Limnology and Freshwater Biology 2023 (3): 96-103 DOI:10.31951/2658-3518-2023-A-3-96

Original Article

ISSN 2658-3518
LIMNOLOGY FRESHWATER BIOLOGY
www.limnolfwbiol.com

Assessment of heavy metal content in groundwaters of Ikpe Community, Akwa Ibom State, Niger Delta, Nigeria

Jonah U.E.*, Anyanwu E.D.

Department of Zoology and Environmental Biology, Michael Okpara University of Agriculture, Umudike, Nigeria

ABSTRACT. Accumulation of heavy metals in groundwater system could portend adverse health consequences to users. Heavy metal content of five randomly selected hand dug wells in Ikpe community, Akwa Ibom State, Nigeria was assessed between April and November 2022. The water was evaluated using standard methods and water quality indices to determine its suitability for human consumption. Eight heavy metals were evaluated using Heavy metal Pollution Index (HPI) and Comprehensive Pollution Index (CPI). The results were compared with the National drinking water standard. Results showed that chromium ranged from 0.001 to 0.20 mg/L, cadmium (0.001 - 0.008 mg/L), nickel (0.01-0.08 mg/L), manganese (0.001- 0.6 mg/L), zinc (0.36 -1.90 mg/L), iron (0.1 - 0.8 mg/L), lead (0.001 - 0.02 mg/L) and arsenic (0.00 - 0.004 mg/L). HPI and CPI ranged between 44.62-126.30 and 0.18-1.33, respectively. Concentrations of these heavy metals exceeded acceptable limits, except lead and arsenic. The concentration of the metals from wells 2, 4 and 5 were generally higher and/or had values that exceeded acceptable limits. This could be attributed with geogenic and anthropogenic influences as well as the general conditions of the wells and their environment. The water quality indices (HPI and CPI) showed varying levels of heavy metal pollution in line with the heavy metal concentrations. Consequently, it can be concluded that water from wells 2, 4 and 5 is not suitable for human consumption, and it can be used for other purposes.

Keywords: Heavy metal, assessment, groundwater, anthropogenic, HPI, CPI

1. Introduction

Globally, groundwater is an indispensible resource; providing the largest reservoir of freshwater with exception of the ice caps (WWQA, 2021). The chemical quality of groundwater is influenced by a number of natural factors like the structure of the geology, lithology and geochemical processes etc. that can work together to degrade its quality (Hassen et al., 2016). However, groundwater can also be degraded from contaminants introduced into the environment from human activities (Zakaria et al., 2020). Yan et al. (2019) observed that heavy metal contamination of groundwater is a complex problem requiring urgent attention.

Heavy metal contamination of groundwater comes from a number of anthropogenic activities like agriculture, industrial activities, mining and indiscriminate dumping of wastes, etc. (Manisalidis et al., 2020; Agrawal et al., 2021; Zhai et al., 2022; Jonah et al., 2023a). Heavy metal contamination of water is associated with huge medical and health implications (Akhilesh et al., 2009). Naturally, groundwater is protected from pollution; as a result it has an advantage over other sources when it comes to drinking water supply (WWQA, 2021). Traditionally, water quality assessment is done by comparing the observed parameters with national and international standards, which may provide limited information on the quality of the water (Xia et al., 2018; Davoudi Moghaddam et al., 2021). However, it is sometimes difficult to draw meaningful inferences on the quality of the water when large number of parameters is involved under varying natural and anthropogenic influences. Hence, the need to introduce water quality indices that is capable of aggregating and reducing large amount of water quality data into a simple and single value (Aljanabi et al., 2021). Water quality and its suitability for human consumption can be assessed using a number of indices like heavy metal pollution index and comprehensive pollution index. Researchers have used these indices to evaluate the overall quality of water for different purposes (Anyanwu et al., 2020; Anyanwu et al., 2022a, b; Prasad et al., 2022; Jonah et al., 2023b).

*Corresponding author.
E-mail address: udemejonah@gmail.com (U.E. Jonah)

Received: June 19, 2023; ***Accepted:*** June 26, 2023;
Available online: June 27, 2023

In Nigeria, greater portion of the population's drinking and domestic water needs are provided by boreholes and hand-dug wells (Okareh et al., 2023). Therefore, the assessment of groundwater quality is very important (Ajibade et al., 2011). Hence, this study is aimed at assessing the heavy metal content of some groundwater sources in Ikpe Community, Akwa Ibom State, Nigeria vis-à-vis its suitability for human consumption.

2. Materials and methods

2.1. Description of study area

Ikpe community is made up of many villages with Ikot Nton, Mbiabet, Nkana, Itie Ikpe being prominent. The community is located in the coastal area of Ini local Government Area, Akwa Ibom State, South-South Nigeria (Fig. 1). The inhabitants of these villages are engaged in fishing, agricultural, sand and gravel mining activities. The community depends on hand dug wells as major source of water for drinking and other domestic purposes because pipe-borne water are lacking due to the terrain of the area.

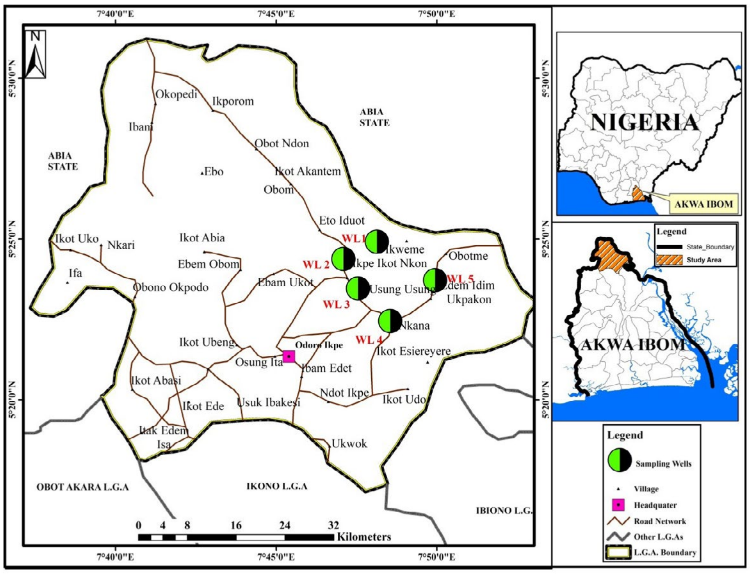

Fig.1. Sampling wells in Ikpe community, Ini L.G.A., Akwa Ibom State, Nigeria

2.2. Sampling Points

Five hand dug wells were randomly selected for this study. Well 1 (Latitude 5°23'29.494N and Longitude 7°46'47.718E) was located in Ikpe Ikot Nkon, within the vicinity of Holy Catholic Church and covered with rusted metal (Fig.2). The water is extracted for domestic use with underground water pump into plastic storage water tanks. No human activities were observed during the study. Well 2 (Latitude 5°23'36.918N and Longitude 7°47'6.498E) was also located in Ikpe Ikot Nkon. The well was located behind a roadside market, and automobile workshops with high surface runoffs. The well was properly constructed but not covered (Fig.2).The well water was extracted for domestic use by the people using a plastic bucket. Wastes generated from the market were discarded into a stream beside the well. Well 3 (Latitude 5°23'45.33N and Longitude 7°47'22.873E) is also located in Ikpe Ikot Nkon. The well was properly constructed and had a wooden cover (Fig.2). No human activities were observed during the study. Well 4 (Latitude 5°22'50.496 North and Longitude 7°47'53.49 East) was located in Itie Ikpe. The well was properly constructed but the edge was at the ground level, uncovered and unkempt (Fig.2). The area is low-lying and experience high runoff during the wet season. The well was located adjacent a wetland where rice and other

Fig.2. Images of studied wells

crops were cultivated. Well 5 (Latitude 5°22'37.028N and Longitude 7°48'22.086E) was also located in Itie Ikpe. The well was properly constructed but the edge was at the ground level, uncovered with some grasses around the edge (Fig.2). The area is also low-lying and experience high runoff during the wet season. The well was located adjacent a wetland where rice and other crops were cultivated; domestic wastes are dump very close to the wetland.

2.3. Samples collection, data analyses and quality control

Water samples for the heavy metals analysis were collected between April 2022 and November 2022 (eight months). The samples were collected monthly with 500 mL polyethylene bottles and acidified with Nitric acid (HNO3). The sampling containers were cleaned with detergent, rinsed with tap water until they were free of detergent and dried in sun rays. The containers were rinsed three times with well water samples before collection. Each sample was collected by submerging the sampling bottle into each hand dug well below the surface with the aid of a PVC pole.

The samples collected were transported on ice chest to the laboratory. The water samples were digested according to standard laboratory procedure. After digestion, eight heavy metals - chromium (Cr), cadmium (Cd), Nickel (Ni), Manganese (Mn), Zinc (Zn),Iron (Fe), Lead (Pb) and Arsenic (As) were analyzed using Unicam Atomic Absorption Spectrophotometer (939/959 model). For quality control, blanks and samples duplicates were included in the heavy metals analytical process. All data were summarized with Microsoft Excel. Single factor ANOVA was used to determine significant differences between the means while Tukey Pairwise posthoc was used to determine the source of variation. $P < 0.05$ was considered as significant.

2.4. Water quality assessment

Water quality assessment was carried out using heavy metal pollution index (HPI) and comprehensive pollution index (CPI).

Heavy metal pollution index (HPI)

The index based on weighted arithmetic mean method was described by Prasad and Bose (2001) based the formula developed by Mohan et al. (1996). The overall water quality in relation to heavy metal concentration has been evaluated with the index (Horton, 1965; Mohan et al., 1996). To compute HPI, unit weightage (Wi) was considered as a value inversely proportional to the recommend standard (Si) for each metals (Prasad and Bose, 2001). The HPI was calculated using the formula:

$$\mathrm{HPI} = \sum \frac{Qi \cdot Wi}{\sum Wi} \quad (1)$$

where, Qi is the sub-index of i-th heavy metals and Wi is the unit weightage of the i-th parameters. The Qi is calculated with the equation below:

$$\mathrm{Qi} = 100 \cdot \frac{Ci}{Si} \quad (2)$$

where, Ci is the measured value of i-th parameter and Si is the standard limit of i-th parameter set by FMEnv (2011). The acceptable range for HPI is 100 for drinking water (Mohan et al., 1996; Prasad and Bose, 2001); any value above 100 is not fit for human consumption.

Comprehensive pollution index (CPI)

The index provides vital information about water quality for effective management. All investigated heavy metals were used to calculate the CPI using the formula below:

$$\mathrm{CPI} = \frac{1}{n} \sum_{i=0}^{n} \mathrm{Pl}i \quad (3)$$

where, n is the number of considered heavy metals and PIi is the pollution index number i. The PIi is calculated using the equation:

$$\mathrm{Pl}i = \frac{Ci}{Si} \quad (4)$$

where, Ci is the concentration of each heavy metal and Si is the acceptable limit for each heavy metal recommended by WHO (2017). The CPI was classified based on Matta et al. (2018) as > 0.21 (clean water), 0.21 – 0.40 (sub-clean water), 0.41 – 1.00 (slightly polluted water), 1.01 – 2.00 (moderately polluted water) and >2.01 (heavy polluted water).

3. Results and Discussion

The summary of the heavy metal results is presented in Table 1. The Cr values ranged from 0.001 to 0.20 mg/L. The lowest was recorded in Well 1 while the highest was in Well 5. The mean values recorded in Wells 4 (0.067 mg/L) and 5 (0.073mg/L) exceeded acceptable limit (0.05 mg/L) set by FMEnv (2011) and were significantly ($p < 0.05$) higher than the others.

This could be attributed to the well construction, lack of cover and general sanitation of the wells. Runoffs laden with inorganic and organic chemicals can also discharge into the well during the wet season because their edges were on the ground level. Wells 1 – 3 had significantly lower values probably because they were well constructed with edges above ground level and covered; though well 2 was not covered. Folorunsho et al. (2022) recorded values (0.00 – 0.006 mg/L) within this study range in hand dug wells around dumpsites in Okene, Kogi State, Nigeria. This could be due to the geology of the area and season because value up to 0.019 mg/L was recorded in the leachates. However, higher values were recorded in related studies in Nigeria. Jagaba et al. (2020) recorded 0.01 – 0.25 mg/L in Rafin Zurfi, Bauchi State, Nigeria and Ogbonna et al. (2022) recorded 0.01 – 0.21 mg/L in Ibadan, Nigeria. Jagaba et al. (2020) attributed the high Cr values recorded to improper waste disposal and community markets.

The Cd values ranged from 0.001 to 0.008 mg/L. The highest values were recorded in Wells 4 and 5 while the lowest were recorded in Wells 1 – 3. The

Table 1. The mean, range values of heavy metals and pollution indices recorded during the study period

Heavy metals (mg/L)	STATION 1 X ±S.E.M	STATION 2 X ±S.E.M	STATION 3 X ±S.E.M	STATION 4 X ±S.E.M	STATION 5 X ±S.E.M	FMEnv (2011)
Cr	0.002±0.0004[a] (0.001 - 0.004)	0.002±0.0003[a] (0.002 - 0.004)	0.006±0.0005[a] (0.005 – 0.009)	0.067±0.011[b] (0.04 – 0.12)	0.073±0.02[b] (0.02 – 0.20)	0.05
Cd	0.001±0.0002[a] (0.001 – 0.002)	0.002±0.0003[ab] (0.001 – 0.003)	0.002±0.0004[ab] (0.001 – 0.004)	0.004±0.0008[bc] (0.002 – 0.008)	0.005±0.0007[c] (0.003 – 0.008)	0.003
Ni	0.037±0.005[ab] (0.02 – 0.06)	0.053±0.0086[b] (0.02 – 0.08)	0.032±0.0053[ab] (0.02 – 0.06)	0.036±0.0077[ab] (0.02 – 0.08)	0.023±0.005[a] (0.01 – 0.05)	0.02
Mn	0.004±0.0007[a] (0.001 – 0.009)	0.312±0.058[b] (0.02 – 0.6)	0.003±0.00036[a] (0.002 – 0.005)	0.187±0.053[c] (0.01 – 0.3)	0.275±0.052[c] (0.1 – 0.6)	0.2
Zn	0.652±0.057[a] (0.36 – 0.83)	0.985±0.163[ab] (0.43 – 1.70)	1.118±0.148[b] (0.67 – 1.90)	0.582±0.057[a] (0.37 – 0.82)	0.967±0.093[ab] (0.65 – 1.40)	3.0
Fe	0.362±0.038 (0.2 – 0.8)	0.312±0.035 (0.2 – 0.5)	0.25±0.033 (0.1 – 0.4)	0.375±0.075 (0.1 – 0.8)	0.35±0.05 (0.2 – 0.6)	0.3
Pb	0.002±0.0003[a] (0.001 – 0.004)	0.028±0.0029[b] (0.02 – 0.04)	0.003±0.0005[a] (0.002 – 0.006)	0.003±0.0007[a] (0.001 – 0.006)	0.002±0.0002[a] (0.002 – 0.003)	0.01
As	ND	ND	ND	0.002±0.0005 (0.00 – 0.004)	0.003±0.0004 (0.001 – 0.005)	0.01
HPI	**44.62**	**126.30**	**65.89**	**100.06**	**112.86**	
CPI	**0.48**	**1.33**	**0.55**	**0.90**	**0.98**	

Note: X = mean, ±S.E.M = standard error of mean; a, b, c = means with different superscripts in the same row are significantly difference at $P < 0.05$; ND = Not detected; FMEnv = national environmental (surface and groundwater quality control) regulation (2011).

highest mean value (0.005 mg/L) was recorded in Well 5 while the lowest (0.001 mg/L) was recorded in well 1. Well 5 was significantly ($p < 0.05$) higher than Well 1-3 while Well 4 was significantly ($p < 0.05$) higher than Well 1. The mean values recorded in Wells 4 and 5 exceeded the acceptable limit (0.003 mg/L) set by FMEnv (2011). This trend was observed in Cr and could be attributed to the same factors. Higher values were recorded in related studies in Nigeria. Folorunsho et al. (2022) recorded values (0.003 – 0.054 mg/L) in hand dug wells around dumpsites in Okene, Kogi State, Nigeria, Ogbonna et al. (2022) recorded 0.01 – 0.23 mg/L in Ibadan, Nigeria and Tsor et al. (2022) recorded 0.007 – 0.015 mg/l in Makurdi, Benue State, Nigeria. Cd is the most toxic element, their presence in drinking water accompanied with deleterious effects on human. Durmishi et al. (2016) reported hypertension, kidney damage and potential prostate cancer in humans subjected to extreme exposure of Cd in contaminated water.

Nickel (Ni) ranged from 0.01 to 0.08 mg/L. The values were generally high in all the wells irrespective of the well conditions. The highest values were recorded in Wells 2 and 4 while the lowest was recorded in Well 5. Well 2 was significantly ($p < 0.05$) higher than well 5. All the mean values exceeded the acceptable limit (0.02 mg/L) set by FMEnv (2011). This could be attributed to geogenic effect exacerbated by anthropogenic effects especially in wells 2 and 4 (Ullah et al., 2022). Geogenic contamination is the natural occurrence of some elements in groundwater at elevated levels above acceptable limits with potential of adverse health effect (CGWB, 2014). Higher values were also recorded in related studies in Nigeria. Folorunsho et al. (2022) recorded values (0.00 – 0.016 mg/L) in hand dug wells around dumpsites in Okene, Kogi State, Nigeria, Jagaba et al. (2020) recorded 0.00 – 0.22 mg/L in Rafin Zurfi, Bauchi State, Nigeria, Ogbonna et al. (2022) recorded 0.25 – 1.30 mg/L in Ibadan, Nigeria and Tsor et al. (2022) recorded 0.00 – 0.016 mg/L in Makurdi, Benue State, Nigeria. According to Salem et al. (2000), cardiovascular and kidney diseases in humans are associate with intake of Ni contaminated water. Other medical consequence associated with Ni toxicity includes skin allergies; lung fibrosis and cancer of the respiratory tract (Kasprzak et al., 2003).

The values of Mn ranged between 0.001 and 0.6 mg/L. The highest values were recorded in Wells 2 and 5 while the lowest was in well 1. Wells 2, 4 and 5 were significantly higher than wells 1 and 3; though well 4 was within acceptable limit. This could be attributed to geogenic effect exacerbated by anthropogenic activities (market and mechanic workshops); well 2 had the highest mean value (0.312 mg/L). Elsewhere in Nigeria, Folorunsho et al. (2022) recorded lower values (0.00 – 0.002 mg/L) in hand dug wells around dumpsites in Okene, Kogi State, Nigeria and Jagaba et al. (2020) recorded 0.00 to 0.45 mg/L in Rafin Zurfi, Bauchi State, Nigeria. However, Ogbonna et al. (2022) recorded higher values (0.20 – 0.75 mg/L) in Ibadan, Nigeria and Tsor et al (2022) recorded 0.04 – 0.61 mg/L in Makurdi, Benue State, Nigeria. Mn is a known human neurotoxin especially when the concentrations exceed the standard limit in drinking water and food (Alikunju et al., 2023). One of the unusual neurotoxic conditions is the hypermanganesemia-induced cerebral toxicity (Reinert et al., 2021). The presentation of the condition include Parkinsonian-like syndrome (manganism), neuropsychiatric symptoms and stroke mimic that is very rare (Bouabid et al., 2016).

The concentrations of zinc were within the acceptable limit (3.0 mg/L) set by FMEnv (2011); ranging between 0.36 and 1.90 mg/L in the wells. The values were relatively high but well 3 was significantly ($p < 0.05$) higher than wells 1 and 4. This could be attributed to geogenic influence. Elsewhere in Nigeria, Folorunsho et al. (2022) recorded lower values (0.003 – 0.054 mg/L) in hand dug wells around dumpsites in Okene, Kogi State, Nigeria and Tsor et al. (2022) recorded 0.08 – 0.50 mg/L in Makurdi, Benue State, Nigeria while Jagaba et al. (2020) recorded values (0.14 – 1.90 mg/L) within the range of this study in Rafin Zurfi, Bauchi State, Nigeria. Zinc is an important mineral element to man; prenatal growth of human associated with intake of Zn in normal concentration (Mahipal et al., 2019). Adverse effect in humans occurs when Zn is deficient or excess in concentration. In children, low concentration of zinc is associated with poor development of brain, and vulnerability to infections (Dutta and Sarma, 2015) while higher concentration affects bone development and normal function of reproductive organ in man (Bytyçi et al., 2018).

Iron (Fe) ranged between 0.1 and 0.8mg/L without any significant ($p > 0.05$) difference among the wells. The highest values were recorded in wells 1 and 4 while the lowest were recorded in wells 3 and 4. All mean values exceeded the acceptable limit (0.3 mg/L) set by FMEnv (2011) except in well 3, suggesting geogenic influence. Okiongbo et al. (2020) observed that Fe concentrations in excess of acceptable limit (>0.03 mg/L) is very common in groundwaters of the Niger Delta. A range of 0.0 – 6.2 mg/L was recorded in groundwaters from 60 locations in eastern Niger Delta by Abam and Nwankwoala (2020) though lower values - 0.005 – 0.738 mg/L and 0.18 – 0.28 mg/L were recorded elsewhere in Akwa Ibom State by Etesin et al. (2021) and Umana et al. (2022) respectively. Jagaba et al. (2020) equally recorded lower values (0.01 - 0.41 mg/L) in northern Nigeria (Rafin Zurfi, Bauchi State). Zhang et al. (2003) pointed that acute exposure to Fe come with neurological dysfunction, while Musa et al. (2013) reported that chronic intake of Fe is associated with gastrointestinal irritation, which could led to high growth of Iron bacteria.

Lead (Pb) ranged between 0.001 and 0.02 mg/l. The highest value was recorded in well 2 and the lowest were in wells 1 and 4. All the values were within the acceptable limit (0.01 mg/l) set by FMEnv (2011) except in well 2 where all the values exceeded limit and significantly ($p < 0.05$) different from the other wells. This could be attributed to anthropogenic influence (wastes from the roadside market and automobile workshops) and well condition. Well 2 was well constructed but had no cover which could predispose it to wet and dry atmospheric depositions (Singh et al., 2022). High values were recorded elsewhere in Nigeria, Folorunsho et al. (2022) recorded 0.00 – 1.60 mg/L in hand dug wells around dumpsites in Okene, Kogi State, Nigeria, Jagaba et al. (2020) recorded 0.01 - 0.87 mg/L in Rafin Zurfi, Bauchi State, Nigeria and Ogbonna et al. (2022) recorded higher values (0.00 – 2.64 mg/L) in Ibadan, Nigeria. However, Pb was not recorded by Tsor et al. (2022) in Makurdi, Benue State, Nigeria. Lead (Pb) is both a toxic and non-essential heavy metal that contributes no nutritional value to living organisms, including humans (Balali-Mood et al., 2021). Pb is injurious even at low concentration in drinking water (Mahipal and Rajeev, 2019). High exposure to lead toxicity is associated with poor coordination of brain, central nervous system and kidney dysfunction (Sanders et al., 2009; Collin et al., 2022). Jonah et al. (2023b) documented that lead toxicity in adult causes constipation and anemia while in children; it causes noxiousness and dysfunction of central nervous system.

The arsenic (As) values ranged between 0.00 and 0.004 mg/L and was recorded only in Wells 4 and 5. These values were lower than the acceptable limit (0.01 mg/L) set by FMEnv (2011). The arsenic values recorded could be attributed to pesticides and fertilizers used in the rice farms around the wells. Studies have shown that fertilizers and agrochemicals are sources of arsenic in groundwater (Ogunkolu et al., 2018; Islam and Mostafa, 2021). Elsewhere in Nigeria, higher values were recorded. Ogunkolu et al. (2018) recorded 0.20 – 0.25 mg/L in wells in Asa Local Government Area, Kwara State, Nigeria, Abubakar et al. (2021) recorded 0.00 – 0.02 mg/L in New Panteka Area, Kaduna, Kaduna State, Nigeria and Mshelia and Bulama (2023) in Kano Metropolis, Kano State, Nigeria. Arsenic is a known carcinogen and toxic at low levels; making its presence in drinking water hazardous (USGS, 2019). Diseases associated with arsenic poisoning include spots on the skin, high blood pressure, diabetes, cancers of the skin, urinary bladder, kidney and lungs (Prakash and Verma, 2021).

Heavy metal pollution index (HPI) and comprehensive pollution index (CP1) has been used to evaluate the overall quality of water for different purposes (Anyanwu and Umeham, 2020; Anyanwu et al., 2020; Anyanwu et al., 2022a, b; Prasad et al., 2022; Jonah et al., 2023b).

The HPI and CPI values are also presented in Table 1. The HPI values ranged from 44.62 to 126.30. The highest was recorded in well 2 while the lowest was in well 1. This could be attributed combined effects of anthropogenic activities and well conditions; reflecting the concentrations of heavy metals in the study area. The HPI value recorded in wells 2, 4 and 5 exceeded the threshold and critical index value (100), indicating moderate metallic contamination (Mohan et al., 1996; Prasad and Bose, 2001). Higher HPI values were recorded elsewhere in Nigeria. Kwaya et al. (2019) recorded extremely high values (2.93 - 19572) in groundwater (boreholes and wells) in Maru Town and environs in Zamfara State, Nigeria and Abubakar Kana (2022) recorded 64.72 – 379.86 in groundwater (boreholes and wells) in Tudun Wada town, Karu, Central Nigeria.

On the other hand, CPI values ranged between 0.48 and 1.33; following the same trend as HPI. The highest value was recorded in Well 2 while the lowest was in well 1; attributed to the same factors. According to Matta et al. (2018), Wells 1, 3 – 5 were classified as slightly polluted while well 2 was classified as moderately polluted. CPI has been previously applied in the assessment of surface water in Nigeria (Anyanwu et al., 2022a; Jonah et al., 2023b) with good results. It has helped in drawing a reliable inference on the water quality of the wells assessed in respect to heavy metal concentrations.

4. Conclusion

All the heavy metals evaluated had values that exceeded acceptable limits except lead and arsenic. Wells 2, 4 and 5 recorded values that were generally higher and/or had values that exceeded acceptable limits. This could be attributed to geogenic and anthropogenic influences as well as the general conditions of the wells and their environment. The water quality indices (HPI and CPI) showed varying levels of heavy metal pollution. Consequently, it can be concluded that water from wells 2, 4 and 5 is not suitable for human consumption. However, it can be used for other purposes.

5. Acknowledgments

The authors thank Mr Utibe Usanga for assisting in map production.

Conflict of interests

The authors declare that they have no competing interests.

References

Abam T., Nwankwoala H. 2020. Hydrogeology of Eastern Niger Delta: A Review. Journal of Water Resource and Protection 12: 741-777. DOI: 10.4236/jwarp.2020.129045

Abubakar A.A., Bashir M.A., Gambo J. 2021. Assessment of Heavy Metals in Groundwater at New Panteka Area of Kaduna, Nigeria. International Journal of Engineering Research & Technology 10(9): 604 – 607.

Abubakar Kana A. 2022. Heavy metal assessment of groundwater quality in part of Karu, Central Nigeria. Water Practice & Technology 17(9): 1802-1817. DOI: 10.2166/wpt.2022.102

Agrawal P.R., Singhal S., Sharma R. 2021. Heavy Metal Contamination in Groundwater Sources. In: Madhav, S. and Singh, P. (Eds). Groundwater Geochemistry: Pollution and Remediation Methods. John Wiley & Sons Ltd. (57 – 78). DOI: 10.1002/9781119709732.ch4

Ajibade O.M., Omisanya K.O., Odunsi G.O. 2011. Groundwater portability and flow direction of urban aquifer, Ibadan, Southwestern Nigeria. Journal of the Nigerian Association of Hydrologists 21: 38 – 55.

Akhilesh J., Savita D., Suman M. 2009. Some trace elements investigation in groundwater of Bhopal and Sehore District in Madhya Predesh, India. Journal of Applied Science and Environmental Management 13 (4): 47 - 50.

Alikunju M., Misiriyyah N., SayeedIqbal S., Khan M. 2023. Manganese Neurotoxicity as a Stroke Mimic: A Case Report. Cureus 15(4): e37247. DOI:10.7759/cureus.37247

Aljanabi Z.Z., Al-Obaidy A.M.J., Hassan F.M. 2021. A brief review of water quality indices and their applications. IOP Conf. Series: Earth and Environmental Science 779: 012088. DOI: 10.1088/1755-1315/779/1/012088

Anyanwu E.D., Adetunji O.G., Nwachukwu E.D. 2020. Application of pollution indices and health risk assessment in the heavy metal content of a South-Eastern Nigeria river. Pollution 6 (4): 909-92. DOI: 10.22059/poll.2020.303140.820

Anyanwu E.D., Adetunji O.G., Nwoke O.B. 2022b. Heavy metal content of water in Ikwu River (Umuahia, Nigeria): pollution indices and health risk assessment approach. Acta Aquatica Turcica 18(3): 345-358. DOI: 10.22392/actaquatr.1060806

Anyanwu E.D., Umeham S.N. 2020. An index approach to heavy metal pollution assessment of Eme River, Umuahia, Nigeria. Sustainability, Agriculture, Food and Environmental Research, 8 (x). DOI: 10.7770/safer-VONO-art2067

Anyanwu E.D., Jonah U.E., Adetunji O.G., Nwoke O.B. 2022a. An appraisal of the physicochemical parameters of Ikwu River, Umuahia, Abia State in Southeastern, Nigeria for multiple uses. International Journal of Energy and Water Resources 2022. DOI: 10.1007/s42108-021-00168-8.

Balali-Mood M., Naseri K., Tahergorabi Z., Khazdair M. R., Sadeghi M. 2021. Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic. Frontiers in Pharmacology 12: 643972. DOI: 10.3389/fphar.2021.643972

Bouabid S., Tinakoua A., Lakhdar-Ghazal N., Benazzouz A. 2016. Manganese neurotoxicity: behavioral disorders associated with dysfunctions in the basal ganglia and neurochemical transmission. Journal of Neurochemistry 136: 677-691. DOI: 10.1111/jnc.13442

Bytyçi P., Fetoshi O., Durmishi B. H. et al. 2018. Status assessment of heavy metals in water of the Lepenci River Basin, Kosova. Journal of Ecological Engineering 19(5): 19-32. DOI: 10.12911/22998993/91273

CGWB. 2014. Concept note on Geogenic contamination of ground water in India (with a special note on Nitrate).Central Ground Water Board, Ministry of Water Resources, Faridabad, India. 99pp. https://cgwb.gov.in/WQ/Geogenic%20Final.pdf

Collin M.S., Venkatraman S.K., Vijayakumar N. et al. 2022. Bioaccumulation of lead (Pb) and its effects on human: A review. Journal of Hazardous Materials Advances 7: 100094. DOI: 10.1016/j.hazadv.2022.100094

Davoudi Moghaddam D., Haghizadeh A., Tahmasebipour N. et al. 2021. Spatial and temporal water quality analysis of a semi-arid river for drinking and irrigation purposes using Water Quality Indices and GIS. Ecopersia 9(2): 79-93.

Durmishi B. H., Abduli S., Reka A.A. et al. 2016. Determination of the content of zinc, copper, lead, and cadmium in the River Shkumbini (Pena) with potentiometric stripping analysis. International Journal of Chemical Material Science 1(1):17-32.

Dutta D., Sarma H.P. 2015. Copper (Cu), Zinc (Zn), and Cadmium (Cd) contamination of groundwater in Dikrong River Basin, Paumpare District, Arunachal Pradesh, India. IOSR Journal of Environmental Science, Toxicology and Food Technology 9 (Ver. II): 20-23

FMEnv. 2011. National Environmental (Surface and Groundwater Quality Control) Regulations, S.I No. 22, Gazette, No. 49, Vol. 98 of 24th May 2011. Federal Ministry of Environment, Abuja, Nigeria.

Folorunsho O.S., Ojo A.A., Ayorinde A.M. et al. 2022. Analysis of Trace Metals in Hand Dug Wells around Dumpsites in Okene Metropolis, Nigeria. Journal of Sustainability and Environmental Management 1(2):136-143.

Hassen I., Hamzaoui-Azaza F., Bouhlila R. 2016. Application of multivariate statistical analysis and hydrochemical and isotopic investigations for evaluation of groundwater quality and its suitability for drinking and agriculture purposes: case of Oum Ali-Thelepte aquifer, central Tunisia. Environmental Monitoring and Assessment, 188: 20. DOI: 10.1007/s10661-016-5124-7

Horton R.K. 1965. An index system for rating water quality. Journal of the Water Pollution Control Federation 27(3): 300-315.

Islam M.S., Mostafa M.G. 2021. Influence of chemical fertilizers on arsenic mobilization in the alluvial Bengal delta plain: a critical review. AQUA - Water Infrastructure, Ecosystems and Society 70 (7): 948–970. DOI: 10.2166/aqua.2021.043

Jagaba A.H., Kutty S.R.M., Hayder G. et al. 2020. Water quality hazard assessment for hand dug wells in RafinZurfi, Bauchi State, Nigeria. Ain Shams Engineering Journal, 11: 983–999. DOI: 10.1016/j.asej.2020.02.004

Jonah U.E., Ekpo I.E., Oribhabor B.J. et al. 2023a. A review of pollution and its effect on community health in Nigeria. In: Ayandele I.A., Udom G. N., Effiong E.O., Etuk U.R., Ekpo I.E., Inyang U.G., Edet G.E. and Moffat I.N. (Eds). Contemporary Discourse on Nigeria's Economic Profile: A Festschrift in Honour of Prof. Nyaudo, U. Publication of University of Uyo, Uyo, Akwa Ibom State. pp. 523 - 350.

Jonah U.E., Mendie C.F., Asuquo U.G. 2023b. Ecological and health risk assessment of trace metals in waters from North-West Zone of Akwa Ibom State, Nigeria. Pollution 9 (1): 271 – 285. DOI: 10.22059/POLL.2022.345817.1538

Kasprzak K.S., Sunderman F.W., Salnikow K. 2003. Nickel carcinogenesis. Mutation Research 533 (1-2): 67 - 97.

Kwaya M.Y., Hamidu H., Mohammed A.I. et al. 2019. Heavy metals pollution indices and multivariate statistical evaluation of groundwater quality of Maru town and environs. Journal of Materials and Environmental Sciences 10 (1): 32-44

Mahipal S.S., Rajeev K., Lalit P. 2019. Zinc impurity in drinking water and its toxic effect on human health. Indian Internet Journal of Forensic Medicine & Toxicology 17(4): 84 – 87

Manisalidis I., Stavropoulou E., Stavropoulos A. et al. 2020. Environmental and health impacts of air pollution: A review. Frontiers in Public Health 8: DOI: 10.3389/FPUBH.2020.00014

Matta G., Naik P.K., Machell J. et al. 2018. Comparative study on seasonal variation in hydro-chemical parameters of Ganga River water using comprehensive pollution index at Rishikesh, India. Desalination and Water Treatment 118: 87-95.

Mohan S.V., Nithila P., Reddy S.J. 1996. Estimation of heavy metals in drinking water and development of heavy metal pollution index. Journal of Environmental Science and Health, Part A: Toxic / Hazardous Substances and Environmental Engineering 32 (2): 283-289.

Mshelia S.S., Bulama L. 2023. Concentration and Comparison of Groundwater Quality in Kano Metropolis, Nigeria, British Journal of Environmental Sciences 11 (2): 23-35. DOI: 10.37745/bjes.2013/vol11n22335

Ogbonna C.C. 2022. Human health implications of heavy metal contaminants in well water used for domestic purposes in Ojoo, Ibadan. Proceedings of the International Academy of Ecology and Environmental Sciences 12(4): 246-257

Ogunkolu A.B., Ogbole M., Njoku M.C. et al. 2018. Assessment of arsenic contamination of underground water resources in Asa Local Government Area of Kwara State, Nigeria. Ethiopian Journal of Environmental Studies & Management 11(4): 450 – 463. DOI: https://ejesm.org/doi/v11i4.6

Okareh T.O., Sokan-Adeaga A. A., Akin-Brandom T. et al. 2023. Assessment of Heavy Metals Contamination in Groundwater and Its Implications for Public Health Education: A Case Study of an Industrial Area in Southwestern Nigeria. IntechOpen. DOI: 10.5772/intechopen.1095

Okiongbo K.S., Oboshenure K.K., Amakiri A.R.C. 2020. Investigation of lithological control of iron enrichment in groundwaterusing geophysical techniques in Yenagoa, Southern Nigeria. SN Applied Sciences. 2:107. DOI: 10.1007/s42452-019-1876-3

Prakash S., Verma A. K. 2021. Arsenic: It's Toxicity and Impact on Human Health. International Journal of Biological Innovations 3(1): 38-47.

Prasad B., Bose J.M. 2001. Evaluation of heavy metals pollution index for surface and spring water near a limestone mining area of the lower Himalayas. Environmental Geology, 41: 183 - 188.

Prasad M., Aswal R.S., Joshi A. et al. 2022. A systematic study on occurrence, risk estimation and health implications of heavy metalsin potable water from different sources of Garhwal Himalaya, India. Scientific Reports 12: 20419. DOI: 10.1038/s41598-022-24925-9

Reinert J.P., Garner M., Forbes L. 2021. Hypermanganesemia-induced cerebral toxicity mimicking an acute ischemic stroke: a case report and review of overlapping pathologies. Journal of Pharmaceutical Technology 37: 127-32.

Salem H.M., Eweida E.A., Farag A. 2000. Heavy metals in drinking water and their environmental impact on human health. ICEHM, 542-556.

Sanders T., Liu Y., Buchner V. et al. 2009. Neurotoxic effects and biomarkers of lead exposure: a review. Reviews on Environmental Health 24 (1): 15 – 45.

Singh A., Sharma A., Verma R.K. et al. 2022. Heavy Metal Contamination of Water and Their Toxic Effect on Living Organisms. IntechOpen. DOI: 10.5772/intechopen.105075

Tsor J.O., Biam J.T., Terver D. et al. 2022. Assessment of Physico-chemical Parameters and Heavy Metal Concentrations in Well Water of Logo – 2 Area of Makurdi, Nigeria. Nigerian Annals of Pure and Applied Sciences 5(1): 139 - 150

Ullah Z., Rashid A., Ghani J. et al. 2022. Groundwater contamination through potentially harmful metals and its implications in groundwater management. Frontiers in Environmental Science 10: 1021596. DOI: 10.3389/fenvs.2022.1021596

Umana I.M., Neji P.A., Agwupuye J.A. 2022. Assessment of underground water quality in Okobo Local Government Area of Akwa Ibom State, Nigeria. Applied Water Science, 12: 106. DOI: 10.1007/s13201-022-01614-6

USGS. 2019.Arsenic and Drinking Water. United States Geological Survey. https://www.usgs.gov/mission-areas/water-resources/science/arsenic-and-drinking-water#:~:text=Arsenic%20also%20can%20be%20released,and%20is%20a%20known%20carcinogen

WWQA. 2021. Assessing Groundwater Quality: A Global Perspective: Importance, Methods and Potential Data Sources. Friends of Groundwater in the World Water Quality Alliance (WWQA). https://groundwater-quality.org/sites/default/files/2021-01/Assessing%20Groundwater%20Quality_A%20Global%20Perspective.pdf

Xia J.J., Xu G.H., Guo P. et al. 2018. Tempo-spatial analysis of water quality in the three Gorges reservoir, China, after its 175-m experimental impoundment. Water Resource Management 32(9): 2937–2954. DOI: 10.1007/s11269-018-1918-4

Yan X., Dong W., An Y. et al. 2019. A Bayesian-based integrated approach for identifying groundwater contamination sources. Journal of Hydrology 579: 124160. DOI: 10.1016/j.jhydrol.2019.124160

Zakaria N., Anornu G., Adomako D. et al. 2020. Evolution of groundwater hydrogeochemistry and assessment of groundwater quality in the Anayari catchment. Groundwater for Sustainable Development 12: 100489. DOI: 10.1016/j.gsd.2020.100489

Zhai Y., Zheng F., Li D. et al. 2022. Distribution, Genesis, and Human Health Risks of Groundwater Heavy Metals Impacted by the Typical Setting of Songnen Plain of NE China. International Journal of Environmental Research and Public Health 19(6): 3571. DOI: 10.3390/ijerph19063571

Zhang W., Aschner M., Ghers-Egea J.F. 2003. Brain barrier system: a new frontier in metal Neurotoxicological Research. Toxicology and Applied Pharmacology 192 (1):1-11.