risk; Yellow: Medium Risk; Blue: No risk

	pH	EC	TDS	TSS	Cl	NO_3^-	SO_4	HCO_3^-	Ca	Mg	Pb	DO
IFELODUN	Yellow	Blue	Blue	Blue	Blue	Blue	Blue	Yellow	Blue	Blue	Red	Red
BORIPE	Yellow	Blue	Blue	Blue	Blue	Blue	Blue	Yellow	Blue	Blue	Red	Red
BOLUWADURO	Yellow	Blue	Blue	Blue	Blue	Blue	Blue	Yellow	Blue	Blue	Red	Red

interference with Vitamin D metabolism and it affects mental development in infants. Bicarbonate, HCO^{3-}, is always expected to be quite high especially in groundwater levels with low levels of calcium and magnesium. It serves as a control on water pH. Well 2 has the highest Bicarbonate level (0.19mg/l). The average value for HCO_3^- across the studied sites is 0.111 mg/l. The highest concentration level of TSS was observed in well 4 (1.5mg/l), and an average of value of 0.696 mg/l across all wells. TSS is well within the permitted level.

It is quite clear that most wells within the study area are quite shallow. Hence, they are susceptible to contamination from activities around. The deepest well is about 12 meters (Table 1). This explains the reason why some of the wells are seasonal. The extraction is from weathered regolith not deep enough to sustain water availability all year round. The shallowness of the well suggests that contaminants get into the freshwater zone rather easily. The pathway through which most of the groundwater within the study area gets polluted is through point sources as observed across the studied wells. From the state of groundwater quality across the studied wells vis-a-vis the WHO (1996a) and NSDWQ (2007), levels Dissolved Oxygen (DO) and Lead (Pb) within the wells poses high risk to human health and survival within the study area (Table 4). Nitrate and pH are just within par while the rest are well within acceptable limit (Table 4). The two high risk parameters are presented in Fig. 3 and 4 to show variation in concentration across the study area.

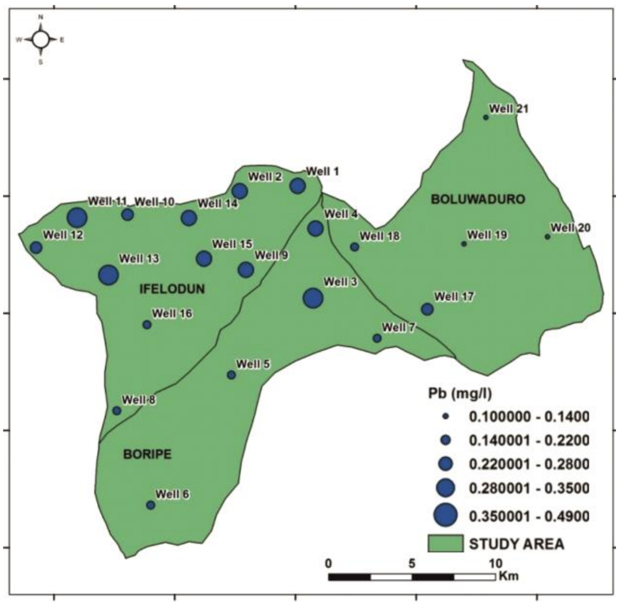

Fig3 Risk map showing Pb concentration in the study area

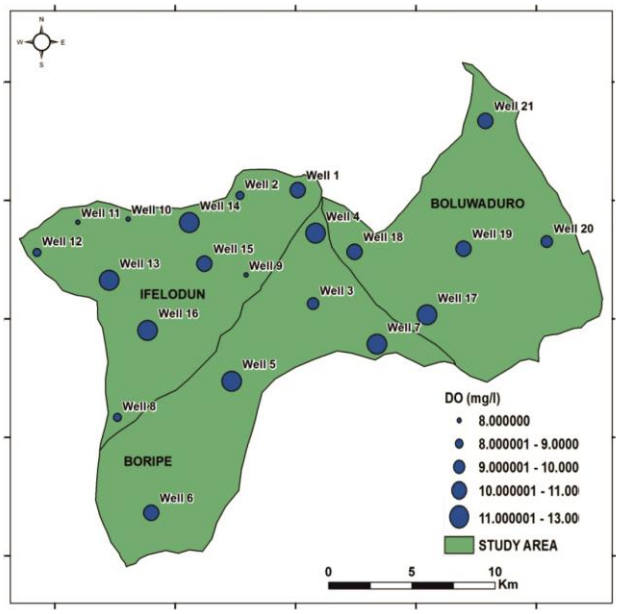

Fig.4 Risk map showing DO concentration in the study area

Response

The cycle of hydrological processes sustains life and serves as a means of providing freshwater on the earth surface (Cap-net, 2016). Freshwater is a natural asset that must be protected to ensure that the essential ecosystem services it provides continue. Expected response based on observed pressures and impact is to recognize that water is a scarce resource used for many different purposes, functions and services; therefore, water management has to be holistic and carefully consider different demands in view of available resources and threats. It is therefore expected that effective management of groundwater should encompass seeking non-conventional water sources, such as reclaiming or desalinizing. Also, addressing source-point pollution (i.e. precluding waste streams from entering natural water bodies) is among measures that can effectively curb this problem. Specifically, all water producing wells within the study area should meet minimum standards for well construction mostly in terms of depth. Furthermore, proper well location with minimum standards from potential sources (auto repair workshops, dumpsites, etc.) of contamination must be set. On the part of the government, regulatory bodies should be empowered and made to employ the polluted pay principle and good practice should be adopted. In order to effectively achieve the expected goal and meet global sustainable demands, alongside desirable socio- economic development by prioritizing social equity, environmental sustainability and economic efficiency, health-sanitation officers should be properly equipped to enforce environmental healthiness. A more drastic approach to solving polluted groundwater across peri-urban centres in LDCs is the establishment of central borehole system careful constructed in clusters of communities based on stakeholder participation right from the feasibility study to the construction of the water system.

CONCLUSION

The information obtained from this shows that two the levels of two parameters were found to be at above the threshold, two parameters were found to be at around the threshold limit while the remaining eight parameters were within the acceptable limits. In addition, the research has shown that groundwater quality levels from the sampled wells are under pressure threat due to increase in population and urban activities. These drivers put a lot of pressure on the environment thereby increasing pollution risk from point sources such as dumpsites, metals from auto-repair workshops and chemicals due to intense agricultural practices. The resultant impact is that there is a grave danger on health especially on the urban poor utilizing groundwater for human consumption without any form of treatment.

Globally, there is little or nothing that mankind can do to change water availability in the natural water cycle. However, on a local scale, natural water cycle supports numerous smaller man-made water cycles that critically alter overall water availability. There is therefore the need for better management, i.e. improved economic efficiency of these man-made water cycles to ensure sustainable development. Reducing pollution and collecting, recycling and reusing wastewater are a first order approach to tackle this menace within these communities and other LDCs in order to sustain human lives and create an environment that is sustainable and liveable.

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