



Impacts of Artisanal Mining Activities on Soil and Groundwater Quality in Rafi and Shiroro Local Government Areas, Nigeria

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ABSTRACT

This study investigates the impacts of mining activities on soil and groundwater quality in Rafi and Shiroro Local Government Areas (LGAs) of Niger State, Nigeria, with a focus on seasonal variations. Using a cross-sectional survey design, data were collected during both wet and dry seasons through field observations, laboratory analyses of soil and water samples, and geospatial mapping. Soil samples were tested for heavy metals such as Cu, Fe, Cd, Mn, Zn, and Pb, while groundwater analyses examined parameters including pH, dissolved oxygen, total hardness, and biological oxygen demand. The results revealed that during the wet season, heavy metal concentrations in soil, such as Cu, Fe, Cd, Zn, and Pb, exceeded WHO limits, indicating significant contamination. In contrast, the dry season recorded lower concentrations within acceptable limits. Similarly, groundwater physicochemical parameters such as total hardness, sulphate, and chloride exceeded permissible levels during the wet season, while most remained within limits during the dry season, except for elevated air and water temperatures in some areas. The study recommends that regulatory authorities enforce stricter mining regulations and monitor activities, especially during the wet season, to mitigate heavy metal contamination. Additionally, local governments should collaborate with environmental experts and NGOs to implement community-based education and alternative livelihood programs, reducing reliance on artisanal mining and its associated risks.

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INTRODUCTION

The management of natural resources has long posed significant challenges for many developing countries, particularly in Africa. Most resource-rich nations on the continent lack effective natural resource governance systems, and where such systems exist, they are often marred by inefficiency and mismanagement. This has led to the exploitation of resources under unfavorable terms, forsaking long-term benefits and sustainable development (UNEP, 2013). In Nigeria, the extractive industry—particularly the

solid minerals sub-sector—has suffered from inadequate regulation despite the country's vast reserves of precious metals and minerals. Historically, Nigeria was a major exporter of tin, columbite, and coal, but the focus shifted to crude oil, which became the country's primary foreign exchange earner (Gutti *et al.*, 2012).

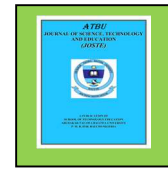
The lack of proper regulation has facilitated the rise of artisanal and small-scale mining (ASM) in many parts of Nigeria, including Rafi and Shiroro Local Government Areas (LGAs) in Niger State. Artisanal mining involves the

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extraction of minerals using rudimentary tools and methods, often operating outside the formal regulatory framework. This practice is widespread in developing countries, serving as an important livelihood source for millions of people (ILO, 2010; World Bank, 2013). However, while ASM provides significant economic benefits, it is also associated with severe environmental challenges, including land degradation, soil and water pollution, and vegetation loss.

In Rafi and Shiroro LGAs, artisanal miners exploit abundant mineral resources, particularly gold and gemstones. These activities often lead to the contamination of soils and waterways with potentially toxic elements (PTEs) such as lead, copper, and zinc. Pollutants are frequently washed into nearby water sources during the wet season, while in the dry season, mining sites generate dust and localized contamination, exposing residents and animals to health risks (Idris-Nda *et al.*, 2018). The impact extends beyond health concerns to broader environmental degradation, including soil infertility, vegetation loss, and disruption of biodiversity.

Environmental impacts of artisanal mining are further compounded by seasonal variations. During the wet season, increased rainfall facilitates the transportation of heavy metals and pollutants from mining sites to surrounding soils and water bodies. This often results in higher contamination levels and widespread environmental damage. In contrast, the dry season presents a different dynamic, characterized by reduced water flow but increased exposure to dust and airborne particles from mining operations. These seasonal variations significantly influence the extent and nature of mining-related environmental damage.

In addition to affecting soil and groundwater quality, artisanal mining activities in the region have profound implications for vegetation cover. Mining pits and abandoned sites disrupt natural landscapes and contribute to the loss of arable land. Vegetation degradation not only impacts local biodiversity but also exacerbates issues such as erosion and reduced carbon sequestration, further amplifying

environmental challenges. Given these dynamics, it is critical to assess the interplay between artisanal mining activities and seasonal variations to better understand the scope and scale of environmental impacts in Rafi and Shiroro LGAs. This study provides a comprehensive evaluation of the impacts of artisanal mining, focusing on the seasonal patterns that influence soil, groundwater, and vegetation conditions.

Statement of the Research Problem

The relationship between humans and the environment has long been a subject of concern, as human survival often involves exploiting natural resources. Ideally, these interactions should balance development with ecological harmony. Industrialized nations, after experiencing severe environmental degradation, have integrated sustainability into resource management, driven by public advocacy and green movements (Efole, 2014). In developing countries like Nigeria, however, unregulated exploitation of resources continues to cause significant environmental challenges. Mining, particularly artisanal and small-scale mining (ASM), is a key contributor to land degradation, water pollution, and vegetation loss. For example, studies in Nigeria have linked mining to water quality issues in Enugu (Nganje *et al.*, 2010) and Zamfara (Ahmed, 2013), as well as soil and groundwater pollution in Taraba State (Ahmed & Oruonye, 2016). These studies highlight how varying methods and tools result in differing environmental impacts.

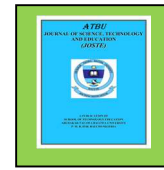
In Shiroro and Rafi LGAs of Niger State, ASM activities have persisted for decades, targeting minerals such as gold and iron ore. These operations, characterized by rudimentary tools and a lack of regulation, have caused observable environmental degradation, including land excavations and vegetation loss. However, the extent and magnitude of these impacts remain undocumented, leaving policymakers without the data needed to mitigate these effects. Despite extensive studies on mining impacts elsewhere in Nigeria, the persistent mining activities in Shiroro and Rafi LGAs have received little attention. This study sought to address this gap by investigating

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the seasonal impacts of artisanal mining on soil, groundwater quality, and vegetation, offering insights to guide sustainable resource management and environmental protection.

Aim and Objectives of the Study

The study aimed at determining the impact of artisanal mining activities on soil and groundwater quality in Rafi and Shiroro LGAs, Nigeria. Specifically, the objectives of the study include:

1. To assess the seasonal variations in heavy metal concentrations in soil and their compliance with permissible limits in Rafi and Shiroro LGAs.
2. To evaluate the physicochemical properties of groundwater and their seasonal variations in relation to mining activities in the study area.

Research Questions

The following research questions guided the study:

1. How do seasonal variations affect the concentrations of heavy metals in soil in Rafi and Shiroro LGAs, and how do these levels compare to permissible limits?
2. What are the seasonal impacts of mining activities on the physicochemical properties of groundwater in the study area?

RESEARCH METHODOLOGY

The study employed a cross-sectional survey design to analyze the environmental impacts of artisanal mining activities in Shiroro and Rafi Local Government Areas (LGAs) of Niger State, Nigeria. This design was appropriate for examining the environmental consequences of mining activities within a defined period, focusing on their effects on soil, groundwater, and vegetation. Data were collected during both wet and dry seasons to capture variations influenced by seasonal changes. Primary data were obtained through field observations, laboratory analyses, and satellite imagery. Field observations provided detailed information on the distribution of mining activities, hydrological conditions, and environmental features such as vegetation and

landforms. Laboratory tests were conducted on soil and water samples collected from 22 locations, including mining sites and control points 200 meters away. The tests analyzed the concentrations of heavy metals such as copper (Cu), iron (Fe), cadmium (Cd), manganese (Mn), zinc (Zn), and lead (Pb), as well as physicochemical parameters including pH, total hardness, and dissolved oxygen. These analyses were essential in determining the extent of contamination and its implications for the ecosystem.

Satellite imagery was employed to assess changes in land use and vegetation cover over time. Images from 1988, 1998, 2006, and 2016 were processed using GIS software, including ArcGIS and AutoCAD Map. These analyses provided a spatial understanding of mining-induced environmental degradation, enabling comparisons of pre- and post-mining conditions. Enhanced Spot 5 imagery and georeferenced Landsat images were processed to detect specific features such as excavations, ponds, and degraded vegetation. The geospatial analyses were critical in quantifying land-use changes associated with mining. Secondary data were obtained from medical records in health facilities within the study area. These records provided insights into health issues linked to mining activities, such as respiratory illnesses and waterborne diseases. Additionally, relevant literature, including reports and articles, was reviewed to support the study findings and provide context for interpreting the results. Data analysis involved both descriptive and inferential statistical methods. Laboratory results were processed using SPSS software for descriptive statistics, such as means and frequencies, while paired sample t-tests were conducted to assess variations in environmental parameters between seasons. GIS and remote sensing techniques were used to produce maps and spatial analyses, highlighting the extent and distribution of environmental impacts. This comprehensive approach ensured that the study objectives were achieved effectively, providing robust evidence of the environmental consequences of artisanal mining in the study area.

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RESULTS

Research Question 1: How do seasonal variations affect the concentrations of heavy metals in soil in Rafi and Shiroro LGAs, and how do these levels compare to permissible limits?

Table 1 and 2 shows the concentration of the heavy metals in the study area which is measured in part per million (ppm).

Table 1: Average Mean Variation of Heavy Metals in Soils in Rafi LGA of Niger State

Month	Station	Cu Ppm	Fe Ppm	Cd Ppm	Mn Ppm	Zn Ppm	Pb ppm
Jan	1	11.20	21.85	1.30	96.81	90.49	41.00
	2	13.20	20.50	0.90	54.70	62.61	40.32
	3	17.10	21.62	1.35	86.22	26.42	15.02
	4	12.50	21.50	1.11	94.03	72.24	60.70
	5	21.30	14.53	1.16	60.24	52.76	24.42
	Average	15.06	20.00	1.16	78.40	60.90	36.29
Feb	1	13.30	51.54	1.54	94.83	3.13	82.21
	2	3.32	50.01	1.01	84.99	3.89	30.25
	3	5.20	40.95	0.95	72.23	12.90	43.22
	4	7.26	52.00	2.00	154.29	5.41	75.00
	5	7.26	61.00	2.00	94.27	5.41	44.10
	Average	7.27	51.10	1.50	100.12	6.15	54.96
Jul	1	25.18	32.96	3.63	643.62	207.43	92.39
	2	32.20	30.26	2.71	742.81	182.96	81.21
	3	29.41	45.30	5.22	453.24	305.27	81.44
	4	32.50	64.50	4.14	464.05	262.24	104.70
	5	33.10	39.25	4.33	543.24	343.51	71.25
	Average	30.48	42.45	4.01	569.39	260.28	86.20
Aug	1	45.00	32.02	7.30	754.40	343.00	101.00
	2	59.03	46.03	3.21	643.30	267.01	202.67
	3	45.09	37.90	3.23	726.40	289.40	123.50
	4	42.20	30.26	4.20	442.80	352.96	151.21
	5	61.10	32.11	3.43	736.20	312.80	98.01
	Average	50.48	35.66	4.27	660.62	313.03	135.28

Permissible limit: Cu = 30 ppm; Fe = 30 ppm; Cd = 3 ppm; Mn = 7000ppm; Zn = 300 ppm Pb = 100 ppm (WHO, 2017).

Table 1 shows the variation of heavy metal concentration in soil samples in Rafi Local Government of Area of Niger State. The result shows that in the month of January, average heavy metal soil content of 15.06 ppm, 20.00 ppm, 1.16 ppm, 78.40 ppm, 60.90 ppm and 36.29 ppm were obtained for Cu, Fe, Cd, Mn, Zn and Pb respectively. Similarly, in the month of February, average heavy metal soil content of 7.27 ppm, 51.10 ppm, 1.50 ppm, 100.12 ppm, 6.15 ppm and 54.96 ppm were obtained for Cu, Fe, Cd, Mn, Zn

and Pb respectively. The implication of this is that between the month of January and February which are typical dry season months, concentration of heavy metals in the soils is not above the permissible limits of Cu = 30 ppm; Fe = 30 ppm; Cd = 3 ppm; Mn = 7000ppm; Zn = 300 ppm Pb = 100 ppm (WHO, 2017). This mean that the soil at this time is not contaminated by the heavy metals.

On the other hand, in the month of July average heavy metal soil content of 30.48 ppm,

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42.45 ppm, 4.01 ppm, 569.39 ppm, 260.28 ppm and 86.20 ppm were obtained for Cu, Fe, Cd, Mn, Zn and Pb respectively. Similarly, in the month of August average heavy metal soil content of 50.48 ppm, 35.66 ppm, 4.27 ppm, 660.62 ppm, 313.03 ppm, and 135.28 ppm were obtained for Cu, Fe, Cd, Mn, Zn and Pb respectively. The implication of this is that between the month of July and August which are typical wet season months, the heavy

metal contents (Cu, Fe, Cd, Zn and Pb) are above the permissible limit of Cu = 30 ppm; Fe = 30 ppm; Cd = 3 ppm; Zn = 300 ppm Pb = 100 ppm (WHO, 2017), except for Mn. During the raining season the soil around the mining sites are polluted with heavy minerals such as Cu, Fe, Cd, Zn and Pb. The high concentration of these minerals in the soils negatively affect plant growth.

Table 2: Average Mean Variation of Heavy Metals in Soils in Shiroro LGA of Niger State

Month	Station	Cu Ppm	Fe Ppm	Cd Ppm	Mn Ppm	Zn Ppm	Pb Ppm
Jan	1	11.20	26.85	1.03	91.01	79.17	101.50
	2	13.20	25.50	1.14	74.77	62.61	40.32
	3	13.12	51.62	1.75	71.49	36.42	19.52
	4	14.50	41.50	1.81	84.03	84.14	60.70
	5	21.30	24.53	2.16	54.24	62.76	54.42
	Average	14.66	34.00	1.58	75.11	65.02	55.29
Feb	1	22.98	53.54	1.54	104.19	3.13	82.21
	2	13.09	54.01	1.01	73.32	3.89	30.25
	3	25.20	40.95	0.95	81.92	12.90	43.22
	4	9.26	62.86	2.54	144.29	5.41	75.00
	5	7.26	61.23	2.08	94.27	5.41	44.10
	Average	15.56	54.52	1.62	99.60	6.15	54.96
Jul	1	25.18	32.96	3.63	643.62	207.43	92.39
	2	45.20	37.26	2.71	742.81	182.96	81.21
	3	40.41	75.36	4.32	453.24	305.27	81.44
	4	32.50	64.31	4.14	464.05	262.24	114.73
	5	33.10	39.25	4.33	543.24	343.51	71.25
	Average	35.28	49.83	3.83	569.39	260.28	88.20
Aug	1	45.00	32.02	7.22	754.74	343.00	101.00
	2	59.03	46.03	3.65	643.13	267.01	192.37
	3	45.09	47.90	2.23	716.94	269.78	143.50
	4	32.20	30.36	3.12	442.80	352.96	151.21
	5	61.10	32.11	3.43	736.20	312.83	118.01
	Average	48.48	37.68	3.93	658.76	309.12	141.22

Permissible limit: Cu = 30 ppm; Fe = 30 ppm; Cd = 3 ppm; Mn = 7000ppm; Zn = 300 ppm Pb = 100 ppm; (WHO, 2017).

Table 2 shows the heavy metal availability in soil in Shiroro Local Government of Area of Niger State. The result shows that in the month January average heavy metal soil content of 14.66 ppm, 34.00 ppm, 1.58 ppm, 75.11 ppm, 65.02 ppm, and 55.29 ppm were obtained for Cu, Fe, Cd, Mn, Zn and Pb respectively. Similarly in

the month of February average heavy metal soil content of 15.56 ppm, 54.52 ppm, 1.62 ppm, 99.60 ppm, 6.15 ppm and 54.96 ppm were obtained for Cu, Fe, Cd, Mn, Zn and Pb respectively. The implication of this is that between the month of January and February which are typical dry season months, there are moderate heavy metal

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contents in the soils around the mining pits which are within the tolerable or permissible limit.

Meanwhile, in the month July average heavy metal soil content of 35.28 ppm, 49.83 ppm, 3.83 ppm, 569.39 ppm, 260.28 ppm, and 88.20 ppm were obtained for Cu, Fe, Cd, Mn, Zn and Pb respectively. Similarly, in the month of August average heavy metal soil content of 48.48 ppm, 37.68 ppm, 3.93 ppm, 658.76 ppm, 309.12 ppm, and 141.22 ppm were obtained for Cu, Fe, Cd, Mn, Zn and Pb respectively. The implication of this is that at the month of July and August which are typical wet season months, there are high heavy metal contents (Cu, Fe, Cd, Zn and Pb) as the value obtained are above the permissible limit Cu = 30 ppm; Fe = 30 ppm; Cd = 3 ppm; Zn = 300 ppm Pb = 100 ppm (WHO, 2017), except for Mn.

Hence, the soil is not fit and appropriate for plant growth. On the whole, it has been observed that presence of heavy metals in the soils varies according to the season. They are highest during wet season.

Research Question 2: What are the seasonal impacts of mining activities on the physicochemical properties of groundwater in the study area?

The findings on the physicochemical analysis of water samples (underground and stream) during wet and dry seasons from Rafi and Shiroro LGAs are presented in Tables 3 and 4.

Table 3: Wet Season Monthly Variation in the Physicochemical Parameters of Rafi and Shiroro Underground and Stream water

Month	Rafi		Shiroro	
	July	August	July	August
pH	6.71±0.08 ^a	7.73±0.02 ^c	7.26±0.15 ^b	6.48±0.15 ^a
Water Temperature (°C)	41.60±0.34 ^c	27.20±0.25 ^b	26.20±0.20 ^a	25.90±0.18 ^a
Conductivity (µs/cm)	6.30±2.36 ^a	75.00±8.21 ^a	47.60±6.13 ^a	154.40±51.57 ^b
Total Alkalinity (mg/L)	67.94±0.54 ^a	74.00±0.58 ^a	62.80±5.19 ^b	81.30±4.35 ^{ab}
Total Hardness (mg/L)	122.04±0.91 ^{ab}	220.10±1.13 ^a	364.50±5.37 ^c	34.40±7.20 ^{bc}
DO (mg/l)	3.00±0.32 ^a	7.70±0.63 ^c	5.90±0.14 ^b	5.80±0.20 ^b
Sulphate (mg/l)	95.25±2.85 ^b	87.85±0.68 ^a	82.69±0.44 ^a	91.80±0.58 ^a
TDS (mg/l)	0.08±0.01 ^a	7.12±3.47 ^b	0.75±0.13 ^a	0.16±0.05 ^a
Chloride (mg/l)	261.11±0.38 ^a	219.95±1.39 ^a	252.24±2.56 ^a	263.59±4.31 ^a
BOD (mg/l)	1.46±0.29 ^a	4.74±0.63 ^b	1.98±0.27 ^a	1.90±0.18 ^a
Air Temperature (°C)	30.70±0.56 ^d	28.00±0.30 ^c	25.00±0.33 ^a	26.90±0.18 ^b

Mean± Standard deviation in the same row with the same superscript has no significant difference ($p > 0.05$).

Table 3 shows during the wet season both underground and stream water pH values are within normal range (6.48 - 7.73) in both Rafi and Shiroro LGAs. On the other hand, water temperature is above accepted standard in the month of July in Rafi when the temperature was 41.6 °C above WHO standards. In terms of conductivity, normal range values of (6.30 - 154.40) were maintained in both LGAs. In respect of the total alkalinity, the result shows normal range (62.80 - 81.30) as compared to WHO standard.

Furthermore, the result shows the total hardness is within the range of (34.40 - 364.50), the total hardness of 364.50 was above BIS standard in the month of July in Shiroro LGA. Similarly, from the result, normal range of (3.00 - 7.70) was obtained for dissolve oxygen (DO) in both Rafi and Shiroro LGAs. The concentration of sulphate in the underground water and stream water (82.69 - 95.25) are above the recommended standard as against the WHO standard. Total Dissolve Solid (TDS) is within the normal range (0.08 - 7.12), concentration of

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chloride is within the range of (219.95 - 263.59), which is above the WHO standard (>250mg/L) that is, 261.11, 252.24, 263.59. The biological oxygen demand was shown to be above the BIS standard, the BOD value of 4.74 was obtained in

the month of August in Rafi LGA. Finally, the Air Temperature (°c) are within normal range (25.00 - 30.70) in both Shiroro and Rafi LGAs.

Table 4: Dry Season Monthly Variation in the Physicochemical Parameters water of Rafi and Shiroro Dam Downstream

Month	Rafi		Shiroro	
	January	February	January	February
pH	8.01±0.022 ^a	7.94±0.01 ^c	7.98±0.43 ^b	8.48±0.28 ^a
Water Temperature (°c)	35.20±0.55 ^c	39.20±0.45 ^b	36.20±0.20 ^a	45.90±0.18 ^a
Conductivity (µs/cm)	15.30±2.36 ^a	85.33±8.21 ^a	47.60±6.13 ^a	144.40±51.57 ^b
Total Alkalinity (mg/L)	20.94±0.32 ^a	17.00±0.44 ^a	31.80±0.49 ^b	19.30±5.67 ^{ab}
Total Hardness (mg/L)	32.11±0.11 ^{ab}	20.10±1.12 ^a	36.50±5.35 ^c	38.40±0.21 ^{bc}
DO (mg/l)	3.00±0.32 ^a	7.70±0.63 ^c	5.90±0.14 ^b	5.80±0.20 ^b
Sulphate (mg/l)	23.35±2.85 ^b	7.85±0.68 ^a	6.69±0.44 ^a	9.80±0.58 ^a
TDS (mg/l)	0.06±0.03 ^a	6.45±4.34 ^b	0.73±0.11 ^a	0.145±0.05 ^a
Chloride (mg/l)	13.01±0.14 ^a	6.33±1.39 ^a	12.26±2.56 ^a	15.47±4.31 ^a
BOD (mg/l)	1.36±0.22 ^a	5.74±0.57 ^b	1.44±0.27 ^a	1.68±0.13 ^a
Air Temperature (°c)	42.70±0.11 ^d	35.00±0.30 ^c	37.00±0.21 ^a	28.90±0.22 ^b

Mean in the same row with the same superscript has no significant difference ($\rho > 0.05$).

Table 4 shows the dry season monthly variation in the physicochemical parameters of underground and stream water at Rafi and Shiroro LGAs. During the dry season, both underground and stream water pH values are within normal range (7.94 - 8.48) in both Rafi and Shiroro LGAs. On the other hand, water temperature is above accepted standard in the month of July in Rafi with the temperature of 45.90 °C above WHO's standards. In terms of conductivity, normal range values of (15.30 - 144.40) were maintained in both LGAs. In respect of the total alkalinity, the result shows normal range of (17.00 - 31.80) as compared to WHO standard.

Furthermore, the result shows the total hardness with the range of (20.10 - 38.40), which is within the acceptable BIS standard in Rafi and Shiroro LGAs. Similarly, from the result, normal range of (3.00 - 7.70) was obtained for dissolve oxygen (DO) in both Rafi and Shiroro LGAs. The concentration of sulphate in the underground water and stream water are within the recommended standard (6.69 - 23.35) as compared with the WHO standard. Total Dissolve Solid (TDS) is within the normal range (0.06 -

6.45), concentration of chloride is within the range of (6.33 - 15.47), which is within the acceptable limit of WHO standard (>250mg/L). The biological oxygen demand was shown to be above the BIS standard, the BOD value of 5.74 was obtained in month of February in Rafi LGA. Finally, the Air Temperature (°c) is above recommended range with 42.70°C in the month of January in Rafi LGA.

DISCUSSION OF FINDINGS

The study revealed significant seasonal variations in the concentrations of heavy metals in the soils of Rafi and Shiroro LGAs. During the dry season (January and February), the concentrations of Cu, Fe, Cd, Zn, and Pb in both LGAs were within permissible limits set by WHO (2017), suggesting minimal soil contamination. This observation aligns with the reduced mobility of heavy metals in drier conditions due to limited water flow, which minimizes leaching and runoff. However, during the wet season (July and August), heavy metal concentrations, particularly for Cu, Fe, Cd, Zn, and Pb, exceeded permissible limits in both

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LGAs. This seasonal spike can be attributed to increased rainfall, which facilitates the leaching and transportation of metals from mining sites into surrounding soils.

The findings support those of Ahmed and Oruonye (2016) and Ako *et al.* (2014), who also documented elevated levels of Fe, Cd, and Zn in soils affected by artisanal mining activities in Nigeria during the rainy season. Furthermore, the study corroborates the work of Akpanowo *et al.* (2021), who highlighted higher soil contamination during the wet season in artisanal mining areas of Anka, Northwest Nigeria. The high concentrations of heavy metals during the wet season pose significant environmental challenges, including soil infertility and the potential for toxic bioaccumulation in crops. This underscores the detrimental impact of artisanal mining on soil quality, particularly in regions with pronounced wet seasons.

The findings on groundwater quality revealed that seasonal variations significantly influenced the physicochemical parameters of underground and stream water in Rafi and Shiroro LGAs. During the wet season, parameters such as water temperature, total hardness, sulphate, and chloride frequently exceeded WHO and BIS standards. For instance, the total hardness in Shiroro LGA reached 364.50 mg/L in July, surpassing the acceptable limits, while chloride concentrations also exceeded 250 mg/L in both LGAs. Elevated Biological Oxygen Demand (BOD) values, such as 4.74 mg/L in Rafi LGA, indicate organic pollution, potentially due to runoff from mining activities. Conversely, during the dry season, most parameters, including pH, sulphate, and chloride, remained within permissible limits. However, anomalies like high air and water temperatures were recorded in Rafi LGA, with values of 42.7°C in January and 45.9°C in February, exceeding WHO standards. This indicates localized impacts of mining activities on groundwater temperature, potentially due to reduced water flow and higher atmospheric exposure during the dry season.

The findings are consistent with those of Ahmed and Oruonye (2016), who documented similar groundwater contamination patterns in

Taraba State, and Akpanowo *et al.* (2021), who reported seasonal groundwater quality variations in artisanal mining areas. These results emphasize the dual impact of artisanal mining on water resources, with the wet season exacerbating the spread of contaminants while the dry season introduces temperature-related challenges. The seasonal variations in soil and water quality highlight the critical need for tailored mitigation strategies that account for these fluctuations. Addressing the environmental impact of artisanal mining requires both regulatory enforcement during the wet season to limit runoff and comprehensive monitoring of groundwater quality throughout the year.

CONCLUSION

The study concludes that artisanal mining activities in Rafi and Shiroro LGAs have a substantial and seasonally dependent impact on the environment. Heavy metals such as Cu, Fe, Cd, Zn, and Pb are found in significantly higher concentrations during the wet season, exceeding WHO permissible limits, due to runoff and leaching from mining sites. This contamination adversely affects soil fertility, plant growth, and biodiversity. Similarly, the physicochemical properties of groundwater and stream water, including parameters such as BOD, total hardness, sulphate, and chloride, frequently surpass recommended standards, particularly during the wet season, posing risks to human health and ecological systems. In contrast, dry season contamination remains within acceptable levels, indicating that wet season dynamics exacerbate environmental degradation. These findings emphasize the critical need for targeted policies and sustainable practices to address the environmental and public health challenges posed by artisanal mining in the region.

RECOMMENDATIONS

Based on the findings of the study, the following recommendations were made:

1. The Federal Ministry of Environment and Niger State Environmental Protection Agency should establish and enforce stricter regulations for artisanal mining, conducting

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- regular inspections and imposing penalties for violations, particularly during the wet season to prevent heavy metal leaching.
2. Local Governments should collaborate with environmental scientists and NGOs to implement community-based monitoring programs, educating miners on sustainable practices and providing alternative livelihood opportunities to reduce dependence on artisanal mining.

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