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Industrial and Residential Ground Water Physico-Chemical Properties Assessment in Lagos Metropolis

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Abstract

This study investigated ground water quality collected from two industrial and residential locations each of Lagos metropolis. Prescribed standard procedures of American Public Health Association (APHA) were used to measure physico-chemical parameters of each of the ground water samples which include pH, EC, DO, TDS, BOD, COD, anions (Cl^-, NO_3^-, SO_4^-, PO_4^-) 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 WHO and NSDWQ except pH, TDS, EC, Pb, Mn and Fe for ground water samples from industrial locations and pH, Pb, Mn and Fe for residential locations. Higher concentrations of TDS and EC reported for ground water 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 to be moderately and strongly correlated with one another at either $p < 0.05$ or < 0.01. In conclusion, ground water samples from residential locations are more suitable for drinking than those from industrial locations.

Keywords: Industrial, Ground Water, Residential, Lagos Metropolis, Physico-Chemical

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, these effluents are characterized with toxic and hazardous materials containing dangerous heavy metals which become sediments in ground water by leaching after their disposal constituting health hazards to Lagos habitants whose major source of water supply for domestic purposes comes from this origin. Thus, assessment of ground water quality based on health and safety regulations specification before domestic use is highly imperative. Many laboratory procedures and tools involving parameters evaluation of ground water 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), heavy metal concentration and so on 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 et al. 2006; Heydari et al. 2012).

Various applicable and efficient techniques of heavy metals removal from industrial effluents had been published (Gunatilake 2015; Aryal et al. 2015) while factors influencing their removal had also been presented elsewhere (Chipasa 2013; Piccirillo et al. 2013). 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 concentrations of heavy metals in ground water 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.

Ground water 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 ground water via leaching. Thus, ground water quality must be regularly monitored in these locations. In this study, ground water samples were obtained from prominent industrial and residential

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Drinking Water Engineering and Science Discussions

locations of Lagos State, Nigeria and were evaluated to know heavy metals (copper, zinc, lead, manganese, iron, colbalt, 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, sulphate and phosphate. The obtained values were compared with standard values set by Nigerian Standard for Drinking Water Quality (NSDWQ) and 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 ground water 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 is approximately lying on longitude 20 42′E and 32 2′E respectively and falls between latitude 60 22′N and 60 2′N with 22% of its 3,577 km^2 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 highest emission level of 8000 tons of hazardous waste yearly, most of which is directly discharged into the Lagos lagoon.

The case study areas are Deli Foods Nigeria limited, located along Apapa-Oshodi (an industrial center 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 ground water collection. The high population with enormous commercial activities attributes geared choosing these industrial and residential areas as case studies for this research work.

Samples Collection

Two litres each of ground water samples were collected from boreholes of Deli foods (IW1) and OK foods (IW2). Also, ground water samples were collected from Oshodi and Agege community boreholes, each located at 40 km away from Deli foods (RW1) and OK foods (RW2) respectively. This sample collection exercise was done during 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 aluminum foil and lids sealed to avoid interference with atmospheric contaminants. Sample bottles were adequately labeled after which samples were analyzed for different physico-chemical properties present in the waste water treatment laboratory of Afe Babalola University, Ado-Ekiti, Ekiti state.

Samples pH were measured using OAKION pH meter (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. Calcium present was determined using EDTA method. Iron was determined using Hach method 8008 (Ferro Ver). Nitrate, sulphate, phosphate 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). Chlorine 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 and DO were 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 analyzed for 23 physico-chemical properties namely pH, EC, DO, TDS, BOD, COD, nitrate, phosphate, Cl, sulphate, solids salinity, ammonia and heavy metals which include chromium, nickel, cadmium, lead, cobalt, mercury, copper, zinc, vanadium, manganese and iron.

pH

pH measures the degree of alkalinity or acidity of a solution and calculated by taking negative logarithm of the hydrogen ion activity. 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 Figure 1. This revealed pH range of 6.35 to 7.58 with minimum and maximum exhibited by RW1 and IW1 respectively. 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 Nigerian Standard for Drinking Water Quality (NSDWQ) (SON, 2007) and 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 percolates into the underground soil via rain water. Slightly acidic nature of RW1 and RW2 may result from the formation of carbonic acid due to the presence of more atmospheric carbon dioxide dissolution arising from larger population in residential areas than industrial areas (Tiwari et al, 2015). This may be transported from soil surface level to form deposits in the ground water via some chemical processes over 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.

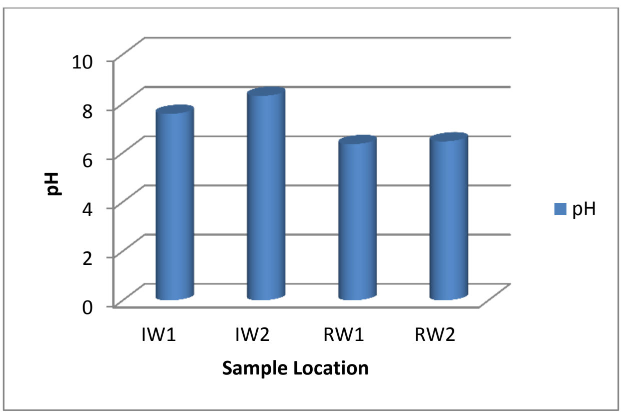


Figure 1: pH Spatial Variation of Water Samples

Total Dissolved Solids (TDS)

This is a measure of total solids (both organic and inorganic substances) present in water sample either in ionized or molecular suspended form. Filtration of water sample through a medium is usually done before being subjected to high temperature to determine its salinity. 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 Figure 2. Only water samples located within industries (IW1 and IW2) revealed maximum TDS values higher than the permissible value (500 mg/L) of NSDWQ and 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) presence of natural solute via dissolution of soils and weathering; and (2) discharge from industrial treatment plants causing soil contamination leaching and point source ground water 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).

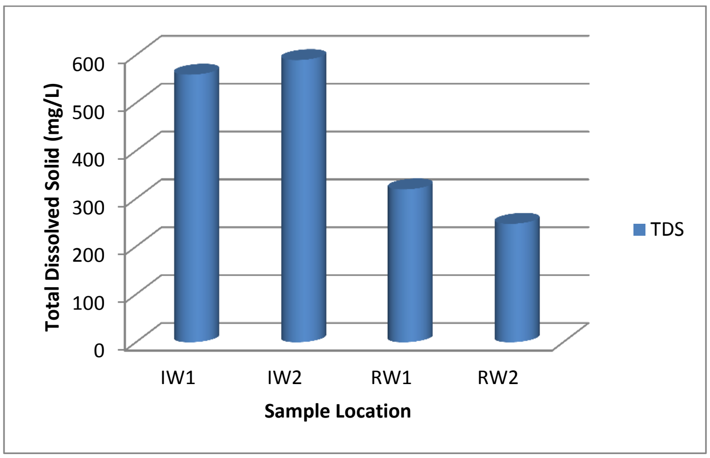


Figure 2: TDS Spatial Variation of Water Samples

Electrical Conductivity (EC)

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 Figure 3. The values range between 450-1190 µS/cm with IW1 exhibiting maximum EC while RW2 exhibited minimum EC. All values obtained were below the permissible value of 1000 µS/cm specified by NSDWQ and 900 µS/cm specified by 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 ground water via leaching of sub-soil layers (Eruola et al. 2012); and (2) higher temperature of the location enhancing movement of ions under electrostatic potential (Oguntona et al. 2012). The side effects are mainly water corrosiveness of water and heavy metals presence make the water unsuitable for drinking.

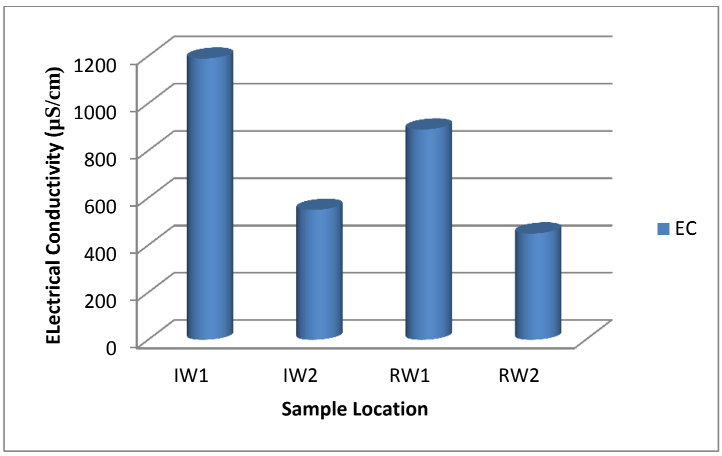
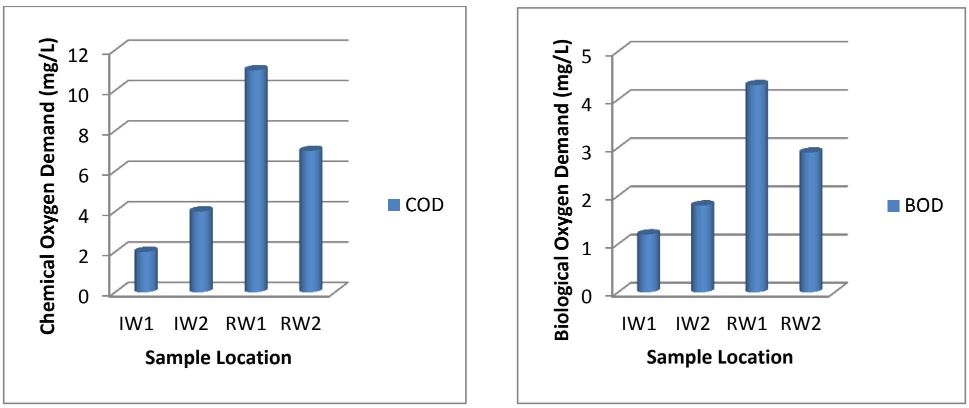


Figure 3: EC Spatial Variation of Water Samples

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 Figures 4(a) and (b) respectively. All values were below the maximum permissible values of 40 and 10 mg/L specified for COD and BOD respectively by 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.



(a) (b)

Figure 4: Water Samples Spatial Variation for (a) COD (b) BOD

Chloride (Cl^-)

Concentration of chloride varies from types of water and has been found to exist naturally in form of sodium and potassium salts. It's a stable water component whose concentration is uninterrupted by both bio- and physio-chemical processes. As shown in Figure 5, the concentration of chloride ranges from 52.2 to 88.6 mg/L with RW1 and IW1 having lowest and highest concentration. All measured concentrations were below the maximum permissible values of 250 and 600 mg/L specified by NSDWQ and WHO respectively. 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

Drink. Water Eng. Sci. Discuss., https://doi.org/10.5194/dwes-2019-2
Manuscript under review for journal Drink. Water Eng. Sci.
Discussion started: 4 March 2019

residents in examined locations for RW1 and RW2 which later found its way into underground water (Gorde et al. 2013) (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 et al. 1989).

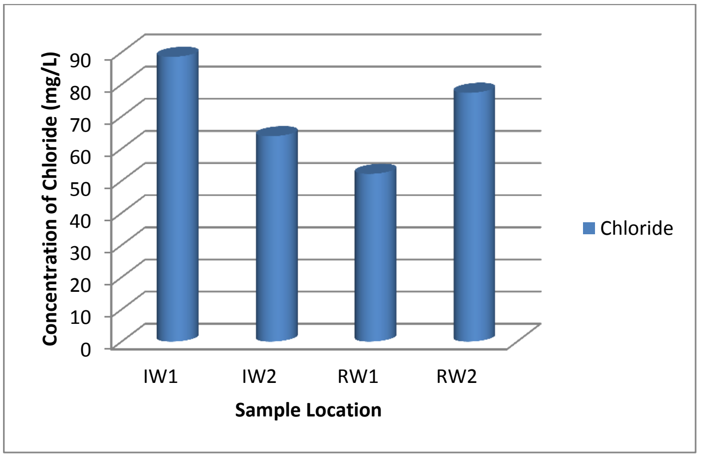


Figure 5: Spatial Variation of Chlorides in Water Samples

Nitrate (NO_3^-)

Nitrate is oxidizing form of N_2 compound which can be produced from decaying vegetables, organic matter of animals, fertilizer companies and discharge from municipal and industrial wastes. 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 shown in Figure 6. All measured values were below the WHO permissible value (5 mg/L). However, a fertilizer company located at about 4km away from sample location IW1 could have contributed to the nitrate concentration in the sample. Highly concentrated wastes containing nitrogen compounds could have oxidized to nitrate when discharged into the environment and found its way into ground water via percolation. Major health implications of excess nitrate in water

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Discussion started: 4 March 2019

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Drinking Water
Engineering and Science
Discussions

are hypertension in adults (Mkadmi et al. 2018) and methaemoglobinaemia in infants (Bruning-Fann et al. 1993).

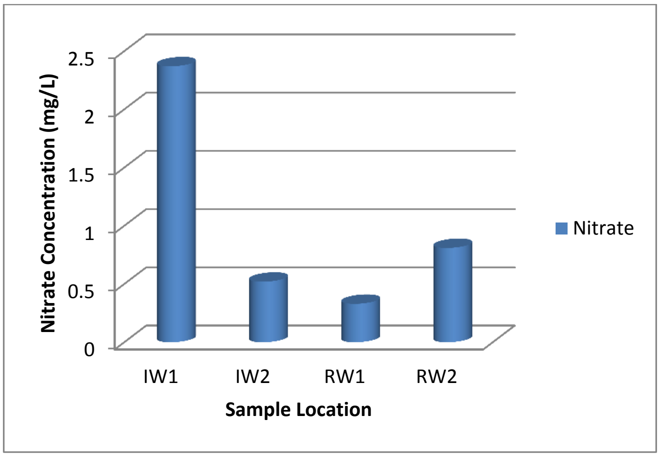

Figure 6: Spatial Variation of Nitrate in Water Samples

Sulphate (SO_4^-)

Sulphates are oxidation results of (1) their ores and (2) H_2S 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 shown in Figure 7. 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 et al. 2011). No other health implication and side effects have been recorded so far for excess sulphate in water.

Drink. Water Eng. Sci. Discuss., https://doi.org/10.5194/dwes-2019-2
Manuscript under review for journal Drink. Water Eng. Sci.
Discussion started: 4 March 2019

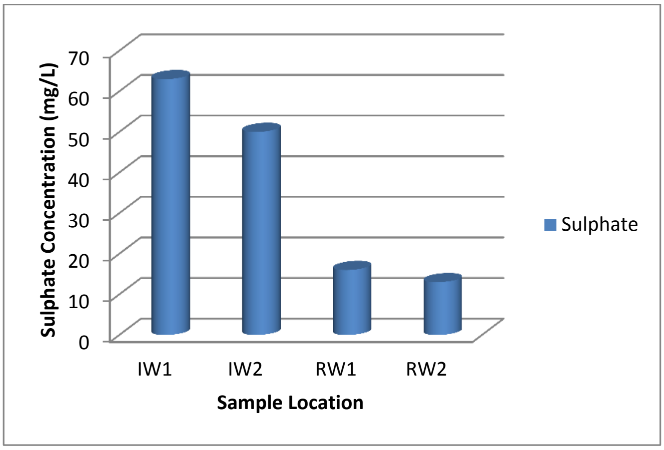

Figure 7: Spatial Variation of Sulphate in Water Samples

Phosphate (PO_4^-)

Phosphate is oxidized form of phosphorus which is an important nutrient for plant growth in aquatic environment. Naturally, phosphate retain ability of soil coupled with its native minerals low solubility enable phosphorus to be present in ground water even at very low concentration (APHA, 2012). The results obtained revealed phosphate concentration varying between minimum and maximum values of 0.09 and 0.19 mg/L for water sample locations IW2 and IW1 respectively (Figure 8). All measured values were below WHO permissible value of 6.5 mg/L. No medical implication has been reported for high concentration level of phosphate in water.

Drink. Water Eng. Sci. Discuss., https://doi.org/10.5194/dwes-2019-2
Manuscript under review for journal Drink. Water Eng. Sci.
Discussion started: 4 March 2019

Open Access Drinking Water Engineering and Science Discussions

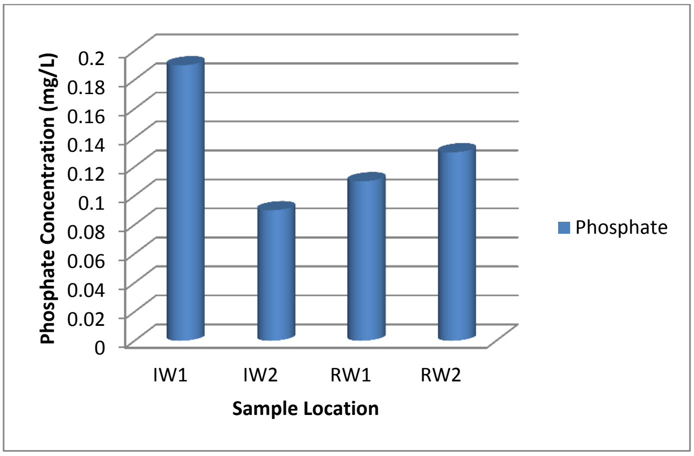

Figure 8: Spatial Variation of Phosphate in Water Samples

Heavy Metals

Copper: From the result obtained (Figure 9a), minimum and maximum copper concentration 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 NSDWQ and WHO. When excess copper is present in water (above the permissible level), gastrointestinal disorder occurs after 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) (Figure 9b). All examined samples revealed zinc concentration below the permissible standard values of 3, 5 and 15 mg/L set by NSDWQ, IS 10500-2012 and 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 concentration (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 (Figure 9c). Lead concentrations of all samples were above the permissible value of 0.01 mg/L indicated by 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. Presence of lead in water beyond permissible level could result to 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) (Figure 9d). All water samples exhibited manganese concentration above the permissible value of 0.05 mg/L specified by WHO. This observation could be due to (1) ground water 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 human.

Iron: Like manganese, iron exists in its natural form as ores (magnetite, taconite and hematite) in rocks, soil and minerals making about 5% of the Earth's crust (Colter et al. 2006). It is dark-gray in colouration when in pure form and exists in ground water as ferric hydroxide. Minimum and maximum iron concentrations of 0.15 and 3.26 mg/L were observed in RW2 and IW1 respectively (Figure 9e). From the analyzed samples, two of the samples (IW1 and RW1) have Fe concentrations above the permissible WHO, EPA, NSDWQ

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and IS 10500-2012 standard value of 0.3 mg/L with maximum concentration level revealed by water sample collected from location IW1. The observed Fe concentration above 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 ground water bodies via leaching. However, anemia has been reported as result of iron shortage in human. Results of extensive consumption of drinking water containing high Fe concentration level are haermosiderosis (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 sulphides and arsenides form as minerals which are linnaet (Co_3S_4), cobaltite (CoAsS), karrolit ($CuCo_2S_4$) and smaltyn ($CoAs_2$) (Turekian et al. 1994). In the examined sample locations, respective minimum and maximum Co concentrations were 0.018 mg/L (RW1) and 0.073 mg/L (IW1) (Figure 9f). Presence of cobalt could be attributed to heavy metals presence in industrial waste effluent discharges (for IW1 and IW2) while 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 WHO and some global agencies. It plays a key role in the synthesis of vitamin B-12 which is an essential vitamin in human's body. However, people exposed to high concentration of cobalt have been reported to have lungs diseases such as wheezing, asthma and pneumonia (Chaney, 1982).

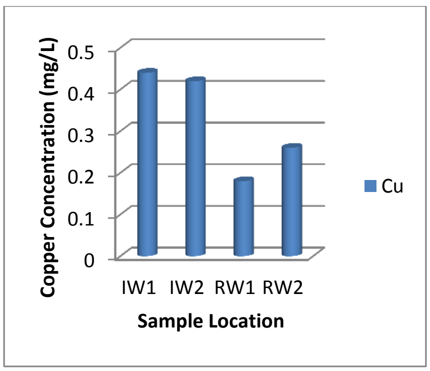
Cadmium: Cadmium exists as (1) natural ores in rocks and soils; and (2) zinc refining by-product (Wang et al. 2006). Presence of cadmium in ground water occurred via leaching when in contact with soil contaminated with discharges from mining, paints, electroplating, petrochemical, plastics and fertilizer industries (DeZuane, 1997). Out of the examined samples from different locations, only three (IW1, IW2 and RW1) exhibited presence of Cd with minimum concentration of 0.001 mg/L (RW1) and maximum concentration of 0.0025 mg/L (IW2) as shown in Figure 9(g). Though Cd concentrations were below the permissible value (0.003 mg/L) specified by 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). 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 sample location (IW2) and (3)

Drink. Water Eng. Sci. Discuss., https://doi.org/10.5194/dwes-2019-2
Manuscript under review for journal Drink. Water Eng. Sci.
Discussion started: 4 March 2019

Open Access Drinking Water Engineering and Science Discussions

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 volcanoes 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 (Figure 9h). Natural deposits erosion and coatings removal from water pipes could have been the major causatives of Cr presence in ground water 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.



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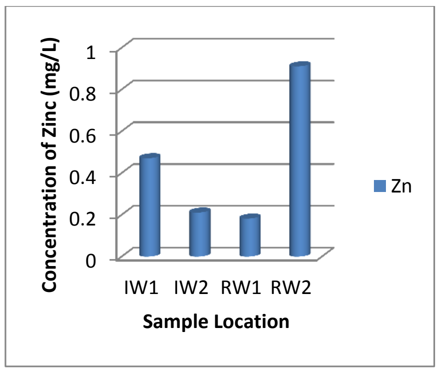

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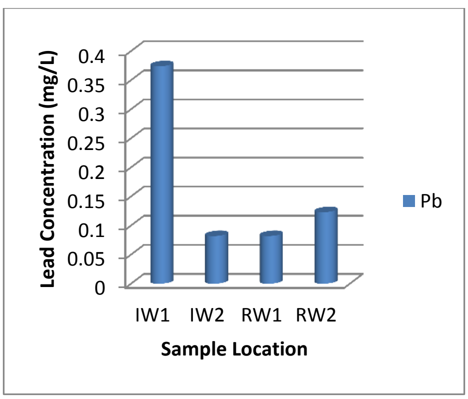

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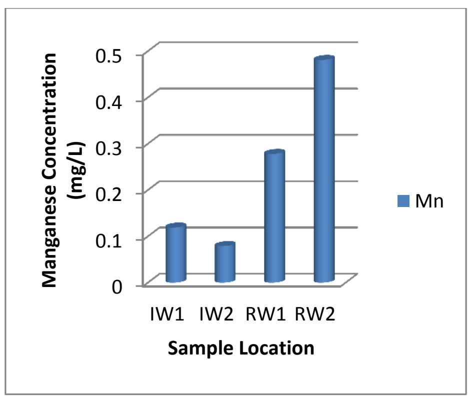
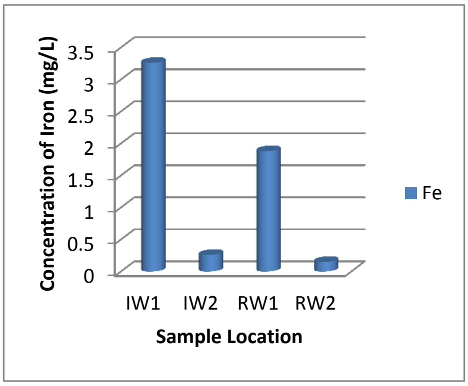
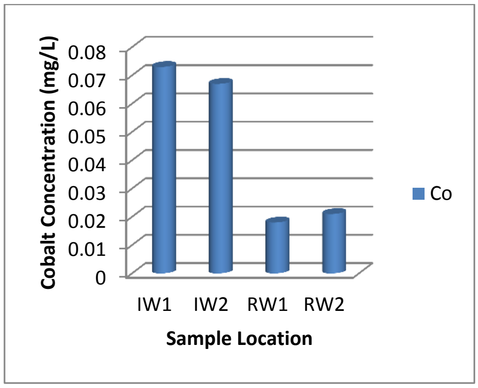


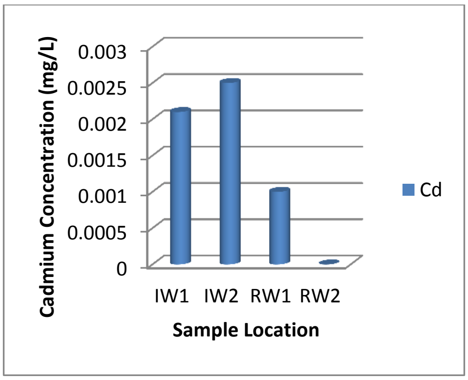
(d)

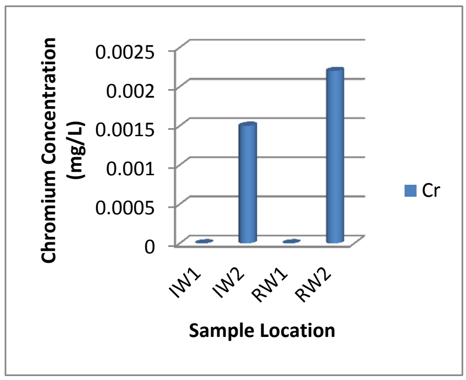
Drink. Water Eng. Sci. Discuss., https://doi.org/10.5194/dwes-2019-2
Manuscript under review for journal Drink. Water Eng. Sci.
Discussion started: 4 March 2019





(e) (f)





(g) (h)

Figure 9: Spatial Variation of (a) Copper (b) Zinc (c) Lead (d) Manganese (e) Iron (f) Cobalt (g) Cadmium (h) Chromium in Water Samples

Statistical Correlation of Ground Water Contaminants

Pearson's correlation (r) reveals existing interaction between minimum of two continuous variables with values ranging between -1 to +1. This statistical tool was used to correlate ground water 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 – 0.7 (Saleem et al. 2012). Table 1 presents the Pearson's correlation

Drink. Water Eng. Sci. Discuss., https://doi.org/10.5194/dwes-2019-2
Manuscript under review for journal Drink. Water Eng. Sci.
Discussion started: 4 March 2019

Open Access
Drinking Water Engineering and Science Discussions

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 influence on other assessed pollutants in water samples located at both industrial (IW1 and IW2) and residential (RW1 and RW2) locations.

Table 1: Pearson's correlation of Physico-Chemical Parameters of Water Samples

	TDS	pH	EC	COD	BOD	Cl^-	NO_3^-	SO_4^-	PO_4^-	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											
NO_3^-	0.192	0.071	0.494	0.545	0.516	0.775	1.00										
SO_4^-	0.905	0.729	0.276	0.787	0.785	0.261	0.481	1.00									
PO_4^-	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

Drink. Water Eng. Sci. Discuss., https://doi.org/10.5194/dwes-2019-2
Manuscript under review for journal Drink. Water Eng. Sci.
Discussion started: 4 March 2019

Open Access Drinking Water Engineering and Science Discussions

Conclusion

This present study examined ground water samples from two different industrial and residential locations of Lagos metropolis for some selected physico-chemical parameters which include: TDS, pH, EC, COD, BOD, Cl^-, NO_3^-, SO_4^-, PO_4^-, Cu, Zn, Pb, Mn, Fe, Co, Cd and Cr. From the executed laboratory analysis for ground water samples from industrial locations, all measured values of physico-chemical parameters were either below permissible values or within ranges specified by Nigerian Standard for Drinking Water Quality and World Health Organization except pH, TDS, EC, Pb, Mn and Fe while only pH, Pb, Mn and Fe violated permissible values for ground water samples collected from residential locations. From the result obtained, higher concentrations of TDS and EC were reported for ground water 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. Thus, ground water samples from residential locations are more suitable for drinking than those from industrial locations. 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.

Recommendations

However, due to presence of higher concentrations of Pb, Mn and Fe in all ground water samples, a low cost water treatment with chlorine should be employed to enhance transformation of the metals into solid settlement which can be filtered out before drinking. Also, blood samples of residents drinking samples of ground water 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.

Drink. Water Eng. Sci. Discuss., https://doi.org/10.5194/dwes-2019-2
Manuscript under review for journal Drink. Water Eng. Sci.
Discussion started: 4 March 2019

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Open Access
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