Mineralogical Characterization of Tailings, Blue-Dust and Waste Rocks Engendered From Fe Mines in India and Liberia and Their Environmental Consequences

Adolphus M.G.D. Gleekia[1], Augustus S. Moore[2], Himanshu B. Sahu[3],

[1]Senior Lecturer/Chair Department of Mining Engineering, College of Engineering, University of Liberia, West Africa, e-mail: *adolphusgkia@gmail.com*; Ph. No.: +231777081149,

[2]Professor/Dean College of Engineering, University of Liberia, West Africa, [3]Associate Professor, Department of Mining Engineering, National Institute of Technology (NIT) Rourkela, Odisha, Inadia;

Abstract

The upsurge of heavy metals in the environment as a result of mining, processing and smelting activities is one of the many challenges being faced by the mining industry worldwide. Water quality results from iron mines in recent years have revealed the presence of harmful heavy metals viz. Si, Hg, Pb, Cu, Zn, Ni, Cr, As, Se, Br, Mo, Co, Al, Ba, Cd, etc. that are of environmental concern. Some of which occur above the acceptable permissible limits in surface and ground water. In recent years very little attention has been placed on the environmental impact of iron ore mining across the globe in terms of environmental pollution due to heavy metals compare to mines extracting mineral such as Uranium, Chromium, Gold, Lead, etc. Surface runoff, effluent, leachates, and airborne particulates, normally result from tailings storage facility (TSF), waste rock dumps (WRD), Ore processing facilities (OPF) and haul roads significantly trigger soil, surface and groundwater bodies, ambient air quality contamination within the mining region and may extend further downstream from the mine workings. Tailings containing unwanted minerals and chemicals are discarded and contained in TSF as a slurry during ore processing operation intended to yield concentrates of the valuable minerals. The particle sizes of slurry are predominant silt to fine sand size (1*u*m - 1mm). Waste rocks (the wall rocks or overburden materials that must be mined or removed to gain access to and mine the ore body), have particle sizes ranging from silt to boulder size fragments and are often disposed of in large piles in waste rocks dumps at an economic distance in proximity to mine. Mechanical and wind-blown actions engender airborne particulates from WRD and TSF thereby degrading the ambient air quality. Respiratory illnesses to persons exposed without the required PPEs may result due to the concentration and constituent of the airborne particulates. The current paper, the mineralogical constituents of solid iron ore mines derived wastes of India and Liberia are investigated to by Scanning Electron Microscope (SEM) and Energy Dispersive Spectroscopy (EDS) analyses to predict their potential environmental impact. Findings from the analyses revealed harmful heavy metals and others chemical constituents viz. Pb, Ni, Cr, Cd, Hg, Cu, Zn, As, Se, Br, Mo, Co, Al, Ba, Si, Sr, etc. samples from both mining regions. The environmental consequences of these pollutants on the environment and suggestions for mitigation have been presented.

Keywords: Iron Ore Mining; Overburden; Tailings; Waste Rocks; Heavy Metal Pollution, India and Liberia

1.0 Introduction

Iron ores from which metallic iron is economically extracted is being mined for the past three thousand years from vast reserves in chemical and classic rocks [1]. It is a metal of global significance and serves as the bedrock of modern civilization. It is the primary ingredient for steel making and the fourth most abundant mineral in the earth's crust. Iron ores are rocks from which metallic iron can extracted in an economically feasible manner, usually occur as hematite (Fe_2O_3) and magnetite (Fe_3O_4). The mining method for extraction of iron ore is predominantly open pit or opencast, since the deposits are normally massive and occur near the surface. However, opencast mines these days are highly mechanized and require removal of substantial amount of vegetation and a large volume of overburden (OB). The extraction of iron ore has adverse consequences on the environment, since it can cause air, water and soil pollution. Nuss and Eckelman **[3]** studied extensively the environmental impact of metals production (mining) in connection with 63 metals in 2008 and found iron ore and aluminum as the metals with the largest environmental impacts on a global scale. Iron ore mining by opencast method normally gives rise to massive erosion, formation of sinkholes, loss of biodiversity, pollution of surface and ground water bodies by the runoff from overburden dumps and tailing ponds and sometimes also release a variety of metals [4,5]. The inhalation of iron ore dust and associated constituents during mining may result in siderosis or welder's lung, silicosis, pneumoconiosis, etc. and may catalyzes radicals that are injurious to biological molecules, cell, tissues, and organisms. Severe overload of iron in water due to mining is detrimental to life, while protracted overload may lead to slow or lethal damage to major organs like heart and liver of organism [9]. Iron ore tailings consist of a number of harmful trace elements viz. Pb, Se, Mn, As, Cu, Ni, Cr. Hg, etc., that may get leach when acid mine runoff is introduced and contaminate water bodies and biodiversity in the mine lease area (MLA) and adjoining environs depending on their concentrations in the generated leachate **[10-12].** Most of the past research studies are confined to individual mines or small areas. In contrast, most of the iron ore mines occur in clusters. There is limited literature available regarding the environmental impacts due to iron ore mining across distinctly different mining regions. In this research work therefore, an attempt has been made to scrutinize the environmental impact of wastes generated from iron ore mining activities on the environment in two prominent iron ore mining regions in two different countries viz. India and Liberia.

1.1 Status of Ore Mining In India and Liberia

India is ranked in 5th position among countries with world highest iron ore reserves after Australia, Brazil, Russia, and China; and 4th in terms of iron ore production after China, Australia, and Brazil. The total in-situ reserves of iron ore in India are about 12,317.3 million tonnes of hematite (Fe_2O_3) and 5395.2 million tonnes of magnetite (Fe_3O_4) [13]. Indian haematite deposits are of pre-Cambrian iron ore series and occur within the banded iron formation (BIF) in massive, friable, laminated and powdery forms. The State Jharkhand, Odisha, Chhattisgarh, Karnataka and Goa host the major deposits of Indian BIF.

Liberia, on the other hand, is a West African nation with major iron ore reserves with reserves of iron ore ranging from 4 to 6.5 billion tonnes with the grade ranging from 30-70% Fe. It is perhaps larger or equal to those of South Africa. The iron ore deposits of Liberia are hosted in Precambrian banded iron formation comparable to those found in Brazil, Australia, India and North America. During the late 1970s and early 1980s, Liberia and India accounted for 6% of world export of Iron ore [14**]**. The mining sector has contributed immensely to the economy of Liberia and is of the major source of revenue generation and job creation. It is worth mentioning that the first iron ore mining concession was concluded at the end of world war one (1945) to mine the high-grade iron ore deposit of Bomi Hills situated in Bomi County, Liberia. The concession agreement between the Government of Liberia (GOL) and the Liberian Mining Company (LMC) had a term of 80 years with exclusive exploration rights in approximately 3 million acres of land. LMC started mining Bomi Hills Iron Ore Deposit in 1951 and the deposit was depleted by 1977. The total worth of iron shipped during the mine's life (27 years) amounted to $540 million USD and the GOL received about 16% of the amount in royalty and other taxes **[15]**.

1.2 Study Area

Koira Joda mining area (KJMA) is situated in Keonjhar and Sundargarh districts in the state of Odisha, India. This region is host to over 73 open pit iron ore mines. Of these, only 23 were operational during the course of the study, while the rest were shut down due to non-compliance with environmental regulations prescribed by the State and Central Pollution Control Boards. Iron ores mined from the region serve as major source of raw materials for steel plants operating within Odisha and in the neighbouring states. KJMA has a long-standing history of iron ore mining which started in the early 1960s and has continued up-to-date. The study area can be found within latitude 21° 52' 48" and 21° 53' 58" N and longitude 85° 08' 37" and 85° 17' 22" E. The ore body is composed of banded hematite-quartzite (BHQ) series of iron ore. The predominant rock types associated with the ore body are band of quartz-jasper and hematite, from which silica was leached out leading to the formation of ore bodies by secondary deposit (iron oxide and hydroxides). These rocks types can be summarized as shale, limestone, sandstone, granite, epidiorite, BHQ, upper shale, lower shale, lava. The iron ore deposit has a variable thickness in range from 21m to 180m while the Overburden (OB) thickness range from 0 to 40m. A map of the study area showing various sampling sites and the ore body in the three mining lease areas of the public sector steel company, viz. Steel Authority India Ltd. (SAIL) in KJMA is presented in Figure 1. The footprint of one of the Iron Ore mine of this area is presented in Figure 2.

Nowadays, there is a proliferation of mining companies within Liberia mining industry, which comprises of three main sectors, viz. (i) Class A Mining Sector, which requires full mechanization of mines and a Mineral Development Agreement (MDA) between GOL and the Investors or company prior to the grant of a Class A Mining License; (ii) Class B Mining Sector, which requires semi-mechanization of mines and a Memorandum of Understanding (MOU) with local communities to be affected by the mining operation; and (iii) Class C

Mining Sector, which requires small scale or artisanal mining operation meant to empower Liberian citizens only, and is done predominantly on a small scale using handheld mining equipment such as shovel, digger, sluice boxes, etc. Previous iron ore mining activities left behind negative footprints on the environment some of which include (i) the Blue Lake of Bomi County-contaminated with Pb and other heavy metals (due LMC operation); and (ii) the Red Creek of Grand Cape Mount – contaminated with iron and other heavy metals.

Fig. 1: Map of BIM situated in KJMA showing three consecutive iron ore deposits within MLA of SAIL. From left to right - (a) Barsua, (b) Taldith (middle-section), and (c) Kalta iron ore mines

Fig. 2: Footprints of an Iron Ore Mining on the Environment in KJMA.

The iron ore mining operations in Liberia is done on a fully mechanized basis by multinational companies. China Union Iron Ore Mine (CUIOM) is situated in Bong and Margibi Counties in the Republic of Liberia. Mining in this region started in 1951 and has since continued till date. Owing to its mining history and high level of mechanization, there are over eight abandoned open pits, five wastes dumps and three TFS within the mine lease area (MLA). The iron ore deposit at CUIOM has the strike direction of N-E 75° and extends 35 Km along the Bong Range about 422 meters above main sea level in terms of elevation. The south-western portion of the deposit is 78 Km in length and lies between latitude 10° 22’ 11” and 10° 13’ 38” N and longitude 6° 48’ 0” and

6° 48' 0" E. The average annual precipitation is approximately 3000 mm. The mine is situated in an undulating terrain, low in the west and high in the east with elevation ranging from 150 to 422 meters above MSL. The MLA contains cover 29 towns with several cultural sites and forests. Towns that were in proximity to active mine pit, mineral processing facility, explosive magazine, etc. were relocated prior to mining, thus causing the inhabitants to vacate the inhabited from their ancestors. The MLA of the company is 613.19 km^2 with total production capacity of 25,140,000 ton per annual (t/a) or 76,182 tons per day (t/d). The ore grade is 35.48% Fe with a cut-off grade of 20.52% Fe. The mineral processing plant (MPP) has a capacity of 76,182 t/d. A combination of magnetic and gravity separations methods are used to yield a concentrate of 65% Fe [16]. An estimated 414,514,000 tons of tailings are expected to be generated during the mine's life, but the current capacity of the tailings storage facility 328, 980,000 m^3. The heap buck density of the tailings in 1.4 t/m^3, while the run of mines (ROM) contains a high level of Silica (SiO_2). ArcelorMittal Liberia Ltd (AML) iron ore mining company, CUIOM (mining, but tentatively closed due to fall in iron ore price on the world market), Severstal/Putu Iron Ore Mining Inc. (obtained mining license), Sesa Sterlite Iron Ore Mining Company (feasibility stage), etc., are the multinational iron ore mining companies currently operating in Liberia. The map showing the mining concession area, abandoned and active pits, OB dumps, tailing storage facilty and major mining facilities of CUIOM is presented in Figure 3.

Fig. 3: Map of CUIOM showing sampling sites, abandoned mine pits, ob dump, and TSF and major mine facilities.

2.0 Sampling and Analysis

In order to obtain representative samples of iron ore mine wastes, sampling was carried out in both the mining regions in 2016. These samples gathered represented the environment and adjoining conditions due to mining and allied activities. The concentration of pollutants found in sample taken after laboratory analysis is thus similar to that of the mine environment. Overburden (OB), tailings, and blue-dust samples were collected from different mine locations that results from mining and allied activities. All samples were collected and handled carefully according to standard protocols to avoid any significant changes taking place during sampling and prior to laboratory analysis. The samples were stored in the Water Quality Analysis laboratory at the Department of Mining Engineering, National Institute of Technology Rourkela, India. In the laboratory, the samples were stored in proper preserving conditions so as to obtain accurate results.

.

The location and details of all samples collected in both mining regions are presented in table 1. Samples gathered from CUIOM were placed in polythene sampling bags and couriered to National Institute of

Technology (NIT), Rourkela India for analysis. All analyses were carried out in the Scanning Electron Microscopy / Energy Dispersive X-Ray Spectroscopy (SEM-EDS) Laboratory of the Department of Metallurgical and Materials Engineering of NIT Rourkela, India.

Table 1: Details and location of all samples analysed.

Sl No.	Sample Description	Sample Id	Location	Coordinates	
India					
1	Overburden # 8 (active)	OB8	KJMA	21°51´54.16´´N	85°8´45.98´´E
2	Overburden#3East (closed)	OB3E	KJMA	21°52´3.87´´N	85°8´58.51´´E
3	Tailings	TI	KJMA	21°15´31.90´´N	85°8´3.10´´E
3	Blue-dust	BD	KJMA	21°52´11.70´´N	85°8´52.58´´E
Liberia					
1	Overburden (active)	OB	CUIOM	6°49´17.63´´N	10°17´6.45’’W
2	Tailings (active)	OB	CUIOM	6°48´28.18´´N	10°16´32.72”W

Figure 4 presents photographic views of the sample locations **(a)** overburden dump number 8 (OB8); **(b)** overburden dump number 3 East (OB3E); **(c)** blue-dust (BD) – a powdery iron ore found in ob and contain predominantly of Cr, Co, Si, Al, Ni, Hg, Pb, Ba, and Br, does not meet processing requirements thus is mined along with ob and transported to the waste dump, and (d) TSF of an iron ore mine KJMA.

Fig. 4a: OB8 dump (active) from which OB8 sample was taken in India.

Fig. 4b: OB3E dump (abandoned) from which OB3E sample was taken in India

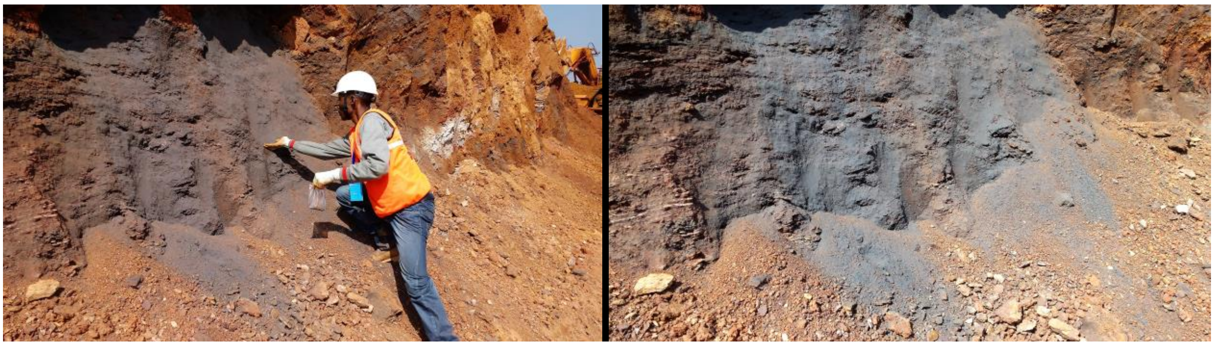


Fig. 4c: Blue-dust with OB being collected in-situ at one of the iron ore mines in India.

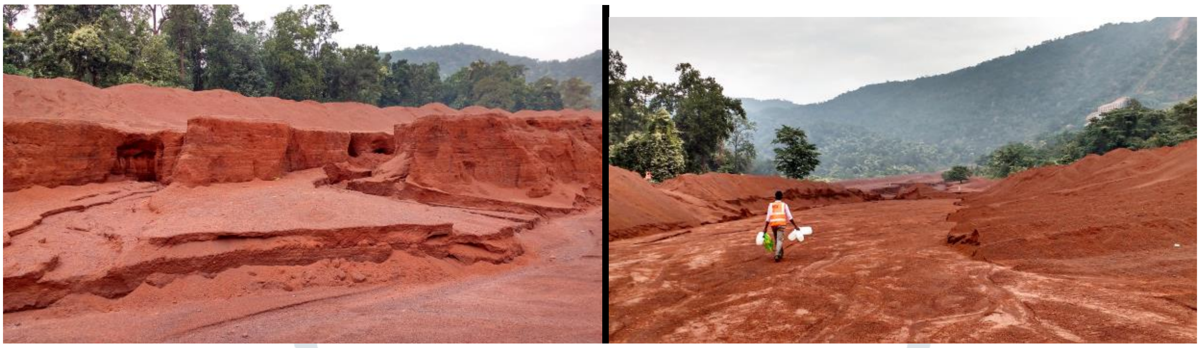


Fig. 4d: Sampling site of TSF of one of the iron ore mines in India.

The locations of OB and tailings sampling sites in Liberia are presented in Figure 5a and b respectively.

Fig. 5a: OB dump of CUIOM from which OB was sample was taken in Liberia.

Fig. 5b: TSF of CUIOM from which tailings sample was collected in Liberia.

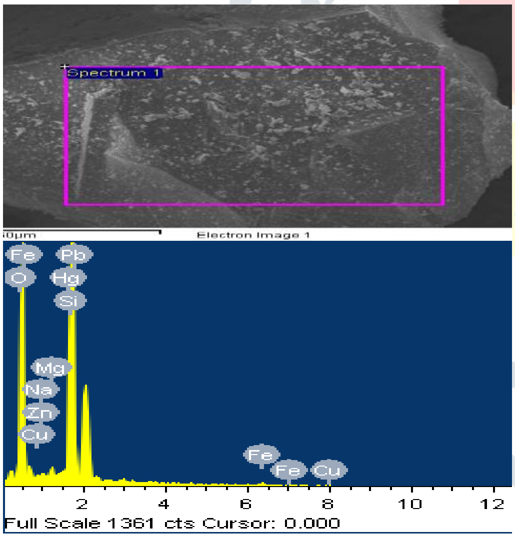
3.0 RESULTS AND DISCUSSION

3.1 Results

3.1.1 Mineralogical Characterization

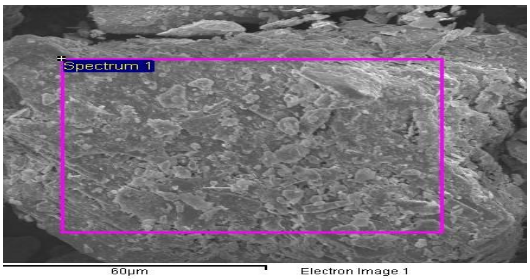
Scanning Electron Microscopy (SEM) utilizes an engaged light emission vitality electrons to create an assortment of signals at the surface of solid samples. The signals that are derived from the electron and the sample's interactions disclose data about the specimen including outer morphology (surface), chemical configuration, and crystalline structure and orientations of constituents of the samples. During analysis, data are gathered over a chose region of the sample's surface and a 2-dimensional images are captured as per the analyst interest spatial varieties from diverse regions of sample being analysed. A range of area from about 1 cm to 5µm in width can be imaged on the sample in scanning mode utilizing routine SEM methods, with amplification ranging from 20X to 30,000X and spatial resolution of 50 to 100 nm or more depending of the types being used. The sample region evaluated with SEM Analysis are analyzed to determine the specific elements that comprise the sample region by utilizing Energy Dispersion Spectroscopy (EDS). X-rays are also released from the surface of the sample that carry a unique energy signature that are specific to elements found in the sample. These X-rays are detected with the EDS detector to give elemental information about the sample. EDS provides data about the chemical composition of the sample and provides additional data about the features that are observed in the SEM micrographs. This combined technique is referred to as SEM-EDS or SEM-EDX Analysis. During the analyses, samples were placed in the evaluation chamber of the SEM-EDS apparatus one after another and scanned by means of an electron beam in a pattern known as a controlled raster. Association of the electron beam with the sample created a range of physical sensations that were utilized to frame pictures and give basic data about the sample.

The SEM-EDS results of the mineralogical characterization of tailings, OBs, and blue-dust of CUIOM and KJMA have been presented in Fig. 6 to 11. The rectangular section on each image represents the area analysed during EDS analysis and elements found after each analysis are presented in table at the right, while EDS generated graph (spectrum) of each sample analysed is presented at the bottom of each SEM image.

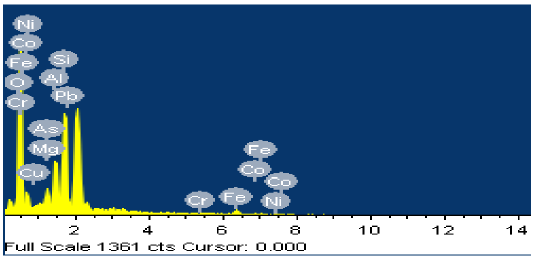


Element	Weight (%)
O	54.26
Na	0.29
Mg	0.67
Si	27.04
Fe	15.94
Cu	0.17
Zn	0.03
Hg	0.20
Pb	1.40
Totals	**100.00**

Fig. 6: SEM-EDS result of CUIOM tailings sample analysed.

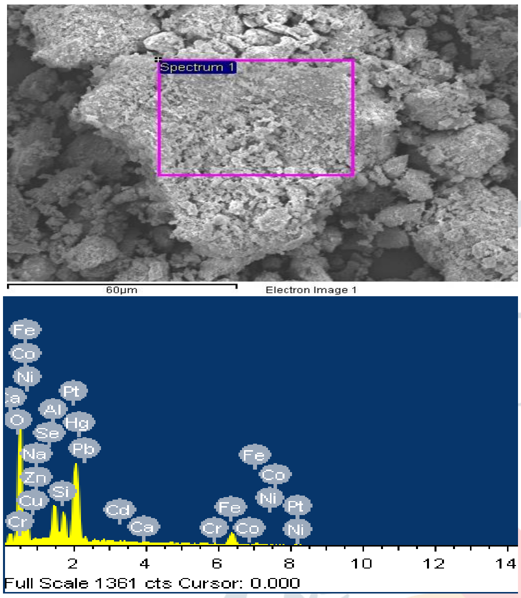


Element	Weight (%)
O	35.05
Mg	1.68
Al	4.04
Si	10.03
Cr	16.40
Fe	24.32
Co	4.68
Ni	1.85



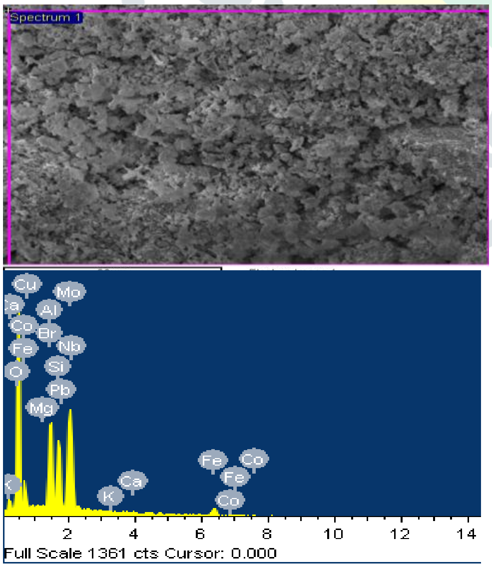
Cu	0.97
As	0.33
Pb	0.64
Totals	**100.00**

Fig. 7: SEM-EDS result of CUIOM OB sample analysed.



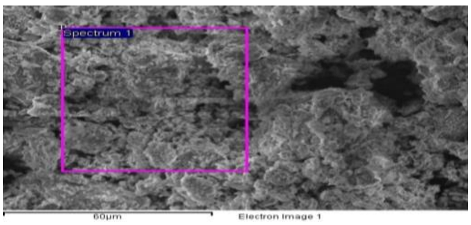
Element	Weight (%)
O	27.10
Na	0.12
Al	3.54
Si	2.87
Ca	0.02
Cr	16.42
Fe	36.19
Co	5.26
Ni	3.59
Cu	2.25
Zn	0.46
Se	0.17
Cd	0.16
Hg	0.70
Pb	1.15
Totals	**100.00**

Fig. 8: SEM-EDS result of BIM (KJMA) tailings analysed

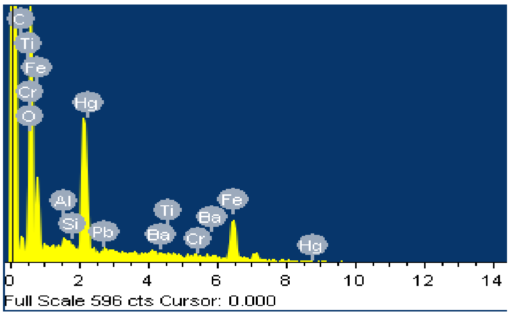


Element	Weight (%)
O	43.61
Mg	0.10
Al	7.34
Si	6.60
K	0.04
Ca	0.34
Fe	32.01
Co	4.99
Cu	0.55
Br	0.89
Nb	1.54
Mo	1.49
Pb	0.51
Totals	**100.00**

Fig. 9: SEM-EDS result of BIM (KJMA) OB8 sample analysed.

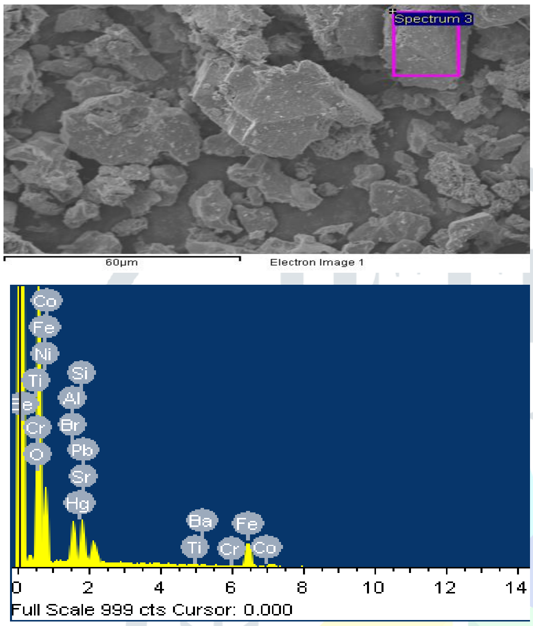


Element	Weight (%)
C	6.17
O	30.25
Al	0.49



Si	0.26
Ti	0.00
Cr	8.55
Fe	52.09
Ba	0.60
Hg	0.68
Pb	0.90
Totals	**100.00**

Fig. 10: SEM-EDS of BIM (KJMA) OB3E sample analysed.

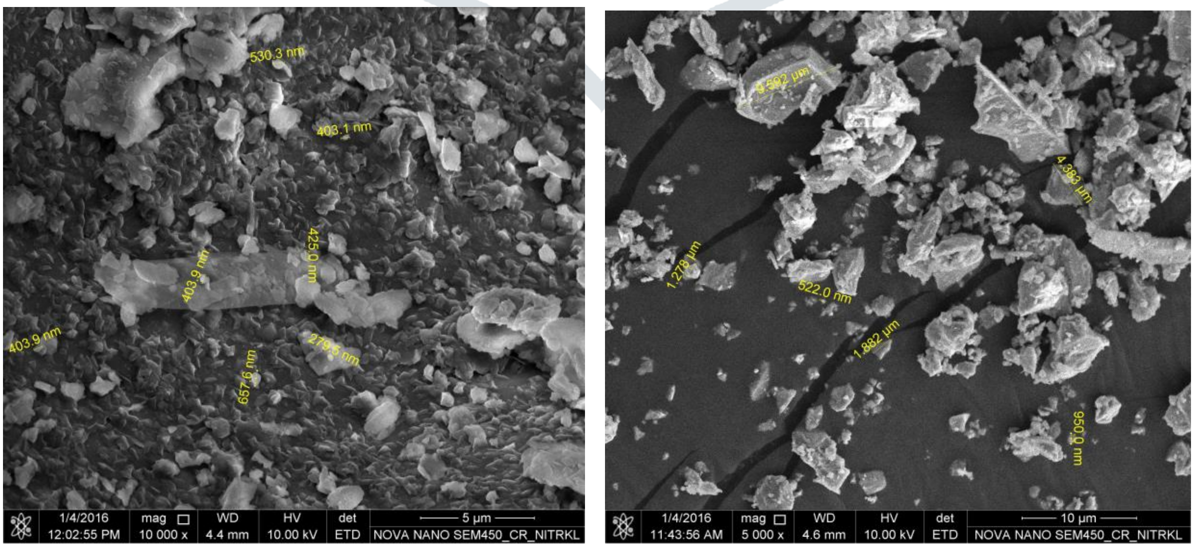


Element	Weight (%)
O	23.42
Al	1.63
Si	2.03
Ti	0.33
Cr	22.26
Fe	41.86
Co	6.27
Ni	1.12
Br	0.12
Sr	0.16
Ba	0.15
Hg	0.35
Pb	0.31
Totals	**100.00**

Fig. 11: SEM-EDS of BIM (KJMA) blue-dust sample analysed.

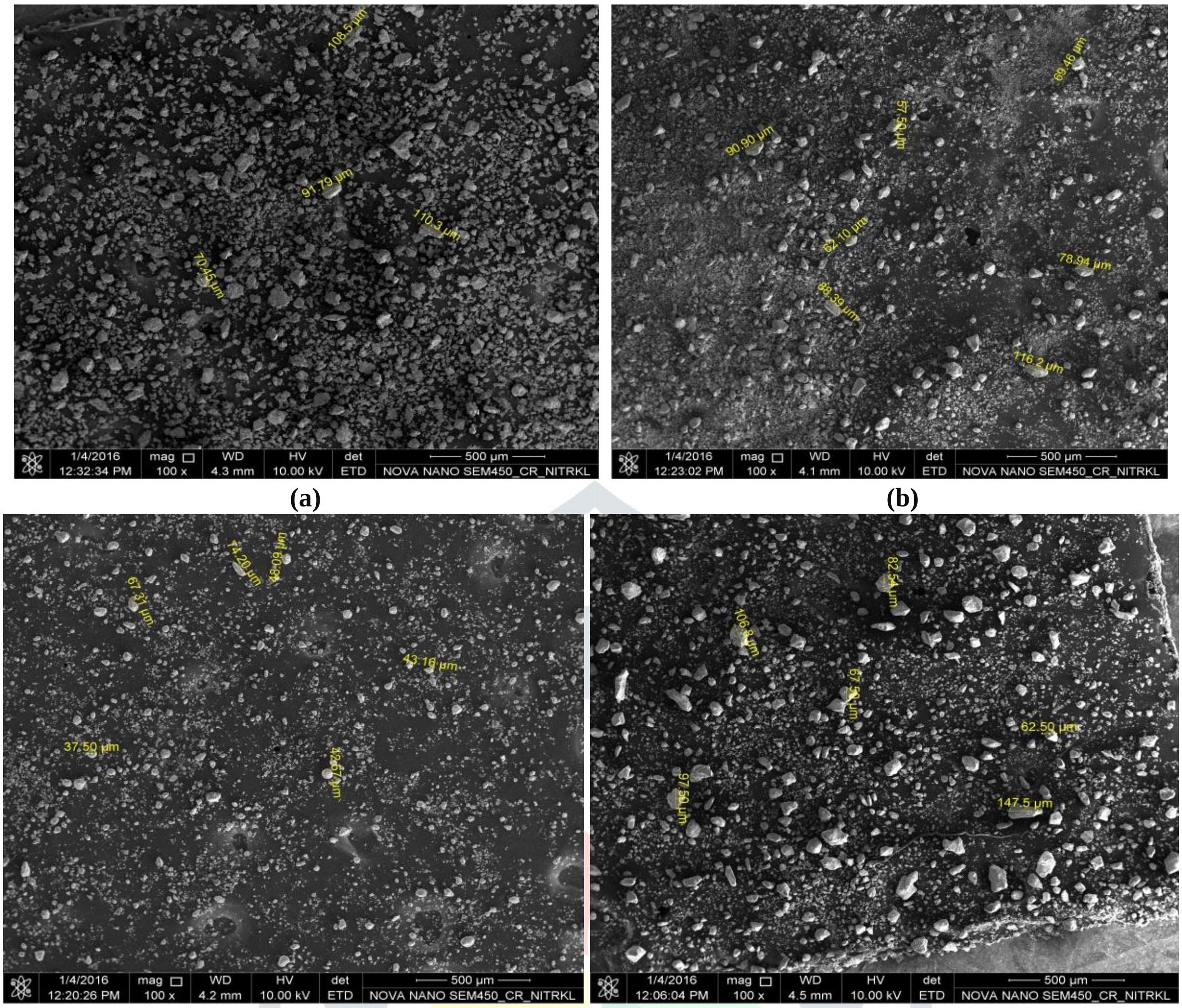
3.1.2 Particle Size Analysis

In an attempt to determine how the particle sizes are distributed in each sample, Field Emission Scanning Electron Microscopy (FESEM) analysis was carried out. The study was helpful in investigating particle sizes distribution in the samples. Figures 12a and b, and 13a, b, c, and d depict FESEM images showing particle sizes distributions in samples analysed at various magnifications.



(a) **(b)**

Fig. 12: FESEM image showing particle size distributions in CUIOM samples: (a) Overburden (OB), (b) Tailings (TL).



(a) (b) (c) (d)

Fig. 13: FESEM image showing particle size distributions in KJMA samples: (a) BD, (b) OB3E; (c) OB8, (d) Tailings (TI)

3.2 DISCUSSION

3.2.1 Mineralogical Characterization

SEM-EDS analysis was helpful in ascertaining the mineralogical constituents of all samples analyzed, as the elemental constituents of each sample were identified and quantified during the analysis. However, it could not detect elemental constituents with less than 0.01% concentration in all the samples analyzed. From the analysis, the elemental constituents having significant environmental impact in samples analyzed from both mining regions were revealed. Those chemical parameters found in larger proposition are highlighted and their environmental and health impact briefly discussed. Details of harmful heavy metal found out from EDS analysis are presented in table 2. The graphical representation of elements found in EDS spectra for CUIOM and KJMA has been presented in Fig. 14 to 16 respectively.

Table 2: Results of harmful chemical parameters found samples analyzed.

	Chemical Parameters (%)															
SID	**Cr**	**Cu**	**Pb**	**As**	**Hg**	**Cd**	**Br**	**Se**	**Zn**	**Ni**	**Co**	**Ba**	**Al**	**Si**	**Nb**	**Mo**
OBL	16.4	0.97	0.64	0.33	-	-	-	-	-	1.85	4.68	-	4.04	10.0	-	-
TL	-	0.17	1.40	-	0.20	-	-	-	0.03	-	-	-	-	27.0	-	-
OB8	-	0.55	0.51	-	-	-	0.89	-	-	-	4.99	-	7.34	6.60	1.54	1.49
OB3E	8.55	-	0.90	-	0.68	-	-	-	-	-	-	0.60	0.49	0.26	-	-
TI	16.4	2.25	1.15	-	0.70	1.16	-	0.17	0.46	3.59	5.26	-	3.54	2.87	-	-
BD	22.3	-	0.31	-	0.35	-	0.12	-	-	1.12	6.27	0.15	1.63	2.03	-	-

SID=Sample ID; OBL= Overburden of Liberia; TL= Tailings of Liberia; OB8=Overburden number 8 of India; OB3E=Overburden number 3 east of India; TI=Tailings of India; BD= Blue-Dust;

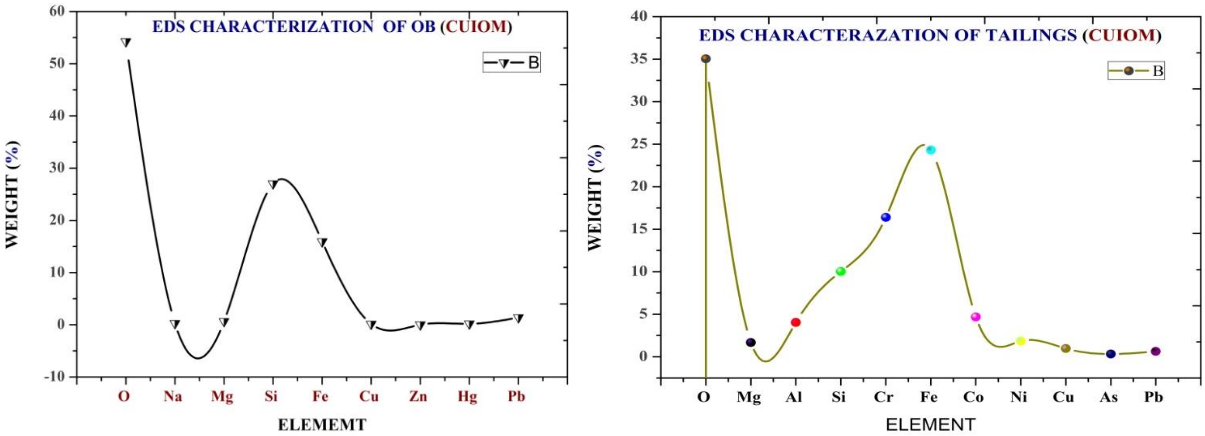


Fig. 14: Graphical representation of elements found in EDS spectra of CUIOM mine wastes: (a) OB and (b) Tailings.

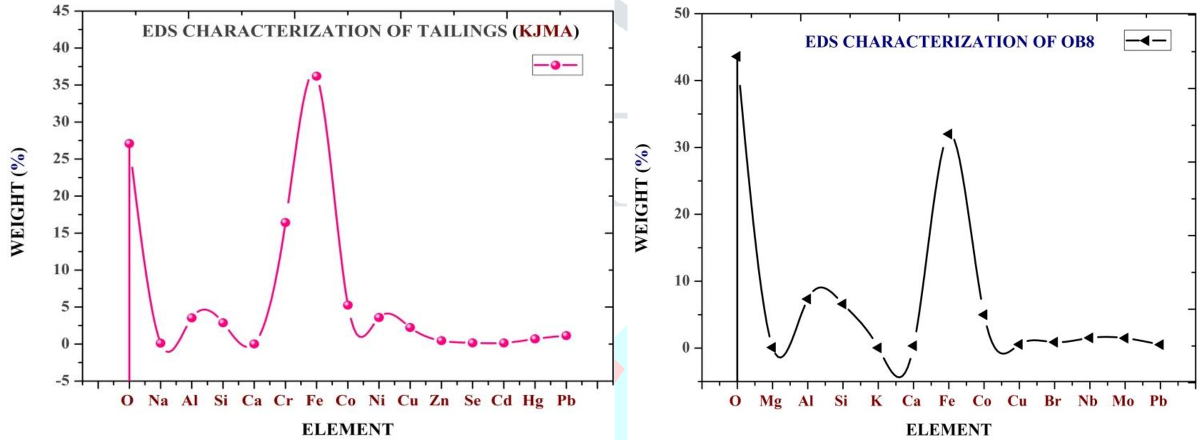


Fig. 15: Graphical representation of elements found in EDS spectra of KJMA mine wastes: (a) Tailings, and (b) OB8.

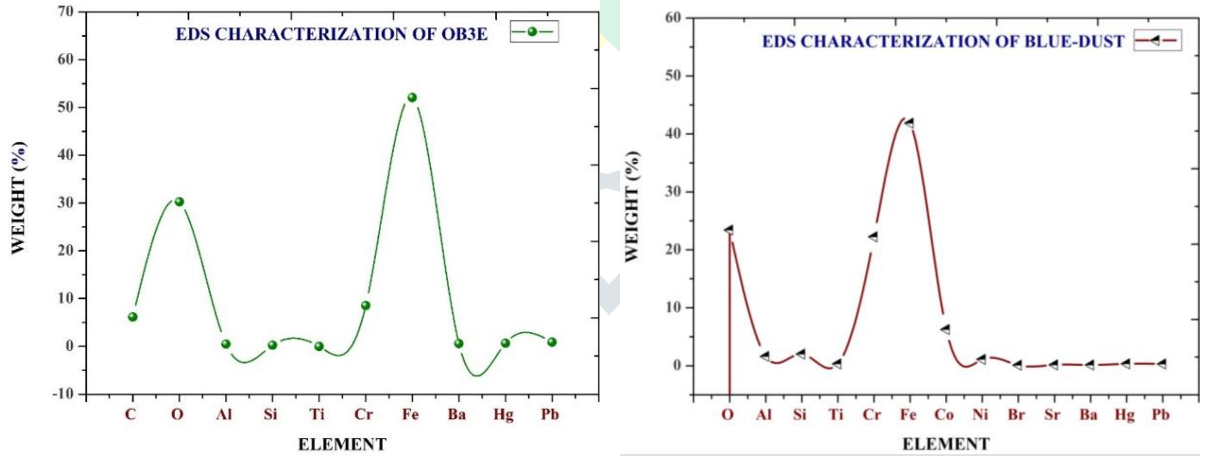


Fig. 16: Graphical representation of elements found in EDS spectra of KJMA mine wastes: (a) OB3E, and (b) Blue-dust.

The EDS spectrum of CUIOM OB sampled revealed Chromium (Cr), Silica (Si), Aluminum (Al),Cobalt (Co), Nickel (Ni), Copper (Cu), Lead (Pb), and Arsenic (As) as the leading harmful chemical constituents (Table 2, Figures 7 and 14a). Similarly, EDS spectrum of CUIOM tailings sampled revealed Si, Cu, Zn, Mercury (Hg), and Pb, as the principal harmful chemical constituents (Table 2, Figures 6 and 14b).

The EDS spectrum of KJMA tailings sampled revealed Al, Si, Cr, Fe, Co, Ni, Cu, Zn, Selenium (Se), Cadmium (Cd), Hg and Pb as the leading harmful chemical constituents (Table 2, Figure 9 and 15a).

The EDS spectrum of KJMA OB8 sampled revealed Al, Si, Fe, Co, Cu, Br, Nb, Mo, and Pb as the dominant harmful chemical constituents (Table 2, Figures 9 and 15b).

EDS spectrum of OB3E of KJMA revealed Al, Si, Cr, Fe, Ba, Hg, and Pb, as the dominant detrimental chemical constituents (Table 2, Figures 10 and 16a) while that of blue-dust revealed Al, Si, Cr, Fe, Co, Ni, Br, Sr, Ba, Hg, Pb, etc., respectively (Table 2, Figure 11 and 16b).

3.2.2 Particle Size Distribution

The particle size distributions in overburden (OB), tailings or blue-dust (a powdery iron associated with the OB) have an important effect on the rate at which they will hydrate when in contact with water. The surface areas of these mine wastes increased (become finer in size) due to mechanical activities such as drilling, blasting, excavation, crushing and grinding, etc. during mining. It was found out from the studies that finer particle sizes have larger surface areas exposed to water and most of their constituents will get leached due to a rise in the rate of chemical reaction. All samples analysed contained predominantly fine particles and thus require proper management for environmental safety. Moreover, due to the presence of harmful pollutants such as Hg, Cr, Pb, Cu, Zn, Ni, Si, etc., the water and air quality in the mining regions studied must be monitored at frequent intervals in accordance with the relevant standards to avoid outbreak of diseases due to these pollutants.

3.2.3 Chemical Parameters and their Consequences

Heavy metals are naturally occurring elements such as Hg, Cr, Pb, Cu, Zn, Ni, Si, etc., that have high atomic mass and with a density at least five times greater than water. The toxicity of heavy metals depends on a number of factors including the dose, means of exposure, chemical species, age, gender, genetics, and nutritional status of the exposed individuals, etc. [17]. Cadmium, arsenic, lead, chromium, and mercury are ranked among the priority heavy metals that are of public health concerns due to their high degree of toxicity [13]. The environmental consequences of chemical parameters found within the mine wastes samples analysed are summarised below [18]:

3.2.3.1 Chromium: The health effects of Chromium (Cr) include but not limited to skin rashes; upset stomachs and ulcers; respiratory problems; weakened immune systems; kidney and liver damage; alteration of genetic material; lung cancer; and death.

3.2.3.2 Aluminum: Aluminum (Al) is one of the most widely used metals and also one of the most frequently found compounds in the earth's crust. Exposure to high concentrations of Al through food, water, air and by skin contact may cause severe damage to the central nervous system; dementia; loss of memory; listlessness; severe trembling, and kidney damage. Al is a risk in certain working environments, such as mines, where it can be found in water and air due to dust from heavy earth moving machines, blasting, and processing activities. Miners endure lung problems when they breathe in Al dust.

3.2.3.3 Cupper: The health effects of Copper (Cu) include but not limited to liver and kidney damage, metal fume fever (copper fumes, dust, or mists), atrophic changes in nasal mucous membranes, hepatic cirrhosis, brain damage, demyelization, renal disease, **Wilson's disease** (chronic Cu poisoning), and even death.

3.2.3.4 Nickel: The health effects of **Nickel** (Ni) include but not limited to lung cancer, nose cancer, larynx and prostate cancer; lung embolism; respiratory failure; birth defects; asthma and chronic bronchitis; allergic reactions such as skin rashes, mainly from jewelry; heart disorders; respiratory irritants and pneumonitis (Ni fumes), dermatitis commonly known as "nickel itch". The first symptom of dermatitis is frequent itching, which occurs up to 7 days before skin eruption occurs. Ni is carcinogenic (cancer causing) according to National Toxicology Program (NTP) and the International Agency for Research on Cancer (IARC).

3.2.3.5 Lead: Lead (Pb) is one out of four metals that have significant damaging effects on human health. Exposure to may cause several undesirable effects, viz. disruption of the biosynthesis of haemoglobin and anaemia; a rise in blood pressure; kidney damage; miscarriages and subtle abortions; disruption of nervous systems; brain damage; declined fertility of men through sperm damage; diminished learning abilities of children; behavioural disruptions of children, such as aggression, impulsive behavior, and hyperactivity. Pb may enter a fetus through the placenta of the mother and cause severe damage to the nervous system and the brains of unborn children. It may enter drinking water through corrosion of pipes, mining, and processing activities, and may initiate when the water is slightly acidic. Pb may enter the human body through uptake of food (65%) water, (20%); and air (15%).

3.2.3.6 Mercury: Exposure to Mercury (Hg) may cause several undesirable effects, viz. disruption of the nervous system; damage to brain functions (severe exposure); DNA and chromosomal damage; allergic reactions such as skin rashes, tiredness, and headaches; negative reproductive effects (sperm damage, birth defects, miscarriages), degrade learning abilities, personality changes, tremors, vision changes, deafness, mongolism (chromosomal damage), muscle incoordination and memory loss of the affected person.

3.2.3.7 Arsenic: Exposure to Inorganic **Arsenic (As)** may result in irritation of the stomach and intestines, decreased production of red and white blood cells, skin changes, lung irritation, skin, lung liver and lymphatic cancers, infertility, miscarriages in women, skin disturbances, declined resistance to infections, heart disruptions and brain damage (within both men and women), DNA damage, nerve injury and stomachaches.

3.2.3.8 Silica: Silica (Si) is the most abundant electropositive element in the earth's crust. Exposure to crystalline Si may irritates the skin (reddening, scaling, and itching) and eyes (watering and redness) on contact, while inhalation may cause irritation to the lungs and mucus membrane, Occupational exposures to crystalline Si specifically quartz and cristobalite may result in lung cancer. Several epidemiological studies have reported significant numbers of excess deaths or cases of immunologic disorders and autoimmune diseases in miners or workers exposed to silica. These diseases and disorders include scleroderma, rheumatoid arthritis, systemic lupus erythematosus, and sarcoidosis.

3.2.3.9 Strontium: Strontium (Sr) exposure may cause several undesirable effects, viz. lung cancer (strontium chromate), disruption of bone development (in children) skin rashes (Sr Salt). Radioactive Sr may cause anaemia and oxygen shortages, cancer and damage to the genetic materials in cells.

3.2.3.10 Bromine: Bromine (Br) exposure may cause several undesirable effects, viz. liver, kidneys, and lungs damages, stomach and gastrointestinal malfunctioning, cancer, damage to nervous system and the thyroid gland, etc.

The leaching behaviours of similar wastes from these regions and their impact on water and air quality have been studied by Gleekia [19] using two leaching fluids: (a) double distilled water (DW) to simulate rainwater, and (b) acidic solution (Nitric acid) to simulate acid mine drainage (AMD) in a mine environment. Toxicity Characteristics Leaching Procedure (TCLP) of US EPA, method 1311[20] was used to investigate the long-term behaviour of these mining generated wastes on the environment. The findings revealed Al, Cu, Mn, Cr, Zn, Hg, Pb, Cu, As, Fe, Si, Ni, etc. to be highly leachable in OB (prior to leaching, pH=3.3, acidic) and leachable tailings (prior to leaching, pH=8.6, basic).

4.0 Conclusion

Iron ore is the essential raw material mined to make steel. However, mining of iron ore predominantly by opencast method have serious environmental footprints, as there is a potential to release harmful contaminants including metals and heavy metals into the environment. It is well known that heavy metals are among the most problematic pollutants, since they are non-biodegradable and can accumulate in ecological systems. With increased concentrations, they can become extremely toxic. Their detection is therefore essential. SEM_EDS method can be used to determine metals and heavy metals very efficiently. The study carried out in two different parts of the world revealed that iron ore mining and beneficiation processes have significant negative impacts on the environment. EDS analysis revealed the presence of Al, Si, Cr, Fe, Co, Cu, Zn, Hg and Pb as the leading harmful chemical constituents in samples from both the iron ore mining regions located across continents. The particle size analysis revealed that the fraction of finer particle size is much more compared to the coarser ones. These have the potential to get air borne or contaminate the water bodies by leaching particularly during monsoon. A short interval robust compliance monitoring must be carried out periodically to monitor pH and heavy metals pollutants of surface run-off generated from mining-related wastes to ascertain their impact on the environment. Moreover, mines are normally located in remote areas and occupants (locals) of mining regions usually consume surface water. Thus, pollution of surface water due to an overload of toxic heavy metals above their acceptable limits as a result of mining operations may trigger severe environmental problems to plants and animals inhabiting the area. The management of both mining regions must put to please all necessary mitigation measures to limit pollution to the environment. The mineralogical characteristics of ore as well as the wastes are required to be characterized along with the study of their leaching potential, so that a preventive and control measure can be put in place. Robust medical examination of miners and inhabitants of these mining regions must be done within a regular interval (weekly, monthly, quarterly, etc.) to determine whether a miner or an inhabitant is medically fit so as to prevent health hazards. Moreover, mechanical action in the mines including drilling and blasting, mineral processing facility (MPF), tailing storage facility (TSF), waste dumps (WS) may give rise to elevated level of dust and fumes which should be avoided by employing proper control measures. Runoff and leachates that are generated from mine wastes must be contained, analysed and treated (when polluted) prior to discharge into the environment.

5.0 References

[1] Morris, R. C. (2012). Genesis of iron ore in banded iron-formation by supergene and supergene-metamorphic processes – a conceptual model. Hand book of Strata-bound and stratiform ore deposits, 13, 73-235.

[2] Banerjee, K. K., Wang, H. And Pisaniello, D. (2006). Iron ore dust and its health impacts, Environmental Health, 6(1), 11-16.

[3] Nuss P., Eckelman M. J. (2014) Life Cycle Assessment of Metals: A Scientific Synthesis. PLoS ONE, 9(7): e101298. doi:10.1371/journal.pone.0101298.

[4] Salomons, W. (1995). Environmental impact of metals derived from mining activities: processes, predictions, prevention. Journal of Geochemical exploration, 52(1), 5-23.

[5] Monjezi, M., Shahriar, K., Dehghani, H., & Namin, F. S. (2009). Environmental impact assessment of open pit mining in Iran. Environmental geology, 58(1), 205-216.

[6] Coates, D. G. (1967). Kikuchi-like reflection patterns obtained with the scanning electron microscope. Philosophical Magazine, 16(144), 1179-1184.

[7] Lottermoser, B. G. (2010). Tailings (pp. 205-241). Springer Ber.lin Heidelberg.

[8] Gleekia, A. M. G. D. (2016). Assessment of Environmental Impact of Iron Ore Mining and its Mitigation Measures, Master Thesis, NIT Rourkela(Unpublished).

[9] Mol, S. (2011). Determination of trace metals in canned anchovies and canned rainbow trouts. *Food and chemical toxicology*, *49*(2), 348-351.

[10] Akcil A. and Koldas S. (2006). Acid Mine Drainage (AMD): causes, treatment and case studies." Journal of Cleaner Production , 14(12), 1139-1145.

[11] Norgate, T. and Haque, N. (2010). Energy and greenhouse gas impacts of mining and mineral processing operations. Journal of Cleaner Production, 18(3), 266-274.

[12] Wong, M. H. (1981). Environmental impacts of iron ore tailings - The case Oi Harbour+++Hong Kong. Environmental management, 5(2), 135-145.

[13] World reserves of iron ore as of 2014, by country, www.statista.com, Accessed on May 5, 2016.

[14] Yachir, F. (1988). Mining in Africa today: strategies and prospects (Vol. 5). United Nations University Press.

[15] Kraaij, F. V. D. (2015). Liberia: from the love of liberty to paradise lost (p. 175).African Studies Centre, Leiden.

[16] Bong Mine Redevelopment Project, Vol. I & II: Environmental and social Impact Assessment; Environment & Social Impact Management Plan, August 2013.

[17] Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K. and Sutton, D. J. (2012). Heavy metal toxicity and the environment. In Molecular, clinical and environmental toxicology (pp. 133-164). Springer, Basel.

[18] Chemical Properties of Nickel, Copper, Zinc, Selenium, etc., -Health effects & Environmental effects. Available at www.lenntech.com/periodic/elements/ni.htm. Accessed on: January 5, 2016.

[19] Gleekia, A. M. and Sahu, H. B. Impacts of iron ore mining on water quality–a comparative study of India and Liberia, Proceedings of 6th Asian Mining Congress, The Mining, geological and Metallurgical Institute of India, February 23-27, 2016, Kolkata, India, 372-380.

[20] USEPA, United States Environmental Protection Agency, Method 1311, Toxicity Characteristics Leaching Procedure, in Wastes, Ed.;1992