



Research Article

Evaluation of Heavy Metal concentrations in Groundwater in a Mining Community: A Case Study of Funakaye LGA, Gombe State

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ARTICLE INFO:

ABSTRACT

Keywords:

Heavy Metals,
Mining,
Groundwater,
Pollution

There is a widespread belief that mining activities have serious negative consequences on the environment, particularly groundwater quality. Based on this, groundwater quality in Funakaye area was investigated because mining operations had occurred there for a long time. This study was aimed at analyzing the quality of groundwater in Funakaye, with emphasis on heavy metal contamination. Groundwater samples were obtained from three boreholes in triplicate, and analysed for heavy metal concentration using Atomic Absorption Spectrophotometer (AAS) machine. The concentrations were compared to the WHO and NESREA standard limits for quality drinking water. The results showed that heavy metal concentrations in the boreholes were generally high, with Fe ranging from 0.369mg/l to 0.490mg/l, Cd ranging from 0.008mg/l to 0.011mg/l, Cr ranging from 0.489mg/l to 0.793mg/l, Pb ranging from 0.181mg/l to 0.428mg/l, and As ranging from 0.748mg/l to 1.115mg/l, thus exceeding the WHO and NESREA recommended limits. Zn and Cu concentrations in the samples were found to be lower than the recommended limits for drinking water, with Zn ranging from 0.009mg/l to 0.178mg/l and Cu from 0.063mg/l to 0.102mg/l. The concentrations obtained for the parameters studied revealed that the sampled boreholes in Funakaye have characteristics of heavy metal contamination in groundwater. Using water from these sources for domestic purposes, including drinking, may lead to fatal cases of arsenic poisoning, cancer, tissue damage, anaemia and neurodegenerative diseases and the study recommends that a continuous water monitoring programme be developed to check and ensure appropriate actions are implemented, as well as the drilling of deep motorised boreholes far away from the contaminant site. In addition, the government should raise community awareness of potential hazards of environmental pollution.

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INTRODUCTION

Water and sanitation are fundamental needs for life on Earth (Mara and Evans, 2011). According to the United Nations Sustainable Development Goals on Water and Sanitation, around 2.4 billion people worldwide live in regions designated as experiencing water stress (UN SDGs Report, 2023). The availability of water resources, both in terms of quantity and quality, is critical for addressing resource sustainability. The rapid increase in global population growth has led to heightened food production, thereby exerting significant pressure on water resources (Kalaivanan *et al.*, 2017). Recently, individuals have turned to groundwater for drinking purposes, particularly in poorer nations (Massally *et al.*, 2017). Observations indicate an increased dependence on groundwater supplies due to quality concerns related to surface water use. The quality of groundwater varies regionally due to geogenic and anthropogenic influences (Annapoorna and Janardhana, 2015), necessitating an evaluation of water quality for its intended application. The assessment of groundwater quality is crucial for socio-economic advancement (Ishaku, 2011). The assessment of water quality for human consumption, agricultural, and industrial purposes has received insufficient attention, particularly in developing countries such as Nigeria. The chemical composition of water can render it unsuitable for human consumption, potentially resulting in health issues. Recent studies have highlighted the significance of groundwater quality in relation to human health (Vasanthavisar *et al.*, 2010). In developing countries, 80% of diseases are directly associated with inadequate drinking water and unsanitary conditions (UNESCO, 2006).

Mining activities may cause detrimental changes to the ecosystems of adjacent communities. These changes impact populations not only via life-threatening diseases but also through the degradation of essential natural resources like groundwater. Groundwater is an important resource for billions of people globally, used largely for drinking, household chores, industrial and agricultural purposes. However, this critical resource is sometimes severely contaminated, owing mostly to industrial discharge, agricultural runoff, and insufficient waste management techniques. Heavy metals such as

Arsenic, Iron, Manganese, Lead, as well as nitrates, offer major health concerns and environmental damage (Argos *et al.*, 2010; Chakraborti *et al.*, 2015; Ghosh *et al.*, 2020; Islam and Mostafa, 2021; Chakraborty *et al.*, 2022). Groundwater contamination by heavy metals arises from the normal weathering of mineral-bearing rocks and human activities. These activities, including coal mining, mineral extraction, industrial discharge, and fertilizers, substantially contribute to the contamination of groundwater with heavy metals (Gupta and Nikhil, 2016). Groundwater contaminants originate from both point sources, such as mining spills, and non-point sources, such as agricultural waste. Mine wastes produce Acid Mine Drainage (AMD), which contains elevated levels of Sulphide-bearing compounds and has the potential to migrate offsite (Hakkou *et al.*, 2008; Khalil *et al.*, 2013; Obasi and Akudinobi, 2015; Moye *et al.*, 2017; Obiora *et al.*, 2018; Rahman and Ferdos, 2024). Sulphide ores, such as galena, consist of heavy metal constituents, notably Lead, Mercury, Copper, Manganese, Zinc, Nickel, Cobalt, Arsenic, Selenium, Molybdenum, Chromium, Silver, and Vanadium (Davies *et al.*, 2005; El Amari *et al.*, 2014). Certain heavy metals are either required nutrients, such as Cobalt and Zinc, or comparatively innocuous, like Silver. Conversely, substances such as Cadmium, Mercury, and Lead are very toxic.

The mining process, which includes drilling, extraction, and dewatering, as well as leaching from waste rock heaps and tailing dams, causes changes in water quality and quantity. Miners inject contaminants directly into water bodies, causing water pollution (Ali *et al.*, 2018). The mining operations in the study area have a negative impact on the health of the Funakaye population, resulting in conditions such as kidney stones and abdominal discomfort. These illnesses are caused by the pollution of groundwater that people commonly consume. In some areas, community members experience incidents of greenhouse gas emissions due to industrial and mining activity, resulting in cough and throat discomfort. The extent of contamination caused by mining activities in Funakaye L.G.A. is challenging to assess due to insufficient pre-mining groundwater quality data, lack of enforcement of regulations, and community awareness programmes. The

objective of this study is to determine the heavy metal concentration and pollution of groundwater due to mining activities from selected boreholes in Funakaye L.G.A., Gombe State.

Hydrogeology

Groundwater is a crucial resource for drinking water, irrigation, and industrial purposes, particularly in areas with scarce surface water (Delgado *et al.*, 2010; Ghalib, 2017). The chemistry of groundwater determines its consumptive use, including domestic, agricultural, and industrial purposes (Krishna Kumar *et al.*, 2014). However, population growth and industrialization have led to intense stress on groundwater resources, making some water unwholesome for human consumption (Tiwari *et al.*, 2015; Khan and Jhariya, 2017). The study area's primary water supply is groundwater, and there is a rapid increase in number of boreholes to meet demand. Groundwater recharge takes place through direct seepage or infiltration, which originates from rivers due to their hydraulic contact. Groundwater circulation is localized due to hills serving as groundwater divides and circulates through quartz veins and fissures, known as fault-brecciated zones. The speed of groundwater circulation is unknown, and domestic wells may not have received pollutants yet. Mining waste pollution in the area can negatively impact users' health, as Sulphide oxidation leads to low pH in water, resulting in the dissolution of metals in groundwater (Muthuminal and Mohana Priya, 2022).

Occurrence of Groundwater Contamination

Groundwater is considered a reliable source of fresh water, and its availability is usually regulated by aquifer characteristics, topography, subsurface activities, climate, and several geochemical processes. The major Emerging Contaminants (ECs) come from heavy metals, antibiotics, fire retardants, pesticides, sunscreens, disinfection byproducts, and sediment (Pradhan *et al.*, 2023). Groundwater contamination can originate from natural (geogenic) or anthropogenic sources. Geogenic Groundwater Contaminants (GGCs) have an impact on drinking water availability and safety, with up to 60% of groundwater sources in some places polluted at higher rates than recommended. As a result, an estimated 300-500 million people are at danger of serious health consequences and early death. The most

common forms of geogenic contamination with human health impacts are elevated concentrations of heavy metals such as arsenic, lead, nickel and fluoride (Mukherjee *et al.*, 2024).

Contaminants Migration in Groundwater

Groundwater contamination has long been a global issue. Contaminants travel and change in soil and groundwater ecosystems, posing possible environmental dangers to humans. Groundwater contamination can result from both point and non-point sources, such as mining spills and agricultural waste (Zhao *et al.*, 2024). Contaminants enter the groundwater through the unsaturated soil zone to the water table, which determines the amount of material that should enter the water from the soil surface (USGS, 2008). Groundwater contamination is on the rise globally due to industrialization and human activities, and these contaminants can be categorized into three main types: chemical contaminants, biological contaminants, and radioactive contaminants. Although they may be roughly divided into three categories: chemical contaminants, biological contaminants, and radioactive contaminants. These contaminants can originate from both natural and anthropogenic sources (Elumalai *et al.*, 2020). Natural causes of groundwater pollution include saltwater, brackish water, low-quality surface waters, and mineral deposits. Human activities, such as aquifer depletion leading to saltwater intrusion, acid mine drainage from mineral resource exploitation, and hazardous chemical leaching from excessive irrigation, can disrupt the natural environmental balance, potentially leading to serious contamination of these natural sources (Li *et al.*, 2018; Su *et al.*, 2020; P. Li *et al.*, 2021).

Heavy Metals

Heavy metal concentration in water is essential to determining the role of mining activities on water quality. Metals are essential components of human physiology; however, some are needed in minute quantities. Higher concentrations of these metals can lead to a multitude of health issues (Mshelia *et al.*, 2024; Singh *et al.*, 2024). Heavy metals are the common pollutants, which are widely distributed in the environment. As the world's population grows, advancement and industrialisation accelerate, becoming one of the primary causes of water pollution. Water is polluted by increased concentrations of heavy

metals and metalloids released from mine tailings, disposal of high metal wastes, growing industrial areas, leaded petrol and paints, inland fertilizer use, animal manures, E-waste, sewage sludge, pesticides, wastewater irrigation, coal and so on (Anubhav *et al.*, 2022). The level of these metals in the area has increased in the past decades as a result of human activities such as mining. Heavy metals are a major source of Acid Rock Drainage (ARD) indicators in natural waters due to mining and industrial waste disposal and are considered highly toxic to aquatic organisms. Due to their non-biodegradability, these elements' compounds remain suspended or partially dissolved in water columns, leading to their accumulation in many aquatic organisms (Luo *et al.*, 2020; Hu *et al.*, 2022).

MATERIALS AND METHODS

The Study Area

Funakaye local government area, is in Gombe State, which is in the northeast geopolitical division of Nigeria. The town of Bajoga serves as the headquarters of the LGA, and the area encompasses several towns and villages, including Ashaka, Maraba, Bajoga, Tango, Wawa, and Kupto. The area has a history of limestone and gypsum mining activities. Currently, Ashaka Cement Industry operates a large-scale mining company that mines gypsum and limestone in the area. Funakaye LGA shares borders with the Gongola River and the Dadin Kowa Lake and is home to the Funakaye Emirate. The LGA boasts an estimated population of 327,300 (NPCN, 2016) inhabitants, with the most populous ethnic affiliation in the area being members of the Hausa and Fulani ethnic groups.



Fig 1: Location of the study area (Source: Google Map, 2021)

Funakaye LGA sits on an area measuring 1,275 km² (NBS, 2016) and witnesses two major seasons: the dry and wet. The average temperature in the area is 33 degrees Celsius, while humidity levels average 21 percent. The soils in the study area consist mainly of clay with fewer patches of laterite, mostly in hilly areas. Farming is a major economic activity for the people of Funakaye LGA, with crops such as sorghum, maize, beans, and millet grown in the area. The LGA has substantially large deposits of minerals such as gypsum,

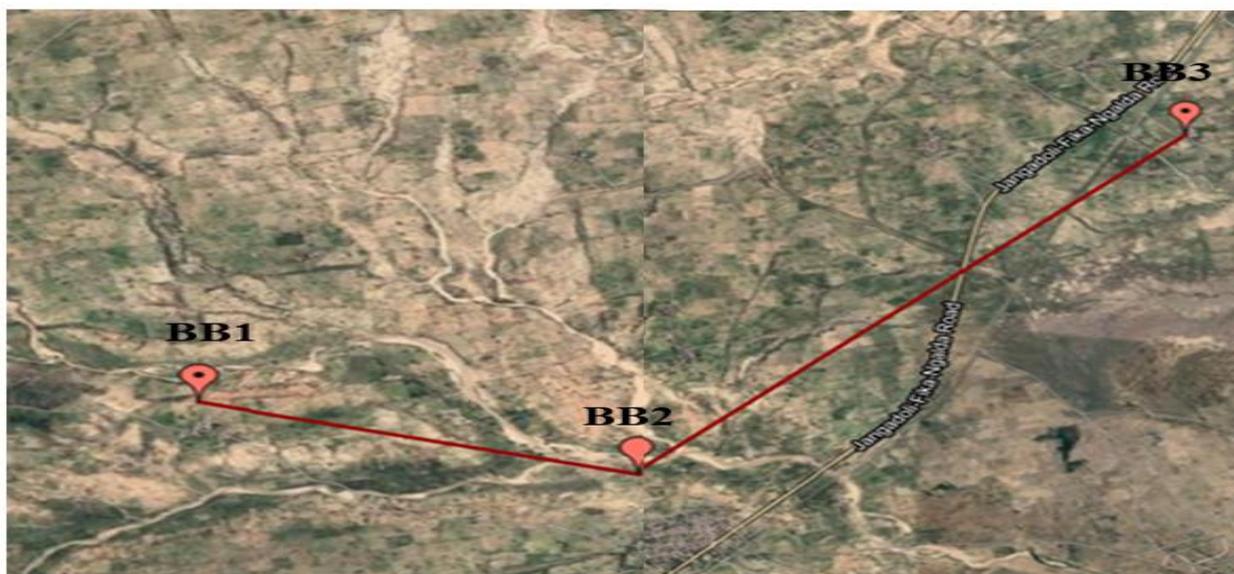
bentonite, and limestone. The area also hosts the Lafarge Africa-owned Ashaka cement plant, which contributes massively to the economic development of the region.

Sample Collection

Three sampling sites were selected using the global positioning system, GPS, as shown in Table 1. The distance from the mining site to the first point (i.e., from the mining site to Mangari) is about 7.54 km; from Mangari to Julahi is 1.939 km; and from Julahi to Mangha is 4.085 km.

Table 1: Locations of the sampled boreholes by GPS.

Location	Sample ID	Latitude (N)	Longitude (E)
Mangari	BB 1	10.7841967	11.3798433
Julahi	BB 2	10.7792133	11.3968550
Mangha	BB 3	10.8059367	11.4225233

**Fig. 2:** Ground Sampling Point within the Study Community (Source: Google Map 2021)

Groundwater Sampling

Three groundwater sources (boreholes) designated for potable consumption were identified. Each point was sampled three times, with a four-day interval between each sample collection. The sample sites were assigned names and serial numbers according to their locations inside Funakaye. All samples were obtained from operational boreholes. The samples were collected in 75cl washed, high-density polyethylene containers. To avoid external contamination during the sample collection, the following measures were taken:

- The samples were obtained directly from the boreholes after allowing the water to run for at least 5 minutes (Reimann *et al.*, 2003).
- All the sampling containers were rinsed three times with the very water to be sampled before every sample was collected.
- Changing of hand gloves after each event to avoid cross contamination.
- Before capping, we filled the sample bottles completely to ensure there was no air space left. This was done to prevent the water from

mixing with the air during the sampling process.

Sample Preservation

Water samples meant for the heavy metal analysis were acidified with 1 ml HNO_3 to achieve a pH of 2.0. The addition of acid to the water sample was to keep the metal ions in the dissolved state as well as to prevent microbial activities (APHA, 2005). The samples were kept in an ice chest loaded with ice blocks, transported to the laboratory, and stored in a refrigerator at 4°C until they were analyzed.

Heavy Metal Analysis

Nine samples were taken and placed in 75cl plastic bottles and transported to the Department of Soil Science, Ahmadu Bello University, Zaria for heavy metal analysis. The test was conducted using Varian AA 240FS Atomic Absorption Spectrophotometer (AAS) machine. The 75cl unfiltered water sample was transferred into a 1000ml beaker, to which 2 ml of concentration HNO_3 was added and heated to boil on a hot plate until the volume was reduced to about 15-20 ml. This was cooled and transferred to a volumetric flask

and made up to the mark. Standard solutions of suitable strength for individual metals were prepared. The blank, standard solutions, and samples were aspirated into the flame atomic absorption spectrophotometer. The calibration curves were plotted, and the concentration of the samples were obtained by extrapolation.

Preparation of Calibration Curve

To determine the concentration of heavy metals in the sample solution, calibration

curves were created. A variety of working standards were used to calibrate the device. Each metal's working standard solutions were made from standard solutions of their respective metals, and their absorbencies were determined using Atomic Absorption Spectrometry (AAS). By graphing absorbance as a function of metal standard concentration, a calibration curve for each metal ion to be examined was created.

Table 2: Graphite Furnace AAS (GF-AAS) Detection Limits ($\mu\text{g/L}$ or ppb)

Metal	Wavelength (nm)	Detection Limit (LOD, ppb)
Arsenic (As)	193.7	0.1 – 0.5
Lead (Pb)	283.3	0.05 – 0.2
Nickel (Ni)	232.0	0.1 – 0.5
Copper (Cu)	324.7	0.05 – 0.2
Chromium (Cr)	357.9	0.05 – 0.3
Iron (Fe)	248.3	0.1 – 0.5
Zinc (Zn)	213.9	0.05 – 0.2

Statistical Analysis

R Studio v4.4.2 was used to conduct statistical analysis. The statistical tests employed were the Chi-square and the student T-test which are typical Parametric tests of Homogeneity carried out for normally distributed data. The student T-test was chosen against the Z-test because the sampled data were less than 30. Chi-square, T-test, and correlation analysis was used to test for data variation between variables for heavy metals analysed.

RESULTS AND DISCUSSION

The statistical analysis for the chi-square result shows BB1, 1.201, BB2, 0.364, and BB3, 0.537. The critical value, calculated at the 95% level of confidence and a significance level of 5%, is 12.592. This implies that the χ^2 value is below the critical value, indicating a lack of significant difference between the samples. The t-test results show BB1, 0.323, BB2, 0.272, and BB3, 0.068, with a critical value of 2.172 at the 95% confidence level and a significance level of 5%. This means the T-

value is less than critical, which means there is no significant difference between the samples.

Heavy Metal Concentrations in the water samples

The heavy metals identified in the water samples collected in the study area are iron, copper, zinc, cadmium, chromium, lead and arsenic.

Iron

The concentration of iron (Fe) in the water samples varied from one point to another; sample BB2 recorded the highest mean value of 0.49 mg/l, BB1 recorded the lowest of 0.369 mg/l, and BB3 recorded a mean value of 0.428 mg/l. This indicates that the values exceed the WHO and NESREA standard value of 0.3 mg/l for drinking water (Figure 3) thereby suggesting a higher source of iron contamination. This outcome is also in line with research done by Bawa *et al.* (2019) in Taraba and Adamawa states, which found an elevated Fe content in groundwater due to mining operations.

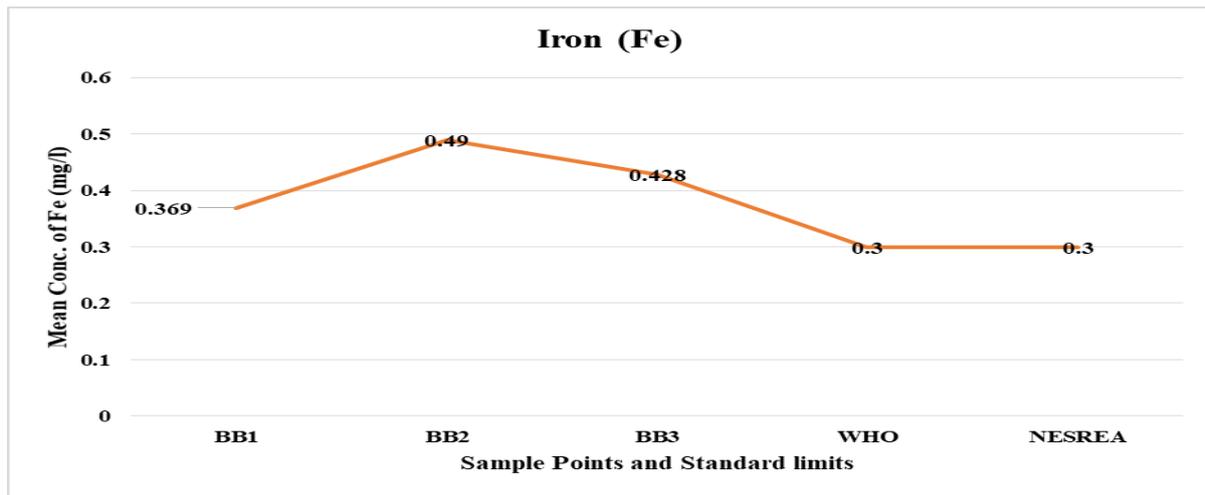


Figure 3: Iron (Fe) Concentration in the water samples

The presence of a high Fe concentration in the groundwater may be due to the natural geology dissolution of iron minerals from rock and soil, precipitation/run off and infiltration activities, use of galvanized materials in handpump construction, agricultural activities and mining activities of the area (Ocheri, 2010; Blarasin *et al.*, 1999). Iron is an essential element in drinking water and food for almost all living organisms as it participates in a wide variety of metabolic processes, including oxygen transport, deoxyribonucleic acid (DNA) synthesis, and electron transport (Zeidan *et al.*, 2024). However, due to iron's capacity to generate free radicals, its concentration in bodily tissues must be carefully managed since excessive levels might result in tissue damage. Iron metabolism disorders are prevalent human illnesses that include a wide array of conditions with varying clinical symptoms,

from anaemia to iron excess, and potentially neurodegenerative diseases (Abbaspour *et al.*, 2014; Rahman *et al.*, 2024). This study revealed a maximum iron concentration of 0.49 mg/L and a minimum concentration of 0.36 mg/L, which is notably lower than the findings of Rahman *et al.* in 2024 and Merrill *et al.* in 2011, who reported iron concentrations of 1.9 mg/L and 2.0 mg/L in potable groundwater from Jalalabad Cantonment in Pakistan and rural Bangladesh, respectively.

Copper

The concentration of copper (Cu) in the water samples varied from one point to another; BB3 had the highest mean value of 0.102 mg/l, BB1 had the lowest of 0.063 mg/l, and BB2 had a mean value of 0.085, showing that the value was less than the WHO and NESREA standard limits of 1.2 mg/l (Figure 4).

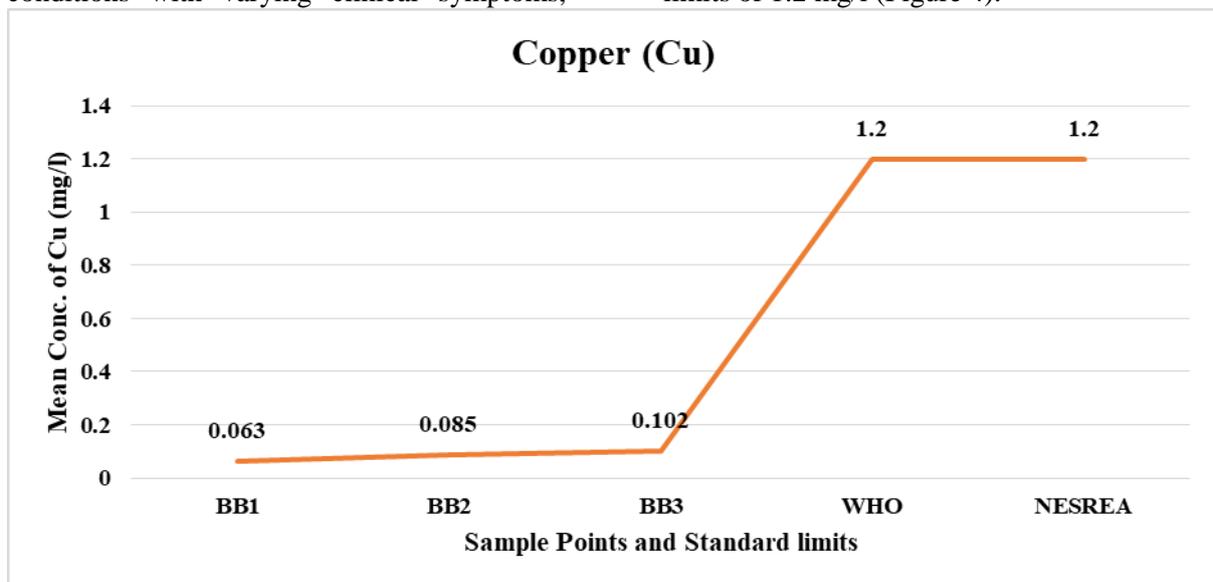


Fig. 4: Copper (Cu) Concentration in the water samples

Consumption of this water would therefore not cause adverse effects on consumers health. Osafo (2011) reported similar results from studies in the East Akim Municipality. Sampling points BB3 recorded the highest mean values, suggesting that the proximity of these sampling points made it easier for them to be influenced by the same conditions leading to similar levels of copper concentrations. This difference in the copper concentrations was significant, attesting to the difference in factors that affect the concentration of heavy metals such as copper. Both natural sources and human activities can release copper into the environment. These include mining, metal production, wood

production, and phosphate fertilizer production. Human activity and natural releases of copper lead to its widespread presence in the environment, particularly near mines, industrial settings, landfills, and waste disposal sites (NRC, 2000; Kegley *et al.*, 2009; MDH, 2024).

Zinc

Sample BB2 recorded the highest mean zinc concentration of 0.178 mg/l while BB3 recorded the lowest concentration of 0.009 mg/l, and BB1 recorded a mean concentration of 0.134, all of which are below the WHO and NESREA standard values of 3 and 5 mg/l respectively (Figure 5).

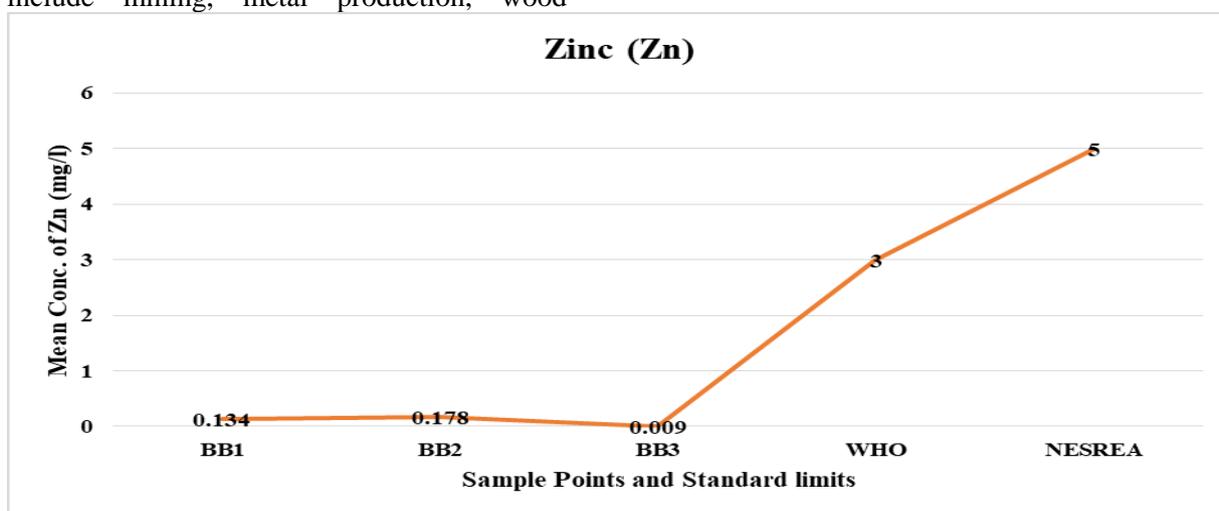


Figure 5: Zinc (Zn) Concentration in the water samples

Due to lower concentrations of zinc in the samples there is no detrimental effect when the water is used for domestic and other purposes at the level obtained in this study. Results obtained in this study are similar to reports by Ankomah-Appiah (2011). However, they fall significantly short of the results obtained by Osafo (2011) from surface water in the East Akim Municipality. The highest mean zinc concentration recorded at sample point BB2, may be due to their location down a slope. Therefore, contamination from either anthropogenic or natural processes in the area could be easily leached or runoff down the slope. The difference in the values recorded at the sampling points was significant, inferring that the conditions that contribute to the

concentration of zinc in the study area differed greatly. Variation in terms of runoffs and flows has the potential to increase the level of contaminants in a water body.

Cadmium

The concentration of Cadmium (Cd) in the water samples varied from one point to another; BB1 recorded the highest mean value of 0.011 mg/l, BB2 recorded the lowest of 0.004 mg/l, and BB3 recorded a mean value of 0.008, indicating that the values are greater than the WHO's and NESREA standard values of 0.003 mg/l for Cd in drinking water (Figure 6). The result is also consistent with a study done by Usman *et al.* (2020) in Gombe state, which found greater Cd concentrations in groundwater due to mining activity.

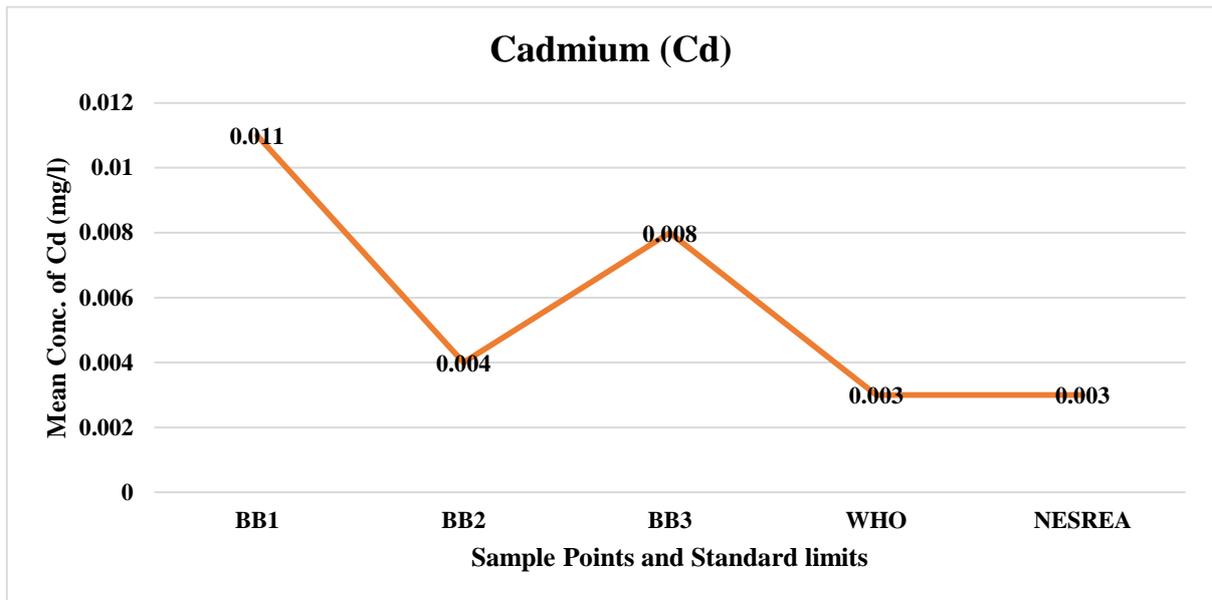


Figure 6: Cadmium (Cd) Concentration in the water samples

The Cadmium concentration remains constant regardless of the sample point and sampling time. Mining and other factors, such as natural geology and water flow, increase the concentrations of cadmium. Therefore, as far as cadmium is concerned, the water is not safe for human consumption due to the Cd concentrations that is above the standards of WHO and NESREA.

Chromium

The concentration of chromium (Cr) in the water samples varied from one point to the other; the highest mean value of 0.793 mg/l was recorded at BB2, while BB3 recorded the lowest of 0.489 mg/l, while BB1 recorded a mean value of 0.527, which shows the value is greater than the standard values of 0.05 mg/l and 0.03mg/l set by WHO and NESREA (Figure 7).

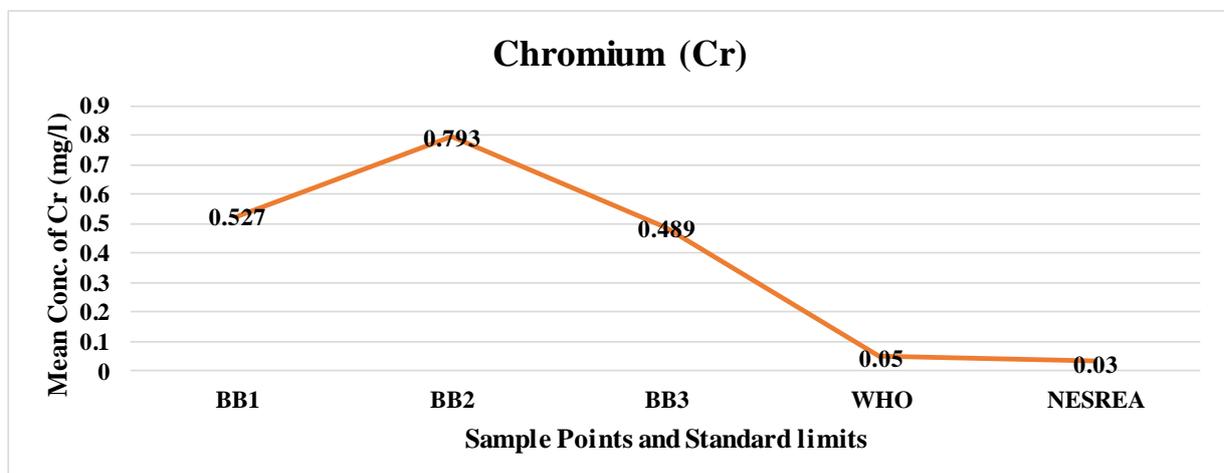


Figure 7: Chromium (Cr) concentration in the water samples

Although chromium does not play a major role when it comes to heavy metals that affect adversely the health of consumers, it is an important element to monitor due to its indicative role. Chromium concentrations in this study ranged from 0.489 mg/l to 0.793 mg/l. Significant differences in concentrations were observed. BB2 sampling points recorded the highest mean concentrations. The natural geological structure of these areas as well as

pollution from anthropogenic activities could contribute significantly to the contamination of water bodies with chromium and many other metals; however, these concentrations did exceed the WHO and NESREA standard of 0.05 mg/l and 0.03 mg/l respectively for drinking water. The excess of these detection limits for drinking water in the study area could potentially impact the health of consumers.

Lead

The concentration of lead (Pb) in the water samples varied from one point to another; BB3 recorded the highest mean value of 0.428 mg/l, BB1 recorded the lowest of 0.181 mg/l, and BB2 recorded a mean value of 0.341, indicating that the value exceeds the WHO and

NESREA standard value of 0.01 mg/l and 0.015 mg/l respectively (Figure 8). This finding is also in tandem with the study conducted by Bawa *et al.* (2019) in Taraba and Adamawa states, which recorded a higher Pb concentration in groundwater due to mining activities.

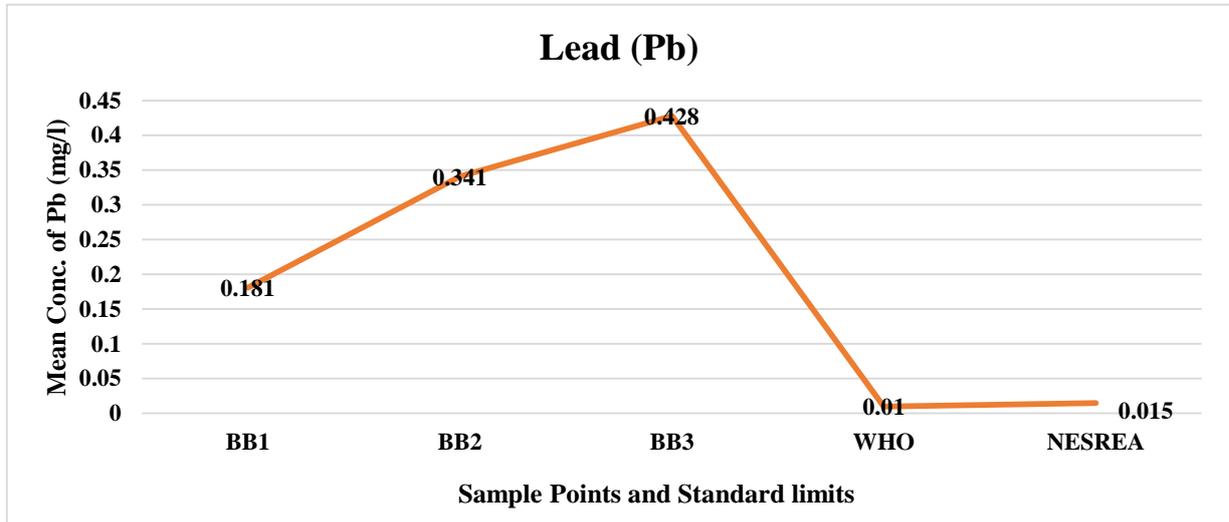


Figure 8: Lead (Pb) Concentration in the water samples

Lead is one of the most prevalent metals in the earth's crust, with an average concentration of 13 mg/kg. Food ingestion, dust and dirt accounts for 80% of daily lead intake by humans (FDE, 2008; WHO, 2023). Avoiding its intake is crucial due to its carcinogenic properties. The recorded values ranged from 0.181 mg/l to 0.428 mg/l, surpassing the WHO and NESREA recommended limit of 0.01 mg/l and 0.015 mg/l for lead in drinking water respectively. The results indicated a higher

level of Pb contamination in the study area. Mining and other factors, such as natural geology, contribute to an increase in lead contamination levels globally (Gupta and Nikhil, 2016; Abanyie *et al.*, 2023).

Arsenic

Arsenic (As) concentrations in the water samples varied from one location to another; BB3 recorded the highest mean value of 1.115 mg/l, BB1 the lowest at 0.748 mg/l, and BB2 has a mean value of 0.887 mg/l (Figure 9).

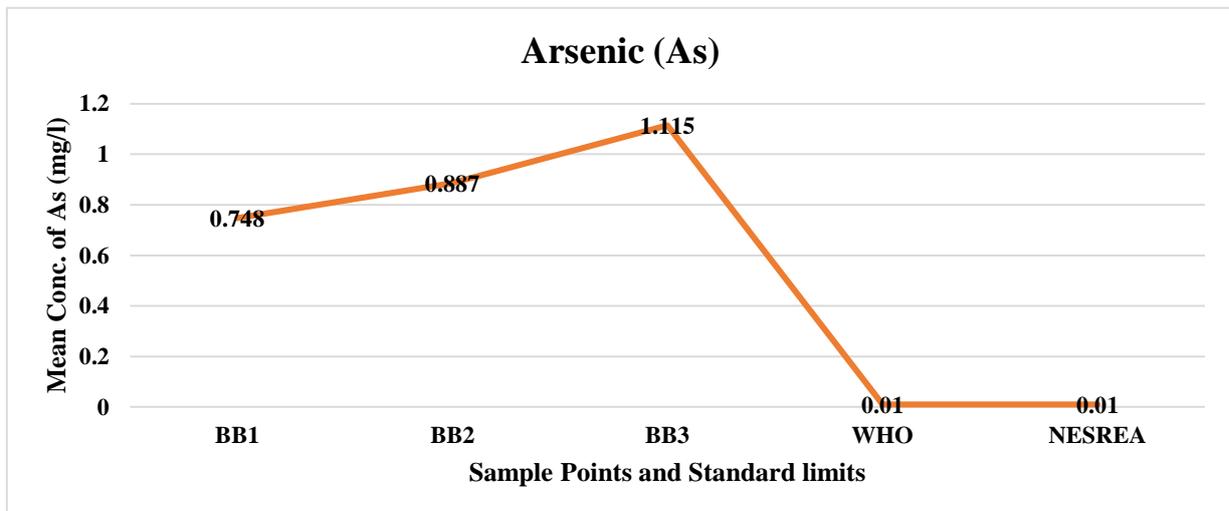


Figure 9: Arsenic (As) Concentration in the water samples

Long-term exposure to low levels of arsenic through drinking water can result in skin cancer (WHO, 2023; Rahimi Kakavandi *et al.*, 2023), and there is also evidence of an increasing risk of bladder, kidney, liver, and lung tumors. The arsenic concentration in this study ranged from 0.784 mg/L to 1.115 mg/L, indicating higher concentrations than the WHO and NESREA standard limits of 0.01 mg/l for Arsenic in drinking water. Therefore, the water samples contain significant Arsenic concentrations. This outcome is also in line with research done by Eze, P.N. *et al.* (2022) in Northeastern Nigeria, which found an elevated As content in groundwater due to mining operations. Using water from these sources for domestic purposes, including drinking, may lead to fatal cases of arsenic poisoning. The high concentration of As in the groundwater could potentially be attributed to the gold mining, sulfide mineral oxidation, geogenic leaching, natural geology of the area and the water flow in the study area (Blarasin *et al.*, 1999; Tabelin *et al.*, 2018; Usman *et al.*, 2020).

Cumulative Toxicity of Multiple Heavy Metals.

Research indicates that co-exposure to heavy metals in groundwater leads to greater-than-additive toxicity through common oxidative stress pathways, competitive metal transport systems, and cumulative DNA damage (Wang *et al.*, 2023; Jaishankar *et al.*, 2022). The combination of As, Pb, and Cd accelerates lipid peroxidation in kidney cells by 40-60% compared to individual metals. In Bangladesh, populations exposed to all three metals develop chronic kidney disease 3.2 times faster than those exposed to only one metal (Ahmad *et al.*, 2024; Rahman *et al.*, 2023). New studies reveal that Cr(VI)-As co-exposure increases bladder cancer risk by 4.7-fold in Taiwanese populations due to strand breaks and As inhibiting repair enzymes. This combination is classified as a Group 1 carcinogenic combination by IARC (Lin *et al.*, 2023; IARC, 2023). Additionally, Fe-Cu interactions produce hydroxyl radicals, leading to 30% more iron deposition in livers of copper-exposed individuals. This explains the faster development of cirrhosis in Indian populations with dual exposure (Zhang *et al.*, 2024; Mehta *et al.*, 2023). Recent studies show that Cd-Pb co-exposure causes 50% more bone accumulation than expected due to common calcium transport pathways, leading to osteoporosis and renal failure in Chinese mining districts (Bonewald *et al.*, 2024; Li *et al.*, 2023). Zinc supplementation can lower Cd absorption by 35% in contaminated

areas, but high zinc intake can cause copper deficiency anemia within 8 weeks (Vesey, 2023; Johnson *et al.*, 2024). A 2024 meta-analysis found that children exposed to Pb-As-Mn had 11.3 points worse IQ scores than those exposed to single metals (Grandjean *et al.*, 2024; Chen *et al.*, 2023). Advanced neuroimaging suggests synergistic injury to the basal ganglia and hippocampus is responsible for the increased risk of cancer. The As-Cr-Cd-Ni combo activates all 10 cancer markers simultaneously (Hanahan *et al.*, 2023). Population studies in Chile show a 5.8-fold increase in liver cancer incidence when all four metals are present (Aguilera *et al.*, 2024). New animal models also show Pb-As-Cd combinations lower sperm counts by 72% compared to controls. Birth defect rates in Michigan's Flint cohort are 2.9 times higher than expected (Pant *et al.*, 2023; Hanna-Attisha *et al.*, 2024).

CONCLUSION

Groundwater contamination of some selected boreholes was assessed in Funakaye L.G.A in Gombe State to determine heavy metal contamination and the study's results indicated the presence of certain heavy metals in the study area, including Fe, Cd, Cr, Pb, As, Zn, and Cu. The concentrations were compared to the WHO and NESREA standard limits for quality drinking water and the results indicated that heavy metal concentrations in the boreholes were generally high, with Fe ranging from 0.369mg/l to 0.490mg/l, Cd ranging from 0.008mg/l to 0.011mg/l, Cr ranging from 0.489mg/l to 0.793mg/l, Pb ranging from 0.181mg/l to 0.428mg/l, and As ranging from 0.748mg/l to 1.115mg/l, thus exceeding the WHO and NESREA recommended limits. Zn and Cu concentrations in the samples were found to be lower than the recommended limits for drinking water, with Zn ranging from 0.009mg/l to 0.178mg/l and Cu from 0.063mg/l to 0.102mg/l. The data from the study indicated that there is heavy metal pollution in the studied boreholes, which may be attributed to the mining activities taking place and natural geology in the study area, indicating that pollutants have leached into the groundwater sources. The presence of these heavy metal pollutants in the groundwater is an indicator of the potential health risks that can be associated with the consumption and uptake of these metals, which can cause so many illnesses such as upper respiratory tract infection, nasal mucous membrane irritation, haemolytic anaemia, constipation, anaemia, high blood pressure, low sperm count, cancer of the nasal cavity and lungs, infant mortality, pancreatitis

and damage of hepatic parenchyma in both humans and animals.

Recommendations

Based on the findings of this study, the following recommendations are made:

- a. A continuous monitoring strategy for water resources management be designed to guarantee that relevant measures are chosen and performed in the area and on time.
- b. To prevent contamination and further exposure to heavy metal pollution in the study area, motorised deep boreholes should be drilled far away from the contaminating locations.
- c. The government through local community leaders should raise public awareness about the potential risk of groundwater pollution. And to provide means for treating polluted water before consumption.
- d. Standard practices for mining activities should be ensured including establishing measures against environmental pollution or buffer zones if necessary.

CONFLICT OF INTEREST

The authors declare no conflict of interest

REFERENCES

- Abanyie, S. K., Apea, O. B., Abagale, S. A., Amuah, E. E. Y., and Sunkari, E. D. (2023). Sources and Factors Influencing Groundwater Quality and Associated Health Implications: A Review. *Emerging Contaminants*, 9(2), 100207. doi:<https://doi.org/10.1016/j.emcon.2023.100207>
- Abbaspour, N., Hurrell, R., and Kelishadi, R. (2014). Review on Iron and Its Importance for Human Health. *Journal of research in medical sciences: the official journal of Isfahan University of Medical Sciences*, 19, 164-174.
- Ahmad, S., Khan, M. H., Rehman, M. F. U., & Liu, G. (2024). Quantifying oxidative stress from arsenic-lead-cadmium co-exposure in renal cells. *Chemosphere*, 349, 140887.
- Ali A. F., Abdullahi A. S., Zangina A. S., (2018). Environmental Issues and the Prospects of Mining in Nigeria. *Dutse Journal of Pure and Applied Sciences (DUJOPAS)*, 4(2): 531-539,
- Annapoorna H. and Janardhana M.R. (2015). Assessment of Groundwater Quality for Drinking Purpose in Rural Areas Surrounding a Defunct Copper Mine. *Aquatic Procedia*, Vol. 4, pp. 685–692.
- Ankomah-Appiah, E. (2011). Assessment of acid rock drainage dissolved trace metal and its impact on water quality in mining areas. Department of Theoretical and Applied Biology, Kwame Nkrumah University of Science and Technology.
- Anubhav, S., Anuj, S., Rohit, K. V., Rushikesh, L. C., Pritam, P. P., Varad, N., . . . Mahipal, S. S. (2022). Heavy Metal Contamination of Water and Their Toxic Effect on Living Organisms. In D. Daniel Junqueira and O. Danielle Palma de (Eds.), *The Toxicity of Environmental Pollutants* (pp. Ch. 2). Rijeka: *IntechOpen*.
- APHA (2005). Standard methods for examination of water and waste water, 21st edn., *American Public Health Association*, Washington, D.C
- Argos, M., Kalra, T., Rathouz, P., Chen, Y., Pierce, B., Parvez, F., ... & Ahsan, H. (2010). Arsenic exposure from drinking water, and all-cause and chronic-disease mortalities in Bangladesh (heals): a prospective cohort study. *The Lancet*, 376(9737), 252-258. [https://doi.org/10.1016/s0140-6736\(10\)60481-3](https://doi.org/10.1016/s0140-6736(10)60481-3)
- Bawa, M. A., Okunola, O. J., & Ezech, G. C. (2019). Impact of artisanal gold mining on water quality in Taraba State, Nigeria. *Journal of Environmental Science and Pollution Research*, 5(2), 112–120.
- Blarasin, M, Corbrera, A. Villegas, M, Frigerio, C and Bettera S. (1999). Groundwater Contamination from Septic tank system in two neighbourhoods in Rio Carto City, Cordoba, Argentina. In Chilton J. (ed) *Groundwater in the Urban Environment Selected City profiles*, Balkema, Rotterdam, p 31-38
- Bonewald, L. F., Smith, S. Y., & Drezner, M. K. (2024). Isotopic tracing of cadmium-lead co-accumulation in bone. *Bone Research*, 12(1), 1–12.
- Chakraborti, D., Rahman, M., Mukherjee, A., Alauddin, M., Hassan, M., Dutta, R., ... & Hossain, M. (2015). Groundwater arsenic contamination in Bangladesh—21 years of research. *Journal of Trace Elements in Medicine and Biology*, 31, 237-248. <https://doi.org/10.1016/j.jtemb.2015.01.003>

- Chakraborty, T. K., Ghosh, G. C., Ghosh, P., Jahan, I., Zaman, S., Islam, M. S., . . . Khan, A. S. (2022). Arsenic, Iron, and Manganese in Groundwater and Its Associated Human Health Risk Assessment in the Rural Area of Jashore, Bangladesh. *J Water Health*, 20(6), 888-902. doi:10.2166/wh.2022.284
- Davies BE, Bowman C, Davies TC, Sellinus O (2005) Medical geology: perspectives and prospects. *Essent Med Geol*, Elsevier Inc., pp 1–14
- Delgado C., Pacheco J., Cabrera A., Batllori E., Orellana R., Bautista F. (2010), “Quality of Groundwater for Irrigation in Tropical Karst Environment: The Case of Yucatan, Mexico”, *Agric Water Manag*, 97. 1423–1433.
- El Amari K, Valera P, Hibti M, Pretti S, Marcello A, Essarraj S (2014) Impact of mine tailings on surrounding soils and ground water: case of Kettaraold mine, Morocco. *Journal of African Earth Sciences* 100. 437–449
- Elumalai, V., Nethononda, V. G., Manivannan, V., Rajmohan, N., Li, P., and Elango, L. (2020). Groundwater Quality Assessment and Application of Multivariate Statistical Analysis in Luvuvhu Catchment, Limpopo, South Africa. *Journal of African Earth Sciences*, 171, 103967. doi:https://doi.org/10.1016/j.jafrearsci.2020.103967
- Eze, P. N., Abdullahi, M. L., & Abba, H. T. (2022). Geogenic and mining-induced arsenic contamination in northeastern Nigeria. *Journal of African Earth Sciences*, 185, 104420.
- Florida Department of Environment. (2008). Monitoring Lead and Copper in Florida Drinking Water. [https://floridadep.gov/water/source-drinking-water/content/monitoring-lead-and-copper-florida-drinking-water] (Accessed on January 2025).
- Ghalib, H. B. (2017), “Groundwater Chemistry Evaluation for Drinking and Irrigation Utilities in East Wasit Province, Central Iraq”, *Appl Water Sci*, 7. 3447-3467.
- Ghosh, G., Khan, M., Chakraborty, T., Zaman, S., Kabir, A., & Tanaka, H. (2020). Human health risk assessment of elevated and variable iron and manganese intake with arsenic- safe groundwater in Jashore, Bangladesh. *Scientific Reports*, 10(1). <https://doi.org/10.1038/s41598-020-62187-5>.
- Gupta, S. K., and Nikhil, K. (2016). Ground Water Contamination in Coal Mining Areas: A Critical Review. *International Journal of Engineering and Applied Sciences (IJEAS)*, 3(2), 69-74.
- Hakkou R, Benzaazoua M, Bussiere B (2008) Acid mine drainage at the abandoned Kettara Mine (Morocco): 1. Environmental characterization. *Mine Water Environ* 27:145–159.
- Hu, X., Peng, M., Sheng, X., Shi, H., Zhang, J., Liu, J., . . . Liu, T. (2022). Continuous and Effective Treatment of Heavy Metal in Acid Mine Drainage Based on Reducing Barrier System: A Case Study in North China. *Journal of Hazardous Materials Advances*, 8, 100152. doi:https://doi.org/10.1016/j.hazadv.2022.100152
- International Agency for Research on Cancer. (2023). IARC monographs on the identification of carcinogenic hazards to humans (Vol. 132). Lyon, France:
- Ibrahim, M. K., Bello, O. S., & Adamu, H. M. (2021). Risk assessment of heavy metals in drinking water from mining areas in Adamawa State. *Environmental Geochemistry and Health*, 43(4), 1899–1915.
- Ishaku J.M, (2011), Assessment of groundwater quality index for Jimeta-Yola area, Northeastern Nigeria. *Journal of Geology and Mining Research*. 3(9), 219-231.
- Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2022). Molecular mechanisms of heavy metal toxicity in synergistic exposures. *Journal of Biochemical and Molecular Toxicology*, 36(4), e23012.
- Kalaivanan K., Gurugnanam, B., Hamid Reza Pourghasemi, Suresh, M. and Kumaravel S., 2017. Spatial assessment of groundwater quality using water quality index and hydrochemical indices in the Kodavanan sub-basin, Tamil Nadu, India. *Sustain. Water Resour. Manag.*, DOI:10.1007/s40899017-0148-x, 15 pp.
- Kegley, S. E., Hill, B. R., Orme, S. and Choi, A. H. (2009). Copper. PAN Pesticide

- Database, Pesticide Action Network, North America (San Francisco, CA), [http://www.pesticideinfo.org], (Accessed March 2011).
- Khalil A, Hanich L, Bannari A, Zouhri L, Pourret O, Hakkou R (2013) Assessment of soil contamination around an abandoned mine in a semi-arid environment using geochemistry and geostatistics: prework of geochemical process modeling with numerical models. *J GeochemExplor* 125:117–129
- Khan, R., and Jhariya, D. C. (2017). Groundwater Quality Assessment for Drinking Purpose in Raipur City, Chhattisgarh Using Water Quality Index and Geographic Information System. *Journal of the Geological Society of India*, 90(1), 69-76. doi:10.1007/s12594-017-0665-0
- Krishna kumar, S., Logeshkumaran, A., Magesh, N. S., Godson, P. S., and Chandrasekar, N. (2015). Hydro-Geochemistry and Application of Water Quality Index (Wqi) for Groundwater Quality Assessment, Anna Nagar, Part of Chennai City, Tamil Nadu, India. *Applied Water Science*, 5(4), 335-343. doi:10.1007/s13201-014-0196-4
- Li, P., Karunanidhi, D., Subramani, T., and Srinivasamoorthy, K. (2021). Sources and Consequences of Groundwater Contamination. *Arch Environ Contam Toxicol*, 80(1), 1-10. doi:10.1007/s00244-020-00805-z.
- Li, P., Wu, J., Tian, R., He, S., He, X., Xue, C., and Zhang, K. (2018). Geochemistry, Hydraulic Connectivity and Quality Appraisal of Multilayered Groundwater in the Hongdunzi Coal Mine, Northwest China. *Mine Water and the Environment*, 37(2), 222-237.
- Li, Y., Wang, J., Zhang, H., & Chen, X. (2023). Osteoporosis and renal dysfunction in Chinese mining populations. *Environmental Health Perspectives*, 131(4), 047016.
- Lin, Y.F., Wu, C.C., & Chen, Y.M. (2023). Mechanistic synergy between chromium and arsenic in bladder carcinogenesis. *Carcinogenesis*, 44(3), 218–229.
- Luo, C., Routh, J., Dario, M., Sarkar, S., Wei, L., Luo, D., and Liu, Y. (2020). Distribution and Mobilization of Heavy Metals at an Acid Mine Drainage Affected Region in South China, a Post-Remediation Study. *Science of The Total Environment*, 724, 138122. doi:https://doi.org/10.1016/j.scitotenv.2020.138122
- Mara, D. and Evans, B. 2011. Sanitation and water supply in low-income countries. Ventus Publishing, 142 pp.
- Massally, R-E.M., Sheriff, A.B., Kaitibi, D., Abu, A., Barrie, M. and Taylor, E. T. 2017. Comprehensive Assessment of Groundwater Quality around a Major Mining Company in Southern Sierra Leone. *Journal of Water Resource and Protection*, 9, 601-613.
- Mehta, K. J., Coombes, J. D., & Brunt, E. M. (2023). Dual exposure to iron and copper in liver cirrhosis epidemiology. *Hepatology Communications*, 7(4), e0178.
- MDH (Minnesota Department of Health), (2024). Copper in drinking water, health effects and how to reduce exposure.
- Merrill, R. D., Shamim, A. A., Ali, H., Jahan, N., Labrique, A. B., Schulze, K., . . . West, K. P. (2011). Iron Status of Women Is Associated with the Iron Concentration of Potable Groundwater in Rural Bangladesh1–3. *The Journal of Nutrition*, 141(5), 944-949. doi:https://doi.org/10.3945/jn.111.138628
- Moye J, Picard-Lesteven T, Zouhri L, El Amari K, Hibti M, Benkaddour A (2017) Groundwater assessment and environmental impact in the abandoned mine of Kettara (Morocco). *Environ Pollut* 231(Pt 1):899–907.
- Mshelia, M. S., Shettima, I. M., Ibrahim, U. A., and Yuguda, U. (2024). Utilising Microflora from Poultry Litter Effluent for Bioremediation of Lead and Nickel Polluted Soil in Maiduguri, Borno State. *Arid-zone Journal of Basic & Applied Research*, 3(2), 60-71. doi: 10.55639/607.343332
- Mukherjee, A., Coomar, P., Sarkar, S., Johannesson, K. H., Fryar, A. E., Schreiber, M. E., . . . Vengosh, A. (2024). Arsenic and Other Geogenic Contaminants in Global Groundwater. *Nature Reviews Earth & Environment*, 5(4), 312-328. doi:10.1038/s43017-024-00519-z.
- Muthuminal, R., and Mohana Priya, R. (2022). An Overview on Techniques Involved in

- Recharging Ground Water and Its Impacts. In S. Muhammad and A. Fiaz (Eds.), *Irrigation and Drainage* (pp. Ch. 3). Rijeka: IntechOpen.
- National Research Council (US) Committee on Copper in Drinking Water. *Copper in Drinking Water*. Washington (DC): National Academies Press (US); (2000). 1, Introduction. Available from:
- National Bureau of Statistic (2016) <http://www.citypopulation.de/php/nigeria-admin.php?adm2id=NGA016005>
- National Population Commission of Nigeria (2016) "Population Projection" <http://www.citypopulation.de/php/nigeria-admin.php?adm2id=NGA016005>.
- Obasi PN, Akudinobi BEB (2015) Geochemical assessment of heavy metal distribution and pollution status in soil/stream sediment in the Ameka mining area of Ebonyi state, Nigeria. *Afr J Geosci Res* 3(4):01–07
- Obiora SC, Chukwu A, Toteu SF, Davies TC (2018) Contamination of the potable water supply sources in the lead–zinc mining communities of Enyigba, Southeastern Nigeria. *Mine Water Environ*. <https://doi.org/10.1007/s10230-018-0550-0>.
- Ocheri, Maxwell Idoko (2010). Distribution of Iron in Rural Groundwater of Benue State, Nigeria. *Journal of Research in Forestry, Wildlife and Environment*, 2, (2).
- Osafo, E. (2011). The Effect of Small-Scale Gold Mining Activities on the Birim River in the East Akim Municipality of the Eastern Region. *Master's Thesis*, Kwame Nkrumah University.
- Pradhan, B., Chand, S., Chand, S., Rout, P. R., and Naik, S. K. (2023). Emerging Groundwater Contaminants: A Comprehensive Review on Their Health Hazards and Remediation Technologies. *Groundwater for Sustainable Development*, 20, 100868. doi:<https://doi.org/10.1016/j.gsd.2022.100868>
- Islam Ph. D, M., and Mostafa, M. (2021). Groundwater Quality and Risk Assessment of Heavy Metal Pollution in Middle-West Part of Bangladesh. *Journal of Environmental Protection*.doi:10.47363/JEESR/2021(3)143.
- Rahimi Kakavandi, N., Mousavi, T., Asadi, T., Moradi, A., Esmaeili, M., Habibian Sezavar, A., . . . Abdollahi, M. (2023). An Updated Systematic Review and Dose-Response Meta-Analysis on the Relation between Exposure to Arsenic and Risk of Type 2 Diabetes. *Toxicology Letters*, 384, 115-127. doi:<https://doi.org/10.1016/j.toxlet.2023.08.001>
- Rahman, I., Wahab, M. A., Akter, M., & Mahanta, T. R. (2024). Iron in Drinking Water and its Impact on Human Health –A Study in Selected Units of Jalalabad Cantonment. *Bangladesh Armed Forces Medical Journal*, 56(2), 58–64.
- Rahman, M. M., Hossain, K. F. B., & Sikder, M. T. (2023). Epidemiology of chronic kidney disease in multi-metal exposed populations in Bangladesh. *Environmental Research*, 228, 115832.
- Rahman, M. W., and Ferdos, J. (2024). A Comprehensive Review of the Contamination of Groundwater in Bangladesh.
- Reimann, C, Bjorvatn, K., Frengstad, B., Melaku, Z., Teklehaimanot, R and Siewers, U. (2003). Drinking water quality in the Ethiopian section of the east African rift valley I – data and health aspects. *The Science of Total Environment*, 311:65-80.
- Singh, V., Ahmed, G., Vedika, S., Kumar, P., Chaturvedi, S. K., Rai, S. N., . . . Kumar, A. (2024). Toxic Heavy Metal Ions Contamination in Water and Their Sustainable Reduction by Eco-Friendly Methods: Isotherms, Thermodynamics and Kinetics Study. *Scientific Reports*, 14(1), 7595. doi:10.1038/s41598-024-58061-3.
- Su, Z., Wu, J., He, X., and Elumalai, V. (2020). Temporal Changes of Groundwater Quality within the Groundwater Depression Cone and Prediction of Confined Groundwater Salinity Using Grey Markov Model in Yinchuan Area of Northwest China. *Exposure and Health*, 12(3), 447-468. doi:10.1007/s12403-020-00355-8
- Tabelin, C. B., Igarashi, T., Villacorte-Tabelin, M., Park, I., Opiso, E. M., Ito, M., and Hiroyoshi, N. (2018). Arsenic,

- Selenium, Boron, Lead, Cadmium, Copper, and Zinc in Naturally Contaminated Rocks: A Review of Their Sources, Modes of Enrichment, Mechanisms of Release, and Mitigation Strategies. *Science of The Total Environment*, 645, 1522-1553. doi:<https://doi.org/10.1016/j.scitotenv.2018.07.103>
- Tiwari, A., Abhay, b., Singh, K., Amit, b., and Singh, M. (2015). Hydrogeochemical Analysis and Evaluation of Surface Water Quality of Pratapgarh District, Uttar Pradesh, India. *Applied Water Science*, 7. doi:10.1007/s13201-015-0313-z.
- UNESCO, (2006), UNESCO water portal newsletter no. 161: Water-related diseases.
- United Nations Sustainable Development Goals Report. (2023). Towards a rescue plan for people and planet.
- Usman, A., Murtala, B. A., & Abdullahi, Y. (2020). Assessment of heavy metals in groundwater near mining areas in Gombe State, Nigeria. *Nigerian Journal of Mining and Geosciences*, 56(1), 45–58.
- Vasanthavigar, K. Srinivasamoorthy, R. Rajiv Gantha, K. Vijayaraghavan and V.S. Sarma, (2010), Characterization and quality assessment of groundwater with special emphasis on irrigation utility: Thirumanimuttar sub-basin, Tamil Nadu, India. *Arabian Journal of Geosciences*, DOI 10 1007/s12517-010 0190-6.
- Wang, L., Chen, J., & Xu, M. (2023). Mechanistic insights into heavy metal mixture toxicity in aquatic systems. *Environmental Science & Technology*, 57(8), 3124–3135.
- WHO, (2023). Exposure to lead: a major public health concern, third edition. Preventing disease through healthy environments.
- WHO, (2023). Guidelines for drinking-water quality: fourth edition incorporating the first and second addenda.
- Zhang, X., Li, W., & Zhao, Y. (2024). Iron-copper interactions in hepatic metal accumulation: An MRI study. *Journal of Trace Elements in Medicine and Biology*, 81, 127339.
- Zeidan, R. S., Martenson, M., Tamargo, J. A., McLaren, C., Ezzati, A., Lin, Y., . . . Anton, S. (2024). Iron Homeostasis in Older Adults: Balancing Nutritional Requirements and Health Risks. *The Journal of nutrition, health and aging*, 28(5), 100212.
- Zhao, Y., Song, J., Cheng, K., Liu, Z., and Yang, F. (2024). Migration and Remediation of Typical Contaminants in Soil and Groundwater: A State of Art Review. *Land Degradation & Development*, 35(8), 2700-2715. doi:<https://doi.org/10.1002/ldr.5>