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Research Paper

Geochemical Evaluation of Itakpe Iron Ore Mine Tailings, Itakpe, Nigeria

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Abstract
The study focus on the characterisation of the tailings attributes with a view to understanding the geotechnical properties, leaching potential and possible major oxides. The samples were composited into five. The composited samples were subjected to both physical and chemical tests. The physical tests include particle size distribution, specific gravity, density, residual humidity and Atterberg limits. The chemical tests include pH, organic matter, and Energy Dispersive X-Ray Fluorescence Spectrometry (ED-XRFS). Mineralogical analyses were also carried out on the composited samples using the Scanning Electron Microscopy (SEM) coupled with Energy Dispersive X-ray Spectroscopy (SEM-EDX). The results from the physical tests show that the tailings are mostly fine-medium sands, having high specific gravity and bulk density, with low residual humidity. The chemical analyses show that the tailings are weakly acidic and neutral with low organic matter. The energy dispersive x-ray fluorescence spectroscopy analysis of the samples shows that they contain high concentrations of Fe_2O_3, SiO_2, and other trace compounds. The Fe_2O_3 of the samples ranged from 15.03 to 20.12% and SiO_2 ranged from 57.26 to 60.10%. SEM micrographs obtained revealed the interlocking nature of the minerals constituting the ore matrix. EDX analysis of the regions within the ore matrix revealed the presence of Si, Fe, Al, K, Ca, Nb, Y, Ag, Zn, Mg, Cl, P, S, Na, Ti, Zr; such that silicon and iron are the major elemental constituents of the ore matrix while other elements exists in trace form.
Keywords: *Tailings, Ccharacterisation; Physical tests; Chemical tests; X-ray Spectroscopy; Scanning Electron Microscopy.*

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I. Introduction

Nigeria has several iron ore deposits located in Itakpe, Ajabanoko, Chokochoko, Agbade-Okudu, Nsude Hills and Agbaja. In Nigeria, the Itakpe iron ore deposit is the principal source for the iron and steel industry. The estimated reserve of the iron ore is about 200 million tonnes with average Fe content of 36% and was designed to supply the iron ore requirements of the Ajaokuta Steel Company Limited, Ajaokuta, Kogi State and Delta Steel Complex, Aladja, Delta State, Nigeria. Waste rocks and tailings dumps were created at the East pit and the Beneficiation Plant. Height of the tailings dump reached a maximum of 40m, while at the East pit waste rocks dump, the maximum height did not exceed 20m to ensure stability of the slopes.

Waste rocks are generated in the extraction of iron ore from the parent rock. These waste rocks are similar rocks that were removed during the iron ore mining process, whereas tailings are produced during the iron ore beneficiation process. (Adebimpe, 2004). After the commercial minerals have been taken from the deposit, the mixture of crushed rocks and by-products from the mineral processing facilities is known as tailings. (Kossoff et al., 2011). Physical and chemical methods are used in the extraction of metals and one of the bye-products is tailings. The tailings was generated because the iron ore deposit has low Fe content of 36% and required to be beneficiated to 63% for Ajaokuta Steel Company and 68% for Delta Steel Company, Aladja, Delta State, Nigeria. The reason for the study is to have proper understanding of the tailings in terms of its characteristics and the leaching potentials of the heavy metals on the environment. Proper characterisation of the tailings would lead to the initiation of effective remediation process. The management of the tailings as a result of the heavy metals can have negative consequence if effective measures are not implemented. Metals have been shown to have negative impacts on plant physiology and reproductive systems, as well as oxidative stress, fluorescence, stomatal resistance, chlorophyll and photosynthesis. [Ngole-Jeme and Fantke, 2017]. Human health may also be at risk from eating of tailings dust, accidental inhalation, and skin contact with mining tailings. (Sarathchandra et al., 2023)

Ore beneficiation at the mine started in 1993 (Adebimpe and Adam, 2011). As at 2001, the mine produced 286, 289 tonnes of beneficiated ores and about 400,000 tonnes of tailings generated out of the 764,217 tonnes of run-of-mine received from the mine. The production of the mine tailings stopped over twenty years ago as a result of the difficulties encountered by the Nigerian government in effectively completing the privatisation process of the iron and steel industry and the impact of the heavy metals contained in the tailings has not been well studied. In Nigeria, records of tailings generated from mineral processing activities are scanty, when compared with other developed countries and this exceeded 7.5 billion tons as reported in China (Tang et al., 2019; Zhizhen et al., 2018; Chen et al., 2012).

The Itakpe iron ore mine's tailings are dark brownish-brown in color and contain both coarse and fine particles, making them ideal for pipeline coatings and tailings dams. (Adebimpe and Fatoye, 2021). The result obtained from the analysis of tailings from the Beneficiation Plant of the company indicated Fe(total) of 15% and SiO_2 of 71% (NIOMP, 2001), however additional studies has shown iron ore tailings (IOTs) with Fe content of approximately 8 wt %–12 wt % on average, and could be as high as 27 wt % (Jiabin et al., 2010; Ajaka, 2009). Praes *et al* (2013) presented the results of the study of the concentration by flotation carried out with a fraction of iron ore made up of the magnetic separation tailings.

The demand for iron ore tailings from the mine is presently limited to the oil and cement industry; however studies have shown that the tailings could also be used for brick production in the housing sector of the Nigerian economy. The cement sector of the Nigerian economy specifically used the tailings in conjunction with iron concentrates to provide additional strength to the cement. In some countries, tailings are used for tailings dam construction. Previously the iron and steel sector in Nigeria was totally controlled by the Federal Government, however the need to improve productivity and rapidly increase revenue necessitated the privatisation drive.

At the mine, the tailings generated are stockpiled within the surrounding of the Beneficiation Plant. Stockpiling the tailings can invariably lead to the leaching of heavy metals which impact the ecosystem negatively. Metal sulphides in tailings could have serious environmental consequence if relevant control strategies are not imposed (Mendez-Ortiz et al., 2017). In this regard, Lim et al (2017) examined the leachability of arsenic and heavy metals from mine tailings of abandoned metal mines. In the process of mining, some of the heavy metals are leached into the subsurface of the mine environment which may lead to environmental problems. Environmental contamination results from mining activities, ore grinding and clustering, and the open discharge of tailings that are carried by wind and flood. (Karn et al., 2021). Excess heavy metals accumulation in soils is toxic to humans and other animals (Barkouch and Pinean, 2016).

Overburdens and tailings from iron ore mines are significant sources of toxic trace elements, such as Pb, Cu, Se, Mn, Cr, Hg, As, Ni, Cd, Zn, Al, and Ba, that are damaging to human health even at low concentrations. (Gleekia and Sahu, 2018). Release and reuse of tailings has become an important subject of discussion in the mining industry because of its wider environmental implications. In this regard, it is important to understand the mineralogical evolutions of the iron ore tailings and the contaminants. Gayana and Chanders (2018) investigated the sustainable use of mine waste and tailings with suitable admixture of aggregates in concrete pavements. Recent developments in the reuse of mine tailings and waste rocks include usage in mine backfill and as water-balance cover (Hefni et al., 2021; Mohammed et al., 2017).

Therefore this study intends to (i) evaluate the geochemical and mineralogical evolutions in mine tailings, and (ii) evaluate the mobility of the principal contaminants with a view to understanding its probability of entering the food chain which can have negative impact on the ecosystem.

1.1 Mine tailings characterization

The attribute of the tailings rest on the type of ore extracted. Tailings physico-chemical properties impact the behavior of soil and hence, give more important information (Sumithra et al., 2013). Geochemical and mineralogical compositions are some of the physical and chemical characteristics of tailings (Environment Australia, 1995; Lottermosser, 2007). Attributes that have an impact on tailings characteristics include; the ore type, clay mineralogy, and physical and chemical methods used to extract the economic product (Lim et al (2017).The chemical composition of tailings is a function of the type of minerals contained in the ore and the type of fluids used in the extraction process (Kossoff *et al*., 2014). The major components of the tailings are presented in Table 1.

Table 1. Chemical composition of the tailings

S/n	Component	Value (%)
a.	SiO_2	71
b.	Al_2O_3	2.62
c.	Fe(total)	15
d.	TiO_2	0.2
e.	CaO	1.2
f.	MgO	0.3
g.	P	0.08
h	S	0.06
i.	Total Alkali (Na_2O + K_20)	1.2

NIOMP (2001)

The Fe (total) of 15% indicates that a reasonable quantity of iron could still be further extracted as the beneficiation process progresses (Adebimpe and Fatoye, 2021). This shows that the ore retrieval is not complete. Other characteristics of the tailings include; permeability (6.24 x10^{-3} cm/s), porosity (35%), while the specific gravity is 3.58 as presented in Table 2.

Table 2. Some physical properties of the tailings

S/n	Parameter	Value
a.	Permeability(cm/sec)	6.24 x10^{-3}
b.	Porosity (%)	35
c.	Specific Gravity	3.58

Adebimpe and Fatoye (2021)

The value of the specific gravity shows that the iron tailings are capable of being more compact. The specific gravity of the tailings is in agreement with values from most metal mines. The amount of silica and their grain sizes affects the porosity of tailings; this is because finer particle sizes ensure smaller porous spaces.

1.2 Location and geology of the study area

The National Iron Ore Mining Project (NIOMP) is located at Itakpe in Okehi Local Government Area of Kogi State, Nigeria. The iron ore deposit is on the eastern part of Kogi State, ten kilometres north of Okene Township. The company (NIOMP) is located within latitude 8° and 9º and longitude 7º and 8º as shown in Figure 1.

Six main rocks identified on the Itakpe iron ore deposit include granite gneiss, amphibolites, quartzites, schists, granite and pegmatites (Akinrinsola and Adekeye,, 1993). Two types of quartzites were identified in the area; ferruginous and non-ferruginous however, non-ferruginous quartzites are rare on the Itakpe deposit (Akinrinsola and Adekeye,, 1993; Olade, 1978). The Itakpe ridge consists of mainly Precambrian rocks, which are represented by (i) migmatite gneiss complex (which are variably migmatised, undifferentiated gneiss with intercalation of amphibolites) (ii) meta – sedimentary rock series (comprises various schist, gneiss, meta conglomerates) and (iii) older granite series (consist of granitoid rocks of plutonic and metasomatic origin) (Olade, 1978). The principal ore minerals are magnetite and hematite (specularite) with quartz, biotite and hornblende as gangue minerals, the magnetite crystals are coarse-grained and may be replaced by martite at the margins (Olade, 1978).

Olade (2019) listed four major types of iron ore on the Itakpe iron ore deposit: (i) magnetite quartzite (ii) magnetite-hematite quartzite (iii) hematite- magnetite quartzite, and (iv) hematite quartzite. Mucke and Neumann (1986) identified more than 25 iron bearing quartzite layers separated by iron free zones ranging from 1 to 40 meters in thickness. Olade (2019) reported that the deposit comprises of over 25 individual ore-bearing layers or lenses (14 are considered minable) that are inter banded with migmatites, gneisses, amphibolites, schists and orthoquartzite, and intruded in places by granites, pegmatites and aplite as shown in Figure 2.
The classification of the deposit is as follows;
(a) Mineralogical classification which are sub-divided to include Magnetite ore -------- Black streak, Heamatite ore -------- Reddish brown, Magnetite – Heamatite ore ------------ 50% magnetite, Heamatite – Magnetite ore ------------ 50% magnetite
(b) Commercial Classification which are further sub-divided to include Rich ores ------- (45% Fe in about 5% of the mine), Medium ores ------- (31 – 45% Fe in about 82% of the mine), Lean ores or poor grade ores ------- (20 – 30% in about 13% of the mine), Coarse grain, Medium grain, Fine grain (NIOMP, 1979).

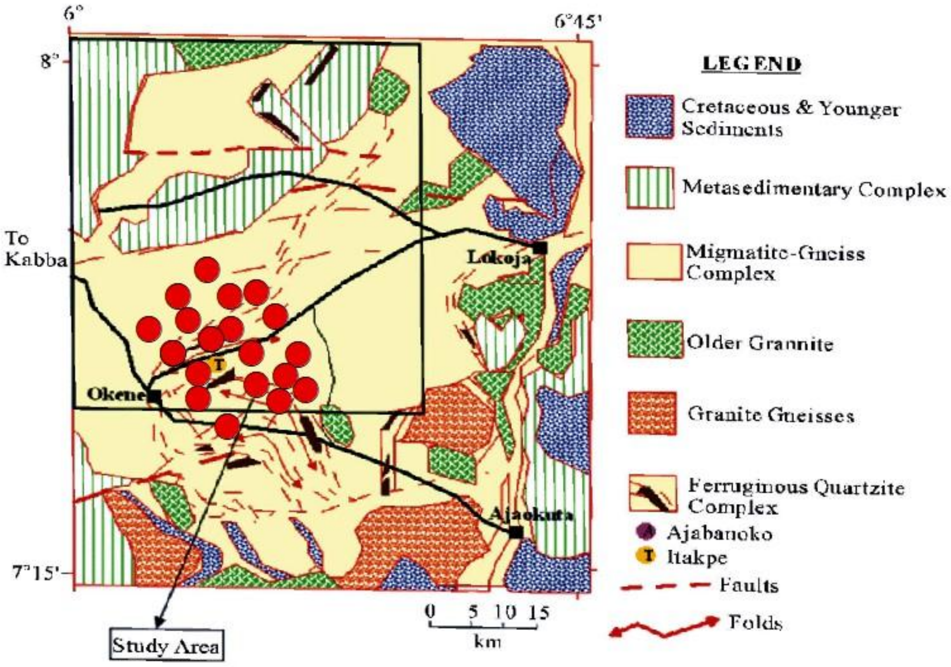


Figure 1. Location and Geologic map of the study area

II. Materials And Methods

2.1 Sample collection and preparation

Samples of iron ore tailings were taken from five different locations within the premises of the Beneficiation Plant of the Itakpe Iron Ore Mine, labeled ITK_1, ITK_2, ITK_3, ITK_4, and ITK_5. Five samples each were collected at the locations at different depths of 10 cm intervals making a total of twenty-five (British Standard 1377, 1990) samples. The samples were kept in polyethylene bags and labeled with respect to the location and depth at which they were taken. Prior to the physical and chemical analyses, the samples were air-dried at 35±2 ^{0}C for 2 weeks, pulverized, homogenized and stored in airtight polyethylene bags.

2.2 Sample Analysis

The <2 mm tailings fraction was used for determination of pH, electrical conductivity (EC), organic matter content (OM), residual humidity, specific gravity, permeability, density, sieve analysis and leaching property analysis. The grain size distribution was determined using the sieving method. The permeability of the tailings was measured using falling head permeability method. Appropriate methods (British Standard 1377, 1990) were used to measure the bulk density, specific gravity and porosity. The Atterberg Limits of the tailings was determined according to the ASTM D4318 (American Society for Testing and Materials, 2010).

Tailings samples were evaluated for pH and electrical conductivity (EC) and was measured by glass electrode pH meter and conductivity meter at ratio (soil: distilled water 1:5) (Zhang, 2013). Organic Matter was determined by wet dichromate acid oxidation method (Umeri et al., 2017). Residual Humidity was determined using appropriate methods as described by Fatoye and Adebayo (2016). Quantitative analysis of the main minerals within the samples was done using X-ray Fluorescence Spectroscopy (Magi X Pro XRF Spectrometer). Morphological, quantitative and qualitative analyses of the tailings samples were carried out using SEM (JEOL 840).

III. Results and Discussion

The basic geotechnical characteristics of the tailings show the wide variation range as shown in Table 3. The pH of all the tailings samples were found to vary from 6.50 to 7.30 indicating slight acidity which may influence the bioavailability and transport of heavy metals in the tailings (Smith, 1996). Residual Humidity content was at equivalent level of 0.42% to 3.15%. Since, residual humidity is proportional to the clay content, tailings with low residual humidity indicated less clay content and vice versa. Organic matter varied widely among the various cultivated tailings horizons selected for the study from 0.65% to 1.24%. It was discovered from research that organic matter could be affected by climate, texture, hydrology, land use and vegetation (Fantappie et al., 2010). The cumulative particle size distribution for the composited tailings (tailings ITK1, ITK2, ITK3, ITK4, and ITK5) is presented in Figure 3. The particle size distribution curve clearly shows that the particle size of all the tailings ranges from coarse sand to coarse silt, with majority of the particles plotting in the medium- and fine-sand field, indicating that these samples are of fine-medium sand. The essence of sieve analysis is to identify the size of the particles which assists in the determination of the physical and mechanical properties.

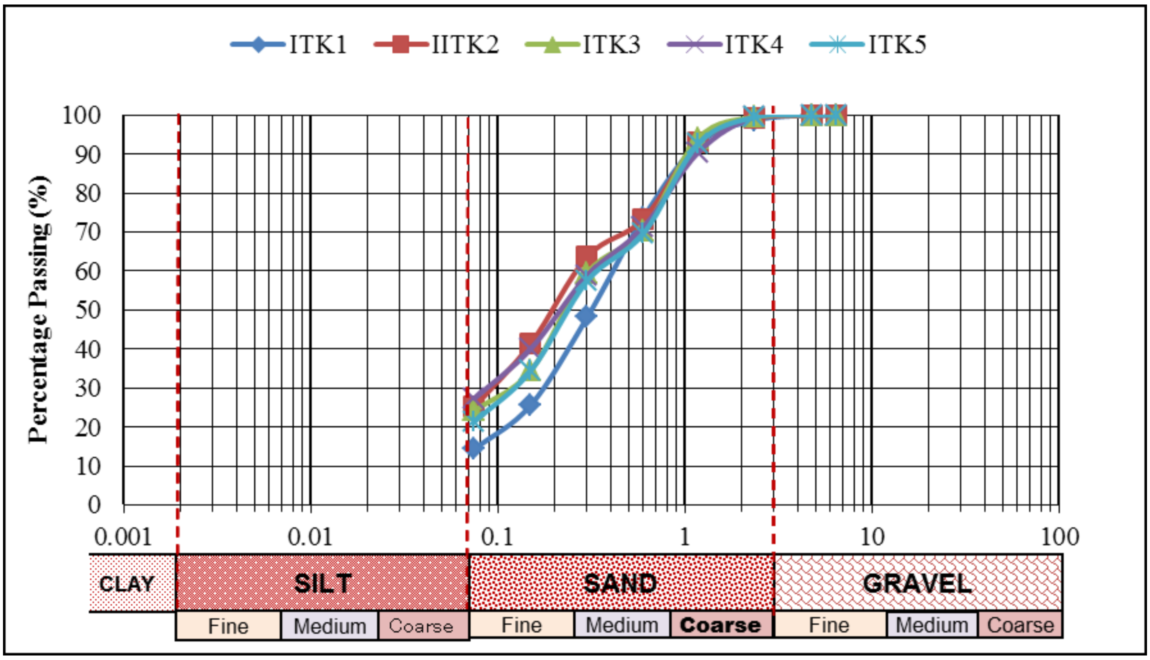


Figure 3: Particle-size distribution of the tailings.

Table 3. Geotechnical characteristics of the tailings

S/n	Tailings	Bulk Density (kg/m^3)	Liquid limit (%)	Organic matter (%)	pH	Residual Humidity
i	ITK1	1970	25.63	1.24	6.5	3.15
ii	ITK2	1910	24.83	0.89	6.5	0.43
iii	ITK3	2000	25.06	0.72	6.8	0.42
iv	ITK4	1900	52.81	0.65	7.3	0.43
v	ITK5	1890	25.5	0.96	7.1	2.52

The bulk density of the tailings varied from 1890 to 2000 kg/m^3. The high bulk density of the tailings is probably due to the high concentration of the Fe. The values obtained for the bulk density of the tailings is consistent with broad range of values for tailings bulk density which is given as 1.8–1.9 t m^{-3} with a specific gravity of 2.6–2.8 (Sarsby, 2000; Bjelkevik, 2005). The liquid limit of the tailings varied from 24.83 to 52.81% and these values are also consistent with Quille and Kelly (2005). The liquid limit of tailings ITK4 is noticeably higher than that of the other tailings.

3.1 Mineralogical properties

The mineralogical composition based on X-ray fluorescence of bulk samples (ITK1, ITK2, ITK3, ITK4 and ITK5) is shown in Table 4. The XRF analysis revealed the presence of 12 major oxides and some traces in all the tailing samples. The major oxides commonly detected in all the samples were; SiO_2, Al_2O_3, Fe_2O_3, P_2O_5, MgO, CaO, TiO_2, K_2O, MnO, La_2O_3 and SO_3. The order of abundance of the major oxides are SiO_2>Fe_2O_3>Al_2O_3 >MgO >K_2O >CaO >P_2O_5 >La_2O_3>MnO > Cl >TiO_2 >SO_3. The most abundant major elements are SiO_2, Fe_2O_3 and Al_2O_3 which indicate the presence of quartz, hematite and alumina (Zhang et al., 2011; Dai et al., 2010). Other major elements such as MgO, K_2O, CaO, P_2O_5, La_2O_3, MnO, Cl, TiO_2 and SO_3 show low concentrations that fall below 2.91%. This is due to leaching during the weathering process and their low concentration in the parents minerals.

The trace quantities detected in tailings samples are CuO, ZnO, Ta_2O_5, WO_3, V_2O_5, Cr_2O_3, CeO_2, As_2O_3, Br, Ga_2O_3, Y_2O_3, SrO and ZrO_2.

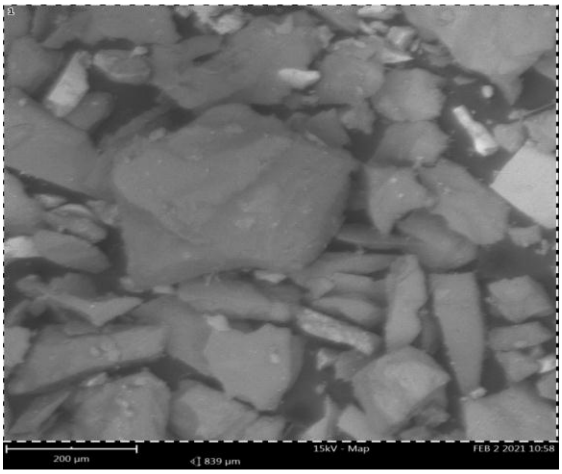
Table 4. The mineralogical properties (%) of tailings samples (n= 25)

OXIDE	ITK1	ITK2	ITK3	ITK4	ITK5
Fe_2O_3	18.70	17.32	19.52	15.03	20.12
MgO	2.91	3.04	2.10	2.15	3.06
Al_2O_3	7.16	7.00	5.63	5.50	5.22
SiO_2	57.27	60.10	59.01	57.26	60.05
P_2O_5	0.37	0.38	0.40	0.36	0.37
SO_3	0.09	0.05	0.03	0.15	0.11
Cl	0.17	0.21	0.25	0.12	0.19
K_2O	1.45	1.37	0.82	0.97	0.81
CaO	0.67	0.63	0.47	0.51	0.49
TiO_2	0.16	0.14	0.15	0.14	0.14
MnO	0.23	0.21	0.19	0.19	0.22
La_2O_3	0.31	0.00	0.23	0.21	0.35

3.2 Morphological, microstructural and micro-elemental properties

EDX-SEM spectroscopy were used to examine surface morphology and microstructure of the tailing samples as presented in the micrographs observed at a magnification of ×2000 (Figures 4-8). The images revealed that the grains in the iron ore tailings appeared compact with irregular shapes and interlocking nature within the crystal aggregates in the ore matrix and minerals. They are separated by coarse grain boundaries that can facilitate their liberation during comminution.

This analysis presents valued observations into the morphological and mineral components of the samples (Sengupta et al., 2008; Nyakuma, 2009). The elements detected were; Si, Fe, K, Al, Y, Ag, Ca, Mg, Zr, Cl, Ti, Nb, S and Na in various quantities. The percentage of all the metallic elements in the tailings support the results obtained in the mineralogical analysis. The Si, Al, Fe, Ca, and O indicate quartz, alumina, kaolinite, wollastonite and limestone respectively. Ferrous content is largely from hematite and magnetite although minerals such as hornblende, kaolinite and chlorite might also contribute to the Fe content. The high aluminum content may be as a result of the presence of aluminous minerals such as kaolinite, hornblende and plagioclase in the iron ore tailings.



Element	Weight Conc. (%)
Si	54.39
Fe	23.71
K	5.28
Al	4.91
Y	2.52
Ag	1.85
Ca	1.37
Mg	1.25
Zr	1.06
Cl	0.87
Ti	0.86
Nb	0.85
S	0.74
Na	0.33

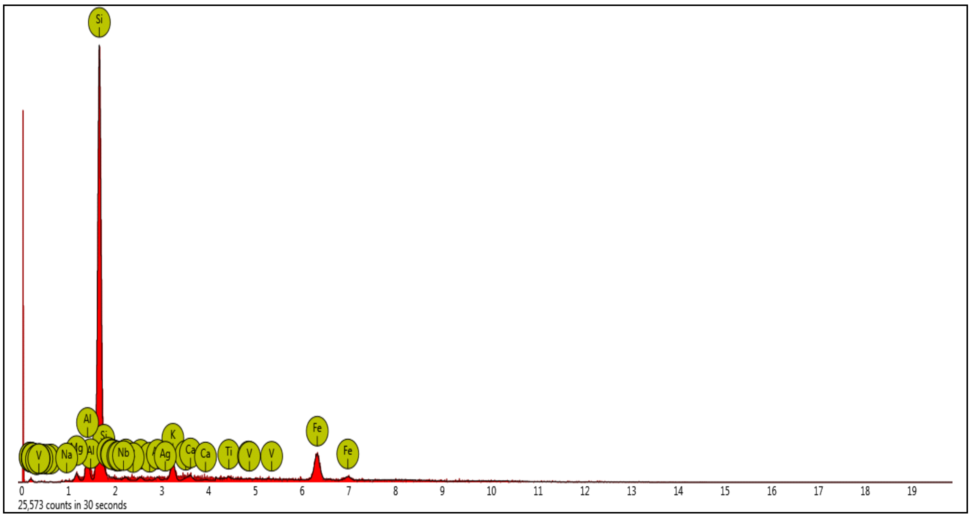
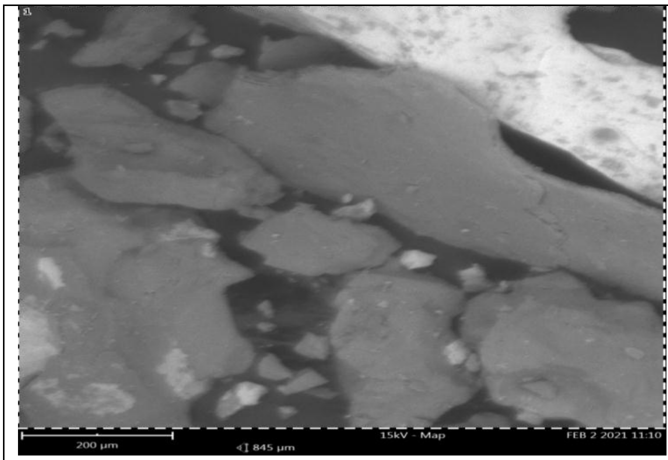


Figure 4: Microprobe image and SEM/EDX Micrographs of **ITK1**



Element	Weight Conc. (%)
Si	33.18
Fe	45.04
K	4.90
Al	1.39
Y	1.55
Ag	1.55
Ca	0.98
Mg	2.34
Zr	1.24
Cl	0.95
Ti	1.32
Nb	0.71
S	0.69
Na	0.23

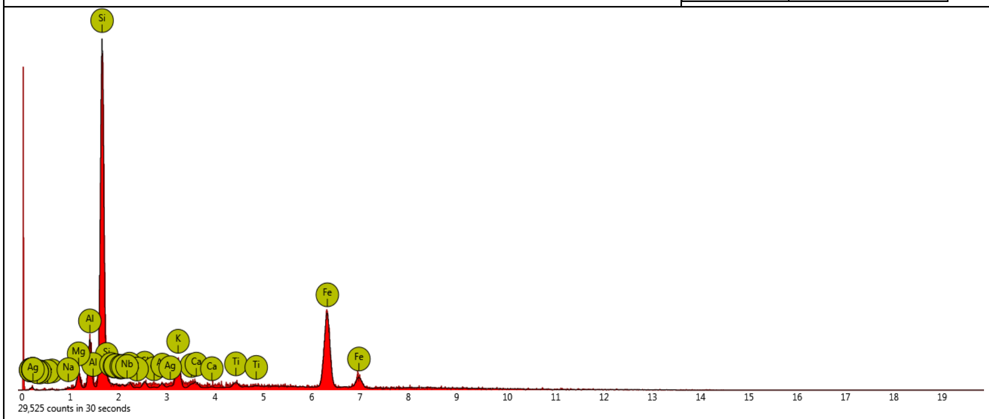
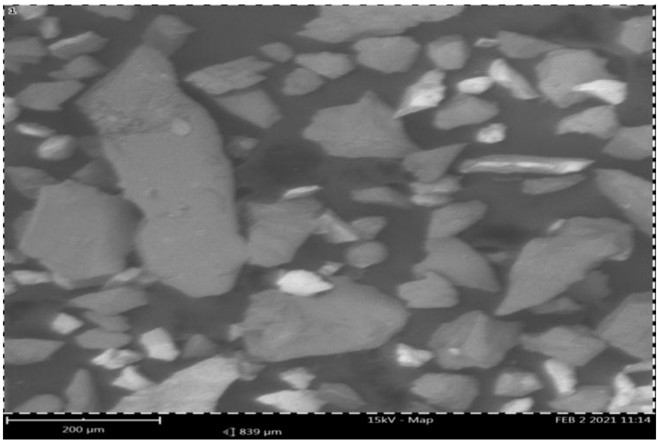


Figure 5: Microprobe image and SEM/EDX Micrographs of **ITK2**



Element	Weight Conc. (%)
Si	41.14
Fe	36.83
K	3.60
Al	4.84
Y	2.08
Ag	3.08
Ca	1.67
Mg	0.83
Zr	1.77
Cl	1.26
Ti	0.00
Nb	1.64
S	0.74
Na	0.53

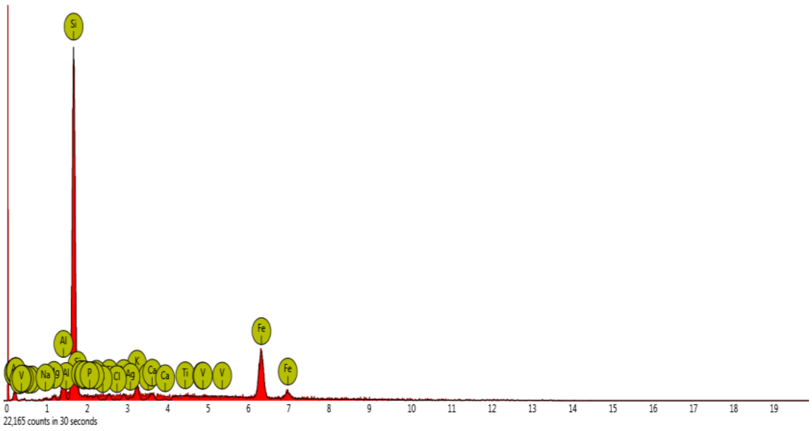
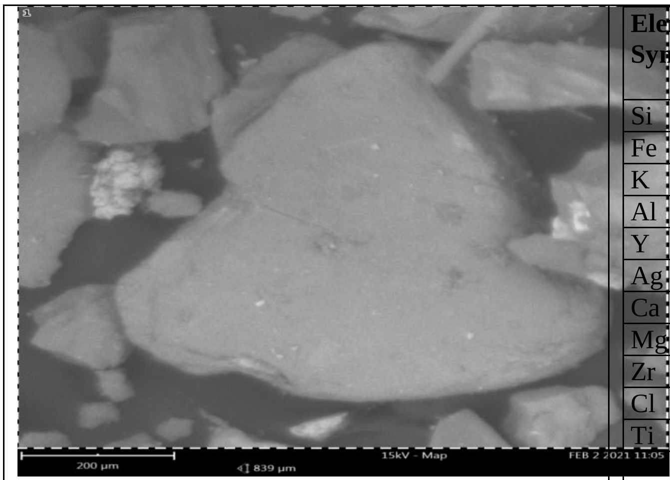


Figure 6: Microprobe image and SEM/EDX Micrographs of **ITK3**



Element Symbol	Weight Conc. (%)
Si	42.54
Fe	26.04
K	2.59
Al	8.33
Y	2.51
Ag	1.81
Ca	3.89
Mg	5.24
Zr	1.53
Cl	0.85
Ti	2.03
[illegible]	1.36
S	0.90
Na	0.38

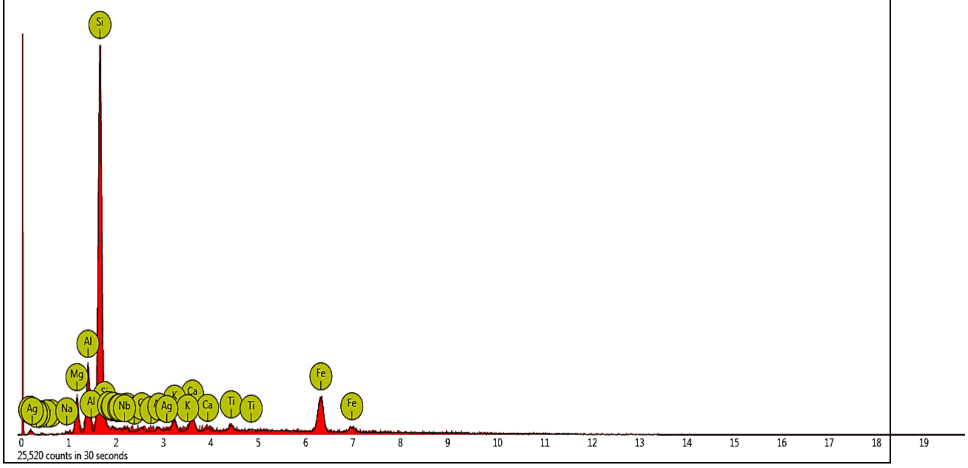
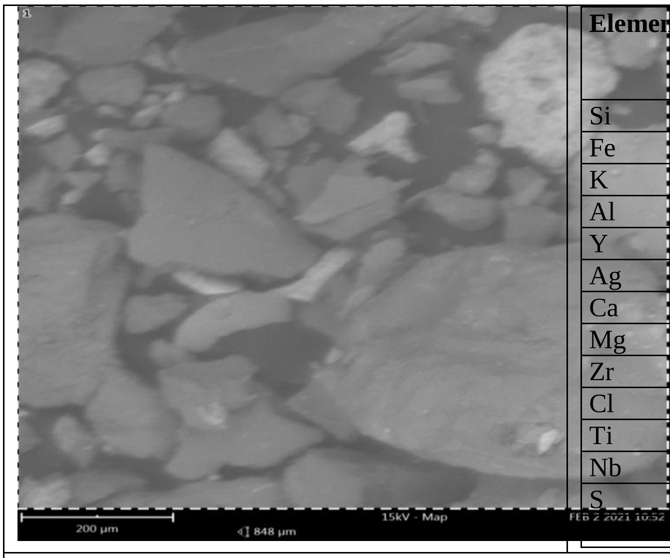


Figure 7: Microprobe image and SEM/EDX Micrographs of **ITK4**



Element	**Weight Conc. (%)**
Si	44.47
Fe	31.81
K	2.89
Al	6.34
Y	2.11
Ag	1.91
Ca	2.27
Mg	1.05
Zr	0.25
Cl	1.04
Ti	0.31
Nb	2.16
S	0.55
	0.49

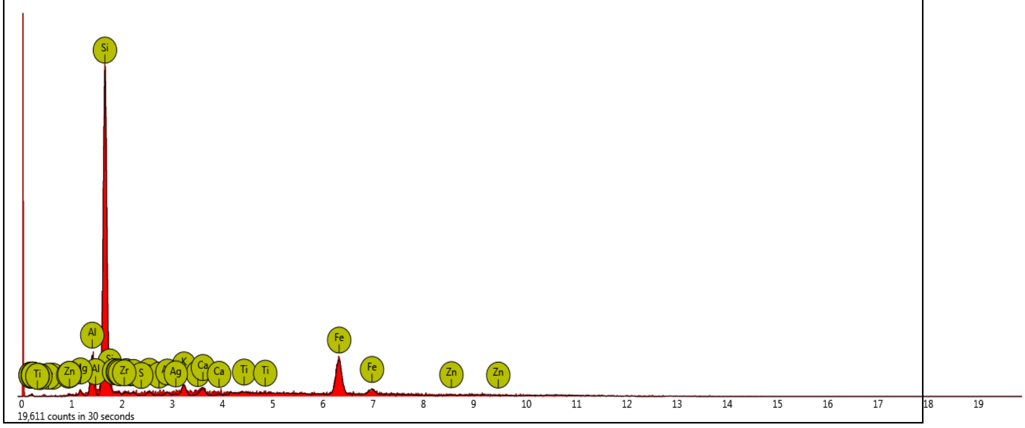


Figure 8: Microprobe image and SEM/EDX Micrographs of **ITK$_5$**

3.3 Leaching Potential

Results of water leaching tests for major cations are shown in Figures 9-16 at different depths. Tailings samples contain low concentration of Ca which varies from 1.50mg/l to 1.90mg/l at a maximum depth of 0.30m. ITK$_4$ at depth 0.00 to 0.10m contain the least amount of Ca in Figure 9 while ITK$_5$ at depth 0.20 to 0.30m contains the highest amount of calcium in Figure 10. Concentration of Pb ranges between 2.10mg/l to 2.32mg/l. ITK$_1$, ITK$_2$ and ITK$_4$ falls within close range while ITK$_3$ and ITK$_5$ falls within the same range and Cr concentration ranges between 0.73mg/l to 0.96mg/l from depth 0.10 to 0.30m respectively as shown in Figure 11. Figures 12 and 13 shows Zn and Cd concentration at less than 5mg/l and varies from 2.30mg/l to 2.88mg/l.

ITK$_1$ ITK$_2$ and ITK$_3$ have similar values at depth of 0.10m to 0.30m and the concentration varies from 2.81mg/l to 4.50mg/l. ITK$_3$ ITK$_4$ ITK$_5$ are of similar range at all depths respectively. Figure 14 shows a high concentration of Fe found in samples ITK$_1$, ITK$_2$ and ITK$_3$ which ranges between 46.60mg/l to 60.50mg/l. Low concentration of Fe in samples ITK$_4$, and ITK$_5$ range from 0.00mg/l to 0.20mg/l. Figure 15 shows that the tailings contain a low level of S concentration which ranges between 1.99mg/l to 2.32mg/l at all depths. Figure 16 shows a high level of concentration of Mn which ranges between 10.20mg/l to 29.60ml/l at all depths.

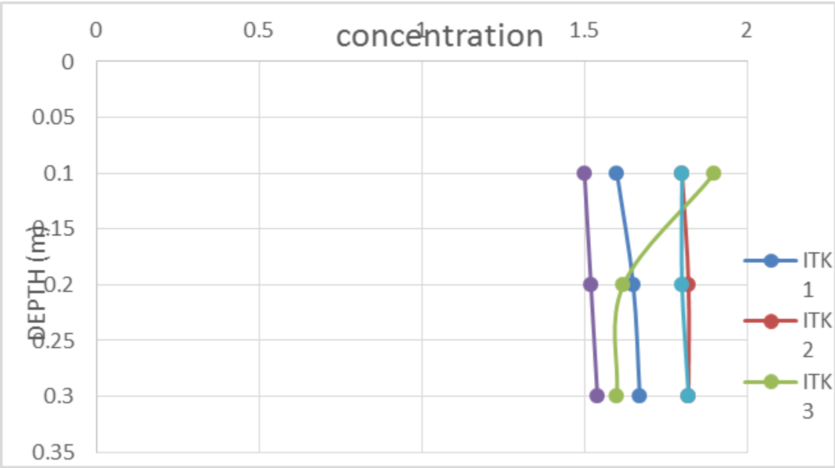


Figure 9: Ca (mg/l)

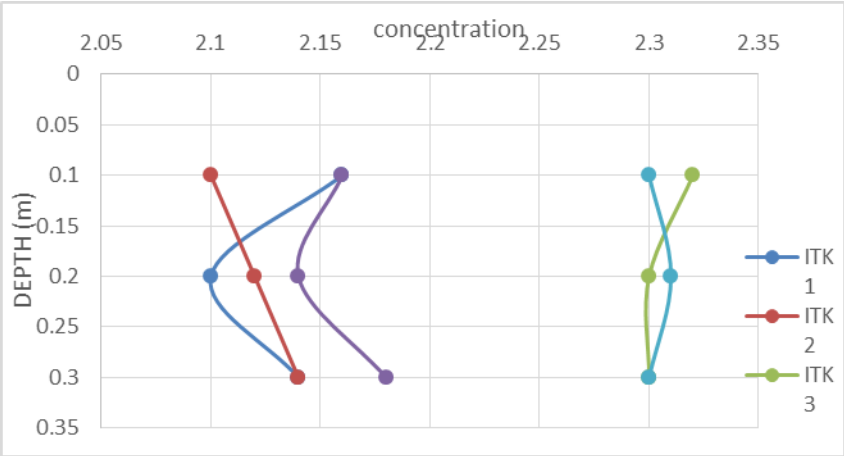


Figure 10: Pb (mg/l)

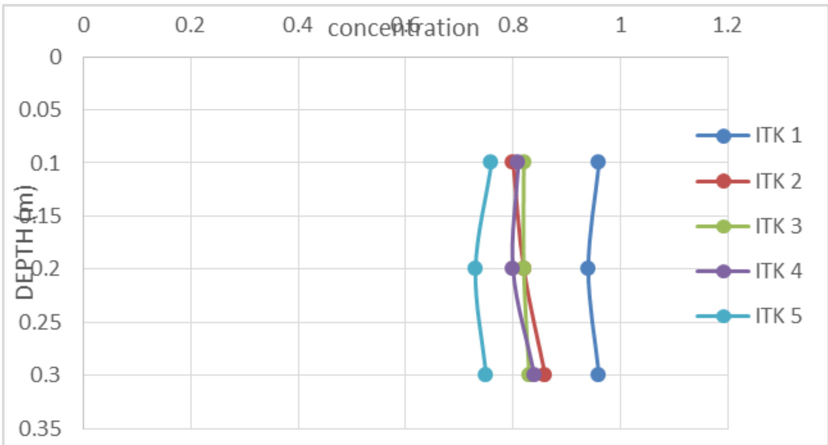


Figure 11: Cr (mg/l)

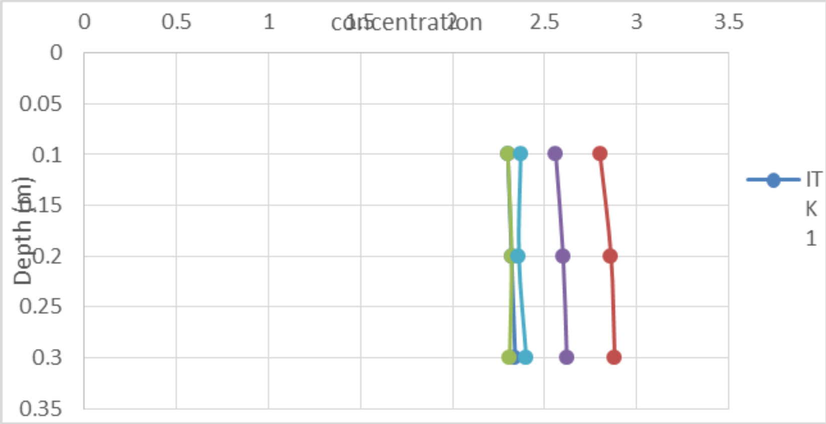


Figure 12: Zn (mg/l)

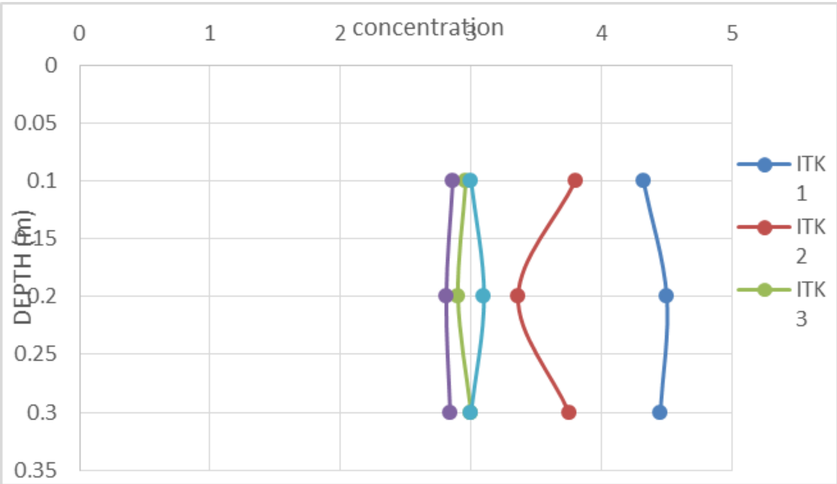


Figure 13: Cd (mg/l)

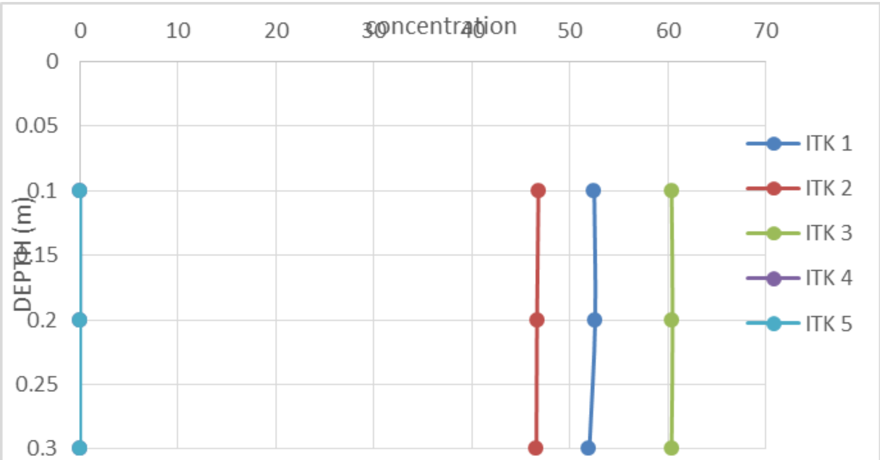


Figure 14: Fe (mg/l)

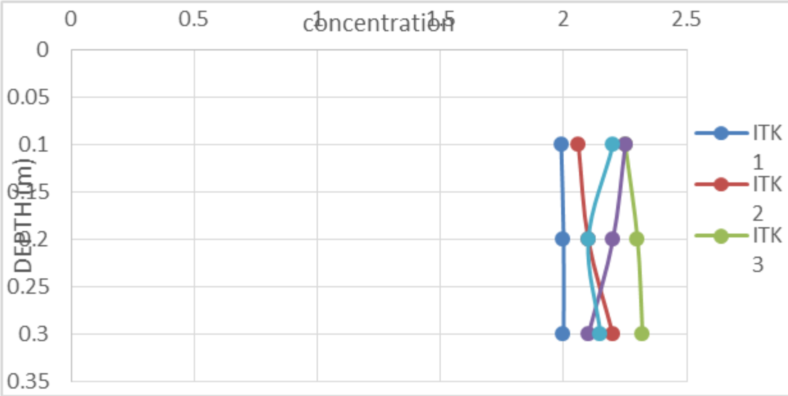


Figure 15: S (mg/l)

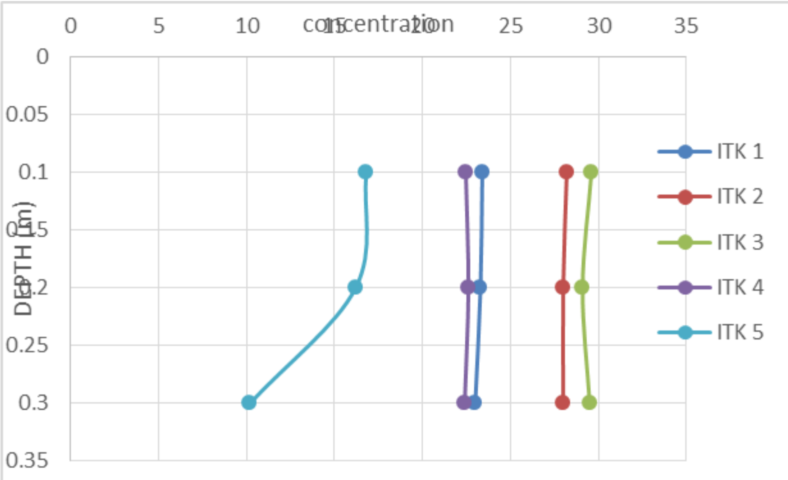


Figure 16: Mn (ppm)

Concentrations of leached metals indicated considerable low presence of Ca, Pb, Cr, Zn and Cd as shown in Figures 17- 21. Figures 17-18 shows higher concentration of Fe and Mn at depth of 0.10m to 0.30m in ITK_{1-3} while Figure 19 have high concentration of ferrous and manganese at all depths. Figures 20 and 21 show that high concentration of manganese is present in ITK_4 and ITK_5 at all depths respectively.

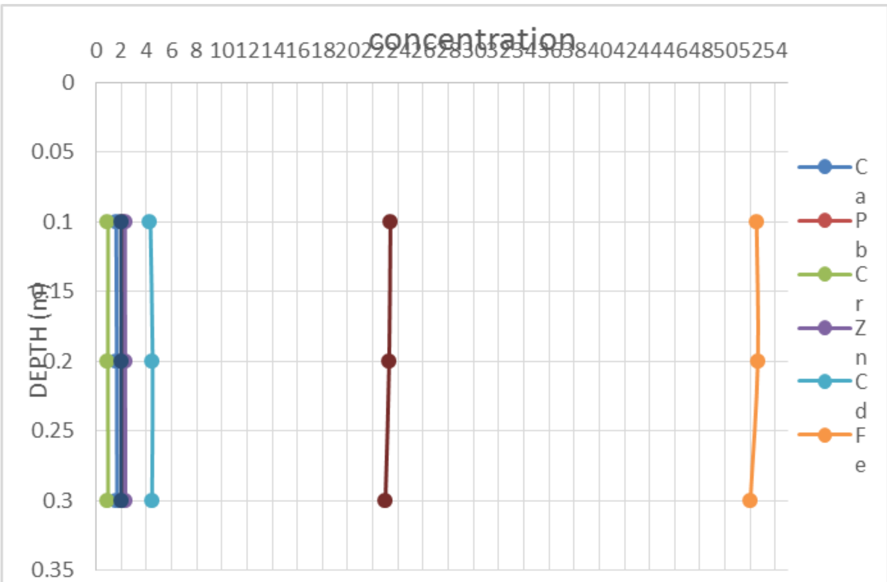


Figure 17: ITK_1

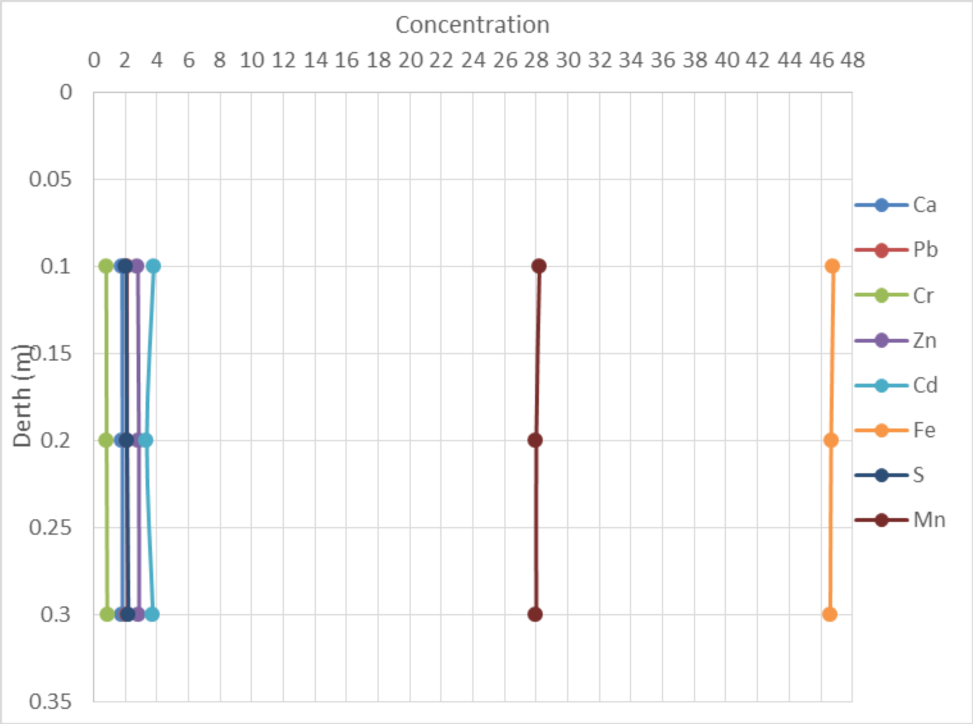


Figure 18: ITK_2

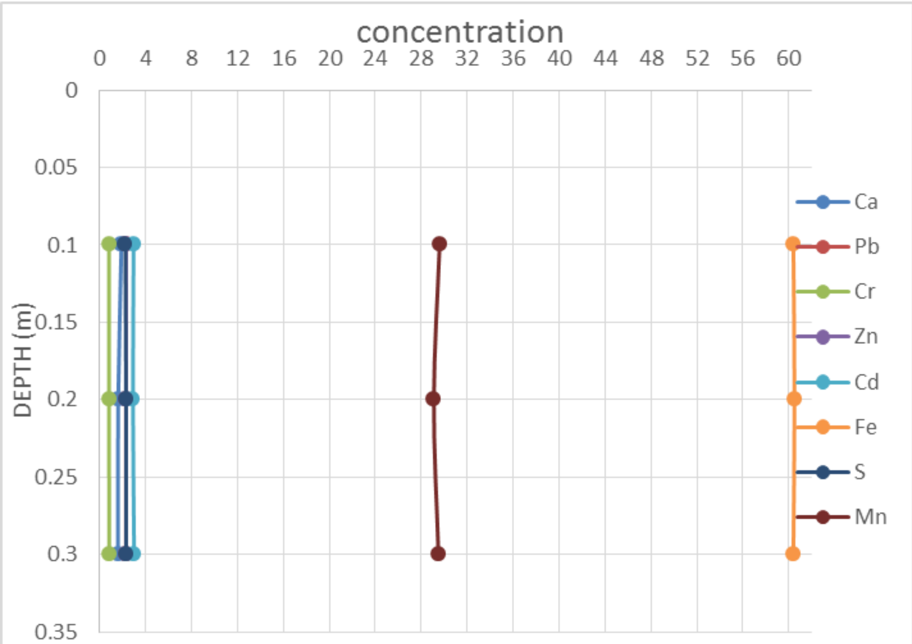


Figure 19: ITK_3

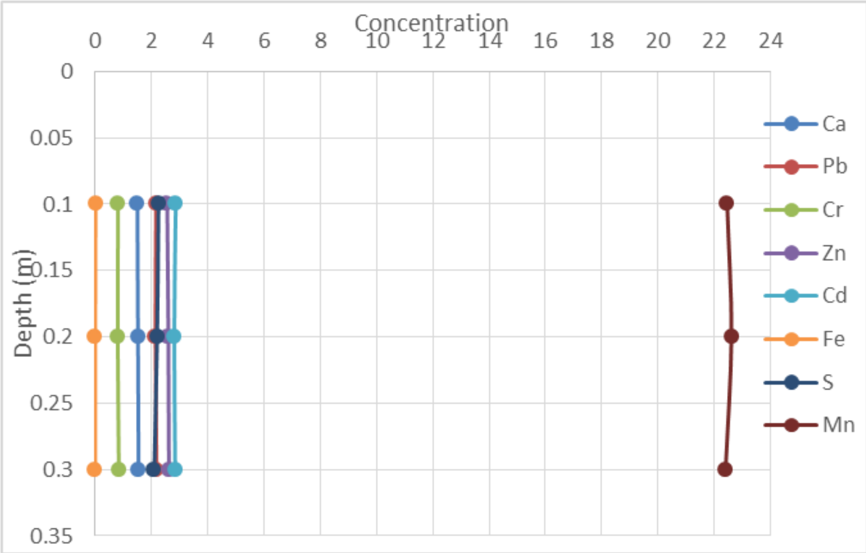


Figure 20: ITK_4

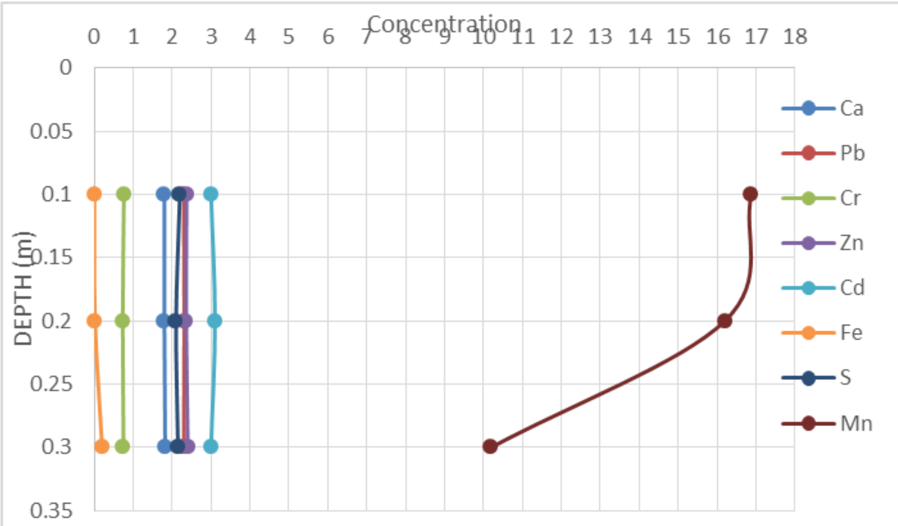


Figure 21. ITK_5

3.4 Statistical Analysis of EDX Results

Table 5: Descriptive statistics on the variables

ITK_1	ITK_2	ITK_3	ITK_4	ITK_5
Min. : 0.090	Min. : 0.0000	Min. : 0.030	Min. : 0.120	Min. : 0.1100
1st Qu.: 0.215	1st Qu.: 0.1925	1st Qu.: 0.220	1st Qu.: 0.180	1st Qu.: 0.2125
Median : 0.520	Median : 0.5050	Median : 0.435	Median : 0.435	Median : 0.4300
Mean : 7.457	Mean : 7.5375	Mean : 7.400	Mean : 6.883	Mean : 7.5942
3rd Qu.: 3.973	3rd Qu.: 4.0300	3rd Qu.: 2.982	3rd Qu.: 2.987	3rd Qu.: 3.6000
Max. :57.270	Max. :60.1000	Max. :59.010	Max. :57.260	Max. :60.0500

The descriptive statistics in Table5 summarize key characteristics of five variables: ITK_1, ITK_2, ITK_3, ITK_4, and ITK_5. These statistics offer valuable insights into the distribution and central tendency of each variable. For instance, ITK_1 has a wide range, from a minimum of 0.090 to a maximum of 57.270, with a relatively high mean of 7.457, suggesting potential outliers or extreme values. In contrast, ITK_2 starts at 0.0000 but also exhibits a broad range up to 60.1000, with a mean of 7.5375. ITK_3, ITK_4, and ITK_5 follow similar patterns of variability, each with a relatively high mean. The quartile values indicate that these variables have a substantial spread.

ITK1 and ITK_2 have notably larger maximum values than the other variables, potentially indicating significant variations in these components. Conversely, ITK_4 appears to have a lower mean and smaller spread than the others, suggesting more consistency in this variable. Overall, these statistics provide a foundational understanding of the distribution and central tendencies of the mineralogical properties represented by these variables, which can inform further data analysis and interpretation.

Table 6: Correlation matrix

	ITK1	ITK2	ITK3	ITK4	ITK5
ITK1	1.0000	0.9993	0.9995	0.9979	0.9992
ITK2	0.9993	1.0000	0.9987	0.9995	0.9983
ITK3	0.9995	0.9987	1.0000	0.9977	0.9998
ITK4	0.9979	0.9995	0.9977	1.0000	0.9973
ITK5	0.9992	0.9983	0.9998	0.9973	1.0000

The correlation matrix shows the pairwise correlations between five variables: ITK_1, ITK_2, ITK_3, ITK_4, and ITK5 (Table 6). Correlation values range from -1 to 1, with -1 indicating a perfect negative correlation, 1 indicating a perfect positive correlation, and 0 indicating no linear correlation. Here's a summary of the correlation matrix:

The variables ITK_1, ITK_2, ITK_3, ITK_4, and ITK_5 exhibit very high positive correlations among each other, as indicated by correlation coefficients close to 1. This suggests a strong linear relationship between these variables. In particular, the correlation coefficients range from approximately 0.9973 to 1.0000, implying that changes in one variable are almost perfectly mirrored by changes in the others. Such high correlations indicate that these mineralogical properties move together, and their variations are strongly interrelated

IV. Conclusions and Recommendation

The chemical characterization of the tailings revealed the presence of relatively high concentration of Fe, which indicates that the iron recovery is incomplete. The physical characteristics of these tailings includes; fine to medium sand-sized particles, high specific gravity and density, low residual humidity and organic matter which makes them applicable in a wide range of geotechnical projects such as dams and ceramic composites. Iron ore tailings contains high concentration of ferrous and manganese at all depths.

The EDX- SEM results indicate the presence of quartz, alumina, hematite, ilmenite, rutile, gypsum and mica. The minerals identified are economically viable and can increase government earnings. The leaching result shows concentration of heavy metals in the tailings, which may affect water and farming when released into the environment and have higher possibility of entering food chain through plants and crops. The beneficiation process currently used at the iron ore mine at Itakpe needs to be improved upon in order to increase the iron recovery from the ore.

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