

Environmental impact assessment of artisanal mining in parts of Isin LGA, southwestern Nigeria

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Abstract: Impact of artisanal mining in parts of Isin LGA, southwestern Nigeria was carried out to ascertain the level of degradation to the immediate environment. Samples from rocks, mines tailings, mine ponds water and rivers and groundwater from immediate community were analysed to assess concentration of elements in the media. Rocks of the study area consist mostly of schist, amphibolite, quartzites and pegmatites. Field relationship revealed that schist and amphibolite were intruded by pegmatites and quartzites thus forming foliations whose major trends are NNE-SSW and eastward dip direction. Petrographic studies show that the dominant minerals are quartz, biotite, plagioclase, microcline, hornblende, orthoclase and opaque minerals. Geochemistry of the solid media revealed average abundance in order of Fe>Mg>K>Ca>Na>Mn>Cu>Zn>Ni, whereas pollution assessment indices using enrichment ratio revealed that the area is unpolluted. Hydrochemical facies of the water using Piper's diagram show that majority of the samples belong to $\text{Ca}^{2+}\text{-Mg}^{2+}\text{-HCO}_3^- + \text{CO}_3^{2-}$ with dominance of $\text{Ca}^{2+} + \text{Mg}^{2+}$ over $\text{Na}^+ + \text{K}^+$ as well as $\text{HCO}_3^- + \text{CO}_3^{2-}$ over $\text{SO}_4^{2-} + \text{Cl}^-$ while Gibbs diagram indicated an interplay of rock-precipitation dominance. Assessment for irrigation purposes using sodium and magnesium hazards, Sodium Adsorption Ratio, Kelley's ratio and Wilcox Plot revealed the suitability. Though concentrations of evaluated parameters indicated low level degree of pollution, continuous opening of mining sites for exploitation and consequence reactions with water bodies may spike up the level of concentration of base metals in the surface and groundwater with resultant great threat to health of plants, animals and humans.

Key words: Odu-Eku; artisanal mining; enrichment; water chemistry; facies; piper.

1. INTRODUCTION

Activities from artisanal mining have been a great concern as a result of impacts ranging from water pollution (Mensah *et al.*, 2015), health implications (Thornton, 1996) to land degradation (Harwood, 1999). The role of geology to water quality is not to be neglected as water circulates through the land surface or as groundwater flow in hard rocks commonly observed to be associated with water bearing discontinuities, such as fractures, joints and faults (Mazurek, 2000; Berkowitz, 2002; Font-Capo *et al.*, 2012) and in the weathered regolith (Wright, 1992). Water is at the core of sustainable development and according to the United Nations Water Development Report (UNWDR, 2020), it is critical for socio-economic development, healthy ecosystems and for human survival itself. Water pollution has become a significant threat to existence of life due to human and natural causes (Mohammed *et al.*, 2016). The need to always ascertain water quality for domestic and irrigation purposes is not to be neglected (Ige *et al.*, 2017) as heavy metals have harmful environmental effects even when they are present in water at $1\mu\text{g}/\text{ml}$ or in air at $1\mu\text{g}/\text{m}^3$ level.

Several studies have been carried out on environmental impact assessment resulting from human activities and/or natural causes and water quality evaluation. Mohammed *et al.* (2019) carried out the assessment of the impact of marble mining in Igarra mining district, southwestern Nigeria. Rock, soil and water samples were subjected to petrographical and geochemical analysis to understand the geology of the area and geochemical concentrations of selected metals (Cd, Co, Cu, Ni, Pb and Zn), respectively. Results from geochemical analysis of the metal concentrations showed that Cd exceeded the allowable limit by WHO and NIS in soil and water, while Pb, Ni exceeded the allowable limit in water by WHO and NIS. Manga *et al.* (2017) worked on the environmental

geochemistry of mine tailings soils in the artisanal gold mining district of Betare-Oya, Cameroon, using ICP-MS to analyse for heavy metals and application of geostatistical tools like enrichment ratio and geo-accumulation for pollution assessment. Cu, Zn, Sr and Ba distribution was found to be associated with mineralization of sulphide-bearing minerals. Cu, Zn, As, W, Mo and Ag were identified as potential pollutants compared to the Dutch soil quality guidelines as these elements were above target values and below the intervention levels. Usman *et al.* (2016) reported the Geochemical Assessment of Toxic Metals Stocking in Top-soil within the area of Limestone Quarry in Gombe state of northeastern Nigeria. A total of 32 soil samples were analysed and results show the order Fe>Mn>Cu>Ni>Cd>Cr>Zn>Hg>Pb. Metals concentration close to the quarry shows greater values when compared to distant samples from the quarry due to piling and proximity to quarry, though the metals show no toxicity when compared to the minimum standard. Paulinus (2015) carried out a research on the heavy metal distribution and contamination in soils around Enyigba Pb-Zn mines district, South-eastern Nigeria. The physico-chemical analyses show that pH is fairly acidic to neutral (5.3-7.0) resulting from the dissolution of the sulphide ore waste dump into the soil. Twelve (12) soil samples and nine (9) heavy metals were analysed and result shows trend of As>Cd>Co>Mn>Cu>Ni>Pb>Zn. Enrichment Factor (EF) shows extremely high enrichment, significant enrichment and low enrichment for some metals. It was also observed that concentration of metals decreases away from the mine site. The Environmental Impact of mining and Pedogeochemistry of Agunjin area, southwestern Nigeria, was reported by Odewumi *et al.* (2015); pollution assessment was done by Visual Impact Assessment by means of a semi-quantitative gridded matrix to assess the overall impact of mining and related activities on the environment, twelve (12) soil samples were collected and analyzed using AAS. Impact score of (-) 3,850 was marked for Agunjin mining, signifying major injurious impact on the environment and needs mitigation of hazards compared to Makrana Marble mining, India, which has a low score. Excess CaO, MgO, Zn, Cu and Mn were due to marble mining in the area. The environmental geochemistry of soil and stream sediments from Birnin-Gwari artisanal gold mining area, northwestern Nigeria was evaluated by Nuhu (2014); a total of fifty-six (56) samples were collected and analysed using XRF. Results show that the concentration of As and Pb exceeded published crustal abundance, whereas the concentrations of Sc, Cr, V, Ni, Cu, Nb, Mo, Sr, Rb, Th, U, Y, La, Ce, Zn, Ba and Zr were below the published continental crust abundance. The abnormal concentration of As was due to external sources which may be from irrigation farming as samples in areas closer to the mine site shows below continental crust abundance.

Thus, for this study, chemical parameters and heavy metals concentration in sediments, rocks, tailings and soil samples were used to ascertain environmental impact assessment of artisanal mining within the research location.

2. MATERIALS AND METHODS

2.1 Study area

The study area comprise of Iwo-Isin, Pamo-Isin, Oke-Aba, Odu-Eku, Odu-Ore and Owode-Ofaro, which are some of the towns in Isin Local Government Area (LGA) bounded by latitude 8°14'00", 8°24'00" and longitude 4°56'00", 5°6'00" and extends for about 17.5 km in length and 18.6 km in width. The drainage is structurally controlled as most streams rises from uplands and flows down slope. The drainage is typical of dendritic pattern with various tributaries connected to the major rivers. Rocks in the study area (Odu-Eku and environs) comprise schist, amphibolites, quartzites and granites (Figure 1). The area indeed is a vivid highlight to the Basement Complex of Nigeria which, according to Caby and Black (1981), is a part of the Pan African mobile belt which lies south of Tuareg shield. Burke and Dewey (1972) described that evidences from eastern and northern margins of the West African Craton indicates that the basement evolved from collision of the passive continental margin of the West African craton and the active continental margin of

(Pharusian) Tuareg shield about 600Ma ago. Ajibade (1980) and Rahaman *et al* (1988) noted that the collision triggered the reactivation of the internal region of the belt thereby creating major structural trends comprising NW-SE, NE-SW, E-W and approximate N-S. This has confirmed the trends of major lithologies (schist and quartzites having trends of NNE-SSW, while pegmatites which hosts tourmaline mineralization in the study area have trends of NW-SE, N-S with minor E-W) and structures like joints having a major trend of NW-SE and minor NE-SW in Odu-Eku and environs.

The oldest rocks in the study area could be the schist belt lithologies (schist and amphibolite) which, according to Oyawoye (1972) and Rahaman (1976), are believed to be relicts of a supracrustal which was infolded into the Migmatite gneiss complex intruded by the Pan African Granitoids.

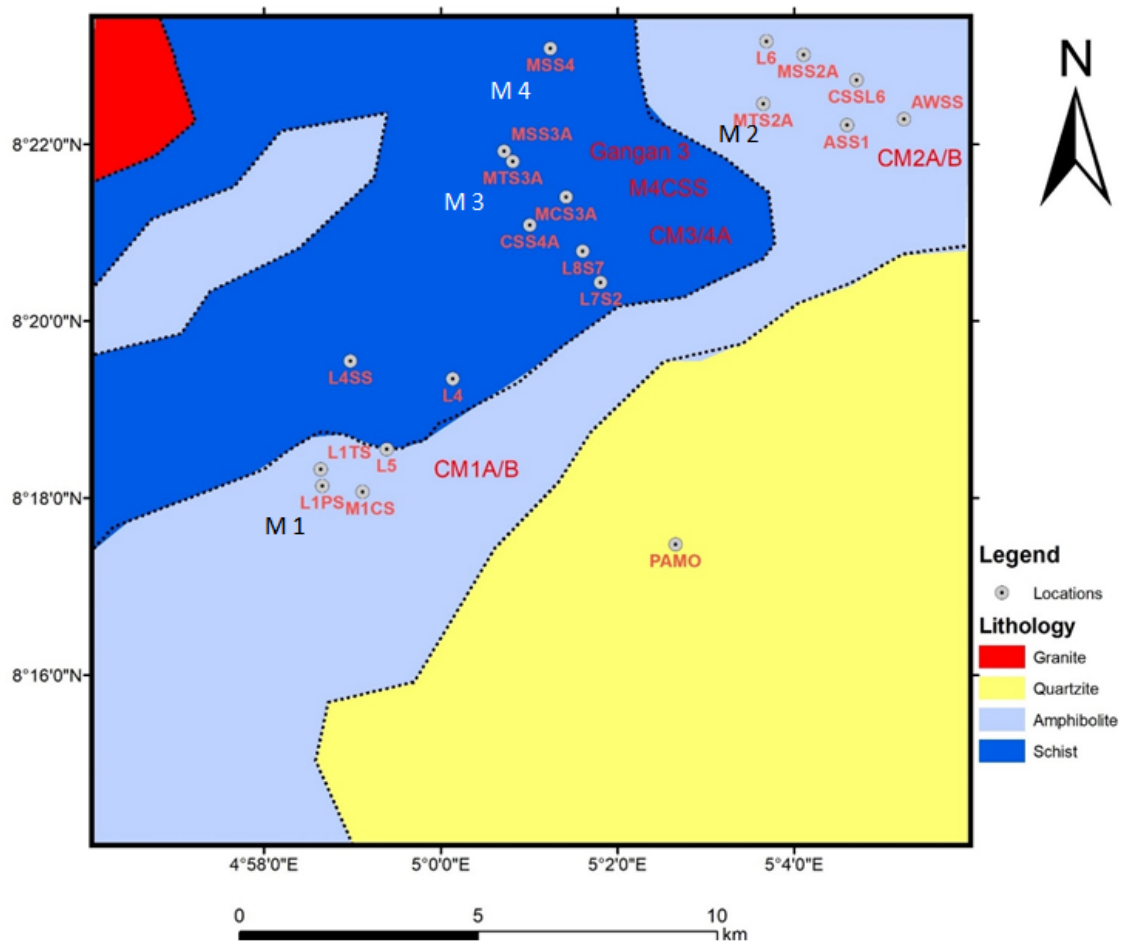


Figure 1. Mining and water sample positions on geological map

2.2 Methodological approach

Four mining sites (M1, M2, M3 and M4) were mapped in the course of the study (Figure 1) and a total of forty (40) samples were collected out of which twenty (20) comprised the solid media (soil and rock) whereas the remaining twenty (20) comprised water samples. 6 rocks and 5 soils taken as control samples from mines, 7 mine tailings and 2 stream sediments make up the solid media, while 8 water samples from mine ponds, 6 from rivers and 6 from wells of adjoining towns to mining sites as control water samples make up the water samples collected (Table 1). 0.5 kg of control soil for each mining site were collected at a depth of 0 -5 cm (Elueze *et al.*, 2009) at a predetermined range of 100-800 m away. Sediment sampling was done, not too close to the bank of the river, at a depth of 15-30 cm, with the aid of a hand trowel and was appropriately labeled in a

ziplock sampling bag. For the collection of water samples, procedures outlined by Ige *et al.* (2017) were followed. 1 litre water bottle were rinsed 3–4 times before filling to capacities and acidified to avoid oxygenation and contamination. Parameters such as electrical conductivity (EC), pH, and TDS were determined in the field while others were done in the laboratory.

Laboratory analysis was carried out using Atomic Absorption Spectrophotometry (AAS) for both the solid media and liquid media. The solid media were analysed for Fe, Mg, K, Ca, Na, Mn, Cu, Zn and Ni, while the water samples were analysed for Ca, Cl, Mg, Fe, Na, K, Zn, Pb, Cu, Mn, Cd, Ni, Co, HCO₃, SO₄ and NO₃ at UNILORIN Central Research Laboratory. Concentration maps were plotted for the solid media and enrichment ratio (ER) was determined for the sediment and control soil samples, while results for the water analysis were subjected to Piper's diagram, Scholler's diagram, Gibbs diagram, Wilcox diagram, Kelley's ratio, and Sodium Absorption Ratio (SAR) (Piper, 1944; Schoeller, 1964; Gibbs, 1970; Wilcox, 1955; Kelley, 1951). Piper and Schoeller's diagrams were used to determine suitability of the water for drinking/domestic purposes, Gibbs diagram was used to assess the source of the pollutants, while Wilcox plots, Kelley's ratio, Magnesium hazard (MH) and Sodium Absorption Ratio (SAR) were used to determine the suitability of the water for irrigation purposes.

3. RESULTS AND DISCUSSION

Results of geochemical analysis for mine tailings, control soil samples, rocks, sediments and water are presented in Tables 2, 3, 4, 5 and 6, respectively. The data obtained were compared to published Upper Continental Crust Abundances (UCCA), World Health Organization Standards and Nigerian Standard for Drinking Water Quality to better understand the influence of anthropogenic activities in the study area.

Table 1. Sample media and their coordinates

Samples	Sample Media	Field name	Coordinates	
			Northings	Eastings
Tailings	Tailings (Mine 1)	L1TS, L1PS	8°18'37.27"	4°58'38.34"
	Tailings (Mine 2)	MTS2A, MSS 2A	8°23'13.098"	5°4'18.26"
	Tailings (Mine 3)	MTS3A, MSS3A	8°21'38.112"	5°1'21.19"
	Tailings (Mine 4)	MSS4	8°21'5.08"	5°1'14.5"
Control Soil Samples	Mine control Soil	M1CS	8°18'35.12"	4°58'37.72"
	Mine control Soil	M2CSS	8°22'56.50"	5°4'58.50"
	Mine control Soil	M3CSS	8°21'31.94"	5°1'29.25"
	Mine control Soil	M4CSS	8°21'21.33"	5°1'21.42"
Rock Samples	Quartzite	R1 (Pamo)	8°17'28.32"	5°2'39.48"
	Schist	R2 (L8S7)	8°20'40.2"	5°2'15.828"
	Amphibolite	R3 (L4)	8°18'40.32"	4°58'46.56"
	Amphibolite	R4 (L6)	8°23'12.84"	5°4'18.48"
	Amphibolite	R5 (L7S2)	8°20'15"	5°2'44.16"
	Schist	R6 (L5)	8°18'37.44"	4°59'17.16"
Sediment	Stream sediment	ASS1	8°23'0.24"	5°4'44.04"
	Stream sediment	AWSS	8°22'53.4"	5°5'13.56"
Water	Mine 1 Pond water	MWS1A, MWS1B	8°18'37.27"	4°58'38.34"
	Mine 2 Pond water	MWS2A, MWS2B	8°23'13.098"	5°4'18.26"
	Mine 3 Pond water	MWS3A, MWS3B	8°21'38.112"	5°1'21.19"
	Mine 4 Pond water	MWS4A, MWS4B	8°21'5.08"	5°1'14.5"
	Control water sample M1	CM1A, CM1B	8°20'00.09"	4°58'55.35"
	Control water sample M2	CM2A, CM2B	8°22'20.12"	5°5'35.36"
	Control water sample M3/4	CM3/4A	8°21'2.68"	5°1'47.6"
	River water	OYWS1A, OYWS1B	8°18'35.12"	4°58'37.72"
	River water	AWS2A, AWS2B	8°23'2.34"	5°4'44.10"
	River water	AWWS2A, AWWS2B	8°22'53.4"	5°5'13.56"

Table 2. Elemental concentrations in mine tailings

Elements (mg/kg)	LITS	LIPS	MTS2A	MSS2A	MSS3A	MTS3A	MSS4	Mean	Min	Max
Fe	6.23	5.86	4.60	3.17	5.70	5.10	3.68	4.91	3.17	6.23
Ca	0.01	0.01	0.39	0.01	1.35	0.01	0.01	0.26	0.01	1.35
Na	0.95	1.06	1.067	1.01	1.027	1.022	0.981	1.018	0.95	1.067
Mg	2.795	3.57	2.835	2.164	3.166	4.102	1.107	2.821	1.107	4.102
K	2.759	3.04	2.109	1.964	2.669	3.526	1.332	2.487	1.332	3.526
Cu	0.36	0.461	0.125	0.085	0.200	0.295	0.065	0.227	0.065	0.461
Zn	0.386	0.837	0.104	0.030	0.090	0.088	0.020	0.222	0.020	0.837
Mn	1.106	1.473	0.586	0.13	1.192	0.480	0.1652	0.733	0.130	1.473
Ni	0.035	0.035			0.01	0.035	0.030	0.029	0.010	0.035

Table 3. Elemental concentrations in control soil samples

Elements (mg/kg)	M1CS	M3CSS	M1CS2	M2CSS	M4CSS	Mean	Min	Max
Fe	2.765	4.774	5.079	4.443	3.481	4.108	2.765	5.0791
Ca	0.596	0.01	0.01	0.01	0.200	0.165	0.010	0.5961
Na	0.962	1.037	1.017	0.932	0.942	0.978	0.932	1.037
Mg	2.034	1.212	2.104	2.174	0.857	1.676	0.857	2.174
K	1.312	1.372	1.868	2.059	0.811	1.485	0.811	2.059
Cu	0.055	0.070	0.135	0.090	0.050	0.080	0.050	0.135
Zn	0.025	0.025	0.025	0.045	0.01	0.026	0.010	0.045
Mn	0.431	0.691	0.366	1.012	0.110	0.522	0.110	1.011
Ni		0.015	0.01			0.013	0.010	0.015

Table 4. Elemental concentrations in rock samples

Elements (mg/kg)	R1	R2	R3	R4	R5	R6	mean
Fe	2.595	1.898	2.429	2.805	2.579	5.615	2.987
Ca	2.565	2.669	10.1	5.485	9.948	0.01	5.129
Na	1.217	1.027	1.598	1.112	1.668	1.042	1.277
Mg	1.868	1.994	2.805	3.371	3.356	3.997	2.898
K	0.576	1.903	1.403	2.925	1.382	3.466	1.943
Cu	0.01	0.015	0.421	0.070	0.145	0.095	0.126
Zn	0.020	0.034	0.125	0.066	0.025	0.122	0.065
Mn	0.055	0.11	0.070	0.751	0.080	0.160	0.204
Ni						0.03	0.030

Table 5. Element concentrations in sediment samples

Elements (mg/kg)	ASS1	AWSS	Mean	Min	Max
Fe	5.529	5.595	5.562	5.529	5.595
Ca	0.01	0.220	0.115	0.010	0.220
Na	1.007	1.092	1.049	1.007	1.092
Mg	3.496	2.129	2.813	2.129	3.496
K	2.860	2.094	2.477	2.094	2.860
Cu	0.270	0.220	0.245	0.220	0.270
Zn	0.029	0.115	0.072	0.029	0.115
Mn	1.192	0.892	1.042	0.892	1.192
Ni	0.035	0.015	0.025	0.015	0.035

3.1 Mine tailing

Base metals are higher in the tailing samples than in soil, stream sediments and control soil samples. From Table 2, it can be seen that Cu, Fe, Zn, Mn, and Ni have their highest concentrations in LIPS (mining site 1 pond sample) and LITS (mining site 1 tailing sample), while on the other hand, elements like Ca, Na, Mg and K tend to be lower in the tailing samples having a range of 0.01-1.35, 0.95-1.067, 1.107-4.102 and 1.332-3.526, respectively. The implication is that the heavy metals concentrate more in the tailings.

Table 6. Elemental concentrations in water samples

	OYWS1A	OYWS1B	AWS2A	AWS2B	MWS1A	MWS1B	CM1A	CM1B	MWS2A	MWS2B
pH	6.87	<u>6.83</u>	6.86	6.88	6.87	6.84	<u>7.09</u>	7.03	6.86	6.84
EC (us/cm)	90	110	70	80	70	80	<u>730</u>	180	80	80
TDS (mg/l)	60	75	50	55	50	55	<u>490</u>	120	55	55
TH (mg/l)	102	114	100	104	<u>98</u>	<u>98</u>	<u>292</u>	156	104	102
Cl (mg/l)	19.23	19.81	17.93	18.79	19.92	<u>17.88</u>	37.89	21.71	20.87	19.77
HCO ₃	<u>98</u>	112	100	100	100	100	<u>286</u>	156	100	98
NO ₃ (mg/l)	0.78	0.73	0.78	0.67	0.7	<u>0.81</u>	0.54	0.43	0.19	0.32
SO ₄ (mg/l)	33	32	30	34	32	34	28	<u>10</u>	30	28
Ca (mg/l)	27.2	28.01	25.61	25.6	24.03	<u>24</u>	76.81	43.2	28.79	28.01
Mg (mg/l)	9.72	11.44	10.3	11.43	10.87	10.85	<u>28.59</u>	13.73	9.15	9.15
Na (mg/l)	7.11	8.08	7.37	6.98	7.13	7.08	<u>15.19</u>	6.02	6.25	6.53
K (mg/l)	5.79	6.15	5.48	4.11	4.14	4.18	<u>11.03</u>	3.78	2.97	3.59
Fe (mg/l)	16.19	19.88	12.24	18.36	<u>22.98</u>	20.03	0.1	<u>0.03</u>	13.82	15.13
Pb (mg/l)	0.85	0.66	0.72	0.69	0.95	0.86	<u><0.05</u>	<u><0.05</u>	0.65	0.67
Zn (mg/l)	0.003	0.003	<u><0.001</u>	<u><0.001</u>	<u><0.001</u>	0.003	<u><0.003</u>	<u><0.003</u>	2.003	0.055
Cu (mg/l)	<u>1.105</u>	1.006	0.05	0.05	<u>0.03</u>	0.06	<u><0.003</u>	<u><0.003</u>	1.002	0.05
Cd(mg/l)	<u>0.005</u>	0.004	0.002	<u>0.005</u>	0.003	0.004	<u><0.002</u>	<u><0.002</u>	0.004	0.002
Ni(mg/l)	0.004	0.003	<u>0.001</u>	0.003	<u>0.005</u>	0.003	<u><0.003</u>	<u><0.003</u>	0.004	0.003
Co (mg/l)	<u><0.001</u>	<u><0.001</u>	<u><0.001</u>	<u><0.001</u>	<u><0.001</u>	0.003	<u><0.003</u>	<u><0.003</u>	0.002	<u>0.004</u>
Mn(mg/l)	<u>0.003</u>	<u>0.003</u>	<u>0.003</u>	0.006	0.005	<u>0.008</u>	<u>0.003</u>	<u><0.003</u>	0.006	0.004
Cr (mg/l)	<u><0.001</u>	<u>0.004</u>	0.003	<u><0.001</u>	<u>0.004</u>	<u><0.003</u>	<u><0.003</u>	<u><0.003</u>	<u><0.001</u>	<u><0.001</u>
MH	37.08	40.24	39.87	42.40	<u>42.72</u>	42.71	38.03	34.39	34.38	35.0
NaH	20.14	20.94	21.04	20.00	<u>21.20</u>	21.10	16.37	<u>13.08</u>	18.85	19.57
SAR	0.1489	0.1625	0.1555	0.1441	0.152	0.151	<u>0.188</u>	<u>0.102</u>	0.129	0.137
KR	0.193	0.205	<u>0.205</u>	0.188	0.204	0.203	0.144	<u>0.105</u>	0.165	0.176

	CM2A	CM2B	MWS3A	MWS3B	CM3/4A	CM3/4B	MWS4A	MWS4B	AWWS2A	AWWS2B
pH	7	7.08	6.87	6.85	7.02	7.03	6.83	6.86	6.84	6.97
EC (us/cm)	520	340	110	120	560	160	<u>60</u>	80	100	110
TDS (mg/l)	350	230	75	80	375	110	<u>40</u>	55	70	75
TH (mg/l)	268	254	110	106	266	120	102	100	108	106
Cl (mg/l)	31.78	29.84	19.96	21.89	<u>39.92</u>	19.92	19.94	22.9	19.92	20.95
HCO ₃	270	250	108	102	266	118	100	100	104	106
NO ₃ (mg/l)	0.78	0.21	0.28	0.28	0.69	<u>0.14</u>	0.16	0.25	0.24	0.39
SO ₄ (mg/l)	24	26	32	<u>36</u>	34	16	34	32	28	30
Ca (mg/l)	79.19	<u>79.98</u>	30.4	29.58	78.4	30.01	28.8	28.01	29.6	28.79
Mg (mg/l)	22.31	15.44	9.72	9.16	20.02	11.44	8.58	<u>8.57</u>	9.72	9.72
Na (mg/l)	13.12	10.22	6.6	6.19	11.91	<u>5.61</u>	6.11	6.17	6.42	6.51
K (mg/l)	<u>2.28</u>	6.64	3.57	3.53	8.01	2.89	3.01	3.86	3.83	3.62
Fe (mg/l)	0.23	0.21	15.21	14.16	0.29	0.11	13.79	15.11	12.98	14.12
Pb (mg/l)	<u><0.05</u>	<u><0.05</u>	0.72	0.69	<u><0.05</u>	<u><0.05</u>	0.75	0.66	0.61	0.18
Zn (mg/l)	<u><0.003</u>	<u><0.003</u>	1.033	2.212	<u><0.003</u>	<u><0.003</u>	<u>3.12</u>	0.002	0.003	<u><0.001</u>
Cu (mg/l)	<u><0.003</u>	<u><0.003</u>	<u>0.003</u>	1.102	<u><0.003</u>	<u><0.003</u>	0.5	1.1	0.2	0.055
Cd(mg/l)	<u><0.002</u>	<u><0.002</u>	<u><0.001</u>	0.003	<u><0.002</u>	<u><0.002</u>	0.003	0.005	<u><0.001</u>	0.004
Ni(mg/l)	<u><0.003</u>	<u><0.003</u>	0.003	<u>0.005</u>	<u><0.003</u>	<u><0.003</u>	0.003	<u><0.003</u>	0.003	<u><0.001</u>
Co (mg/l)	<u><0.003</u>	<u><0.003</u>	<u>0.001</u>	<u><0.001</u>	<u><0.003</u>	<u><0.003</u>	<u><0.001</u>	<u><0.001</u>	0.003	0.002
Mn(mg/l)	<u><0.003</u>	<u><0.003</u>	0.005	0.004	<u><0.003</u>	<u><0.003</u>	0.004	<u>0.003</u>	<u>0.003</u>	0.005
Cr (mg/l)	<u><0.003</u>	<u><0.003</u>	0.003	0.003	<u><0.003</u>	<u><0.003</u>	0.003	0.003	<u><0.001</u>	0.004
MH	31.72	<u>24.15</u>	34.52	33.80	29.63	38.60	32.94	33.53	35.13	35.76
NaH	16.20	13.70	18.68	18.26	14.79	15.87	18.79	18.92	18.42	18.95
SAR	0.168	0.137	0.133	0.128	0.155	0.110	0.128	0.131	0.131	0.130
KR	0.129	0.107	0.165	0.159	0.121	0.135	0.163	0.169	0.163	0.169

MH: Magnesium Hazard, NaH: Sodium Hazard, SAR: Sodium Absorption Ratio, KR: Kelley's Ratio

3.2 Soil

A total of five (5) soil samples were collected from the study area to serve as control samples to the four mining sites in the study area. Concentrations of elements show that they are within the background values compared to the standards of Wedepohl (1995) and Taylor and McLennan

(1985). The concentrations of trace metals (Cu, Zn, Mn, Ni and Fe) tend to be lower compared to that of stream sediments and tailings from the mining sites.

3.3 Stream sediment

Two (2) sediments were sampled from the two rivers (Aku and Awere) that cut across the mining site in Owode-Ofaro (M2 and M2B). Cu generally does not precipitate at pH values lower than 5.5 (Hawkes and Webb, 1962) and so the low concentrations of Cu and Ni in the sediments may have been caused by low acidity of the solution. Fe, Mn and elements like Mg, K, Na and Ca tend to be high and show possibilities of contribution from the local geology of the area (Elueze *et al.*, 2009).

3.4 Rock

Six rock samples (R1-R6) comprising of quartzite, schists and amphibolites were collected and analysed for trace and major elements. Concentrations of metals in the various rocks are shown in Table 4. The trace elements show a fickle pattern of Fe>Cu>Mn>Zn>Ni, while the major element is in order of Ca>Mg>K>Na.

3.5 Heavy metals concentration in sediments, rocks, tailings and soil

Table 7 shows the comparative analysis of the various sample media analysed. A vivid look on the mean concentration shows that the concentration pattern of metals (Fe, Cu, Zn, Mn and Ni) is of great significance. It can be observed that the concentrations of metals tend to be higher in the mining sites and concentration decreases closer to the settlements in the study area as evident in the control soil samples (Figures 2-5).

The metallic concentration, especially for Cu, Fe and Mn, tends to be higher in the stream sediment than that of the rock and soil samples. This is true because the river system serves as the watershed for the geological system having representation of weathered and transported dissolve metals.

Table 7. Mean concentration of solid media

Elements	Mean concentrations (mg/kg)			
	Rock (6)	Soil (5)	Tailings (7)	Stream sediment (2)
Fe	2.9870	4.1084	4.9052	5.5625
Ca	5.1292	0.1653	0.2569	0.1152
Na	1.2773	0.9778	1.0183	1.0494
Mg	2.8985	1.6760	2.8208	2.8125
K	1.9426	1.4847	2.4866	2.4769
Cu	0.1261	0.0801	0.2268	0.2454
Zn	0.0654	0.0259	0.2222	0.0721
Mn	0.2045	0.5219	0.7335	1.0419
Ni	0.0301	0.0125	0.0291	0.0250

To evaluate the contamination of metals in rocks, sediments, soils and tailings, comparison was made with the background value of the Upper Continental Crust by Wedepohl (1995) and Taylor and McLennan (1985) (Table 8). Pollution assessment indices, like enrichment ratio (ER), were used to evaluate the source of accumulation of the various metals.

Table 8. Mean concentration of this study compared to standards

S/No	Elements	Mean concentration (this study) (mg/kg=ppm)	Wedepohl (1995) (ppm)	Status	Taylor and McLennan (1985) (ppm)
1	Fe	4.196	30890	Very low	
2	Ca	1.682	29450	Very low	
3	Na	1.089	25670	Very low	
4	Mg	2.557	13510	Very low	
5	K	2.072	28650	Very low	
6	Cu	0.162	14.3	Low	25
7	Zn	0.111	52	Low	71
8	Mn	0.553	527	Low	600
9	Ni	0.025	18.6	Low	20

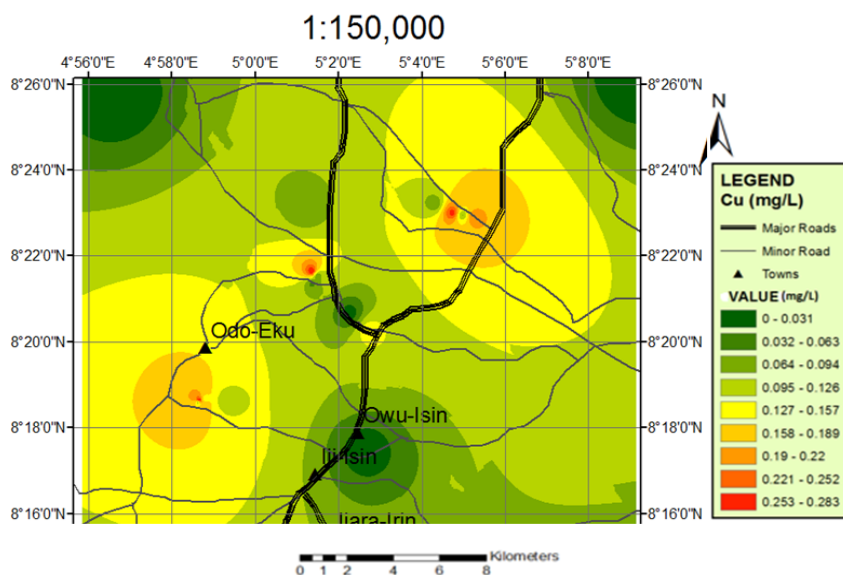


Figure 2. Concentration map of Copper (Cu)

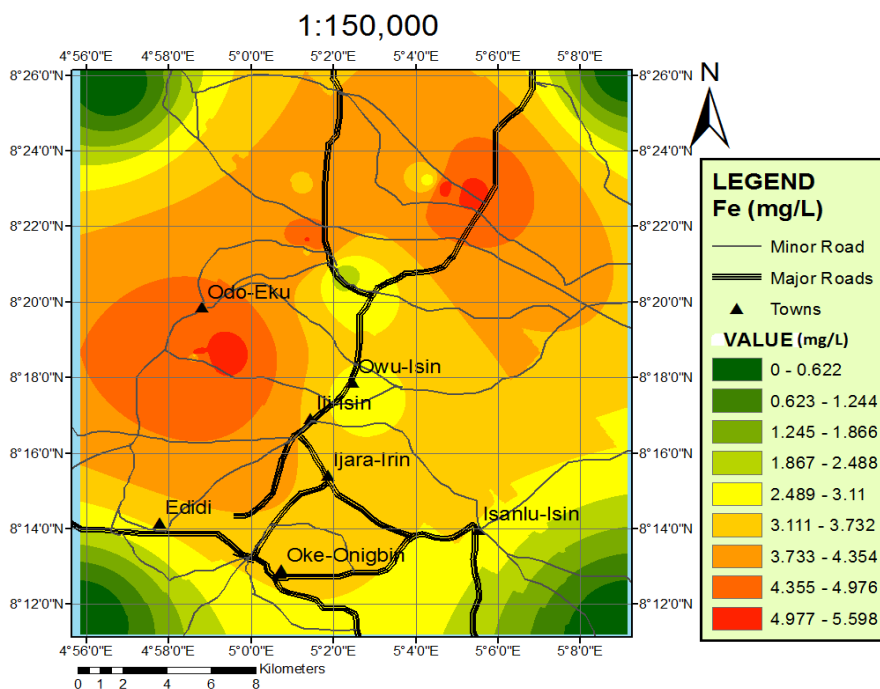


Figure 3. Concentration map of Iron (Fe)

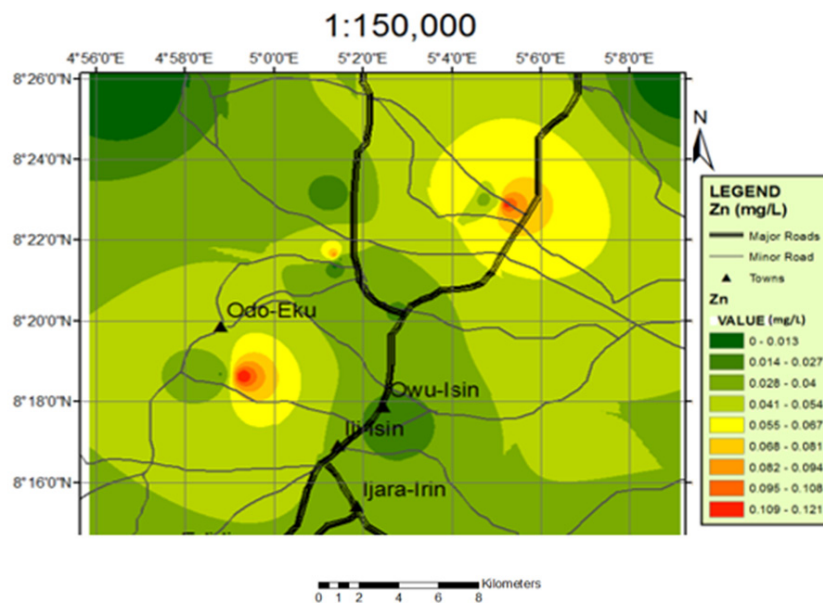


Figure 4. Concentration map of Zinc (Zn)

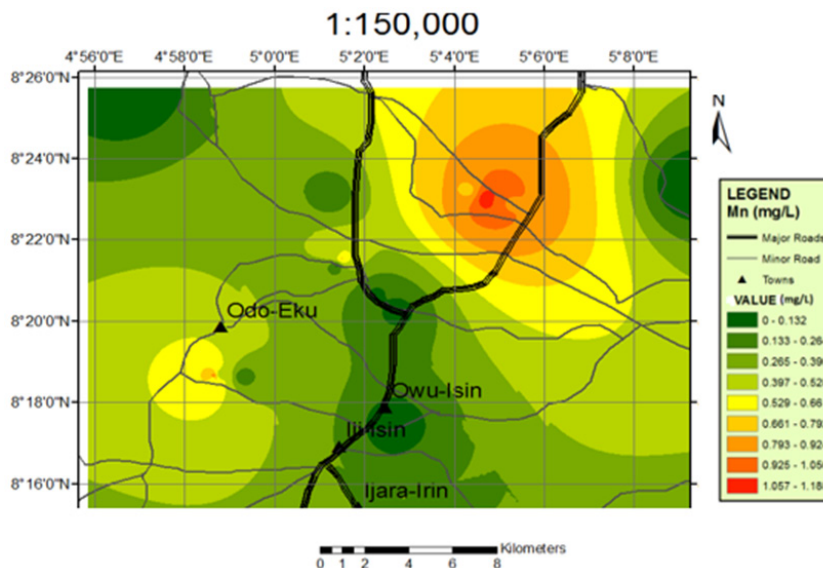


Figure 5. Concentration map of Manganese (Mn)

3.6 Enrichment ratio (ER)

Element enrichment ratios (Albright, 2004) were calculated in order to assess the extent of enrichment and/or depletion of trace elements in the soil and sediment of the study area relative to their crustal concentrations. Upper Continental Crust concentrations of the elements presented by Taylor and McLennan (1995) and Wedophl (1995) were used as baseline or background values.

Enrichment ratio (ER) was calculated using the equations:

$$ER = C_n/B_n \quad (1)$$

where; C_n is the concentration of an element measured in a sample and B_n is the background or baseline concentration which in this case, the upper crustal concentration of the element.

- $ER < 1$ indicates depletion
- $ER = 1$ indicates that the rock is neither enriched nor depleted
- $ER > 1$ signifies enrichment

Table 9. Background values for selected metals (adapted from Nuhu, 2014)

Elements (ppm)	Nuhu (2014)	Continental crust		Soils	Sediments
		UCCA: Taylor and McLennan (1985)	Wedopfl (1995)	USEPA (2000) Soil guideline value	SSNN
Ni	16	20	56	22	16.9
Cu	11	25	25	22	16.5
Zn	30	71	65	66	41
Fe	4.6	5	6.3		4.5

Table 10. Calculated enrichment ratio for soil and sediments

Media	Soil Samples					Sediment Samples	
	MICS	M3CS	M1CS2	M2CSS	M4CSS	ASS1	AWSS
Cu	0.0025	0.0032	0.0061	0.0041	0.0023	0.016393	0.013357
Zn	0.0004	0.0004	0.0004	0.0007	0.000152	0.000709	0.00281
Ni		0.0007	0.0005			0.002075	0.000889

From Table 10, it can be seen that the control soil and sediment samples are all having enrichment ratios (ER) lower than 1, which indicates that the soil and sediments are unpolluted or there is depletion of the trace metals. More so, it suggests bulk contribution of the local geology rather than anthropogenic sources as confirmed to the geochemistry of rocks and tailings in the study area.

3.7 Heavy metal concentration in surface and groundwater

For the purpose of this work, water sources were divided into two, namely surface and groundwater. Groundwater comprised water from hand-dug wells, while surface water was regarded as water sampled from mine ponds and rivers. Eight (8) of the water samples were collected from mine ponds of four mining sites visited, i.e. two from each site, six (6) water samples were collected from River Oyi, Awere and Aku, while the remaining six (6) water samples were collected from adjoining towns to the mining sites to serve as control water samples.

Table 11. Parameters in water analysed compared to the standards of NSDWQ (2007) and WHO (2011)

Parameters	Present study		WHO (2011)	NSDWQ (2007)
	Min	Max		
pH	6.83	7.09	6.5-8.5	6.5-8.5
Conductivity (us/cm)	60	730	1000	1000
Turbidity (FTU)	0.19	16.21		
Total dissolved Solid (mg/l)	40	490	1000	NE
Total Hardness (mg/l CaCO ₃)	98	292	440	200
Total Alkalinity (mg/l CaCO ₃) (Methyl Orange)	98	286	350	NE
Chloride (mg/l)	17.88	39.92	200	250
Bicarbonate (mg/l)	98	286	NE	NE
Nitrate (mg/l)	0.14	0.81	1.8	NE
Sulphate (mg/l)	100	36	56.1	200
Calcium (mg/l)	24	79.98	200	NE
Magnesium (mg/l)	8.57	28.59	150	NE
Sodium (mg/l)	5.61	15.19	500	500
Potassium (mg/l)	2.28	11.03	NE	NE

The pH values range from 6.83 to 6.97, 7.0 to 7.09 for surface and groundwater, respectively, which is indicative of slightly acidic to alkaline, showing they are fit for domestic and irrigation purposes. Analysed parameters are shown in Table 6, while comparison of the measured parameters to that of WHO (2011) and NSDWQ (2007) are presented in Table 11. Concentrations of base

metals (Mn, Ni, Pb, Cu, Zn and Fe) are higher in surface waters and very low in the groundwater. This may be as a result of the interaction of the mineralization in the other sample media compared to the control samples (groundwater). Fe is having a mean concentration of 16 mg/l in surface water and <5 mg/l in all the other sample media (Table 6). This may be due to the oxidation of the ferromagnesian minerals being concentrated along the drainages and the mining ponds water observable in the study area. For example, Fe was higher in MWS1A (Mine Water Sample 1) and MWS1B (Mine Water Sample 2) having a concentration of 22.98 mg/l and 20.03 mg/l, respectively (Table 6). It can be true, as the water in the pond can only be pumped out by the artisans or in other words the pond has no outlet unlike other mining sites that do have gentle slope where water can be drained and as such gradual depletion of metals to the environment being possible.

3.8 Water quality

Generally, the hydro-chemical facie classification of the water samples using Piper's and Schoeller's diagrams (Figures 6, 7 and 8) shows that 85% of the water falls within CaHCO₃ water type, while the remaining 15% fall within Ca(Mg)Cl water type. The Wilcox diagram (Figure 9) reveals that all water samples are within the region of excellent to good, thus, all the water samples can be used for irrigation. For Kelley's ratio, water samples having ratio values greater than 1 are not fit for irrigation. The results (Table 6) show that all the water samples are fit for irrigation. Sodium Absorption Ratio (SAR) is an index of the sodium hazard of water. It gives a clear idea about the adsorption of sodium by soil. If water used for irrigation is high in Na⁺ and low in Ca²⁺ the ion-exchange complex may become saturated with Na⁺ which destroys the soil structure, due to the dispersion of the clay particles (Todd, 1980) and reduces the plant growth. Water with SAR < 3 has no restriction to be used for irrigation purpose, thus, all the tested water samples can be used for irrigation with no restriction.

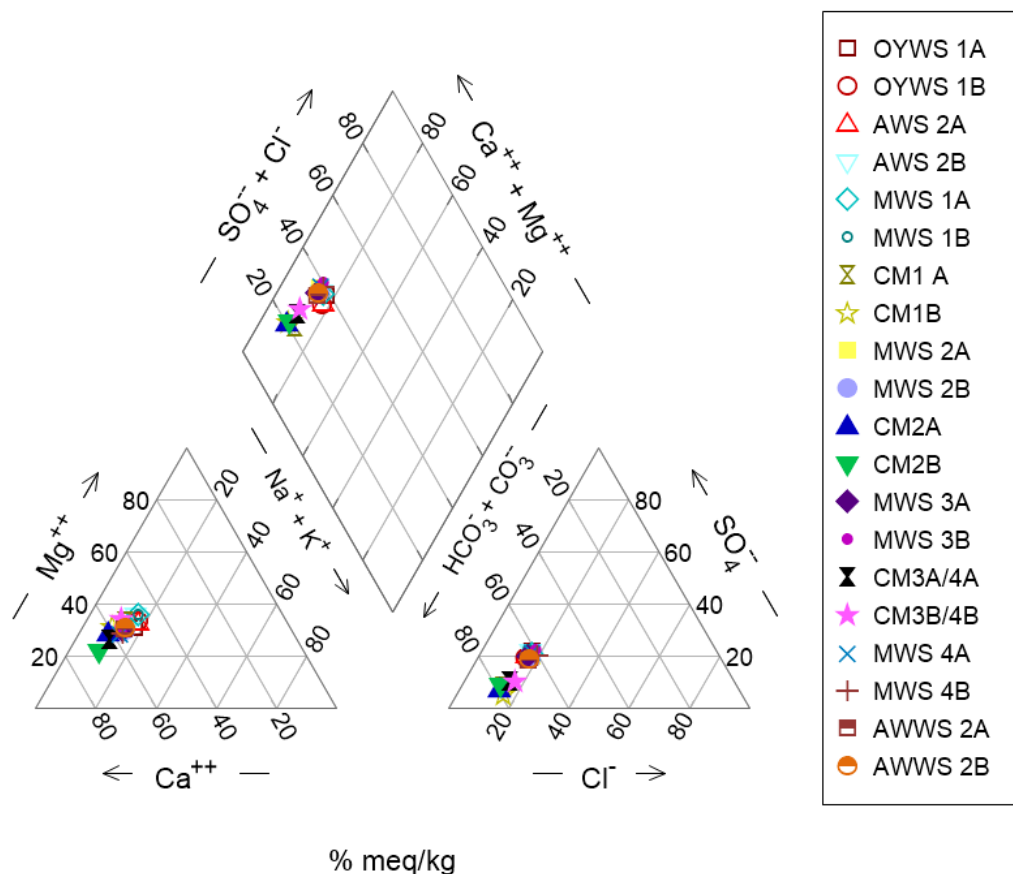


Figure 6. Piper's plot

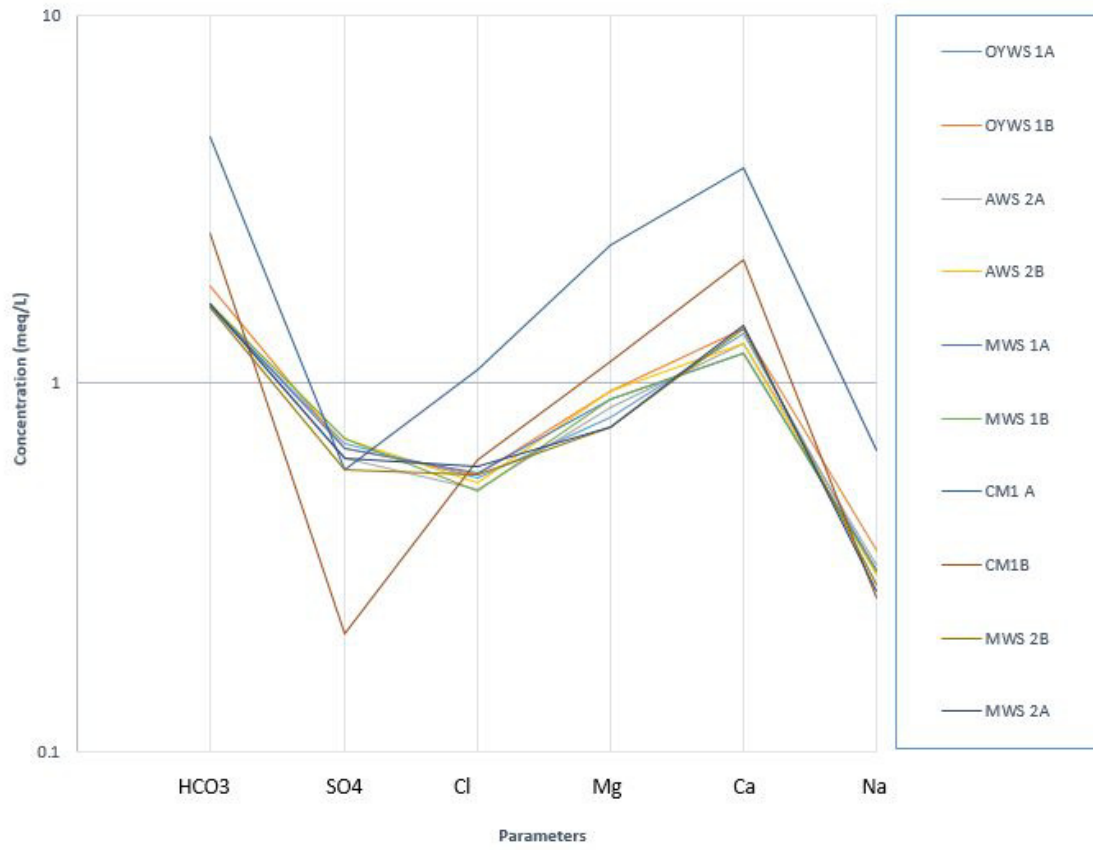


Figure 7. Schoeller's plot

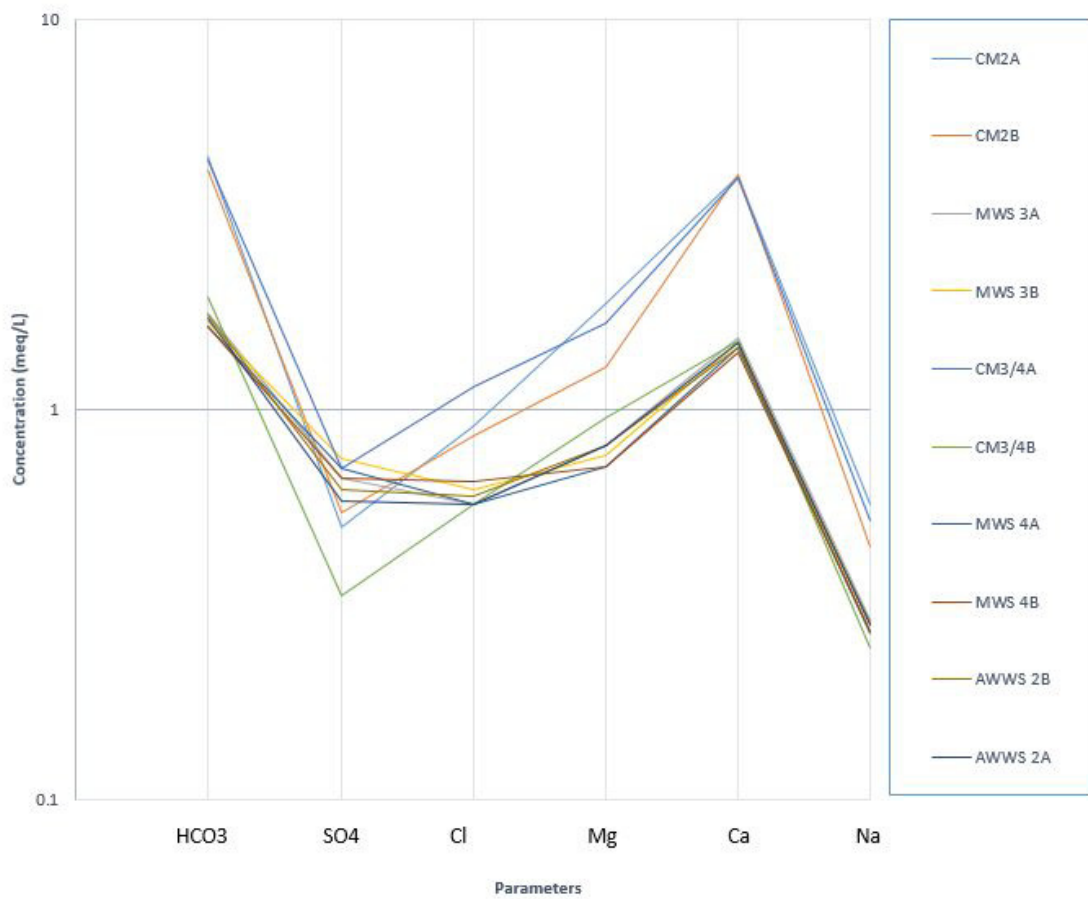


Figure 8. Schoeller's plot

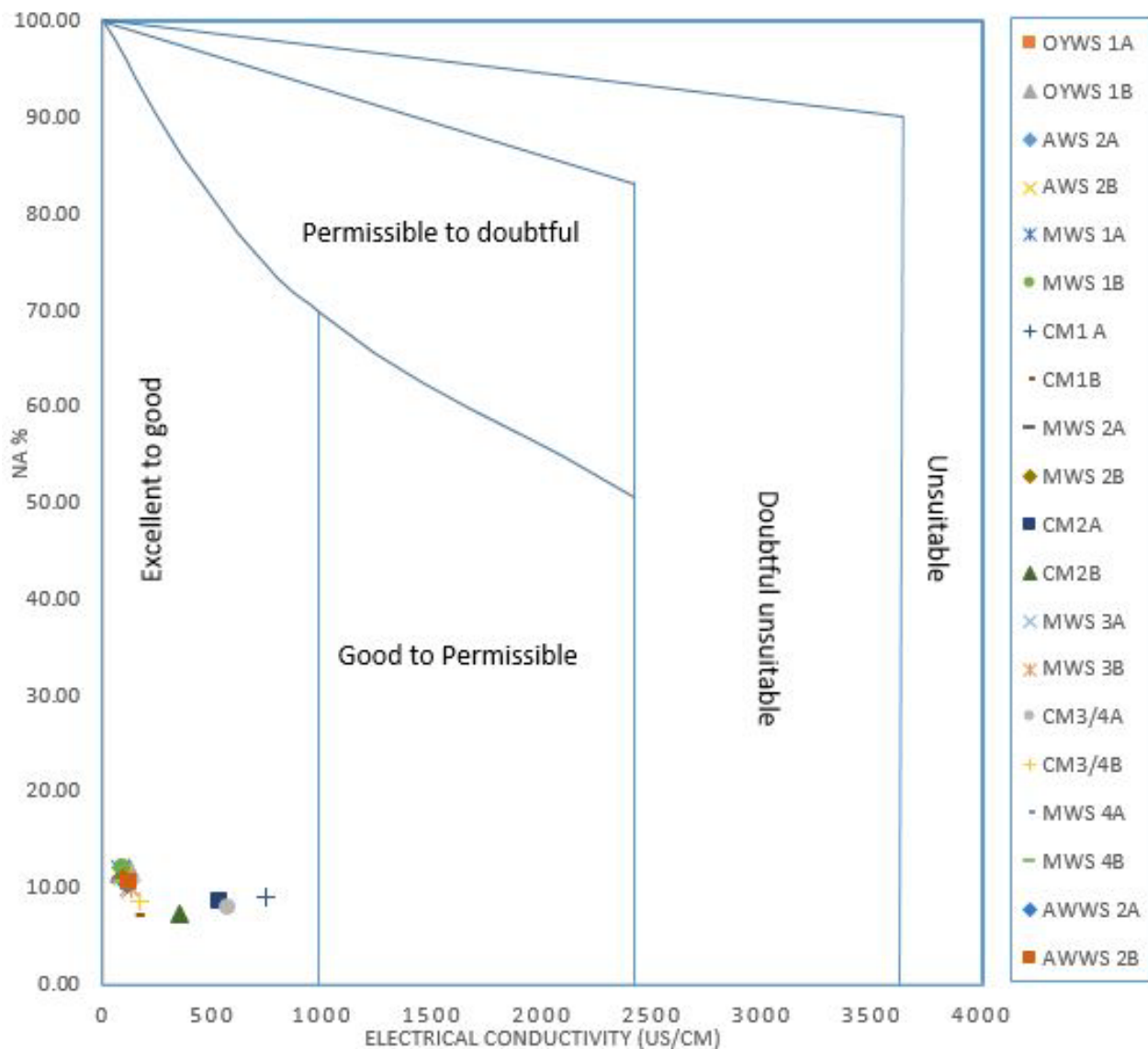


Figure 9. Wilcox plot

For Magnesium hazard evaluation, the presence of magnesium in soil and water would adversely affect their quality and render the soil unfit for cultivation. Magnesium ratio of more than 50% in a body of water sample will make the water poisonous to plants (Rajmohan and Elango, 2005). Table 6 reveals that 100% of the samples showed magnesium ratio less than 50%, which confirms the suitability of the water samples for irrigation.

3.9 Mechanism controlling water quality

Source of the dissolved ions (contaminant) in groundwater can be understood by Gibb's diagram (Figures 10 and 11). All the groundwater control samples plotted within the rock dominance field, which suggests that chemical weathering of the rock forming minerals is the main process which contributes to the ions concentration in the water, while all the surface water samples from mine ponds and rivers plotted within the precipitation dominance field depicting effect of dilution of the water and less interaction with the rocks of the study area.

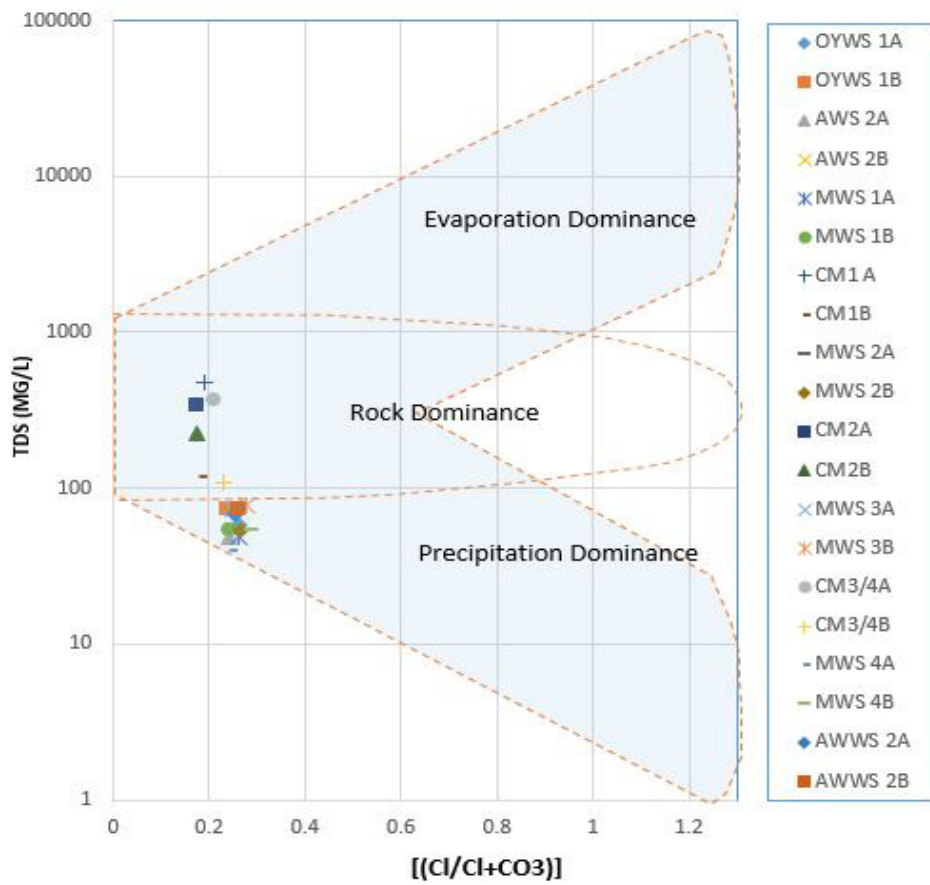


Figure 10. Gibbs diagram for anions

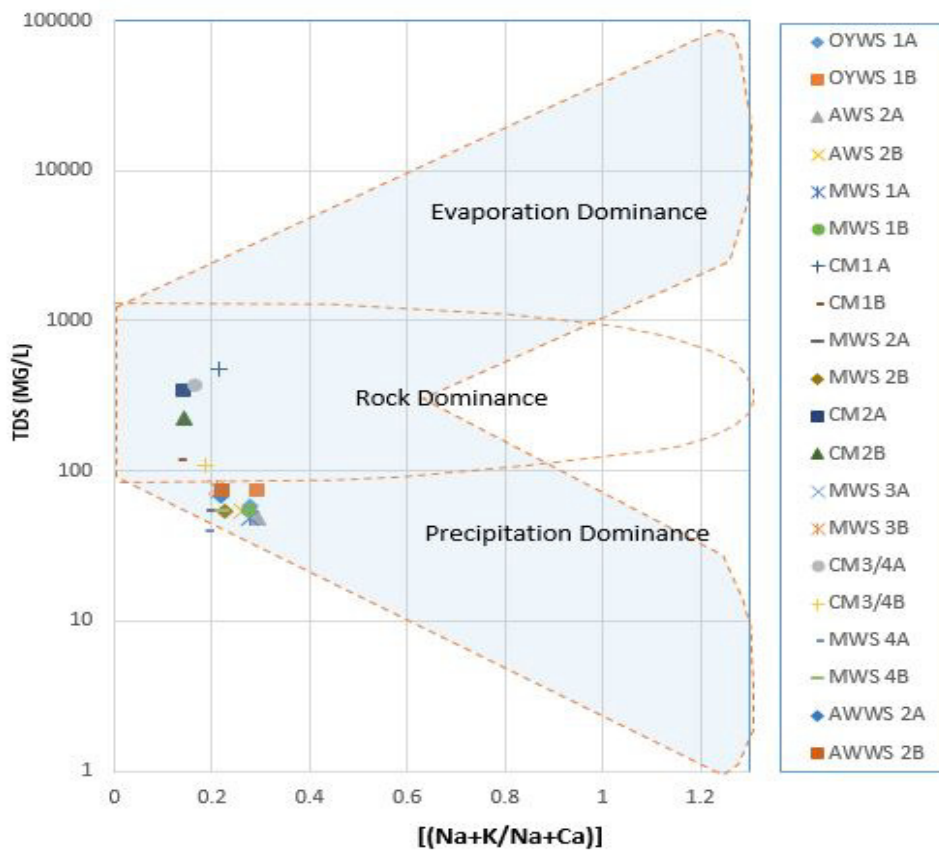


Figure 11. Gibb's diagram for cations

3.10 Environmental implications

The studies revealed that the concentration of metals in the sample media (rock and mine tailings) in the mining sites are relatively higher compared to the base control stations to monitor the concentration differences. Elemental abundances compared to the established standards of Wedepohl (1995) and Taylor and McLennan (1985) showed that the mean concentrations of the metals are lower.

Even though the pollution assessment indices of the studied area as at the time of research showed that the sites are unpolluted and safer for the environment, it is still of much concern to the environment because the presence of such metals with continuous mining through undue excavation of the environment has a direct and indirect implication on the water chemistry of the environment. There is possibility of continual leaching of the disaggregated metals through cracks of rocks, weathering and erosion of some metals from mine tailings to nearby river drainages as well as percolation of some metals to groundwater thereby concentrating the metals and having a direct consequent to plants and animals as well as human beings when water is assessed through wells and boreholes for consumption and domestic usage. Population explosion or possible migration to nearby mining locations can be a direct linkage to exposure to some of these metals that continual intake and concentration in the body has potential risks.

4. CONCLUSION

Concentrations of base metals commonly used for as pollution indices in mining environments have been studied in this work. From the different media that were assessed, mine tailings have the highest concentration of the base metals (Cu, Fe, Zn, Mn, and Ni) followed by stream sediments and soil samples as seen in the concentration maps. Rock medium shows a fickle pattern of Fe>Mg>K>Ca>Na>Mn>Cu>Zn>Ni while water samples shows a pattern of Ca>Cl>Mg>Fe>Na>K>Zn>Pb>Cu>Mn>Cd>Ni>Co. Pollution assessment indices using enrichment ratio (ER) calculated for the sediment and soil samples shows that there is no enrichment of the metals in the media. The present hydrochemical status of the study area shows concentration levels of ionic species to be controlled by geogenic processes rather than being influenced by the artisanal mining activities. Majority of the samples belong to Ca^{2+} - Mg^{2+} - HCO_3^- + CO_3^{2-} with dominance of Ca^{2+} + Mg^{2+} over Na^+ + K^+ as well as HCO_3^- + CO_3^{2-} over SO_4^{2-} + Cl^- . Gibbs diagram show sources of water as rock dominance for groundwater and precipitation dominance for surface water. The results were compared with standards and show suitability for domestic and irrigation purposes.

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