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Public health effects due to insufficient groundwater quality monitoring in Igando and Agbowo regions in Nigeria: A review

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Abstract

This paper emphasizes the need for monitoring groundwater resources by analyzing the health implications of inadequate monitoring. It highlights the importance of groundwater quality monitoring in Nigeria—a country where population dependence on groundwater is 60%. The effects of Soluos dumpsite leachate in Igando, Lagos–Nigeria, and septic tank seepages in Agbowo, Ibadan–Nigeria on groundwater quality are analyzed. All samples used in this study appeared to be microbially contaminated. This is linked to too close distances [< 50 ft (15.24 m) the United States Environmental Protection Agency recommendation] between septic tanks and groundwater wells, as well as non-engineered dumpsites used for waste disposal. This shows that groundwater within the study area is unsafe for drinking purposes. Even with the clayey soil stratigraphy of the study area which is believed to influence the natural attenuation of leachate into groundwater, high concentrations of lead (Pb) and manganese (Mn) were seen in some locations around the dumpsite. The study points to the inherent cost for individuals and government due to insufficient groundwater quality which could have been otherwise avoided through groundwater monitoring and proper waste management. This review accentuates the need for improved water quality towards achieving SDG 6.1 (universal and equitable access to safe drinking water) and SDG 3 (Good health and well-being) in Nigeria.

Keywords Groundwater monitoring · Microbial contamination · Water-borne diseases · Water quality · Nigeria

Introduction

Sustainable management of water and sanitation for all (sustainable development goal—SDG 6) is the key towards achieving many other sustainable development goals including good health (SDG 3) and economic growth (SDG 8) among others. Water, being essential to human existence, makes up about 71% of the Earth's surface of which only 2.5% is freshwater (USGS 2016). Graham et al. (2010) noted that about 22–30% of freshwater is stored in underground aquifers—this portrays the significance of groundwater in the provision of good quality water. However, unwholesome environmental practices could impact the natural quality of groundwater resources, impairing its quality.

Apart from agricultural and industrial activities, dumpsite and landfill leachates could pose a significant threat to groundwater quality (Egbi et al. 2017), especially in the absence of groundwater quality monitoring. Several related cases have been reported in some African countries, some of which are the impact of the Abloradjei solid waste disposal site on groundwater quality in Ghana (Egbi et al. 2017) and the effects of anthropogenic activities, such as ineffective management of domestic waste on groundwater quality in Burkina Faso (Sako et al. 2018). Groundwater monitoring studies such as that of Egbi et al. (2017) and Sako et al. (2018) have provided evidence of leaching and seepages from waste into aquifers, thereby making groundwater unfit for human consumption. Moreover, the most populous nation in Africa, Nigeria, is not left out of this growing challenge.

Nigeria, a country in western Sub-Saharan Africa, is located between latitudes 4°20′N and 13°58′N, and longitude 2°40′E and 14°40′E. According to the United Nations, the land area of 923,768 km^2 occupies an estimated population of 195 million as of July 2018; indicating an average

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of 211 people/km^2. With an average growth rate of 2.61% per annum, Nigeria's expected 2030 population stands at 264 million (Worldometer 2018). According to Food and Agriculture Organization, FAO (2016), of the $12{,}475 \times 10^6$ m^3 of water withdrawal in 2010, agriculture accounted for about 44%, while municipalities and industry accounted for approximately 40% and 16%, respectively. They also noted that almost 75% of municipal water withdrawal comes from groundwater resources.

Studies by Nwankwoala (2011) showed that the quantity Nigeria's groundwater resource is thousands of times larger than that of surface water resources. Compared to surface water, groundwater is less susceptible to pollution (Babiker et al. 2005). Given this, and its large storage capacity, it has become an important water source for agricultural, municipal, and industrial purposes. Land use activities, among other factors, have, however, posed a threat to groundwater quality (Babiker et al. 2005). Often referred to as a "hidden resource", groundwater is trapped beneath the ground surface, making it a bit difficult to be monitored compared to surface water. This resource requires more monitoring attention, as it is being threatened by increased anthropogenic activities and unsustainable practices (Nwankwoala 2011).

Urbanization rate, coupled with industrial activities, and indiscriminate disposal of waste (municipal and industrial) have impacted groundwater quality in Nigeria (Ocheri et al. 2014). According to Omole (2013), following the backdrop of potable water infrastructural decay, not less than 60% of Nigeria's population rely on groundwater as a source of drinking water. Weak institutional capacity towards groundwater regulations makes it vulnerable to pollution (Omole 2013). Ekiye and Luo (2010) noted that the increase in industrial activities has resulted in increased pollution load in groundwater bodies, especially in industrial cities. This calls for more attention to groundwater monitoring. Increased demand for groundwater, both for industrial and domestic use—in Nigeria, for instance—stems from insufficient/lack of public water supply. Sustaining groundwater resources and its potability, given the increased number of private water wells in Nigeria, requires continuous quality monitoring (Deborah 1996; Raihan and Alam 2008).

Lack of municipal water supply, rapid and unplanned urbanization, and the relatively cheaper cost of accessing groundwater make it a favourable choice for households in Nigeria. Groundwater usage cuts across various sectors, accounting for 42% agricultural, 36% domestic, and 27% industrial purposes in Nigeria; hence, it remains a vital resource (Olusola et al. 2017). It is accessed either as shallow, hand-dug wells, or as deep, borehole wells (Omole 2013). Given its abundance and relatively cheaper cost of development (Soladoye and Ajibade 2014), virtually every household in urban cities in Nigeria owns private hand-dug water wells to make up for lack of municipal water supply. It makes abstraction points so close to one another, with no adequate space to site wells at an appropriate distance away from pollution sources such as soak-away and septic tanks (Adekile and Olabode 2009). The essence of groundwater monitoring is evident in the possibility of natural source pollution (dissolved solids, chloride, nitrate, arsenic, etc.). Regulatory gaps have also exposed groundwater resources to point sources and non-point sources (Nyanganji et al. 2011).

The paper seeks to shed light on the public health and some economic costs of groundwater data collection gaps and weaknesses in Nigeria. This was done by reviewing the previous works on the extent to which dumpsite leachate and septic tanks seepages have impacted groundwater quality. The implication of reported physicochemical characterisation and microbial enumeration of groundwater samples in the vicinity of septic tanks and dumpsite were analyzed. The search engines primarily used for this research are Google and Google scholar. Some of the search words include groundwater quality, dumpsites, landfill, groundwater quality monitoring in Nigeria, water-borne disease outbreak in Nigeria, groundwater contamination by leachate, groundwater contamination from septic tanks, etc. Literatures reviewed include both peer-reviewed papers and gray literature.

Groundwater monitoring in Nigeria

Groundwater contamination is a widespread environmental problem across the globe, which requires long-term monitoring. This could be challenging in the event of an unexpected storm, which could result in abrupt changes in contaminant levels which might not be captured by periodic manual sampling (Chao 2018). However, Schmidt et al. (2018) developed a low-cost, real-time method of monitoring pollutants using the Kalman filter. It allows continuous in situ monitoring of groundwater contamination. Technological advances like this are largely missing in most of the developing countries such as Nigeria, which is militating against efficient groundwater monitoring operations.

According to Omole (2013), unavailability of data has made it difficult to ascertain the actual water derived from groundwater resources in Nigeria. Macheve et al. (2015) noted that the national average for water metering in Nigeria is only 16%. Apart from the large-scale industrial sector, some small-scale industries and domestic private well owners, for example, are not metered, which has made it impossible to have accurate groundwater consumption data, and in the same manner, it has also made quality monitoring less effective. However, Olusola et al. (2017) noted that agriculture depends mostly on groundwater resources, followed by the domestic and industrial sectors.

Lack of adequate monitoring by appropriate agencies has resulted in cases of reported microbial contamination of drinking water in various states in Nigeria (Adekunle et al. 2007). As noted by Olowe et al. (2017), reports of microbial contamination of drinking water sources, which links to a lack of public water system (potable water) and inadequate groundwater monitoring, have resulted in high rates of water-borne diseases such as cholera, typhoid fever, dysentery, and diarrhoea. Groundwater vulnerability is made evident by studies conducted in Ado-Ekiti, Southwestern-Nigeria by Olowe et al. (2015), where 300 samples of groundwater wells and boreholes were assayed for microbial parameters. About 37% of these samples tested positive for *Escherichia coli* (*E. coli*). In another study, Weli and Ogbonna (2015) reported water-borne diseases associated with groundwater in Emohua—a rural community of Rivers state, Southern Nigeria. As reported by Weli and Ogbonna (2015), the prevalence of these diseases has affected the economy of the local inhabitants. On an individual basis, it comes with a considerable cost and financial burden which includes medications and medical treatment costs among others. Corporations suffer the loss of workforce, and the government incurs humanitarian cost in some cases. In Lagos state, southwestern-Nigeria, as reported by Nigerian Vanguard (2017), out of 27 people affected by diarrhoea outbreak, two were reported dead. The state's commissioner for health hinted that the suspected root cause was faecal contamination of their drinking water source, which is mostly groundwater—about 63% of Lagos' population rely on privately dug boreholes and shallow wells (Adeyi and Majolagbe 2014). According to the Lagos state government, over 50% of water-related ailments are recorded on daily basis in Lagos state, as water-borne diseases cost Nigeria about $2.5 billion per annum (Afuwape 2017). This presents some of the health and economic costs associated with gaps and weakness in water monitoring.

According to Tuinhof et al. (2006), the main goal of groundwater monitoring is to control the effects of groundwater abstraction and contamination—developing policy strategies to monitor and control anthropogenic influences on groundwater. Rapid urbanization and industrialisation have necessitated the specialised focus on groundwater quality monitoring, as it would provide early warnings on groundwater pollution from a specific activity and the need for taking mitigative and control measures where necessary. In many developing countries like Nigeria, the goal of ensuring the sustainable management practices for water and sanitation for the citizens (SDG 6) will not be possible without adequate water monitoring. The proportion of people using safely managed drinking water can only be increased and maintained through ensured water quality. The benefit of which will translate into overall good health and well-being (SDG 3), as water-related diseases remain the major causes of death in children below the age of five (WHO 2017).

According to British Geological Survey (2018), the Nigeria Hydrological Services Agency (NIHSA), an agency responsible for groundwater monitoring in Nigeria, has implemented programmes for groundwater-level monitoring in few areas—only 43 monitoring points nationwide, out of which 32 are equipped with data loggers. However, full programmes are yet to be in place for groundwater quality monitoring due to lack of resources. In addition, lack of health data relating to water-borne diseases, and policy lapses, in Nigeria, are some of the other factors that have deprived groundwater monitoring of its required attention.

As noted by MacDonald et al. (2005), water chemistry is mainly dependent on the depth and geology of the geoenvironment which emphasizes that the chemical characteristics differ based on aquifers' depth and geology (Ocheri et al. 2014). A 1999–2001 study by Adelana et al. (2005) showed contaminants were associated with anthropogenic activities mainly due to the shallow depth of the Lagos aquifer. Eni et al. (2011) also affirmed the effect of urbanization on groundwater quality. Their assessment of groundwater in Calabar, South-southern Nigeria, revealed acidity, nitrate, and faecal coliform contamination. Another study by Amadi et al. (2010) showed water samples close to the dumpsite, in Makurdi, North-central Nigeria, exhibit low pH, high content of total dissolved solids (TDS), iron (Fe), manganese (Mn), calcium (Ca), and coliform—linked with poor waste management—compared to samples farther from dumpsite.

Following this backdrop, this study investigates the microbial contamination of groundwater and the effect of waste management, septic tanks, landfills, and dumpsites on groundwater's quality, reviewing existing data, information, and knowledge. Drinking microbially contaminated water may cause diarrhoea, cramps, nausea, cholera, and typhoid fever (USEPA 2009). The presence of some heavy metals (Pb, Mn, and Fe) was also reviewed from the previous literature. According to the USEPA (2017), in a concentration above 0.01 mg/l, Pb ingestion results in slow growth, lower IQ and anemia in children; reduced fetus growth and premature birth in pregnant women; and cardiovascular effect, kidney dysfunction, and reproductive problems in adults. In addition, the presence of Fe in a concentration above 0.3 mg/l gives reddish-brown colouration to water and promotes the growth of "iron bacteria" (WHO 2011), while manganese above 0.4 mg/l provides undesirable taste for water and leads to the accumulation of deposits in the distribution system (WHO 2011).

Aside threats from dumpsite and septic tanks in part, discussed in this review; indiscriminate disposal of wastewater and industrial effluents as well as inadequate sanitation contributes to groundwater quality issues. In other climes, such as the oil-producing southern part of Nigeria, pipeline vandalisation and unsustainable oil and gas practices have contributed to groundwater degradation (UNEP 2011).

Study areas

The two most populous cities—Lagos and Ibadan—in Southern Nigeria (Fig. 1) were selected as the study area. Groundwater around Soluos dumpsite, situated in Igando—Alimosho local government area (LGA) of Lagos state (a state with 5th largest economy in Africa), was analyzed. Though no population estimate is available for the local community, Igando is in a local government area with a population of over 2 million (Lagos Bureau of Statistics 2012). Groundwater samples in the Agbowo area (Fig. 1) of Ibadan—Oyo state, which is home to staff and students of the polytechnic and University of Ibadan, were also analyzed. Situated in Ibadan North, an LGA of 308,119 population (National Population Commission 2010), Agbowo is one of the major communities in Ibadan North located on latitude 7°26′N and longitude 3°54′E. Both states have recorded outbreaks of water-borne diseases (Nigerian Vanguard 2011 and 2017).

The Soluos dumpsite (Fig. 1) is a non-engineered dumpsite established in 2008. It is about 15 m deep and covers approximately 78,000 m^2 (Aderemi et al. 2011). Located at coordinate 6°34′N and 3°15′E, the Soluos is surrounded by commercial and residential setups, and it receives about 4000 tons of waste per day (Adeyi and Majolagbe 2014; Afolayan et al. 2012). The waste composition is mostly from commercial and domestic sources with additional wastes from a nearby poultry farm and abattoir (Aderemi et al. 2011).

Case study of groundwater quality in Agbowo

Quality parameters considered to have significant health effects and a relationship with anthropogenic activities were selected for the study. Microbial parameter (total coliforms) and organic content parameter (biological oxygen demand—BOD) were considered in the study. To reiterate groundwater vulnerability as a result of inefficient waste management in Southern Nigeria, the study analyzed the effect of septic tank seepages on groundwater in Agbowo community, Oyo state. Microbial load in groundwater samples close to septic tanks reported by Adetunji and Odetokun (2011) were analyzed using the Pearson *R* test. BOD in groundwater samples in

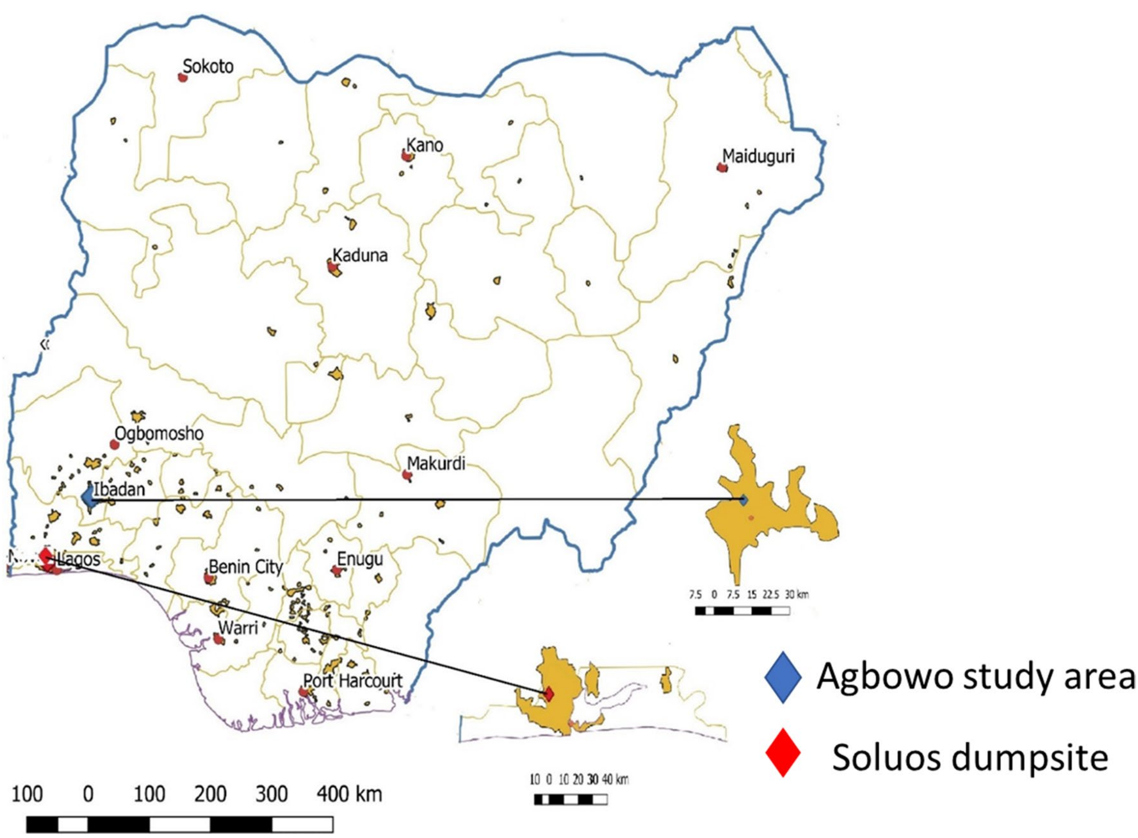

Fig. 1 Map of Nigeria showing the study locations

other locations within a range of 1.3–17.2 km from Agbowo, reported by Ujile et al. (2012), were also reviewed.

Adetunji and Odetokun (2011) sampled 40 groundwater wells for microbial analysis. The samples were randomly collected aseptically from Agbowo area in Ibadan, Nigeria. The samples were collected into sterile 10 ml bijou bottles, fitted with screw caps, and well-labelled. Two samples were collected from each well, stored on ice (to prevent loss of microbial life), and transported to the laboratory for immediate analysis. Distances between the septic tanks and groundwater wells were taken using a tape rule (details as presented in Table 1). Ujile et al. (2012) collected water samples from hand-dug wells in eight (8) communities within Ibadan metropolis to assess the extent of contamination. They maintained the samples between a temperature of 0–4 °C, by storing in a refrigerator, before analysis (their results are as presented in Table 2).

The 50 ft (15.24 m) USEPA recommended distance between septic tank and domestic groundwater source, which are not adequately enforced and monitored in Nigeria, forms a basis for groundwater microbial contamination. As shown in Table 1, total coliforms in sampled groundwater wells exceeded the World Health Organization (WHO) zero threshold for drinking water. None of the sampled wells was at a minimum distance of 15.24 m (50 ft) from the septic tank. Groundwater samples taken from wells at about 7.44 m from septic tank showed the highest total coliform of 2.64 log CFU/ml (mean), while those at 12.90 m from septic tanks had 1.93 log CFU/ml (mean) total coliform load. In the absence of a secondary source of pollution, groundwater wells could be said to be better protected from contamination by sitting them far from septic tanks.

Pearson *R* test, corroborating the relationship between groundwater pollution and distance from septic tank, gave a correlation coefficient '*r*' of −0.49, an indication of reduced coliform contamination in groundwater wells away from septic tanks (Takal and Quaye-Ballard 2018). The Pearson *R* test indicated a moderately negative correlation between coliform contamination and distance of well from septic tanks for the data set. This moderate correlation could be attributed to different rates at which each well is vulnerable to contamination from septic tanks. For instance, in a situation, where one or two wells are linked to the same aquifer, there is a tendency of cross contamination between such wells.

All groundwater wells sampled by Ujile et al. (2012), in eight (8) other communities within a distance range of 1.3–17.2 km from Agbowo community—where Adetunji and Odetokun (2011) had reported high total coliform count (Table 1)—were reported to have high BOD, an indication of high content of organic matter in the groundwater samples. This shows widespread groundwater contamination in Ibadan metropolis.

Case study of ground water quality in Igando

Further analyzing the extent of groundwater contamination in southern Nigeria, the presence of Enterobacteriaceae and heavy metals (Pb, Mn, and Fe) in groundwater samples were considered in Igando. Results reported by Aderemi et al. (2011) and Salami and Susu (2013) reflects the effect of dumpsite leachate on groundwater in Igando, Lagos state.

To assess the extent of groundwater contamination, Aderemi et al. (2011) sampled eight (8) groundwater wells within a 550 m radius from Soluos dumpsite, Igando, Lagos-Nigeria. The samples collected at the beginning of the rainy season (April 2009), were collected in clean 500 ml plastic bottles. Since there was no leachate collector system, leachate samples from three different locations were randomly collected from the base of the dumpsite; from which a composite sample of the leachate was prepared. The samples were immediately stored at 4 °C, transferred to the laboratory, and analyzed the same day. They plated sample dilutions on MacConkey agar using the spread plate technique (Harrigan

Table 1 Microbial analysis (mean values) of household groundwater samples near septic tanks in Agbowo, Ibadan (Adapted from Adetunji and Odetokun 2011)

Sample	Distance from septic tank (m)	Total coliform (log CFU/ml)
S_1	7.44 ± 2.64	2.64
S_2	7.92 ± 3.54	2.3
S_3	10.06 ± 4.16	2.54
S_4	10.21 ± 3.59	1.79
S_5	10.60 ± 0.00	1.01
S_6	10.79 ± 1.12	2.11
S_7	12.90 ± 4.16	1.93

Table 2 Biological oxygen demand (BOD) in eight (8) other communities outside Agbowo community (Adapted from Ujile et al. 2012)

Communities	Orogun	Bodija	Agodi	Sango	Beere	Oke-Ado	Apete	Ajakanga
Distance from Agbowo community (km)	1.3	2.9	5.9	5.9	9.3	10.8	13.7	17.2
BOD (mg/l)	21.12	20.93	19.71	20.47	25.89	21.96	17.85	16.82

Table 3 Microbial analysis of groundwater samples near the Soluos dumpsite (Adapted from Aderemi et al. 2011)

Sample	Distance from Soluos dumpsite (m)	Total viable count of Enterobacteriaceae (log CFU/ml)
Dumpsite leachate		5.1
GS_1	0	6.02
GS_2	80	4.20
GS_3	100	4.34
GS_4	240	4.00
GS_5	260	4.22
GS_6	280	4.95
GS_7	370	5.02
GS_8	550	3.6

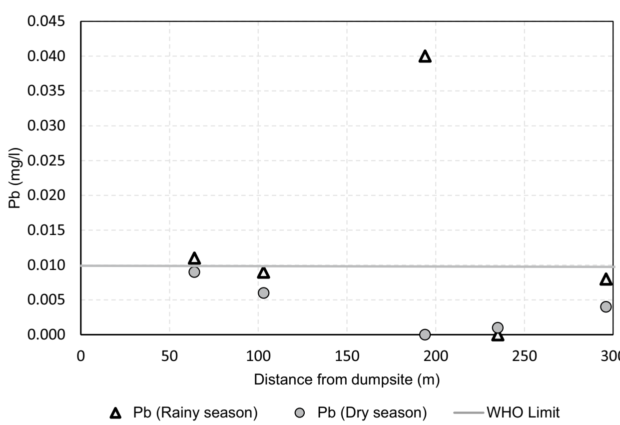

Fig. 2 Lead (Pb) concentration in groundwater away from the dumpsite in dry and rainy seasons (Data adapted from Salami and Susu 2013)

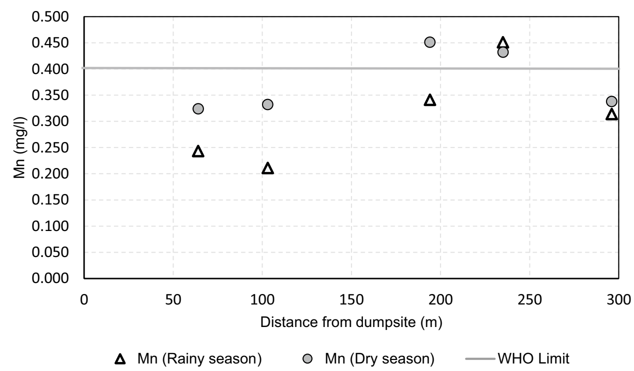

Fig. 3 Manganese (Mn) concentration in groundwater away from dumpsite in dry and rainy seasons (Data adapted from Salami and Susu 2013)

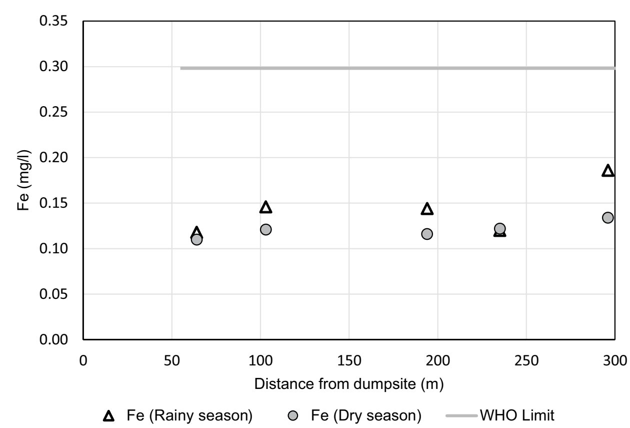

Fig. 4 Iron (Fe) concentration in groundwater away from the dumpsite in dry and rainy seasons (Data adapted from Salami and Susu 2013)

and McCance 1976) for the enumeration of Enterobacteriaceae (their results are presented in Table 3).

In the same manner, Salami and Susu (2013) sampled five (5) groundwater wells within 500 m from the dumpsite. These samples were taken during rainy and dry seasons. Samples were collected using disinfected 1-l plastic bottles. Samples were stored at 4 °C, and quickly transported to the laboratory for immediate analysis. Salami and Susu analyzed for heavy metals in the samples using atomic absorption spectrophotometer (AAS), with their results, as shown in Figs. 2, 3, and 4.

As shown in Table 3, all the groundwater samples within a 550 m radius from the Soluos dumpsite are laden with a microbial load (Enterobacteriaceae). Since no leachate collector was installed in this dumpsite, leachate accumulating at the base of the dumpsite was randomly sampled by Aderemi et al. (2011)—this might, however, not be an accurate representative sample of the dumpsite's leachate. The total viable count of Enterobacteriaceae in the Soluos leachate was 5.1 log CFU/ml, while it was 6.02 log CFU/ml in the Soluos well sample (a well approximately at a zero distance from the dump site). A considerable distance away from the dumpsite, the microbial load of sampled groundwater reduced to 4.20 log CFU/ml at 80 m away and, finally, 3.60 log CFU/ml at 550 m away. The Soluos dumpsite can, therefore, be said to contribute to groundwater microbial load in the area.

Enterobacteriaceae—found in soil and water—are Gram-negative bacteria, including pathogens such as *E. coli* and *Salmonella* among others. The presence of Enterobacteriaceae in leachate and subsequent infiltration into groundwater could be attributed to open defaecation on the Soluos dumpsite and the composition of wastes deposited, which includes animal wastes (Opeolu et al. 2010).

The Pearson *R* test also gave a moderately negative correlation ($r = -0.53$) between Enterobacteriaceae contamination and distance of wells from the Soluos dumpsite. This moderate correlation could be attributed to the presence of a secondary source of pollution (Mishra et al. 2017; Dalakoti et al. 2018)—other than the Soluos leachate—such as run-offs from abattoir and poultry farms within the study area.

According to Adelekan and Abegunde (2011), high Pb concentration in soil and groundwater is majorly due to anthropogenic activities, one of which is the use and disposal of lead paints and batteries. There are naturally existing Mn compounds in soils and water; however, human and industrial activities in the use of fossil fuels and the use of manganese pesticides contribute to elevated concentration (above WHO limit) of Mn in groundwater (Lenntech Water Treatment 2019a, b). Sources of Fe in groundwater include natural weathering processes, industrial effluent, sewage, and dumpsite leachate (Lenntech Water Treatment 2019c; Illinois Department of Public Health 2010; Regional District of Nanaimo 2007).

From Fig. 2, contaminant migration (Pb) from dumpsite into groundwater wells was seen to have been elevated above WHO standard, in some locations, during the rainy season as compared to the dry season. Different compositions of wastes deposited in the dumpsite throughout the year could have influenced different Pb contamination rates in groundwater per given time. Pb in the groundwater samples shows that the dumpsite waste composition could include disposed Pb batteries, Pb-based paints, and pipes (Ujile et al. 2012). According to Lenntech Water Treatment (2019a), Pb ends up in water through solid waste combustion, as well as corrosion of leaded pipelines and leaded paints. Widespread poor waste management culture in the area, which includes hazardous and careless dumping of refuse (pockets of refuse heaps at various locations away from Soluos dumpsite), indiscriminate combustion of solid wastes and indiscriminate disposal of lead-containing products such as batteries, pipes, and paints (Momodu et al. 2011; Babayemi and Dauda 2009; Ogunniran 2019) could be attributed to the wide variation between dry and rainy season's Pb content in groundwater samples around 194 m away from Soluos dumpsite. During rainy season, the corrosion and percolation rate increases, which can contribute to elevated concentration of Pb in groundwater at this location. The Pearson R test, with a weak correlation coefficient 'r' of -0.39 on Pb concentration in the two seasons, further corroborates varying input source of lead in dry and rainy season (Mishra et al. 2017).

Figure 3 also shows Mn concentration above WHO limits in some of the sampled groundwater in both seasons. Correlation analysis shows a strong positive relationship ($r = 0.78$) between Mn in groundwater samples in both seasons, an indication of a common input source in both seasons (Mishra et al. 2017). Fe concentration in groundwater in sampled locations falls well below the WHO acceptable limit both in dry and rainy seasons (Fig. 4). In addition, a strong positive correlation coefficient between Fe in groundwater samples ($r = 0.83$) in dry and rainy seasons also shows a common input source in the two seasons (Mishra et al. 2017). As noted by Aderemi et al. (2011), the minimal impact of the Soluos dumpsite leachate on the physicochemical parameters of surrounding groundwater can be attributed to the soil stratigraphy, consisting of clay—which is deduced to have a substantial influence on natural attenuation of leachate into groundwater.

Problems related to groundwater monitoring, policy, and framework

Most reported cases of water-borne diseases are caused by microbial contamination. In another report by Nigerian Vanguard (2016), Lagos state government disclosed 45 cases of cholera, with six deaths. As reported by the State Health Commissioner, the laboratory report (Nigerian Vanguard 2016) revealed the presence of *Vibrio cholerae, E. coli,* and *Salmonella* species in one of the two groundwater wells sampled within the area of the epidemic. Groundwater quality, in the study area and Nigeria as a whole, is being threatened. This cannot be dissociated from cursory federal and state legal, policy, and regulatory frameworks guiding groundwater resources and its monitoring. As much as there are federal government laws, described as perfunctory and fragmented by Ogunba (2015), there is no law specific to groundwater resource monitoring in most Nigerian states. The Lagos State Water Regulatory Commission (LSWRC), for instance, only aims at accomplishing sustainable water supply and wastewater management services. Apart from ineffective municipal water supply and groundwater abstraction, regulatory lapses which have made groundwater vulnerable to contamination, and ineffective environmental management practices in Nigeria, further exacerbate this problem. According to the Multiple Indicator Cluster Survey (NBS and UNICEF 2017), safe drinking water is not accessible in Nigeria, as over 96% of Nigerians still consume contaminated water.

Lack of policy, unregulated/unmonitored groundwater well construction, and weak institutional capacity are some of the factors posing a significant challenge to groundwater monitoring. As noted by the British Geological Survey (2018), lack of resources has also prevented groundwater monitoring in Nigeria. The effect of groundwater contamination from inadequate waste disposal—not limited to the study area—is a pressing issue across Nigeria (Tariwari and Jasper 2017). Another resultant effect in other parts of Lagos state is that water from some wells and boreholes usually smells and is of yellowish appearance, making it unsuitable for human consumption (Nigerian Vanguard, 2012). "The water problem in Nigeria has, however, reached crisis point. No day passes without stories or news about cases of water-borne diseases caused by a chronic shortage of safe water making the rounds" (Nigerian

Premium Times 2017). Given the significant dependence on groundwater and the statement accredited to Nigerian Premium Times (2017), a substantial number of water-borne diseases are attributable to poor groundwater quality standards in Nigeria. On average, the cost of an affected household is one-tenth of their monthly income per infected person (Weli and Ogbonna 2015). A similar study in a rural community in Pakistan (another LMIC country) by Malik et al. (2012) reported a direct cost of US$ 0.6–2.3 spent on water-borne ailments per day and an indirect cost of US$ 2.3–4.7 per day. Even advanced countries like the United States are not left out, as the Centers for Disease Control and Prevention (2010) reported that water-borne diseases could cost the US well over US$ 500 million annually. The Walkerton event in southern Ontario, Canada that claimed seven lives as a result of drinking water from a polluted groundwater source is another instance (Salvadori et al. 2009). Worldwide, in contrast to surface water, groundwater has, therefore, been given little attention regarding water monitoring.

Consequently, groundwater quality monitoring, involving baseline and time-variant characterisation, is critical to groundwater management and protection. This, however, comes with some costs which include:

1. The capital cost of installing monitoring/observation wells, the cost of network installation for data gathering towards groundwater reference monitoring, protection monitoring, and pollution containment.
2. Sampling costs, which involves instrumentation, personnel, and logistics costs.
3. Analytical costs, including laboratory, data processing, and storage costs (Tuinhof et al. 2006).

The cost of groundwater monitoring processes often considered expensive varies depending on the soil geology and extent of risks and contamination. However, whatever cost expended on water quality monitoring is offset by the reaped benefits. Some of these benefits include reduced burden on health care (Preker et al. 2016), enhanced workforce productivity (Van Grieken et al. 2013) and improved foreign direct investment (Cole et al. 2011). Quality monitoring would provide early warnings on groundwater pollution and the need for taking mitigative and control measures as necessary. Groundwater monitoring can, therefore, only yield a return on investment on a longer term if data are judiciously managed (Tuinhof et al. 2006).

Conclusions and recommendations

A large population of Nigerians depending on groundwater wells gives significance to the importance of the findings of this study. The observed elevated levels of Pb and Mn concentrations, above the WHO limits, in some groundwater wells neighbouring the Soluos dumpsite, indicate a potential threat to groundwater resources. Non-engineered dumpsites and lack of enforced standard distance between septic tanks and groundwater wells are the key factors adversely affecting groundwater quality. The hazard of groundwater contamination via ineffective waste management would be a national issue in Nigeria that might extend beyond the study sites. Ensuring availability and sustainable management of water and sanitation for all (SDG 6), as well as maintaining good health and well-being (SDG 3), remains a pressing issue in regions overly dependent on groundwater resources. Groundwater monitoring could help accelerate this process in such regions if the following recommendations are implemented.

State and local governments should take initiatives for groundwater monitoring prioritisation in the areas where groundwater is severely affected by excessive pumping and contamination by septic tanks and dumpsites. This will provide timely data for making decisions towards groundwater and public health protection. Regulations should be extended to encourage private well owners to test their well water samples regularly; incentives and in situ training for the private well owners to conduct groundwater sampling (samples should be subsequently taken to government approved laboratories for analysis). Groundwater testing would generate better results towards achieving SDG 3 and 6. A robust, coordinated database should be put in place by relevant agencies (state and local governments) for groundwater monitoring and subsequent use in decision making. Subsequent groundwater well construction should follow the USEPA standardised distance of 15.24 m (50 ft) from septic tanks. Local government should approve construction of household groundwater wells after thorough assessment of health and environmental conditions and standards. Given the current rate at which groundwater wells are drilled, without due attention to the distance from septic tanks, the government should intensify efforts towards making municipal water available for a larger population. This would discourage dependence on polluted groundwater for drinking purposes. In addition, neighbourhoods near non-engineered dumpsites and communities, where no reference is made to the USEPA recommended 15.24 m (50 ft) distance between septic tanks and groundwater sources should be placed under boil-water advisory or another source of water should be introduced to minimize the health impacts.

Solid waste management practices that would convert the waste to commercial use rather than being stored in piles for years—posing threats to groundwater resources and human health should be adopted. In the same vein, local and state governments should focus on more coordinated means (centralised or decentralised) of domestic and industrial waste management, while employing engineered/controlled landfills for solid waste management, all to curtail anthropogenic pollution effects on groundwater.

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