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ORIGINAL ARTICLE

Heavy metal assessment on groundwater quality around abandoned borrow pit environment: evidence from hydrogeology and geochemistry

O. M. Omorogieva[1] · O. I. Imasuen[2] · E. A. Adanu[3] · J. A. Tonjoh[1]

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Abstract
Selected heavy metal, Chromium (Cr), Lead (Pb), Nickel (Ni), and Iron (Fe) based on their health index has been determined in Asoro, Otofure, and Ikhueniro satellite towns in Benin Metropolitan City (BMC), Nigeria. The areas are heavily populated and depend on groundwater for drinking purposes. Literature review showed that groundwater quality in the study areas is adversely affected due to rapid urban and economic growth. The study combines hydrogeological and geochemical techniques in evaluating the subsurface geology, the interrelationship between abandoned borrow pit, contaminants transportation, and the concentration of Cr, Pb, Ni, and Fe in groundwater in and around the study vicinity. The results obtained showed that the excavated average depth of the borrow pits in the area is 27 m deep, whereas the depths to the aquifer were 53.22 m, 77 m, and 50 m at Ikhueniro, Otofure, and Asoro, respectively. The mean value of Cr in the groundwater samples was, 2.23, 0.04, and 0.03 mg/L with a corresponding Coefficient of Variation (CV) of 150%, 22.24% and166.67% in Asoro, Ikhueniro, and Otofure, respectively. It was observed that groundwater around Asoro and Ikhueniro were impacted with Cr when the result was compared to the WHO and SON permissible limit of 0.05 mg/L except in Otofure where the mean value of 0.03 mg/L was below the tolerable limit for potable water. Based on the results obtained in the study, the groundwater in the study areas cannot be consumed unless routine treatment is administered considering the health impact of the selected metals.

Keywords Urbanization · Environmental mismanagement · Groundwater · Contamination and public health

Introduction

The term borrow pits are used to describe an area of land where earth materials such as soil, sand, clay, gravel, and other economic minerals have been removed for construction, landscaping, and raw materials for industries (Charalampidesa et al. 2014; Nwachukwu et al. 2017). Globally, borrow pit is a household name that is often referred to as sandbox; it can be either enclosed or open; often located near construction sites in an area devoid of human habitation because of its detrimental environmental effects if not professionally managed (Akujieze and Oteze 2006; Nwachukwu et al. 2017; Omorogieva and Tonjoh, 2020). They are often operated by a licensed individual and government agencies for employment generation, profit maximization, economic growth, and national development. Although, there are strict measures set by regulatory agencies through government policy in the operation of borrow pits but the lack of monitoring, and strict enforcement of existing laws has led to its poor management; a situation that has led to the environmental menace of monumental consequences (Word Bank 2007; Egharevba et al. 2013; Akujieze and Emmanuel, 2014; Nwachukwu and Eburukevwe, 2019; Word Bank 2019; Ayade, 2020; USAID, 2020; Bankrate, 2020; Green Road for Water 2020). In recent times, it is observed that abandoned borrow pits are converted to a refuse dumpsite; this development is common in developing nations like Nigeria (Imasuen and Omorogieva 2013a; Egharevba et al. 2013; Omorogieva, 2014; Omorogieva et al. 2016; Mor et al. 2005). The practice of converting borrow pits into a refuse dumping site is

✉ O. M. Omorogieva
osakpolor.omorogieva@nmu.edu.ng

[1] Department of Marine Geology, Faculty of Marine Environmental Management, Nigeria Maritime University, Okerenkoko, Delta State, Nigeria

[2] Department of Geology, Faculty of Physical Sciences, University of Benin, Benin City, Nigeria

[3] National Water Resources Institute Mado, Kaduna, Nigeria

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worrisome and calls for urgent concern, because the waste materials dumped contain toxic substances that could percolate into the adjacent aquifer; this could be detrimental to groundwater resources and human health through oral ingestion (Perlmuter et al. 1963; Vodela et al. 1997; Selinus et al. 2013; ATSDR 2012; Unyimadu and Enekwechi, 2004; Doyi et al. 2018; Omorogieva, 2018; Adimalla et al. 2020; Omorogieva and Tonjoh, 2020).

In view of the foregoing, the study became necessary to enable the researchers assess the impact of the abandoned borrow pits use as refuse dumpsites on groundwater quality in the study areas. The following metals of known public health impact; Chromium (Cr), Iron (Fe), Lead (Pb), and Nickel (Ni) were carefully selected based on a previous report in BMC, Nigeria (Omorogieva, 2018). The study areas which include Asoro, Otofure and Ikhueniro were initially an outskirt of BMC but due to population growth and technological improvement, they are now part of BMC, and the abandoned borrow pit therein converted to refuse dumpsite following the approval of the state government (Akujieze 2004; Omorogieva 2016; Omorogieva and Imasuen 2018). Wastes in these open dumpsites are capable of groundwater underflow because of the frequent precipitation, which is capable of facilitating the percolation of contaminants into the aquifer through porous soil media. When this occurs, groundwater becomes vulnerable to contamination, because the percolating water contains toxic substances and other decomposing bye products of the wastes heap find their way into groundwater system (Adriano 1986; Mandishona et al. 1995; Imasuen and Omorogieva 2013b; Selinus et al. 2013; Longe and Balogun 2010; Taylor et al. 2010; Adimalla et al. 2020; Mackay et al. 2009; Falowo and Omorogieva 2020). The key objectives of the study are to determine the depth of the excavated borrow pits, evaluate the borehole log, and correlate boreholes around the pits, evaluate the quality of groundwater by assessing the heavy metal load of Cr, Fe, Ni, and Pb in the groundwater system in the study areas. The outcome of the study will directly contribute to groundwater resources planning, management, and the attainment of a sustainable environment for sustainable development, because attaining environmental sustainability requires transformational leadership across the board with a long-term and collective goal to secure environmental, social, and economic prosperity (Willetts 2017).

The geology of the study area and groundwater proliferation

The study area falls within the Benin Formation (BF); the formation is overlain by the drifts and soil-cover which according to Akujieze (2004), Ikhile (2016), Maju-Oyovwikowhe and Malomi (2019), Onyeobi (1985), Omorogieva and Okiti (2021) are lateritic, with reddish-brown coloration, clayey sand highly porous friable white sandstone of about 90% sand grains with clay stringers. The Benin Formation has its origin linked to the succession of tectonic events that occurred in the south Atlantic province during the Late Cretaceous, is underlain by the Agbada and Akata Formations respectively (Short and Stauble 1967; Oteze 1981; Nwajide and Reijers 1996; Akujieze and Oteze 2006; Edegbai 2019; Ilevbare and Omorogieva 2020). These Formations collectively belong to the Niger Delta Sedimentary Basin of Eocene to Recent (Egbule et al. 2018; Edegbai et al. 2019). Figure 1 represents the geologic map adopted from Akujieze (2004). Benin Formation currently supports over 30,000 boreholes (Akujieze et al. 2003; Oteze, 2019), and is described as the most prolific aquifer in Nigeria.

Materials and methods

Site description

The study areas form parts of the satellite towns in BMC beside Asoro (Fig. 2). The coordinates lie within 6° 19′ 20″ N and 005° 35′ 20″ E (Asoro); Otofure (6° 27′ 44.6″ N and 005° 36′ 03.9″ E) and Ikhueniro (6° 19′ 38.1″ N and 005° 44′ 50.2″ E), respectively. The population of Benin metropolis is estimated to be over 3 million (3,000,000) according to National Population Commission (NPC 2006). However, the targeted population is estimated to be one million (1,000,000) according to the Edo State Bureau of Statistics (2013). The areas exhibit typical characteristics of a tropical climatic weather condition with an annual rainfall of more than 1500 mm (60 inches) and an annual mean temperature of 27 °C, respectively (Ojo et al. 1999; Omorogieva and Tonjoh 2020). A previous study showed that the area is plane, except in the northwestern part where the terrain is undulating rising to a peak of 672 m above sea level (Omorogieva 2016). At Asoro and Otofure, there is a valley through which Ogba and Ikpoba Rivers flow (Fig. 1). Interestingly, the studied areas share a common feature in that the abandoned borrow pits present in each location were initially used as sites where earth material for road construction was removed but are currently converted, and been used as open refuse dumpsites.

Data acquisition

Access to the study sites were granted by Edo State Environmental and Waste Management Board (ESEWMB) to enable the researchers to gather data by assessing the pits, drill well (borehole), and collect groundwater samples for the study. Nine (9) study wells (boreholes), three (3) in each location were drilled at random positions within the study

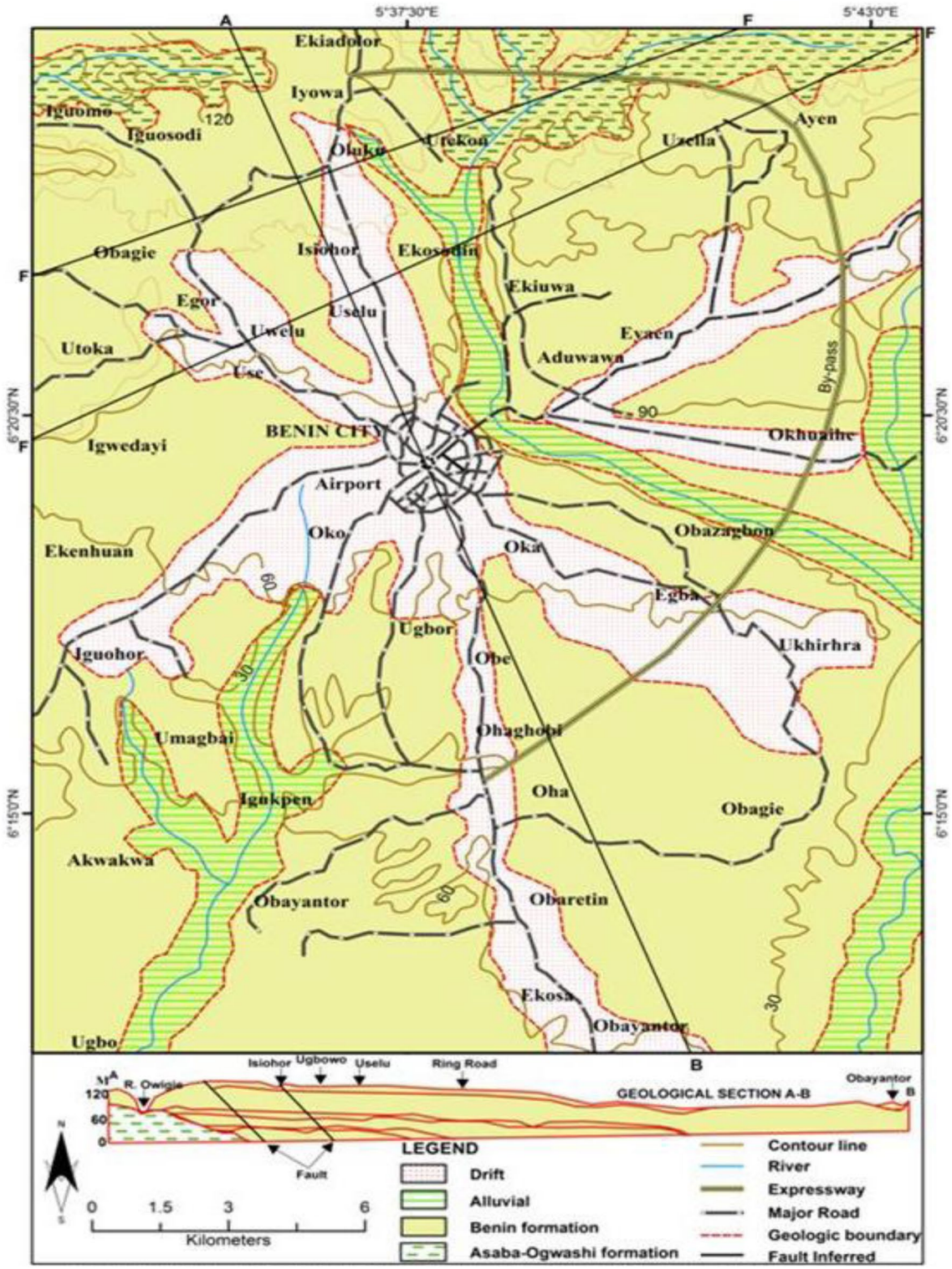


Fig. 1 Geological map guide X-section A–B of Benin City and environs (Akujieze 2004)

environment using the rotary manual method of drilling (Omorogieva and Imasuen, 2018; Module 2 (2020). Soil samples derived from each well during the drilling of the wells were used to produce the litho logs (Isikhuemen and Omorogieva 2015b). The positions of the boreholes were recorded using Global Positioning System (GPSMAP) 78 s Marine Handheld model. The borehole litho logs and their

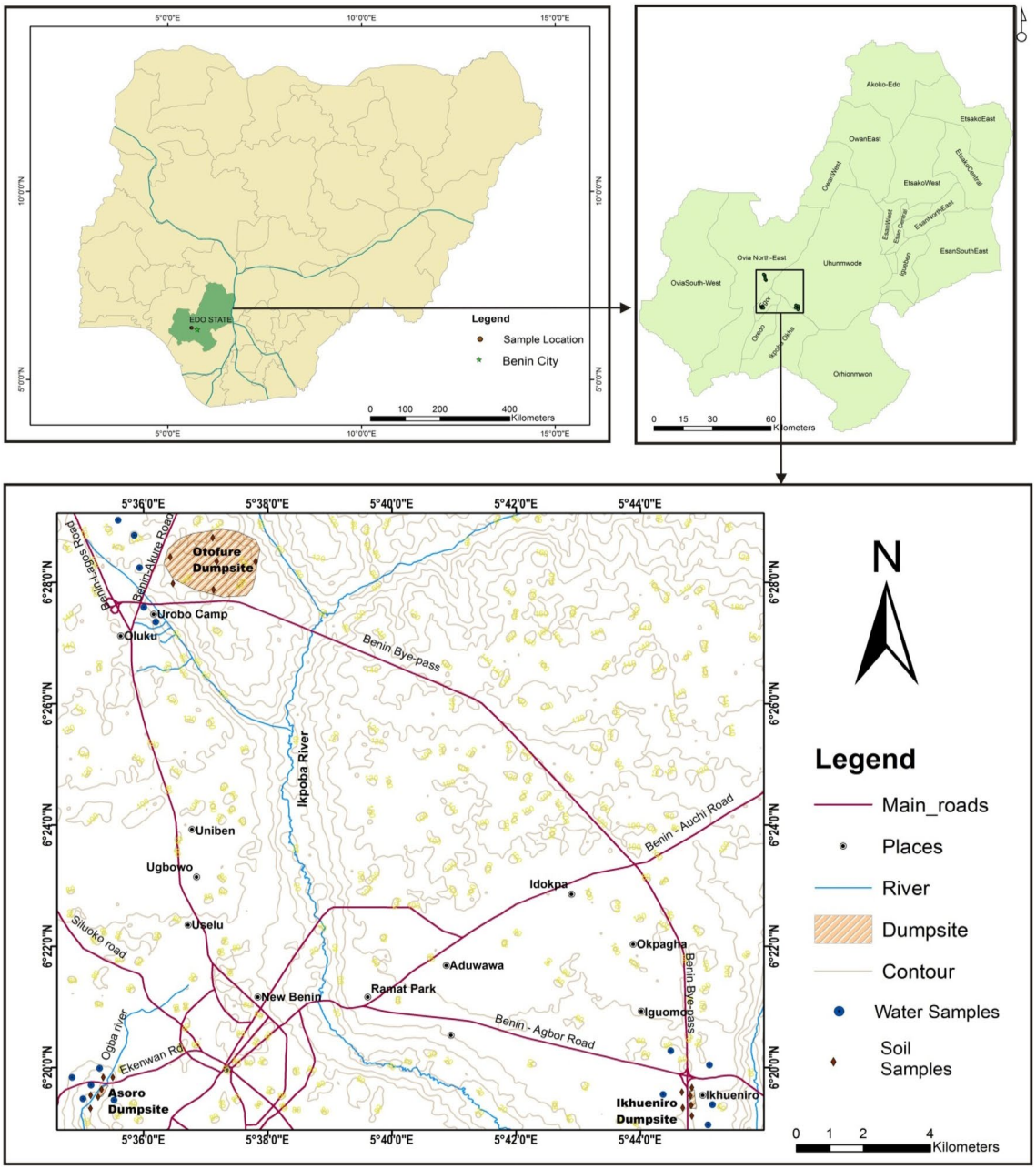


Fig. 2 Location, access and sampling points map of the study areas (Omorogieva 2018)

corresponding correlations are represented in Figs. 3, 4, and 5 for Ikhueniro, Otofure, and Asoro, respectively.

Groundwater sample collection and analysis

Five borehole water (groundwater) samples in each location were obtained with the aid of a water pumping machine from the drilled well into a 75 centiliters (cl) plastic bottle which was pre-rinsed with groundwater from the drilled boreholes to avoid external influence. The samples were immediately transported to the laboratory for analysis. The method outlined in 3005a (2022) for water sample digestion and analysis after Sciortino and Ravikumar (1999), Marcovecchio et al. (2007); Ponka et al. (2007); APHA (2005) were carefully followed with slight modification. First, the samples were digested by adding 2 mL concentrated HNO_3 in a volumetric flask of 250 mL capacity containing groundwater sample. Furthermore, 5 mL of concentrated HCl was added to the solution, and afterward covered foil paper and subjected

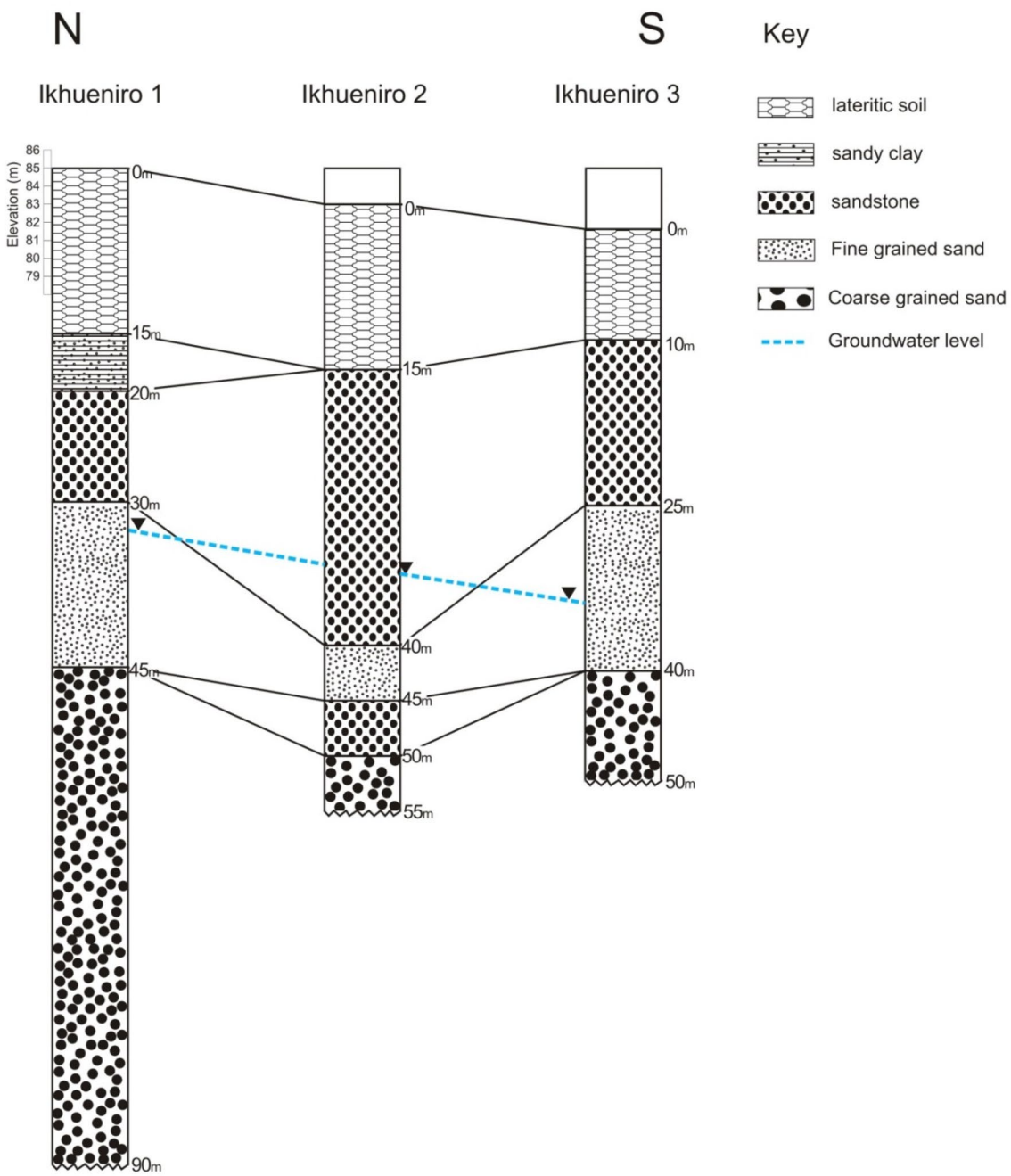


Fig.3 Borehole log indicating the thicknesses of each bed and depth to aquifer in Ikhueniro study area

to heat on an electric hot plate up to a temperature range of 75–85 °C for about 20 min. It was allowed to cool, and thereafter filtered into 120 mL. The concentrations of Cr, Ni, Fe, and Pb contained in the digested groundwater samples were read off with Atomic Absorption Spectrophotometer (AAS) model 969 with air acetylene at the University of Benin, Faculty of Agricultural Science Central Laboratory, Nigeria. The mean values of the triplicate reading are presented in Tables 1, 2, 3, and 4, respectively.

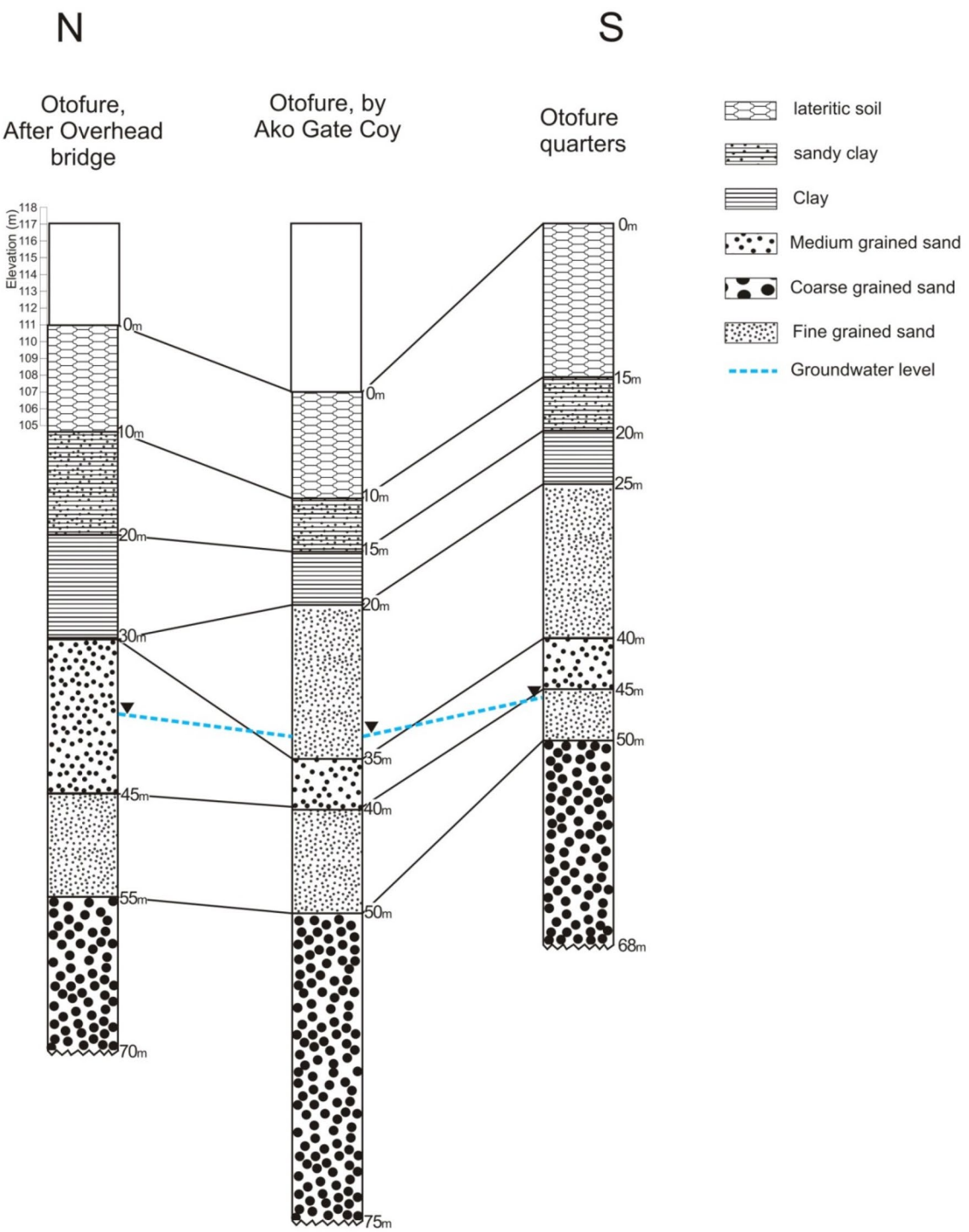


Fig. 4 Borehole log indicating the thicknesses of each bed and depth to aquifer at Otofure of the study area

Statistical analysis

Microsoft excel 2007 version was applied in the determination of the mean and standard deviation of the dataset obtained from laboratory analysis for groundwater samples. Furthermore, the Coefficient of Variation (CV) sometimes referred to as the Relative Standard Deviation (RSD) expressed in percentage (%) was determined by the application of Eq. 1.

$$\mathrm{CV}(\%) = \frac{\mu}{\sigma} \times 100 \tag{1}$$

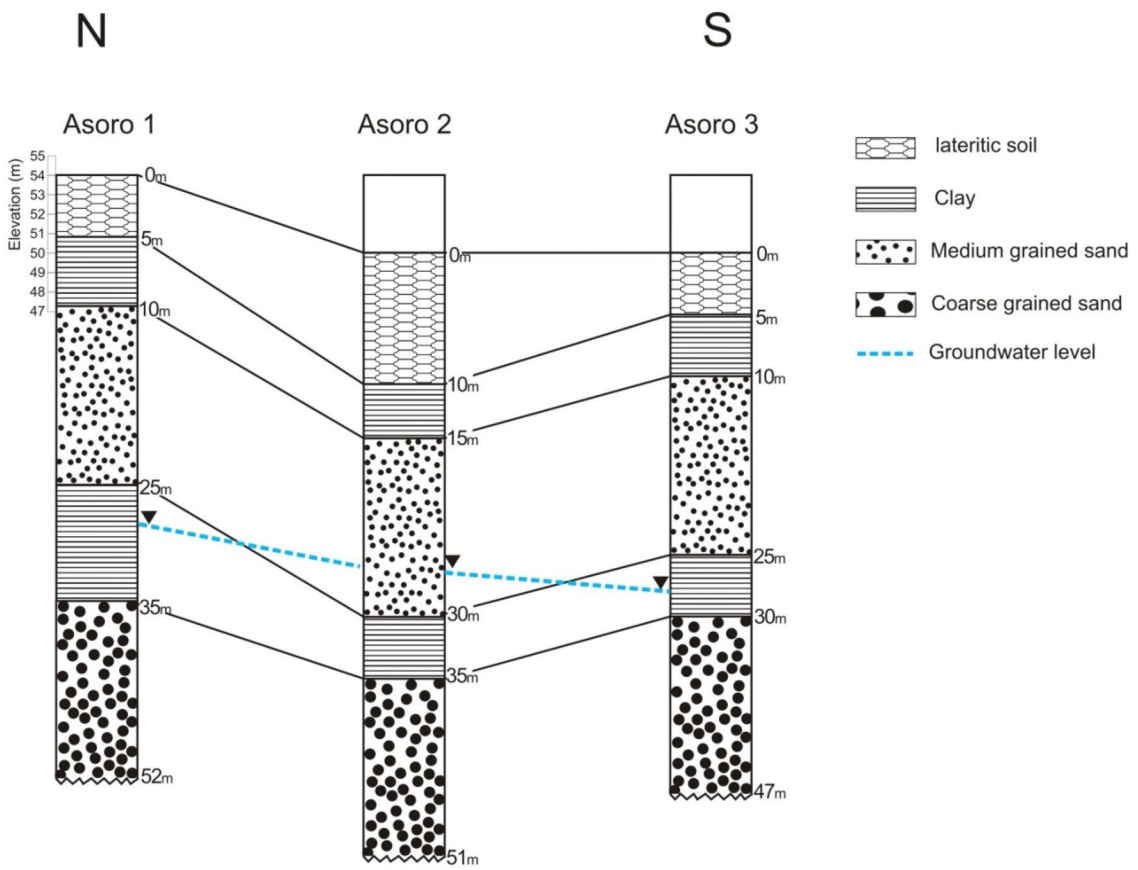


Fig. 5 Borehole log indicating the thicknesses of each bed and depth to aquifer in Asoro study area

Table 1 Variation of chromium concentration in groundwater samples (mg/L) $n=5$

Sampling points	Mean	Minimum	Maximum	SD	CV	WHO	SON
Ikhueniro	0.04	0.03	0.15	0.06	150	0.05	0.05
Asoro	2.23	1.20	4.05	0.50	22.42	0.05	0.05
Otofure	0.03	0.00	0.12	0.05	166.67	0.05	0.05

Table 2 Variation of lead concentration in groundwater samples (mg/L) $n=5$

Sampling points	Mean	Minimum	Maximum	SD	CV	WHO	SON
Ikhueniro	0.03	0.001	0.05	0.02	66.67	0.01	0.01
Asoro	0.92	0.49	1.67	0.21	22.83	0.01	0.01
Otofure	0.03	0.001	0.05	0.02	66.67	0.01	0.01

Table 3 Variation of iron concentration in water (mg/L) $n=5$

Sampling Points	Mean	Minimum	Maximum	SD	CV	WHO	SON
Ikhueniro	0.64	0.2	1.43	0.52	81.25	0.3	0.3
Asoro	5.82	4.25	8.90	1.93	33.16	0.3	0.3
Otofure	0.64	0.20	0.73	0.52	81.25	0.3	0.3

where σ = standard deviation and μ = mean. The Coefficient of Variation is used to determine the precision of the mean value of a result obtained from a given dataset. According to the Institute for digital research and education, statistical

Table 4 Variation of nickel concentration in groundwater (mg/L) $n=5$

Sampling points	Mean	Minimum	Maximum	SD	CV	WHO	SON
Ikhueniro	0.03	0.05	0.73	0.34	1133.33	0.07	0.2
Asoro	5.32	2.86	9.68	1.21	22.74	0.07	0.2
Otofure	0.32	0.05	0.73	0.34	106.25	0.07	0.2

consulting, the University of California Los Angeles (UCLA 2020), and the Institut National De La Statistique et Des Etudes Economiques (INSEE 2016), when the value of CV is high, the implication is that the level of dispersion of the parameter in quotes around the mean is great. Conversely, when the value of CV is low, it implies that the parameters (s) under investigation are more precise or confined around the source; it was applied in this study to aid the interpretation of the heavy metal dispersion in groundwater systems (hydrodynamic dispersion).

Results and discussion

The borehole logs developed around Ikhueniro borrow pit (Fig. 3) showed that the aquifer in the area is relatively shallow and unconfined with an average depth of 53.22 m. From the log, the subsurface beds are characteristics of fine to coarse sand grain with high permeability and porosity. These attributes of Ikhueniro soil tend to facilitate the flow of leachate and bio-solids into groundwater (Imasuen et al. 2016; Omorogieva 2016). The logs revealed that the Ikhueniro aquifer is capped by sandy clay; a situation that could be termed ''leaky aquifer'' (Toth 2020; Module 2 2020). Aquifers with such geometry may be vulnerable to leachate and other toxicants inflow; especially when the aquifer is shallow, and the area is high in anthropogenic activities, in addition to the climatic condition.

In the Otofure axis of the study area, the borehole logs revealed that the aquifer in this area is relatively deep with an average depth of 77 m (Fig. 4) compared to Ikhueniro with a depth of 53.22 m. The aquifer in this location is capped with thick clay beds of about 10 m thick. Clay can perform the function of suction by absorbing the incoming contaminants from the porous and permeable overlying rock strata. The wells drilled in and around the Asoro area of the study showed an average depth of 50 m to the aquifer. This is inconsonant with the results recorded at the Ikhueniro location. The result may have been influenced by the topography and the nearness of the locations to the river that drain the study area (Fig. 1). Aquifers that are close to rivers in an area with flat topography like the coastal environment are usually shallow and vulnerable to contamination (Akpoborie et al. 2015; Tonjoh and Omorogieva 2020). Although the boreholes around Asoro have a thin bed of clay that could perform the function of a seal the average depth to the aquifer is relatively shallow and can be influenced by anthropogenic activities. Hydrogeological study of the study area buttresses the influence of the anthropogenic activities arising from the excavated pits as the main factor influencing the vulnerability of the aquifers and groundwater quality. Other factors include the poor casing of the boreholes in and around the study area, dumping of refuse in the pits, and the interaction between the surface water (rivers) and groundwater. Hence, a geochemical appraisal of the known health impact of Fe, Pb, Cr, and Ni was carried out on the groundwater samples from the drilled boreholes in the study areas to ascertain the levels of concentration of the selected metals.

Juxtaposing the hydrogeological result with the geochemical assessments of the selected metals in the groundwater samples collected, and by comparing the outcome with the standards set by WHO (2011, 2012a, b, 2020; WHO-UNICEF 2000), and the Nigerian Standard for Drinking Water Quality under the domain of the Standard Organization of Nigeria (SON 2015) shows that the groundwater quality in the areas compromise the minimum value as standard for potable water. This could be traced to the deeply excavated borrow pits which are currently being used as a dumpsite. Tables 1, 2, 3, and 4 represent the results of each heavy metal measured in mg/L across the study areas. Table 1 shows that Cr has a mean value of 2.23, 0.04, and 0.03 (mg/L) in Asoro, Ikhueniro, and Otofure, respectively. The mean value shows that groundwater around Asoro and Ikhueniro respectively is impacted with Cr when compare to the maximum permissible limit of 0.05 (mg/L) set by WHO and SON, except in Otofure where the mean value of 0.03 mg/L was below the tolerable limit for potable water. The Coefficient of Variation (CV) revealed that Cr concentrations were higher in Otofure with a value of 166.67%, while Ikhueniro and Asoro have CV values of 150% and 22.24%, respectively. This implies that Cr in Otofure and Ikhueniro are well dispersed from the source as compared to Asoro which is confined within the source. The concentration and the spread of Cr in the groundwater system call for concern because the accumulation of Cr in the human system could be detrimental to human health (Exler 1974; Adimalla et al. 2020). Other metals measured include Pb, Fe, and Ni, respectively (Tables 2, 3, and 4). A mean value of 0.9 mg/Pb in Asoro and 0.03 mg/L were recorded in boreholes around Ikhueniro and Otofure, respectively. These values compared to WHO recommended value of 0.01 mg/L for potable water are outrageous. The value of

22.83% and 66.67% CV recorded in Ikhueniro and Otofure, respectively, for Pb showed that the metal is more confined in Asoro than in Otofure and Ikhueniro. Excess Pb in the human system through oral injection has been reported to be responsible for low intelligent quotient (IQ), brain damage, reproductive disorder, and cardiovascular diseases (Bakare-Odunola 2005; Taylor et al. 2010; Akujieze and Idehai 2014; Hime et al. 2015). Conversely, a mean value of 5.3, 0.03, and 0.32 mg/L of Ni was recorded in groundwater at Asoro location, Ikhueniro, and Otofure, respectively. These values were also higher than WHO and SON 0.02 mg/L tolerable limit for potable water. Juxtaposing the level of Ni dispersion in groundwater from the source for the calculated CV of 1133.33%, 22.74%, and 106.25%, respectively, for Ikhueniro, Asoro, and Otofure revealed that Ni in the groundwater system has spread considerably. Nickel is known to be responsible for respiratory failure, cancer, birth defects, and blood pressure (Dai et al. (2014).

The concentration of Fe in the groundwater samples at the three locations were significantly high; a mean value of 0.64 mg/L was recorded in Asoro, 5.82 mg/L in Ikhueniro, and 0.64 mg/L in Otofure, respectively. When these values were compared to the WHO and SON minimum tolerable limits of 0.3 mg/L for potable water, it was found that the groundwater samples obtained in the boreholes in these study areas were impacted with Fe.

Heavy metal like Cr, Pb, Ni, Fe, and other environmental toxicants could find their way into groundwater system through percolation of polluted storm water from the neighborhood during precipitation, sewage sludge from the septic tank, leachate from wastes heap, weathering of bedrocks, and human interaction with nature during excavation, engineering construction, mineral mining, and wastes dumping (Boxter et al. 1986; Selinus et al. 2013; Omorogieva and Imasuen 2013b; Liu 2016; Raspanti et al. 2016; Ezenabor 2000; Omorogieva 2016).

In this study, the presence of these metals in the groundwater in and around the study area was attributed to the relatively shallow aquifer in and around Ikhueniro and Asoro; couple with the average depth of 27 m of the excavated abandoned pits that were converted to refuse dumpsite. Imasuen and Omorogieva (2013b), Omorogieva and Imasuen (2018); Omorogieva and Andre-Obayanju (2020) Omorogieva and Tonjoh (2020) revealed that wastes dumped in these abandoned pits contains deleterious heavy metal, and other hazardous substances such as dioxin, organic and inorganic components. Mobility of these geoenvironmental contaminants could be facilitated by regular precipitation as well as the porous and permeable geologic media through which the contaminants infiltrate into the groundwater system (aquifer). Consequently, aquifer occurring in such geologic formation becomes vulnerable to contamination especially when the aquifer lacks seal material like clay (Kuypers et al. 2008; Onyeobi and Akujieze 2014; Isikhuemen and Omorogieva 2015a).

The presence of heavy metal like Pb, Cr, Fe, and Ni in groundwater is detrimental to human health through oral ingestion without preliminary treatment. Heavy metals are non-biodegradable, and can cause myriad diseases like respiratory challenge, cancer, reproductive and kidney dysfunction, low birth weight and intelligent quotient, and cardiovascular related diseases (Taylor et al. 2010; Omorogieva and Tonjoh 2020; Zhou et al. 2020; Adimalla et al. 2020). Iron overload in groundwater could result in gene mutations; a condition known as hemochromatosis. Other health challenges caused by excess Fe in drinking water include organ failure, fatigue, weight loss, joint pains, heart, and liver failure (Searle et al. 2001). Excess Fe in drinking water calls for regular monitoring because of the detrimental effects on human health and other environmental problems like staining of material.

Based on this assertion, water laden with heavy metals like Pb, Ni, Cr, and Fe could be treated by the application of the following methods; depending on the type of metal and the level of contamination. For example, Fe is commonly removed from groundwater by the process of chemical oxidation or aeration followed by swift sand filtration. Conversely, Cr (VI), Pb, and Ni in groundwater can be removed by the processes of adsorption–reduction mechanism, reverse osmosis, Treatment Residual (TR), adsorbents as well-selective ion exchange resin as detailed in Sharma et al. (2005), Liu et al. (2018), Wolowiec et al. (2019) and Lenntech (2020); these processes are cost-effective and highly dependable.

Given the foregoing, it is evident that soil characteristic, aquifer geometry, groundwater flow, and the depth to aquifer as a concept of the hydrogeological study, and human interaction with nature plays a vital role in groundwater vulnerability and quality. This is because when soil media is porous and permeable, and the aquifer in the environment is shallow and leaky, the aquifer becomes vulnerable to contamination and consequently contaminates groundwater in the shallow unconfined aquifer (Falowo and Omorogieva 2020; Toth 2020). The situation can jeopardize the attainment of environmental sustainability and increase water-borne diseases (Apadjan et al. 2012; ATSDR 2012; Adimalla et al. 2020).

Conclusions

Heavy metal contamination in plants, soil, and water is one of the most important environmental issues currently been discussed by global scholars in the field of environmental, earth, and allied sciences. Therefore, appropriate steps need to be taken to reduce or eliminate its presence in the geoenvironment (water, land and air). The geochemical and

hydrogeological results recorded in the study area showed that groundwater from the boreholes assessed compromise the standard set by the World Health Organization, and the Standard Organization of Nigeria for drinking water purpose. This was traced to the leachate emanating from the wastes dumpsites, facilitated by the climatic condition and the geology of the study area. As a result of the detrimental effects of the metals assessed, the situation call for urgent concern, and the need to protect the endangered groundwater resources, because more than half of the world population depends on groundwater for daily activities and proper functioning of the ecosystem. It is recommended that excavated borrow pits follow the due process of closure to avoid it been converted to a refuse dumpsite. Deeply excavated pits with enormous wastes heap can contaminate shallow aquifer, especially when the aquifer is unconfined. This will eventually lead to an increase in the demand for groundwater, and consequently impede the attainment of sustainable groundwater resource, access to potable water, as well as jeopardizing the health status of the consumers. Heavy metals are non-biodegradable, carcinogenic, and are precursors to myriad health issues. It is suggested that all stakeholders involved in waste and environmental management processes, construction companies, among others should consult, and or collaborate with experts to work as a team in advancing environmental sustainability for societal development.

Data availability Data used in this work will be made available on request.

Declarations

Conflict of interest No conflict of interest; the research was designed by Dr O.M Omorogieva in consultation with Professor O.I Imasuen. The field exercise was carried out by Dr O.M Omorogieva and Mr. J.A Tonjoh, while Professors O.I Imasuen, E.A Adanu and Dr O.M were responsible for the interpretation of the data set. The initial manuscript was written by the corresponding author and was read through by all the contributing authors for approval.

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