Assessing Heavy Metal Contamination in Stream Sediment and Water in Idofian, Kwara State: A Geochemical Perspective

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Abstract

Environmental geochemistry examines the presence, dispersion, and movement of elements on the Earth's surface. This research explores the environmental geochemistry of the Idofian area in Kwara State, Nigeria, with a particular emphasis on water and stream sediments. The heavy metals were ascertained using X-ray diffraction (XRD) and atomic absorption spectrometer (AAS). The study revealed the presence of marble, diorite, gneiss, pegmatite and amphibolite in the Idofian area. Furthermore, the XRD analysis provided information about the mineral composition including quartz, micas, lepidolite, laumontite, orthoclase, plagioclase, dolomite and anthophyllite. The findings revealed the absence of sediment contamination, while highlighting substantial contamination in the study area's water. This contamination, attributed to a combination of geogenic and anthropogenic factors, underscores the crucial necessity for implementing sustainable management practices in the region.

1. Introduction

Heavy metals can be referred to as any metallic element with a relatively high density. A few metals, in very small quantities, are required for human metabolic function, whereas other metals induce acute and chronic illnesses, both geogenic (natural) and anthropogenic (man-made) sources of heavy metals reach the aquatic system, these factors are the main source of both environmental and socioeconomic problems with regard to water contamination [1]. To protect water from contamination, a number of water quality management techniques have been put into place. Some key metals of biological and environmental toxicity, such as iron (Fe), lead (Pb), and zinc (Zn), copper (Cu), manganese (Mn), cobalt (Co), nickel (Ni) are included in the heavy metals reviewed in this work [2].

The Idofian area in Kwara State is blessed with substantial deposits of various types of diorites, gneiss, pegmatite, marble, including calcitic and dolomitic. These deposits are closely associated with Gneiss Rock and Diorite [3]. The marble and diorite deposits in the area are being exploited and mined for many purposes. Contaminants have various routes to enter groundwater, including percolation from the land surface or shallow subsurface sources, direct entry through wells from the land surface, contamination between aquifers in wells that are open to multiple aquifers, inflow of contaminated or saline water into freshwater aquifers due to pumping, interactions between groundwater and surface water bodies, and interactions with geological

formations containing natural contaminants like arsenic and radon. Once contaminants reach the water table, their movement to surface water discharge areas or deeper parts of the groundwater system is hindered by low groundwater velocities, resulting in slow transport [4]. Stream sediments are composed of fragments that result from the erosion of weathered rocks by flowing water. These sediments originate from near-surface layers of igneous, sedimentary, and metamorphic rocks [5]. While some rocks are easily eroded, crystalline and metamorphic rocks are typically affected only when altered in surface layers. Another source of stream sediments is the soil, which inherits its mineral constituents, with some modifications, from the underlying bedrock. In tropical regions, the soil may contain completely new minerals [6]. Sediment contamination with heavy metals can originate from natural geogenic sources or be derived from human activities [7]. Stream and river channels have the capacity to accumulate heavy metals through the transport and deposition of products resulting from natural weathering, erosion, industrial waste, and atmospheric deposition [8].

1.1 Geology of the Study Area

The study area lies within the Basement Complex and consists of rocks of Pan-African granitoids and Migmatite-Gneiss complex. Rocks seen to outcrop in the area include marble, gneiss, granitic gneiss, granites, amphibolite, pegmatite and Diorite [9]. It has a longitude 8°29'17"N and latitude 4°44'51"E, situated within Kwara state. The area encompasses various major towns, including Isale-Osin, Budo-Oku, and Elerinjare. The region is characterized by a mixed road network, with some villages lacking proper road infrastructure, making vehicular access challenging. However, other villages have well-established roads, and there are both minor and major roads as well as footpaths connecting them to neighboring towns and states. Settlement patterns vary, with some towns exhibiting nucleated settlement while others do not. The primary occupations of the inhabitants revolve around farming and trading. The area of study exhibits a rugged topography with undulating terrain and ridges, and there are several locations where rock exposures are visible. The topography is characterized by high relief and steep slopes, with some rocks rising several meters above sea level in certain areas. The drainage system in the area is classified as both Dentritic and Trellis, indicating a branching pattern of streams and rivers. Figure 1 provides a topographic map illustrating the location of Idofian and its surrounding area [10].
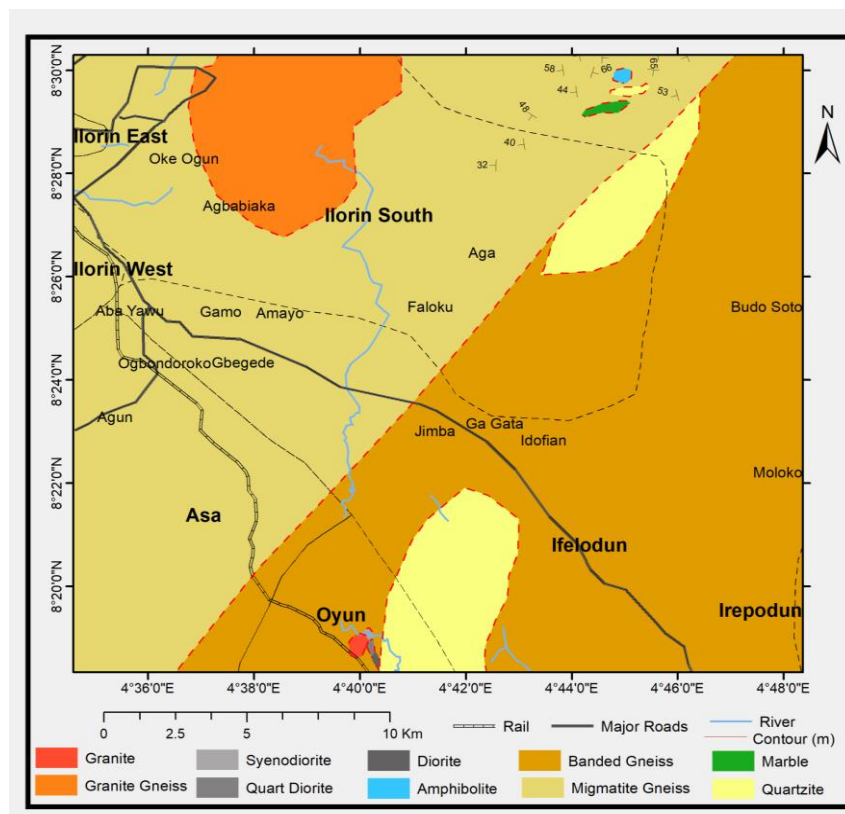

Fig. 1 *Geological map of the area*

2. Materials and Methods

The methods and procedure applied in this work are fieldwork and laboratory work exercises. The field work is essentially the geological field mapping, during the field mapping ten water samples and eight stream sediments which was taken at different intervals. The stream sediments were taken at a depth of 15-30 cm at confluence points of two or more rivers and at the center of some drainage system. The water sample was removed from the refrigerator and underwent digestion using Aqua-Regia method with a 3:1 ratio of concentrated nitric acid and concentrated hydrochloric acid [1]. The stream sediment samples collected in the field were subjected to air drying to remove excess moisture, facilitating the subsequent pulverization process. Once dried, the samples were pulverized using a milling machine available in the Department of Geology and Mineral Science at the University of Ilorin. To prevent contamination between samples, the milling machine was cleaned with acetone after each sample was pulverized. After pulverization, approximately 5.0 g of each sample was carefully weighed and transferred into small transparent plastic tubes with lids, ensuring proper packaging and labeling. These packaged and stored samples were then transported to the geochemistry laboratory in the Department of Geology for further analysis. The sample digestion process was carried out in this laboratory, allowing for the extraction and analysis of various elements present in the stream sediment samples, then the samples was then carried to University of Ilorin Research Center for Atomic absorption spectrum analysis. The labeled samples, namely BM1, BM2, and BM3, representing potential rock types of diorite, marble, and pegmatite, respectively, underwent comprehensive analysis using both X-ray diffraction (XRD) and photomicrography techniques. These methods were employed to gain further insights into the mineralogical composition, crystal structure, and textural characteristics of the samples. XRD analysis provided information about the arrangement of atoms in the crystalline structure of the rocks [12], while photomicrography allowed for detailed examination of the rock textures and the identification of individual mineral grains within the samples. The combined results of XRD and photomicrography analysis offered valuable data for the comprehensive understanding and interpretation of the rock samples' properties and geological significance.

3. Result

3.1 Rock Sample BM1 (Quartz-Diorite)

The mineralogical composition of BM1, determined through XRD phase quantification, indicates the presence of several minerals (Figure 2 & 3). The dominant mineral in the sample is quartz, accounting for approximately 56% of the composition. Anorthite makes up around 16% of the mineralogy, while muscovite comprises about 4%. Orthoclase is present at a lower proportion of 1.3%, followed by albite at approximately 18%. Lepidolite is also detected in the sample, constituting around 7% of the mineralogy. The result confirms the Quartz-Diorite field name given to the rock sample since Quartz has the highest percentage in the rock sample and minor silicate (anorthite, muscovite, orthoclase, albite and lepidolite) content.
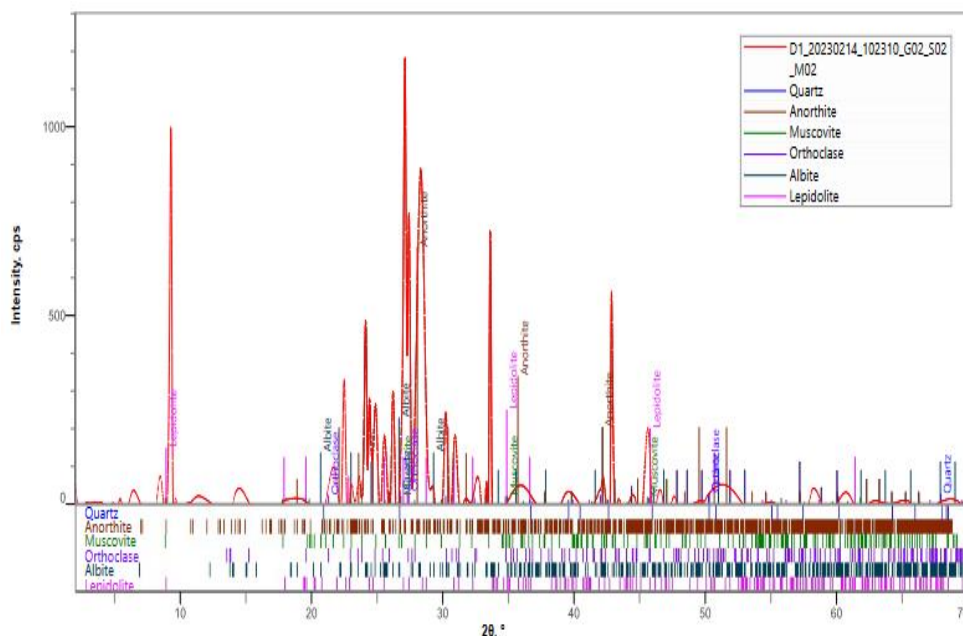

Fig. 2 *X-ray powder diffraction patterns of rock sample BM1*

Fig. 3 *Mineralogical composition of BM1 which was estimated by XRD phase quantification*

3.2 Rock Sample BM2 (Pegmatite)

The XRD phase quantification analysis of sample BM2, as depicted in Figure 4 & 5, reveals the presence of quartz, muscovite, albite, orthoclase, and laumontite. The proportions of these minerals in sample BM3 are as follows: quartz accounts for 68%, muscovite for 14.0%, albite for 1.7%, orthoclase for 1%, and laumontite for 14.8% as shown Figure 5. The result confirms the pegmatite field name given to the rock sample since there is a relative abundance of Quartz and less silicate (albite and muscovite, orthoclase) content.
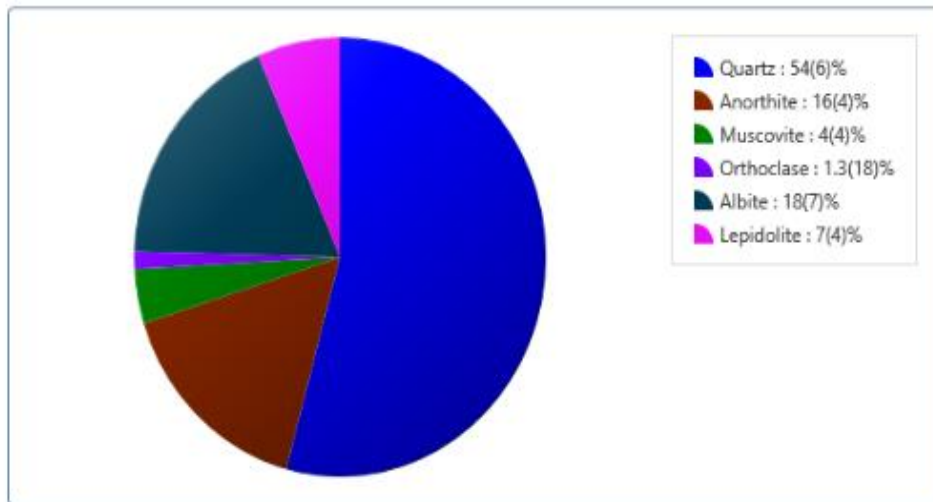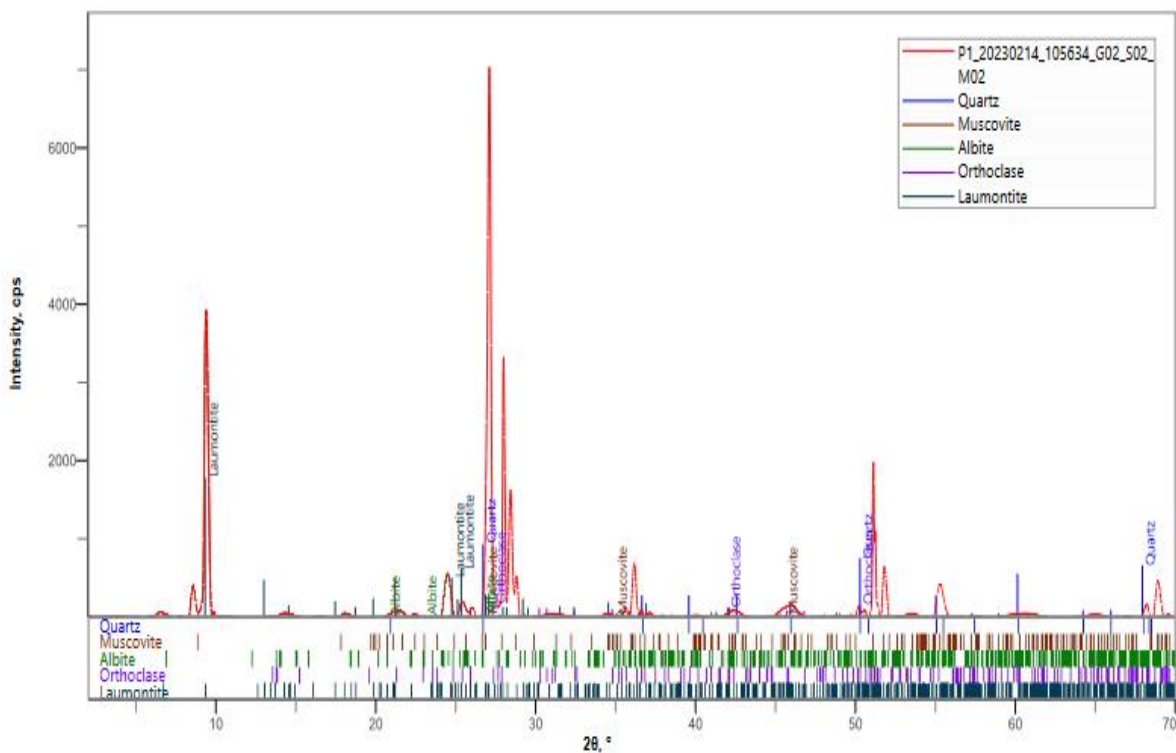

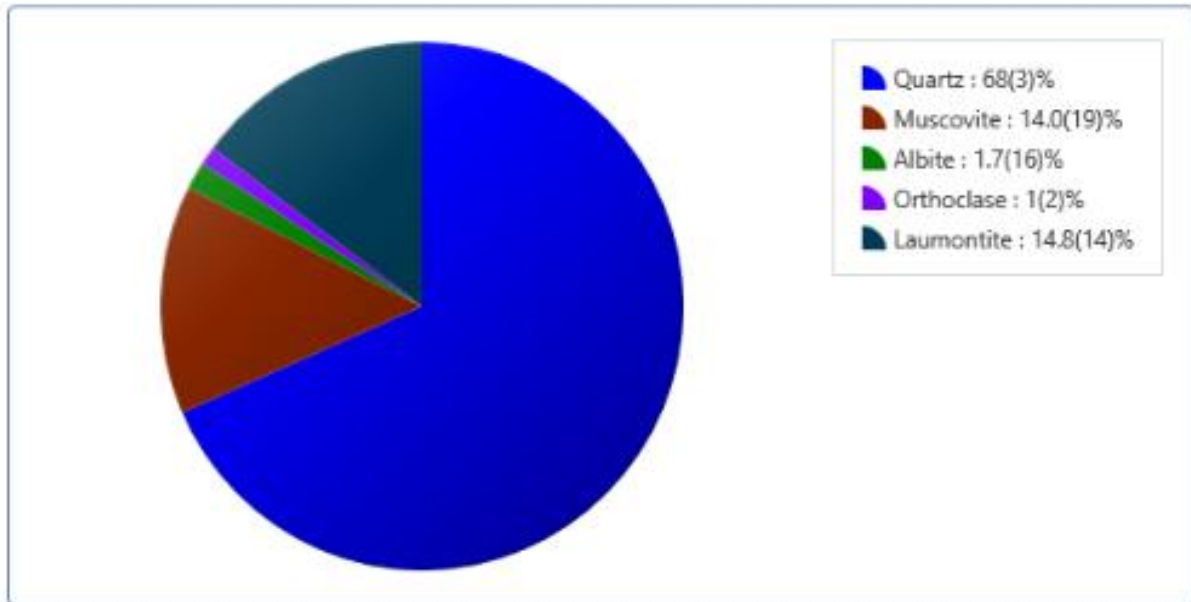**Fig. 4** *X-ray powder diffraction patterns of rock sample BM2*

Fig. 5 *Mineralogical composition of BM2 which was estimated by XRD phase quantification*

3.3 Rock Sample BM3 (Marble)

The XRD phase quantification analysis of sample BM3, as presented in Figure 7, reveals the presence of calcite, dolomite, orthoclase, anthophyllite and albite. The proportions of these minerals in sample BM3 are as follows: calcite accounts for 40.5%, dolomite for 44%, orthoclase for 8%, anthophyllite for 4.6%, and albite for 3.7%. The result confirms the marble field name given to the rock sample since there is a relative abundance of carbonate minerals (calcite and dolomite) and minor silicate (orthoclase, anthophyllite and albite) content.
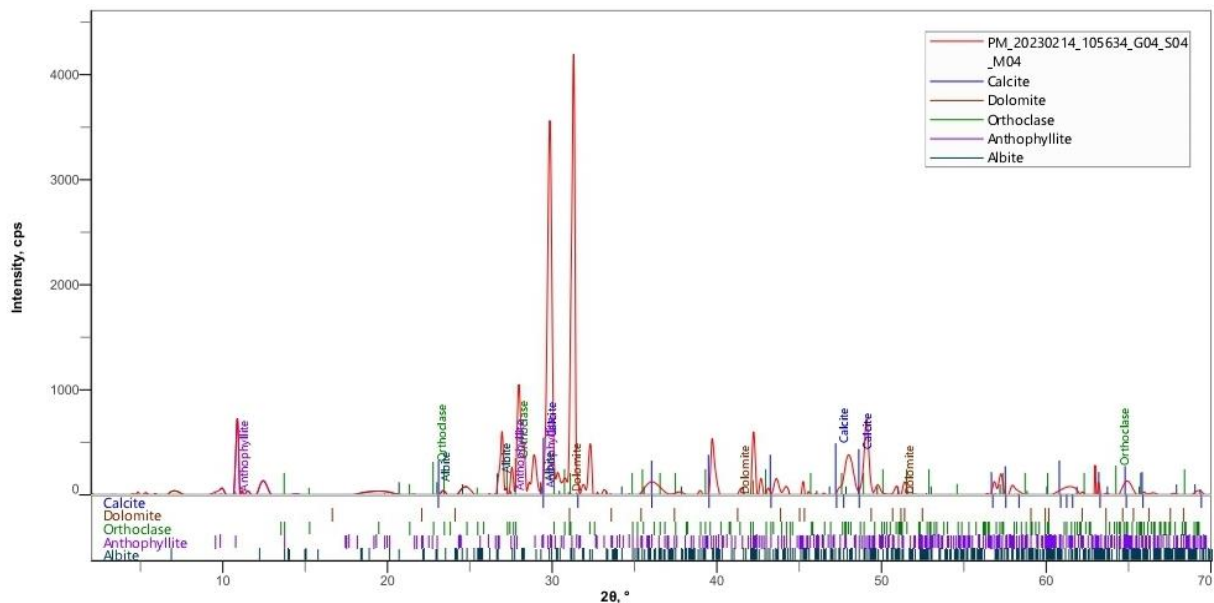

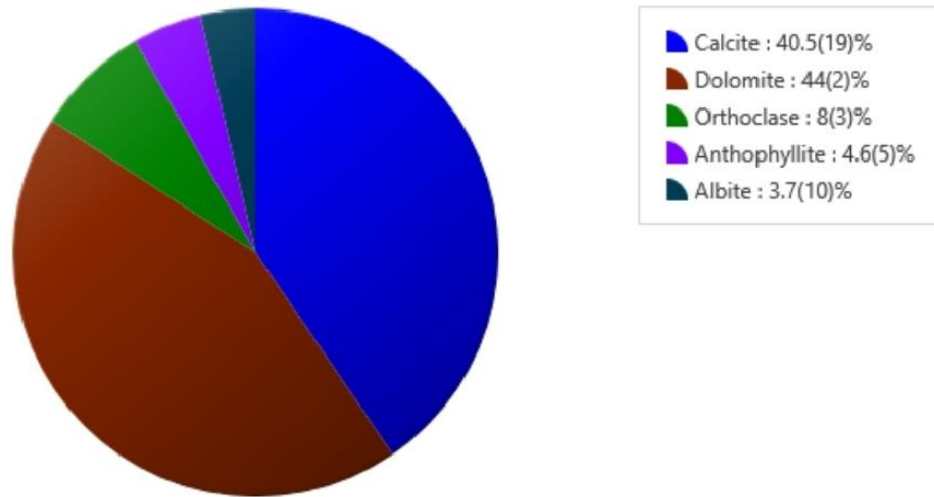**Fig. 6** *X-ray powder diffraction patterns of rock sample BM3*

Fig. 7 *Mineralogical composition of BM3 which was estimated by XRD phase quantification*

3.4 Interpretation of Water and Stream Sediment Analysis

The analysis of heavy metal concentrations in water and sediment samples revealed distinct ranges for Copper (Cu), Lead (Pb), Zinc (Zn), Iron (Fe), Manganese (Mn), Nickel (Ni), and cobalt (Co) (Table 4-4). In water samples, Cu ranged from 0.1125 mg/L to 0.2505 mg/L, Pb ranged from 0.0085 mg/L to 0.1625 mg/L, Zn ranged from 0.436 mg/L to 0.856 mg/L, Fe ranged from 15.1425 mg/L to 15.6955 mg/L, Mn ranged from 0.8765 mg/L to 7.168 mg/L, Ni ranged from 0.205 mg/L to 1.337 mg/L, and Co ranged from 0.12 mg/L to 0.812 mg/L. Sediment samples exhibited Cu ranges of 0.2995 mg/Kg to 0.544 mg/Kg, Pb ranges of 0.115 mg/Kg to 0.639 mg/Kg, Zn ranges of 0.69 mg/Kg to 1.363 mg/Kg, Fe ranges of 15.229 mg/Kg to 15.77 mg/Kg, Mn ranges of 3.811 mg/Kg to 7.168 mg/Kg, Ni ranges of 0.205 mg/Kg to 0.7985 mg/Kg, and Co ranges of 0.12 mg/Kg to 0.396 mg/Kg. These findings provide valuable insights into the distribution and potential environmental impact of heavy metals in the studied area, enabling a comprehensive assessment of their environmental impact [13].

Table 1 *Result of heavy metal AAS analysis (mg/L) of water and sediment samples*

Sample ID	Sample Type	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Co (mg/L)
EB1	Water	0.2345	0.0215	0.7120	15.3815	1.6225	0.9210	0.5310
EB2	Water	0.2030	0.1625	0.6070	14.6170	2.7925	0.7810	0.5615
EB3	Water	0.2095	0.0770	0.5950	15.2150	3.0355	0.6850	0.5440
EB4	Water	0.1925	0.1525	0.6230	15.1450	1.2890	0.5660	0.5710
EB5	Water	0.2100	0.0085	0.5880	15.2345	1.5240	0.7725	0.6905
EB6	Water	0.1755	0.1195	0.5150	15.1480	1.2790	0.5835	0.8120
EB7	Water	0.2505	0.0885	0.6840	15.3380	1.7015	0.9590	0.5910
Control	Water	0.1535	0.1570	0.4895	15.6375	1.1670	0.4765	0.5910
EB9	Water	0.1980	0.1415	0.6175	15.1425	1.4435	0.6437	0.7120
EB10	Water	0.1125	0.1520	0.4360	15.4335	0.8765	0.3590	0.6190
EB11	Sediment	0.3875	0.2370	0.7650	15.6955	4.3345	1.3370	0.3960
EB12	Sediment	0.3835	0.1150	0.8560	15.5135	5.0515	0.6455	0.3455
EB13	Sediment	0.3575	0.1735	0.6890	15.4060	5.0815	0.4765	0.1595
EB14	Sediment	0.2995	0.2140	0.7100	15.4395	3.8110	0.4310	0.2620
Control	Sediment	0.5440	0.6390	1.3630	15.7700	6.6970	0.2830	0.2520
EB16	Sediment	0.3630	0.4795	0.8750	15.5190	7.1680	0.2050	0.3455

EB17	Sediment	0.3625	0.3230	0.6900	15.2290	5.1040	0.7430	0.1200
EB18	Sediment	0.4456	0.2700	0.8010	15.5060	5.7130	0.7985	0.3080

4. Discussion

4.1 Enrichment Factor (EF)

Table 2 shows the enrichment factor of each metal in the water and stream sediment samples, and since all the values are below 1.0, it can be deduced that there is no enrichment of the heavy metals from anthropogenic activities in the study area.

Table 2 *Enrichment factor computation for each heavy metal analyzed in the water samples*

Sample ID	Sample Type	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)	Mn (mg/L)	Ni (mg/L)	Co (mg/L)
EB1	Water	0.015	0.001	0.046	0.105	0.060	0.035
EB2	Water	0.014	0.011	0.042	0.191	0.053	0.037
EB3	Water	0.014	0.005	0.039	0.199	0.045	0.036
EB4	Water	0.013	0.010	0.041	0.085	0.037	0.037
EB5	Water	0.014	0.001	0.039	0.100	0.050	0.045
EB6	Water	0.012	0.008	0.034	0.085	0.039	0.054
EB7	Water	0.016	0.006	0.045	0.111	0.063	0.038
Control	Water	0.010	0.010	0.031	0.074	0.030	0.038
EB9	Water	0.013	0.009	0.041	0.095	0.042	0.047
EB10	Water	0.007	0.010	0.028	0.057	0.023	0.040
EB11	Sediment	0.025	0.015	0.049	0.275	0.087	0.025
EB12	Sediment	0.025	0.007	0.055	0.326	0.042	0.022
EB13	Sediment	0.023	0.011	0.045	0.331	0.031	0.010
EB14	Sediment	0.019	0.014	0.046	0.247	0.028	0.017
Control	Sediment	0.034	0.040	0.086	0.424	0.018	0.016
EB16	Sediment	0.023	0.031	0.057	0.460	0.014	0.022
EB17	Sediment	0.024	0.021	0.045	0.336	0.048	0.008
EB18	Sediment	0.029	0.017	0.052	0.369	0.052	0.020

4.2 Contamination Factor (CF)

Table 3 shows the contamination factor index (CF) for the sediment and water samples. In the sediment samples, there is no contamination since CF is <1 for all the metals when compared to the corresponding metal values in world shale values. However, in the water samples, there is no contamination for Cu and Pb. However, there is significant enrichment of Mn, Fe, and Ni when compared with the WHO maximum permissible limits for these metals in drinking water. It is important to note that Ni is carcinogenic, while Fe and Mn only alter the taste of water [14].

Table 3 *Contamination factor index for water and sediment samples*

Sample ID	Sample Type	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Co (mg/L)
EB1	Water	0.117	0.002	0.000	51.2717	4.0563	46.0500	0.000
EB2	Water	0.102	0.016	0.000	48.7233	6.9813	39.0500	0.000
EB3	Water	0.105	0.008	0.000	50.7167	7.5888	34.2500	0.000
EB4	Water	0.096	0.015	0.000	50.4833	3.2225	28.3000	0.000
EB5	Water	0.105	0.001	0.000	50.7817	3.8100	38.6250	0.000
EB6	Water	0.088	0.012	0.000	50.4933	3.1975	29.1750	0.000

EB7	Water	0.125	0.009	0.000	51.1267	4.2538	47.9500	0.000
Control	Water	0.077	0.016	0.000	52.1250	2.9175	23.8250	0.000
EB9	Water	0.099	0.014	0.000	50.4750	3.6088	32.1850	0.000
EB10	Water	0.056	0.015	0.000	51.4450	2.1913	17.9500	0.000
EB11	Sediment	0.009	0.012	0.008	0.00033	0.00510	0.01966	0.021
EB12	Sediment	0.009	0.006	0.009	0.00033	0.00594	0.00949	0.018
EB13	Sediment	0.008	0.009	0.007	0.00033	0.00598	0.00701	0.008
EB14	Sediment	0.007	0.011	0.007	0.00033	0.00448	0.00634	0.014
Control	Sediment	0.012	0.032	0.014	0.00033	0.00788	0.00416	0.013
EB16	Sediment	0.008	0.024	0.009	0.00033	0.00843	0.00301	0.018
EB17	Sediment	0.008	0.016	0.007	0.00032	0.00600	0.01093	0.006
EB18	Sediment	0.010	0.014	0.008	0.00033	0.00672	0.01174	0.016

4.3 Geoaccumulation Index (Igeo)

Table 4 shows the geoaccumulation index (Igeo) for the water and sediment samples. The values reveal that there is no contamination (Igeo<0) for the sediments as a result of mining quarrying activities in the study area. Additionally, there is no contamination of the water samples for the heavy metals Cu and Pb. However, there is extreme contamination (Igeo >5) of the water samples by Fe. Regarding Mn, two water samples (Control and S10) fall in the uncontaminated to moderate contamination range (0<Igeo<1), while six samples (S1, S4, S5, S6, S7, and S9) fall in the moderate contamination range (1<Igeo<2). Two samples (S2 and S3) are in the moderate to strong contamination range (2<Igeo<3). For Ni, the contamination in the water samples varies across the spectrum from "strong contamination (3<Igeo<4)" to "strong to extreme contamination (4<Igeo<5)" [1].

Table 4 *Geoaccumulation Index (Igeo) for water and sediment samples*

Sample ID	Sample Type	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)	Fe (mg/L)	Mn (mg/L)	Ni (mg/L)	Co (mg/L)
EB1	Water	-3.68	-9.45	0.00	5.10	1.44	4.94	0.00
EB2	Water	-3.89	-6.53	0.00	5.02	2.22	4.70	0.00
EB3	Water	-3.84	-7.61	0.00	5.08	2.34	4.51	0.00
EB4	Water	-3.96	-6.62	0.00	5.07	1.10	4.24	0.00
EB5	Water	-3.84	-10.79	0.00	5.08	1.34	4.69	0.00
EB6	Water	-4.10	-6.97	0.00	5.07	1.09	4.28	0.00
EB7	Water	-3.58	-7.41	0.00	5.09	1.50	5.00	0.00
Control	Water	-4.29	-6.58	0.00	5.12	0.96	3.99	0.00
EB9	Water	-3.92	-6.73	0.00	5.07	1.27	4.42	0.00
EB10	Water	-4.74	-6.62	0.00	5.10	0.55	3.58	0.00
EB11	Sediment	-7.44	-6.98	-7.54	-12.14	-8.20	-6.25	-6.17
EB12	Sediment	-7.46	-8.03	-7.38	-12.16	-7.98	-7.30	-6.37
EB13	Sediment	-7.56	-7.43	-7.69	-12.17	-7.97	-7.74	-7.48
EB14	Sediment	-7.82	-7.13	-7.65	-12.16	-8.39	-7.89	-6.77
Control	Sediment	-6.96	-5.55	-6.71	-12.13	-7.57	-8.49	-6.82
EB16	Sediment	-7.54	-5.97	-7.35	-12.16	-7.47	-8.96	-6.37
EB17	Sediment	-7.54	-6.54	-7.69	-12.18	-7.96	-7.10	-7.89
EB18	Sediment	-7.24	-6.80	-7.47	-12.16	-7.80	-7.00	-6.53

4.4 Pollution Load Index (PLI) and Metal Pollution Index (MPI)

Table 5 show the values and distribution of the Pollution Load Index (PLI) and Metal Pollution Index (MPI). There is low pollution (PLI < 1 and MPI < 1) in all sediment samples. However, water shows a high level of pollution (PLI ≥ 3 and MPI ≥ 3) [15].

Table 5 *Pollution Load Index (PLI) and Metal Pollution Index (MPI) values for water and sediment samples*

Sample ID	Sample Type	PLI (mg/L)	MPI (mg/L)
EB 1	Water	4.078	10.7983
EB 2	Water	4.062	10.0368
EB 3	Water	4.071	9.8704
EB 4	Water	3.788	8.7812
EB 5	Water	3.997	9.5059
EB 6	Water	3.801	8.4965
EB 7	Water	4.095	11.4569
CONTROL	Water	3.662	7.8608
EB 8	Water	3.907	9.1914
EB 10	Water	3.503	6.8366
EB 11	Sediment	0.007	0.0044
EB 12	Sediment	0.008	0.004
EB 13	Sediment	0.007	0.0032
EB 14	Sediment	0.008	0.0029
CONTROL	Sediment	0.013	0.0046
S16	Sediment	0.011	0.0043
S17	Sediment	0.009	0.0032
S18	Sediment	0.01	0.0036

The results of the chemical analysis will be compiled and presented in a tabular format, allowing for easy interpretation and comparison of the data. In addition to the chemical analysis results, various contamination indices such as the enrichment factor (EF), contamination factor (CF), geoaccumulation index (Igeo), and pollution load index (PLI) will be calculated. These indices serve as quantitative measures to assess the level of contamination in both the water and sediment samples, providing valuable insights into the environmental quality of the studied area. World shale values of Turekian & Wedepohl [16] were used as background values for the sediment contamination indices, while the maximum allowable concentrations were used for the water samples [17]. According to Turekian and Wedepohl's World Shales [16] the concentrations of certain elements in the shales are as follows: Copper (Cu) at 45 mg/kg, Lead (Pb) at 20 mg/kg, Zinc (Zn) at 95 mg/kg, Iron (Fe) at 47,200 mg/kg, Manganese (Mn) at 850 mg/kg, Nickel (Ni) at 68 mg/kg, and Cobalt (Co) at 19 mg/kg. According to the World Health Organization (WHO, 2004) guideline for drinking water quality, the maximum allowable limits for certain elements in milligrams per liter (mg/L) are as follows: Copper (Cu) - 2 mg/L, Lead (Pb) - 10 mg/L, Zinc (Zn) - No specific guideline provided, Iron (Fe) - 0.3 mg/L, Manganese (Mn) - 0.4 mg/L, Nickel (Ni) - 0.02 mg/L, and Cobalt (Co) - No specific guideline provided [18].

5. Conclusion

The research conducted in the Idofian and its environs of Kwara State, Nigeria has yielded valuable insights into the environmental geochemistry of the region and the impacts of mining activities on the natural environment. The study successfully assessed the composition, characteristics, and contamination levels of water, stream sediments, and rocks in the area, shedding light on the geological processes and features that shape the region. Significant deposits of marble and diorite were identified, each with distinct mineral compositions. Chemical analysis using atomic absorption spectrometry (AAS) indicated potential contamination in water samples, with certain heavy metals exceeding permissible limits. These findings emphasize the need for effective monitoring and management of mining activities to mitigate environmental risks, particularly regarding water quality. This research contributes to the development of sustainable resource management practices and the preservation of

the natural environment in Kwara State, Nigeria, providing a foundation for future studies and decision-making processes focused on promoting sustainable development and ecological integrity.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: **study conception and design:** *Bamikole Emmanuel Ayobami, Omolayo Ajoke Omorinoye, Olufemi Sijuade Bamigboye, Oniyangi Abdulhameed Kayode;* **data collection:** *Bamikole Emmanuel Ayobami, Omolayo Ajoke Omorinoye, Olufemi Sijuade Bamigboye, Oniyangi Abdulhameed Kayode;* **analysis and interpretation of results:** *Bamikole Emmanuel Ayobami, Omolayo Ajoke Omorinoye, Olufemi Sijuade Bamigboye, Oniyangi Abdulhameed Kayode;* **draft manuscript preparation:** *Bamikole Emmanuel Ayobami, Omolayo Ajoke Omorinoye, Olufemi Sijuade Bamigboye, Oniyangi Abdulhameed Kayode. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Omorinoye, O.A., Assim, Z.B., Jusoh, I.B., Durumin-Iya, N.I., Umaru, I.J. (2019) Review of the Sedimentological and Geochemical Approaches for Environmental Assessment of River Sadong, Samarahan-asajaya District Sarawak, Malaysia, *Nature Environment and Pollution Technology, 18(3),* 815-823.

[2] Saha, Priti & Paul, Biswajit (2016) Assessment of Heavy Metal Pollution in Water Resources and their Impacts: A Review, *Journal of Basic and Applied Engineering Research, 3(8)*, 671-675.

[3] Umar, H. A. (2020). Evaluation of Suitability of Some Selected Basement Complex Rock Exposures for Dimension Stone Quarry in Southwestern Nigeria [Doctoral Thesis, Kwara State University].

[4] Bertolino, S. R., Zimmermann, U., & Sattler, F. J. (2007) Mineralogy and geochemistry of bottom sediments from water reservoirs in the vicinity of Córdoba, Argentina: Environmental and health constraints, *Applied Clay Science*, *36 (1–3)*, 206–220.

[5] Bamigboye, O., Adekeye, J. (2011) Stream sediment survey of Eruku and its environs, Central Nigeria: Implication for exploration, *Internat. Jour. Res. Rev. Appld. Sci*, *7(2)*, 160â.

[6] Irion, G., Müller, J., Nunes de Mello, J. *et al* (1995)*.* Quaternary geology of the Amazonian Lowland, *Geo-Marine Letters*, *15*, 172–178. https://doi.org/10.1007/BF01204460

[7] Giouri, A. N., Christoforidis, K., Melfos, V., & Vavelidis, M. K. (2010) Assessment of heavy metals concentrations in sediments of Bogdanas river at the Assiros-Lagadas area, northern Greece, *Scientific Journal of the Department of Geology (AUTh)*, *100*, 63–70.

[8] Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B. B., & Beeregowda, K. N. (2014) Toxicity, mechanism and health effects of some heavy metals, *Interdisciplinary Toxicology*, *7(2),* 60.

[9] Obiora S.C. (2005). *Field Descriptions of Hard Rocks, With Examples from the Nigerian Basement Complex* [M]. SNAAP Press.

[10] Nigeria Geological Survey Agency (NGSA). (2020). *Geological Maps*. Nigeria Geological Survey Agency. https://ngsa.gov.ng/geological-maps/

[11] Helmenstine, A., Marie. (2020). How to Make Aqua Regia Acid Solution. Retrieved from https://www.thoughtco.com/making-aqua-regia-acid- solution-603641.

[12] Bernard Dennis Cullity, & Stock, S. R. (2001). Elements of X-ray Diffraction. Pearson.

[13] Thornton, I. (2012). Environmental geochemistry: 40 years research at Imperial College, London, UK. *Applied Geochemistry, 27(5),* 939–953

[14] Sule I F, Istifanus D I Y M D, Senthilmurugan S, Tamizhazhagan V. (2021) Analysis of Heavy Metals in Waste Water and Plants in Gombe Metropolis, Nigeria. *Entomol. Appl. Sci. Lett. 8(1)*, 6-13. https://doi.org/10.51847/lOWswUEL0W

[15] Sakan, Sanja & Dordevic, Dragana & Manojlović, Dragan & Predrag, Polić. (2009). Assessment of heavy metal pollutants accumulation in the Tisza river sediments. *Journal of Environmental Management, 90 (11)*, 3382-3390.

[16] Turekian, K.K. and Wedepohl, K.H. (1961) Distribution of the Elements in Some Major Units of the Earth's Crust. *Geological Society of America Bulletin, 72*, 175-192.

[17] WHO. (2004). *Guidelines for drinking-water quality* (Vol. 1). World Health Organization.

[18] Hahladakis, J., Smaragdaki, E., Vasilaki, G., & Gidarakos, E. (2013) Use of sediment quality guidelines and pollution indicators for the assessment of heavy metal and PAH contamination in Greek surficial sea and lake sediments. *Environmental Monitoring and Assessment, 185*, 2843–2853.