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POTENTIAL HEALTH RISK OF SELECTED HEAVY METALS LEVELS; pH, TEMPERATURE, AND CONDUCTIVITY OF GROUNDWATER: A CASE STUDY OF OMI-ADIO AREA, IBADAN, NIGERIA

[†1]Oyeleke, P.O., [2*]Abdulrahman, A.A., [1]Okparaocha, F.J., [3]Abejide, T.B. and [4]Hammed, S.O.

[1]Department of Science Laboratory Technology, Federal College of Animal Health and Production Technology, Moor Plantation, P.M.B 5029, Ibadan, Nigeria

[2]Department of Chemistry, Faculty of Physical Sciences, University of Ilorin, Ilorin, P.M.B 1515, Kwara State, Nigeria

[3]School of Science, College of Science and Engineering, University of Derby, DE221GB, United Kingdom

[4]Department of Chemistry and Industrial Chemistry, Kwara State University, Malete, P.M.B 1530, Ilorin, Kwara State, Nigeria

*Corresponding author: semsodium@gmail.com (+2347061945398)

*ORCID: https://orcid.org/0009-0005-2546-2142

†ORCID: https://orcid.org/0000-0001-7405-2629

ABSTRACT

The concentrations of selected heavy metals, along with pH, temperature, and conductivity, in hand-dug well water were assessed in Omi-Adio, a low-income suburb of Ibadan, Nigeria, where hand-dug wells serve as the primary water source. Twenty water samples were analyzed to assess the quality of drinking water. Heavy metals, including lead (Pb), cadmium (Cd), nickel (Ni), and chromium (Cr), were determined using atomic absorption spectrophotometry. Additionally, pH, temperature, and conductivity were also measured. Pb, Cd, Ni, and Cr concentrations ranged from not detected (ND)–0.77 mg/L, ND–0.03 mg/L, ND–0.13 mg/L, and ND–0.26 mg/L, respectively. Temperature ranged from 29.25–30.00°C, conductivity from 80–932 µS/cm, and pH from 4.97–6.13. Most samples contained one or more metals at varying levels, exceeding World Health Organization guidelines in up to 75% (Pb), 20% (Cd), 20% (Ni), and 70% (Cr) of samples. The low pH values further indicated acidity below the World Health Organization's acceptable limits. Overall mean concentrations followed the decreasing order Pb > Cr > Ni > Cd. The calculated hazard index (HI) indicated potential non-carcinogenic health risks, with Pb > Cr > Cd > Ni. The findings reveal that the groundwater in Omi-Adio is unsuitable for direct consumption without treatment, as prolonged intake poses significant health hazards to humans and animals. Authorities should provide alternative, safe water sources, raise community health awareness, and implement monitoring programs to regularly evaluate groundwater quality and identify pollution sources, thereby ensuring access to safe and potable water.

Keywords: Groundwater, heavy metals, permissible limits, atomic absorption spectrophotometer, WHO

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INTRODUCTION

Groundwater has been described as the water that occupies the spaces created within the geological movements, which could be a result of atmospheric precipitation either directly by rainfall infiltration in the soil or indirectly from streams, rivers, and lakes, which could be accessed through hand-dug wells, hand-pump operated shallow wells and a submersible pump operated deep wells or boreholes (Ojo *et al.,* 2012). The problem of potable water for domestic purposes has been a global issue, and access to clean and potable water is one of the targets of Millennium Development Goals (MDG 6). Today, more than half of the world's population depends on groundwater as the only available source of drinking water (Reddy *et al.,* 2012). Water pollution means the contamination of water bodies such as lakes, rivers, streams, oceans, and groundwater (hand-dug wells and boreholes). Water is a universal solvent with a wide range of uses, irrespective of the source. Water is used for domestic, industrial, agricultural, and general purposes to fit both human, plant and animal needs. The different sources of water pose different risks to human and animal health (Savic *et al.,* 2013). Groundwater is an important source of potable water in developing countries like Nigeria. The availability of a clean drinkable water supply is one major factor that determines the development of a nation, and this is not obtainable in most African countries, where more than 300 million people cannot access clean water (Behailu *et al.,* 2017). Water pollution occurs when contaminants are released to the ground and infiltrate or leach into water bodies, including the aquifer. Water contaminants mainly consist of heavy metals, microorganisms, fertilizers, and toxic organic compounds. Heavy metals can occur in trace amounts in water but are more toxic to the human body if present beyond permissible levels (Mohod and Dhote, 2013; Oyeleke and Okparaocha, 2016). The important sources of heavy metals in developing countries like Nigeria are municipal refuse dumpsites (Adelekan and Alawode, 2011; Adeyi and Oyeleke, 2017), vehicular exhaust, landfill leachates, industrial effluents, and automobile mechanic workshops (Adelekan and Abegunde, 2011). Anthropogenic activities such as painting, mining, chemical production and agricultural activities are also sources of heavy metals (Reddy *et al.,* 2012), as well as geogenic (natural origin) (Rahman *et al.,* 2020). Heavy metals or trace metals persist in the environment, as they are not biodegradable and constitute a natural component (background concentration) of the earth's crust. However, human activities do enrich the soil, which results in higher concentrations of the metals that become toxic to humans due to their bioconcentration, bioaccumulation, and biomagnification in food chains since they are not biodegradable and tend to build up in living bodies. Heavy metals such as Pb, Cu, Cd, Ni, and Cr are potential pollutants in water. Some acute and chronic diseases have been associated with high levels of these heavy metals in humans (Järup, 2003).

Although heavy metals in small quantities are essential for the normal functioning and metabolism of the human body, their excess could be toxic to human health. Nevertheless, heavy metals are not easily degradable biologically or chemically and therefore accumulate for longer periods, causing health deterioration to a considerable level. Humans could be exposed to heavy metals in three main ways, namely, direct ingestion, inhalation, and dermal absorption through exposure to contaminated air and water (US EPA, 1989; Wagh *et al.,* 2018). However, ingestion and dermal absorption are common

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routes for water exposure (Belkhiri *et al.,* 2018).

In Nigeria, ca. 70% of the population depends on groundwater for survival (Isah *et al.,* 2015). This groundwater is sourced through hand-dug wells, which are usually shallow in depth in most cases, ca. 30 – 60 ft or less and are common to low-income residential areas. This depth makes them prone to several sources of pollution easily. In the Omi-Adio community of Ibadan metropolis, the major source of water for general purposes is hand-dug wells due to the low cost of the system, because there is no adequate treated water supply for the community. Proper surface drainage is also lacking, in addition to refuse dumpsites located in the area. There have been comparisons of reports on levels of heavy metals in groundwater with recommended standards over the years. However, this alone is insufficient to quantitatively assess the health risk of toxic metals exposure through the consumption of groundwater. Human health risk assessment mathematical models are introduced to ascertain whether toxic metal exposure could increase the possibility of carcinogenic and non-carcinogenic effects on the health of the population (Alidadi *et al.,* 2019). In the study area, Omi-Adio community, no research has been carried out to the best of our knowledge on the heavy metals contamination of the source of drinking water (groundwater) and its effect on human health.

This study, therefore, aims to assess the levels of selected heavy metals and other physical properties in some of the hand-dug wells in the community and compare the data obtained with the recommended limits. The study also assessed the potential health risk of heavy metals to the human population.

MATERIALS AND METHODS

Description of study area

This study was carried out in the Omi-Adio community, a suburb of Ibadan metropolis in southwestern Nigeria. Ibadan is located between the latitudes 7° 02’49” and 7° 43'21” N, longitudes 3° 31’58” and 4° 08'20” E. Omi-Adio is located between 7° 23’ 23.93’’ N and 3° 45’ 13.20’’ E (Fig. 1). The two major seasons are rainy (March-October) and dry seasons (November-February). Mean annual rainfall was about 1,205 mm, while the mean temperature was 28°C (Egbinola and Amanambu, 2014).

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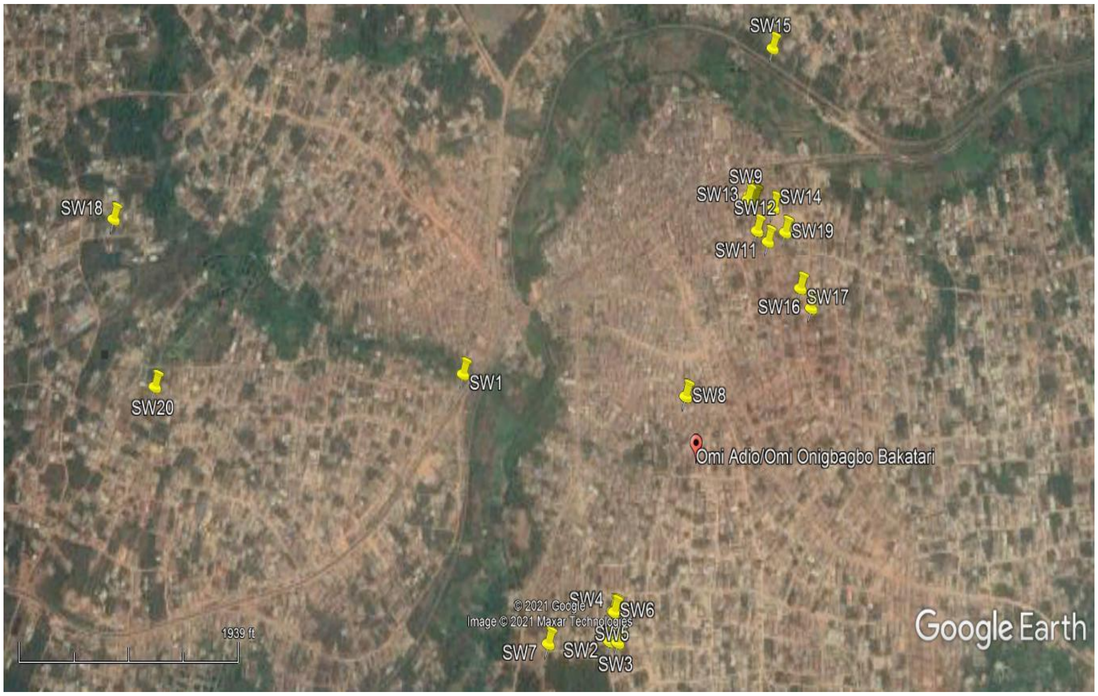

Fig. 1: Map of study area showing sampling locations

Sampling and sample analysis

A total of forty hand-dug well water samples were collected from twenty hand-dug wells in the month of July 2019. Twenty water samples were used for heavy metals analysis using the method described by (Momodu and Anyakora (2010); Oyeleke and Okparaocha 2016), with slight modifications. The remaining twenty water samples were used for the determination of pH, temperature and electrical conductivity using standard analytical methods. A long rope was attached to a pre-cleaned rubber bucket to collect the water after using the bucket to create turbulence inside the well to ensure homogeneity. The coordinates of each sampling point were recorded by a global positioning system (GPS) device (Table 1). The water samples in each well were used to rinse the sample bottles three times before sample collection and were tightly covered immediately to minimize contamination. Each water sample (about 750 mL) was pretreated for heavy metals analysis by adding 1 mL concentrated nitric acid to bring the water pH < 2 and minimize the activity of microbes to maintain the integrity or reliability of the samples. All the water samples were transported to the laboratory in an ice chest for further analysis.

Table 1. The coordinates of sample locations

Sample code	Latitude	Longitude	Location activities	Well cover type
WS1	7°23’28.30’’N	3°44’51.70’’E	Worship centre	Iron

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WS2	7°23'10.10''N	3°45'04.96''E	Barber's shop	Iron
WS3	7°23'10.01''N	3°45'05.70''E	School	Iron
WS4	7°23'12.10''N	3°45'05.47''E	Railway	No cover
WS5	7°23'12.03''N	3°45'05.40''E	Tailor's shop	Iron
WS6	7°23'12.08''N	3°45'05.30''E	Worship center	Iron
WS7	7°23'09.90''N	3°44'59.52''E	Commercial	No cover
WS8	7°23'26.71''N	3°45'12.04''E	Bush	No cover
WS9	7°23'40.68''N	3°45'18.08''E	Roadside	No cover
WS10	7°23'40.65''N	3°45'18.70''E	Block industry	No cover
WS11	7°23'37.62''N	3°45'19.83''E	School	Iron
WS12	7°23'38.41''N	3°45'18.85''E	Residential	Iron
WS13	7°23'40.98''N	3°45'18.22''E	Residential	Iron
WS14	7°23'40.08''N	3°45'20.44''E	Welding work	Iron
WS15	7°23'51.86''N	3°45'20.74''E	Uncompleted building	No cover
WS16	7°23'32.89''N	3°45'23.65''E	Poultry	Iron
WS17	7°23'34.29''N	3°45'22.70''E	Worship centre	Iron
WS18	7°23'39.21''N	3°44'19.30''E	School	Iron
WS19	7°23'38.30''N	3°45'21.45''E	Hairdressing shop	Iron
WS20	7°23'27.36''N	3°44'23.72''E	Worship centre	Iron

Digestion of water samples was carried out with 10 mL of concentrated nitric acid added to 100 mL of the water sample in a beaker. The nitric acid method was preferred for digestion due to good recovery study, cost-effectiveness and time efficiency (Hseu, 2004). The mixture in the beaker was placed on the hot plate in a fume cupboard and heated at about 160°C until the mixture was less than half. The beaker was removed from the hot plate and allowed to cool before filtration through Whatman No.42 filter paper into a 100 cm^3 standard flask, and the mixture was made to the mark with distilled water. The procedure was carried out for all the samples, and analysis of heavy metals (Pb, Cd, Ni, and Cr) was performed in duplicate using an Atomic Absorption Spectrophotometer (210/211 VGP Bulk Scientific, USA). The temperature was determined *in situ* using a mercury-in-glass thermometer (thermometric method) while pH and conductivity were determined by a pH meter (potentiometry) and a conductivity meter (conductimetry), respectively.

All glassware and sampling materials used were thoroughly washed with soap and water, soaked in 0.1% (v/v) nitric acid solution overnight, and rinsed thoroughly with distilled water before the study. A blank sample was prepared and analyzed at intervals of a batch of five samples for results confirmation. All the reagents used for analysis and instrument calibration were analytical reagents (Analar) grade and commercial BDH stock standards.

RESULTS AND DISCUSSION

The results of the heavy metal contents, temperature, and pH of the well water samples in Omi-Adio are presented in Tables 2 and 3. The data gives a summary of the values of the parameters investigated. A comparison of mean levels of heavy metals in groundwater from the study with levels

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obtained in groundwater from other places is presented in Table 6. The pH of the well water sample had a minimum mean value of 4.97±0.07 and a maximum mean value of 6.13±0.19. A pH is the degree of acidity or alkalinity of a substance. In other words, it's the negative log of the hydrogen ion concentration in a substance. Actually, pH, which is regarded as one of the vital water quality parameters in the water bodies system may have no direct health concerns on humans but indirectly, it is the key parameter that brings about or influences considerable changes or alteration in other water quality parameters such as solubility of metal ions and survival of pathogen as well as all biochemical reactions (Muhammad *et al.,* 2011; Behailu *et al.,* 2017). Acidic groundwater can dissolve minerals (Rao and Latha, 2019). The overall mean value of the pH of groundwater in this area was 5.83±0.29. The water samples were slightly acidic, which renders the water unfit for domestic, industrial, and agricultural purposes. Acidic water could cause irritation and stomach disorder, discomfort or upset and cause diarrhea as well as irritation to the skin and eye, mucous membrane cell damage, and acidosis, particularly to children (Rao and Latha, 2019). Acid water can lead to corrosion of water pipes. The low pH could be attributed to the soil formation or rock weathering of the area. The pH values recorded for all the water samples were not within the WHO permissible limit of 6.5 - 8.5 for drinking water (Ojekunle *et al.,* 2020). The values of pH recorded were below the values of 7.1 - 7.9

Table 2. Heavy metal concentrations (mg/L), temperature, pH, and conductivity values in well water samples in Omi-Adio

Sample code	Lead (Pb)	Cadmium (Cd)	Nickel (Ni)	Chromium (Cr)	Temp. (°C)	pH	Cond (μS/cm)
WS1	0.77±0.08	0.01±0.01	ND	0.09±0.12	29.50±0.50	6.08±0.06	932.00±1.20
WS2	ND	0.003±0.01	ND	0.04±0.05	30.00±0.00	6.06±0.05	730.00±0.50
WS3	ND	ND	ND	0.03±0.04	30.00±0.00	5.80±0.01	535.00±1.40
WS4	0.15±0.03	0.01±0.01	ND	ND	30.00±0.00	5.78±0.01	194.00±0.20
WS5	0.21±0.01	ND	ND	ND	30.00±0.00	5.98±0.03	494.00±0.00
WS6	0.05±0.01	ND	ND	0.08±0.07	29.75±0.25	6.00±0.04	451.00±1.10

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WS7	0.11±0.07	ND	ND	0.09±0.03	29.00±0.00	6.13±0.07	495.00±0.20
WS8	0.09±0.01	0.01±0.01	ND	0.04±0.04	30.00±0.00	6.03±0.04	287.00±0.10
WS9	ND	ND	ND	0.03±0.04	30.00±0.00	6.02±0.04	550.00±0.20
WS10	0.23±0.60	ND	ND	0.07±0.01	30.00±0.00	6.12±0.06	353.00±0.00
WS11	0.06±0.11	ND	0.03±0.01	0.10±0.08	30.00±0.00	5.27±0.13	150.00±0.00
WS12	0.70±0.05	0.01±0.01	ND	0.10±0.01	29.00±0.00	4.97±0.19	80.00±1.10
WS13	ND	0.01±0.01	0.01±0.05	0.10±0.02	29.25±0.25	6.03±0.05	565.00±0.10
WS14	0.02±0.01	0.01±0.01	0.01±0.02	0.10±0.09	29.50±0.50	6.05±0.05	346.00±0.50
WS15	0.07±0.01	ND	0.03±0.01	0.19±0.01	29.75±0.25	5.91±0.02	381.00±0.10
WS16	ND	ND	0.03±0.00	0.26±0.04	29.00±0.00	5.60±0.05	147.00±1.20
WS17	0.09±0.05	ND	0.09±0.00	0.19±0.05	30.00±0.00	5.75±0.02	144.00±0.70
WS18	0.17±0.01	ND	0.09±0.00	0.20±0.02	29.00±0.00	5.69±0.03	144.00±0.40
WS19	0.10±0.01	ND	0.12±0.01	0.24±0.02	29.25±0.25	5.74±0.02	147.00±0.90
WS20	0.11±0.10	0.03±0.01	0.13±0.04	0.23±0.01	29.75±0.25	5.63±0.05	145.00±0.00
WHO (2011)	0.01	0.003	0.07	0.05	NA	6.5-8.5	1000.00

NA = Not Available; ND = Not Detected

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obtained at Hardo ward, Bauchi, Nigeria (Isah *et al.,* 2015). The overall pH value was also below the pH value of 5.90±0.32 obtained in groundwater at Ibese, Lagos, Nigeria (WHO, 2011) and pH of 7.4 (range 6.9 – 7.9) from groundwater, south of Setif Area, East Algeria (Belkhiri *et al.,* 2018). Another study also recorded a higher average pH value of 7.69 (range 6.50-8.30) in the dug wells around the industrial area in the Coastal Stretch of Maharashtra State, India (Ayedun *et al.,* 2012). However, the pH values in this study agreed with the values of 4.24 - 6.87 (mean 5.50) recorded in groundwater within the lower Pra Basin of Ghana in the wet season (Naik *et al.,* 2007) and 4.88 – 7.99 obtained in groundwater in crude oil flow stations in the Niger Delta area of Nigeria, Dorleku *et al.,* 2019). The acidic condition could also favor solubility and hence higher concentration of metals, which tend to be more mobile under the acidic condition (Alloway, 1990); Bukar *et al.,* 2012). It has been reported that acidic water results in corrosion of iron and steel materials and clogging of distribution pipes. It causes an objectionable taste in drinks and food and may stain clothes and cause rust in cooking utensils (Agbalagba *et al.,* 2011). Therefore, it could be recommended that the water of some locations with pH values below 6.5 should be treated to increase the values to acceptable limits.

The minimum and maximum mean values of the temperature of water samples recorded were 29.00°C and 30.00°C, respectively. The permissible limit for drinking water has not been set by WHO, but generally, cool water appears more soothing to drink than warm water. The water temperature usually varies depending on the time of day (ambiance). Temperature affects physical, chemical, and biological processes in water bodies. The dissolved oxygen decreases at increased water temperature (Behailu *et al.,* 2017). High water temperatures may enhance micro-organism growth, taste, odour, and colour of water (Dandwate, 2012). The overall mean temperature value of 29.64°C recorded was higher than the mean value of 26.80°C recorded for protected, semi-protected, and unprotected wells investigated in Ibadan, Nigeria (Ayantobo *et al.,* 2013), and higher than the range values of 27.20-28.90°C obtained from Hardo Ward, Bauchi, Nigeria (Isah *et al.,* 2015). This study's temperature was, however, similar to the temperature values of 28.00-30.00°C recorded in the groundwater of an industrial area in India (Rahim and Hussain, 2011). The similarities could be due to the weather conditions of the area at the time of sample collection.

Electrical conductivity is a measure of the ability of an aqueous solution (water) to carry an electric current, which is mostly determined by dissolved solids or the presence of ions. The highest conductivity value in this study was 932 µS/cm, and the lowest value was 80 µS/cm. All the conductivity values obtained for water samples in all the sample locations fall below the WHO permissible limit of 1000 µS/cm for electrical conductivity. This indicates a low total of dissolved particles/solids in the groundwater studied. However, these observed values were much higher than those of 0.396 to 1.554 µS/cm obtained in groundwater around the Konso area, southwestern Ethiopia (Behailu *et al.,* 2017).

Lead (Pb) concentration has a maximum value of 0.77±0.08 mg/L (WS1), while the concentrations were not detectable in some locations (WS2, WS3, WS9, WS13, and WS16). Except for the locations where Pb was below the detection level, all water samples in other locations contain Pb content far above the WHO permissible limit of 0.01 mg/L in drinking water. The maximum value of Pb recorded was higher than the maximum values of 0.020 mg/L and 0.660 mg/L

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recorded in well water in Surulere, Lagos, Nigeria (Momodu and Anyakora, 2010) and groundwater around an irrigated part of the Cauvery River basin, Tamil Nadu, India (Vetrimurugan *et al.,* 2017), respectively. The overall Pb mean value of 0.09±0.07 mg/L (range 0.02- 0.36) was obtained in groundwater of south of Setif Area, East Algeria (Belkhiri *et al.,* 2018), and 0.01 mg/L (range bdl - 0.020) detected in well water in Ibadan, Nigeria (Adelekan and Oguntoso, 2014) were lower than the overall Pb mean value of 0.1±0.21 mg/L (Table 3) recorded in the study. Higher mean Pb content of 1.00 mg/L (range 0.29-1.96) was, however, recorded in the groundwater of Kadava River Basin, Nashik, India (Momodu and Anyakora, 2010) (Table 6). Acute (short-term) Pb poisoning includes headache, irritability, abdominal pain, proximal renal tubular damage, lead encephalopathy (sleeplessness and restlessness, psychosis, confusion, and reduced consciousness), loss of appetite, fatigue, hallucinations, vertigo, renal dysfunction, hypertension, and arthritis. Chronic (long-term) exposure to Pb may cause kidney damage, anemia, diminished intellectual capacity in children (learning and concentration difficulties), lung cancer, stomach cancer, gliomas, birth defects, mental retardation, autism, psychosis, allergies, paralysis, weight loss, dyslexia, hyperactivity, muscular weakness, brain damage, coma and may even cause death (Järup, 2003; Obasi and Akudinobi, 2020).

Cadmium levels in the well water samples ranged from bdl – 0.03 mg/L with an overall mean level of 0.003±0.01 mg/L. Cadmium contents were detected in 8 locations out of the well water samples studied, in which water samples in 4 locations (WS1, WS4, WS12, and WS20) were above the WHO permissible limit of 0.003 mg/L for drinking water. The Cd maximum values of 0.09 mg/L, 0.060 mg/L and 0.05 mg/L were obtained in well water in Surulere, Lagos, Nigeria (Momodu and Anyakora, 2010), in groundwater around an irrigated part of the Cauvery River basin, Tamil Nadu, India (Vetrimurugan *et al.,* 2017), and in groundwater of Kadava River Basin, Nashik, India (Wagh *et al.,* 2018), respectively, and were higher than the maximum value obtained in this study. However, the overall mean Cd content was precisely within the WHO recommended limit for drinking water. Also, in another study, a lower maximum Ni content of 0.02 mg/L (mean 0.03 mg/L) was recorded in well water from Shush and Andimeshk plains, south of Iran (Nouri *et al.,* 2006) (Table 6).

Cd occurs naturally in ores together with zinc, lead, and copper. Cd exposure may cause kidney damage, and long-term high cadmium exposure may cause skeletal damage, first reported in Japan, where the *itai-itai* (ouch-ouch) disease (a combination of osteomalacia and osteoporosis) was discovered in the 1950s (Järup, 2003). Cd tends to be more available in water when the pH is acidic (low). The human body does not excrete Cd, and the body reabsorbs Cd, thereby limiting its excretion. Short-term exposure to Cd can cause lung and respiratory irritation, stomach irritation, vomiting, and diarrhea. Long-term exposure to Cd may lead to Cd deposition in bones and lungs, causing bone and lung damage. Cd causes renal dysfunction and kidney disease, calcium metabolism disturbances, renal stone formation and hypercalciuria (Obasi and Akudinobi, 2020). The International Agency for Research on Cancer (IARC) also classified Cd, along with Pb, as 'probable human carcinogens'.

The highest concentration of Ni in the water samples was 0.13 mg/L at WS20, with an overall mean of 0.03±0.04 mg/L. The study showed that the concentration of Ni in some sample locations (WS17, WS18, WS19 and

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WS20) was higher than the WHO recommended limit of 0.07 mg/L for drinking water. However, Ni contents were not detected in some sample locations, while some well water samples (WS11, WS12, WS13, WS14, WS15 and WS16) recorded Ni levels that fall within the WHO recommendation, including the overall mean Ni content. It was recorded that higher maximum Ni contents of 0.17 mg/L (mean 0.12±0.02) were observed when examining the suitability of groundwater for drinking around an irrigated part of the Cauvery River Basin, Tamil Nadu, India (Vetrimurugan *et al.,* 2017). Similarly, higher Ni concentrations, which range from 0.11 – 0.23 mg/L (mean 0.17 mg/L), were recorded in the groundwater of the Kadava River Basin, Nashik, India (Wagh *et al.,* 2018). However, another study obtained a lower maximum Ni content of 0.08 mg/L (mean 0.03 mg/L) in well water from Shush and Andimeshk plain, south of Iran (Nouri *et al.,* 2006). A study shows that Ni has an extensive range of carcinogenic mechanisms that can regulate transcription factors, control the expression of specific genes and generate free radicals. Ni has been involved in regulating the expression of specific long non-coding ribonucleic acids (RNA) (Obasi and Akudinobi, 2020).

Chromium concentrations ranged from ND – 0.26 mg/L (mean 0.11±0.08 mg/L). Cr was not detected in only two of the water samples studied (WS4 and WS5). All other locations contain higher Cr contents than the WHO permissible limits of 0.05 mg/L for drinking water, except water samples WS2, WS3, WS8 and WS9. The overall mean Cr concentration was also far above the WHO recommended limit. A higher mean Cr content of 1.6 mg/L (range 0.03-3.52 mg/L) was obtained in the groundwater of the Kadava River Basin, Nashik, India (Wagh *et al.,* 2018). The studies showed that the reduction of Cr(VI) to Cr(III) can occur under suitable conditions in the aqueous environment, which is favored under acidic conditions (Kimbrough *et al.,* 1999). Cr(VI) is the most toxic species of Cr, and Cr (III) compounds are much less toxic and cause little or no health problems. Cr(VI) has the tendency to be corrosive and also cause allergic reactions in the body. Therefore, exposure to high levels of Cr(VI) can cause irritation to the lining of the nose and nose ulcers. It can also cause anemia, irritation and ulcers in the small intestine and stomach, damage sperm and the male reproductive system. The allergic reactions due to chromium include severe redness and swelling of the skin. Exposure to extremely high doses of Cr(VI) compounds to humans can result in asthma, cough, shortness of breath, wheezing, severe cardiovascular, respiratory, hematological, gastrointestinal, renal, hepatic and neurological effects and possibly death (Engwa *et al.,* 2018; Obasi and Akudinobi, 2020; Wilbur *et al.,* 2000).

Table 3. Statistical summary of values of the parameters studied

Parameter	Minimum	Maximum	Mean±SD
Pb (mg/L)	ND	0.77	0.15±0.21
Cd (mg/L)	ND	0.03	0.003±0.01
Cr (mg/L)	ND	0.26	0.11±0.08
Ni (mg/L)	ND	0.13	0.03±0.04

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Temp (°C)	29.00	30.00	29.64±0.41
pH	4.97	6.13	5.83±0.29
Cond(µS/cm)	80	932	363.50±229.81

ND = Not detected

Therefore, the levels of heavy metals in the water samples were in order of Pb > Cr > Ni > Cd

Human Health Risk Assessment

Human health risk assessment is defined as the process of estimating the probability of occurrence of an event and the probable magnitude of adverse health effects over a specified time (Punia and Siddaiah, 2017; Belkhiri *et al.,* 2018). The health risk assessment of individual metals is a quantification of the risk level expressed as carcinogenic or non-carcinogenic (US EPA, 2009). The cancer slope factor (CSF) for carcinogenic risk characterization and the reference dose (RfD) for non-carcinogenic risk characterization are the two principal toxicity risk factors (US EPA, 1997). In this study, non-carcinogenic human health risks were calculated through the consumption of heavy metals present in the groundwater of the study area. Hazard Quotient (HQ) and Hazard Index (HI) were measured, and the targeted group of the area was adult individuals. The hazard index (HI) is used for the estimation of a non-carcinogenic risk due to the consumption of groundwater containing various heavy metal ions according to the following equations (US EPA, 1989).

$$\text{LADD} = \frac{\text{C x IR x ED x EF}}{\text{BW x AT}} \qquad (1)$$

where LADD is the lifetime average daily dose of ingestion/direct intake of heavy metal through drinking water (mg/kg/day), C is the concentration of heavy metal in drinking water (mg/L), IR is the ingestion rate of water (2.5 L/day/adult person), EF is the exposure frequency (365days/year), ED is the exposure duration (70 years), BW is the body weight (70 kg/adult person), and AT is the average time (25,550 days i.e. assume 70 years x 365 days/year).

The above could be modified with the assumption that water is consumed every day throughout the year (exposure frequency) for the entire lifespan (exposure duration) of a person. This makes both exposure frequency (EF) and exposure duration (ED) equal to the average time (AT). So, the above equation is modified as:

$$\text{LADD} = \frac{\text{C x IR}}{\text{BW}} \qquad (2)$$

Hazard quotient (HQ) index, US EPA (1989), can then be calculated by the following equation:

$$\text{HQ} = \frac{\text{LADD}}{\text{RfD}} \qquad (3)$$

Eq. 3 could thus be rewritten as:

$$\text{HQ} = \frac{\text{C x IR}}{\text{BW x RfD}} \qquad (4)$$

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where HQ is the hazard quotient, and RfD is the reference dose for a heavy metal that an individual can be exposed to in a day over his/her lifetime without experiencing any deleterious health effects (mg/kg/day) (Vetrimurugan *et al.,* 2017). Table 5 presents the RfD values of various heavy metals analyzed in this study.

The non-carcinogenic risk given by HI is the sum of the HQs calculated for all metals in the study area.

$$HI = \sum_{i=1}^{n} HQ_i = HQ_{Pb} + HQ_{Cd} + HQ_{Ni} + HQ_{Cr} \quad (5)$$

Therefore, for the risk assessment, in case of a mixture of contaminants, the individual HQs are combined to get the hazard index (HI) (eq. 5). Based on calculated HQ/HI values, samples were grouped in different categories of non-carcinogenic health effects i.e. <0.1(very low), ≥ 0.1 < 1 (low), ≥ 1 < 4 (medium) and ≥4 (high) (; US EPA,1999; Punia and Siddaiah, 2017). Thus, HI values ≤ 1 are regarded to be safe, and HI values ≥ 1 indicate the non-carcinogenic risk (Wagh *et al.,* 2018).

Table 4. Hazard Quotient (HQ) indices of heavy metals through drinking water in Omi-Adio area

Location	Pb	Cd	Ni	Cr	HI
WS1	7.61	0.36	0.00	1.07	9.04
WS2	0.00	0.21	0.00	0.42	0.63
WS3	0.00	0.00	0.00	0.36	0.36
WS4	1.48	0.43	0.00	0.00	1.91
WS5	2.08	0.00	0.00	0.00	2.08
WS6	0.49	0.00	0.00	0.95	1.44
WS7	1.13	0.00	0.00	1.01	2.14
WS8	0.84	0.14	0.00	0.54	1.52
WS9	0.00	0.00	0.00	0.30	0.30
WS10	2.27	0.00	0.00	0.89	3.17
WS11	0.55	0.00	0.05	1.25	1.84
WS12	6.98	0.93	0.00	1.13	9.04
WS13	0.00	0.14	0.02	1.13	1.29
WS14	0.22	0.14	0.02	1.19	1.57
WS15	0.67	0.00	0.06	2.26	2.98
WS16	0.00	0.00	0.05	3.04	3.09
WS17	0.90	0.00	0.16	2.26	3.33

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WS18	1.67	0.00	0.16	2.44	4.27
WS19	0.99	0.00	0.22	2.92	4.13
WS20	1.09	2.07	0.24	2.80	6.20
Minimum	0.00	0.00	0.00	0.00	0.30
Maximum	7.61	2.07	0.24	3.04	9.04
Mean	1.45	0.22	0.05	1.30	3.02
SD	2.12	0.49	0.08	0.98	2.51
Total	28.97	4.43	0.97	25.95	60.32

SD = Standard deviation

Table 5. The oral (toxicity) reference dose for heavy metals according to US EPA database

Heavy metal	Reference dose, RfD (mg/kg/day)
Pb	3.6×10^{-3}
Cd	5.0×10^{-4}
Cr	3.0×10^{-3}
Ni	2.0×10^{-2}

Source: (Wagh *et al.,* 2018)

Human Health Risk

A comparison of contaminant levels in drinking water with available standards alone may not be sufficient to ascertain the suitability of drinking water. The hazard index (HI) is a tool to calculate the non-carcinogenic risk, considering that groundwater is consumed by the entire population. The estimated HQ and HI values for each metal in the water sample for each location are presented in Table 4. If HI values ≤ 1, the exposed population is assumed to be safe, while HI values ≥ 1 indicate that the exposed population has a non-carcinogenic risk. This applies to either one or several metals in an area. In this study, the calculated HI indicates that the entire area investigated has a potential human non-carcinogenic risk via consumption of groundwater in the area (Table 4). The minimum and maximum HI calculated were 0.298 and 9.044, respectively, with an overall mean of 3.0±2.5 (Total HI = 60.324). The concentrations of Pb and Cr contributed to higher HI, due to which more potential risk was associated. This corroborated the finding by (Wagh *et al.,* 2018). The order of potential risk as regards HQ values in the area is Pb > Cr > Cd > Ni. As regards individual water sample location, HI values > 1 in all the locations except WS2, WS3 and WS9. WS12 recorded the highest HI value, followed by WS1 and WS20. This indicates that the groundwater in the study area was seriously contaminated with the studied heavy metals (by leaching or infiltration into the ground) through anthropogenic (agricultural and domestic)

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activities as well as natural (geogenic) processes.

Table 6. Comparison of heavy metals mean (range) levels (mg/L) in groundwater from this study with other places

City/Country	Pb	Cd	Ni	Cr	Reference
Kasur, Pakistan	0.14 (0.04-0.26)	0.04 (0.01-0.11)	0.11 (0.08-0.22)	1.32 (0.82-2.25)	(Afzal *et al.*, 2013)
South of Setif, Algeria	0.09 (0.02-0.29)	0.07 (0.01-0.17)	-	-	(Belkhiri *et al.*, 2018)
Ibese, Nigeria	0.01 (ND-0.01)	ND	0.01 (ND-0.01)	-	(WHO, 2011)
Lagos, Nigeria	0.01 (0.00-0.02)	0.02 (0.00-0.09)	-	-	(Momodu and Anyakora, 2010)
Khozestan, Iran	-	0.003 (ND-0.02)	0.03 (0.01-0.08)	-	(Nouri *et al.*, 2006)
Tarapur, India	0.01 (0.01-0.01)	0.01 (0.00-0.01)	-	-	(Ayedun *et al.*, 2012)
Jamalpur, Bangladesh	0.02 (0.00-0.06)	0.01 (0.00-0.03)	-	0.01 (0.00-0.01)	(Zakir *et al.*, 2020)
Kilimambogo, Kenya	42.0 (10.7-121.4)	6.4 (4.4-8.0)	6.9 (ND-16.1)	-	(Nyambura *et al.*, 2010)
Nashik, India	0.10 (0.29–1.96)	0.03 (0.01–0.05)	0.17 (0.11–0.23)	1.60 (0.03–3.52)	(Wagh *et al.*, 2018)
Tamil Nadu, India	0.38 (0.19-0.66)	0.00 (ND-0.06)	0.12 (0.09-0.17)	0.00 (ND-0.02)	(Vetrimurugan *et al.*, 2017)
Meghna Ghat, Bangladesh	0.40 (0.02-0.40)	0.01 (0.00-0.02)	-	0.07 (0.01-0.21)	(Rahman *et al.*, 2020)

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Ibadan, Nigeria	0.15 (ND-0.77)	0.003 (ND-0.03)	0.03 (ND-0.13)	0.11 (ND-0.26)	This study

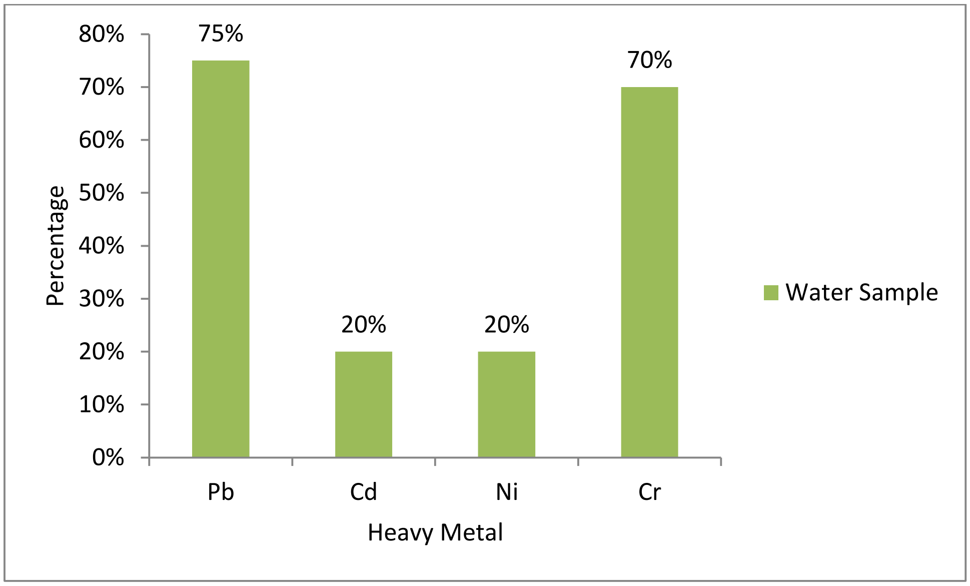

Fig 2. Percentage of water samples with heavy metals above permissible limits

CONCLUSION

This study revealed that the groundwater in the study area is highly contaminated with the heavy metals investigated. The pH of the water was acidic, which could enhance the dissolution and mobility of the metals. Most of the samples analyzed contain heavy metal contents that exceed the WHO recommendations for drinking water. All the water samples contain at least one of the metals studied. The HI calculated indicates that the exposed population in the area has a high potential human non-carcinogenic risk. The contents of Pb and Cr contributed largely to the percentage of HI, which could pose a greater potential risk. The groundwater in the study area was, therefore, not suitable for drinking. A better alternative water supply source, such as treated water, should be provided by the authorities concerned, as well as potential health risk sensitization in the affected area should be made. There should be regular and close monitoring of the quality status of groundwater, as well as further research to find out the sources of groundwater pollution in the area, to ensure good potable water.

CONFLICT OF INTEREST

The authors declared no conflict of interest.

AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all five authors. Oyeleke P.O. designed the study and wrote the protocol. Oyeleke, P.O., Okparaocha, F.J., Abdulrahman, A.A., and Hammed, S.O. managed the literature searches. Also, Oyeleke P.O. and Abejide T.B. wrote the first draft of the manuscript. All five authors contributed to the study's analysis, read, and approved the final manuscript.

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