

Physicochemical Impact on Water Quality within Rimin Gado Granite Quarry Sites,

Kano State, Nigeria

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ABSTRACT

Granite quarry activities release pollutants that can degrade water quality and threaten public health. This study evaluated the quality of open wells and surface water used for drinking around the Rimin Gado granite quarry sites in Kano State, Nigeria. Physicochemical parameters were analyzed using standard methods. The results were temperature: 18.0 ± 0.8 – 34.1 ± 0.7 °C, pH (6.3 ± 0.4 – 9.1 ± 0.1), electrical conductivity (146.7 ± 5.8 – 4546.7 ± 12.0 $\mu\text{S/cm}$), turbidity (2.0 ± 0.6 – 288.3 ± 6.1 NTU), alkalinity (3.2 ± 0.3 – 476.7 ± 5.8 mg/L), total dissolved solids (40.7 ± 6.1 – 3836.8 ± 45.0 mg/L), total suspended solids (0.7 ± 0.6 – 99.3 ± 23.4 mg/L), hardness (115.2 ± 29.2 – 1028.0 ± 29.4 mg/L), and major ions including Ca^{2+} (28.3 ± 271 mg/L), Mg^{2+} (7.5 – 118.5 mg/L), Cl^- (20.4 – 878.7 mg/L), PO_4^{3-} (0.3 – 10.3 mg/L), NO_3^- (0.2 – 10.3 mg/L), SO_4^{2-} (1.1 – 18.2 mg/L). Most parameters were within World Health Organization limits, except at study sites designated HM, KT, SC, ZD, ZM, and DG, where some parameters exceeded permissible levels. Water Quality Index (WQI) values indicated moderate quality at BK (50.38) and DG (57.86), while others exceeded 100, following the descending order: $\text{KT} > \text{ZS} > \text{SCL} > \text{ZD} > \text{HM}$. ANOVA analysis revealed no significant difference ($p = 0.05$) among the sites. The findings revealed contamination of water near quarry sites, emphasizing the need for continuous monitoring and better management of quarry effluents to protect groundwater resources.

Keywords: Quarry, granite, water quality assessment, physicochemical parameters, contamination

INTRODUCTION

Water is a vital component of human life and its quality is crucial for human health, economic development, and environmental sustainability [1]. However, water resources are facing increasing pressure from human activities such as industrialization, urbanization, and mining, which can lead to water pollution [2]. Quarrying activities have been linked to environmental degradation, including water pollution [3]. The release of dust, heavy metals, and other pollutants from quarrying activities can contaminate surface and groundwater sources, posing a risk to human health and the environment [4]. The rapid expansion of the construction industry has led to an increased demand for granite, resulting in the widespread proliferation of quarrying activities globally [5]. In Nigeria, the quarrying sector significantly contributes to the national economy, with granite being one of the most extensively quarried materials [4].

The availability of clean water is crucial for human health, economic development, and environmental sustainability, as emphasized in the United Nations' Sustainable Development Goals (SDGs), particularly Goal 6 (Clean Water and Sanitation) [6]. The impact of quarrying activities on water quality is a major concern, as it can adversely affect human health, aquatic ecosystems, and the environment, thereby impeding progress towards achieving SDGs 3 (Good Health and Well-being), 6 (Clean Water and Sanitation), 11 (Sustainable Cities and Communities), 12 (Responsible Consumption and Production), and 13 (Climate Action) [6].

The Rimin Gado granite quarry sites in Kano State, Nigeria, represent some of the largest granite quarrying operations in the region. Despite their economic significance, there is increasing concern regarding the potential environmental impacts of these quarrying activities, particularly on water quality [3]. To date, much of quarrying and water pollution researches in Nigeria have been focused in the southern regions [7, 8], leaving the northern zones understudied. Our findings thus offer important baseline data, especially in areas with potential public health concerns in the northern part of the country. The observation of elevated phosphate (PO_4^{3-}) concentrations as a key pollutant is particularly novel in the context of quarrying studies, which often emphasize heavy metals and sediment loads. Phosphate enrichment has been implicated in eutrophication and downstream ecological stress [9], and recent geostatistical studies have used phosphate-metal coupling to trace contaminant sources in groundwater [10].

Therefore, this study aims to assess water quality in the vicinity of the Rimin Gado granite quarry sites, an area in Kano State, Nigeria, where cancer has been reported.

MATERIALS AND METHODS

All chemical reagents used in this study were prepared using analytical-grade chemicals and deionized water. All glassware were thoroughly cleaned with detergent, rinsed with water and acetone, and dried in an oven at 105 °C.

Study Area

Rimin Gado, a local government area in Kano state, is situated approximately 20 km west of the state capital and spans an area of 225 square kilometers between the latitude of 11.965°N and longitude of 8.25°E. The area was selected because of the recent cancer outbreak, which might be linked to the anthropogenic activities of granite quarry that affect their drinking water. Seven sampling stations were identified in the vicinity of the quarrying sites.

Table 1: The Sampling Sites

SN	Name	Symbol
1	Sample point 1	ZG
2	Sampling point 2	DG
3	Sampling Point 3	BK
4	Sampling point 4	KT
5	Sampling point 5	ZG
6	Sampling point 6	MR
7	Sampling point 7	SC

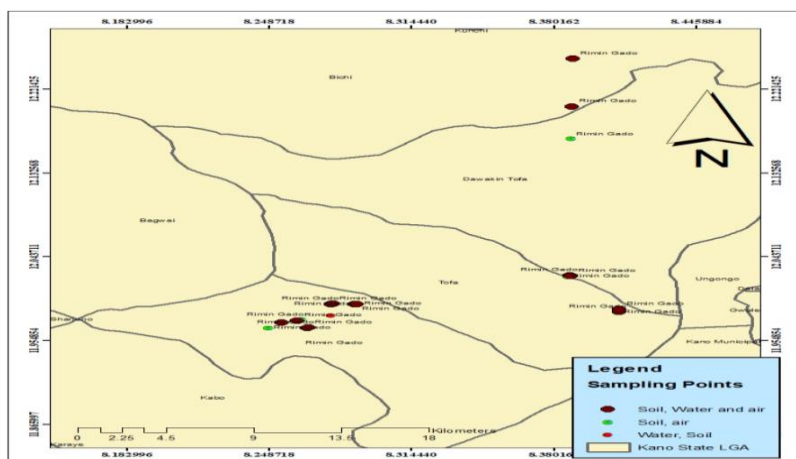


Figure 1: Map of the Study Area (Source: Geography Department, Northwest University Kano)

Water Sample Collection and Preparation

Water samples were collected from twenty-one wells and surface water (dam) used for drinking from various locations in triplicates to form a composite sample within the vicinity of the seven quarry sites. These samples were stored in polythene plastic containers covered with black polythene bags to prevent light exposure and then immediately placed in a refrigerator at 4 °C to prevent the growth of algae.

Portable pH/E.C/TDS/Temp. meter (HI 9813-6) was used for the determination of pH, Electrical conductivity, Total dissolves solid and Temperature at the sampling sites. The meter was calibrated with a buffer solution, and 1M KOH for the calibration of electrical conductivity. A spectrophotometer (DR-6000) was used to determine the concentrations of nitrate, phosphate, sulfate, and TSS, while a turbidity meter (Wag.WT3030) was used in determining the turbidity, and the titration method was used to determine the total hardness, chloride ions, calcium ions, and magnesium ions in the water samples.

Water Quality Assessment

This is the process of evaluating the quality of water by analyzing physical, chemical and biological characteristics based on specific criteria usually to determine its suitability for a particular purpose [11]. In this research, water quality index (WQI) was used to evaluate the overall quality of water in one single value to determine its suitability for drinking purposes as reported by Brown *et al.* and Debnath *et al.* [12, 13].

Table 2: Classification of Water Quality index

Water Quality Index (WQI) Value	Classification
0 – 25	Excellent
26 – 50	Good
51 – 75	Moderate
76 – 100	Poor
Above 100	Very Poor

RESULTS AND DISCUSSION

Table 3 presents the results obtained for the physicochemical parameters analyzed.

Table 3: Results for Physicochemical Parameters

S/N	Sampling Sites	Temp. (°C)	pH	E.C (μS/cm)	Turbidity (NTU)	Alkalinity (mg/L)	TDS (mg/L)	TSS (mg/L)	Hardness (mg/L)
1	ZSA	30.2±1.2	6.7±0.2	310.0±10.0	95.8±2.5	133.3±20.2	225.3±7.0	27.3±0.6	177.5±5.7
2	ZSB	28.4±0.1	7.0±0.2	320.0±17.3	31.5±22.0	135.0±26.4	228.3±13.4	7.0±7.0	130.9±24.9
3	ZSC	29.9±0.7	6.9±0.1	783.3±28.9	56.9±17.5	108.3±37.9	567.8±1.5	16.3±5.5	130.9±24.9
4	ZDA	33.1±0.1	7.5±1.0	380.0±60.8	29.6±15.9	3.2±0.3	295.7±1.5	20.0±7.4	172.1±34.8
5	ZDB	32.9±0.3	7.4±0.2	740.0±0.0	2.8±1.0	6.0±0.0	523.3±4.9	4.0±1.0	851.5±11.3
6	ZDC	32.9±0.5	7.8±0.1	1646.7±5.8	2.9±2.9	4.2±0.0	1185.7±5.0	3.0±2.7	728.7±76.5
7	HMA	32.7±0.6	9.1±0.1	150.0±0.0	41.4±3.6	140.0±0.0	111.7±0.6	21.0±0.0	124.2±11.3
8	HMB	32.6±0.15	9.0±0.1	150.0±0.0	45.0±6.9	121.7±2.9	112.0±2.1	16.3±2.1	115.2±29.2
9	HBC	32.6±0.5	9.0±0.6	146.7±5.8	37.3±3.9	118.3±2.9	111.7±2.9	20.0±1.7	118.2±14.4
10	SCA	30.5±0.4	6.9±0.2	833.3±5.8	10.4±1.2	195.0±10.0	594.0±2.0	5.8±3.1	636.0±6.9
11	SCB	30.4±0.2	6.3±0.4	534.7±26.6	288.3±6.1	35.0±5.0	40.7±6.1	99.3±23.4	190.04±9.3
12	SCC	30.5±0.0	7.2±0.4	553.3±5.8	62.6±2.0	58.3±5.8	392.0±2.0	24.0±2.0	264.9±13.5
13	KTA	33.9±0.1	7.9±0.2	4546.7±23.1	23.2±7.2	463.3±15.3	3836.8±45.0	9.0±3.6	873.9±36.3
14	KTB	33.5±1.3	7.3±0.1	2690.0±17.0	68.5±9.1	476.7±5.8	1931.8±23.0	18.3±4.9	876.9±11.3
15	KTC	34.1±0.7	7.5±0.1	4546.7±12.0	70.8±23.1	420.0±34.6	2923.7±94.0	13.7±3.5	1028.0±29.4
16	BAK	31.3±1.3	6.9±0.0	490.0±10.0	2.0±0.6	220.0±36.6	352.0±2.0	1.0±0.0	296.3±15.6
17	BKB	18.0±0.8	6.8±0.2	1213.3±5.8	2.7±0.1	347.0±23.4	870.0±7.6	0.7±0.6	335.2±42.4
18	BKC	32.1±0.1	6.9±0.2	1206.0±32.0	3.0±1.7	376.7±66.6	867.3±22.0	2.3±1.2	293.3±18.7
19	DGA	32.6±0.2	7.9±0.2	246.7±5.8	5.1±0.6	248.3±10.4	178.0±4.4	1.0±0.0	186.0±5.7
20	DGB	32.5±0.2	7.8±0.2	246.7±5.8	4.8±0.1	182.0±3.5	178.0±2.0	2.7±0.6	172.9±5.8
21	DGC	32.1±0.1	8.0±0.4	246.7±5.8	3.8±0.5	200.0±0.0	179.7±3.1	2.3±0.6	170.2±5.2
22	WHO [1]	35	6.5-8.5	1500	5	250	1000	500-2000	500

Temperature is an important physical factor in monitoring water quality because it affects the solubility of gases such as oxygen and carbon dioxide, influences the rates of chemical reactions, and is crucial for the biological activity and metabolic processes of aquatic organisms [14]. In this study, water temperatures were recorded between 18 °C and 34.1 °C, as shown in Table 2, all falling below the World Health Organization (WHO) guideline of 35 °C for drinking and domestic water sources [15]. Nonetheless, higher temperatures approaching the upper threshold may indicate human impacts such as industrial discharges, deforestation, or increased solar heating due

to the loss of vegetation. Even minor changes in temperature can affect the distribution of aquatic species, microbial activity, and overall ecological stability of freshwater ecosystems.

Recent research indicates that quarrying activities can have a considerable effect on water temperature. For instance, Eyankware *et al.* noted changes in physicochemical properties, including higher temperatures, in the waters of abandoned quarries in southeastern Nigeria [16]. Likewise, Ikpi *et al.* discovered that surface water near active quarry locations in Akamkpa had increased temperatures, which could impact water quality and aquatic ecosystems [7]. Hassan measured water temperatures reaching 37.9 °C in areas influenced by quarrying in Ogun State, linking this rise to the reduction of vegetation and greater exposure to sunlight [17]. Okafor and Njoku also established that quarrying activities in Ebonyi State led to thermal pollution, with water temperatures in certain areas surpassing WHO standards [18]. These results highlight the necessity for continuous monitoring and management of water bodies in and near quarry sites to avoid ecological harm.

pH is another critical parameter in water quality assessment, representing the concentration of hydrogen ions and indicating the acidity or alkalinity of water [19]. In this study, pH values ranged between 6.3 and 9.1, with most sampling sites falling within the World Health Organization (WHO) recommended range of 6.5–8.5 for drinking and domestic water use [20]. However, samples from HM (A, B, and C) recorded higher pH values of 9.1, 9.0 and 9.0 respectively as presented in Table 2. These elevated values may be attributed to the dissolution of carbonate, bicarbonate, and hydroxide minerals from surrounding rock formations, common in quarry zones, as well as the runoff of alkaline agricultural inputs such as fertilizers. Similar findings were reported by Peace *et al.* [19] who observed elevated pH levels in surface waters near limestone quarries, linking them to geogenic factors and anthropogenic agricultural practices.

Recent studies have shown the influence of quarrying activities on pH alterations in nearby water bodies. Eyankware *et al.* [16] reported that abandoned quarry pits in Abakaliki, southeastern Nigeria, exhibited pH values as high as 9.2, largely due to the leaching of alkaline compounds from surrounding rock strata. Similarly, Hassan recorded pH values ranging from 6.3 to 9.5 in quarry-adjacent waters in Ogun State [17], noting that sites closer to active quarry zones showed significantly higher pH due to increased rock-water interactions and soil disturbances. Ikpi *et al.* also observed alkaline shifts in water near quarry operations in Akamkpa, attributing the changes to the weathering of calcareous rocks and occasional runoff from nearby construction and

agricultural activities [7]. These consistent observations across multiple studies suggest that the slightly elevated pH values in the current study, particularly at HM sites, are characteristic of quarry-influenced environments and emphasize the need for continuous pH monitoring to safeguard aquatic ecosystems and ensure water usability.

The electrical conductivity (EC) serves as a measure of the concentration of dissolved ionic substances in water, reflecting the total dissolved solids and mineral content [21]. In this study, EC values ranged from 146.7 $\mu\text{S}/\text{cm}$ to 4546.7 $\mu\text{S}/\text{cm}$. The sites BK B, ZD C, KT A, KT B, and KT C exceeded the WHO recommended maximum limit of 1000 $\mu\text{S}/\text{cm}$ for drinking water [15] as shown in Table 2, indicating higher levels of dissolved inorganic ions. These elevated values may result from the exposure of mineral-rich rocks due to quarrying, weathering, and agricultural runoff. Galadima and Umar also observed increased EC in waters near quarries in northern Nigeria [21], attributing it to intensified rock-water interactions and ion leaching. Similar findings have been reported in other quarry regions. Eyankware *et al.* documented EC levels surpassing 4000 $\mu\text{S}/\text{cm}$ in abandoned quarry pits in southeastern Nigeria [16], while Hassan noted similar increases in Ogun State, particularly near active blasting sites [17]. Ikpi *et al.* identified EC values exceeding 3000 $\mu\text{S}/\text{cm}$ in water bodies around quarries in Akamkpa, linked to weathered calcareous rocks and human activities [7]. These findings corroborate the current study's results and highlight quarrying as a significant factor influencing the ionic composition and electrical conductivity in surface waters.

Turbidity is also a key parameter in assessing water quality, representing the presence of suspended and colloidal matter such as silt, clay, organic detritus, plankton, and microbial populations [22]. In this study, turbidity levels ranged between 2.0 and 288.3 NTU, with the majority of the sites exceeding the World Health Organization permissible limit of 5 NTU for drinking water [20] as presented in Table 2. Elevated turbidity is commonly linked to land disturbances, particularly those caused by quarrying, which removes vegetative cover and mobilizes sediments into nearby water bodies. Such increases in particulate load reduce light penetration, disrupt aquatic ecosystems, and often correlate with higher microbial and heavy metal concentrations [17, 23]. The highest turbidity readings in this study may also reflect rainfall-induced runoff and slope instability, typical of active or poorly managed quarry sites. Similar patterns have been observed. Eyankware *et al.* reported turbidity values exceeding 300 NTU in southeastern Nigeria's quarry ponds [16], while Okoye and Ogbebor linked excessive turbidity

near granite quarries in Edo State to suspended debris and runoff [22]. Globally, Paikaray *et al.* documented turbidity levels ranging from 150 to 480 NTU near stone quarry sites in eastern India, citing poor drainage and monsoonal erosion as major contributors [24]. In Uganda, Ssebiyonga and Eze found that unregulated sand and stone mining activities led to turbidity levels far above WHO limits, posing health risks to rural communities [25]. These studies underscore the widespread impact of quarrying on turbidity across diverse environmental settings and reinforce the need for mitigation measures such as sediment retention basins and controlled blasting practices.

Alkalinity refers to the buffering capacity of water, representing its ability to neutralize acids, primarily due to the presence of carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), and hydroxide (OH^-) ions [11]. In this study, total alkalinity ranged from 3.2 mg/L to 476.7 mg/L. While most sites fell within the World Health Organization recommended limit of 500 mg/L for drinking water [15], DG A, BK C, and BK B showed values approaching this threshold. Notably, KTR C, A, and B recorded the highest alkalinity values (420.0, 463.3, and 476.7 mg/L), as shown in Table 2. This is likely due to geological formations rich in carbonate minerals and prolonged water-rock interactions common in quarry environments. Similar patterns have been documented in other quarry-influenced areas. Eyankware *et al.* reported alkalinity values as high as 485 mg/L in abandoned quarry ponds in southeastern Nigeria, linked to carbonate weathering [16]. In India, Paikaray *et al.* found elevated alkalinity levels (up to 470 mg/L) in water bodies near limestone quarries, attributing it to increased bicarbonate concentrations [21]. Ssebiyonga and Eze observed total alkalinity above 450 mg/L near quarry sites in eastern Uganda [25], while Yadav *et al.* documented alkalinity between 420–480 mg/L in India Rivers downstream of quarry zones [26]. These results align with the present study, highlighting the influence of lithology and quarry activities on water alkalinity levels.

The total dissolved solid (TDS) represents the concentration of dissolved inorganic substances such as chlorides, sulphates, carbonates, and bicarbonates in water, and serve as a key indicator of water taste and overall quality [1]. In this study, TDS values ranged significantly across the sampling sites, with most falling below the WHO acceptable limit of 1200 mg/L. However, samples from KTB (1931.8 mg/L), KTC (2923.7 mg/L), and KTA (3836.8 mg/L) as presented in Table 2 exceeded this threshold, indicating poor water quality and unsuitability for drinking. Such elevated TDS concentrations are often associated with geological formations rich

in soluble minerals, mining activity, and reduced water dilution which is common in quarry-impacted environments. High TDS levels not only impair taste but also contribute to scaling in boilers, pipes, and kitchen utensils. Similar findings have been reported in other quarry-related studies. Subodh and Mahendra observed TDS values exceeding 3000 mg/L near sandstone quarries in central India, attributing the rise to mineral dissolution and runoff [27]. Eyankware *et al.* recorded TDS concentrations up to 2800 mg/L in abandoned quarry ponds in southeastern Nigeria [16]. In Uganda, Ssebiyonga and Eze reported TDS levels of 2500–3100 mg/L near artisanal mining sites [25], while Paikaray *et al.* documented high TDS levels (above 2700 mg/L) in quarry-impacted streams in Odisha, India [24]. These studies are consistent with the present findings, highlighting the detrimental effects of quarry activities on water chemistry and emphasizing the need for monitoring and mitigation.

Total Suspended solids (TSS) in water consist of fine inorganic particles such as clay and silt, as well as organic materials like algae and bacteria [28]. In this study, all samples had concentrations below the WHO guideline of 500 mg/L as shown in Table 2, suggesting relatively low particulate pollution despite nearby quarrying activities. This may be due to limited runoff or effective natural filtration. Comparable findings have been reported in similar environments. Okoye and Ogbebor observed suspended solids below 450 mg/L near quarries in Nigeria [22]. Yadav *et al.* recorded levels between 300–480 mg/L downstream of Malaysian quarries [26]. Paikaray *et al.* found values around 470 mg/L near Indian quarry sites [24], while Eyankware *et al.* reported <400 mg/L in Nigerian quarry ponds [16]. These align with the present results, indicating moderate impact from quarry operations.

Hardness in water arises mainly from the presence of divalent metal ions, particularly calcium (Ca^{2+}) and magnesium (Mg^{2+}), originating from geological weathering and anthropogenic activities such as quarrying [8]. In the current study, as presented in Table 2, the total hardness ranged from 115.2 mg/L to 1028.0 mg/L, placing the water in categories ranging from moderately hard to extremely hard. The highest concentrations were recorded at KTR A, B, and C, likely due to enhanced mineral dissolution from disturbed rock surfaces and soil as a result of quarry operations. Similar hardness levels have been reported in quarry-affected waters elsewhere. Akinbile *et al.* documented hardness values up to 980 mg/L in water near quarry sites in southwestern Nigeria [8]. Tetteh *et al.* found levels between 450–960 mg/L in Ghanaian communities exposed to open-pit mining [29]. Mohan and Yadav recorded values exceeding 1000

mg/L in groundwater near marble quarries in Rajasthan [26], India, while Balamurugan *et al.* observed total hardness levels above 900 mg/L near stone quarries in Tamil Nadu, indicating a consistent pattern of elevated hardness due to mining and quarrying impacts [30]. Elevated hardness levels are commonly reported in mining areas. Mohan and Yadav observed values above 1000 mg/L in groundwater near marble quarries in Rajasthan, India [31], which aligns with the high hardness recorded at KT sites in this study.

Figures 2-7 provide the levels of ions present in the samples. Calcium ion concentrations in the study ranged from 28.3 to 271 mg/L, with most values falling within the WHO maximum contaminant level of 200 mg/L, except for SC A, KT A, ZD C, and KT B as shown in Figure 2. Elevated calcium levels are typically associated with the presence of limestone and other calcium-rich rocks, which contribute to both temporary and permanent hardness in water [32]. Similar results have been observed in quarry-influenced areas [33]. Wamalwa *et al.* and Okonkwo *et al.* noted geological influence and quarry runoff as contributors to calcium enrichment [34, 35].

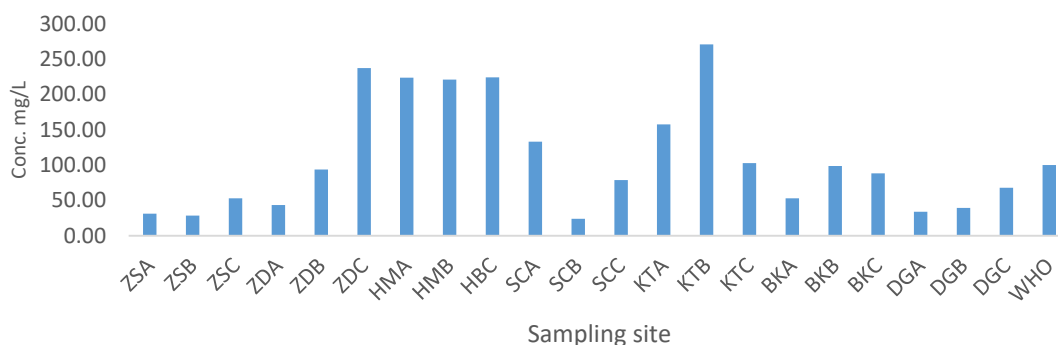


Figure 2: Calcium Ion Concentration

The concentrations of magnesium ions in the samples ranged widely, with KT B, SC A, ZD B, and KT C exceeding the WHO guideline of 50 mg/L, reaching up to 189 mg/L as presented in Figure 3. This is consistent with findings that ferromagnesian rocks and magnesium carbonate-bearing sedimentary formations significantly contribute to elevated Mg^{2+} in water [32]. Comparable high magnesium levels were reported in quarry-affected waters in Ethiopia [36] and central India [37], where the geology and anthropogenic disturbances played a crucial role.

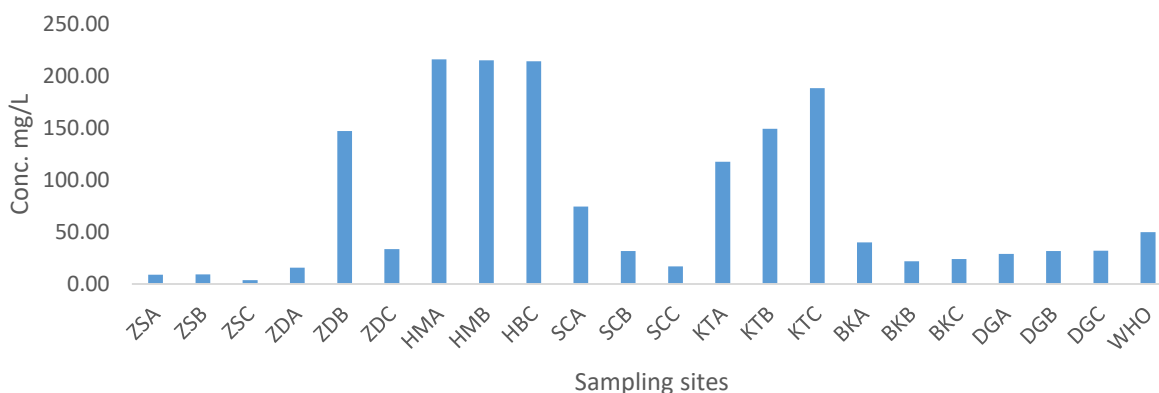


Figure 3: Magnesium Ion Concentration

Chloride ion concentrations in the water samples ranged from 20.4 to 878.7 mg/L, with ZD C, KT A, KT B, and KT C exceeding the WHO limit of 250 mg/L as shown in Figure 4. Elevated chloride levels often result from anthropogenic activities such as organic waste contamination and quarry effluents [21]. Similar elevated values have been recorded near quarry and mining operations in Bangladesh [38]. Also, Tadesse *et al.* and Putra *et al.* reported that water runoff and exposed rock materials contribute to chloride enrichment in surface and groundwater [36, 39].

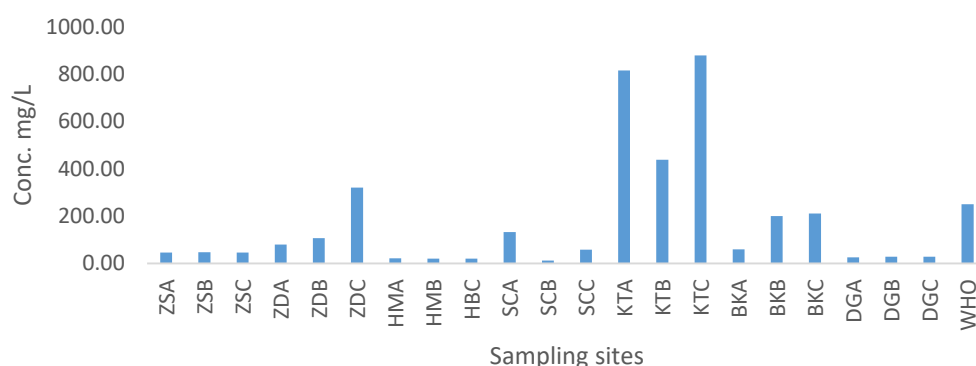


Figure 4: Chloride Ions Concentration

The sulphate ion concentrations ranged from 1.1 to 18.2 mg/L, all of which are below the WHO permissible level of 5.99 mg/L as presented in Figure 5. High sulphate levels suggest interactions with sulphate-bearing rocks and quarry-related discharges [32]. In a similar study, Okoye *et al.*

[22] and Gebremariam *et al.* [40] reported that mining and excavation increased sulphate levels through mineral oxidation and leaching.

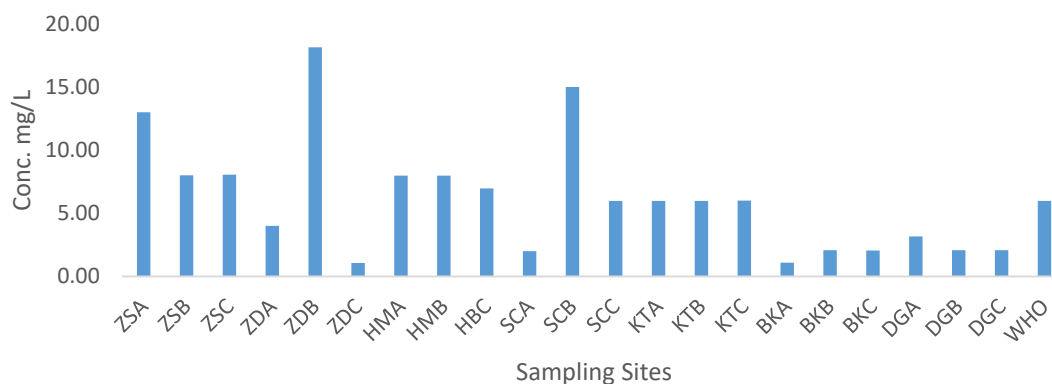


Figure 5: Sulphate Ions Concentration

Phosphate concentrations in the samples exceeded the WHO limit of 0.4 mg/L in most sites, particularly in KT A and ZS C as shown in Figure 6. Though phosphate is not directly toxic, it promotes eutrophication by encouraging excessive algal and microbial growth [21]. Similar trends were reported by Bhat *et al.* in India [41]. Also, Yeboah *et al.* [42] and Kusumawati *et al.* [43] reported that agricultural runoff and quarry exposure increased phosphate levels in water bodies.

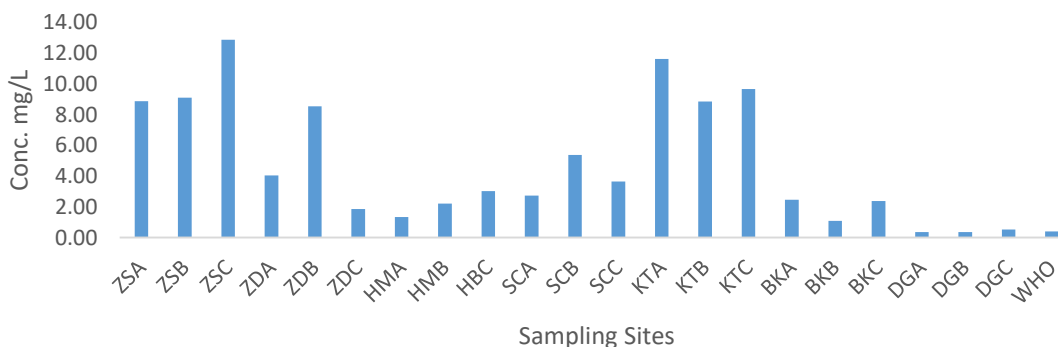


Figure 6: Phosphate Ions Concentrations

Nitrate levels across all sampling sites were within WHO permissible limit of 50 mg/L this was also presented in Figure 7. Nitrate originates from fertilizer use, septic tank leakage, and organic decay [44]. Studies from Pakistan [45], Nigeria [14] and Kenya [46] confirm low nitrate in undisturbed areas but show high levels where quarry activities and agricultural practices intersect.

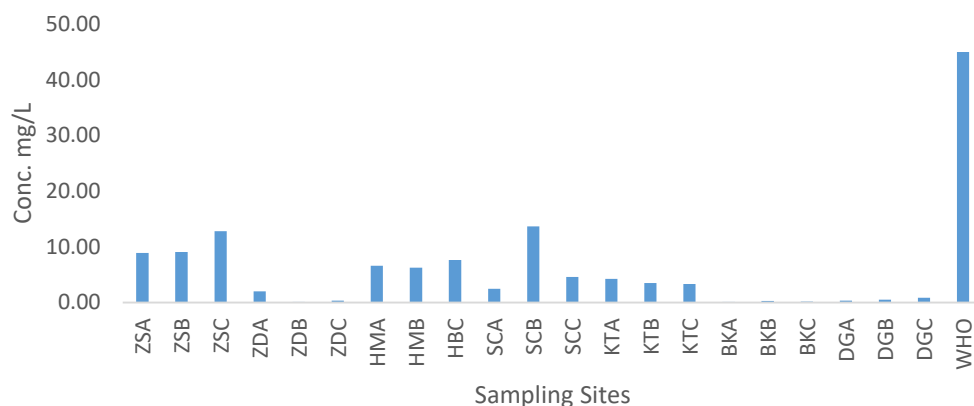


Figure 7: Nitrate Ion Concentration

Water Quality Assessment

The Water Quality Index is a widely adopted tool for evaluating the cumulative effect of various water quality parameters into a single, comprehensive score, facilitating an overall assessment of water's suitability for drinking [12, 13]. The WQI values in this study ranged from moderate to very poor. BK and DG had WQI scores of 50.383 and 57.863, respectively, indicating moderate water quality, while other sites KT (380.515), ZS (267.06), SC (184.296), ZD (137.075), and HM (78.834) recorded values exceeding the WHO threshold of 100, signifying that the water is unsuitable for drinking purposes.

Comparable studies have showed similar deteriorations in water quality around quarrying and mining zones. For instance, Yadav *et al.* reported WQI values above 300 in sandstone quarry areas in India due to high TDS and hardness levels [26]. Likewise, Abubakar and Lawal found WQI values over 200 in Nigerian granite quarry sites [47], attributing the degradation to runoff and leachates. Ali *et al.* noted very poor WQI values near cement factories in Pakistan [48], linking the poor quality to industrial discharge, while Gebremariam and Tadesse observed WQI values above 150 in Ethiopian quarry zones impacted by erosion and anthropogenic activities [49]. These findings align with the present results, confirming that quarry-related activities pose a significant risk to water quality and public health.

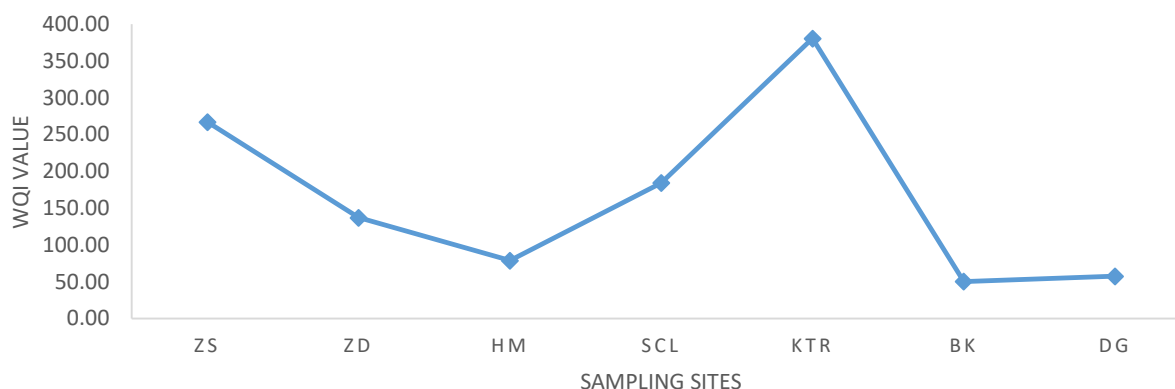


Figure 8: Variation in Water Quality of the Sampling Sites

Correlation Analysis

Table 5 presents the results for the correlation analysis of the parameters

Table 5: Correlation Analysis

Parameters	Temp.	pH	E.C	Turbidity	Alkalinity	TDS	TSS	TS	Hardness	Ca ²⁺	Mg ²⁺	Cl ⁻	PO ₄ ³⁻	SO ₄ ²⁻	NO ₃ ⁻
Temperature	1														
pH	0.421984	1													
E.C	0.200305	-0.04356	1												
Turbidity	0.00926	-0.33425	-0.06683	1											
Alkalinity	-0.0487	-0.04765	0.705068	-0.18973	1										
TDS	0.20097	-0.02588	0.989198	-0.07756	0.700928	1									
TSS	0.031102	-0.2501	-0.16935	0.977533	-0.30072	-0.16596	1								
TS	0.202314	-0.03059	0.98888	-0.05761	0.696931	0.999782	-0.14563	1							
Hardness	0.249553	-0.12229	0.828648	-0.11336	0.451937	0.802845	-0.1922	0.801597	1						
Ca ²⁺	0.115234	-0.12972	0.630601	-0.18471	0.41287	0.629704	-0.23586	0.626978	0.783247	1					
Mg ²⁺	0.310088	-0.03865	0.723791	-0.0603	0.365867	0.684873	-0.13375	0.684602	0.845816	0.34838174	1				
Cl ⁻	0.217896	-0.01731	0.993856	-0.05169	0.681968	0.978345	-0.14975	0.978465	0.82534	0.60510697	0.739518092	1			
PO ₃ ²⁻	0.097347	-0.11239	-0.12308	0.575683	-0.36229	-0.11834	0.566859	-0.10762	0.037768	-0.26060896	0.201193215	-0.12595	1		
SO ₄ ²⁻	0.132374	-0.32434	0.518529	0.278236	0.182367	0.525361	0.174238	0.529849	0.414692	0.19973116	0.395212225	0.472883	0.5296993	1	
NO ₃ ⁻	-0.04372	-0.10687	-0.175	0.727678	-0.27669	-0.1616	0.705587	-0.1479	-0.35264	-0.36486681	-0.291134073	-0.1925	0.578269	0.503429	1

Numerous important interrelationships between the water quality measures were found by correlation analysis, which reflected the underlying hydro-chemical processes and possible sources of pollutants as shown in Table 5. Electrical conductivity (EC) and total dissolved solids (TDS) showed a virtually perfect positive correlation ($r = 0.9997$), suggesting that EC is a good alternative for determining dissolved ionic content. The fact that total solids (TS) primarily consist

of both dissolved and suspended fractions was confirmed by the substantial correlations that TS displayed with both total suspended solids (TSS) ($r = 0.6846$) and total dissolved solids ($r = 0.9835$).

The recognized involvement of these cations in hardness levels was supported by the substantial correlation between water hardness and calcium (Ca^{2+}) ($r = 0.8458$) and the moderate correlation with magnesium (Mg^{2+}) ($r = 0.6051$). Moderate positive correlations were found among phosphate (PO_4^{3-}), sulfate (SO_4^{2-}), and nitrate (NO_3^-) ($r = 0.5783$ and $r = 0.5034$, respectively), suggesting a shared origin likely linked to agricultural runoff or domestic wastewater. Additionally, EC showed moderate correlation with chloride (Cl^-) ($r = 0.3951$), indicating its partial contribution to conductivity. In a similar study, Eyankware and Akakuru assessed groundwater quality around an abandoned limestone quarry site in Nkalagu, Nigeria [50]. Strong positive correlations between important ions and heavy metals were found in their study, indicating that the contamination most likely came from common geogenic and anthropogenic sources connected to quarry operations. This supports the findings of the current study, which show that quarrying has an impact on the composition of groundwater due to substantial connections between key ions including calcium and magnesium ions, electrical conductivity, hardness, and total dissolved solids.

CONCLUSION

This study evaluates human-environment interactions and their ecological and health impacts in Rimin Gado, Kano State, Nigeria, a granite quarry region with suspected cancer outbreak. Results obtained in this research show that quarry activities significantly alters water chemistry, with electrical conductivity (146.7–4546.7 $\mu\text{S}/\text{cm}$), total dissolved solids (40.7–3836.8 mg/L), hardness (115.2–1028 mg/L), and calcium, magnesium, chloride, and phosphate ion levels often exceeding WHO (2020) limits, particularly at sites KT, ZS, SC, ZD, and HM. Elevated phosphate, a novel focus in Nigerian quarry studies, indicates eutrophication risks. Water Quality Index values classify most sites as “very poor” (KT: 380.515; ZS: 267.06), unsuitable for domestic use, with potential health implications, including cancer risks.

This research, specifically targeting northern Nigeria’s semi-arid quarry zone, fills a regional information gap with regards to quarry activities relating water quality degradation and public health. It supports Sustainable Development Goals (SDGs) 3 (Good Health and Well-Being)

and 6 (Clean Water and Sanitation) by advocating continuous hydrochemical monitoring, strict effluent regulations, and adaptive strategies like sediment retention and water treatment. These measures aim to protect groundwater, reduce community exposure, and inform future cancer-related epidemiological research in quarry regions.

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