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Assessment of Physicochemical Parameters, Potentially Toxic Elements and their Contamination Levels in Water from Abandoned Quarry Site in Rano Area of Kano State, Nigeria

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Abstract

Abandoned quarries present long-term environmental challenges as they occasionally receive little remediation attention compared to active sites. PTEs are of particular concern as they are non-biodegradable, persist in water systems, accumulate in biota, and transfer through food chains, endangering both human health and ecosystems. This study evaluated the physicochemical characteristics, potentially toxic elements (PTEs), and contamination levels of water sources around an abandoned quarry site in Rano, Kano State, Nigeria. Ten water samples and one control were collected and analyzed for physicochemical parameters (pH, temperature, EC, TDS, turbidity, alkalinity, chloride, hardness) and PTE concentrations (Cd, Cr, Cu, Fe, Mn, Ni, Pb) using standard procedures and Atomic Absorption Spectrophotometry. Contamination indices (WQI, CF, EF) and statistical analyses were applied. Turbidity levels (35.40–710.20 NTU) exceeded WHO limits (5 NTU) at all locations, while pH (7.40–7.63), EC (21.03–672.60 µS/cm), TDS (14.05–436.72 mg/L), chloride (12.63–42.07 mg/L), and hardness (12.83–187.23 mg/L) were generally within permissible limits. The Heavy metal concentrations revealed significant pollution: Cd (0.012–0.021 mg/L), Cr (0.071–0.847 mg/L), Fe (0.059–29.56 mg/L), Mn (0.383–2.723 mg/L), Ni (0.059–0.138 mg/L), and Pb (0.103–0.463 mg/L) all exceeded WHO standards. WQI values (52.1–70.5) indicated fair to poor water quality. CF showed significant to extremely high contamination in all samples, while EF revealed background to minimal enrichment at most sites but excessive enrichment at one hotspot. Correlation analysis demonstrated strong associations among dissolved ionic parameters and among Fe–Mn–Cr–Ni–Pb, suggesting common geochemical and anthropogenic sources. Water around the abandoned quarry is moderately to severely degraded and unsuitable for direct consumption without treatment. Continuous monitoring and remediation are required to safeguard public health.

Keywords: Abandoned Quarry, Physicochemical Parameters, Potentially Toxic Elements (PTEs), Contamination Factor (CF), Enrichment Factor (EF)

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1. Introduction

Stone quarrying involves the removal of building rocks (sandstone, granite, marble, limestone) from surface or subsurface deposits. Despite its economic importance in providing construction materials, quarrying is associated with significant environmental degradation, including land deterioration, habitat loss, noise and dust pollution, and contamination of nearby soil and water resources (Makoka and Malaza 2025; Simon *et al*, 2020). Mining and quarrying activities rank as the third largest source of Potentially Toxic Elements (PTEs) in European soils, with high volumes of waste materials deposited without adequate environmental mitigation (Panagos *et al*, 2013).

Heavy metal water pollution refers to the contamination of waterways by toxic, non-biodegradable elements such as lead, arsenic, mercury, and cadmium, which pose a serious risk to human health and ecosystems. These metals, often originating from industrial, mining, and agricultural activities, accumulate in living organisms and are linked to cancer, organ damage, and neurological disorders (Azzaoui *et al.,* 2019; Hama Aziz *et al*, 2023). Removal methods include chemical precipitation, ion exchange, membrane filtration, and the promising ecological biosorption, often requiring a multi-step treatment process to achieve safe levels (Dhanam, 2017; El Hammari *et al.,* 2022; Hama *et al*, 2023).

Abandoned quarries present unique long-term environmental challenges as they often receive less rehabilitation attention than active sites. Weathering of exposed rock surfaces, erosion of waste materials, and leaching from spoil heaps can release sediments and trace elements into nearby water bodies for many years after closure (Hancock *et al*, 2020; Ikpi *et al*, 2024). PTEs are particularly concerning as they are non-biodegradable, persist in water systems, accumulate in biota, and transfer through food chains, thereby endangering both human health and ecosystems (Shuaibu *et al*, 2025).

In developing nations, including Nigeria, abandoned or poorly regulated quarry sites frequently lack proper rehabilitation, placing nearby communities at greater risk of long-term contamination. Rano Local Government Area of Kano State hosts several abandoned quarry sites adjacent to residential settlements and agricultural lands. Rural communities in this area commonly rely on shallow hand-dug wells for drinking water, which are highly vulnerable to contamination from adjacent soils and quarry-derived materials through infiltration and surface runoff (Ikpi *et al*, 2024)

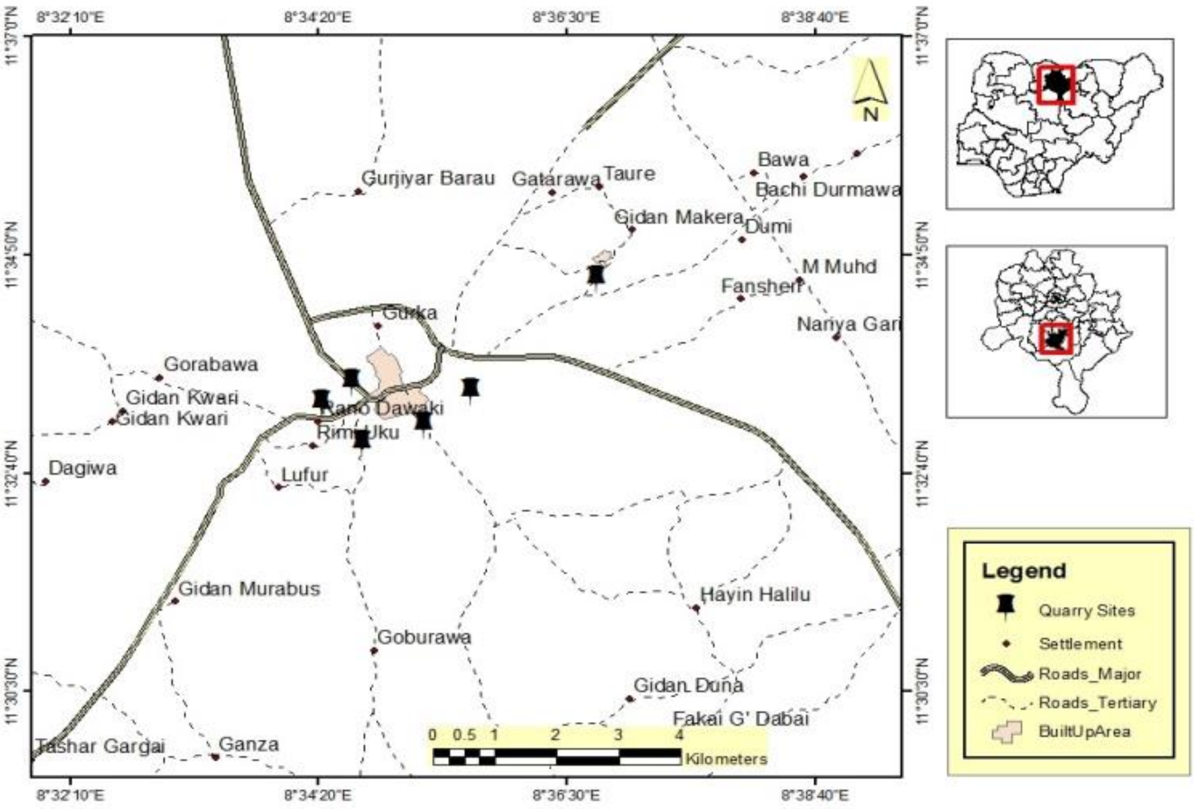
Despite known contamination risks associated with abandoned quarry landscapes, limited integrated data exist on combined assessments of physicochemical parameters, PTE levels, and contamination indices in water matrices within abandoned quarry settings of northern Nigeria (Adams *et al*, 2024)

This study therefore evaluates the physicochemical quality of drinking water, determines concentrations of selected PTEs, and assesses contamination levels using standard pollution indices around an abandoned quarry site in Rano, Kano State.

2. Materials and Methods

2.1.Description of the Study Area

The study was conducted in Rano Local Government Area, Kano State, Nigeria, located at approximately 11°33′N and 8°35′E. The abandoned quarry site is situated near Tal-udu Fulani settlement along the Karfi–Rano road. The area is characterized by exposed igneous rock formations, quarry ponds, shallow wells, and sparse vegetation due to prolonged excavation activities. W1, W2-W10 were assigned to water sample 1, 2 -10 respectively.



2.2.Materials: Some of the materials used during this research work includes the following;

i. pH Meter (Hanna HI 9813-6 portable Meter)
ii. Spade
iii. EC Meter (Hanna HI 9813-6 portable Meter)
iv. Filter paper or Centrifuge
v. Laboratory Weighing Balance (METTLER TOLEDO AB54)
vi. Sampling Container
vii. Lab Mortar and Pestle
viii. Atomic Absorption Spectroscopy (PerkinElmer PinAAcle 900H AAS)
ix. Beaker
x. Hot plate
xi. Thermometer

2.3.Reagents

Some of the reagents used in the research are listed in Table 2.3.

2.4. Methods

2.4.1. Sample Collection

A 1L of 10 water samples were purged from wells approximately 1000m radius away from the quarry site in a polyethylene (PET) bottle. Each sample was taken in triplicate and made as composite sample. Also control sample was taken 10000m away from the quarry vicinity.

Table 2.3 Some of the Reagents used in the Analysis

Reagents used in this research work			
S/N	**Name**	**Purity**	**Company**
1.	Hydrochloric Acid	35.4%	MOLYCHEM INDIA LLP
2.	Nitric Acid	66%	LOBA Chemie
3.	Buffer Solution (pH 4 & pH 7)		School Lab
4.	Distilled Water	Dis. H_2O	MOLYCHEM INDIA LLP
5.	Potassium Chloride	99.5%	MOLYCHEM INDIA LLP
6.	EDTA	99.4%	LOBA Chemie
7.	Eriochrome Black T.	99%	MOLYCHEM INDIA LLP
8.	Ammonium chloride	99.9%	MOLYCHEM
9.	Phenolphthalein		Hach
10	Sulfuric Acid	98.07%	LOBA Chemie
11	Formazin		Hach
12	Potassium chromate	98%	LOBA Chemie
13	Silver nitrate	95%	MOLYCHEM INDIA LLP

2.4.2. Physicochemical Parameters Analysis

The pH, electrical conductivity (EC), total dissolved solids (TDS), and temperature of the water samples were measured using a calibrated Hanna HI 9813-6 Portable meter. The probe was immersed in each sample, and stable readings were recorded sequentially, with temperature displayed automatically. Standard titrimetric methods (APHA, 2012) were used to determine total hardness, Alkalinity and chloride, while Turbidity was determined using Wag. WT3030 Turbidity meter.

2.4.3. Digestion of Water Sample

A 100 ml of the water sample was measured in a beaker, followed by 9 ml of HCl and 3 ml HNO_3. The mixture was heated on hot plate for about 1-2 hours set at 95^0C. After cooling, the cleared solution was made to 50ml with distilled water, filtered with a 0.45µm filter paper. Then analyzed with AAS (APHA *et al*, 2017)

2.5.Analysis

A series of calibration standards for each metal was prepared within the desired concentration range by pipetting appropriate aliquots from a 1000 mg/L stock solution into separate 50 or 100ml volumetric flasks. To each flask, 1 ml of concentrated nitric acid (HNO_3) was added, and the solutions were diluted to the mark with distilled water. The solutions were then filtered, and a reagent blank was prepared using laboratory water following the same procedure. The Atomic Absorption Spectrophotometer (AAS) was subsequently switched on, and the appropriate hollow cathode lamp for each metal was selected. The lamp current was adjusted according to the manufacturer's recommendations, while the monochromator and slit width were set to the specified operating conditions.

The sample, standard and blank were aspired in to flame AAS and operated at the wavelength recommended for the metal. The absorbance value was recorded for each standard, sample. Also distilled water was aspired between measurements and allow the reading to a stable baseline. Then a calibration curve was constructed by plotting Absorbance measured with standard against metal concentration, and the concentration was calculated and displayed in mg/L.

2.6.Pollution Assessment

2.6.1. Contamination Factor (CF): The Contamination Factor (CF) was calculated using the relation in equation 1.1

$$CF = \frac{(Cs)Sample}{(Cn)background} \quad \text{.............................}1.1$$

where Cs is the metal concentration in sample and Cn background is the crustal average value. (Hakanson, 1980) CF < 1 indicates low contamination; 1–3 moderate; 3–6 considerable; >6 very high contamination

2.6.2. Enrichment Factor (EF): The Enrichment Factor (EF) was calculated using the relation in equation 1.2

$$EF = \left(\frac{Cn}{CFe}\right) Sample \Big/ \left(\frac{Cn}{CFe}\right) background \quad \text{................}1.2$$

EF < 1 indicates background concentration; 1–2 depletion to minimal enrichment; 2–5 moderate; 5–20 significant; 20–40 very high; >40 extremely high enrichment.

2.6.3. Water Quality Index (WQI): the water quality Index (WQI) was determined using equation 1.3 below

$$WQI = \frac{\sum (Qi \times Wi)}{\sum Wi} \quad \text{...}1.3$$

where Qi is the sub-index for parameter i and Wi is the unit weight (Brown *et al*, 1972) WQI values 0–25 (Excellent), 26–50 (Good), 51–75 (Moderate/Fair), 76–100 (Poor), >100 (Very Poor).

2.7.Statistical Analysis

Pearson correlation analysis and one-way ANOVA were applied to evaluate relationships and differences among parameters using Microsoft Excel and SPSS software.

3. Results and Discussion

3.1. Physicochemical Characteristics of Water

The result of Physicochemical Parameters of the water samples were recorded as mean and standard deviation as shown in Figure 2 below. Water temperature (28–32°C) reflected tropical climatic conditions rather than quarry influence and remained within acceptable limits. The quarry water pH (7.40–7.63) fell within WHO acceptable range (6.5–8.5), indicating neutral to slightly alkaline conditions with no active acidification. This stability is typical of abandoned quarries due to natural dilution, vegetation recovery, and reduced chemical inputs after blasting cessation. Similar pH values have been reported in other Nigerian abandoned granite quarries (Ogbonna *et al*, 2020).

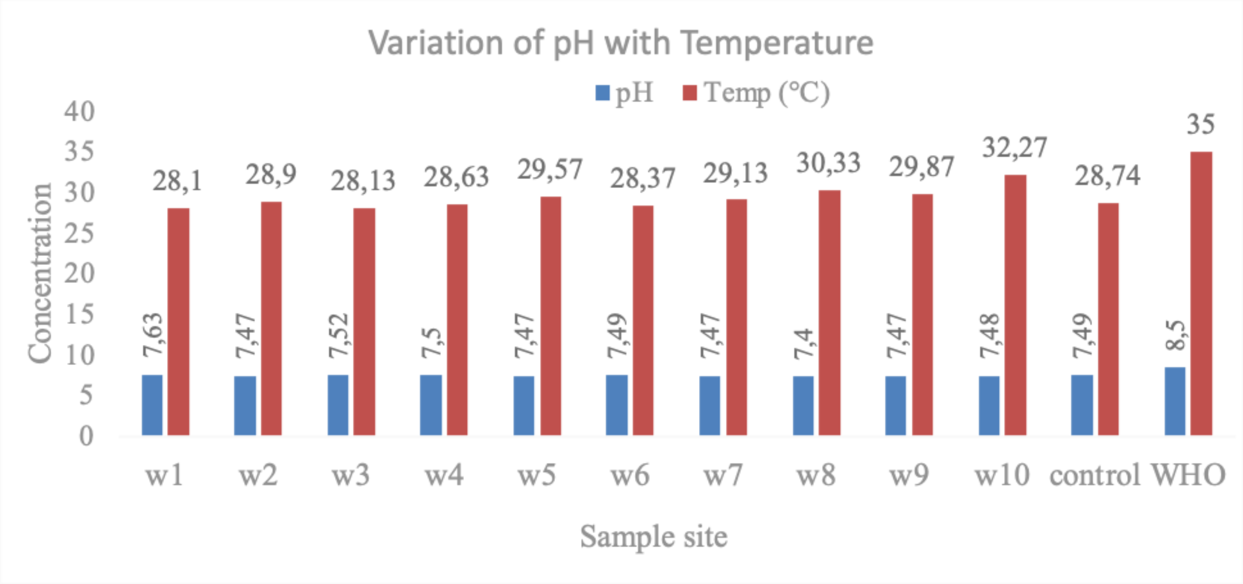


Figure 2. Variation of pH with Temperature in Water samples

Other result of Physicochemical Parameters of the water samples were recorded as mean and standard deviation as shown in Table 1 below. Electrical conductivity (21.03–672.60 µS/cm) and total dissolved solids (14.05–436.72 mg/L) were low to moderate and below WHO thresholds, indicating weak mineralization dominated by rainwater recharge with minimal post-abandonment solute input. Slightly higher EC and TDS at W8 and W9 likely resulted from localized evaporation and ion leaching in stagnant zones. Alkalinity showed the greatest variability (10.77–404.27 mg/L), with unusually high values at W3 likely linked to carbonate weathering and runoff from nearby farmland. Such elevated alkalinity in abandoned quarries can result from exposure of fresh mineral surfaces and leaching from waste rock (Ogbonna *et al*, 2020). Total hardness (12.83–187.23 mg/L) ranged from soft to moderately hard, typical of silicate basement terrains with low Ca^{2+} and Mg^{2+}. Chloride (12.63–42.07 mg/L) remained below guideline limits, indicating minimal influence from blasting residues or sewage contamination.

Table 1. Physicochemical Parameters of Water Samples

Sample	EC (µS/cm)	Alkalinity (mg/L)	TDS (mg/L)	Cl^- (mg/L)	Hardness (mg/L)	Turbidity (NTU)
W1	42.73±0.64	13.10±1.10	27.65±2.02	12.63±5.12	23.56±7.82	156.10±4.17
W2	486.50±9.10	203.67±4.15	314.77±6.15	34.07±4.12	187.23±5.15	141.10±2.10
W3	508.33±0.58	404.27±5.25	330.20±2.20	42.07±6.12	111.33±8.58	144.33±2.58
W4	480.43±2.51	198.33±3.58	311.67±1.58	38.38±2.42	116.23±2.25	126.23±6.28
W5	37.34±6.95	16.10±2.10	24.26±3.02	38.13±3.15	116.27±0.95	710.20±4.28
W6	34.57±0.15	11.40±4.20	22.38±4.02	13.33±7.05	14.53±4.06	140.93±7.21
W7	328.10±4.17	98.90±3.36	213.33±5.40	32.47±1.42	74.03±6.06	95.37±5.01
W8	166.77±3.25	63.13±1.15	436.72±0.33	27.07±2.06	150.47±2.50	35.57±3.25
W9	672.60±2.53	63.30±6.27	436.35±1.23	27.33±0.98	150.17±1.15	35.40±1.20
W10	230.30±1.27	88.93±4.21	149.67±0.95	16.10±1.10	94.17±0.85	271.13±4.15
Control	21 .03±0.47	10.77±1.21	14.05±2.13	16.43±3.40	12.83±1.21	24.00±1.01
WHO	1500	250	1000	250	500	5

Turbidity was extremely high at all sites (35.40–710.20 NTU), far exceeding the WHO limit of 5 NTU and representing the most severe water quality problem. This is mainly caused by sediment-laden runoff from steep, sparsely vegetated slopes, loose spoil materials, and ongoing weathering of exposed rock, which continue to supply fine particles long after quarry closure (Adie and Osibanjo, 2021).

3.2.**Potentially Toxic Elements**

Cadmium concentrations (0.012–0.021 mg/L) exceeded WHO guidelines (0.003 mg/L) at all quarry points, with W5 having highest concentration and the control much lower (0.002 mg/L). Elevated Cd is mainly linked to weathering of granitic rocks and quarry disturbance, posing public health risks including kidney damage and bone demineralization with long-term exposure (Laniyan and Adewumi, 2019). Chromium concentrations varied from 0.071–0.847 mg/L, with W6 having the highest value (0.847 mg/L) reaching nearly 17 times the permissible limit. All samples exceeded WHO guidelines (0.05 mg/L). Elevated Cr levels are probably caused by chromite-bearing inclusions in basement terrains, weathering of ultramafic/granitic minerals, and equipment or blasting residues from quarries (Ogbonna *et al*, 2020)

Copper concentrations ranged between 0.032–0.111 mg/L, falling within WHO limits (2.0 mg/L) and indicating no major Cu contamination. Granite-derived quarry waters generally contain moderate Cu derived from biotite and chalcopyrite traces (Afolabi *et al*, 2019). Iron concentrations showed very large variation (0.059–29.56 mg/L), with highest values at W6 (29.56 mg/L) and W1 (27.41 mg/L). Nearly all samples exceeded WHO limits (0.3 mg/L), consistent with Fe enrichment reported in quarry waters from Kano State (Ikpi *et al*, 2024). Elevated Fe is attributed to oxidation of iron-bearing minerals (biotite, hornblende) and leaching from ferruginized overburden. Manganese concentrations ranged from 0.383–2.723 mg/L, with W6 recording the highest level. Most samples exceeded WHO guidelines (0.4 mg/L).

Manganese often co-occurs with Fe in basement rocks, and elevated Mn in quarry waters is commonly linked to reductive dissolution in stagnant ponds (Ikpi *et al*, 2024)

Nickel values (0.059–0.138 mg/L) exceeded WHO guidelines (0.07 mg/L) in most samples, indicating trace metal mobilization from rock weathering and metallic components used in blasting activities (Hassan 2022; Okafor and Njoku, 2021). Lead values (0.103–0.463 mg/L) were uniformly high, surpassing WHO limits (0.01 mg/L) by 10–46 times. Pb contamination is a major concern due to severe health implications, resulting from dust from blasting residues, metallic fragments from quarry machinery, and fine-grained sediments washed into the pit (Adie and Osibanjo, 2021).

Table 2. Concentrations of Potentially Toxic Elements in Water Samples (mg/L)

Sample	Cd	Cr	Cu	Fe	Mn	Ni	Pb
W1	0.013±0.003	0.584±0.015	0.111±0.030	27.41±0.058	1.826±0.002	0.138±0.022	0.262±0.073
W2	0.012±0.001	0.113±0.016	0.068±0.008	3.856±0.126	1.062±0.006	0.059±0.018	0.171±0.071
W3	0.012±0.001	0.088±0.014	0.044±0.004	2.284±0.041	0.946±0.014	0.084±0.007	0.202±0.025
W4	0.019±0.001	0.071±0.012	0.033±0.001	2.609±0.026	0.952±0.002	0.079±0.016	0.190±0.025
W5	0.021±0.001	0.220±0.018	0.032±0.005	19.53±0.112	0.630±0.002	0.062±0.009	0.103±0.069
W6	0.013±0.001	0.847±0.020	0.075±0.007	29.56±0.035	2.723±0.008	0.129±0.002	0.270±0.021
W7	0.016±0.001	0.071±0.006	0.035±0.002	4.922±0.606	0.383±0.002	0.093±0.007	0.190±0.054
W8	0.014±0.001	0.188±0.014	0.059±0.010	0.059±0.010	1.037±0.008	0.090±0.009	0.463±0.045
W9	0.018±0.003	0.193±0.007	0.042±0.006	7.670±0.027	0.434±0.013	0.094±0.013	0.254±0.032
W10	0.016±0.002	0.308±0.023	0.078±0.009	23.57±0.022	1.614±0.006	0.103±0.013	0.294±0.019
Control	0.002±0.002	0.032±0.014	0.024±0.009	0.31±0.068	0.050±0.004	0.01±0.015	0.01±0.009
WHO	0.003	0.050	2.000	0.300	0.100	0.070	0.010

3.3. **Water Quality Index (WQI)**

WQI values (52.1–70.5) in Table 3 indicated spatial variation in overall water quality. Most samples fell within the Fair category (W1, W4–W9), meaning water is moderately polluted and generally suitable for domestic use but requires basic treatment before drinking. Three samples (W2, W3, W10) were classified as Poor, indicating water unsuitable for direct consumption due to elevated physicochemical parameters and PTEs. The absence of Good or Excellent ratings suggests overall water quality degradation in the area.

Table 3. Water Quality Index Classification

Sample	Water Quality Index (WQI)	Quality
W1	63.2	Fair
W2	58.1	Poor
W3	54.5	Poor
W4	60.3	Fair
W5	61.9	Fair
W6	70.4	Fair
W7	65.1	Fair
W8	70.5	Fair
W9	67.2	Fair
W10	52.1	Poor

3.4.Enrichment Factor (EF)

Most samples showed low enrichment: W1, W6, and W10 had EF < 1, indicating predominantly geogenic control. Samples W2, W3, W4, W5, W7, and W9 (EF = 1.08–1.80) indicated minimal anthropogenic input. In contrast, W8 exhibited extreme enrichment (average EF = 59.11), with very high EF values for Pb, Mn, Cd, and Ni, indicating strong anthropogenic contamination typically associated with mining-related activities and waste disposal as above.

Table 4. Enrichment Factor of Water Samples

Sample	Cd	Cr	Cu	Mn	Ni	Pb	Average EF	Remark
W1	0.73	0.21	0.05	0.41	0.16	0.30	0.31	Background
W2	1.02	0.28	0.23	1.71	0.48	1.37	0.78	Background
W3	1.63	0.37	0.25	2.57	1.14	2.74	1.45	Minimum
W4	2.31	0.26	0.16	2.27	0.93	2.32	1.38	Minimal
W5	1.67	0.11	0.09	1.99	0.98	1.64	1.08	Minimal
W6	0.44	0.28	0.03	0.57	0.14	0.29	0.29	Background
W7	1.71	0.14	0.11	1.52	1.23	3.17	1.31	Minimal
W8	69.97	3.04	3.21	107.03	27.90	143.53	59.11	Very high due to Pb, Mn, Cd &Ni
W9	2.34	0.24	0.07	2.43	1.17	4.53	1.80	Minimal
W10	0.66	0.26	0.04	0.42	0.19	0.37	0.32	Background

3.5.Contamination Factor (CF)

CF results in Table 5 indicate that all quarry water samples are contaminated, with average CF values ranging from 9.07–32.26, reflecting a high overall pollution burden. Very high contamination was observed in W1, W5, W6, W8, W9, and W10, mainly driven by elevated Fe, Mn, Pb, Cr, Ni, and Cd. The highest contamination occurred at W6 (CF = 32.26), indicating severe multi-source pollution. Extremely high Pb levels, particularly in W8, are of major concern due to persistence and toxicity.

3.6.Correlation Analysis

The Correlation Analysis for the Physicochemical Parameters of water sample as shown in Table 6, showed EC has very strong positive correlation with TDS ($r = 0.9417$, $p < 0.01$), confirming EC is mainly governed by dissolved ionic content. Hardness correlated strongly with EC ($r = 0.9206$), TDS ($r = 0.9367$), and chloride ($r = 0.9362$), indicating dissolved Ca–Mg and chloride salts as principal contributors. Strong correlation between pH and chloride ($r = 0.9630$) suggests ionic enrichment influences acid-base balance. Turbidity displayed weak negative correlations with dissolved parameters, indicating control by suspended particulate matter rather than dissolved ions.

Table 5. Contamination Factor of Water Samples

Sample	Cd	Cr	Cu	Fe	Mn	Ni	Pb	Average CF	Status
W1	6.50	18.25	4.63	88.42	36.52	13.80	26.20	27.76	Very high due to Fe, Mn, Cr &Ni
W2	6.00	3.53	2.83	12.44	21.24	5.90	17.10	9.86	High due to Mn, Pb, & Fe
W3	6.00	2.75	1.83	7.37	18.92	8.40	20.20	9.35	High due to Pb & Mn
W4	9.50	2.22	1.38	8.42	19.04	7.90	19.00	9.64	High due to Pb, Mn & Cd
W5	10.50	6.88	1.33	63.00	12.60	6.20	10.30	15.83	Very high due to Fe, Mn, Cd & Pb
W6	6.50	26.47	3.13	95.35	54.46	12.90	27.00	32.26	Very high due to Fe, Mn, Pb, Cr & Ni
W7	8.00	2.22	1.46	15.88	7.66	9.30	19.00	9.07	High due to Fe, Pb, & Cd
W8	7.00	5.88	2.46	0.19	20.74	9.00	46.30	13.08	Very high Pb, Mn & Ni
W9	9.00	6.03	1.75	24.74	8.68	9.40	25.40	12.14	Very high due to Pb, Fe & Ni
W10	8.00	9.63	3.25	76.03	32.28	10.30	29.40	24.13	Very high due to Fe, Mn, Pb, Ni & Cr

Table 6. Correlation Matrix of Physicochemical Parameters

	pH	*EC*	*Temp.*	*Alkalinity*	*TDS*	*Chloride*	*Hardness*	*Turbidity*
pH	1							
EC	0.8164*	1						
Temp.	0.7533	0.6977	1					
Alkalinity	0.3375	0.6186	0.152	1				
TDS	0.7577	0.9417**	0.7312	0.5621	1			
Chloride	0.9630**	0.8847*	0.7918	0.4368	0.8565*	1		
Hardness	0.8464*	0.9206**	0.8176*	0.4855	0.9367**	0.9362**	1	
Turbidity	-0.2458	-0.3854	-0.1022	-0.2222	-0.4501	-0.2092	-0.1931	1

Note: * Strong Correlation, ** very Strong Correlation

The result for PTEs (Table 7) indicated that Cr showed strong positive correlations with Fe (r = 0.8465) and Mn (r = 0.8879), suggesting control by redox processes and adsorption/co-precipitation with Fe–Mn oxides. Cu correlated strongly with Mn (r = 0.8441) and moderately with Fe (r = 0.5836), indicating association with Fe–Mn oxide phases. Ni showed moderate-strong correlations with Mn, Cu, and Pb (r = 0.7213–0.7839), while Pb correlated with Cu and Ni, implying common transport pathways and anthropogenic sources. Cd had weak correlations with other metals, indicating distinct localized anthropogenic sources.

Table 7. Correlation Matrix of Potentially Toxic Elements

	Cd	*Cr*	*Cu*	*Fe*	*Mn*	*Ni*	*Pb*
Cd	1						
Cr	0.1184	1					
Cu	0.0851	0.6594	1				
Fe	0.3304	0.8465*	0.5836	1			
Mn	0.1488	0.8879*	0.8441*	0.743	1		
Ni	0.4943	0.6756	0.7213	0.5911	0.7641	1	
Pb	0.3258	0.4018	0.7048	0.2142	0.5605	0.7839	1

*Strong correlation

3.7.ANOVA Results

ANOVA results in Table 8 and 9 respectively revealed statistically significant differences among sampling groups for both physicochemical parameters (F = 5.81 > Fcrit = 2.13; $p = 1.84 \times 10^{-5}$) and

PTEs (F = 6.91 > Fcrit = 2.23; p = 8.53 × 10^{-6}). These significant spatial variations suggest influence of both natural and anthropogenic factors including geological heterogeneity, quarrying operations, surface runoff, and leaching processes.

Table 8. ANOVA for Physicochemical Parameters

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	702617.2	7	100373.9	5.805694	1.84E-05	2.126324
Within Groups	1383109	80	17288.87			
Total	2085727	87				

Table 9. ANOVA for Potentially Toxic Elements

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	662.4091	6	110.4015	6.914565	8.53E-06	2.231192
Within Groups	1117.656	70	15.96652			
Total	1780.065	76				

Conclusion

This study assessed physicochemical characteristics, potentially toxic elements, and contamination indices of water sources around an abandoned quarry site in Rano, Kano State, Nigeria. Key findings reveal that most basic physicochemical parameters (pH, EC, TDS, chloride, hardness) were within WHO limits, while turbidity levels were extremely high (35.40–710.20 NTU) across all locations, indicating severe particulate pollution. Concentrations of Cd, Cr, Fe, Mn, Ni, and Pb exceeded WHO (2017) limits in most samples, with Pb and Cr surpassing guideline values by up to 46 and 17 times respectively, indicating serious chemical pollution.

WQI values (52.1–70.5) classified most samples as Fair to Poor, indicating moderate pollution and unsuitability for direct consumption. CF analysis confirmed significant to extremely high contamination in all samples, with average CF values ranging from 9.07–32.26. EF results showed background to minimal enrichment at most sites but extreme enrichment at W8 (EF = 59.11), identifying a localized pollution hotspot.

Correlation analysis revealed strong associations among dissolved ionic parameters (EC-TDS-hardness-chloride) and among Fe–Mn–Cr–Ni–Pb, suggesting common geochemical and anthropogenic sources. ANOVA results confirmed statistically significant spatial variations in both physicochemical parameters and PTEs. The study concludes that the abandoned quarry site constitutes an environmental and public health concern, and water sources within the area are unsafe for domestic use without appropriate treatment.

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