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Water quality and health risk assessment of metals within the vicinity of Gosa dumpsite, Abuja Nigeria

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SUMMARY

Introduction: The quality of surface and groundwater and associated public health issues have not received the attention it deserves among the communities within the vicinity of Gosa dumpsite, Abuja, Nigeria. **Aim:** To assess the physicochemical quality and potential health risks of heavy metals in drinking water resources around the Gosa dumpsite, Abuja, Nigeria. **Methodology:** Analysis of total dissolved solids and dissolved oxygen was done using the gravimetric method and azide modification of Winkler's method respectively. Sulphates, nitrates and fluorides concentrations were determined by UV/Vis spectrophotometric methods. Chlorides were determined by argentometric method. Carbonates were analysed using titrimetric method while analysis of metal concentrations was by atomic absorption spectrophotometer. **Results:** The mean levels of turbidity, DO, Fe, Pb, Cd, As, Cr and Mn exceeded the maximum permissible limits. Among all the metals in this study, Fe, Pb, Cd, Cr, Ni, and Mn had metal indices greater than 1.0 in both surface water and groundwater while the water quality index (WQI) exceeded the threshold value of 100. The mean hazard quotient for Pb, Cd and As exceeded one, while hazard index (HI) was higher than threshold value (1.0) in all the metals evaluated indicating associated potential chronic health risks. The study revealed that incremental lifetime cancer risks for Cd, As, Cr and Ni were higher than the acceptable safe limits ($< 1 \times 10^{-4}$). **Conclusion:** The higher water index of water revealed that water was polluted and unsafe for drinking. Incremental lifetime cancer risks for Cd, As, Cr and Ni exceeded the safe limits ($< 1 \times 10^{-4}$), indicating a potential cancer risk associated with ingestion of these carcinogenic metals through consumption of water by adult population.

Keywords: water quality index, hazard quotient, hazard index, incremental lifetime cancer risks

RESUMEN

Evaluación de la calidad del agua y los riesgos para la salud de los metales en las proximidades del vertedero de Gosa, Abuja, Nigeria

Introducción: La calidad del agua superficial y subterránea y los problemas de salud pública asociados no han recibido la atención que merece entre las comunidades cercanas al vertedero de Gosa, Abuja, Nigeria. **Objetivo:** Evaluar la calidad fisicoquímica y los riesgos potenciales para la salud de los metales pesados en los recursos de agua potable alrededor del vertedero de Gosa, Abuja, Nigeria. **Metodología:** El análisis de sólidos disueltos totales y oxígeno disuelto se realizó mediante el método gravimétrico y modificación con azida del método de Winkler respectivamente. Las concentraciones de sulfatos, nitratos y fluoruros se determinaron mediante métodos espectrofotométricos UV/Vis. Los cloruros se determinaron por el método argentométrico. Los carbonatos se analizaron mediante el método titrimétrico mientras que el análisis de las concentraciones de metales se realizó mediante espectrofotómetro de absorción atómica. **Resultados:** Los niveles medios de turbidez, DO, Fe, Pb, Cd, As, Cr y Mn superaron los límites máximos permisibles. Entre todos los metales en este estudio, Fe, Pb, Cd, Cr, Ni y Mn tuvieron índices metálicos superiores a 1,0 tanto en aguas superficiales como subterráneas, mientras que el índice de calidad del agua (ICA) superó el valor umbral de 100. El peligro medio El cociente de Pb, Cd y As superó uno, mientras que el índice de peligrosidad (HI) fue superior al valor umbral (1,0) en todos los metales evaluados, lo que indica posibles riesgos crónicos asociados para la salud. El estudio reveló que los riesgos incrementales de cáncer a lo largo de la vida para Cd, As, Cr y Ni eran superiores a los límites de seguridad aceptables ($< 1 \times 10^{-4}$). **Conclusión:** El índice de agua más alto reveló que el agua estaba contaminada y no era apta para beber. Los riesgos incrementales de cáncer a lo largo de la vida para Cd, As, Cr y Ni excedieron los límites seguros ($< 1 \times 10^{-4}$), lo que indica un riesgo potencial de cáncer asociado con la ingestión de estos metales cancerígenos a través del consumo de agua por parte de la población adulta.

Palabras clave: índice de calidad del agua, cociente de peligro, índice de peligro, riesgos incrementales de cáncer a lo largo de la vida

RESUMO

Avaliação da qualidade da água e do risco à saúde de metais nas proximidades do lixão de Gosa, Abuja, Nigéria

Introdução: A qualidade das águas superficiais e subterrâneas e as questões de saúde pública associadas não têm recebido a atenção que merecem entre as comunidades nas proximidades do lixão de Gosa, Abuja, Nigéria. **Objetivo:** Avaliar a qualidade físico-química e os potenciais riscos para a saúde dos metais pesados nos recursos de água potável em torno do lixão de Gosa, Abuja, Nigéria. **Metodologia:** A análise do total de sólidos dissolvidos e oxigênio dissolvido foi realizada utilizando o método gravimétrico e a modificação da azida do método de Winkler, respectivamente. As concentrações de sulfatos, nitratos e fluoretos foram determinadas por métodos espectrofotométricos UV/Vis. Os cloretos foram determinados pelo método argentométrico. Os carbonatos foram analisados pelo método titulométrico enquanto a análise das concentrações metálicas foi realizada por espectrofotômetro de absorção atômica. **Resultados:** Os níveis médios de turbidez, OD, Fe, Pb, Cd, As, Cr e Mn ultrapassaram os limites máximos permitidos. Entre todos os metais neste estudo, Fe, Pb, Cd, Cr, Ni e Mn apresentaram índices metálicos superiores a 1,0 nas águas superficiais e subterrâneas, enquanto o índice de qualidade da água (IQA) excedeu o valor limite de 100. O perigo médio o quociente para Pb, Cd e As excedeu um, enquanto o índice de perigo (HI) foi superior ao valor limite (1,0) em todos os metais avaliados, indicando potenciais riscos crônicos à saúde associados. O estudo revelou que os riscos incrementais de cancro ao longo da vida para Cd, As, Cr e Ni foram superiores aos limites de segurança aceitáveis ($< 1 \times 10^{-4}$). **Conclusão:** O índice hídrico mais alto da água revelou que a água estava poluída e imprópria para beber. Os riscos incrementais de câncer ao longo da vida para Cd, As, Cr e Ni excederam os limites seguros ($< 1 \times 10^{-4}$), indicando um risco potencial de câncer associado à ingestão destes metais cancerígenos através do consumo de água pela população adulta.

Palavras-chave: índice de qualidade da água, quociente de perigo, índice de perigo, riscos incrementais de câncer ao longo da vida

INTRODUCTION

Surface water and groundwater pollution has constituted serious public health concerns in suburban and urban areas of most developing countries including Nigeria [1].

This is a consequence of increasing population explosion or growth, and unauthorized discharge of untreated sewage and industrial effluent. Surface and groundwater adjacent to waste disposal sites are at risk of being contaminated. Pollutants are washed into surface water or leached into groundwater through the aquifer, thereby contaminating these water resources [2, 3]. Municipal solid waste is generated in most cities of Nigeria due to increasing consumption of household resources, solid wastes, hazardous wastes, radioactive wastes, agricultural and sewage [4]. Solid waste management has become one of the most persistent environmental challenges faced by mainly the urban areas in Nigeria. With an estimated population of over 200 million, Nigeria appeared to be the greatest producer of solid waste in Africa [5-7]. Municipal waste disposal methods in Nigeria comprise open dumping, open burning, incineration, unregulated landfills, composting, and dumping into drain channels, streams and rivers. The most common method of municipal waste disposal in Nigeria is the open dumps consisting of open holes or fields on the ground where trash, inert and recyclable and non-recyclable wastes are dumped. Burning of wastes controls bacterial activities and is an effective weight volume reduction method, but a vast source of air pollutants [8].

Groundwater and surface water are the main source of water for drinking and other domestic purposes without any form of treatment in most urban and sub-urban regions in Nigeria [9]. This is partly because the removal of pollutants in water followed a somewhat complex process in addition to the high cost involved [10-14]. There is a community of residents that live in the Gosa dumpsite which depends on shallow wells for drinking water. Also, inhabitants leaving adjacent to the solid waste disposal sites called Jiyita drink water from a lake that drains from the dumpsite and three boreholes [5, 15]. Heavy metals could impact the water quality within the communities; hence it becomes expedient that there should be periodic monitoring.

The present study was designed to determine the levels of physicochemical properties and concentrations of eleven heavy metals in drinking water (surface water and groundwater) within the vicinity of the Gosa dumpsite and to evaluate the health risks associated with the oral ingestion of heavy metals. The outcome of this research will make available some awareness of the degree of heavy metal pollution in the water resources at Gosa for the relevant authorities to proffer mitigation measures.

Methods

Study area

Samples were collected in March 2022 within vicinity of the Gosa dumpsite and Jiyita village. The sampling stations were accessed through Idu -Airport Road in Abuja. The

Gosa dumpsite is located off the Nnamdi Azikiwe Airport Road, Abuja within coordinates N09° 01.270’ E007° 19.59’ and N09° 01 173’ E007° 20.510. The sample description and the map of the study area are shown in Table 1 and Figure 1 respectively.

Table 1. Description of sample locations, coordinates and elevation

Sample ID	Coordinates of sample locations		Elevation (m)
	Latitude	Longitude	
SW1	N09° 01 32.7’	E007° 20 15.5’	391
SW2	N09° 01 20.7’	E007° 20 19.6’	378
SW3	N09° 01 11.1’	E007° 20 21.8’	376
SDP1	N09° 01 10.8’	E007° 20 21.9’	373
SDP2	N09° 01 15.3’	E007° 20 12’	390
JL1	N09° 01 08.8’	E007° 20 07.5’	392
JL2	N09° 01 08.8’	E007° 20 07.6’	400
BH1	N09° 01 43.1’	E007° 20 12.9’	414
BH2	N09° 01 00’	E007° 20 4.2’	392
BH3	N09° 01 00’	E007° 20 6.7’	385

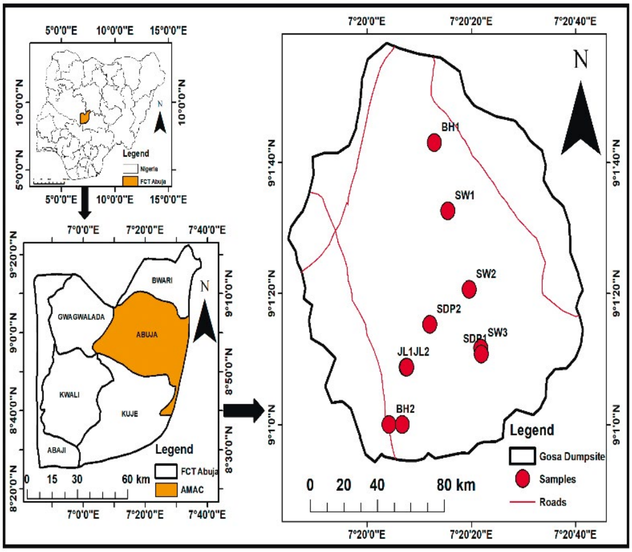

Figure 1. Location map of Gosa dumpsite, Abuja Nigeria

Sample collection and pre-treatment

A total of twenty water samples were collected from the study area during the dry season in March 2022. These include fourteen (14) surface water and six (6) groundwater samples. Three (6) surface water samples (SW1, SW2, SW3, SW4, SW5 and SW6) were collected from the flowing stream within the waste dumpsite at different points of almost equal intervals, starting from its source. Four (4) other surface water samples two each from (SDP1 and SDP2) were collected from very shallow hand dug just besides the flowing stream, while the last two (2) surface water samples (JL1 and JL2) were collected from a minor lake in Jiyita community. The groundwater samples were from one borehole within the perimeter of the waste dumpsite, and two different boreholes within the Jiyita community which is located at the western flank behind the dumpsite fence. The water samples were collected at the same time in a clean 2 litre transparent sample container. The residence time of borehole water in the overhead tank was less than 24 hours for each sample at the time of collection. Physical parameters such as temperature, pH, electrical conductivity, total dissolved solids, and dissolved oxygen were measured in Insitu, in triplicate using the appropriate instrument. The samples were then transported to the laboratory and stored at 4 °C before analysis.

Data Analysis

Metal Index

The metal index was calculated from the formula in equation 1 [16].

$$\mathrm{MI} = \sum \frac{\mathrm{C}}{\mathrm{MAC}} \tag{1}$$

where, MI is the metal index; C is the concentration of each element in solution; MAC is the maximum of allowed concentration of each element. A metal index of less than 1.0 implies no pollution while a metal index greater than 1.0 revealed that pollution has occurred concerning that metal.

Water Quality Index (WQI)

The computed water quality index evaluates the suitability of water for drinking purposes; hence the formulae below were used to calculate the water quality rating scale, relative weight and Water Quality Index (WQI) respectively [16].

The water quality rating and water quality index were computed from the formula in equation 2 and 4 respectively [16, 17].

$$\mathrm{qi} = \frac{\mathrm{Ci}}{\mathrm{Si}} \times 100 \tag{2}$$

Where qi, Ci, and Si denote the quality rating scale for parameter i, concentration for parameter i and the standard value of i parameter correspondingly. The relative weight was calculated thus;

$$\mathrm{wi} = \frac{1}{\mathrm{Si}} \tag{3}$$

Lastly, the water quality index was computed thus;

$$\mathrm{WQI} = \sum \mathrm{qiwi} / \sum \mathrm{wi} \tag{4}$$

Health risks assessment

Estimated daily intake, Hazard quotient (HQ), Hazard index, and Incremental lifetime cancer risk were calculated with the formula below to access the health risks through ingestion of water.

Estimated daily intake

The estimated daily intake (mg/kg/day) is calculated with the formula in equation 5 [17, 18].

$$\mathrm{EDI} = \frac{\mathrm{CR}}{\mathrm{BW}} \times \mathrm{IR} \tag{5}$$

where CR is the metal concentration, IR and BW signify the daily water consumption rate and the mean body weight of Nigerians respectively. 64 kg and 2.0 L were the average body weights of Nigerian adults and the daily ingestion rate through oral consumption of water in adult Nigerian respectively [19].

Hazard quotient (HQ)

Non-carcinogenic health risks of heavy metals were assessed by calculating the HQ [20, 21].

$$\mathrm{HQ} = \frac{\mathrm{EDI}}{\mathrm{RfD}} \tag{6}$$

where RfD refers to oral reference dose which is the estimated maximum permissible health risk related to daily human consumption or contact with heavy metals. RfD can be expressed in mg/kg/day [17, 18]. The collective effects of more than two heavy metals on the potential human health risk is called hazard index (HI). HI is calculated with the formula in equation 7 [15-18].

$$\mathrm{HI} = \Sigma\,\mathrm{HQ} \tag{7}$$

HI <1, indicates no potential health risk, whereas HI >1 indicates potential chronic health risk [15-18].

Carcinogenic risk

An index that is appropriately used to evaluate the carcinogenic risk is the incremental lifetime cancer risk [15-18]. Incremental lifetime cancer risk (ILCR) is expressed with the formula in equation 8 [22, 23].

$$\mathrm{ILCR} = \mathrm{CDI} \times\ \mathrm{CSF} \tag{8}$$

where CDI is the chronic daily intake of carcinogenic chemical substances (mg/kg bw/day). CSF is the cancer slope factor, which is estimated with the formula in equation 9 [22, 23].

$$\text{But, } \mathrm{CDI} = \frac{\mathrm{EDI} \times \mathrm{EF} \times\ \mathrm{ED}}{\mathrm{AT}} \tag{9}$$

where, EF is the exposure frequency in days/year (365 days per year), ED is the exposure duration in years or life expectancy. The life expectancy for adult Nigerians is 54 years [24]. AT is the average time or period of exposure which is 365 days per year multiplied by 54 years (19,710 days.) while CF is the correction factor [25].

Determination of physicochemical properties

Triplicate values of the physicochemical parameters were measured using the appropriate instruments and the mean of each was recorded.

Analysis of pH and temperature

The pH of the water samples was measured on the sampling spot with the aid of PHS-25 Laboratory Water pH Meter. Prior to the measurement, the pH meter was recalibrated with buffer solutions of pH 4 and 9 respectively. The pH meter was used to measure the temperature while 110°C mercury thermometer was used to validate all temperature readings.

Electrical Conductivity

A high-powered microcomputer conductivity meter JENWAY 40710 model HI 9032 with a degree of accuracy of 0.01 was used to measure the conductivity of the water samples in situ. The instrument was initially calibrated using standard solution of conductivities 500 µs/cm and 1500 µs/cm. Duplicate values were taken and units were in microsiemens per centimetre.

Total dissolved solids (TDS)

Analysis of TDS was performed by gravimetric method according to the American public health association [26]. 20 cm^3 of sample was filtered into a clean pre-weighed 100 cm^3 beaker and dry to a constant weight in the oven set at 105 °C and TDS was obtained by weight difference relating it to sample volume.

Dissolved Oxygen (DO)

Dissolved Oxygen (DO) was measured by azide modification of Winkler's method using Hanna 83200 multiparameter [27, 28]. The sample was filled in a 60 mL glass bottle and 5 drops of reagent A (HI 93732A-0) and 5 drops of B (HI 93732B-0). The bottle was then covered and inverted severally. The orange yellow solution was allowed to stand for two minutes followed addition of 10 drops of HI 93732C-0 and inverted severally until flocculent dissolved completely. The prepared sample was transferred into the cuvette and DO was measured after untreated water sample was used to zeroed the meter.

Turbidity

Turbidity of the water samples was measured in situ with a microprocessor turbidimeter JENWAY 3071, model HI93703 (0.0001 degree of accuracy). The instrument was first calibrated by dipping the probe into standard solution with turbidity values of 0.00 and 10.00 Nephelometric Turbidity Unit (NTU) before measuring the turbidity values of the samples.

Sulphate

Sulphate determination was by the turbidimetric method in which sulphate is converted to barium sulphate suspension and the resultant turbidity was then measured using a spectrophotometer at 420 nm and compared with standard curved prepared from standard sulphates solution.

Nitrates

The concentration of nitrates was determined by spectrophotometric method [29, 30]. 50 cm^3 of water sample was acidified with 1N HCl in a 100 cm^3 volumetric flask and mixed thoroughly followed by the addition of 0.5 cm^3 of brocine-sulfanilic acid and heating in a water bath for 25 minutes. After cooling, the absorbance was read at 410nm including the blank using the Shimadzu UV-visible spectrophotometer (UV-180 series). This procedure was repeated on the standard solutions for preparing standard calibrations.

Phosphates

Analysis of phosphate was done by the molybdenum blue method [31, 32]. 10 cm^3 of each of the standards, blank and samples were measured into a test tube. 2 cm^3 of combined reagent were added to the standards, blanks and samples. 1 drop of phenolphthalein indicator was added to the solutions upon which pink colour develops and 5N sulfuric acid was added drop wise to discharge the colour. Ten minutes was allowed to elapse, after which absorbance of each solution was measured at 880 nm on a UV-Vis spectrophotometer.

Chloride

Chloride in water was determined using the argentometric method involving titration of the sample against a silver nitrate indicator [33]. 25 cm^3 water sample was transferred to 250 cm^3 conical flask and 1 cm^3 potassium dichromate solution was added. The solution was titrated from yellow to brick red using 0.001N silver nitrate. Chloride ion was calculated as follow:

$$\mathrm{Cl^-}\ (\mathrm{mg/L}) = \frac{\mathrm{A - B \times 0.001}}{25} \times 1000 \tag{10}$$

Floride

A Shimadzu UV-visible spectrophotometer (UV-180 series)) was used to measure the absorbance of the sample. 1.0 ppm fluoride stock solution was prepared by dissolving 2.22 g of dried sodium fluoride in 1 L of deionized water. A range of calibration standards were prepared by serial dilution to determine fluoride levels. 0.12 g Eriochrome Black T was used to prepare 0.001 M dye solution. Flouride concentration was then determined at wavelength of 535 nm and results were comparable to that obtained using HI83200 multiparameter with 2 mL of HI 93729-0 SPADNS reagent on the same water sample in the central laboratory.

Carbonate and bicarbonates

The levels of carbonate and bicarbonates in water were determined by the titrimetric method. Carbonates was determined titrimetrically by transferring 25 mL of the water into 250 mL conical flask, followed by addition of 2 drops of phenolphthalein and followed by addition of sample 0.1 M sulfuric acid using burette until the disappearance of pink colour which signalled end point for carbonate. Bicarbonates was determined by repeating the same titration steps except usage of methyl orange which change colour from yellow to pink at neutralization point. Amount of carbonate and bicarbonate in mg/L was determined.

Determination of metal ions

The method described by the Association of Official Analytical Chemists (AOAC) was used for metal analysis [34]. The samples were digested by boiling with 10 mL of 20% hydrochloric acid in a beaker and then filtered into a 100 mL standard flask. This was made up to the mark with deionized water. The concentrations of. Na, K, Ca, Mg, Fe, Pb, Cd, As, Cr, Cu, Co, Ni, Zn, Mn, and Hg were measured at 589, 766.5, 422.7, 285.2, 248.3, 217, 228.8, 193.7, 357.9,324.8, 240.7, 232, 213.9, 279.5 and 253.7 nm respectively, using atomic absorption spectrophotometer (Agilent 280FS AA) with a hydride generator. Both calibration and rinse blanks were used to establish calibration curve and flush atomic absorption spectrophotometer between samples and standards respectively. The blanks were prepared under the same sample preparation procedure as the samples. The AAS instrument was set to automatically recalibrate after each five sets of samples analysed, while triplicate measurements were done and the mean value of each metal was recorded in order to enhance the reliability and reproducibility of measurements. All reagents used were of analytical grade. The atomic absorption spectrophotometer functioned under optimal conditions such as measurement mode (integrated), Slit with (0.5 nm), gain (57%), lamp current (10.0 mA), flame type (air/acetylene), air flow (13.5 L/min), acetylene flow (2.0 L/min), burner height (13.5mm), measurement time (10.0 seconds), while the detection limit was of 0.001 ppm.

Method validation for metal analysis

Samples were spiked with 0.5 mg/L of standard solutions of the respective metals before digestion in order to establish the accuracy of the analysis. Spiked samples were subsequently exposed to similar analytical conditions as the test sample. Percentage recovery was then calculated using the equation below:

$$\% \text{ Recovery} = \frac{\text{Concentration of spike sample} - \text{Concentration of unspiked sample}}{\text{Actual spike concentration}} \tag{11}$$

Recovery percentages of results for Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, Pb^{2+}, Cd^{2+}, As^{3+}, Cr^{3+}, Cu^{2+}, Co^{2+}, Ni^{2+}, Zn^{2+}, Mn^{2+}, and Hg^{2+} ranged from 91 – 102 %.

RESULTS AND DISCUSSION

The results for geochemical properties of both surface water and groundwater samples from Gosa Dumpsite and its environs are presented in Table 2. The pH of surface water (Table 2) ranged from 6.20±0.10 to 7.10±0.01 with a mean value of 6.77±0.01 while the pH of groundwater (Table 2) ranged from 6.30±0.12 to 8.20±0.03. The pH of both surface and groundwater samples was within the recommended standard limit (6.5-8.5) for drinking water [35]. The results were similar to that of Longe and Balogun who reported groundwater samples' pH, mostly within the acidic range, with a mean value of 6.62 which falls within the permissible WHO standard [36]. Also, pH values that ranged from 6.0 to 6.9 were reported by Saheed *et al.* [37] which correspond to values obtained in this study. As earlier observed by Daniel *et al.* [38], low pH values of natural water sources may be attributed to the first stage of leachate formation. The levels of TDS in surface water ranged from (110±0.15 to 2000±1.02) mg/L with a mean value of 939.29±0.53 mg/L. Shallow well water samples, SW1, SW2 and SW3 recorded higher values of TDS above recommended standard limit of 1000 mg/L. Total dissolved solids in groundwater samples ranged from (196±0.60 to 562±0.12) mg/L with an average value of 321±0.31 mg/L. TDS is a measure of the aggregate dissolved content of all organic and inorganic substances existing in a liquid. TDS level less than 600 mg/L is typically believed to be optimal for portable water but at TDS levels higher than 1000 mg/L water gradually becomes unpalatable. Water samples with lower or higher values of TDS may exhibit a characteristic insipid taste or objectionable mineral taste respectively. Excessive scaling in heaters, boilers and water pipes has been attributed to very higher levels of total dissolved solids in water. The electrical conductivity (EC) of surface water ranged from (0.15±0.01 to 3.72±0.01) µS/cm with a mean value of 1.57±0.02 µS/cm, while that of groundwater ranged from (0.27±0.02 to 0.78±0.06) µS/cm with an average value of 0.45±0.03 µS/cm. The mean electrical conductivity of surface water in this study was higher than that of groundwater but values were well below the standard recommended limit (1000 µS/cm), indicating that the contaminating species do not adversely affect the electrical conductivity, maintaining it at permissible values [39]. Saheed *et al.* [37], reported mean electrical conductivity (409 µS/cm) which was higher than the range of values in the present study but was within WHO's Standard Maximum Permissible limits. Similarly, the mean electrical conductivity (199.4 µS/cm) reported by Oyelami *et al.* [40] was higher than the result in the present study but falls within WHO/SON maximum permissible limits.

The amount of dissolved inorganic and organic substances as well as pH determine to a greater extent the electrical conductivity of water [41]. The temperature of surface water and groundwater ranged from (29.60±0.12 to 32.30±0.10) °C and from (31.10±0.07 to 32.70±0.02) °C, respectively, but it was within the ambient temperature. The level of turbidity (Turb) in surface water varies between samples while the minimum and maximum levels of turbidity were 12.0±0.05 NTU and 175±0.06 NTU respectively. In groundwater, turbidity ranged from (0.5±0.01 to 1.0±0.01) NTU with an average value of 0.67±0.01 NTU in groundwater. The levels of turbidity in groundwater samples were lower compared to surface water samples, however, values of turbidity in surface water were higher than 5 NTU recommended by standard organizations [42]. Turbidity is the degree of cloudiness of water brought about by suspended particles such as clay, silts, chemical precipitation of manganese and iron, organic particles and organisms [42]. High levels of turbidity affect the clarity of water to transmit light and consequently reduce the acceptability of drinking water. The surface water samples are therefore polluted concerning turbidity.

The levels of dissolved oxygen (DO) and biochemical oxygen demand (BOD) in surface water ranged from (4.35±0.04 to 5.55±0.10) mg/L and from (2.95±0.05 to 3.88±0.10) mg/L, respectively. Dissolved oxygen in groundwater ranged from (5.54±0.11 to 5.66±0.06) mg/L with a mean value of 5.59±0.09 mg/L, while from (2.85±0.05 to 2.95±0.05) mg/L was the range for levels of biochemical oxygen demand. DO level of 5.0 is recommended and suitable for the survival of aquatic life [35]. The DO level for SW1-SW3 and SDP2 in surface water and all the groundwater samples were slightly higher than the permissible limit but may not constitute any serious health hazard.

The metal concentrations in both surface water and groundwater are shown in Table 2. Sodium ion (Na^+) concentrations ranged from (9.45±0.14 to 10.5±0.10) mg/L with a mean value of 9.09±0.08 mg/L in surface water whereas, in groundwater, sodium recorded a maximum concentration of 8.29±0.05 mg/L (BH3) and a minimum level of 7.39±0.03 mg/L (BH1). These results correspond to the mean concentration of 11.75 mg/L reported in groundwater within the vicinity of a dumpsite in Ibadan Nigeria [40]. The concentrations of sodium in surface water were generally higher than that of groundwater but lower than the provision guideline level (200 mg/L) recommended by the World Health Organisation [42], indicating that the two categories of water samples were not polluted concerning sodium metal. Sodium is a beneficial element that enhances plant growth in a good number of ways but may not be very necessary for the accomplishment of the life cycle for such plants. The levels of potassium ion (K^+) in surface water ranged from (0.05±0.00 to 0.29±0.02) mg/L with an average value of 0.15±0.01 mg/L. Sample BH3 had the least concentration of potassium (0.05±0.01 mg/L) while BH1 recorded the highest concentration (0.15±0.01 mg/L) in groundwater. Surface water had slightly higher levels of potassium compared to groundwater but the difference is not highly significant.

The concentrations of potassium in both groundwater and surface water were much lower but within the maximum recommended limits of 200 mg/L in drinking water. This result appeared to be lower than those reported which varied from 1.04 to 24.41 with an average value of 5.66 mg/L [40]. The slightly higher concentration of potassium was attributed to the underlying geology of the study area [40]. Potassium is an essential element that is absorbed by plants roots and is required for the accomplishment of plants' life cycle and growth. The concentrations of calcium ion (Ca^{2+}) in surface water ranged from 0.04±0.01 - 0.67±0.02 mg/L with an average value of 0.27±0.02 mg/L while the levels of Ca^{2+} in groundwater ranged from (0.02±0.01 to 0.12±0.01) mg/L and a mean value of 0.06±0.01 mg/L. The concentrations of Ca^{2+} were lower than the maximum recommended limits (75 mg/L) in drinking water, indicating that all the water samples were unpolluted concerning Ca^{2+}. The minimum and maximum concentrations of Mg^{2+} in surface water were 0.99±0.12 mg/L (SW2) and 1.19±0.02 mg/L (SDP1) respectively. Similarly, in groundwater the concentrations of Mg^{2+} ranged from (0.98±0.04 to 1.16±0.01) mg/L whereas BH1 and BH2 had the lowest and highest levels respectively.

The concentration Mg^{2+} was lower than 20 mg/L and 50 mg/L maximum permissible limits recommended by World Health Organisation and Nigeria's industrial water standard for drinking water respectively [42, 43]. These results for Ca^{2+} and Mg^{2+} correspond with those of Adeyemo *et al.* [44], with mean Ca^{2+} and Mg^{2+} concentrations of 23.42 mg/L and 4.39 mg/L respectively. The concentration of Fe ranged from (0.82±0.07 to 2.76±0.04) mg/L in surface water with an average value of 1.22±0.06 mg/L, whereas a concentration range of (0.77±0.03 to 2.06±0.02) mg/L was recorded for Fe in groundwater. These values appeared to be higher than the provisional guideline value of 0.3 mg/L proposed by the World Health Organization [42] and the maximum permissible limit of 0.3 mg/L recommended by Nigeria's standard for drinking water quality [43]. This result corresponds to a range of 0.00 to 1.36 with an average of 0.23 mg/L reported for groundwater within the vicinity of the refuse dump in Ibadan Nigeria [40]. The concentrations of lead in surface water vary from minimum and maximum values of 0.29±0.05 mg/L to 0.41±0.01 mg/L with an average value (0.33±0.03 mg/L) respectively. However, for groundwater samples, the concentrations of Pb ranged from (0.49±0.05 to 0.56±0.02) mg/L with a mean value of 0.51±0.05 mg/L.

Interestingly, the concentrations of Pb in all the samples evaluated in this study were higher than WHO maximum permissible limits. This is a strong indication that both surface water and groundwater samples were polluted concerning lead and may not be safe for drinking. The enrichment of lead is similar to the results of Adelekan and Abegunde [45] and Saheed *et al.* [37]. The high lead concentrations may be associated with the combustion of fossil fuel, dumping of metal products rich in lead, cosmetics and waste batteries which has leached into the soil. Cadmium concentrations in surface water vary from one sample to the other but ranged from (0.06±0.01 to 0.22±0.05) mg/L with an average value of 0.10±0.03 mg/L. Similarly, the cadmium concentrations in groundwater samples ranged from (0.11±0.01 to 0.20±0.02) mg/L with an average value of 0.16±0.02 mg/L. These values were higher than WHO guideline values of 0.003 mg/L for drinking water, indicating a higher level of pollution of the groundwater and surface water in the study area [46]. The high concentration of Cd^{2+} is similar to the results of Saheed *et al.* [37]. Which may be attributed to leachate from agricultural farmland within the vicinity of the dumpsite where phosphate fertilizer may have been used.

The bioavailability or adsorption of cadmium compounds depends largely on the solubility of the compounds. Cadmium bioaccumulates in the kidney which is its primary target organ for toxicity and is classified as probably carcinogenic to humans (Group 2A) by International Agency for Research on Cancer (IARC) [47]. The concentration of arsenic (As^{3+}) in surface water samples was below the detection limit while that of groundwater ranged from 0.03±0.01 – 0.13±0.03 mg/L with an average value of 0.06±0.02 mg/L. The provisional guideline value for arsenic in drinking water is 0.01 mg/L [42, 43], but the values for the concentrations of As^{3+} in groundwater were higher than the provisional value. The groundwater mainly from boreholes in communities within the vicinity of the Gosa dumpsites was polluted concerning arsenic.

Arsenic is one of the toxic substances or elements thought to be responsible for widespread health effects as a result of drinking water exposure. The ingesting of higher concentrations of arsenic through drinking water will result in the growth of cancer in the body. Other toxicity of arsenic exposure through drinking water includes hyperpigmentation and hypopigmentation, exterior neuropathy, cancer of the skin, bladder and lung cancers and peripheral vascular disease [42]. The concentrations of chromium (Cr^{3+}) in surface water samples ranged from (0.04±0.01 to 0.10±0.02) mg/L with a mean value of 0.08±0.01 mg/L. Besides, (0.03±0.01 to 0.12±0.01) mg/L was the range of concentrations of Cr^{3+} in groundwater samples but the levels of chromium in water samples were higher than the standard provisional guideline value of 0.05 mg/L [42]. This result corresponds to the mean chromium concentration (0.098 ± 0.002 mg/L) reported by Ibironke *et al.* [48] on surface water due to Leachate from the municipal dumpsite. Chromium occurs in valences that ranged from +2 to +6 in its compounds but most stable at Cr^{3+}. A strong association has been established between exposure to the hexavalent form of chromium through the inhalation pathway and lung cancer. Hexa-valence form of chromium (Cr^{6+}) is a Group 1 human carcinogen according to International Agency for Research on Cancer (IARC) [47].

The concentrations of copper ions (Cu^{2+}) in surface water samples ranged between (0.07±0.01 and 0.16±0.05) mg/L with a mean value of 0.11±0.02 mg/L. The range of copper concentrations (0.21±0.02 to 0.27±0.03 mg/L) in groundwater was higher than those of surface water. Copper (Cu^{2+}) concentrations in this study were lower than the recommended standard guideline value of 2 mg/L [42]. Copper is a contaminant of water and also an essential nutrient for plant growth. Wilson disease, metabolic disorders, and gastrointestinal disorders are the most likely toxicity of copper. The minimum concentrations of cobalt recorded in surface water and groundwater were 0.18±0.02 mg/L and 0.30±0.01 mg/L respectively. On the other hand, the maximum concentrations of cobalt (Co^{2+}) in surface water and groundwater samples were 0.44±0.12 mg/L and 0.40±0.02 mg/L respectively.

The nickel ion (Ni^{2+}) concentrations ranged from (0.10±0.01 to 0.25±0.03) mg/L with an average value of 0.16±0.02 mg/L in surface water. The minimum and maximum concentrations of Ni^{2+} in groundwater were 0.03±0.01 mg/L and 0.08±0.02 mg/L respectively. The levels of Ni were higher in surface water samples than in groundwater samples. The guideline value of Ni in drinking water is 0.07 mg/L [42]. The levels of Ni in surface water samples exceeded the recommended guideline value, indicating that all the surface water samples were polluted concerning nickel. The high concentration of Ni is above WHO/SON permissible limits was reported in soil and groundwater around a refuse dump in Ibadan, Nigeria [37]. Nickel is an essential nutrient for plant growth. The most common toxicity of nickel is allergic contact dermatitis. Inhaled nickel compounds and nickel metal are carcinogenic to humans and have been classified by the IARC as Group 1 and Group 2 carcinogenic, but there is the dearth of evidence on possible carcinogenic health risks through oral exposure to nickel [47].

The minimum concentrations of zinc ions (Zn^{2+}) in surface water and groundwater were 0.11±0.05 mg/L and 0.17±0.02 mg/L respectively. Conversely, the maximum concentrations of Zn^{2+} in surface water and groundwater samples were 0.43±0.01 mg/L and 0.20±0.01 mg/L respectively. The levels at which Zn is found in water are not of health concern hence there is no guideline value recommended by the world health organization. Nevertheless, a concentration of zinc higher than 3.0 mg/L is not suitable and acceptable for drinking water [49]. Zinc is an essential element required by both plants and humans for healthy growth. The concentrations of manganese (Mn^{2+}) in surface water samples ranged from (1.55±0.20 to 2.32±0.05) mg/L with a mean value of 1.86±0.21 mg/L. In groundwater, the levels of Mn^{2+} ranged from (1.72±0.01 to 2.01±0.31) mg/L. Manganese concentrations higher than 0.1 mg/L in water supplies are linked to objectionable taste in beverages and staining of wares and laundry, coating on pipes and black precipitate results at manganese levels of 0.2 mg/L. However, the health base value of 0.5 mg/L has been proposed for manganese [35]. The concentrations of manganese in this study exceeded the recommended health base value and may adversely impact human health, especially children, hence the water samples were polluted with respect to manganese. Daniel *et al.* [38] observed the enrichment of Mn in natural water sources above the drinking water standard limits and attributed possible sources of Mn^{2+} to agricultural activities (extensive use of fungicides and fertilizers) and automobile parts as well as tools from the dump site. Manganese is an essential trace element required for the healthy growth of plants, humans and other animals. Manganese has been linked to adverse effects on learning in children [35].

The levels of mercury in both surface water and groundwater samples are below the detection limits of the atomic absorption spectrophotometer and hence is not of any health concern. The guideline value for mercury in drinking water is 0.006 mg/L [42]. The study area is not polluted concerning mercury. The concentrations of anions in both surface and groundwater are also presented in Table 2. The sulphates (SO_4^{2-}) concentrations in both surface water and groundwater samples ranged from (4.96±0.32 to 24.32±0.02) mg/L and from (5.80±0.22 to 6.16±0.02) mg/L, respectively. The average concentration of SO_4^{2-} in surface water (9.37±0.23 mg/L) seems to be higher than that of groundwater samples (6.27±0.15 mg/L). Nevertheless, sulphate concentration between (250 and 300) mg/L is very suitable for the support of fisheries and aquatic life. The sulphate concentrations for all the borehole water in this study were within the acceptable maximum permissible limits (500 mg/L) recommended [42], indicating that the groundwater samples were not polluted with respect to sulphate ions. The sulphate concentrations were within the range previously reported on groundwater in the vicinity of dumpsites at Aduramigba Estate within Osogbo Metropolis [40], and Lagos in Southwestern Nigeria [50].

Phosphates (PO_4^{3-}) had minimum and maximum concentrations of 0.40±0.02 mg/L and 0.92±0.02 mg/L in surface water respectively. The phosphate ion concentration in groundwater ranged from (0.01±0.00 to 0.79±0.02) mg/L with an average value of 0.29±0.01 mg/L. The concentration of phosphate ions appeared to be greater in surface water than in groundwater. Nonetheless, the phosphate ions concentrations in both groundwater and surface water were below the maximum permissible limit of 5.0 mg/L, indicating that groundwater is not polluted with respect to phosphate ions.

The nitrate (NO_3^-) concentrations ranged from (0.35±0.21 to 16.47±0.11) mg/L with a mean concentration of 7.97±0.12 mg/L. The nitrate (NO_3^-) concentrations in groundwater ranged from (8.93±0.12 to 11.81±0.22) mg/L with a mean value of 10.58±0.22 mg/L. The results of nitrate concentrations in most of the boreholes (BH2, BH3) appeared to be lower than the standard maximum limits of 50.0 mg/L for drinking water [49, 51]. The nitrate enrichment of groundwater in the present study corresponds to the range (0.1 to 10) mg/L, reported by Adeyemo *et al.* [44].

Chloride ion (Cl^-) had a concentration in surface water that ranged from (5.0±0.01 to 280±0.62) mg/L with a mean of 127.86±0.47 mg/L. The results of chloride ions concentrations were within the standard maximum permissible limits of 250 mg/L in most of the surface water samples except for SW1 (280 mg/L) and SW3 (240 mg/L). Chloride had concentrations in groundwater that ranged from (15.0±0.30 to 230±0.20) mg/L with a mean value of 96.7±0.20 mg/L. Chloride ions comparatively had lower concentrations in groundwater than in surface water but appeared to be within the standard recommended limits of 250 mg/L in all the groundwater samples. The mean chloride concentration of 268.87 mg/L was reported on groundwater in the vicinity of dumpsites at Aduramigba Estate within Osogbo Metropolis [40], higher than the ones in the present study but above the recommended standards for drinking water. Higher concentrations of chloride could enhance the corrosion rate in water distribution systems [51]. Fluoride ions (F^-) concentrations in surface water were below the detection limit of the AAS instrument while fluoride ions (F^-) concentrations for groundwater were below the detection limit in most of the samples (BH1, BH2), except BH3 (0.01±0.00 mg/L).

The maximum standard permissible limit of fluoride in drinking water is 1.5 mg/L and the concentration levels of fluoride ions were within the acceptable recommended limit. The carbonate (CO_3^{2-}) and hydrogen bicarbonate ions (HCO_3^-) concentrations in surface water ranged from (52.0±0.12 to 188.0±0.30) mg/L and from (15.20±0.55 to 43.70±0.50) mg/L in both surface water and groundwater respectively. The CO_3^{2-} and HCO_3^- ions in groundwater had concentration levels that ranged from (116.0±0.19 to 140.0±0.08) mg/L and from (26.60±0.22 to 45.60±0.70) mg/L respectively. The levels of bicarbonate were comparable to the range of values previously reported [40].

The computed metal index for surface and groundwater are presented in Table 3 and 4 respectively.

Table 2. Geochemistry of surface water and groundwater within the vicinity of Gosa dumpsite (mean ±SD)

Parameter	Surface water							Ground water				Standards	
	SW1	SW2	SW3	SDP1	SDP2	JL1	JL2	BH1	BH2	BH3	mean	WHO	SON/ NIN
pH	7.10 ±0.01	6.90 ±0.20	7.30 ±0.12	6.20 ±0.10	6.50 ±0.12	6.70 ±0.02	6.70 ±0.10	6.30 ±0.12	7.40 ±0.01	8.20 ±0.03	6.93 ±0.07	6.5 -8.5	6.5 - 8.5
TDS (mg/L)	2000 ±1.02	2000 ±0.91	2000 ±0.53	110 ±0.15	231 ±0.10	117 ±0.11	117 ±0.92	562 ±0.12	196 ±0.60	205 ±0.22	753.8 ±0.47	1000	500
EC (μS/ cm)	2.96 ±0.02	3.72 ±0.01	3.54 ±0.05	0.15 ±0.01	0.32 ±0.03	0.16 ±0.01	0.16 ±0.01	0.78 ±0.06	0.27 ±0.02	0.29 ±0.01	1.24 ±0.02	1000	1000
Temp (°C)	31.40 ±0.10	30.60 ±0.20	29.60 ±0.12	30.50 ±0.10	30.90 ±0.05	32.30 ±0.08	32.30 ±0.10	31.10 ±0.07	32.30 ±0.20	32.70 ±0.02	31.37 ±0.14	25-30	-
Turb (mg/L)	12.00 ±0.10	61.00 ±0.18	65.00 ±0.50	164.00 ±1.01	175.00 ±0.06	12.00 ±0.05	13.00 ±0.01	0.50 ±0.02	0.50 ±0.01	1.00 ±0.01	50.4 ±0.20	5.0	-
DO (mg/L)	5.55 ±0.10	5.27 ±0.08	5.19 ±0.05	4.98 ±0.03	5.10 ±0.08	4.35 ±0.04	4.38 ±0.01	5.56 ±0.11	5.66 ±0.06	5.54 ±0.11	5.16 ±0.07	5.0	-
BOD (mg/L)	3.45 ±0.01	3.30 ±0.10	3.25 ±0.12	2.95 ±0.05	3.00 ±0.04	3.85 ±0.02	3.88 ±0.10	2.85 ±0.09	2.85 ±0.05	2.95 ±0.05	3.23 ±0.06	-	-
Na$^+$ (mg/L)	7.84 ±0.10	9.45 ±0.14	9.02 ±0.11	10.50 ±0.10	8.85 ±0.08	8.18 ±0.02	9.79 ±0.04	7.39 ±0.03	8.25 ±0.11	8.29 ±0.05	8.76 ±0.08	200	200
K$^+$ (mg/L)	0.13 ±0.01	0.16 ±0.01	0.16 ±0.01	0.29 ±0.02	0.16 ±0.01	0.05 ±0.00	0.10 ±0.02	0.15 ±0.01	0.14 ±0.03	0.05 ±0.01	0.14 ±0.01	200	-
Ca^{2+} (mg/L)	0.04 ±0.01	0.37 ±0.03	0.61 ±0.02	0.67 ±0.02	0.07 ±0.01	0.05 ±0.01	0.08 ±0.01	0.12 ±0.01	0.05 ±0.01	0.02 ±0.01	0.21 ±0.02	75	-
Mg^{2+} (mg/L)	1.04 ±0.10	0.99 ±0.12	1.01 ±0.05	1.19 ±0.02	1.15 ±0.07	1.14 ±0.05	1.16 ±0.10	0.98 ±0.04	1.16 ±0.01	1.12 ±0.01	1.09 ±0.06	50	20
Fe^{2+} (mg/L)	0.82 ±0.07	1.15 ±0.05	1.28 ±0.11	2.76 ±0.04	0.92 ±0.10	0.88 ±0.01	0.76 ±0.03	2.06 ±0.02	0.94 ±0.02	0.77 ±0.03	1.23 ±0.05	0.3	0.3

(*Continued*)

Parameter	Surface water							Ground water				Standards	
	SW1	SW2	SW3	SDP1	SDP2	JL1	JL2	BH1	BH2	BH3	mean	WHO	SON/ NIN
Pb^{2+} (mg/L)	0.30 ±0.01	0.29 ±0.05	0.35 ±0.04	0.37 ±0.01	0.32 ±0.03	0.41 ±0.01	0.30 ±0.05	0.49 ±0.05	0.56 ±0.02	0.49 ±0.10	0.39 ±0.04	0.01	0.01
Cd^{2+} (mg/L)	0.07 ±0.03	0.06 ±0.01	0.08 ±0.02	0.10 ±0.01	0.22 ±0.05	0.12 ±0.03	0.05 ±0.04	0.11 ±0.01	0.18 ±0.02	0.20 ±0.02	0.12 ±0.02	0.003	0.003
As^{3+} (mg/L)	ND	ND	ND	ND	ND	ND	ND	0.03 ±0.01	0.13 ±0.03	0.03 ±0.01	0.06 ±0.01	0.01	0.01
Cr^{3+} (mg/L)	0.09 ±0.01	0.10 ±0.01	0.09 ±0.02	0.04 ±0.01	0.06 ±0.01	0.05 ±0.01	0.10 ±0.02	0.03 ±0.01	0.12 ±0.01	0.09 ±0.02	0.08 ±0.01	0.05	0.05
Cu^{2+} (mg/L)	0.07 ±0.01	0.07 ±0.01	0.12 ±0.02	0.10 ±0.01	0.13 ±0.01	0.16 ±0.05	0.12 ±0.02	0.27 ±0.03	0.21 ±0.02	0.24 ±0.01	0.15 ±0.02	2.0	1.0
Co^{2+} (mg/L)	0.20 ±0.01	0.21 ±0.03	0.18 ±0.02	0.44 ±0.12	0.41 ±0.05	0.31 ±0.01	0.26 ±0.01	0.40 ±0.02	0.32 ±0.03	0.30 ±0.01	0.31 ±0.03	-	-
Ni^{2+} (mg/L)	0.22 ±0.01	0.25 ±0.03	0.19 ±0.04	0.12 ±0.02	0.14 ±0.01	0.10 ±0.01	0.11 ±0.01	0.08 ±0.02	0.03 ±0.01	0.05 ±0.02	0.13 ±0.02	0.07-1.0	0.02
Zn^{2+} (mg/L)	0.16 ±0.05	0.20 ±0.02	0.18 ±0.02	0.43 ±0.01	0.39 ±0.06	0.26 ±0.08	0.11 ±0.05	0.17 ±0.02	0.20 ±0.01	0.19 ±0.05	0.23 ±0.04	3.0	3.0
Mn^{2+} (mg/L)	1.66 ±0.10	2.11 ±0.12	1.84 ±0.90	2.32 ±0.05	1.66 ±0.02	1.55 ±0.20	1.86 ±0.05	2.01 ±0.02	1.72 ±0.01	2.01 ±0.31	1.87 ±0.18	0.5	0.2
Hg^{2+} (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	-	-	0.001
SO_4^{2-} (mg/L)	6.56 ±0.11	7.00 ±0.80	7.48 ±0.05	24.32 ±0.02	7.56 ±0.40	7.68 ±0.62	4.96 ±0.32	5.80 ±0.22	6.84 ±0.21	6.16 ±0.02	8.64 ±0.28	500	100
PO_4^{3-} (mg/L)	0.92 ±0.02	0.75 ±0.10	0.40 ±0.20	2.57 ±0.05	0.45 ±0.01	0.47 ±0.03	0.40 ±0.02	0.79 ±0.02	0.01 ±0.00	0.07 ±0.01	0.68 ±0.05	5.0	-
NO_3^- (mg/L)	2.28 ±0.02	8.13 ±0.10	5.65 ±0.01	0.35 ±0.21	7.14 ±0.34	14.48 ±0.05	16.47 ±0.11	8.93 ±0.12	11.01 ±0.32	11.81 ±0.22	8.63 ±0.15	50.0	50

(*Continued*)

Parameter	Surface water							Ground water				Standards	
	SW1	SW2	SW3	SDP1	SDP2	JL1	JL2	BH1	BH2	BH3	mean	WHO	SON/ NIN
Cl^- (mg/L)	280.0 ±0.62	240.0 ±1.32	260.0 ±0.83	30.00 ±0.02	65.00 ±0.42	15.00 ±0.21	5.00 ±0.01	230 ±0.20	15.00 ±0.30	45.00 ±0.10	118.5 ±0.40	250	250
F^- (mg/L)	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.01 ±0.00	-	1.5	1.5
CO_3^{2-} (mg/L)	176.0 ±0.42	188.0 ±0.30	176.0 ±1.12	52.00 ±0.12	124.0 ±0.91	68.00 ±0.40	60.00 ±0.51	140 ±0.08	116.0 ±0.19	116.00 ±0.92	121.6 ±0.48	-	-
HCO_3^- (mg/L)	32.30 ±0.12	38.00 ±0.82	34.20 ±0.10	43.70 ±0.50	19.00 ±0.90	15.20 ±0.55	19.00 ±0.05	45.60 ±0.70	32.30 ±0.12	26.60 ±0.22	30.59 ±0.41	-	-

ND: Not detected

Table 3. Metal index for cations and heavy metals in surface water

Metals	SW1	SW2	SW3	SDP1	SDP2	JL1	JL2	Mean
Na	0.0392	0.0473	0.0451	0.0525	0.0443	0.0409	0.0490	0.0455
K	0.0007	0.0008	0.0008	0.0015	0.0008	0.0003	0.0005	0.0008
Ca	0.0005	0.0049	0.0081	0.0089	0.0009	0.0007	0.0011	0.0036
Mg	0.0208	0.0198	0.0202	0.0238	0.023	0.0228	0.0232	0.022
Fe	2.733	3.833	4.266	9.222	3.066	2.933	2.533	4.066
Pb	30.00	29.00	35.00	37.00	32.00	41.00	30.00	33.00
Cd	23.33	26.66	26.66	33.33	73.33	40.00	16.66	33.33
Cr	1.800	2.00	1.80	0.80	1.20	1.00	2.00	1.60
Cu	0.035	0.035	0.06	0.05	0.065	0.08	0.06	0.055
Ni	3.143	3.571	2.714	1.714	2.000	1.428	1.571	2.285
Zn	0.053	0.066	0.06	0.143	0.13	0.086	0.037	0.083
Mn	3.32	4.22	3.68	4.64	3.32	3.10	3.72	3.72

Table 4. Metal index for cations and heavy metals in ground water

Metals	BH1	BH2	BH3	mean
Na	0.0370	0.0413	0.0415	0.0399
K	0.0008	0.0007	0.0003	0.0006
Ca	0.0016	0.0007	0.0003	0.0008
Mg	0.0196	0.0232	0.0224	0.0218
Fe	6.8667	3.123	2.567	4.200
Pb	49.00	56.00	49.00	51.00
Cd	36.67	60.00	66.67	53.33
As	3.33	43.33	10.00	20.00
Cr	0.60	2.40	1.80	1.60
Cu	0.135	0.105	0.12	0.12
Ni	1.142	0.429	0.714	0.714
Zn	0.057	0.067	0.063	0.063
Mn	4.02	3.44	4.02	3.82

A metal index greater than one indicates pollution of the water sample has occurred while a metal index less than one implies no pollution. In surface water, the mean metal index for Na, K, Ca, Mg, Cu and Zn were 0.0455, 0.0008, 0.0036, 0.022, 0.055 and 0.083 respectively. These values of the metal index for Na, K, Ca, Mg, Cu and Zn were less than 1, reinforcing the fact that surface water was not polluted with respect to these metals. Similarly, the average metal index for Fe, Pb, Cd, Cr, Ni, and Mn in freshwater samples were 4.066, 33.00, 33.33, 1.60, 2.285 and 3.72 respectively. Conversely, Fe, Pb, Cd, Cr, Ni, and Mn had metal indices greater than 1, hence surface water samples were polluted with respect to each of these metals. The mean metal index for Na, K, Ca, Mg, Cu, Ni and Zn in groundwater were 0.0399, 0.0006, 0.0008, 0.0218, 0.12, 0.714 and 0.063 respectively. Nevertheless, Fe, Pb, Cd, As, Cr and Mn had computed metal indices of 4.20, 51.00, 53.33, 20.00, 1.60 and 3.82, respectively, which are greater than the threshold value of 1.0 indicating pollution of groundwater with respect to these heavy metals. The computed Water Quality Index (WQI) for metals in both surface and groundwater is shown in Fig. 2 below. BH2 had the highest value (13501.85) of WQI whereas SW1 had the lowest value (6447.52). The WQI in all the water samples and sampling sites were greater than 100, which is a strong indication that water from these sources wears unsuitable and unsafe for drinking purposes.

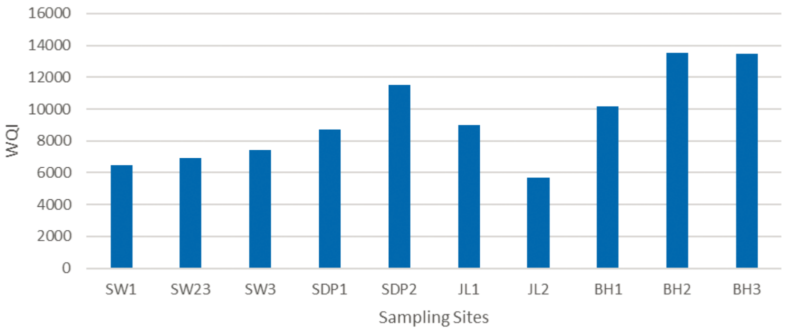

Figure 2. WQI of Cations in both surface and groundwater samples

The quantity, exposure duration and toxicity of heavy metals in addition to other chemical substances determine the human health risks [52].

The estimated daily intake of water by an adult was calculated and presented in Table 5. The mean estimated daily intake for Fe, Pb, Cd, As, Cr, Cu, Co, Ni, Zn and Mn were 0.0039, 0.0123, 0.00378, 0.00061, 0.00249, 0.00470, 0.00961, 0.00409, 0.00727 and 0.05950, respectively.

The calculated hazard quotients of heavy metals are presented in Table 6. RfD values for Cd (0.001), Cr (0.003), As (0.0003), Ni (0.02), Hg (0.0001), Pb (0.004), Cu (0.04), Zn (0.3), Mn (0.14), Fe (0.70) and Co (0.02) were used for computing the hazard quotients [46]. The non-carcinogenic health risks for each heavy metal in both surface and groundwater samples were assessed by calculating the hazard quotient. Table 6 revealed that the mean hazard quotient (HQ) for Fe, Pb, Cd, As, Cr, Cu, Co, Ni, Zn and Mn were 0.056, 3.078, 3.780, 6.778, 0.830, 0.118, 0.481, 0.205, 0.024 and 0.425, respectively. The mean hazard quotient (HQ) values were less than one (1.0) for Fe, Cr, Cu, Co, Ni, Zn and Mn while Pb, Cd and As had HQ values that exceeded the threshold hazard quotient (HQ) values of one (1.0), suggesting the possibility of potential health risk associated with Pb, Cd and As through consumption of drinking water. Table 6 also revealed that hazard index (HI) values ranged from 6.195 - 31.593 with JL2 and BH2 having the minimum and maximum HI, respectively. The HI values in this study exceeded the acceptable value of one, indicating the associated chronic health risk effects of these heavy metals combined. Nickel, cadmium, chromium, arsenic and lead were designated as group 1 and 2 potential carcinogenicity metals respectively by the International Agency for Research on Cancer (IARC) but Zn, Al, Mn and Cu were classified as non-carcinogenic metals [53]. Cancer slope factor for Pb, Ni and Cd are 0.009, 1.7 and 0.6, respectively [54, 55], while that of As and Cr are 1.5 and 0.501 correspondingly [47, 53]. The calculated values of incremental life cancer risk for the adult population are shown in Table 7.

Incremental life cancer risks for Pb, Cd, As, Cr and Ni ranged from 8.28×10^{-5} to 1.05 × 10-4, 9.6×10^{-4} to 4.2×10^{-3}, 1.5×10^{-3} to 6.15×10^{-3}, 2.51×10^{-4} to 1.90×10^{-3} and 1.7×10^{-3} to 1.34×10^{-2}, respectively. The Incremental lifetime cancer risk (ILCR) values for lead were within the acceptable safe limit of 1.0×10^{-4} to 1.0×10^{-6}, and has the least chance of cancer risks. However, Cd, As, Cr and Ni had cancer risk values higher than the acceptable limits and have a very high chance of cancer risks through ingestion of water.

CONCLUSION

Most of the physicochemical parameters evaluated in the present study were within the acceptable limits while the mean concentrations of Fe, Pb, Cd, As, Cr and Mn exceeded the maximum permissible limits. Metal index and weighted water quality index for Fe, Pb, Cd, Cr, Ni, and Mn in all the stations were higher than the threshold values, indicating that the water samples were contaminated and unsafe for drinking purposes. The range of cancer risk values for lead (8.28×10^{-5} to 1.602×10^{-4}) was within the safe limit and may not poses potential cancer risks. Incremental lifetime cancer risks for Cd, As, Cr and Ni were higher than the safe limits ($< 1 \times 10^{-4}$), suggesting a high probability of potential cancer risk associated with consumption of these carcinogenic metals by the adult population who depending on these sources of water for livelihood.

Table 5. The estimated daily intake (mg/kg/day) EDI.

Metal (mg/L)	Surface water							Groundwater			
	SW1	SW2	SW3	SDP1	SDP2	JL1	JL2	BH1	BH2	BH3	mean
Fe	0.0260	0.0365	0.0406	0.0876	0.0292	0.0279	0.0241	0.0654	0.0298	0.0244	0.0039
Pb	0.0095	0.0092	0.0111	0.0117	0.0102	0.0130	0.0095	0.0156	0.0178	0.0156	0.0123
Cd	0.0022	0.0019	0.0025	0.0032	0.0070	0.0038	0.0016	0.0035	0.0057	0.0064	0.00378
As	-	-	-	-	-	-	-	0.0010	0.0041	0.0010	0.00061
Cr	0.0029	0.0032	0.0029	0.0013	0.0019	0.0016	0.0032	0.0010	0.0038	0.0029	0.00249
Cu	0.0022	0.0022	0.0038	0.0032	0.0041	0.0051	0.0038	0.0086	0.0067	0.0076	0.00470
Co	0.0064	0.0067	0.0057	0.0140	0.0130	0.0098	0.0083	0.0127	0.0101	0.0095	0.00961
Ni	0.0070	0.0079	0.0060	0.0038	0.0044	0.0032	0.0035	0.0025	0.0010	0.0016	0.00409
Zn	0.0051	0.0064	0.0057	0.0137	0.0124	0.0083	0.0035	0.0054	0.0064	0.0060	0.00727
Mn	0.0527	0.0670	0.0584	0.0737	0.0527	0.0492	0.0591	0.0638	0.0546	0.0638	0.05950

Table 6. Hazard Quotient (HQ) for heavy metals in adult population

Metal (mg/L)	Surface water							Groundwater			
	SW1	SW2	SW3	SDP1	SDP2	JL1	JL2	BH1	BH2	BH3	Mean HQ
Fe	0.037	0.052	0.058	0.125	0.042	0.040	0.034	0.093	0.043	0.035	0.056
Pb	2.375	2.300	2.775	2.925	2.550	3.250	2.375	3.900	4.450	3.900	3.078
Cd	2.20	1.90	2.50	3.20	7.00	3.800	1.600	3.500	5.70	6.40	3.780
As	-	-	-	-	-	-	-	11.67	19.00	3.333	6.778
Cr	0.967	1.066	0.967	0.433	0.633	0.533	1.067	0.333	1.267	0.967	0.830
Cu	0.056	0.055	0.095	0.08	0.103	0.128	0.095	0.215	0.168	0.190	0.118
Co	0.320	0.335	0.285	0.70	0.650	0.49	0.415	0.635	0.505	0.475	0.481
Ni	0.350	0.395	0.300	0.190	0.220	0.16	0.175	0.125	0.050	0.080	0.205

(*Continued*)

Metal (mg/L)	Surface water							Groundwater			
	SW1	SW2	SW3	SDP1	SDP2	JL1	JL2	BH1	BH2	BH3	Mean HQ
Zn	0.017	0.021	0.019	0.046	0.041	0.028	0.012	0.018	0.021	0.020	0.024
Mn	0.376	0.479	0.417	0.526	0.376	0.351	0.422	0.456	0.390	0.456	0.425
HI=∑HQ	6.698	6.604	7.416	8.226	11.62	8.780	6.195	20.94	31.59	15.86	--

Table 7. Incremental lifetime cancer risk (ILCR) of carcinogenic human health risks through ingestion of water from the study area

Metal (mg/L)	Surface water							Groundwater		
	SW1	SW2	SW3	SDP1	SDP2	JL1	JL2	BH1	BH2	BH3
Pb	8.55×10^{-5}	$8.28 \times 1^{0}-5$	9.99×10^{-5}	1.05×10^{-4}	9.18×10^{-5}	1.17×10^{-4}	8.55×10^{-5}	1.40×10^{-4}	$1.602 \times 1^{0}-4$	1.40×10^{-4}
Cd	1.32×10^{-3}	1.14×10^{-3}	1.5×10^{-3}	1.92×10^{-3}	4.2×10^{-3}	2.28×10^{-3}	9.6×10^{-4}	2.1×10^{-3}	3.42×10^{-3}	2.05×10^{-3}
As	-	-	-	-	-	-	-	1.5×10^{-3}	6.15×10^{-3}	1.5×10^{-3}
Cr	1.45×10^{-3}	1.60×10^{-3}	1.45×10^{-3}	6.51×10^{-4}	9.52×10^{-4}	8.02×10^{-4}	1.60×10^{-3}	2.51×10^{-4}	1.90×10^{-3}	1.46×10^{-3}
Ni	1.19×10^{-2}	1.34×10^{-2}	1.02×10^{-2}	6.46×10^{-3}	7.48×10^{-3}	9.25×10^{-3}	5.95×10^{-3}	4.25×10^{-3}	1.7×10^{-3}	2.72×10^{-3}

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