Applied Water Science (2021) 11:24
https://doi.org/10.1007/s13201-020-01355-4

ORIGINAL ARTICLE

Environmental risk assessment of the intake of contaminants in aquifers in the vicinity of a reclaimed waste dumpsite in Owerri municipal, Southeastern Nigeria

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Received: 26 December 2019 / Accepted: 26 December 2020 / Published online: 18 January 2021

Abstract

The study investigated groundwater sources within reclaimed municipal waste dumpsites around Akachi road in Owerri, Southeastern Nigeria. The research evaluated the pollution and risk inherent in the consumption of groundwater in the vicinity of the reclaimed waste dumpsite using standard procedures. Results showed acidic pH values for some groundwater samples within the reclaimed waste dumpsite. Elevated nitrate (NO_3^-), aluminium (Al) and chromium (Cr) concentrations above the World Health Organization (WHO) limits for drinking water samples were recorded in some of the groundwater samples from the study area. The observed strong positive correlations between the metallic contaminants indicated that the distribution of the pollutants has a strong relationship with organic contaminants in the reclaimed waste dumpsite. Low contamination factor was exhibited by all metals for the individual samples except for Cr in sample A and Al in sample A and D. The pollution load index for all the samples was low, except for sample C with a pollution load index of unity. Elevated hazard quotient > 1 and hazard index > 1 were observed for both adults and children due to high Cr levels. The chronic daily intake risk assessment revealed values < 1, while carcinogenic risk values greater than 10^{-6} and 10^{-4} were observed for the samples suggesting potential health risk for children and adults. The water quality index of samples from the reclaimed waste dumpsite calls for concern due to elevated levels of Al and Cr. These findings, therefore, suggest the need to treat the groundwater from the reclaimed dumpsite before consumption to avert serious health risks. Finally, waste dumpsites should be remediated or allow to undergo natural remediation before reclamation, erecting residential structures, and sinking of boreholes for water supply within such areas.

Keywords Risk assessment · Waste dumpsite · Contaminants · Metallic pollutants · Aquifers

Introduction

Management of solid waste and disposal sites is a serious ecological concern all over the world (Vincent et al. 2012), due to the tendency of such dumpsites to contaminate ground and surface water sources (Ejiogu et al. 2017). Lack of proper waste management and disposal system is an unavoidable problem in most developing countries like Nigeria due to the increasing population, rapid urbanization, industrialization, and lax environmental laws (Okere et al. 2018). The waste management practises within the study area are simply based on the collection and dumping out of the city boundaries in open excavated waste dumps (Arukwe et al. 2012). This consequently results in irregular disposal of waste thereby creating major waste dumpsites in many parts of the city (Ikem et al. 2002). The waste dumpsites form a major breeding grounds for micro-organisms and other disease vectors like rats which put the health of the inhabitants at risk (Adewuyi and Opasina 2010; Bellebaum 2005). This is in addition to air pollution which results from offensive odour and uncontrolled burning of these wastes, which may jeopardize human health and deteriorate the air quality of the area (Enyoh et al., 2019; Ibe et al. 2016; Ibe et al. 2020a, b; Njoku et al. 2016; Opara et al. 2016). Due

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to different components of municipal wastes, the dumpsites may contain heavy metals as well as other pollutants that generally infiltrate into the groundwater system, thereby posing a great risk to the human population when such water is consumed (Obasi et al. 2015). Documented pieces of evidence have shown that improperly managed waste dumpsites are inimical to human health and has shown their possibility of contaminating the soil and underlying aquifers (Amadi et al. 2012; Boateng et al. 2019; David and Oluyege 2014; Ibe et al. 2017, 2018; Muze et al. 2020; Obasi et al. 2017; Temilola et al. 2014). This arises from leachate infiltration aided by intense precipitation into the surroundings which subsequently contaminate the soil as well as the groundwater systems (Mor et al. 2006; Taylor and Allen2006; Teta and Hikwa 2017). This is possible due to vertical and lateral migration of the pollutants which could threaten the health and life of animals and humans (Bukar et al. 2012; Ibe et al. 2019a).

It has been reported that consumption of contaminated groundwater could result in the weakening of human health, heart problems as well as other health abnormalities (Su 2008). The risk of the onset of cancer and skin lesions have been reported in arsenic-contaminated groundwater (Smith et al. 2000). Studies have also shown that exposure to constituents of leachates from waste dumpsites above a certain threshold may be linked to an over abundance of bioaccumulated metallic components. These components are associated with heavy metal related poisoning symptoms and ailments such as vomiting and convulsion, asthma, hypertension, renal and cardiovascular diseases, ataxia, neurological illness, gastrointestinal problems, pneumonitis, cancer, skeletal deformities, anaemia, and diarrhea (Abarikwu et al. 2013; Farombi et al. 2012; Vrijheid 2000).

The importance of this study lies in the fact that most developing countries like Nigeria and Africa in general lack adequate supply of potable water due to poor sanitation, which results in ill health and death of many children under the age of five years (FRN 2000; WHO/UNICEF 2000). Therefore, a greater number of the population living in urban centres, semi-urban, and rural areas in Imo State and Nigeria at large depends solely on underground water sources like boreholes for domestic uses as well as for irrigation and industrial purposes (Longe et al. 2010; Pat-Mbano et al. 2010). This is unfortunately due to the inability of government agencies to provide pipe born water to the majority of the households (Chukwu 2015; FRN 2000; Ishaku et al. 2011). The demand and significance of groundwater supply have continued to increase tremendously as a result of climatic factors (De Giglio et al. 2015; Kumar 2012). This has continued to increase due to the contamination and alteration of this all-important resource as a result of anthropogenic factors such as urbanization, industrialization, and population growth (Obeta 2017). Another issue that calls for regular risk assessment of groundwater sources especially in Owerri Municipal is that most of the open waste dumpsites are located in the proximity of residential areas and some cases around wetlands (Abdus-Salam et al. 2011). Thus, the surface, as well as the groundwater sources are rendered unwholesome, since the waste dumpsites have no basement or thick shale lining to selectively absorb some of the contaminants in the leachates (Ikem et al. 2002; Teta and Hikwa 2017). As a result of these factors, most underground water studies conducted in Owerri and its environs have revealed low pH (Duru et al. 2017a, 2019; Ekeleme et al. 2014), high electrical conductivity (Ijeh 2014a), and heavy metal levels above tolerable limits (Duru et al. 2019; Ejiogu et al. 2017; Ogoko 2017). Also, the previous report of trace metal analysis of soil and edible plant leaves from the reclaimed waste dumpsite under investigation by the authors revealed the presence of aluminium, chromium, copper, iron, manganese, and zinc (Ibe et al. 2017). Moreover, no other documented report has used all the pollution risk assessment models to study groundwater sources such as boreholes in the area.

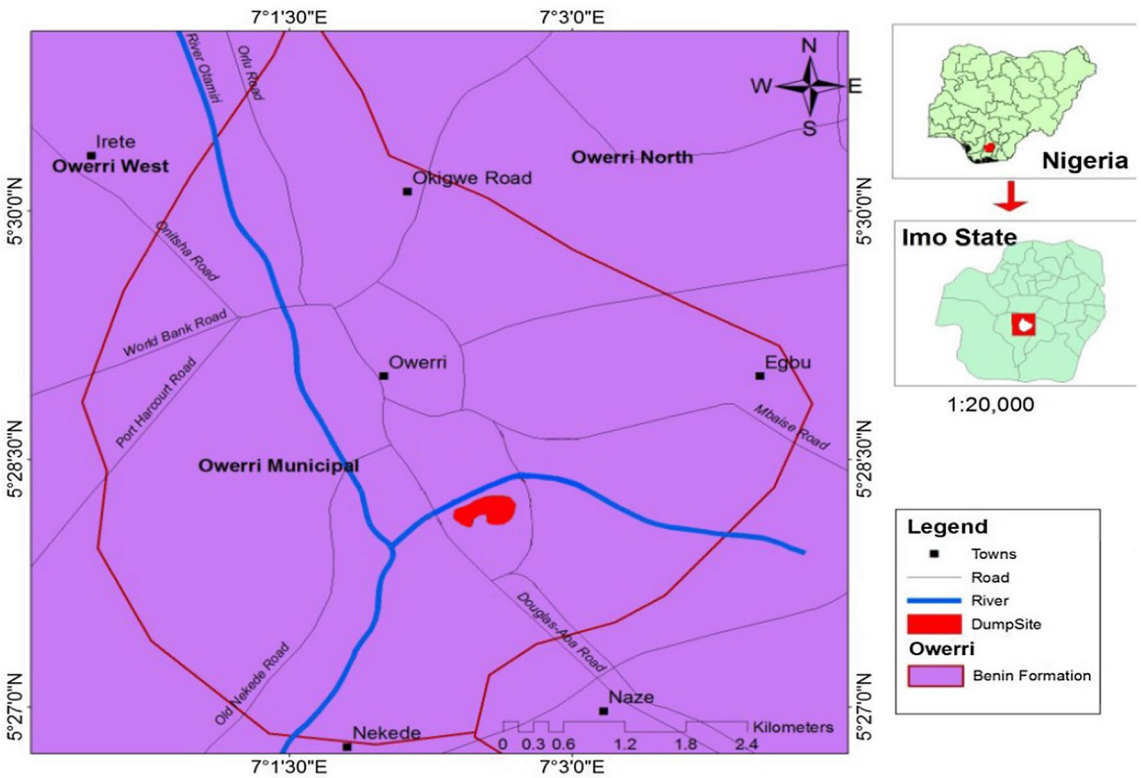
The present study, therefore, investigated the risk inherent in the consumption of groundwater sources like boreholes within the reclaimed waste dumpsite around Akachi Road in Owerri Municipality, Nigeria. To achieve this, borehole water samples were collected in the vicinity of the reclaimed waste dumpsite and analyzed for the presence of contaminants. Pollution risk assessments were carried out using contamination factor (CF), pollution load index (PLI), water quality index (WQI), hazard quotient (HQ), hazard index (HI), chronic daily intake (CDI) of metal contaminants, carcinogenic risk (CR), and human exposure due to ingestion (Exp_{ing}) of the groundwater from the reclaimed waste dumpsite.

Materials and methods

Study location

The map of the study location is presented in Fig. 1a, b. The investigation was carried out in Owerri Municipal, the capital city of Imo state, which is located in the eastern part of Nigeria. Owerri Municipal lies within the coordinates defined by longitudes 6° 50′ E–7° 25′ E and latitudes 4° 23′ N–7° 15′ N. The city has a population of 125,337 according to the 2006 population census (FRN 2007). The demographic information was projected at 200,413 in 2010 (NBS 2011), with these statistics believed to have increased significantly after a decade. The reclaimed waste dump site is located at Akachi Road, Owerri, Imo State, Nigeria, as shown in Figs. 1a, b, Fig. 2a, b. The site was abandoned for more than 10 years before being reclaimed with the majority of the wastes being buried in the soil. The area was

(a)



(b)

Fig. 1 **a** Google map of study location. **b** Geological map of Owerri and environs showing the reclaimed dumpsite. *Ibe et al. (2017)

Fig. 2 **a** undeveloped section of the reclaimed dumpsite, **b** developed section of the reclaimed dumpsite along Akachi Road

opened up following the construction of a bypass known as Akachi Road across the reclaimed waste dump site (Fig. 2a, b). Residential and commercial buildings like shopping malls, hotels, and stores were subsequently erected on this reclaimed dumpsite. Most of these residential and commercial buildings dug their boreholes with overhead storage tanks to provide water for their domestic and commercial uses. So, all the inhabitants of this area depend on these boreholes drilled in the reclaimed dumpsite for domestic water uses since there is presently no public water supply in the area and the city in general. This development, therefore, calls for concern and pollution risk assessment which the inhabitants are exposed to when groundwater sources in this area are consumed.

Climate and geology of the study area

The weather condition of the area is occasioned by the varying high temperature which shows seasonally distributed rainfall. The study area has a bi-modal climate made up of the dry and wet seasons. March signals the beginning of the wet season which ends in early October, while the dry period starts from the end of October up to the early part of March. Intense sunlight is usually observed between November and December which lasts up to February. Shorter sunlight hours are observed in the wet period between May and October.

Daylight temperatures in the area ranged from 18 up to 34 °C, with the average daily minimum and maximum temperatures of 19 and 28 °C, respectively (Akinsanola and Ogunjobi 2014). The approximated evapotranspiration rate in the area is between 1450 and 1460 mm/year (Chineke et al. 2011). Rainfall is a critical climatic factor in pollution studies with far-reaching ecological consequences. The rainy period is controlled by the advance of northward maritime air which is linked to the Atlantic Ocean. The months of July and August are the wettest seasons in this area. There is usually an alternating period of sunshine and rainfall situations due to the conventional nature of the heavy downpour. The wet period usually begins from March to October with the mean yearly rainfall estimated at 2500–4000 mm. About 89% of the rainfall is witnessed between May and October (Okoro et al. 2014, 2019). The regularity and intensity of the rainfalls result in massive runoff occasioned by the presence of steep slopes which renders the area vulnerable to flooding. Sometimes, the intense rainstorm events go with enormous flooding which causes leaching of the topsoil that subsequently infiltrate into the underground water (Ibe 1999; Ibe et al. 2018).

A comprehensive report of the geological and geomorphological study of the area has been previously documented (Onyeagocha 1980). Stratigraphically, the location and the surrounding areas are underlain by the Benin Formation (Fig. 1b). The Benin Formation is mostly made of sands, sandstones, and occasionally clays. These clays occur as intercalations with the largely massive sandstone beds with the thickness of the clay units increasing with depth. Texturally, the sands and sandstones are finely separated particles that range in size from fine to coarse sediment particles. Sands in the area have variegated colours, unattached and crumbly, with highly ferruginous sandstone in some places. The formation has a varying thickness of about 2000 m (Uma 1989). The Benin Formation is poorly compacted with high porosity and permeability (Onyeagocha 1980). Therefore, absorptivity, spread-ability, and storability of groundwater and other fluids are usually elevated due to the sand component which forms over 90% of the formation in the area (Ijeh 2014b; Uma 1989). Usually, the safety and protective capacity of the aquiferous units are determined by the geologic formations in addition to other factors. The susceptibility of the groundwater to surficial contamination is influenced by certain factors such as lithology of the overlying formations as well as the hydraulic properties (Ijeh and Onu 2012). The high porosity, transmissivity, permeability, and elevated hydraulic attributes of the Benin Formation renders the aquifers in the study area vulnerable to percolation and

infiltration by contaminants from the waste dumpsite (Ibe 1999; Okiongbo and Akpofure 2012).

Sample collection and analysis

Groundwater samples were collected from five different boreholes within the reclaimed waste dumpsite as indicated in Table 1 and Fig. 1a. The borehole water samples were collected within July 2018 using previously cleaned plastic containers. At each point of the sample collection, the container was rinsed twice with the water sample to be collected. Borehole water samples collected from the reclaimed waste dumpsite were labelled A–E. Another set of borehole water samples were collected from Ouspuc avenue, Alaubi layout Egbu in Owerri North LGA, Imo State, to serve as the control as shown in Table 1 and Fig. 1a. The borehole water sample points were geo-referenced using the Garmin GPSmap 76.

The physicochemical parameters including temperature (T), electrical conductivity (EC), pH, total dissolved solids (TDS), phosphate (PO_4^{-3}), sulphate (SO_4^{-2}), and nitrate (NO_3^-) were determined for the groundwater samples. The concentrations of the metallic elements which include aluminium (Al), chromium (Cr), copper (Cu), Iron (Fe), manganese (Mn), and zinc (Zn) were also determined in the water samples. At each sample point, the temperature was determined with the aid of the LCD portable digital multistem (− 50 to 150 °C) centigrade thermometer, while the pH was determined with the Hanna pH metre Hi 98,107. The electrical conductivity and total dissolved solids (TDS) were determined using a portable digital EC/TDS metre (Ketotek). The concentrations of the anions in the groundwater samples were determined in the laboratory using Hanna Hi 83,200 Multi-parameter bench photometer. Nitrate in the samples was determined using cadmium reduction with Hanna H1 83,200 multi-parameter bench photometer at 525 nm. 10 mL of each water sample was transferred into two separate sample cells, with one as a blank to zero the instrument. Nitrate reagent was introduced into the second one, placed into the sample cell compartment, and allowed for 4 min and 30 s for the nitrate concentration (mg/L) in the sample to be displayed. Determination of phosphate was by the amino acid method with the aid of the Hanna H1 83,200 multi-parameter bench photometer at 525 nm. 10 drops of molybdate reagent and phosphate HR reagent B was added to the sample cell containing 10 mL of the water sample, while a second sample containing water to be analyzed was used to zero the instrument. The mixture was allowed to dissolve by shaking gently, inserted into the cell compartment, and phosphate concentration (mg/L) taken after 5 min. The Turbidimetric method using Hanna H1 83,200 multi-parameter bench photometer at 466 nm was used in the determination of sulphate levels in the water samples. 10 mL of the sample contained in two separate sample cells with one containing suphate reagent and the second one to zero the photometer. This was placed in the cell compartment, allowed for 5 min and sulphate concentration (mg/L) displayed (Duru et al. 2019; Ibe and Ibe 2016). Water samples for metallic content analysis were preserved with two drops of 2 M HNO_3. 50 mL of each groundwater samples were digested with 5 mL of a concentrated solution of HNO_3 acid in a beaker and heated on a hot plate. The heating was discontinued when the volume of the mixture reduced to 20 mL, filtered with a Whatman filter paper into a 100 mL volumetric flask and made up to the mark with deionized water. The concentrations of the metals were determined with the atomic absorption spectrophotometer (AAS), Agilent 240FS AA model (USA).

Quality control

Reagents used throughout the experiments were of high-quality analytical grade, which was purchased from BDH Chemical Ltd, UK, and Sigma- Aldrich Chemie GmbH,

Table 1 The coordinates and description of the borehole water sample points

Sample points	Coordinates	Elevation	Description
A	05° 28′ 18.6″ N 007 02′ 21.4E	74 m	Residential building within the reclaimed waste dumpsite along Akachi road
B	05° 27′ 57.0″ N 007° 02′ 37.1″E	77 m	A car wash beside a hotel within the reclaimed waste dumpsite along Akachi road
C	05° 28′0.62″ N 007 02′36.4″ E	79 m	Shopping mall located within the reclaimed waste dumpsite
D	05° 28′ 02.2″ N 007° 02′23.5″ E	78 m	A hotel complex located within the reclaimed waste dumpsite
E	050 28′21.8″N 007° 02′27.3″ E	67 m	A residential area that is very close to the reclaimed waste dumpsite
Control (CL)	050 28′57.3″N 007° 03′43.4″ E	58 m	Sample collected from a residential area where there is no history of usage as a waste dumpsite

Germany. Detergents and deionized water were used to wash the glassware and sample bottles. They were soaked overnight with a solution of 10% HNO_3 in a 1% HCl solution, followed by rinsing with deionized water. Also, reagents used for the determination of anion concentrations with the Hanna Hi 83,200 Instrument were sourced from Hanna Instruments. The instrument (Agilent 240FS AA) used for the détermination of the concentrations of metallic elements in the samples has high sensitivity—typically > 0.9 absorbance with a precision of < 0.5% RSD from ten-second integrations for 5 mg/L Cu standard.

Data analysis

Data were subjected to mean, standard deviation, variance, and coefficient of variation, correlation and quantitative health risk analysis using Microsoft Excel 2010 and IBM SPSS version 20.0.

Quantitative health risk assessments

Human exposure pathways to heavy metal contamination in water could be through direct ingestion and dermal absorption. The human exposure risk through the ingestion of the underground water samples was calculated using the USEPA risk assessment guidelines as shown in Eq. (1) (Li and Zhang 2010; Naveedullah et al. 2014; USEPA 1989).

$$\mathrm{Exp_{ing}} = \frac{\mathrm{Cw} \times \mathrm{RI} \times \mathrm{FE} \times \mathrm{DE}}{\mathrm{Bw} \times \mathrm{AT}} \text{ in mg/kg/day} \quad (1)$$

where Cw = concentration of metal in water sample (mg/kg), RI = rate of ingestion, for adult = 2.2L/day and 1.8 L/day for children, FE = frequency of exposure = 365 days/year, DE = duration of exposure = 70 years and 6 years for children, Bw = average body weight for adult = 70 kg and 15 kg for children, AT = average time = 365 × 70 days/year for adults and 365 days/year × 6 years for children (Asare-Donkor et al. 2016; Li and Zhang 2010; Naveedulla et al. 2014).

Hazard quotient

The exposure risks due to the ingestion of metallic pollutants present in the underground water samples were estimated as the hazard quotient (HQ) with the help of Eq. (2).

$$\mathrm{HQ_{ing}} = \frac{\mathrm{Exp_{ing}}}{\mathrm{RFD}} \quad (2)$$

where $HQ_{non.car}$ = hazard quotient (HQ) for non-carcinogenic risk, Rfd = Reference dose of the metal (Iqbal and Shah 2013; Li and Zhang 2010; USEPA 1989)

Hazard index

The risk due to ingestion of the borehole water contaminated by more than one metallic pollutants and sources were determined by the summation of individual HQ of the metallic pollutants as the hazard index (HI) using Eq. (3) (Ibe et al. 2019a). Hazard index values, above one (HI > 1), are an indication of health risk which may result from intake of the water samples (Li and Zhang 2010; Naveedullah et al. 2014).

$$\mathrm{HI} = \sum_{i=1}^{n} \mathrm{HQ_{ing(Al)}} + \mathrm{HQ_{ing(Cr)}} + \mathrm{HQ_{ing(Cu)}} + \mathrm{HQ_{ing(Fe)}} + \mathrm{HQ_{ing(Mn)}} + \mathrm{HQ_{ing(Zn)}} \quad (3)$$

where HI is a hazard index resulting from the ingestion of the underground water from the reclaimed waste dump site due to its use for drinking and domestic purposes.

Chronic daily intake of metallic contaminants

The health risk associated with the ingestion of heavy metal through the consumption of underground water in the study area was assessed using the chronic daily intake and hazard index parameter [Eq. (4)] (Boateng et al. 2015; Muhammad et al. 2011; Wu et al. 2009).

$$\mathrm{CDI} = \frac{\mathrm{Cw} \times \mathrm{Di}}{\mathrm{Bw}} \quad (4)$$

where Cw = concentration of the metallic element in water in mg/L, Di and Bw represent the average daily intake of water and body weight, respectively, average daily intake of water (2.2 L/day for adults; 1.8 L/day for children) and body weight (70 kg for adults; 15 kg for children), respectively (Asare-Donkor et al. 2016; Li and Zhang 2010; Naveedullah et al. 2014).

Carcinogenic risks

A carcinogenic risk explains the increased likelihood of developing cancer by individuals living in the area after some time due to their exposure to carcinogens through the consumption of the groundwater. The tolerable range of carcinogenic risks is within 1.0E−06 to 1.0E−04 (USEPA 2010). The Carcinogenic risks exposure by inhabitants of the reclaimed waste dump site was estimated according to Eq. (5) as described by Iqbal and Shah (2013) and Naveedullah et al. (2014).

$$\mathrm{CR} = \frac{\mathrm{Exp_{ing}}}{\mathrm{SF}} \quad (5)$$

where CR is the carcinogenic risk due to the ingestion of polluted water and SF is the carcinogenic slope factor, ingestion

$(mg/g/day)^{-1}$. CR was estimated to show the lifetime carcinogenic risk of consuming contaminated water from the study area. The *SF* value is 0.5 mg/kg/day for Cr (Boateng et al. 2019; Edokpayi et al. 2018; Naveedullah et al. 2014). The SF values for other metals were not available.

Contamination assessment factor

The level of metallic contamination was assessed as the contamination factor, which was estimated as the proportion of the individual metallic pollutants to its background values using Eq. (6).

$$C_f = \frac{C_{\text{metal}}}{C_{\text{background}}} \tag{6}$$

where C_f represents contamination factor, C_{metal} represents the concentration of heavy metal, and $C_{\text{background}}$ is the background value of the metal. The guidelines for safe drinking water were taken as background values (WHO 2004a).

The pollution load index (PLI)

To estimate the overall heavy metal pollution of the underground water in the study area, pollution load index (PLI) of the heavy metals studied was estimated according to Eq. (7) (Ibe et al. 2019a).

$$\text{PLI} = \sqrt[n]{C_{f1}} \times C_{f2} \times C_{f3} \times \ldots \ldots C_{fn} \tag{7}$$

where PLI = Pollution load index, n = number of investigated metallic elements,

Water quality index (WQI)

The water quality index was estimated with thirteen chemical properties of the underground water samples as presented in Table 2, using Eq. (8) (Chatterjee and Raziuddin 2002; Lele et al. 2018).

$$\text{WQI} = \frac{\sum_{i=1}^{n} W_i q_i}{\sum_{i=1}^{n} W_i} \tag{8}$$

where WQI is the water quality index, W_i indicates the unit weight, while q is the quality rating. The WQI values were classified as; WQI < 50 indicating excellent water quality, 50 < WQI ≤ 100 means good water quality, 100 < WQI ≤ 200 indicates poor water quality, 200 < WQI ≤ 300 implies very poor water quality, and WQI > 300 indicates that the water is unsuitable for consumption (Ramakrishnaiah et al. 2009).

Results and discussion

Physicochemical properties

The results of the analyzed groundwater samples are presented in Table 2. Low-temperature values ranging from 5.82 to 7.25 °C was observed in the water samples. The values are not unexpected since the groundwater samples were collected in the morning hours in July during the onset of the rainy season in the area. The recorded temperature values are within the WHO recommended values for safe drinking water. At higher temperatures, there is an increased respiration rate leading to the consumption of more oxygen as well as increased decomposition of organic materials (Nishizaki and Carrington 2014). Elevated groundwater temperature

Table 2 Physicochemical properties of the groundwater samples

Parameter	A	B	C	D	E	CL	Mean	STD	Var	% CV	WHO
pH	7.21	6.28	6.18	6.15	6.50	6.24	6.427	0.403	0.163	6.27	6.5–8.5
T (°C)	6.40	7.25	5.82	6.61	6.50	6.40	6.49	0.447	0.163	6.88	30
EC (µs/cm)	8.10	10. 30	9. 70	7. 30	13. 80	4.30	6.20	2.687	7.22	43.33	100
TDS (mg/L)	55.00	15.00	45.00	15.00	40.00	12.00	30.33	18.57	344.67	61.20	250
NO_3^- (mg/L)	16.30	5.50	36.80	2.30	18.70	2.10	13.62	13.40	179.42	98.37	10
PO_4^{-3} (mg/L)	0.20	0.40	0.40	2.60	0.01	0.12	0.60	0.99	0.987	164.68	5
SO_4^{-2} (mg/L)	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	0.00	0.00	0.00	0.00	100
Zn (mg/L)	0.15	0.13	0.12	0.17	0.21	0.15	0.15	0.03	0.00	20.71	5.00
Mn (mg/L)	0.30	0.10	0.30	0.20	0.10	0.01	0.17	0.11	0.01	70.33	0.40
Cr (mg/L)	0.06	0.09	0.04	0.01	0.02	0.01	0.04	0.03	0.00	83.19	0.05
Al (mg/L)	0.25	0.08	0.15	0.26	0.18	0.04	0.16	0.09	0.00	55.48	0.20
Fe (mg/L)	0.03	0.02	0.01	0.02	0.01	0.01	0.02	0.01	6.67E–05	48.98	0.30
Cu (mg/L)	0.40	0.01	0.02	0.02	0.001	0.01	0.08	0.16	0.03	206.37	2.00

WHO World Health Organization standard for drinking water, *CL* control, *STD* standard, *Var* variance, *%CV* percentage coefficient of variation

may be attributed to increased solar radiation (Ekwe et al. 2013). Change in the global climate resulting from increased temperatures could influence groundwater availability as a result of low rainfall as well as variation in seasonal rainfall, which may cause a serious decrease in the quantity of water available for aquifer recharge (Sun et al.2014). Some physical and chemical properties, as well as biological constituents of water, are also influenced by temperature. The observed low-temperature levels of the groundwater samples imply low decomposition of organic materials in the water which means decreased bacteria population (Ramana and Singh 2000).

The observed pH values of the water samples ranged from 6.15 to 7.21 with some of the pH values of the water samples been slightly lower than the WHO recommended pH levels for safe drinking water as shown in Table 2. Sample A has the highest pH value (7.21) indicating weak alkaline water samples while samples B, C, D, and CL with pH levels of 6.28, 6.18, 6.15, and 6.24 respectively indicate water samples with low acidity. The low pH values recorded in most of the water samples may be attributed to anthropogenic acidification and the presence of autochthonous constituents in the reclaimed dumpsite. The susceptibility of most groundwater sources like boreholes in the area to acidification is believed to be associated with the shallow groundwater levels in the area which makes them easily accessible to contaminants (Anornu et al. 2012; Ejiogu et al. 2017; Ijeh and Onu 2013). Dependence of most groundwater sources on wetlands is another factor that may result in groundwater acidification. Wetlands containing oxidizeable sulphur compounds tend to severely acidify groundwater sources (Appleyard et al. 2004). Another major cause of groundwater acidification is due to the presence of sulphidic peaty sediments; this is more especially where groundwater systems depend on wetland supplies (Appleyard et al. 2004). Therefore, the observed low pH in most of the groundwater samples may be associated with the presence of waste deposits like used coal and other bituminous materials in the dumpsites (Obodo and Ibe 2017). The pH of the water to a great extent determines the solubility of most chemical components like metallic elements, as well as the availability of nutrients for biological activities in water (Rubiat et al., 2017). Acidosis which leads to peptic ulcer may result from the intake of water with a low pH level (Akubugwu and Duru 2001). Also, earlier reports have shown that the ingestion of water with low pH levels may cause unbalanced electrolyte levels and irregular heartbeats, which may result in coma (Duru et al. 2017a, b; Ibe et al. 2020a, b). Similar findings were reported in the study of borehole water from Uzoubi Umunna Orlu (Lele et al. 2018). Also, low pH levels were reported in groundwater resources of parts of Owerri Metropolis (Ibe et al. 2020a, b).

Electrical conductivity (EC) values recorded in the present study ranged from 4.30 to 13.80 µs/cm. Elevated EC values were obtained in all the samples except sample D and the control. High EC values were observed for the entire samples collected within the reclaimed waste dumpsite. However, these high EC values are within the WHO acceptable EC limit. Higher EC values in groundwater sources within waste dumpsites indicate increased ionic concentrations which could be associated with the migration of leachates. Electrical conductivity is usually dependent on the number of dissolved materials (Corwin and Yemoto 2017). Electrical conductivity determines the quality and acceptability of water for domestic and industrial usage and could be greatly influenced by charged particles (Pradeep1998). Total dissolved solids (TDS) indicate the presence of dissolved inorganic salts and organic materials present in water solution, which tends to impair the taste of water (Rubiat et al. 2017). TDS levels of the water samples from the study area ranged from 12 to 55 mg/L and were within the WHO limit for drinking water quality. However, samples A, C, and D showed elevated TDS levels, which could be associated with the infiltration of leachates from the reclaimed waste dumpsite (Okiongbo and Akpofure 2012). Gastrointestinal problems could result from the intake of water with elevated TDS levels. TDS could also cause significant variation in water quality since the chemical constituents of groundwater are influenced by soil solubility and aquifer depth (Goeppert and Goldscheider 2001). Water with low salt content generally results when water flows through the poor soluble soils for short distances, whereas high salt content of groundwater usually results if aquifer recharge is accomplished by water flowing through soluble soil possibly due to the presence of carbonate rocks (De Giglio et al. 2015).

Concentration of anions

Observed phosphate values in the water samples were within the range of 0.01–2.60 mg/L. The phosphate levels recorded in the samples were within the WHO permissible limit for safe drinking water. The higher phosphate levels recorded in sample D compared to other samples could be due to leachates from decomposed solid wastes in the reclaimed waste dumpsite, as well as runoff from the nearby farmlands as a result of the application of agrochemicals (Singh et al. 2012). The use of phosphate-based fertilizers for crop cultivation could increase the phosphate levels in groundwater sources (Elinge et al. 2011). This, therefore, is very possible since some part of this reclaimed waste dumpsite is used for cultivation of vegetables (Ibe et al. 2017). Other sources of phosphate in groundwater could be through the breakdown of minerals and rocks, accumulation of sediments, decay of dead or waste from wildlife, and animals (Singh et al. 2012). Though phosphate is needed in the body for proper functioning, however, a concentration above the tolerable limit could be deleterious and may result in osteoporosis

and damage to the kidney (Calvo and Uribarri 2013). Phosphorous has been identified as a restrictive nutrient in water bodies, therefore, monitoring its level in water sources will help to control eutrophication and maintain suitable water quality (Holman et al. 2008).

The nitrate levels ranged from 2.10 to 36.80 mg/L with elevated nitrate levels recorded in samples A, C, and E above the WHO limit for safe drinking water. The observed high nitrate levels in the samples call for concern and need for these water samples to be treated before consumption. Elevated nitrate and pH levels were reported in groundwater quality studies of Densu Basin, Ghana (Tay and Kortatsi 2008). Also, a high nitrate level was reported in a study of water resources in Imo State (Ejiogu et al. 2017). Similar findings have been reported in a related study (Vincent et al. 2012). The observed elevated nitrate levels could be attributed to anthropogenic activities due to indiscriminate dumping of wastes such as agricultural wastes. Nitrate contamination of surface and groundwater sources may arise through many sources such as the use of inorganic and organic fertilizers in crop cultivation, release of organic waste and sewage into the surrounding environment as well as atmospheric depositions (Egereonu 2005; Egereonu and Ozuzu 2005; Ibe et al. 2016). Also, groundwater contamination by nitrate may be due to discharge of effluents from companies such as textile, metal processing, plywood, household cleaning, pharmaceutical, and plastic industries (Acharya and Ballav 2011; Lee et al. 2011; Singh et al. 2006). Elevated nitrate levels in the human body could interfere with the transport of oxygen by the red blood cells. Ingestion of water containing high nitrate concentrations by infants may result in difficulties in breathing due to reduced oxygen circulation, and methaemoglobinaemia which is also known as a blue baby syndrome (Follet and Follet 2008; Majumdar 2003).

Very low sulphate levels (< 0.001 mg/L) were observed in all the water samples. The observed sulphate levels in the present study were comparable to earlier reports of borehole water assessment in Nekede Mechanic Village, Owerri (Duru et al. 2019). High sulphate concentrations in contaminated rivers and groundwater sources are the major sources of increased sulphur fluctuation levels in wetlands (Geurts et al. 2009). Though sulphates occur naturally in drinking water, anthropogenic factors could increase the concentrations in water bodies. Sulphates are also released into groundwater sources through the dissolution of sulphate bearing minerals in the soil (Bashir et al. 2012). The observed sulphate levels in the samples could be attributed to the shallow depth of the groundwater sources, which renders them vulnerable to contamination due to anthropogenic influence (Ejiogu et al. 2019; Ekeleme et al. 2015; Ijeh 2014a). There is presently no substantiated unpleasant health problem in humans and animals due to prolonged intake of sulphate contaminated water, though, infants show higher sensitivity to sulphate pollution. Some members of the population could be at higher risk from the laxative effects of sulphate contamination when there is a sudden change from the intake of water with low sulphate contents to the ingestion of water with high sulphate level (Abdulrafiu 2011).

The concentration of metallic elements

Zn concentrations in the water samples ranged from 0.12 to 0.21 mg/L. These values were generally low and within the accepted WHO standard for safe drinking water. Zinc is an important component of numerous proteins in flora and fauna. The antioxidant properties of Zn and its ability to protect against rapid skin and muscle aging in humans are well documented (Wu et al. 2009). However, the concentration of Zn in drinking water above a certain threshold could be toxic. Anthropogenically, Zn could be introduced into the environment through its industrial usage as well as its presence in some liquid manure, composted materials, and agrochemicals such as animal feeds, fertilizers, and pesticides (Nitasha and Sanjiv 2015). The presence of Zn in groundwater samples may be due to leachates from metallic wastes or Zn containing materials disposed of in the waste dumpsite before it was reclaimed. Another major source of Zn ion in the environment is through erosion of roofing materials such as zinc, aluminium and galvanized metal roofing sheets, as well bulk atmospheric deposits (Ibe et al. 2016; Ibe and Ibe 2016; Chang et al. 2004; Gromaire-Mertz et al. 1999). Elevated concentrations of dissolved Zn ion in drinking water especially tap water may result from oxidation and leaching of the metal from water supply fittings and pipes (Duru et al. 2017b). Ingestion of water containing high levels of Zn may cause fever, stomach cramps, vomiting, and diarrhea as well as an increase in Cu deficiency (Elinder 1986). The concentration of Zn obtained in the present study is comparable to the values reported by Ogoko (2017) and Iheme et al. (2018).

Mn levels observed in the water samples ranged from 0.10 to 0.30 mg/L and are therefore slightly less than the WHO standard for safe drinking water. Average Mn concentration of 0.15, 0.09, and 0.1 mg/L for groundwater, reservoirs, and distribution networks, respectively, were reported in Qom city, Iran (Fahiminia et al. 2015). The major source of Mn in groundwater is from rainfall, dissolution of Mn minerals in nearby rocks, and leaching /percolation of Mn through the soil (Ichu et al. 2018). Acidic groundwater sources tend to show elevated Mn levels in reduced form (Manganese Fact Sheet 2013). It has been reported that other sources (metal alloys, batteries, glass, and ceramic materials) of Mn in wastes dumpsite could contribute to Mn concentrations in the soil as well as in groundwater sources (Kabata-Pendias 2011). Though Mn is a biologically essential element, intake of Mn through groundwater above the WHO permissible

limit of 0.40 mg/L may result in neurological injury (WHO 2011; Manganese Fact sheet 2013). Manganese is considered to possess low toxicity through the oral route due to the limitations posed by homeostasis to gastrointestinal absorption. There is evidence of increasing neurotoxicity through the oral route mainly in infants. Little children have a more sensitive nervous system, unlike adults, in addition to the fact that they have less developed homeostasis. Though low levels of Mn is contained in breast milk, minimal levels of Mn may be found in infant food formulations, which tends to increase Mn concentrations in infants. In addition, since infant foods are usually in powdered form, the food is dissolved in water which naturally contains Mn, thereby significantly increasing infant's exposure to Mn concentrations (Ljung and Vahter 2007). A documented report suggested that Mn toxicity may result in adverse health consequences on the brain and respiratory system, as well as the possibility of Parkinson's disease and bronchitis. The report further indicated that myasthenia, insomnia, and imbecility, including headache, are some of the symptoms of Mn poisoning (Kiani et al. 2013).

The observed value of Al for the samples ranged from 0.04 to 0.26 mg/L. Elevated concentration of Al was recorded in most of the water samples. Sample A (0.25 mg/L) and D (0.26 mg/L) revealed a higher concentration of Al above WHO permissible limit (0.20 mg/L), while the Al concentration in sample C (0.15 mg/L) and E (0.18 mg/L) were slightly below the WHO limit for drinking water. Lower concentrations (0.11 mg/L and 0.12) of Al were reported in Sungai Lembing and Bukit Ubi, Kuantan, Malaysia respectively (Dzulfakar et al. 2011). A filtrable concentration of Al was reported in buffalo pound water treatment plant (BPWTP) (Srinivasan and Viraraghavan 2002). The presence of high Al concentrations in the present study could be attributed to the several used aluminium materials dumped in the dumpsite over the years in addition to other sources, as Al is widespread in nature, and the element is found in water, air, plants as well as food materials (Narin et al. 2004). The Earth's surface is covered by about 8% of Al and its compounds are considered among the most abundant elements and naturally, it is found in bauxite, silicates, and cryolite (Dzulfakar et al. 2011; Krewski et al. 2007). Al has several uses such as in product packaging, drug, water treatment, food, and in many consumer goods, mainly due to its chemical and physical properties (Health Canada 2008). Anthropogenic activities such as disposal of Al metal scraps, and used Al foils may result in subsequent leaching and infiltration of Al and its compounds into the underlying aquiferous units. This could be true since food wastes like beans pudding, roasted fish, pizza, can drinks, etc., are usually disposed of with the Al packaging materials in the waste dumpsites (Habian 2011; Centre for Food Safety 2013). Al is an essential element, but can be toxic when excess concentration is ingested into the body. Intake of an excess concentration of Al has neurotoxicity potential and has been associated with Alzheimer's disease (Habian 2011; Centre for Food Safety 2013). Therefore, the consumption of water with elevated Al levels could increase the risk of Alzheimer's disease in the area. A study of correlation of Al levels in drinking water and Alzheimer's disease revealed that concentrations greater than 0.1 mg/L were linked to increased risk of Alzheimer's disease and dementia (Rondeau et al. 2000).

Elevated Cr levels were observed in some of the water samples analyzed in the study area. Concentrations of Cr in the samples were in the range of < 0.001–0.06 mg/L. The concentration of Cr in sample A was above the WHO stipulated value for safe drinking water. High Cr (0.282 mg/L) concentration was reported in Obite Rivers State Nigeria (Nnaji et al. 2016). Cr is introduced through the combustion of oil and coal, crude oil with Ferro-chromate refractory constituents, drilling of oil wells, chromium steel, plating, tanneries, pigment oxidants, and catalysts. Other anthropogenic activities such as fertilizer application and sewage disposal could also introduce Cr into the environment (Ghani 2011). Also, Cr could be introduced into the environment through copper alloys, rubber, paper, paints, and magnetic tapes (Martin and Griswold 2009). Cr is considered one of the most abundant elements in the earth's crust (Mohanty and Kumar 2013). It exists in different oxidation numbers (Rodriguez et al. 2007), with trivalent Cr^{+3} and hexavalent Cr^{+6} forms having greater toxicity on man and animals (Mohanty and Kumar 2013). According to the International Agency for the Research on Cancer, Cr is regarded as group one human carcinogen due to its high toxicity (Jaishankar et al. 2014). Acute Cr toxicity results in the onset of diffuse hyperplasia of the small intestine, which is the most responsive end point and precursor of malignant growth in humans (Health Canada 2015). Also, it has been reported that chronic exposure to Cr reduces fertility in males (Hong et al. 2001). This implies that the ingestion of Cr contaminated water could put the health of consumers at risk of cancer-related illness and infertility.

The concentrations of Fe observed in the study ranged from 0.01 to 0.03 mg/L, which were within the WHO permissible limit (0.03 mg/L) for safe drinking water. The levels of Fe obtained in this study were less than the lowest concentration (0.957 mg/L) recorded in the Kumasi landfill site (Boateng et al. 2019). Fe levels recorded in the present study were comparable to values reported by Duru et al. (2019) and Ejiogu et al. (2017). Iron is an essential element needed for the development and the continued existence of living organisms; it plays a crucial role in the metabolism of living organisms (Ibe et al. 2019b; Valko et al. 2005). Naturally, the metal occurs in groundwater due to weathering of iron-containing soils like laterites.

Leachates from waste dumps and landfills, drainages from acid-mine, sewage, and industrial effluents are some of the anthropogenic sources of iron which could contribute to iron concentration in groundwater sources (Water Stewardship Information Series 2007). Little children are very sensitive to iron toxicity because of their exposure to products with elevated Fe concentration (Albretsen, 2006). Overdose of iron intake results in gastrointestinal problems, increased risk of cancer, and could be lethal (Sane et al. 2018).

Cu concentrations ranged from 0.01 to 0.40 mg/L in the water samples. Though low concentrations of Cu were obtained in all the water samples as well as the control samples, a slightly higher concentration of Cu was recorded in sample A (0.04 mg/L), sample C (0.02 mg/L), and 0.02 mg/L also for sample D. The concentrations of Cu recorded in the present study were within the WHO permissible limit (2.00 mg/L) for safe drinking water. The concentration of Cu in the present study is similar to the values obtained in a previous study as reported in Corlu, Turkey (Ongena et al. 2008). As a trace mineral element, Cu exists naturally in plants where it participates in most decisive vital mechanisms. Cu is considered essential in the regulation of some biological processes and the maintenance of vascular and skeletal integrity (Ibe et al. 2019c). Prolonged intake of Cu contaminated water could result in haematuria, gastrointestinal bleeding, intravascular haemolysis, hepatocellular toxicity, oliguria, and acute renal failure (Agarwal et al. 1993; Ashish et al. 2013; Hefnawy and Elkhaiat 2015; WHO 2004b).

Correlation analysis

The level of association of the pollutants was established using the Pearson product-moment correlation analysis. The result of the correlation analysis is presented in Table 3. The result revealed that strong positive correlations were observed between pH and EC ($r=0.950$, $p>0.05$). Also, pH showed a significant positive association with Cu ($r=0.935$, $p>0.05$), indicating that there is pH dependency of metal concentration in the groundwater samples, which implies that elevated concentration of metals in the water samples may be due to high solubility of metals at low pH (Enyoh et al. 2018). Similarly, EC had a very strong positive correlation with Cu ($r=0.999$, $p>0.01$). It was further observed that moderate positive correlation existed between Zn and Cr ($r=0.636$, $p>0.05$) and between Mn and Cu ($r=0.590$, $p>0.05$), while Cu and Fe ($r=0.809$, $p>0.01$) showed a high positive correlation. The observed correlations between the metallic pollutants suggested possible similar sources of origin. Therefore, it could be deduced that the observed concentrations of the metals are associated with metallic scraps disposed of in the reclaimed waste dump site.

Human health risk

Table 4 is the result of the calculated exposure dose (mg/kg/day), through the ingestion of underground water from the reclaimed waste dump site. Since most of the inhabitants of the study area ingest and use the underground water

Table 3 Correlation matrix for the physiochemical parameter in water

	Correlations												
	pH	Temp	EC	TDS	NO_3^-	PO_4^{-3}	SO_4^{-2}	Zn	Mn	Cr	Al	Fe	Cu
pH	1	− 0.053	0.950*	0.697	0.027	− 0.458	0	0.129	0.347	0.256	0.414	0.677	0.935*
Temp		1	− 0.121	− 0.697	− 0.857	0.118	0	0.115	− 0.749	0.471	− 0.331	0.353	− 0.139
EC			1	0.646	0.016	− 0.275	0	− 0.094	0.559	0.279	0.496	0.802	0.999**
TDS				1	0.721	− 0.626	0	0.012	0.619	− 0.034	0.281	0.066	0.640
NO_3^-					1	− 0.539	0	− 0.269	0.532	− 0.092	− 0.160	− 0.512	0.021
PO_4^{-3}						1	0	0.072	0.045	− 0.503	0.492	0.144	− 0.247
SO_4^{-2}							1	0	0	0	0	0	0
Zn								1	− 0.489	0.636*	0.412	− 0.200	− 0.123
Mn									1	− 0.078	0.471	0.299	0.590*
Cr										1	− 0.637	0.410	0.273
Al											1	0.418	0.508
Fe											0.418	1	0.809
Cu											0.508	0.809**	1

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

Table 4 Exposure dose (mg/kg/day) due to the intake of the groundwater

Parameter	A		B		C		D		E		C1	
	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch
Zn (mg/L)	0.047	0.018	0.041	0.0156	0.038	0.0144	0.0535	0.0204	0.0661	0.0252	0.047	0.018
Mn (mg/L)	0.094	0.036	0.0315	0.012	0.094	0.036	0.063	0.024	0.0315	0.012	0.0031	0.0012
Cr (mg/L)	0.019	0.0072	0.028	0.011	0.0126	0.0048	0.0031	0.0012	0.0063	0.0024	0.0031	0.0012
Al (mg/L)	0.079	0.03	0.025	0.0096	0.047	0.018	0.082	0.0312	0.057	0.0216	0.0126	0.0048
Fe (mg/L)	0.0094	0.0036	0.0063	0.0024	0.0031	0.0012	0.0063	0.0024	0.0031	0.0012	0.0031	0.0012
Cu (mg/L)	0.126	0.048	0.0031	0.0012	0.0063	0.0024	0.0063	0.0024	0.00031	0.00012	0.0031	0.0012

Key: *Ad* Adult, *Ch* Children

for drinking and other domestic activities, the health risk posed by the investigated metallic pollutants on children and adults through ingestion was estimated using Eq. (1)–(5). It was observed that the exposure dose due to ingestion of the groundwater for all the metallic pollutants was < 1 for adults and children. This suggests less health risk to the inhabitants of the reclaimed waste dumpsite.

The estimated HQ for direct ingestion of the water for both adults and children varied for the metallic pollutants (Table 5). The HQ for Zn was below unity indicating little adverse health effect due to consumption of the groundwater. HQ for Fe and Cu showed similar trend except for Fe concentration in adults for sample A and Cu for both adults and children in sample B. Elevated HQ values > 1 were observed for both adults and children in all the samples for Cr, suggesting tendency of adverse health effect. HI (Table 5) for the investigated water samples showed values greater than unity for both adults and children. This suggests that the prolonged consumption of water samples from these groundwater sources could cause serious health damages, if adequate measures were not taken to remediate the reclaimed waste dumpsite, especially due to Cr contamination. The health risk assessment indicates that the presence of Cr in the water samples resulted in serious pollution of the groundwater sources within the reclaimed waste dumpsite. Exposure to elevated levels of Cr could result in serious health challenges (Hong et al. 2001). Experimental studies have shown that compounds of Cr could lead to deoxyribonucleic acid (DNA) damage, which results in the creation of DNA adducts, altered DNA repetition, and DNA's inability to be accurately transcribed (O'Brien et al. 2001; Matsumoto et al. 2006).

The result of the chronic daily intake risk assessment (CDI) for the metals in the groundwater samples through ingestion pathways is shown in Table 6. CDI like other health risk assessment tools such as hazard quotient and hazard index values of < 1 are usually suggestive of minimal health risk (Wu et al. 2009). The observed overall CDI values were all less than unity. This indicates less significant health risk through the ingestion of the groundwater (Asare-Donkor et al. 2016; Zhao et al. 2009). However, the prolonged consumption of the groundwater may cause major damages to human health due to the tendency of these metallic pollutants to bioaccumulate. The CDI values for children varied between 1.2 E−3 and 4.8 E−2, while that of adults ranged from 3.1 E−4 to 47.1 E−3. The highest CDI value for children was observed in sample A, while sample E revealed the highest CDI value for adults. The CDI indices for the metallic contaminants were found to follow the decreasing order of Al > Mn > Zn > Cu > Cr > Fe, suggesting that Al had the highest CDI value, followed by Mn, while Fe showed the least CDI value. This is evident in the observed levels of Al in some samples from the study area which were above WHO Standard limits for drinking water.

Table 5 Hazard quotient and Hazard index

Metals	Sample points												RfD
	A		B		C		D		E		Cl		
	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch	
Zn	0.157	0.06	0.137	0.052	0.127	0.048	0.173	0.068	0.220	0.084	0.157	0.06	0.3
Cr	63.33	24	93.33	36.67	42.00	16.00	10.33	4.00	21.00	8.00	10.33	4.00	0.0003
Fe	1.343	0.514	0.90	0.343	0.443	0.171	0.90	0.343	0.443	0.171	0.443	0.171	0.007
Cu	3.15	1.20	0.0775	0.03	0.1575	0.06	0.1575	0.06	0.00775	0.003	0.0775	0.03	0.04
HI	67.98	25.774	94.4445	37.095	42.728	16.279	11.561	4.471	21.671	8.258	11.001	4.261	

The Carcinogenic risks (CRs) value for Cr is shown in Table 7. The carcinogenic risk of Cr for the groundwater samples was estimated for both children and adults, but it could not be established for Al, Cu, Fe, Mn, and Zn due to the absence of their carcinogenic slope factor values in the literature. Carcinogenic risk values between 10^{-6} and 10^{-4} for an individual suggests potential risk. Therefore, the estimated result shows that the levels of Cr in the investigated borehole water samples for both adults and children could pose a serious health risk. Adequate control measures should be taken to protect human health and consumers of the groundwater from the study area. Elevated CR values have been reported in a related study of groundwater samples in South Africa (Edokpayi et al. 2018). Geological processes such as weathering and the use of fertilizers and pesticides in agriculture must have contributed to the elevated Cr levels in the groundwater in the study area (He et al. 2004; Ndimele and Kumolu-Johnson 2012). Studies have revealed the tendency of elevated Cr (III) levels in the cell to damage DNA in humans (Kart et al. 2016; Novotnik et al. 2016). The groundwater in the study area should be properly treated before consumption to make the water safe for the inhabitants of the area.

Pollution assessment

The contamination factor and pollution load index of the heavy metals investigated are presented in Table 8. The contamination factor values recorded in the present study were categorized according to a previous study (Nweke and Ukpai 2016). Contamination factor values recorded in the present study ranged from 0.0005 to 1.3, with the least value recorded in sample E, while the highest value was observed in sample D. It was observed that the high contamination factor value in sample D was due to elevated Al levels in the groundwater samples. The contamination factor values for the metallic contaminants, therefore, followed the decreasing order of Cr > Al > Mn > Fe > Cu > Zn, indicating that Zn had the least contamination factor among the studied elements. Generally, a low contamination factor was exhibited by all

Table 6 The Chronic Daily Intake of Metal contaminants in the study area

Metal	Sample Points											
	A		B		C		D		E		C1	
	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch
Zn	0.00471	0.0156	0.00377	0.0156	0.00377	0.0144	0.00534	0.0204	0.0066	0.0252	0.00471	0.018
Mn	0.00943	0.0360	0.0031	0.012	0.0094	0.036	0.0063	0.024	0.0031	0.012	0.00031	0.0012
Cr	0.0019	0.0072	0.0028	0.011	0.0013	0.0048	0.00031	0.0012	0.0006	0.0024	0.00031	0.0012
Al	0.0079	0.0300	0.0025	0.0096	0.0047	0.018	0.0082	0.0312	0.0251	0.0216	0.0013	0.0048
Fe	0.00094	0.0036	0.00063	0.0024	0.00031	0.0012	0.00063	0.0024	0.00031	0.0012	0.00031	0.0012
Cu	0.0126	0.048	0.00031	0.0012	0.00063	0.0024	0.00063	0.0024	0.000031	0.00012	0.00031	0.0012

Table 7 Carcinogenic risks due to Cr contamination

Metal	A		B		C		D		E		C1	
	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch
Cr(mg/L)	0.038	0.0144	0.056	0.022	0.0252	0.0024	0.0062	0.0024	0.0126	0.0048	0.0062	0.0024

Table 8 Contamination factor and pollution load index of borehole water sample

Parameter	Contamination factor					
	A	B	C	D	E	C1
Zn	0.03	0.026	0.024	0.034	0.042	0.03
Mn	0.75	0.25	0.75	0.5	0.25	0.025
Cr	1.20	1.80	0.80	0.20	0.40	0.20
Al	1.25	0.40	0.75	1.3	0.9	0.20
Fe	0.10	0.067	0.03	0.067	0.03	0.03
Cu	0.20	0.005	0.01	0.01	0.0005	0.005
PLI =	0.296	0.108	1.00	0.12	0.062	0.041

metals for the individual sampling sites except for Cr (1.20) in sample A and Al (1.3) in sample D. Control site (C1) was observed to generally have low contamination factor. Though a low pollution index was observed for all samples, sample C has a pollution load index of unity. The PLI followed the decreasing order of C > A > D > C > E > C1. Chromium exposure over an extended period could cause serious health damages affecting the kidney, liver, circulatory, and nervous tissue (Njar et al. 2012). A similar observation indicating an elevated concentration of Cr in fifty-two (52) borehole water samples from twelve Local Governments Areas in Nasarawa State, Nigeria has been reported (Tukura et al. 2014). The observed elevated contamination factor for Cr and Al could, therefore, be attributed to anthropogenic inputs and geological sources (Arukwe et al. 2012).

Levels of metal contamination factor in the groundwater samples are presented in Fig. 3. Comparing the contamination factor of the control water sample with sample A–E revealed considerably high contamination of individual heavy metals. Al and Cr were found to be more pronounced in Fig. 3, in terms of high pollution load index. The observed elevated contamination factor and pollution load index for Al and Cr suggested that the studied reclaimed waste dumpsite received enormous waste materials containing Al and Cr compounds. Based on deductions from Fig. 3, the contamination factor of the metallic contaminants is in the order Cr > Al > Mn > Cu > Fe > Cu > Zn, with Cr showing elevated PLI value.

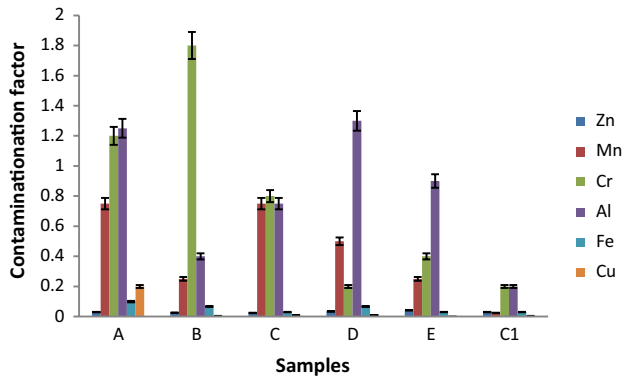


Fig. 3 Contamination factor of individual metals in borehole water samples

Water quality index

The water quality index (WQI) of the groundwater samples was estimated according to Eq. (7). The WQI values of the present study were classified according to Chatterjee and Raziuddin (2002). Table 9 shows the water quality index of the groundwater samples from the reclaimed waste dump site (Ci) and the control groundwater sample (CL). The WQI of Ci is an indication that the groundwater samples need to undergo further purification before consumption. The observed WQI of the study location was due to elevated levels of Al and Cr in some samples which call for serious concern. A previous toxicological study indicated that Al could pose a significant risk to humans and animals as well as plants as it could result in numerous diseases (Barabasz et al. 2002). Cr and its compounds are known for their toxicity in humans at elevated levels and are considered as carcinogens (Jaishankar et al. 2014). Borehole water studies in Orji, Owerri North in Imo State revealed that the WQI was of poor quality due to anthropogenic activities in the area (Duru et al. 2017a, b; Enyoh et al. 2018). Similar findings were observed by Abdul et al. (2010), while WQI values above 101 were reported for the Inyishi River (Ibe et al. 2019a).

Table 9 Water quality index of borehole water samples

Parameter	Mean (Ci)	CL	W_i	q (Ci)	q (CL)	W q (Ci)	W q (CL)
pH	6.464	6.24	3.9E−3	− 53.6	− 76	− 0.209	− 0.2964
T (°C)	6.508	6.40	1.0 E−3	21.69	21.33	0.0217	0.0213
EC (µs/cm)	8.10	4.30	3.1E−4	8.1	4.30	2.51E−3	1.33E−3
TDS (mg/L)	34	12.00	1.24E−4	13.6	4.8	1.69E−3	6.0 E−4
NO_3^- (mg/L)	15.92	2.10	3.1E−3	159.2	21	0.494	0.0074
PO_4^{-3} (mg/L)	0.722	0.12	6.2 E−3	14.44	2.4	0.0895	0.0149
SO_4^{-2} (mg/L)	0.001	0.001	3.1E−4	0.001	0.001	3.1E−7	3.1E−7
Zn (mg/L)	0.156	0.15	6.2 E−3	3.12	3	0.0193	0.0186
Mn (mg/L)	0.2	0.01	0.0775	50	2.50	3.875	0.1938
Cr (mg/L)	0.044	0.01	0.62	88	20	54.56	12.4
Al (mg/L)	0.184	0.04	0.155	92	20	14.26	3.1
Fe (mg/L)	0.018	0.01	0.1033	6	3.33	0.6198	0.344
Cu (mg/L)	0.0902	0.01	0.0155	4.51	0.5	0.070	0.0078
			$\sum W_i = 0.992$			WQI = 73.804	WQI = 15.469

Conclusion and recommendation

The groundwater samples from the reclaimed waste dump site were examined using several risks and pollution evaluation models to reveal the water quality and its suitability for consumption. It was observed that groundwater samples A and C were mainly contaminated by NO_3^-, while samples A and B were polluted due to elevated Cr concentration. Al levels in samples A and D were above the WHO tolerable value for safe drinking water. The significant positive correlations between pH, EC, and Cu are indications of pH dependency of EC and Cu. The observed correlations between the metallic pollutants suggested similar sources of origin of these heavy metals and therefore may be associated with metallic scraps disposed in the waste dump site before reclamation. Though the exposure dose for both adult and children were < 1, elevated HQ values > 1 were observed for both adults and children in some samples, while HI values > 1 for both adult and children were also recorded. CDI risk assessment revealed values < 1, but carcinogenic risk values greater than 10^{-6} and 10^{-4} were observed for the samples due to Cr, suggesting potential health risk for children and adults. Low C_f and PLI were observed for the entire samples except for sample C with a pollution load index of unity with the PLI following the decreasing order of C > A > D > C > E > C1. It was observed that the WQI of groundwater from the reclaimed dumpsite could pose serious health risk due to elevated levels of Al and Cr recorded in the samples. Therefore, there is a serious need to treat water from the reclaimed dump site before consumption especially due to Al, Cr, and NO_3^- pollution. The above observations revealed that prolonged consumption of groundwater from this reclaimed waste dump site may cause serious health challenges. It is, therefore, recommended that adequate measures should be taken by Government Agencies to remediate the reclaimed waste dumpsite, in order to avert possible health risk which may arise due to prolong intake of groundwater sources from the area.

Acknowledgments The authors wish to acknowledge the support of the Staff of Chemistry Research Laboratory, Imo State University, Owerri, for their technical support. We appreciate Martins Ashabelem and Franklin Ogwurumba for their participation during the fieldwork. The authors are also thankful to Engr. Clement Johnson of Laboratory Services and Environmental Research Department/UNIDO RAC for Pollution Monitoring and Assessment, Ministry of Environment and Petroleum, Imo State, Nigeria, for permission to carry out the research in the reclaimed dumpsite.

Author contributions Project conceptualization, investigation, methodology, and the first draft of the manuscript [Francis Chizoruo Ibe], the final draft of the manuscript and literature searches [Francis Chizoruo Ibe, Opara Alexander Iheanyichukw, Collins Emeka Amaobi, assisted by Bridget Onyekachi Ibe]. The final manuscript was read and approved by all the authors.

Funding No funding or grant was received for this study.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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