

ORIGINAL RESEARCH ARTICLE

Pollution Status of Groundwater Resource by Some Heavy Metals Using Index Approach in Some Parts of Nasarawa Area, Kano State, Nigeria

Mudassir Hassan¹  and Lawal Idris Sada¹ .¹Department of Geography, Umaru Musa Yar'adua University, P. M. B 2218, Katsina, Nigeria.

ABSTRACT

Groundwater is the world's most significant natural resource, providing water for different purposes, including drinking, domestic, industrial and irrigational. However, polluted groundwater may endanger human survival. This research evaluated the status of groundwater resource pollution caused by some heavy metals in some parts of the the Nasarawa local government area of Kano State. Fifteen groundwater samples were collected from functional boreholes in the area. Heavy metals concentrations evaluated include Zn, Mn, Cr, Mg, Cd, Fe, Cu, and Pb and were compared with the World Health Organization and Nigerian Standard for Drinking Water Quality to establish their suitability for human consumption. Descriptive statistics was employed to summarize the analyzed data. Metal index was used to determine the pollution status of the groundwater. The result revealed that Zn, Fe, Cu, and Mn with the mean value of (0.090, 0.160, 0.191 and 0.11) were found within the stipulated limit set by WHO (3.0, 0.3, 2.0 and 0.5) and NSDWQ (3.0, 0.5-50, 1.0 and 0.2), while Pb, Cd, Cr, and Mg (0.105, 0.127, 0.206 and 0.82) exceeded the permissible limits recommended by WHO (0.01, 0.003, 0.05 and 0.5). A high concentration of Pb, Cd, Cr, and Mg may be attributed to anthropogenic influences possibly deriving from improper municipal and Bampai industrial waste disposal. The values of the metal index (MI) revealed that the water is seriously affected by Pb, Cd and Cr, which can pose serious health damage to consumers. It is recommended to constantly monitor Pb, Cd and Cr in groundwater in the study area due to its proximity to Bampai and Sharadda industrial sites.

ARTICLE HISTORY

Received July 30, 2023.

Accepted November 17, 2023.

Published March 7, 2024.

KEYWORDS

Heavy Metals, Groundwater, Metal Index, Pollution status, Nasarawa, Kano state

© The authors. This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 License (<https://creativecommons.org/licenses/by-nc/4.0/>)

INTRODUCTION

The most significant natural water resource on the planet is groundwater. In times of drought and when surface water sources are limited and precipitation patterns are uncertain, groundwater has shown to be an important source of water supply for a range of uses, including household, industrial, and irrigation (Saha and Ray, 2019; Rahmot *et al.*, 2022). Around a third of people worldwide consider groundwater their main water source for various uses (FAO, 2017; Tsor *et al.*, 2022). Some essential conditions for maintaining human life and civilization include a sufficient amount and quality of freshwater (Agrawal *et al.*, 2021). Indeed, during the past few decades, groundwater use for irrigation, industry, and home reasons has multiplied globally due to the enormous population rise and astonishing advances in science and technology (Agrawal *et al.*, 2021).

Both natural and artificial sources contribute to water contamination in wells, but the latter seems to do so to a greater extent (Narsimha & Rajitha, 2018; Khalid, 2019).

Pollutants in domestic, industrial and agricultural water constitute high environmental and health risks (Billing *et al.*, 2023). Improper treatment of these pollutants may increase heavy metal concentrations in groundwater (Folorunsho *et al.*, 2022). In addition to the wide variety of contaminants that harmed water resources, heavy metals drew special attention due to their high hazardous level, even at low concentrations. Heavy metal poisoning of the groundwater ecosystem is a global environmental problem (Yahaya *et al.*, 2019; Tsor *et al.*, 2022). Trace element concentrations in water can differ due to physiologic, environmental, and other factors.

Heavy metals can accumulate in the human body system and cause major harm to the nervous system, including cardiovascular illnesses, reproductive problems, and cancer. Heavy metals are not biodegradable (Li *et al.*, 2022; Umar *et al.*, 2023). Heavy metals, for example, Fe, Cu, Zn, and Ni, are essential micronutrients for animal life and vegetation but are dangerous at excess levels, whereas Cr,

Correspondence: Mudassir Hassan. Department of Geography, Umaru Musa Yar'adua University, P. M. B 2218, Katsina, Nigeria. ✉ mudassir.hassan@umyu.edu.ng. Phone Number: +234 806 504 7825.

How to cite: Hassan & Sada. (2024). Pollution Status of Groundwater Resource by Some Heavy Metals Using Index Approach in Some Parts of Nasarawa Area, Kano State, Nigeria. *UMYU Scientifica*, 3(1), 95 – 102. <https://doi.org/10.56919/usci.2431.011>

MATERIALS AND METHODS

Study area

This study is conducted in some parts of Nasarawa's local government area of Kano state. The area is located within the Kano metropolis, approximately at 11°57'37"N 8°33'0"E to 12°1'30"N 8°37'00"E (Figure 1). It covers a total landmass of about 34km² with a population of 596,411 according to 2006 population census. Climatologically, the area is strongly influenced by the tropical continental and maritime air masses. The two air masses control the climate, making it dry and wet. The area experiences high temperatures ranging from 32°C to 38°C. In the study area, irregularities in time and space characterize rainfall and do not exceed 650 mm/year, and the highest rainfall period was recorded in August and September (Olofin, 2014). The relative humidity is higher during the wet season by about 80% and lowers during the dry season by about 20% (Mustapha and Aris 2012a).

The geology of the area under study is underlain by a Crystalline Basement Complex of Pre-Cambrian origin, which loses its identity by disappearing into the Chad Formation. The basement complex consists of granite rocks, generally gneiss and commonly developed in a mixture of pegmatite of schist granite, gneiss, and irregular masses of pegmatite. Aeolian sand from wind deposits covers most of the area (Tasi'u, 2019). Sudan's savannah vegetation type covers the area. The natural vegetation in this area has been modified due to several human activities, such as urban construction.

Cd, Pb, and Co have no known physiological functions but are harmful at a certain level (Aktar *et al.*, 2010; Nasiru *et al.*, 2021). Furthermore, Cr, Cd, and Ni are carcinogenic, while Pb may cause damage to human health (Okegye & Gajere, 2015; Rezaei and Hassani, 2018; Kamalu & Habibu, 2023). The damages include gastrointestinal, liver, renal, lung, intestinal, neurological, and reproductive disorders. Infants, the elderly, and pregnant women are especially vulnerable to the consequences (WHO, 2007; Tsor *et al.*, 2022). As the World Health Organization (WHO, 2007) indicated, inappropriate or polluted water causes around 80% of all diseases in human beings.

Groundwater can harm humans through consumption and skin contact (Wu and Sun, 2016; Zhang *et al.*, 2022). Nasarawa local government is situated within the Kano metropolis. As a result of rapid urbanization and population growth, the demand for potable water has increased. Most inhabitants rely on groundwater as a major source. Several private and public boreholes are operating to meet the water demand of the people in the area. In metropolitan regions where industrial and occupational activity is primarily concentrated, there is a specific increase in the pollution of heavy metals. Unfortunately, trustworthy information about the concentration of heavy metal pollutants in a given area like Nasarawa local government of Kano state Nigeria is lacking. Therefore, this study aims to evaluate groundwater pollution status by some heavy metals and compare the parameters with the Nigerian Drinking Water Quality Standard (NDWQS, 2007) World Health Organization (WHO, 2006) to ascertain its portability.

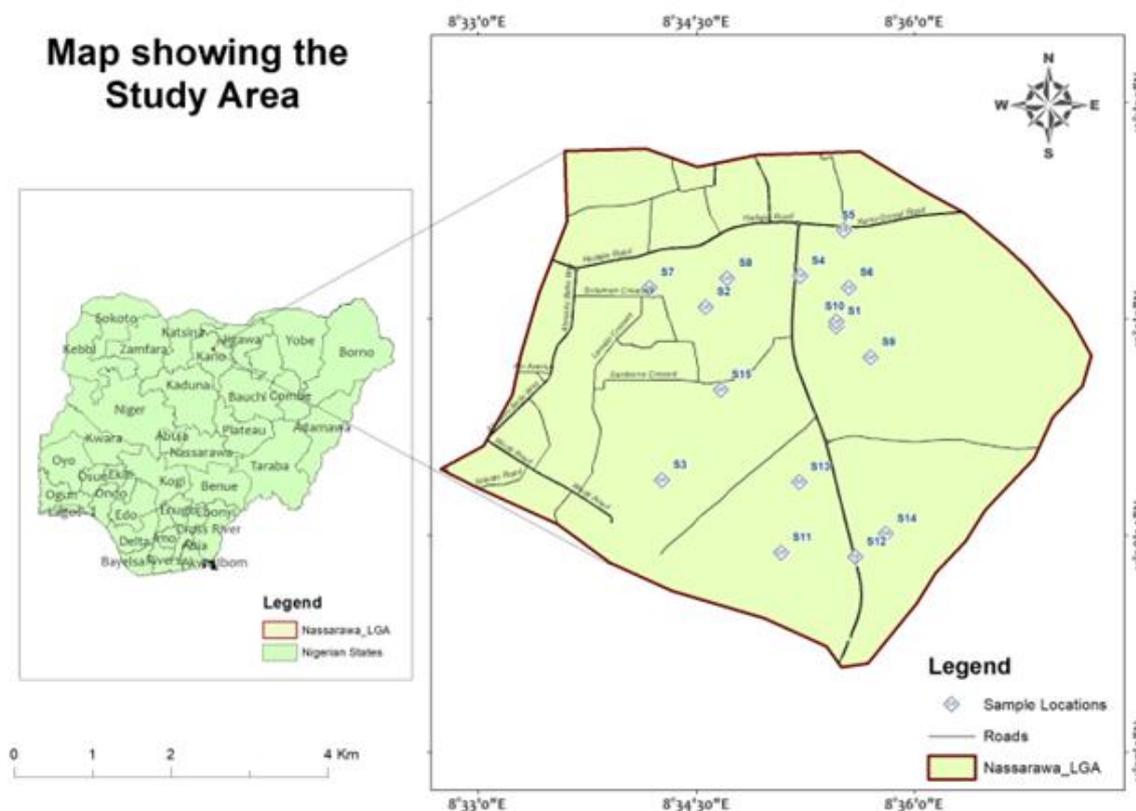


Figure. 1. Map of Nasarawa local government showing the study area

Groundwater sampling and analysis

Groundwater samples were collected randomly from fifteen functional boreholes during the rainy season of 2019 (May to September). Standard procedure for water sample collection using APHA, 2012 methods were adopted. All water samples were collected in pre-washed polythene sample bottles of 1-litre capacity. The sample bottles were washed several times with the water to be sampled and acidified with HNO₃ at the collection site. After labelling, the samples were transported to the laboratory (Department of Geography, Bayero University Kano) and stored at room temperature before laboratory analysis. The sample water was filtered in the laboratory, and 50cm³ of the sample water was measured into the beakers.

5 cm³ of concentrated HNO₃ was added to the measured samples. Hot plates were used to heat the sampled water in a fume cupboard to near dryness with a characteristic color indicating complete digestion. After which, the samples were allowed to cool, then transferred to a 50cm³ acid-washed volumetric flasks and volume filled to 50 marks with deionized water. All filtered samples were in sample bottles ready for the laboratory's atomic absorption spectrophotometer (AAS) (Greenberg *et al.*, 1992).

Metal index (MI)

The metal index (MI) of groundwater samples under study was calculated to determine the level of heavy metal contamination to assess the water quality's suitability for drinking (Caerio *et al.*, 2005).

Table 2: Heavy metals concentration in groundwater samples

Sample location	Parameters (ppm)							
	Pb	Zn	Cd	Cr	Mg	Fe	Cu	Mn
BH1	0.043	0.129	0.1	0.375	1.0	0.185	0.272	0.1
BH2	0.174	0.065	0.1	0.25	0.6	0.111	0.181	0.05
BH3	0.174	0.097	0.2	0.125	1.2	0.148	0.363	0.15
BH4	0.043	0.055	ND	0.125	0.8	0.370	0.090	0.1
BH5	0.130	0.194	0.1	0.50	1.6	0.259	0.363	0.2
BH6	0.033	0.042	0.1	0.421	0.5	0.121	0.218	0.18
BH7	0.123	0.074	ND	0.165	0.7	0.146	0.067	0.03
BH8	0.165	0.186	0.2	0.230	1.3	0.171	0.221	0.16
BH9	0.120	0.073	0.1	0.312	0.8	0.108	0.193	0.09
BH10	0.133	0.107	0.1	0.173	1.4	0.127	0.204	0.12
BH11	0.027	0.028	ND	0.097	0.3	0.106	0.196	0.04
BH12	0.056	0.013	ND	0.042	0.8	0.103	0.117	0.07
BH13	0.127	0.095	0.1	0.067	0.7	0.112	0.103	0.15
BH14	0.163	0.146	0.2	0.121	0.4	0.111	0.115	0.13
BH15	0.057	0.041	0.1	0.083	0.2	0.216	0.167	0.08
Min	0.027	0.013	0.1	0.042	0.2	0.103	0.067	0.03
Max	0.174	0.194	0.2	0.5	1.6	0.37	0.363	0.2
Mean	0.105	0.090	0.127	0.206	0.82	0.160	0.191	0.11
St. Dev	0.055	0.054	0.045	0.141	0.400	0.072	0.089	0.050
NSDWQ	0.01	3.0	0.03	0.05	0.2	0.5-50	1.0	0.2
WHO	0.01	3.0	0.003	0.05	0.5	0.3	2.0	0.5

BH = Borehole, St. Dev = Standard deviation, ND = Not detected, NSDWQ = Nigerian Standard for Drinking Water Quality, WHO = World Health Organization.

$$MI = \sum_n^i Ci/MACi \dots\dots\dots(1)$$

MPI = is the metal index, Ci is the metal concentration (mg/l) in the water sample, and MACi is the maximum allowable concentration (WHO, 2004). The higher the value of MPI, the greater the risk of water to human health (Ogunkunle *et al.*, 2016).

Table 1: Classification of metal index (Caerio *et al.*, 2005).

S/No.	Categories	Degree of pollution
Class I	< 0.3	Very pure
Class II	0.3-1.0	Pure
Class III	1.0-2.0	Slightly affected
Class IV	2.0-4.0	Moderately affected
Class V	4.0-6.0	Strongly affected
Class VI	> 6.0	Seriously affected

Statistical analyses

Data were subjected to descriptive statistical analysis (minimum, maximum, mean and standard deviation) and are presented in Table 2. Furthermore, results were compared with the World Health Organization (WHO, 2006) and Nigeria Standard for Drinking Water Quality (NSDWQ, 2007) to understand the suitability for human consumption in the area under study.

RESULTS AND DISCUSSION

Heavy metals concentration

The analysis of heavy metals concentration of groundwater samples along with (NSDWQ and WHO) for human consumption are presented in Table 2.

Lead: lead concentration varied from 0.027 to 0.174 with a mean value of 0.105mg/l, which exceeded the permissible limit (0.01) recommended by WHO for drinking water. This follows the findings of [Hassan *et al.* \(2021\)](#) in their comparative analysis of heavy metals in groundwater around Bampai and Sharadda industrial sites Kano metropolis. This high lead concentration may be due to several anthropogenic activities within the study sites, such as toxic waste disposal. Research has indicated that prolonged exposure to lead (Pb) might result in anaemia and hypertension, particularly in middle-aged and older adults. Males who are exposed to high concentrations may have kidney and brain damage, while toddlers and fetuses whose brain tissues are still growing may experience behavioural changes and possible neurological impairment from water containing less than 0.05 mg/L of lead ([Jaishankar *et al.*, 2014](#); [Fisseha *et al.*, \(2016\)](#); [Edokpayi *et al.*, 2018](#)).

Zinc: The analyzed value of zinc concentration in the groundwater sample revealed the range of 0.013 to 0.194 with a mean value of 0.090 mg/l, found within the WHO and NSDWQ permissible limit for drinking water. This concentration in the borehole water samples could be traced to the leaching of chemicals and other particulate matter deposited in the area. The low concentration of Zn in the area suggests that fewer fluorescent lamps and batteries were leaked into the ground. The low concentration of zinc value is similar to the findings of [Guti *et al.* \(2014\)](#). Hence, all borehole water has little to no health effects because Zn is known to have antioxidant properties that protect humans against accelerated ageing of muscles and skin. It also helps heal after an injury if a moderate and recommended dosage is ingested ([Asare-Donkor *et al.*, 2016](#); [Edokpayi *et al.*, 2018](#)).

Cadmium: The level of Cadmium in the groundwater samples ranged from 0.1 to 0.2, and the average mean value of 0.127 mg/l. The mean value of dissolved cadmium is higher than the permissible level. It may be due to the proximity of Bampai industrial areas of urban Kano, which may influence high levels of reported cadmium concentration. However, this study suggests that the main possible source of heavy metals in groundwater can be attributed to leachate percolation. This result is similar to [Hassa *et al.*'s \(2021\)](#); [Boateng *et al.*, 2019](#) findings). A high concentration of cadmium may cause several damages, such as kidney damage and obstructive lung diseases. Experimental studies conducted on humans and animals show that cadmium may cause cancer in humans ([Nordberg *et al.*, 2002](#)). In comparison with other studies from developing nations, studies revealed that blood levels of this metal (Cd) in children showed increased levels, and one causative factor among many is the consumption of polluted groundwater due to industrial effluents ([Horton *et al.*, 2013](#); [Mohankumar *et al.*, 2016](#)).

Chromium: In the present study, chromium concentration in groundwater samples gave the range values between 0.042 and 0.5 with a mean of 0.206 mg/l, which is higher

than the recommended limit by WHO and the NSDWQ guidelines for drinking water. The high concentration of chromium was more pronounced than the other trace metals, as shown in [Figure. 2](#). This result is in accord with the study of [Agrawal *et al.* \(2021\)](#). The maximum value obtained from this study could be sourced through septic systems or industrial discharge, possibly Bampai and Sharadda industrial sites. The disposal of metal products around this area could have led to a high concentration of Cr in the boreholes. High Cr content in the water has a possible risk of inducing gastrointestinal cancer following long-term exposure, undesirable taste and slight nausea in humans. Furthermore, an in vitro study has shown that high Cr(III) concentration in the cell could cause DNA damage in humans ([Edokpayi *et al.*, 2018](#)).

Magnesium: Magnesium is another essential mineral required to maintain the proper functioning of human health ([Agagaw *et al.*, 2021](#)). It helps to maintain the stable equilibrium of water; excess amounts of magnesium, however, slowly react with other minerals ([Zhu *et al.*, 2022](#); [Muthusamy, *et al.*, 2023](#)). The consumption of magnesium through water helps regulate the human body's cardiovascular and immune systems. Magnesium concentration ranges between 0.2 and 1.6, with an average value of 0.82 mg/l. The value is above the acceptable limit recommended by WHO and the NSDWQ guidelines for human consumption. Natural sources such as the weathering of parent rock and ion exchange are significant sources of magnesium in groundwater. Long-term exposure to manganese may lead to serious human health effects such as muscular dystrophy, renal failure and multiple sclerosis.

Iron: The concentration of iron in this study varied from 0.103 to 0.37, with a mean value of 0.160 mg/l. The observed average value falls within the allowable range recommended by WHO and NSDWQ. These findings slightly coincide with [Abdulsalam *et al.* \(2019\)](#). Although iron in water has less effect on human health, higher iron concentration may cause Diabetes, hemochromatosis, stomach problems, nausea, and vomiting, as reported by [Agrawal *et al.* \(2021\)](#). Water with a Fe concentration of less than 0.3 mg/L slightly affects taste and other marginal aesthetic effects, such as slightly stained white clothes if used for laundry ([Edokpayi *et al.*, 2018](#)).

Copper is also characterized as unwanted heavy metals in drinking water and can infiltrate the water system. The concentration of copper in the groundwater sample ranged from 0.067 to 0.363, and a mean value of 0.191 was observed. This value is within the acceptable limit set by WHO and NSDWQ for human consumption. The lower value of copper obtained in this study is in concurrence with the values reported by [Abdulsalam *et al.* \(2019\)](#). The concentrations of copper in the studied groundwater samples were also comparable with earlier studies. [Boateng *et al.* \(2019\)](#) reported a similar to this study. [Mahapatra, *et al.* \(2020\)](#) in North Chennai recorded Cu concentration higher than in this study. Thus, copper might have been removed by precipitation and

complexation processes before getting to the groundwater (Folorunsho *et al.*, 2022). The other reason for the low copper concentration in groundwater could be that a few discharged solid wastes at the nearest sample sites do not contain bioavailable copper forms (Ferrara *et al.*, 2013) to be released into the groundwater.

Manganese: Observed manganese concentration ranges from 0.03 to 0.2, with a mean value of 0.11 mg/l. This value falls within WHO and NSDWQ stipulated limit for drinking water. The low concentration of Mn may be attributed to the less dissolution of Mn from the surface onto the groundwater. It may also be attributed to nonbiodegradable wastes, which might have inhibited solid waste biodegradation, as Folorunsho *et al.* (2022) reported. Musa *et al.* (2013) reported similar to these findings. Mahapatra *et al.* (2020) in the North Chennai region also reported Mn concentration higher than in this study.

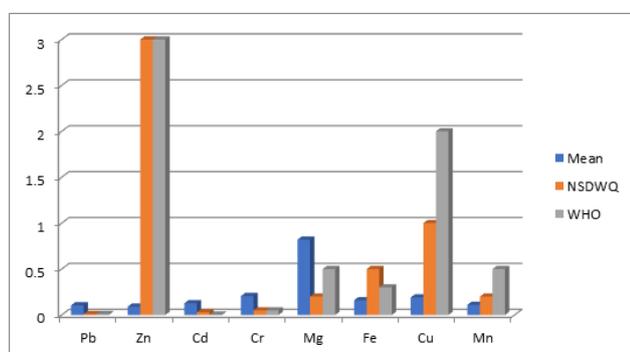


Figure. 2: The mean value of heavy metals concentration in groundwater samples collected from fifteen boreholes in some of the Nasarawa local government, Kano state.

Table 3: Calculation of metal index

Sample ID	Parameters (ppm)								$\sum_n^i MPI$
	Pb	Zn	Cd	Cr	Mg	Fe	Cu	Mn	
BH1	4.3	0.04	33.3	7.5	2	0.62	0.14	0.2	48.1
BH2	17.4	0.02	33.3	5.0	1.2	0.37	0.09	0.1	57.48
BH3	17.4	0.03	66.7	2.5	2.4	0.49	0.18	0.3	90
BH4	4.3	0.02	ND	2.5	1.6	1.23	0.05	0.2	32.4
BH5	13	0.06	33.3	10	3.2	0.86	0.18	0.4	52.26
BH6	3.3	0.01	33.3	8.2	1.0	0.40	0.11	0.36	46.68
BH7	12.3	0.02	ND	3.3	1.4	0.49	0.03	0.06	17.6
BH8	16.5	0.06	66.7	4.6	2.6	0.57	0.11	0.32	91.46
BH9	12	0.02	33.3	6.2	1.6	0.36	0.10	0.18	53.76
BH10	13.3	0.05	33.3	3.5	2.8	0.42	0.10	0.24	53.71
BH11	2.7	0.01	ND	1.9	0.6	0.35	0.10	0.08	5.74
BH12	5.6	0.00	ND	0.8	1.6	0.34	0.06	0.14	8.54
BH13	12.7	0.03	33.3	1.3	1.4	0.37	0.05	0.3	49.45
BH14	16.3	0.05	66.7	4.2	0.8	0.37	0.06	0.26	88.74
BH15	5.7	0.01	33.3	1.7	0.4	0.72	0.08	0.16	42.07

BH = Borehole, ND = Not detected, MI = Metal Index

Pollution Status using Metal Index (MI)

It can be seen from Table 3 that the majority of the groundwater samples in the study were unsafe. The metal index (MI) of groundwater samples shows great contamination by Cd and Pb in the study area. MI_{Cd} is in order BH3, 8, 14 (66.7) > BH1, 2, 5, 6, 9, 10, 13 & 15 (33.3), and MPI_{Pb} BH2, & 3 (17.4) > BH8 (16.5) > BH14 (16.3) > BH10 (13.3) > BH5 (13) > BH13 (12.7) > BH7 (12.3) > BH9 (12) > BH15 (5.7) > BH12 (5.6) > BH1&4 (4.3) > BH6 (3.3) > BH11 (2.7). MI_{Cr} BH5 (10) > BH6 (8.2) > BH1 (7.5) > BH9 (6.2) > BH2 (5.0) > BH8 (4.6) > BH14 (4.2) > BH10 (3.5) > BH7 (3.3) > BH3 & 4 (2.5) > BH11 (1.9) > BH15 (1.7) > BH13 (1.3) > BH12 (0.8). These MI values indicated that Pb (Class V & VI) strongly and seriously affected the studied groundwater. Furthermore, it was seriously affected by Cd (Class VI). Cr falls in Class IV, V & VI, and Mg were slightly and moderately affected, Zn and Mn falls in (Class I & II), and Fe and Cu in (Class II). The overall MPI of all studied boreholes were found above class VI, indicating seriously affected. Table 4 revealed the classification of groundwater based on the metal index. It can be observed that only station 11 was strongly affected concerning heavy metal contamination. The remaining 14 stations were seriously affected. These findings demonstrate the need for quick action to lower the heavy metal concentration in groundwater. Anthropogenic activities were the primary cause of the heavy metals found in groundwater; industrial and e-waste activities contribute more to the accumulation of heavy metals.

Table 4: Classification of groundwater based on metal index (Caerio *et al.*, 2005).

Classes	MI	Degree of pollution	Sampling Sites
Class I	< 0.3	Very pure	
Class II	0.3-1.0	Pure	
Class III	1.0-2.0	Slightly affected	
Class IV	2.0-4.0	Moderately affected	
Class V	4.0-6.0	Strongly affected	BH11
Class VI	> 6.0	Seriously affected	BH1 - 10, BH12 - 15

LIMITATION

There was a minimal sample size used (15 samples). A comprehensive investigation should be conducted to determine the levels of heavy metals pollution in Nasarawa local government area, Kano state.

CONCLUSION

The results revealed that Zn, Fe, Cu, and Mn fall within the acceptable limit set by WHO and NSDWQ, while Pb, Cd, Cr, and Mg exceeded the permissible limits recommended by WHO. The MPI reveals the

groundwater resource is seriously affected since the obtained values are greater than 6.0. It is concluded that immediate measures to be taken to control the pollution as the water can pose a serious health effect to consumers. This study gives an idea of the status of heavy metal contamination in the study area and can be utilized by governmental organizations and other organizations to create a thorough plan to lower the amount of heavy metals in this location. It was also recommended that continuous monitoring of groundwater need to be made in the studied area. Domestic and industrial waste should be disposed of properly to safeguard public health from water-borne diseases.

REFERENCES

Abdulsalam, H., Nuhu, I. & Lawal, Y. (2019) Physicochemical and heavy metals assessment of some selected borehole water in Dutse town of Jigawa state. *FUDMA Journal of Sciences*, 3 (4), 212 –223.

Agrawal, P., Sinha, A., Kumar, S., Agarwal, A., Banerjee, A., Villuri, V. G. K., Annavarapu, C. S. R., Dwivedi, R., Dera, V. V. R., Sinha, J. & Pasupuleti, S. (2021). Exploring artificial intelligence techniques for groundwater quality assessment. *Water*, 13(9), 1172. [Crossref]

Aktar, M. W., Paramasivam, M., Gamjuly, M. Purkait, S., & Sengupta, D. (2010). Assessment and occurrence of various heavy metals in surface water of Ganga river around Kolkata: a study toxicity and ecological impact. *Environ Monitor Assess.* 160: 207-213. [Crossref]

APHA, (2012). Standard Methods for the Examination of Water and Wastewater, twenty-second ed. American Public Health Association, Washington, DC.

Aragaw, T. T. & Gnanachandrasamy, G. (2021). Evaluation of groundwater quality for drinking and irrigation purposes using GIS-based water quality index in urban area of Abaya-Chemo sub-basin of Great Rift Valley, Ethiopia. *Appl. Water Sci.*, 11, 148. [Crossref]

Asare-Donkor, N. K., Boadu, T. A., & Adimado, A. A. (2016). Evaluation of groundwater and surface water quality and human risk assessment for trace metals in human settlements around the Bosomtwe Crater Lake in Ghana. *SpringerPlus*, 5(1), 1812. [Crossref]

Billing, P. T. N., Feumba, R., & Ndjigui, P. (2023). Hydrogeochemical appraisal of groundwater quality in Ngoua watershed (Douala-Cameroon): Implication for domestic purposes. *Scientifi African*, 22. [Crossref]

Boateng, T. K., Opoku, F., & Akoto, O. (2019). Heavy metal contamination assessment of groundwater quality: a case study of Oti landfill site, Kumasi. *Applied water science*, 9(2), 33. [Crossref]

Caerio, S., Costa, M. H., Ramos, T. B., Fernandes, F., Silveira, N., Coimbra, A., & Painho, M., (2005). Assessing heavy metal contamination in Sado Estuary sediment: an index analysis approach. *Ecol. Ind.* 5, 155–169. [Crossref]

Edokpayi, J. N., Enitan, A. M., Mutileni, N., & Odiyo, J. O. (2018). Evaluation of water quality and human risk assessment due to heavy metals in groundwater around Muledane area of Vhembe District, Limpopo Province, South Africa. *Chemistry Central Journal*, 12, 1-16. [Crossref]

FAO, (2017). AQUASTAT: FAO's global information system on water and agriculture: Eagriculture. [WWW Document]. URL. fao.org accessed 12.14.19.

- Ferrara, L., Iannace, M., Patelli, A. M. & Arienzo, M. (2013). Geochemical survey of an illegal waste disposal site under a waste emergency scenario (Northwest Naples, Italy). *Environment*, 185(3), 2671–82. [[Crossref](#)]
- Fisseha, G. W., Bereket, A. & Tanweer, A. (2016). Assessment of heavy metals concentration in Togona river of Goba town, Oromia region, Ethiopia. *Int. J. Chem. Sci.*: 14(4), 3207-3214.
- Folorunsho, O. S., Ojo, A. A., Ayorinde, A. M. & Olumuyiwa, A. O. (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. <https://www.nepjol.info/index.php/josem>
- Greenberg, A. E., Clesceri, L. S., & Eaton, A. T. (1992). *Standard methods for the examination of water and wastewater* 18th edition. American Public Health Association. 221-260.
- Gutti, B., Zubairu, B. & Buba, D. (2014). Impact assessment of heavy metals contamination of groundwater in Mubi, Adawawa state, Nigeria. *International Journal of Science, Environment and Technology*, 3, (6), 2120 – 2126.
- Hassan, F. Y., Usman, B., Yalwa, I. R., Rilwanu, T. Y., & Abdulhamid, A. (2021). Comparative analysis of heavy metals in groundwater around Sharada and Bompai industrial areas, Kano Metropolis, Nigeria. *J. Mater. Environ. Sci.*, 12(01), 66-77. <https://www.jmaterenvironsci.com>
- Horton, L M, Mortensen, M. E., Iossifova, Y., Wald, M. M., Burgess, P. (2013). What Do We Know of Childhood Exposures to Metals (Arsenic, Cadmium, Lead, and Mercury) in Emerging Market Countries? *International Journal of Pediatrics*. 2013:872596. [[Crossref](#)]
- Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., Beeregowda, K. N. (2014). Toxicity, mechanism and health effects of some heavy metals. *Interdiscip Toxicol* 7(2):60–72. [[Crossref](#)]
- Kamalu, T., & Habibu, H. (2023). Analysis of Physico-Chemical Characteristics and Heavy Metals Content in Water Samples Utilizing Atomic Absorption Spectrophotometry in Kafin Hausa, Jigawa State, Nigeria. *UMYU Scientifica*, 2(4), 122 – 129. [[Crossref](#)]
- Khalid, S. (2019). An assessment of groundwater quality for irrigation and drinking purposes around brick kilns in three districts of Balochistan province, Pakistan, through water quality index and multivariate statistical approaches. *J. Geochem. Explor.* 197, 14–26. [[Crossref](#)]
- Li, P., Wu, J., & Shukla, S. (2022). Achieving the one health goal: highlighting groundwater quality and public health. *Water*, 14(21), 3540. [[Crossref](#)]
- Mahapatra, S. R., Venugopal, T., Shanmugasundaram1, A., Giridharan, L., & Jayaprakash, M. (2020). Heavy metal index and geographical information system (GIS) approach to study heavy metal contamination: a case study of north Chennai groundwater. *Applied Water Science*, 10:238. [[Crossref](#)]
- Mohankumar, K., Hariharan, V., & Rao, N. P. (2016). Heavy metal contamination in groundwater around industrial estate vs residential areas in Coimbatore, India. *Journal of clinical and diagnostic research: JCDR*, 10(4), BC05. [[Crossref](#)]
- Musa, O. K., Shaibu .M .M. & Kudamnya .E. A. (2013). Heavy metal concentration in groundwater around Obajana and its environs, Kogi state, north central Nigeria. *American International Journal of Contemporary Research*, 3 (8), 170-177.
- Mustapha, A., & Aris, A. Z. (2012). Spatial aspects of surface water quality in the Jakara Basin, Nigeria using chemometric analysis. *J Environ Sci Health Part A* 47:1455– 1465. [[Crossref](#)]
- Muthusamy, P., Pancerselvam, B., Kaliyappan, S. P., Almohamad, H., Aldosari, A. A. & Abdo, H. G. (2023). Pollution Source identification and suitability assessment of groundwater quality for drinking purposes in Semi-arid regions of the Southern part of India. *Water*, 15, 3995. [[Crossref](#)]
- Narsimha, A., & Rajitha, S., (2018). Spatial distribution and seasonal variation in floride enrichment in groundwater and its associated human health risk assessment in Telangana State, South India. *Hum. Ecol. Risk Assess. Int. J.* 24 (8), 2119–2132. [[Crossref](#)]
- Nasiru, S., Aliyu, A., Garba, M. H., Dambazau, S. M., Nuraddeen, A., Abba, B. Murtala, Y. (2021). Determination of some heavy metals in groundwater and table water in Tudun Murtala, Nassarawa Local Government Area, Kano-Nigeria. *Dutse Journal of Pure and Applied Sciences*, 7(4b), 124 - 130. [[Crossref](#)]
- Nordberg, G., Jin, T., Bernard, A., Fierens, S., Buchet, J. P., Ye, T., Kong, Q. & Wang, H. (2002). Low bone density and renal dysfunction following environmental cadmium exposure in China. *AMBIO: J Hum Environ*, 31(6), 478–481. [[Crossref](#)]
- NSDQW. Nigerian Standard for Drinking Water Quality. Nigerian Industrial Standard NIS 554, Standard Organization of Nigeria, 2007, pp: 30.

- Ogunkunle, C. O., Mustapha, K., Oyedeji, S., & Fatoba, P. O. (2016). Assessment of metallic pollution status of surface water and aquatic macrophytes of earthen dams in Ilorin, north-central of Nigeria as indicators of environment health. *Journal of King Saud University-Science*, 28, 324-331. [\[Crossref\]](#)
- Okegye JI, Gajere JN (2015) Assessment of Heavy Metal Contamination in Surface and Ground Water Resources around Udege Mbeki Mining District, North-Central Nigeria. *J Geol Geophys* 4: 203. [\[Crossref\]](#)
- Olofin, E. A. (2014). *Location, Relief and Landform. In: (ed) Tanko and Momale, Kano: environment, society and development*, Adonis and Abbey, London and Abuja. 1 -11.
- Prasad, B., & Sangita, K. (2008). Heavy Metal Pollution Index of Ground Water of an Abandoned Open Cast Mine Filled with Fly Ash: a Case Study. *Mine Water Environ* 27, 265–267. [\[Crossref\]](#)
- Rahmot, M. B. A., Joy, T. A. & Ramon, O. A. (2022). Assessment and impact of metal recycling on groundwater quality in Ogijo, Ogun State, Nigeria. *FUOYE Journal of Engineering and Technology*, 7(2), 244 – 247.
- Rezaei, A., Hassani, H. (2018). Hydrogeochemistry study and groundwater quality assessment in the north of Isfahan, Iran. *Environ Geochem Health* 40, 583–608. [\[Crossref\]https://doi.org/10.1007/s10653-017-0003-x](https://doi.org/10.1007/s10653-017-0003-x)
- Rezaei, A., Hassani, H., Hayati, M., Jabbari, N. & Barzegar, R. (2018). Risk assessment and ranking of heavy metals concentration in Iran's Rayen groundwater basin using linear assignment method. *Stoch Environ Res Risk Assess*, 32(5), 1317–1336. [\[Crossref\]](#)
- Saha, D., & Ray, R.K. (2019). Groundwater Resources of India: Potential, Challenges and Management. In: Sikdar, P. (eds) *Groundwater Development and Management*. Springer, Cham. [\[Crossref\]](#)
- Tasi'u, Y. R. (2019) Groundwater potential assessment for urban water supply in Kano metropolis, Nigeria. *Journal of Geography, Meteorology and Environment*, 2(2), 107- 124.
- Tsor JO, Biam JT, Terver D, Shimlumun AP, Jombo GTA. (2022). Assessment of Physico-chemical Parameters and Heavy Metal Concentrations in Well Water of Logo-2 Area of Makurdi, Nigeria. *Nig Annals of Pure & Appl Sci*. 5(1):137-148. [\[Crossref\]](#)
- Umar, S., Muhammad, A., & Elijah, S. (2023). Assessment of heavy metal contamination in groundwater from motorized boreholes in Maitumbi, Tipa Garage Area, Minna, Niger State. *Science World Journal*, 18(2), 212-215. [\[Crossref\]](#)
- World Health Organization (2006). Guidelines for Drinking water quality: First Addendum to 3rd Edition, 1, 491–493.
- WHO (2007). *Health Risks of Heavy Metals from Long-range Transboundary Air pollution*. WHO Europe, 2007. ISBN 978 92 890 7179 6. Accessed online on March 4th , 2022.
- Wu, J., & Sun, Z. (2016). Evaluation of shallow groundwater contamination and associated human health risk in an alluvial plain impacted by agricultural and industrial activities, Mid-west China. *Expo Health*, 8(3), 311-329. [\[Crossref\]](#)
- Yahaya, T., Doherty, V. F., Akinola, O.S. & Shamsudeen, A. (2019). Heavy Metal Profiles and Microbial count of Selected Water brands in Birnin Kebbi Metropolis. *Ife Journal of Science* 21(1), 229 –233. [\[Crossref\]](#)
- Zhang, Q., Li, P., Lyu, Q., Ren, X., & He, S. (2022). Groundwater contamination risk assessment using a modified DRATICL model and pollution loading: A case study in the Guanzhong Basin of China. *Chemosphere*, 291, 132695. [\[Crossref\]](#)
- Zhu, G., Liu, Y., Shi, P., Jia, W., Zhou, J., Liu, Y., Ma, X., Pan, H., Zhang, Y., Zhang, Z., Sun, Z., Yong, L. & Zhao, K. (2022). Stable water isotope monitoring network of different water bodies in Shiyang River basin, a typical arid river in China. *Earth Syst. Sci. Data*, 14, 3773–3789. [\[Crossref\]](#)