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Assessment of natural groundwater physico-chemical properties in major industrial and residential locations of Lagos metropolis

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Abstract

This study investigated groundwater quality collected from two industrial and residential locations in each of Lagos metropolis. Prescribed standard procedures of American Public Health Association were used to measure physico-chemical parameters of each of the groundwater samples which include pH, EC, DO, TDS, BOD, COD, anions (Cl^-, NO_3^-, SO_4^{2-}, PO_4^{3-}) and heavy metals (Cu, Zn, Pb, Mn, Fe, Co, Cd and Cr). From laboratory analysis, measured physico-chemical parameters were within the permissible ranges specified by the WHO and NSDWQ except pH, TDS, EC, Pb, Mn and Fe for groundwater samples from industrial locations and pH, Pb, Mn and Fe for residential locations. Higher concentrations of TDS and EC reported for groundwater samples from industrial locations were attributed to heavy discharge of effluents from industrial treatment plants as well as dissolution of ionic heavy metals from industrial activities of heavy machines. Statistical Pearson's correlation revealed physico-chemical parameters of water quality to be moderately and strongly correlated with one another at either $p < 0.05$ or < 0.01.

Keywords Groundwater · Physico-chemical · Heavy metals · Anions · Water quality

Introduction

Lagos has been identified as the most populous mega-city in Nigeria controlling 40% of the country's industrial and manufacturing activities contributing 8000 tons of hazardous waste per year into the environment (Adewolu et al. 2009). Due to these attributes, enormous waste effluents are being generated on an hourly basis through industrial and residential activities with higher demand for domestic water consumption linked to her densely populated instinct. However, natural groundwater contamination occurred due to transportation of toxic and hazardous materials resulting from residential and industrial activities via leaching into underground within Lagos metropolis. This posed alarming health hazards to Lagos habitants whose major source of water supply for domestic purposes comes from underground water.

Thus, assessment of groundwater quality based on health and safety regulations specification before domestic use is highly imperative. Many laboratory procedures and tools involving parameters evaluation of groundwater assessment such as pH, acidity, temperature, salinity, turbidity, alkalinity, electrical conductivity, total soluble solids (TSS), total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO) and heavy metal concentration have been applied (Edwin et al. 2015; Rahmanian et al. 2015; Dissmeyer 2000). It is believed that estimated parameters with concentrations higher than those specify by the World Health Organization (WHO) and other health regulatory bodies suggest poor drinking water quality (WHO 2011). This great challenge has motivated researchers and governmental agencies around the globe to engage in series of investigations (Tuzen and Soylak 2006; Heydari and Bidgoli 2012).

Many laboratory analytical techniques such as inductively coupled plasma and mass spectrometry (ICP-MS) (Faisal et al. 2014), flame atomic absorption spectrometry (FAAS) (Behailu et al. 2017), direct extraction/air acetylene flame method (Rahmanian et al. 2015) and graphite furnace atomic absorption spectrophotometer (AAS-GF) (Mkadmi et al. 2018) had been applied to evaluate

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concentrations of heavy metals in groundwater samples with different statistical analytical tools such as principal component analysis (PCA) (Faisal et al. 2014; Duan et al. 2015), statistical package for social scientists (SPSS) (Lovelyn et al. 2014), analysis of variance (ANOVA) (Edwin et al. 2015), least significance difference (LSD) (Sabhapandit et al. 2010) and single factor analysis of variance (*t* test) (Shigut et al. 2017) to analyse the results.

Groundwater is the major source of drinking water in Lagos metropolis due to high disposal of wastes in different forms into water bodies enhanced by her densely populated feature, thereby contaminating other water sources. However, waste effluents from industrial treatment plants and solid wastes from residential areas find their ways into groundwater via leaching. Thus, groundwater quality must be regularly monitored in these locations. In this study, groundwater samples were obtained from prominent industrial and residential locations of Lagos State, Nigeria, and were evaluated to know the concentration of heavy metals (copper, zinc, lead, manganese, iron, cobalt, cadmium and chromium) that are present and other physico-chemical properties such as total dissolved solid, pH, electrical conductivity, chemical oxygen demand, biological oxygen demand, chloride, nitrate and sulphate (Mohsin et al. 2013). The obtained values were compared with standard values set by the Nigerian Standard for Drinking Water Quality (NSDWQ) and the World Health Organization (WHO) guidelines to ensure high water quality before drinking and other domestic purposes. Statistical Pearson's correlation was used to check the level of correlation of physico-chemical parameters at $p < 0.05$ or < 0.01 in groundwater samples collected from examined locations.

Materials and methods

Study area

Lagos has been known as the largest and most populous city in Nigeria with a population of 17.5 million (Adewolu et al. 2009). It lies on the geographical coordinates of 6°27′11″N, 3°23′44″E with 22% of its 3577 km² to be lagoons and creeks. Lagos has 29 industrial estates and 4 central business districts attributed with 26.7% Gross Domestic Product (GDP) out of Nigeria's total GDP. It has the highest emission level of 8000 tons of hazardous waste yearly, most of which is directly discharged into the Lagos lagoon (Adewolu et al. 2009).

The case study areas (shown in Fig. 1) are Deli Foods Nigeria limited, located along Apapa-Oshodi (an industrial centre known with many manufacturing activities) and OK Foods, located at Ladipo in Mushin area of Lagos whose major productions are biscuits and confectioneries. Oshodi and Agege community boreholes were chosen as sites for residential groundwater collection. The aquifer in all the study areas was characterized as unconfined under saturated zone which is coastal plain sand comprising of silt, clay and sand (Akinlalu and Afolabi 2018), while the respective borehole depths for Deli foods, OK foods, Oshodi and Agege community boreholes were 117, 134, 109 and 143 m (LSWRC 2018).

Fig. 1 Map of Lagos showing sample locations
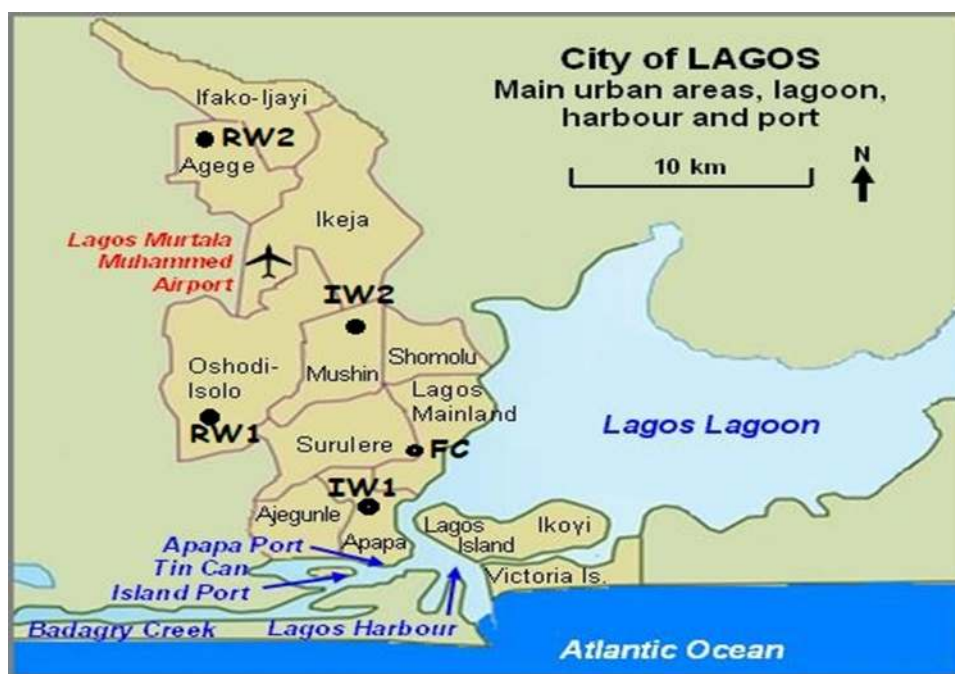
Samples collection

Two litres of groundwater samples were collected from boreholes of Deli foods (IW1) and OK foods (IW2). Also, groundwater samples were collected from Oshodi and Agege community boreholes, each located 40 km away from Deli foods (RW1) and OK foods (RW2), respectively. A total of four samples were collected from the locations. This sample collection exercise was done during rainy season (May 2018), and samples were kept in 5-L-capacity plastic kegs rinsed with hexane and distilled water in the laboratory to remove impurities that may be present before collection. The kegs were instantly covered with aluminium foil and lids sealed to avoid interference with atmospheric contaminants. Sample bottles were adequately labelled after which samples were analysed for different physico-chemical properties.

Materials and methodology

All chemicals and reagents (sodium hydroxide, distilled water, buffer solution, indicators, silver nitrate, sodium trioxocarbonate IV, ethylenediamminetetraacetic acid (EDTA), bleaching powder, potassium iodide, sodium thiosulphate solution, manganese sulphate and hydrochloric acid used for laboratory analysis were of analytical grade and purchased from TopJ Scientific in Ado-Ekiti, Ekiti State, Nigeria. Laboratory analysis was conducted inside the waste water treatment laboratory of Afe Babalola University, Ado-Ekiti, Ekiti state.

Samples' pH was measured using OAKION pH metre (S/N 2202625, Eutech Instruments, Singapore). Electrical conductivity (EC), dissolved oxygen (DO) and total dissolved solid (TDS) were calculated by electrometric method. Salinity was determined using ion exchange electrode method (Atekwanaa et al. 2004). Calcium present was determined using EDTA method. Iron was determined using Hach method 8008 (Ferro Ver). Nitrate, sulphate and chemical oxygen demand (COD) were determined using colorimetric method with HACH standards/methods 8039 high range, 8051, 8190 and 8155 low range, respectively. Colorimetric salicylate method (HACH method 8155 Low Range) was used to calculate ammonia present. Biological oxygen demand (BOD) was determined using azide modification method (5210A) prescribed by American Public Health Association (APHA 2012). Chloride content was determined using argentometric method, while heavy metals concentrations were calculated using flame absorption spectrophotometer (Buck Scientific AAS VGP 210 model). All parameters were measured in mg/L with the exception of EC measured in µS/cm while pH was unitless. Analysis of variance (ANOVA) was the statistical tool used together with computer SPSS 16.0 windows application.

Results and discussion

Each of the samples collected was analysed for 23 physico-chemical properties, namely pH, EC, DO, TDS, BOD, COD, nitrate, chloride, sulphate, solids salinity, ammonia and heavy metals which include chromium, nickel, cadmium, lead, cobalt, mercury, copper, zinc, vanadium, manganese and iron. Table 1 presents the laboratory results of all examined physico-chemical properties as compared with values from the existing studies.

pH

The pH values for water samples obtained for IW1, IW2, RW1 and RW2 were 7.58 ± 0.06, 8.31 ± 0.02, 6.35 ± 0.15 and 6.46 ± 0.05, respectively, as shown in Table 1. The industrial water sample (IW2) was alkaline, while residential borehole water samples (RW1 and RW2) were slightly acidic and values were not within the permissible range (6.5–8.0), specified by the Nigerian Standard for Drinking Water Quality (NSDWQ) (SON 2007) and the World Health Organization (WHO 2009). The alkalinity of water sample (IW2) may be attributed to the presence of bicarbonates (part of essential raw materials for production) lost into the soil and percolated into the underground soil via rain water. Also, biological degradation of waste in the soil may be a major influence of this observation. Slightly acidic nature of RW1 and RW2 may result from carbonic acid deposit formed via reaction of carbon dioxide with rain water (Tiwari et al. 2015). This may be transported from soil surface level to form deposits in the groundwater via some chemical processes over a period of time. Water with high alkalinity has proven to cause swelling of hair fibres and gastrointestinal irritation (Rose 1986). Acidic water has been identified to cause damage to cells of mucous membrane, eyes and skin irritation (WHO 1986; Meinhardt 2006). Also, acidic water contributes majorly to corrosion of metals coupled with disinfection efficiency causing indirect effect on human health.

Total dissolved solids (TDS) and electrical conductivity (EC)

The respective TDS obtained for samples IW1, IW2, RW1 and RW2 were 559.2, 589.7, 319.5 and 247.5 mg/L, as shown in Table 1. Only water samples located within industries (IW1 and IW2) revealed maximum TDS values higher than the permissible value (500 mg/L) of the NSDWQ and the WHO. Minimum variation below permissible value was exhibited by RW1 and RW2. Maximum TDS exhibited by IW1 and IW2 is an indication of saline water which may be attributed to (1) the presence of natural solute via dissolution of soils and weathering; and (2) discharge from industrial

Table 1 Data of physico-chemical properties of groundwater examined in sample locations and previous studies

Physico-chemical properties	Sample locations				The WHO permissible range	Previous studies	References
	IW1	IW2	RW1	RW2			
pH	7.58 ± 0.06	8.31 ± 0.02	6.35 ± 0.15	6.46 ± 0.05	6.5–8.0	6.10–6.97	Oyem et al. (2014)
						5.80–7.50	Edwin et al. (2015)
						5.57–8.00	Ayodeji et al. (2017)
TDS (mg/L)	559.2	589.7	319.5	247.5	500.0	390–1756.67	Behailu et al. (2017)
						166–184	Ezeribe et al. (2012)
						450–1350	Buridi and Gedala (2014)
EC (μS/cm)	1190.0	550.0	890.0	450.0	900.0	42.69–320	Okoro et al. (2012)
						333–1572	Ikeme et al. (2014)
						566.33–627.33	Shigut et al. (2017)
BOD (mg/L)	1.20	1.80	4.30	2.90	10.0	4.70–8.90	Obi and Okocha (2007)
						1.60–5.0	Adefemi and Awokunmi (2010)
						5.90–9.0	Amanial (2015)
COD (mg/L)	2.0	4.0	11.0	7.0	40.0	51.0–93.0	Oyem et al. (2014)
						37.0–49.0	Patil and Patil (2010)
						7.0–28.0	Eid (2017)
Chloride (mg/L)	88.60	63.90	52.20	77.40	600.0	18.40–82.10	Ezeribe et al. (2012)
						73.50–89.30	Mohammed and Nur (2013)
Nitrate (mg/L)	2.37	0.52	0.33	0.81	5.0	9.78–24.20	Ezeribe et al. (2012)
						3.20–6.40	Mohsin et al. (2013)
Sulphate (mg/L)	63.0	50.0	16.0	13.0	400.0	23.30–37.90	Farrukh and Qureshi (2004)
						8.04–24.0	Ezeribe et al. (2012)
Copper (mg/L)	0.44	0.42	0.18	0.26	1.0	0.012–0.176	Behailu et al. (2017)
						0.26–0.38	Adefemi and Awokunmi (2010)
Zinc (mg/L)	0.471	0.211	0.182	0.911	15.0	0.001–1.054	Birke et al. (2010)
						5.692–12.421	Fakayode (2005)
Lead (mg/L)	0.374	0.082	0.082	0.123	0.01	0.071–0.122	Faisal et al. (2014)
						0.068–0.103	Saddozai et al. (2009)
Manganese (mg/L)	0.119	0.079	0.278	0.481	0.05	0.002–0.078	Behailu et al. (2017)
						0.083–0.098	Adeyeye (1994)
						0.116–0.361	Laluraj and Gopinath (2006)
						0.093–0.205	Farrukh and Qureshi (2004)
Iron (mg/L)	5.26	1.60	4.71	2.20	0.30	4.84–7.45	Behailu et al. (2017)
						0.26–1.37	Eruola and Adedokun (2012)
Cobalt (mg/L)	0.073	0.067	0.018	0.018	–	0.237–0.289	Khan et al. (2012)
						N/A	Imam (2012)
Cadmium (mg/L)	0.0021	0.0025	0.001	0.000	0.003	0.013–0.026	Shigut et al. (2017)
						N/A	Tiwari et al. (2015)
						N/A	Sumant et al. (2015)
						0.001–0.002	Eruola and Adedokun (2012)
Chromium (mg/L)	0.000	0.0014	0.000	0.0022	0.05	0.014–0.018	Buridi and Gedala (2014)
						N/A	Saleem et al. (2012)
						N/A	Oguntona et al. (2012)

treatment plants causing soil contamination leaching and point-source groundwater pollution (Boyd 1999). Implications of high TDS are: (1) organoleptism in human and; (2) reduction in performance of pipes, filters and valves due to scale accumulation (Atekwanaa et al. 2004).

EC is directly related to TDS as it measures ionic content of water sample which determines its ability to conduct

an electric current. As TDS concentration of water sample increases, the ionic strength also increases. The values of EC obtained for IW1, IW2, RW1 and RW2 were 1190, 550, 890 and 450 μS/cm, respectively, as presented in Table 1. All values obtained were below the permissible value of 1000 μS/cm specified by the NSDWQ and 900 μS/cm specified by the WHO for drinking water except IW1. The intolerable EC value exhibited by IW1 could be attributed to (1) dissolution of ionic heavy metals from industrial activities of heavy machines which later found their ways into groundwater via leaching of sub-soil layers (Eruola and Adedokun 2012); and (2) higher temperature of the location enhancing movement of ions under electrostatic potential (Oguntona et al. 2012). The side effects are mainly corrosiveness of water and presence of heavy metals that make the water unsuitable for drinking.

Biological and chemical oxygen demands (BOD and COD)

COD measures oxygen requirement for organic matter chemical oxidation to take place via assistance of strong chemical oxidant, while BOD gives a measure of oxygen requirement for biodegradation of carbonaceous matter in a sample. The values revealed by IW1, IW2, RW1 and RW2 for COD and BOD were 2, 4, 11 and 7 mg/L; and 1.2, 1.8, 4.7 and 2.9 mg/L, as presented in Table 1. All values were below the maximum permissible values of 40 and 10 mg/L specified for COD and BOD, respectively, by the WHO and make them suitable for domestic usage. IW1 revealed minimum COD and BOD, while RW1 revealed maximum COD and BOD levels. This is due to sufficiently large volume of municipal and solid wastes generated within the densely populated region, transported into the ground via leaching, constituting to water pollution by increasing the organic content amount (Sumant et al. 2015). Thus, more oxygen is required by the microbes for their degradation.

Chloride (Cl⁻)

Concentration of chloride varies from types of water and has been found to exist naturally in the form of sodium and potassium salts. It is a stable water component whose concentration is uninterrupted by both bio- and physico-chemical processes. As shown in Table 1, the concentration of chloride ranges from 52.2 to 88.6 mg/L with RW1 and IW1 having the lowest and highest concentrations. All measured concentrations were below the maximum permissible values of 250 and 600 mg/L specified by the NSDWQ and the WHO, respectively. The presence of chlorides could be due to (1) chloride-containing soils and rocks undergoing leaching which later got in contact with underground water for all examined locations (Aremu et al. 2011), (2) high chloride-rich sewage and municipal

effluents discharged by residents in examined locations for RW1 and RW2 which later found its way into underground water (Gorde and Jadhav 2013) and (3) chloride salts used as essential ingredients for confectionaries production discharged as industrial effluents in investigated locations for IW1 and IW2. Chlorides have been investigated as essential ingredient for activities involving human body metabolism (Mohsin et al. 2013).

However, excessive chlorides concentration in water could lead to (1) laxative effect, (2) metallic pipes damage and (3) unsuitability of water for agricultural irrigation (Raviprakash and Krishna 1989).

Nitrate (NO₃⁻)

The results obtained revealed nitrate content with minimum and maximum concentrations of 0.33 and 2.37 mg/L for RW1 and IW1, respectively, as presented in Table 1. All measured values were below the WHO permissible value (5 mg/L). However, a fertilizer company located at about 4 km away from sample location IW1 could have contributed to the nitrate concentration in the sample. Highly concentrated wastes containing nitrogen compounds could have been oxidized to nitrate when discharged into the environment and found its way into groundwater via percolation. Major health implications of excess nitrate in water are hypertension in adults (Mkadmi et al. 2018) and methaemoglobinaemia in infants (Bruning-Fann and Kanaeme 1993).

Sulphate (SO₄²⁻)

Sulphates are oxidation results of (1) their ores and (2) H₂S by some bacteria activities such as chlorothiobacteria and rhodothiobacteria. Their ions exist naturally in water with little or no health implications recorded so far. The respective sulphate concentrations obtained for IW1, IW2, RW1 and RW2 were 63, 50, 16 and 13 mg/L, as presented in Table 1. The minimum concentration of 13 mg/L was revealed by water sample taken at location RW2, while maximum concentration of 63 mg/L was obtained for water sample taken at location IW1. All values were below the WHO, NSDWQ, EPA and IS 10500-2012 permissible values of 400, 100, 250 and 200 mg/L, respectively. However, accumulation of sulphate in water may lead to increase in water pH causing acidosis (Asamoah and Amorin 2011). No other health implication and side effects have been recorded so far for excess sulphate in water.

Heavy metals

Copper

From the result presented in Table 1, the minimum and maximum copper concentrations of 0.18 mg/L and 0.44 mg/L

were exhibited by RW1 and IW1, respectively. However, all values obtained were below the permissible concentration of 1 mg/L specified by the NSDWQ and the WHO. When excess copper is present in water (above the permissible level), gastrointestinal disorder occurs after a long period of exposure.

Zinc

Research has recorded approximately 0.05 g/kg of zinc to be present naturally in the earth crust (Dohare et al. 2014). From the study areas, the maximum and minimum zinc levels were 0.911 mg/L (RW2) and 0.182 mg/L (RW1) (Table 1). All examined samples revealed zinc concentration below the permissible standard values of 3, 5 and 15 mg/L set by the NSDWQ, IS 10500-2012 and the WHO, respectively. This could be that the zinc in its natural mineral form (sphalerite) did not dissolve into underground water bodies via leaching in all examined locations (Broadly et al. 2007). However, medical experts have reported electrolyte imbalance, vomiting, acute renal failures and abdominal pain as symptoms of excessive exposure of human to zinc.

Lead

Of all heavy metals, lead is the most significant due to its toxic and harmful instinct even at very small concentrations (Gregoriadou et al. 2001). It can accumulate in body tissue posing threat to human health. From the examined samples at different locations, concentration of lead ranges from minimum and maximum concentrations of 0.082 mg/L (IW2 and RW1) and 0.374 mg/L (IW1), respectively (Table 1). Lead concentrations of all samples were above the permissible value of 0.01 mg/L indicated by the WHO and NSDWQ. Due to the toxic nature of lead, EPA permissible level is zero mg/L.

High concentrations of lead in samples located at IW1 and IW2 could be attributed to (1) discharge of lead-rich waste effluents from nearby paint industry deposited in the soil which later found its way into underground water via leaching and (2) dissolution by heavy rain of emitted aerosols and dusts into the soil from industrial heavy plants which are transported by wind. The major influence of high lead concentrations in water samples from RW1 and RW2 could be from (1) leaching of natural deposits of lead ores in the soil into the groundwater (Imam 2012), (2) higher volume of leaded gasoline exhausts from motor vehicles in the residential area and (3) reaction of water with removed coated-lead from pipe's surface due to turbulent motion of transporting water from ground level to surface level.

The presence of lead in water beyond the permissible level could result in hypertension, interference with Vitamin D and calcium metabolism, brain development hindrance in foetus and young children, damage to tissues and organs in human and many more.

Manganese

Manganese is ores and rocks constituent which is widely distributed naturally. It is a vital element for biological systems whose chemical behaviour is a function of pH, oxidation and reduction reactions (Shand et al. 2007). The concentration of manganese in examined samples ranged from 0.079 mg/L (IW2) to 0.481 mg/L (RW2) (Table 1). All water samples exhibited manganese concentration above the permissible value of 0.05 mg/L specified by the WHO. This observation could be due to (1) groundwater contact with dissolved soil, rock and minerals of manganese in the aquifer for all sample locations, (2) leaching of industrial effluents discharge into the soil for sample locations IW1 and IW2 and (3) leachate from landfill and sewage deposited over time in residential locations for RW1 and RW2. Effects of high manganese concentration in water include (1) metallic and unpleasant taste to water, (2) blackish staining of laundry and plumbing fixtures and (3) formation of darkish scales in water pipes (Takeda 2003). However, no record of excess manganese health risk has been recorded in humans.

Iron

Like manganese, iron exists in its natural form as ores (magnetite, taconite and haematite) in rocks, soil and minerals making about 5% of the Earth's crust (Colter and Mahler 2006). It is dark-grey in colouration when in pure form and exists in groundwater as ferric hydroxide. The minimum and maximum iron concentrations of 0.15 and 3.26 mg/L were observed in RW2 and IW1, respectively (Table 1). From the analysed samples, two of the samples (IW1 and RW1) have Fe concentrations above the permissible WHO, EPA, NSDWQ and IS 10500-2012 standard value of 0.3 mg/L with the maximum concentration level revealed by water sample collected from location IW1. The observed Fe concentration above the permissible level could be linked to (1) weathering of minerals and rocks (mineralogical and piezometry features) of iron in the soil for the examined locations (IW1 and RW1) and (2) dissolution of iron natural deposits into groundwater bodies via leaching. However, anaemia has been reported as a result of iron shortage in humans. Results of extensive consumption of drinking water containing high Fe concentration level are haemosiderosis (liver-damage disease), diabetes mellitus, arteriosclerosis and many other neurodegenerative diseases (Nagendrappa et al. 2010; Brewer 2009).

Cobalt

Cobalt can hardly be found in its native state but exists in sulphide and arsenide form as minerals which are linnaeite (Co_3S_4), cobaltite (CoAsS), carrollite ($CuCo_2S_4$) and smaltite ($CoAs_2$) (Turekian and Scott 1994). In the examined sample locations, respective minimum and maximum Co concentrations were 0.018 mg/L (RW1) and 0.073 mg/L (IW1) (Table 1). The presence of cobalt could be attributed to heavy metals presence in industrial waste effluent discharges (for IW1 and IW2), while the presence in all samples could result from leached minerals of cobalt present in the soil into underground water. No permissible concentration of cobalt has been specified by the WHO and some global agencies. It plays a key role in the synthesis of vitamin B-12 which is an essential vitamin in the human body. However, people exposed to high concentration of cobalt have been reported to have lung diseases such as wheezing, asthma and pneumonia (Chaney 1982).

Cadmium

Cadmium exists as (1) natural ores in rocks and soils, and (2) zinc refining by-product (Wang et al. 2006). The presence of cadmium in groundwater occurred via leaching when in contact with soil contaminated with discharges from mining, paints, electroplating, petrochemical, plastics and fertilizer industries (DeZuane 1997). Out of the examined samples from different locations, only three (IW1, IW2 and RW1) exhibited the presence of Cd with the minimum concentration of 0.001 mg/L (RW1) and the maximum concentration of 0.0025 mg/L (IW2), as presented in Table 1. Though Cd concentrations were below the permissible value (0.003 mg/L) specified by the WHO and NSDWQ, epidemiological studies have shown that long-term exposure to Cd could cause (1) kidney damage, (2) lung cancer, (3) high blood pressure and (4) bone defects (osteoporosis and osteomalacia). The presence of cadmium in examined samples could be attributed to (1) leaching of waste runoff from battery industry located at about 2.5 km away from sample location (IW1) into the soil, (2) leaching of waste discharge from paint industry located few kilometres away from the sample location (IW2) and (3) galvanized steel pipe corrosion used in conveying water from the ground level to surface level (RW1) (El-Harouny et al. 2009).

Chromium

Chromium exists naturally as element in rocks, soil, plants, animals and volcano emissions. It is found in drinking water in trivalent (chromium 3) and hexavalent (chromium 6) principal forms. Only IW2 and RW2 exhibited minimum and maximum Cr concentrations of 0.0014 mg/L and 0.0022 mg/L, respectively (Table 1). Natural deposits erosion and coatings removal from water pipes could have been the major causatives of Cr presence in groundwater samples. Though Cr concentrations were below the WHO and NSDWQ permissible value of 0.05 mg/L, health implications of excessive exposure to chromium are as stated for cadmium.

Statistical correlation of groundwater contaminants

Pearson's correlation (r) reveals existing interaction between minimum of two continuous variables with values ranging between -1 and $+1$. This statistical tool was used to correlate groundwater contaminants in examined locations. A negative value implies negative correlation, while a positive value implies positive correlation between variables. A value of $r = 0$ is an indication of negligible connection between parameters. In most cases, strong correlation exists within parameters when $r > 0.7$, while moderate correlation exists when r ranges between 0.5 and 0.7 (Saleem et al. 2012). Table 2 presents the Pearson's correlation results of physico-chemical parameters of assessed water samples. The result revealed approximately 32%, 10% and 58% of the physico-chemical parameters to be strongly ($r \geq 0.7$), moderately ($0.5 < r < 0.7$) and poorly ($r < 0.5$) correlated. At $p < 0.05$, parameters that correlated positively with one another include: TDS with pH ($r = 0.894$) and Cu ($r = 0.805$); pH with Cu ($r = 0.818$), Co ($r = 0.843$) and Cd ($r = 0.812$); EC with Fe ($r = 0.878$) and Cr ($r = 0.842$); COD with Co ($r = 0.808$); BOD with Co ($r = 0.8133$); SO_4^- with Cu ($r = 0.886$); Fe with Cr (0.805) and lastly Co with Cd ($r = 0.821$). At $p < 0.01$, parameters that strongly correlated with one another include: TDS with Co ($r = 0.947$) and Cd ($r = 0.956$); COD with BOD ($r = 0.999$) and Cu ($r = 0.949$); BOD with Cu ($r = 0.956$); NO_3^- with PO_4^- ($r = 0.908$) and Pb ($r = 0.990$); SO_4^- with Co ($r = 0.980$); PO_4^- with Pb ($r = 0.926$); Cu with Co ($r = 0.932$); and lastly Mn with Cd ($r = 0.987$). Though none of the remaining parameters was negatively correlated, they were poorly significantly correlated with r values of less than 0.7 at $p < 0.05$ or < 0.01. However, majority of the measured physico-chemical parameters correlated with one another at either $p < 0.05$ or < 0.01 which is an indication that availability of specified pollution indicators will definitely have an influence on other assessed pollutants in water samples located at both industrial (IW1 and IW2) and residential (RW1 and RW2) locations.

Conclusion

The present study examined groundwater samples from two different industrial and residential locations of Lagos metropolis for some selected physico-chemical parameters

Table 2 Pearson's correlation of physico-chemical parameters of water samples

	TDS	pH	EC	COD	BOD	Cl⁻	NO₃⁻	SO₄⁻	PO₄⁻	Cu	Zn	Pb	Mn	Fe	Co	Cd	Cr
TDS	1.00																
pH	**0.894**	1.00															
EC	0.138	0.003	1.00														
COD	0.612	0.627	0.059	1.00													
BOD	0.623	0.649	0.049	**0.999**	1.00												
Cl⁻	0.063	0.050	0.084	0.597	0.574	1.00											
NO₃⁻	0.192	0.071	0.494	0.545	0.516	0.775	1.00										
SO₄⁻	0.905	0.729	0.276	0.787	0.785	0.261	0.481	1.00									
PO₄⁻	0.026	0.001	0.522	0.262	0.237	0.698	**0.908**	0.205	1.00								
Cu	**0.805**	**0.818**	0.059	**0.949**	**0.956**	0.374	0.398	**0.886**	0.135	1.00							
Zn	0.270	0.153	0.120	0.015	0.013	0.392	0.063	0.102	0.137	0.008	1.00						
Pb	0.180	0.051	0.593	0.466	0.437	0.693	**0.990**	0.460	**0.926**	0.340	0.036	1.00					
Mn	0.913	0.716	0.226	0.332	0.339	0.003	0.098	0.754	0.005	0.534	0.547	0.107	1.00				
Fe	0.001	0.088	**0.878**	0.005	0.009	0.024	0.299	0.039	0.449	0.010	0.056	0.395	0.031	1.00			
Co	**0.947**	**0.843**	0.163	**0.808**	**0.813**	0.219	0.369	**0.980**	0.118	**0.932**	0.106	0.340	0.768	0.004	1.00		
Cd	**0.956**	**0.812**	0.157	0.402	0.412	0.003	0.094	0.784	0.002	0.615	0.474	0.096	**0.987**	0.006	**0.821**	1.00	
Cr	0.097	0.002	**0.842**	0.002	0.004	0.013	0.135	0.129	0.157	0.005	0.405	0.208	0.265	**0.805**	0.065	0.174	1.00

Significant correlation at 0.01 and 0.05 levels are in bold

which include pH, TDS, EC, BOD, COD, Cl⁻, NO₃⁻, SO₄²⁻, Cu, Zn, Pb, Mn, Fe, Co, Cd and Cr with respective mean values of 7.175 ± 0.07, 428.975 mg/L, 770 μS/cm, 2.55 mg/L, 6 mg/L, 70.525 mg/L, 1.008 mg/L, 0.325 mg/L, 0.444 mg/L, 0.165 mg/L, 0.239 mg/L, 3.443 mg/L, 0.044 mg/L, 0.0014 mg/L and 0.0009 mg/L. From the executed laboratory analysis for groundwater samples from industrial locations, all measured values of physico-chemical parameters were either below permissible values or within ranges specified by the Nigerian Standard for Drinking Water Quality and the World Health Organization except pH, TDS, EC, Pb, Mn and Fe, while only pH, Pb, Mn and Fe violated permissible values for groundwater samples collected from residential locations. From the result obtained, higher concentrations of TDS and EC were reported for groundwater samples collected from industrial locations than those from residential locations due to heavy discharge of effluents from industrial treatment plants as well as dissolution of ionic heavy metals from industrial activities of heavy machines. In conclusion, various industrial and residential activities have influence on the parameters of water quality examined. Also, the statistical Pearson's correlation result revealed measured physico-chemical parameters to be moderately and strongly correlated with one another at either p ˂ 0.05 or ˂ 0.01.

Recommendation

Blood samples of residents drinking samples of groundwater collected from locations should be examined for future research work to know the levels of Pb, Mn and Fe in their blood streams. This will enable them to know their health status in this regard and also help medical experts in the field to recommend drugs if need be for residents exposed to excess concentrations of these heavy metals. Government of Lagos should be strict with industrial laws guiding waste disposal and treatment from industries as this is a major contributor to increase in concentrations of heavy metal in groundwater. Also, industrial activities contributing to this should be checked and controlled. Nonetheless, there should be consistent enlightenment to residents on proper waste disposal techniques as decays from these are also major contributors.

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