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Drinking Water Quality, Nitrate and Heavy Metal Quantification, and Health Risk Assessment of Water Sources around a Tsauni Gold Mine, Gwagwalada, Abuja-Nigeria

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ABSTRACT

Mining activities, especially gold extraction, have been widely documented to significantly disrupt the natural environment, often resulting in release of harmful contaminants. This study assesses the drinking water quality in the Babban Tsauni artisanal gold mining community by analyzing physicochemical parameters and heavy metal concentrations, using standard methods. Parameters include pH, temperature, total dissolved solids, conductivity, dissolved oxygen, nitrate, and heavy metals (As, Pb, Ni, Mn, Cr, Zn, Cu). Heavy metal pollution indices and health risks were evaluated. Results show that physicochemical parameters and nitrate concentration were within safe limits, and heavy metal concentrations were in the range of 0.724-2.886, 0.004-0.017, 0.001-0.243, 0.037-6.910, 0.051-0.268, 0.006-0.151, 0.009-0.060 (ppm) for As, Pb, Ni, Mn, Cr, Zn and Cu, respectively. Of the seven heavy metals considered, only Zn and Cu had values within the WHO permissible limit. The contamination factor for Mn was 20.0, with other heavy metals having values of less than 1. However, the overall pollution index for the heavy metals was 0.52, interpreted as non-pollution. There was no severe significant cancer risk, although there may be concern for potential non-carcinogenic effects in children due to As exposure (dermal route, hazard index: 19.27). The study therefore recommends that necessary measures should be taken to prevent potential risk.

Keywords: Water quality, Gold mining, Contamination, Health risk.

INTRODUCTION

Water is a major resource for all living things to survive, it is an indispensable and essential commodity, hence it should be available, accessible, and contaminant-free; potential pollutants may arise from human activity (mining, industrial activities, application of pesticides or fertilizers and so on) or natural sources (weathering, leaching, erosion, drought and many more) (WHO, 2011; Odelami *et al.,* 2024)

Mining activities have been shown to modify the natural state of the environment, leading to elevated levels of contaminants, such as radioactive, microbial, and heavy metals, and an alteration in the physicochemical parameters, with a resultant adverse health effect. In Babban Tsauni gold mining sites, Gwagwalada, Abuja, Nigeria, these activities have potentially exposed the areas to increased levels of contamination of the drinking water sources. Gold mining activities, such as excavation, exploration, and processing, are environmental disturbances that may distort the natural state of the sources of drinking water in locations where mines are located because of the quest for water in the processing of gold ore. The wastewater generated, filth, and mud in addition to pesticides and fertilizers used for agricultural purposes in such areas has the potential to consequently leach into nearby water sources thereby altering the physicochemical parameters such as pH, temperature, color turbidity, dissolved oxygen, and so on, nitrate and heavy metal concentrations, rendering it unfit for consumption (Owusu *et al.,* 2024). Because they support the health and vitality of species that depend on this ecosystem service, dissolved salts and minerals are essential elements of high-quality water (Khatri & Tyagi, 2015). However, high turbidity, total dissolved solids (TDS), and dissolved oxygen render water a flat taste, unpalatable, and unacceptable for consumption. Some of

the heavy metal contaminants in gold mines that have been shown to cause adverse health effects in humans as a result of prolonged exposure through drinking water are; lead, copper, cadmium, mercury, chromium, arsenic, and so on. The presence of these elements in water at concentrations above acceptable levels indicates pollution with resultant adverse health effects. The natural occurrence of these elements is relatively common in water supplies around the world in both developing and developed countries. Therefore, these pollutants should be assumed to be potentially present, and consideration should be given as to whether they are present in the concentration of concern (WHO, 2011). Ingestion of contaminated water, either long or short term, has been reported to cause nausea, vomiting, kidney failure, ulceration, diarrhea, and so on (Fazal-ur-Rehman, 2019). With high lead concentration, metabolic poisoning manifests in symptoms like abdominal discomfort, fatigue, irritation, and behavioral changes in the case of children (Levallois *et al*., 2018). Long-term exposure to arsenic has been reported to cause skin cancer through drinking contaminated water (Garcia & Matthews, 2024).

Babban Tsauni community, like most rural communities where artisanal mines are located, has no access to treated potable water and, therefore, relies solely on ground and surface water, which may have been contaminated due to the mining activities. Despite the ongoing active mining in this community, no comprehensive reports on this effect, especially on drinking water sources, but; most prominent studies on this site have been focused on gold mineralization, radon assessment, soil and food crop contamination (Okunola *et al.,* 2005; Ekeleme *et al*., 2023; Odelami *et al*., 2024). Although so much has been reported on different mining communities around the world, including but not limited to an assessment of drinking water quality and health risks by Cobbina *et al.* (2013), Okolo *et al*. (2018), Jiménez-Oyola *et al.* (2023), Owusu *et al.* (2024), and Ulla *et al.* (2025). Therefore, the objectives of this study were to assess the physicochemical properties of the drinking water sources (ground and surface), nitrate and heavy metal concentration. The measured concentration of the heavy metals was used to estimate the pollution indices and the human health risk assessment.

MATERIALS AND METHODS

The study area, as described by Odelami *et al.* (2024), is presented in Figure 1.

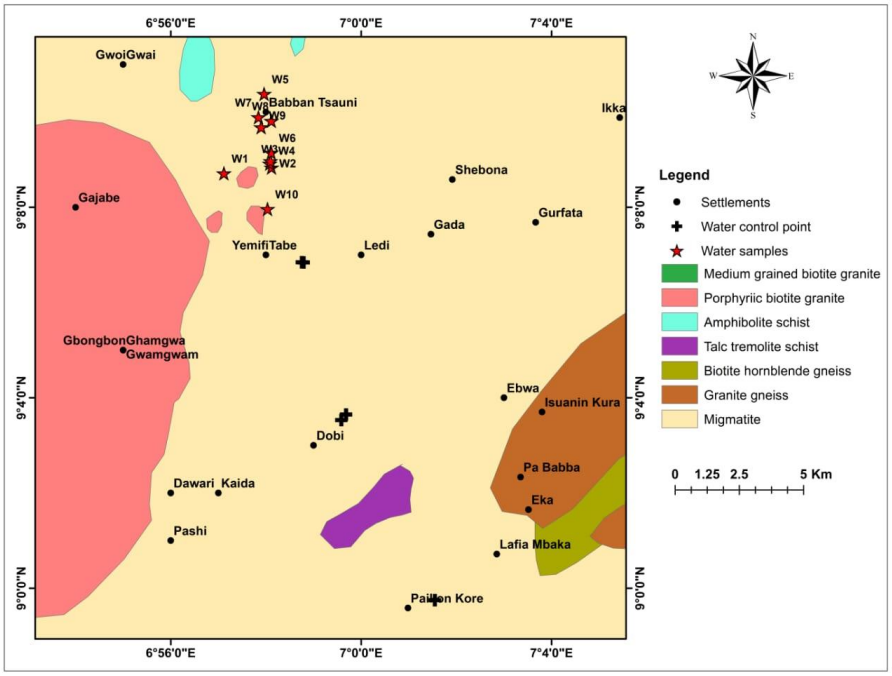

Figure 1: Digitized Geological Map of the Sampling Area

Sample Collection

Random sampling was adopted for sample collection, which was because the water sources were closely located around the small community under study, and to allow for an unbiased conclusion (Odelami *et al.,* 2024). A total of fifteen plastic containers, each of 50 mL, 2 L, and 20 mL, were collected (surface and groundwater), for physicochemical parameters, heavy metal, and nitrate analysis, respectively, based on availability and proximity to the mining community. All containers were thoroughly washed and rinsed with distilled water before setting out for sample collection. The borehole water samples were evacuated for a few minutes before being collected into already rinsed containers. The well water

was initially purged by drawing it out several times before pouring it into the pretreated containers, while for the surface water, containers were submerged in water each instance. pH and temperature of the water samples to be analyzed for physicochemical parameters were measured in situ with a pH meter and a clinical thermometer, respectively. 4 ml of HNO_3 was immediately added to the 2 L samples to be analyzed for heavy metals for preservation purpose.

Sample Preparations

Physiochemical parameters

10 ml of a colorless and clear water sample to be tested is taken in a colorimetric bottle, and the instrument (Hannah Multiparameter portable meter D0700) is inserted for zeroing or calibration at each instance before measuring each parameter as described by Kwarteng, E. (2012).

Nitrate Concentration

Using a disposable syringe, 2 mL of the water sample to be tested is measured and dispensed into a reaction tube. This is then diluted to a 15 mL mark with distilled water and is ready for analysis.

Heavy Metal Concentration

As described by Bello *et al* (2019b), the water samples were transferred into already cleaned beakers, and 10 mL of HNO_3 and 5 mL of HCL in the ratio (2:1) were added and mixed properly using a glass rod. The mixture was heated on a hot plate for about an hour without boiling until the volume was reduced to about 20 ml. The samples were allowed to cool and thereafter filtered into a 100 mL standard volumetric flask and made up with distilled water. The solution of the samples was then aspirated and ready for analysis.

Experimental Measurement

Physiochemical Parameters (Total Dissolved Solids, Conductivity, and Dissolved Oxygen)

The multiparameter water quality meter was used to test multiple parameters simultaneously by immersion of its multiple sensors and probes (sondes) in the water samples to measure distinct parameters. This was done by pressing the COND key, which displays for parameter to be measured at each instance (Kwarteng, 2012). Data collected by these sensors is shown for analysis on the meter's interface. The readings were recorded, saved, and processed further to provide a thorough analysis of the data.

Heavy Metal Quantification Using the Atomic Absorption Spectrophotometer Method

Standard solutions were run on the instrument to obtain the calibration curves for each metal using measured absorbance at the corresponding concentration. Before measuring the samples, the instrument was initially set to zero by reading a reagent blank. Thereafter, the prepared samples were aspirated into the instrument and read three (3) times, and a mean concentration value was recorded for each heavy metal in each sample. For validation purposes, standard reference materials were digested and analyzed using the same procedure as Bello *et al.* (2019b).

Nitrate Measurement

The already prepared water samples were analyzed using a self-filling Vacu-vial's ampoule water testing kits, CHEMetrics V-2000 photometer at the Center for Energy Research and Training, Ahmadu Bello University, Zaria. This was carried out in duplicate, and the result was recorded.

Assessment of Contamination Level

Statistical tools were applied in processing, analyzing, and assessing the contamination level in water using the concentration of heavy metals obtained from the experiment. These are of two types: single index and complex or integrated index. The single indices are used to determine one metal contamination. These include: contamination factor, pollution load index, geo-accumulation index, and ecological risk factor.

Single Pollution Indices

Contamination Factor.

An index used to estimate which heavy metal poses the highest threat to the area under study. The contamination factor can be calculated through Equation 1, suggested by Harikumar *et al.* (2009)

$$CF = {}^{C_n}/_{C_r} \qquad (1)$$

where C_n is the concentration of metals in the area under study, and C_r is the metal concentration of the reference area (background or control area). The *CF* levels are interpreted on the scale as shown in Table 1

Table 1: Classification of Contamination Factor Source (Hakanson, 1980)

Contamination Factor	Rating/ Classification
CF <1	Low
1 ≤ CF <3	Moderate
3 ≤ CF <6	Considerable
CF ≥ 6	Very high

Geo-Accumulation Index

This is used to determine the degree of contamination of a specific heavy metal of interest in the environment under study. It can be calculated using Equation 2 (Mandeng *et al*., 2019) and interpreted using Table 2

$$I_{geo} = log_2 (C_n/1.5B_n) \quad (2)$$

where, I_{geo} is the geo-accumulation index, C_n is the concentration of specific heavy metal, the factor 1.5 is used to account for possible variation of the background data due to lithological variation, and Bn is the geochemical background value (natural concentration of heavy metal in an undisturbed area)

Table 2: Classification of Geo-Accumulation Index Source (Hakanson, 1980)

I_{geo} Value	Classification	Level of contamination
$5<I_{geo}\leq 10$	6	Extremely Serious
$4<I_{geo}\leq 5$	5	Strong to Extremely Serious
$3<I_{geo}\leq 4$	4	Strong
$2<I_{geo}\leq 3$	3	Moderate to Strong
$1<I_{geo}\leq 2$	2	Moderate
$0<I_{geo}\leq 1$	1	Light to Moderate
$I_{geo}\leq 0$	0	Unpolluted

Ecological Risk Factor

This is the measure of risk associated with heavy metal concentration, especially those with toxic response values as suggested by Hakanson (1980). It is determined through Equation 3

$$ER = CF * TRF \quad (3)$$

where ER is the potential ecological risk factor/index, CF is the contamination factor, and TRF is the toxic-response factor. The following indications are used to describe the risk factor; $ER < 40$, represents low potential ecological risk; $40 \leq ER < 80$ moderate potential ecological risk; $80 \leq ER < 160$, considerable potential ecological risk; $160 \leq ER < 320$, high potential ecological risk; $ER \geq 320$ very high ecological risk (Hakanson, 1980). The toxic response values of some heavy metals are given as: *Cd* = 30, *As* = 10, *Pb* = 5, *Cr* = 2, *Ni* =*5, Cu* =*10,* and *Zn* = 1.

Enrichment Factor (EF)

EF estimates the degree to which anthropogenic activity has influenced the concentration of heavy metals in the soil. It is calculated through Equation 4 (Sutherland, 2000; Almasoud *et al*., 2015), and the reference elements are usually *Fe*, *Al*, *Ca*, *Ti*, *Sc*, and *Mn*.

$$EF = \left(\frac{C_n}{C_{im}}\right) \Big/ \left(\frac{C_r}{C_{imr}}\right) \quad (4)$$

where, C_n is the concentration of elements in the target area, C_{im} is the concentration of the immobile element in the sample of interest, C_r is the concentration of elements in the reference area, and C_{imr} is the concentration of the immobile element in the reference area. According to Liu *et al.* (2005), if the value of *EF* ranges from 0.5 to 1.5, then the content of the specific heavy metal was caused by a natural process, but if the value of *EF* exceeds 1.5, there is a probability that the heavy metal contamination occurred because of anthropogenic activity. For this study, *Mn* was selected as the immobile element, similar to Liu *et al*. (2015) and Bello *et al*. (2019b)

Complex or Integrated Indices

Indices in this group are used to estimate comprehensively the total concentration of all analyzed heavy metals in samples using individual values of calculated indices.

Pollution Load Index (PLI)

This can be determined through Equation 5 and interpreted by Harikumar *et al*. (2009)

$$PLI = \sqrt[n]{CF_1 \times CF_2} \times CF_3 \times \ldots\ldots\ldots CF_n \quad (5)$$

where *PLI* represents the pollution load index, *CF* is the contamination factor, and n is the number of elements. The *PLI* > 1 indicates pollution, while *PLI* <1 indicates no pollution. It gives a means of determining the pollution level.

Degree of Contamination (DC)

The degree of contamination expresses the extent of heavy metal pollution, obtained by computing all the contamination factors determined for all the heavy metals in the soil and their average, and gives the average pollution index (Pl_{av}) used to estimate the soil quality. Expressed by Equations 6 and 7, respectively.

$$DC = \sum_i^n CF \quad (6)$$

$$PL_{av} = \frac{1}{n}\sum_{i=1}^{n} DC \quad (7)$$

here *n* is the number of counts of heavy metal species. The degree of toxic heavy metal contamination has been categorized as follows: *DC* < n, is a low degree of contamination; $n \leq DC < 2n$, is a moderate degree of contamination; $2n \leq DC < 4n$, a considerable degree of contamination; $DC > 4n$, a very high degree of contamination

Potential Ecological Risk (RI)

This is an index used to assess the degree of ecological risk caused by heavy metal concentration in water, air, and soil. It was calculated using Equation 8 as suggested by Hakanson (1980).

$$RI = \sum_{i=1}^{n} E_r^i \quad (8)$$

where, E_r^i is the ecological risk of individual heavy metals. RI is interpreted according to five classes of soil quality: $RI < 150$, low ecological risk; $150 \leq RI < 300$, moderate ecological risk; $300 \leq RI < 600$, considerable ecological risk; and $RI > 600$, very high ecological risk.

Human Health Risk Assessment Theory

Heavy metals are natural components of the earth's crust, which, through natural or anthropogenic processes, are released into the environment through various pathways (Volcanic eruption, soil erosion, mining operation, fertilizer application, and so on) (Odelami *et al.,* 2025). Human health risk assessment is, therefore, a procedure used to calculate the health effects that could result from exposure to carcinogenic and non-carcinogenic metals. The risk assessment procedure comprises four basic steps: hazard identification, exposure assessment, toxicity (dose-response) assessment, and risk characterization (USEPA, 1989; Bello *et al.,* 2019a). Hazard identification aims to investigate metals that are present at any given location, their concentrations, and their spatial distribution. Usually, exposure assessment is carried out to estimate the intensity, frequency, and duration of human exposure to environmental contamination. The dose-response assessment estimates the toxicity due to exposure levels of heavy metals. Non-carcinogenic risk characterization predicts the potential non-cancerous health risk of children and adults in the study area by integrating all the available information necessary for estimating quantitative hazard indices based on American international publications, while considering the potential exposure pathways.

Exposure Assessment

Ingestion of Heavy Metals Through Water

Ingestion exposure occurs when an individual consumes water. The average daily intake was estimated using Equation 9 (Bello *et al.,* 2019a)

$$ADI_{ing} = \frac{C_n \times IR_{ing} \times EF \times ED \times CF}{BW \times AT \times 10^6} \quad (9)$$

where, ADI_{ing} is the average daily intake of heavy metals ingested from water in mg $kg^{-1}day^{-1}$, and C_n is the concentration of heavy metal in mgL^{-1} for water. IR_{ing} in $Lday^{-1}$ is the ingestion rate, EF in days/year is the exposure frequency, ED is the exposure duration in years, BW is the body weight of the exposed individual in kg, AT is the time over which the dose is averaged in days, CF is the conversion factor in Lcm^{-3}

Dermal Contact: this occurs when the human skin surface area is in contact with contaminated water (during bathing, panning, and washing). For dermal contact, the average daily dose is estimated using Equation 10 (Bello *et al*., 2019a).

$$ADI_{dermw} = \frac{C_w \times SA \times PC \times ET \times ED \times CF}{BW \times AT} \quad (10)$$

where ADI_{dermw} in mg kg^{-1} day^{-1} is the average daily intake of heavy metals via dermal contact from water, C_w in mgL^{-1} is the concentration of metal in water, SA in cm^2 is the exposed skin area, PC in cm/h is the dermal permeability coefficient, ET in hr day^{-1} is the exposure time during bathing and shower. Table 3 gives the exposure parameters used for the risk assessment for standard residential exposure scenarios through different exposure pathways.

Table 3: Exposure Parameters Used for The Health Risk Assessment

Parameter	Unit	Child	Adult	References
Body weight (BW)	Kg	18.6	80	(USEPA, 1989)
Exposure frequency (EF)	$Daysyr^{-1}$	350	350	(Bello *et al.*, 2019a)
Exposure duration (ED)	Years	6	30	
Ingestion rate (IRing)	Lday-1	1	2	
Skin surface area (SA)	cm^2	2800	5700	(USEPA, 1989)
Soil adherence factor(AF)	$mgcm^{-2}$	0.2	0.07	(Bello *et al.*, 2019a)
Dermal absorption factor (ABS)	None	0.1	0.1	
Dermal exposure ratio(FE)	None	0.61	0.61	(Bello *et al.*, 2019a)
Particulate emission factor(PEF)	m^3kg^{-1}	1.36×10^9	1.36×10^9	(USEPA, 1989)
Conversion factor	Lcm^{-3}	10^{-3}	10^{-3}	(Bello et al., 2019a)
Average time				
Non-carcinogenic	Days	365×ED	365×ED	(USEPA, 1989)
Carcinogenic		365×80	365×80	
Exposure time during bathing (ET)	Min	60	35	(USEPA, 1989)
Dermal Permeability Coefficient	cmh^{-1}	0.001	0.001	(Bello *et al.,* 2019a)
Unit Conversion Factor	Lcm^{-3}	0.001	0.001	(Bello et al., 2019a)

Non-Carcinogenic Hazards Assessment

This was estimated by comparing the calculated contaminant exposures for each exposure route and the reference dose to obtain the hazard quotient (*HQ*). It expresses the toxicity an individual may suffer from exposure to a single element via a single route. It is unitless, expressed by Equation 11 (Armah *et al.,* 2012; Bello *et al.,* 2019a). $HQ = \frac{ADI}{RFD}$ (11)

where *HQ* is the hazard quotient via ingestion or dermal contact, and *RFD* is the reference dose in mgkg^{-1} day^{-1} of a specific heavy metal.

For n number of heavy metals, the non-carcinogenic effect on the population due to exposure to the same potentially hazardous metals in the environment is obtained from the summation of individual hazard quotients and is equal to the hazard index. This is expressed by Equation 12 (Bello *et al.,* 2019a).

$$HI = \sum_{k=1}^{n} HQ_k = \sum_{k=1}^{n} \frac{ADI_k}{RFD_k} \quad (12)$$

where HI is unitless, HQ_k, ADI_k, and RFD_k are the values of heavy metal *k*. Where $HI < 1$, there may be no concern for potential human health risk due to exposure to non-carcinogenic heavy metal, whereas $HI > 1$, there may be a concern for potential human health risk due to exposure to non-carcinogenic heavy metal. Table 4 presents the *RFD* values.

Table 4: Reference Doses (RFD) in (mg kg^{-1} day^{-1}) Adapted from Bello *et al.* (2019a)

Heavy Metal	Ingestion RFD	Dermal RFD	References
As	3.0×10^{-4}	3.0×1k0^{-4}	US EPA, 2011
Pb	3.6×10^{-3}	-	
Cr (VI)	3.0×10^{-3}	-	USEPA, 2011
Co	2.0×10^{-2}	5.7×10^{-6}	US EPA, 2011
Ni	2.0×10^{-2}	5.6×10^{-3}	
Zn	3.0×10^{-1}	7.5×10^{-2}	USEPA, 2011
Cu	3.7×10^{-2}	2.4×10^{-2}	USEPA, 2011

Carcinogenic Risks Assessment

It is an estimation of the probability of an individual developing cancer over a lifetime due to exposure to a potential carcinogen. Equation 13 is used for calculating the excess lifetime cancer risk (Bello *et al*., 2019a).

$$Risk_{pathway} = \sum_{k=1}^{n} ADI_k \, CSF_k \quad (13)$$

where, Risk (unitless) is the probability of an individual developing cancer over a lifetime, ADI_k (mg/kg/day) and CSF_k are the average daily intake and the cancer slope factor, respectively, for the kth heavy metal, for several heavy metals. The factor CSF_k converts the estimated daily intake of the heavy metal, averaged over a lifetime of exposure, directly to the incremental risk of an individual developing cancer. (Bello *et al*., 2019a). The total excess lifetime cancer risk for an individual was calculated from the average contribution of the individual heavy metals for two pathways (ingestion and dermal route), using Equation 14

$$Risk_{total} = Risk_{ing} + Risk_{dermal} \quad (14)$$

where, $Risk_{ing}$ and $Risk_{dermal}$ There are risks of contributions through ingestion and dermal pathways. Table 5 gives values of cancer slope factors used for calculating the carcinogenic risk assessment.

Table 5: Cancer Slope Factors (CSF) in (mg kg^{-1}day^{-1})

Heavy Metal	Oral CSF	Dermal SCF
As	1.50	1.5
Pb	8.5×10^{-03}	-
Cr(VI)	5.0×10^{-1}	-
Co	-	-

RESULTS AND DISCUSSION

Physicochemical Analysis of Water Samples

The results obtained for each of the parameters measured are presented in Table 6. The temperatures and pH of the water samples taken in situ range from 32.6-37.0℃ and 6.1-7.3, with average values of 35.75 ℃ and 6.71, respectively. The temperature was observed to be above 25℃ of normal pure or neutral water temperature; this could lead to a reduction in the solubility of oxygen in the water. The pH < 7 (acidic water) could be because of leached metals (Pb, As, Mn, Co, Cr, and Fe) identified in the soil samples through groundwater movement and run-offs. This may pose a health risk (poisonous) when present in high concentrations, especially when they bioaccumulate (Butt *et al*., 2020). Consumption of water with high concentrations of these heavy metals may lead to kidney, liver, and intestinal damage, anemia, and cancer (Lubal, 2024). Although the values obtained fall within permissible limits (6.5-8.5), the risk is considered low.

The total dissolved solids (TDS) alone (high or low) is not considered a health hazard; this explains why most regulatory organizations, especially the WHO, did not set guidelines for it. A low TDS has been reported to give a flat taste (undesirable to many people) while a high concentration of dissolved solids can stain household fixtures, corrode fixtures, and have a metallic taste (Wilson *et al*., 2014). The average value for this study is significantly low, with no resultant health effect except for the undesirable flat taste. TDS is directly related to the conductivity of water because it provides an approximate value for the TDS concentration, and both are used to determine water quality for the public. Therefore, the low values in both parameters show a strong correlation.

For water quality purposes, dissolved oxygen is a key component in drinking water. The dissolved Oxygen result ranged from (42.9-90.0) % with an average value of 59.45 %. The DO takes up some space in the drinking water when it is high. Other dissolved substances become low, and this gives a better taste to the water. However, when it is low, other minerals dissolve in the water easily, and this affects the overall quality of the drinking water.

The average concentration of nitrate in the water sources was 0.035, a significantly low value compared to USEPA's maximum acceptable concentration of 10 mgL^{-1} and 50 mgL^{-1} by WHO; therefore, the nitrate level does not pose any hazard.

All the results obtained for the physicochemical parameters were within WHO and USEPA permissible limits except the temperature, with a value slightly above the ambient; hence, the water sources are safe for drinking. These observations show a similar trend when compared with the results of physicochemical values within the WHO safe limit reported by Nagabhushana *et al.* (2020)

Table 6: Physiochemical Parameters and Nitrate Concentrations in Drinking Water Samples

Sample ID	Latitude	Longitude	pH	Temperature ℃	TDS (g/l)	Conductivity (mS/m)	Do %	NO_3 (ppm)
TW 1	09° 8′45"	06° 57' 56"	6.8	37.0	8.77	10.27	54.6	0.0315
TB 2	09° 8′ 50"	06º 58' 1"	6.1	37.0	10.10	11.48	42.9	0.0324
TW 3	09° 8′ 54"	06º 58' 3"	6.3	32.6	11.60	13.74	50.8	0.0385
TW 4	09° 8′55"	06º 58' 5"	7.0	37.0	9.22	10.59	43.1	0.0525
TB 5	09° 8′ 58"	06º 58' 6"	7.1	36.0	7.99	9.97	57.8	0.0311
TW 6	09° 9′ 10"	06º 58' 6"	6.9	33.3	10.20	11.83	46.4	0.0289
TS 7	09° 9′ 15"	06º 58' 7"	7.0	37.0	10.30	11.93	48.6	0.0560
TW 8	09° 9′ 12"	06º 58' 6"	6.8	37.0	10.20	11.92	59.7	0.0490
TB 9	09° 8′ 41"	06º 57' 54"	6.4	36.0	10.60	12.15	54.3	0.0331
TS 10	09° 7′ 58"	06º 58' 2"	7.3	37.0	9.63	10.94	47.9	0.0301
DC B	09º 3' 32"	06º 59' 35"	6.3	35.0	12.80	10.80	80.0	0.0287
DC W	09°3′39"	06°59"41	6.6	35.0	12.60	11.00	80.5	0.0290
PC B	09°06′53"	06°58'43"	6.5	32.6	10.60	12.10	86.5	0.0250
AC W	09°01'18"	07°10'5"	6.7	37.0	77.40	62.70	48.9	0.0330
PK C W	08°59'45"	07° 1' 33"	6.8	36.8	4.41	8.82	90.0	0.0310
Average			6.71	35.75	14.43	10.51	59.45	0.0353
Permissible limits (WHO)			6.5-8.5	25	500	1	80-110	50 mg/L

Heavy Metal Concentrations

Seven heavy metals were analyzed as presented in Table 8, and their values were compared to the WHO acceptable limits and other literature. As presented, it was observed that out of the seven heavy metals, only two (Zn and Cu) had values below the WHO acceptable limit, although guidlines have not been established for Mn in water. When compared to other reports, the values did not follow a specific trend but corroborated the report by Serfer-Armah *et al.* (2016). These variations may be attributed to differences in geographical location, geological formation, and the water sources.

Table 7: Comparison of The Measured Heavy Metals Concentration (Ppm /(Mgl^{-1}) With Other Literature

As	Pb	Ni	Mn	Cr	Zn	Cu	Reference
-	0.105	-	-	-	0.291	0.407	(Munene *et al.,*2023)
4.13	11.42	1.26	63.45	14.60	10.53	-	(Obasi & Akudinobi, 2020)
-	0.0032	-	-	0.0051	0.047	0.0068	(Ghaderpoorri *et al.,*2018)
1.67	0.08	0.09	1.08	0.15	0.05	0.03	This work
0.01	0.01	0.07	NA	0.05	5.00	2.00	WHO, 2011

NA; Not available

Exposure to elevated As concentration has been reported to cause the development of inflammatory processes and oxidative stress, in addition to skin lesions or cancer (Fatoki & Badmus, 2022), while symptoms of Pb toxicity are paralysis, coma, other nervous-related diseases, and death may eventually occur (Munene *et al.,* 2023). Humans exposed to excessively high concentrations of chromium (VI) compounds may experience serious effects on their hearts, lungs, kidneys, liver, gastrointestinal tract, and nervous systems, as well as may even pass away (Obasi & Akudinobi, 2020). A wide range of carcinogenic mechanisms, such as the formation of free radicals, the regulated expression of specific genes, and transcription factor regulation, are associated with nickel. It has been demonstrated that nickel plays a role in controlling the expression of particular lengthy non-coding ribonucleic acids (RNA). Additionally, it has been shown that nickel can produce free radicals, which are a factor in the processes that cause cancer (Engwa *et al.,* 2019; Obasi & Akudinobi, 2020). Mn is one of the essential elements for the proper functioning of the body, which occurs naturally in food and water sources. Although it may not be present at a concentration of health concern in water, but can affect its acceptability for drinking. Neurotoxicity may arise from prolonged exposure to high manganese concentrations. A neurological condition called manganism is caused by manganese and is typified by stiffness, trembling in actions, a mask-like expression, abnormalities in gait, bradykinesia, micrographia, memory and cognitive impairment, and mood swings. Parkinson's disease symptoms and those of manganism are strikingly similar (Obasi & Akudinobi, 2020).

Heavy Metal Contamination

The CF values decreased in the order: Mn > Zn > As > Cr > Pb > Cu > Ni. The CF values were less than the acceptable limit of 1.0 for all the heavy metals of interest, except for Mn with a value of 20.07, as presented in Table 7. This reveals that the water samples were contaminated only with Mn, which is regarded to be very high. The Mn may have its origin from weathering as a result of gold mining and agricultural practices. The lower concentrations of other heavy metals may be related to the high amount of diffusion in soil due to their solubility and other phenomena such as adsorption (Men *et al*., 2018). The I_{geo} values decreased in the order: Mn > As > Cr > Cu > Pb > Ni > Zn, ranging from moderate to unpolluted. The Ecological risk values for all the heavy metals detected in the water samples were < 40 (low potential ecological risk), and they decreased in the order of As > Pb > Cu > Ni > Zn > Cr. The sequence was in the order Mn > Cr > As > Zn > Pb > Cu > Ni for the enrichment factor, with all values less than 1. This reveals that heavy metal concentrations in the water samples were a result of natural processes (Liu *et al.,* 2015; Bello *et al.,* 2019a).

Table 8: Mean Values of Single Pollution Indices

Parameter	Heavy Metals						
	As	**Pb**	**Ni**	**Mn**	**Cr**	**Cu**	**Zn**
CF	0.56	0.49	0.23	20.07	0.54	0.42	0.58
Igeo	-1.59	-2.45	-3.87	1.09	-1.67	-2.08	-5.21
ER	5.59	2.48	1.16	NA	1.08	2.11	1.15
EF	0.42	0.32	0.00	1.00	0.43	0.31	0.39

NA: Not Available

The summary of all the integrated indices estimated was PLI < 1 (0.52), RI < 150 (13.53), Pl_{ave} > 1 (3.21). This reveals that the quality of the water is safe for drinking, although it may be unpalatable due to high Mn concentration.

Non-Carcinogenic and Carcinogenic Hazard Assessment

Non-Carcinogenic Risk Assessment

For individual heavy metals, both routes (HQ_{ing} and HQ_{derm}) and both ages had values less than 1, except for As in the dermal route, with a value of 18.98 for the children. Similarly, the *HI* for all ages and routes was less than 1, except for children, which was contributed by As in the dermal route, with a value of 19.27. This meant that the children's population was at risk of non-carcinogenic effects. This high value of risk to the dermal route due to As may result in children developing skin lesions, hyperpigmentation, or keratosis.

Table 9: Hazard Quotients for Different Receptor Pathways for Both Adults and Children

Receptor	Pathway	Heavy Metals							Total
		As	Pb	Cr	Ni	Zn ($\times10^{-03}$)	Mn	Cu (10^{-03})	
Children	Ingestion	0.289	0.001	0.003	0.0003	0.0086	0.004	0.036	0.295
	Inhalation	NA	NA	NA	NA	NA	NA	NA	NA
	Dermal	18.983	NA	NA	0.0598	2.30	NA	0.004	19.047
	Total	19.271	0.001	0.003	0.0601	2.31	0.004	0.004	19.342
Adult	Ingestion	0.134	0.001	0.001	0.0001	0.0039	0.002	0.017	0.138
	Inhalatio	NA	NA	NA	NA	NA	NA	NA	NA
	Dermal	0.256	NA	NA	0.0008	0.03	NA	0.049	0.257
	Total	0.389	0.001	0.001	0.0009	0.034	0.002	0.066	0.394

Table 10: Excess Lifetime Cancer Risk Due to Heavy Metal Exposure to all Pathways

Receptor	Route	Heavy Metals			Total
		As	Pb	Cr	
Children	Ingestion	1.5×10^{-05}	4.0×10^{-09}	4.3×10^{-07}	1.5×10^{-05}
	Inhalation	NA	NA	NA	NA
	Dermal	9.7×10^{-04}	NA	NA	9.7×10^{-04}
	Total Excess LCR	9.2×10^{-04}	4.0×10^{-09}	4.3×10^{-07}	9.2×10^{-04}
Adults	Ingestion	3.4×10^{-05}	9.4×10^{-09} NA	1.0×10^{-06}	3.5×10^{-05}
	Inhalation	NA	NA	NA	NA
	Dermal	1.2×10^{-04}	9.4×10^{-09}	NA	1.2×10^{-04}
	Total Excess LCR	1.5×10^{-04}		1.0×10^{-06}	1.6×10^{-04}

NA; not available

Carcinogenic Risk Assessment

Table 10 presents the excess lifetime cancer risk estimated due to ingestion and dermal contact with groundwater; an inhalation route was not available. The CR_{derm} due to dermal exposure was higher in both ages than the $CR_{ing.}$ This indicates that the dermal route was the predominant pathway of exposure, especially for children. The results show that all values for both ages and routes were within the USEPA acceptable range (1×10^{-06} to 1×10^{-04}) except for the dermal route in children. Indicating that the exposed receptors are not severely at risk due to exposure to the groundwater sources in the area under study. The values reported in this study were lower than the values reported in drinking water in Khorramabad, Iran (Mohammadi *et al.*, 2019).

Table 10: Excess Lifetime Cancer Risk Due to Heavy metal exposure to all pathways

CONCLUSION

This study evaluated the drinking water quality in Babban Tsauni mining community by analyzing physicochemical parameters (pH, temperature, total dissolved solids, conductivity, and dissolved oxygen) and quantifying nitrate and heavy metal (As, Pb, Ni, Mn, Cr, Zn, Cu) concentrations. The heavy metal data was used to assess contamination levels and human health risks. Results showed: Physicochemical parameters and nitrate concentrations within WHO permissible limits (WHO, 2011). Zn and Cu concentrations were within safe limits, while other heavy metals exceeded limits. Overall, heavy metal pollution indices indicated non-contamination. Health risk assessment revealed a potential non-carcinogenic risk for children through dermal exposure, with no significant cancer risk for exposed receptors. Despite ongoing active mining, the water sources in this community are relatively safe for drinking, although there may be a potential cancer risk due to dermal exposure. Therefore, continued monitoring is recommended to ensure water quality.

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