Investigating the Impacts of Iron Ore Mining Activities on Surface Water Quality: A Case Study of the Savage River in Buchanan, Grand Bassa County

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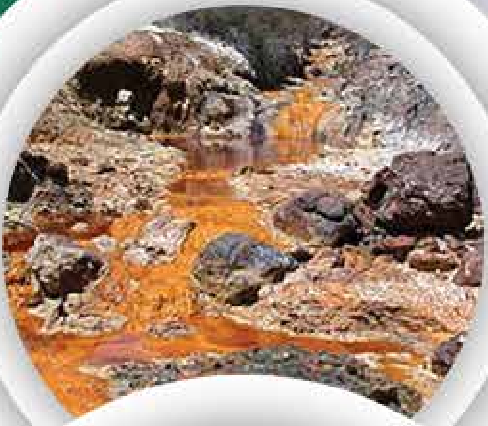
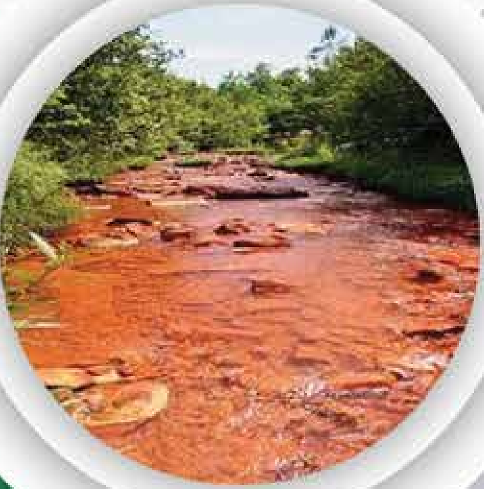
By: **K. Marvie Reed**





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Abstract

Almost every stage of mining operations requires adequate water supply for functioning directly and indirectly, in contrast mining is also one of the major causes of water pollution. Main sources of water pollution from mines are mine water drainage, erosion, acid mine drainage and water from spoil heaps, dumps or tailing facilities. This research seeks to investigate the impacts of ArcelorMittal Liberia Mining operations on the quality of River Savage's water in Buchanan, Grand Bassa County. Water pollution is heading overall reason for deaths and diseases. According to the World Health Organization, such diseases account for an estimated 4.1% of the total disability-adjusted life year (DALY) global burden of disease, and cause about 1.8 million human deaths annually with unsafe water supply, sanitation and hygiene being the measure causes (Sen, 1999). The researcher used quantitative method in gathering and analyzing the research data. Five samples were collected from River Savage and nearby water (Motown Creek), around the stockpile in Buchanan, Grand Bassa County. These samples were analyzed with a HORIBA Multi-Parameter Water Quality Analyzer. Water quality can be measured by analyzing it for different physical and chemical parameters of it. Thirty-six (36) different physical and chemical parameters were analyzed. The main findings are as follows; the entire total unfiltered metals including Iron, Mercury, and Arsenic, Chromium, Copper, Lead, Nickel and Zinc concentrations in the rivers were generally higher than the limit of Liberian Standard and WHO standards. Concentration levels of all other toxicologically relevant dissolved filtered metals, including Chromium, Chromium trivalent, Chromium hexavalent and Vanadium were either below the limit of detection or lower than the standard set by WHO for drinking water which is a plus, except for Boron and Manganese that were above the Liberian and WHO Standards. Relatively high levels of Chloride (especially for Sample SW-84), Cyanide and Dissolved Solid were found in all river samples due to probably the effect of salt water from the sea. ArcelorMittal has done a good job at keeping the concentration of some of parameters within the permissible limits. River Savage water sample were found to be of average good water quality satisfying basically Class III water quality standards for Liberia. However, all the water samples were found to be above the WHO and Class I (drinking water) of the Liberian Standard which may be due to run-off from their stockpile into the river, or previous operations carried out by the Liberian American-Swedish Mineral Company (LAMCO). Proper measures must be taken to curb this. Water must be properly treated before allowing it to drain into nearby creeks or ocean.

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Chapter One: Introduction

Background to the Study

The Savage River is used for irrigation, drinking, recreation, fishing, watering stock etc. The river and its tributaries are the main river system draining the Buchanan concession and the Port of Buchanan. The original outfall of the river was changed by The Liberian American-Swedish Minerals Company Joint Venture (LAMCO-JV) following a channel diversion during the construction of the sea port in 1961. The current outfall of the main channel to the sea, which discharges the majority of the river flow, is located approximately 3 km to the east of the sea port. The river flows into the lagoon that has developed behind the sand bar along the coastline and eventually discharges into the sea. A secondary channel, which carries less flows from the Savage catchment and follows the original course of the river discharges directly into the port after the bifurcation. ArcelorMittal Liberia's production area is located to the East-Northeast of Monrovia, in Nimba County, Yekepa, near the international boundary with Guinea and the Ivory Coast, the crushed ore Direct Shipment Ore (DSO) is transported by train to the Port of Buchanan to be shipped out of Liberia. See appendix for Figure One showing the map of Liberia showing location of ArcelorMittal concession area in Liberia

Statement of the Problem

Liberia has a rich history of iron ore exploitation and exportation, which are mainly attributed to LAMCO-JV and ArcelorMittal, before these DSOs are shipped out of Liberia; they are stored in the stockpiles near the River Savage in Buchanan, Grand Bassa County, for a long these leachates or runoffs water from the stockpiles has been polluting the nearby waters. This raises serious environmental concerns, which is the primary reason for the conduct of this research.

Significance of the Problem

This investigation will demonstrate that though mining is a destructive and most importantly, economically viable venture, it can be done in sustainable manners without posing lasting adverse effects on the environment or less impacts on the general ecosystem. This study will enlighten the relevant stakeholders and concessionaire to carry out regular monitoring exercises and build efficient stockpiles facilities respectively.

Research Question

1. How does iron ore mining activities by ArcelorMittal impacts River Savage?
2. What class of the Liberian Water Quality Standard does River Savage satisfied?

Purpose of the Study

At the end this project, this research seeks:

1. To analyze the impacts of iron ore mining on River Savage with respect to major pollutants, erosion, leachate from stockpile and etc.
2. To determine the parameters of the water quality index (Physical and Chemical Parameters) examined during such analysis and to present the desired Liberian and World Health Organization (WHO) standards and ArcelorMittal Liberia Limits of Detection for Water Quality.

Delimitations of the Study

The study is limited to the Savage River near the Sea Port of Buchanan in Grand Bassa County. Also the focus of the study on the Stockpile facilities that stores the DSO that is ready for shipment. The river flows into the lagoon that has developed behind the sand bar along the coastline and eventually discharges into the sea.

Limitations of Study

One of the challenges encountered during the course of this research was the difficulty in obtaining cardinal data pertinent to the smooth conduct of this research. Another constraint was the deprivation of site visitation and investigation. Lastly, the findings of this study cannot be generalized to other mining areas in Liberia. However, the overall objectives of this research were met.

Chapter Two: Literature Review

The first step towards controlling water pollution in mining is to know firstly the history of the commodity causing the pollution and then the causes and effects leading from the extraction of such mineral. This literature review will highlight these causes and the proper mitigation measures can be taken to control them. It will also study the impacts of pollution on water quality. We need to know how water quality is affected due to all these factors and how will the water quality affect life and operations. This section will also provide the different essential physical and chemical parameters that are to be studied.

History of exploration and mining of iron ore in Liberia

(Tomlinson, 2004) This paper investigates potential iron ore prospects, in its assessment for potential iron ore production prospects it ranks Liberia amongst countries with rich history of iron ore mining. It also ascertains that Liberia currently viewed as one of the most prospective locations for exploration since its emergence from civil war in 2003. Liberia's political environment has been stable for seven years and is currently attracting significant international investment, with major mining companies including BHP Billiton active in the country.

(Coakley, 2004) This article provides the name of iron ore mining companies that operated in Liberia, beginning with the Liberia Mining Company (LMC) which was the first of four iron ore companies, which produced and shipped large quantities of iron ore in the 1960s and 1970s making Liberia Africa's largest iron ore exporter and third on the world list at that time. In 1958 the National Iron Ore Company (NIOC) signed a concession agreement for the exploitation of the Mano river iron ore deposits. The Liberian American-Swedish Minerals Company Joint Venture (LAMCO JV) became operational and commenced iron ore production in 1960/61. LAMCO JV exploited the extremely rich Nimba mountains iron ore deposits. The fourth mining company, Bong Mining Company (BMC), was created following a concession agreement with German investors in 1958. The mine opened in 1965. 'Bong mine' as the company was and still is colloquially called in Liberia, was then the largest German investment in Sub-Saharan Africa.

Figure Two in the appendix shows the locations of the four mining companies that operated in Liberia before ArcelorMittal Liberia.

Impacts of Mining on Water Resources

(Gleekia, Pradhan, & Sahu, 2016) As per the scope of this research, this paper substantiate that mining indeed poses adverse effects on both the environs and its inhabitants, and as such; it calls for mining to be done in a sustainable manner that will aid in the minimization of negative impacts imposed such as; land degradation, disturbance and destruction of wildlife and biodiversity, air pollution and water pollution which is of great importance to this proposal writing. Mining method especially opencast degrades natural landscapes, surface and ground water, Flora and Fauna, as well as the ambient air quality within the mining area and its environs. Water quality is degraded as a result of surface runoff and leachate that are frequently generated from large volume overburden and tailings that are produced during iron ore mining and subsequent processing activities. This paper also stress out that most of the mines use overburden as backfilling material for mined out areas, ground water contamination may also result from leaching activities, which may have Spartan health impacts on miners and inhabitants of the of the area. Iron is the most needed ingredient in manufacturing steel which is the widely used metals and has found many applications in constructions, manufacturing of motor cars, machines, pipelines, military equipment, electrical appliances, etc. Iron ore has been mined for the past three thousand years by ancient and modern mankind. However, mining of iron ore has some negative impacts on the environment.

(Environment Australia, 2002) According to a study commissioned by the European Union**:** "Because of the large area of land disturbed by mining operations and the large quantities of earthen materials exposed at sites, erosion can be a major concern at hard-rock mining sites. The associated impacts could include substantial pH depression or metals loading to surface waters and/or persistent contamination of ground water sources Another impact it accesses acid mine drainage which implies mined materials (such as the walls of open pits and underground mines, tailings, waste rock, and heap and dump leach materials) are excavated and exposed to oxygen and water, acid can form if iron sulfide minerals (especially pyrite, or 'fool gold') are abundant and there is an insufficient amount of neutralizing material to counteract the acid formation. Finally, the study looks at the impacts of wet tailings impoundments, waste rock, heap leach, and dump leach facilities on water quality can be severe. These impacts include contamination of groundwater beneath these facilities and surface waters. Toxic substances can leach from these facilities, percolate through the ground, and contaminate groundwater, especially if the bottoms of these facilities are not fitted with an impermeable liner. See Appendix for Figures 3 and 4 that shows impacts of acid mine drainage and erosion on water quality resulting from mining respectively.

Some Compounds that Affect the Quality of Water

(Naik, 2015) This article attempted to assess the impact due to disposal of tailings from iron ore mines on surface water quality at Bolani, Sundargarh. Four samples were collected from the river, one on upstream, one at confluence point and two on downstream side of the effluent discharge point. Temperature and pH were measured on site where as Fe, Mn, Al, Cu and Zn were analyzed. Cr, Mo, Ni and Co was measured by Inductive Couple Plasma (ICP). A higher concentration of iron in comparison to Indian standards was found. Pollutant contribution to the surface water bodies through tailing ponds were more prominent in terms of Fe, Mn and suspended solids. This paper concluded that naturally occurring heavy metals often get released into water during the mineral extraction process. Metals like Co, As, Cd, Hg, Cu, Pb, Zn etc. are contained in the rock may leach out and get carried downstream by water. Chemical agents like Cyanide (CN) and Hydrogen Sulfate (H_2SO_4) from the mining site get spilled, leached or leaked in to nearby water bodies. This article asserts that water bodies closer to mining locations have high hardness values due to mining activities. Alongside hardness, most nearby surface water polluted by mine seepage generally has higher pH and lower acidity, aggregate iron, manganese, aluminum, and suspended solids than untreated surface mine waste which is of relevance to this paper.

Health Disorders Due To Poor Water Quality

(Naik, 2015) This paper provides the major health disorders or diseases caused by exposure to contaminants by heavy metals, which is another component of this research paper. The frequent exposure of residents to mercury (heavy metals) in few iron ore mining concession regions are characterize by health hazards such as; In the womb: may cause neurological problems including slower reflexes, learning deficits, delayed or incomplete mental development, autism and brain damage, in adults: Parkinson's disease, multiple sclerosis, Alzheimer's disease, heart disease, and even death. From research, other waterborne diseases caused by polluted water include: rashes, ear ache, pink eye, respiratory infections, hepatitis, encephalitis, gastroenteritis, diarrhea, vomiting, and stomach aches. Other health disorders related to water polluted by chemicals (persistent organic pollutants, heavy metals) are: Cancer including prostate cancer and non-Hodgkin's lymphoma, hormonal problems that can disrupt reproductive and developmental processes, damage to the nervous system, liver and kidney damage and damage to the DNA.

Water Quality Analysis

(Gleekia, Pradhan, & Sahu, 2016) This article summarizes the physical, chemical and biological characteristics that defined the quality of water. It defines water quality as the measure of condition of water so as to the requirement of different species of the ecosystem. Water quality must support a rich and wide-ranging community of organisms and must not harm public health in a healthy environment. Uses of water like irrigation, drinking, recreation, fishing and watering stock are dependent on water quality suitable for them. Ecological processes are sustained by water quality. Apart from farming, fishing and other domestic uses, water is also used for drinking purposes by both humans and other living organisms. This paper suggests that it is important to measure the water quality time to time in order to maintain the quality else the environment will suffer.

Physical and Chemical Parameters of Water

(Singh, 1997) This paper highlights that water quality can be measured by analyzing it for different physical and chemical parameters, these parameters have different methods of analysis. Each parameter is compared with the standards specified by different agencies to determine whether the water is suitable for use or not. Table 1 below shows some physical and chemical parameters of water.

Table 1: Some Physical and Chemical Parameters of Water

Physical Parameters	Chemical Parameters
Temperature	pH
Conductivity	Dissolved Oxygen
Turbidity	Salinity
Total Dissolved Solids	Oxidation Reduction potential
	Nitrate, Chloride & Sulphate compounds
	Hardness

Definition of Some Key Physical and Chemical Parameters

- **pH:** It is the measure of the H+ ions present in water. It can be any value in between 0 to 14. For acidic water the value lies within 0 to 7 whereas for basic water it lies in between 7 to 14. The lesser the value of pH the more acidic the water is and the more the value of pH the more is the alkalinity of it. pH affects the solubility of water and also it governs the amount of nutrients dissolved in water. This affects how water is used by aquatic animals. The more acidic the water more is the chances of dissolving heavy metals. pH must lie within 6.5 to 8.5 for drinking water as per the standards.
- **Dissolved Oxygen:** It is the amount of oxygen dissolved in water. It can be measured in mg/L or expressed in % of dissolved oxygen. The dissolved oxygen is utilized by the aquatic life. Hence the amount of dissolved Oxygen must be sufficient for sustaining the life under water. Dissolved oxygen varies inversely with temperature. The lower the temperature the more is the ability of water to dissolve oxygen.
- **Biochemical Oxygen Demand (BOD):** It is the measure of how much of O2 is utilized by microbes for aerobic oxidation and breaking down of organic matter present in water. More is the BOD, less is the availability of O2 for aquatic life and more is the organic matter present in it. It is measured for a period of 5 days and expressed in mg/L. It should be less than 5mg/l as per drinking water standards.
- **Conductivity:** Conductivity of water is an indirect measure of ion concentration of the solution. More is the ions concentration more will be the conductivity. Ions like Na+, Mg2+, K+, and Ca2+ etc. increase the conductivity. The conductivity is measured in µS/cm at 25ºC and should be within 0 to 70.
- **Total Dissolved Solid (TDS):** It is a measure of the amount of particulate solids that are present in the solution. TDS is an indicator of pollution problems associated with land use practices. TDS is directly proportional to conductivity and conductivity is used to measure TDS indirectly. More TDS results in hardening of water. It also causes corrosion of pipes that it flows in. It creates a salty and bitter taste of water. It is measured in mg/L.
- **Turbidity:** Turbidity is a measure of the clarity of water. The more the amount of suspended (organic or mineral) solids, more is the turbidity. It is a measure of the light scattering properties of water. Sediments from human construction can runoff with water to cause turbid conditions. Quarrying and mining operations also result in turbid water due to colloidal rock particles. High turbidity can inhibit the effect of

disinfection against microbes and enables bacterial growth. Turbidity is measured in NTU and must be less than 10 for drinking water.

- **Hardness:** Hardness in water is caused by the dissolved Calcium and Magnesium salts which get dissolved in water from soil or minerals containing limestone or dolomite. If hardness is found to be more than 300 mg/L then the water is hard and for less than 70 mg/L it is soft. Hard water can cause scaling in utensils and makes it difficult for foam creation hence causes use of more soap and detergent. It should be less than 300 mg/L in drinking water.
- **Iron:** Iron content in water can result from leaching of iron pipes in water distribution system. Also near iron ore mining areas, iron tailings can enter into surface runoff water. Presence of iron in water can cause bitter and metallic taste of water. It can cause brownish green stains in clothes, blackening of water with rusty sediments and discoloring of beverages. Iron content should be less than 0.3 mg/L.
- **Chloride:** Chloride content of water can increase if it comes in contact with fertilizers and Industrial wastes. Chloride can also result from sea water and different minerals. Presence of chloride more than the permissible limit of 250 mg/L can cause health effects like high blood Pressure. It also causes salty taste of water, corrosion of pipes and blackening of stainless steel.
- **Arsenic:** Arsenic enters into water through different pesticides, glass or electronic wastes which are not disposed properly and from natural sources like rocks. Presence of arsenic more than the permissible limit of 0.05 mg/L can cause weight loss and make water toxic to skin and nervous system.
- **Chromium:** Chromium enters into water from industrial and mining wastes. High concentration of chromium can cause skin and nasal ulcer. It can cause adverse health effects like lung tumors, gastro-intestinal damage and nervous system damage. It can also accumulate in spleen, kidney and liver causing complications. It should always be less than 0.1mg/L in drinking water.
- **Copper:** Copper enters into water through leeching from copper tubes, industrial and mining wastes. High copper concentration causes health effects like Anemia, digestive disturbance, liver and kidney damages and gastro-intestinal irritation. It also causes bitter and metallic taste of water and staining of clothes. Copper concentration should be less than 0.05 mg/L in drinking water.

- **Cyanide:** Cyanide (CN) sources in water are fertilizers, electronic wastes, steel, plastic and mining wastes and some natural sources. CN is very poisonous and can cause nervous damages and thyroid problems. The concentration of CN must be less than 0.05 mg/L in drinking water.
- **Lead:** The major sources of lead are paints, diesel fuel, batteries, pipes and solder. Lead also occurs naturally and can enter water from any of these sources. Lead can cause metal poisoning and other adverse health effects like mental retardation, kidney and neurological damages, hearing loss, blood disorders and even death at higher concentration. Lead should be less than 0.05 mg/L in water to make it suitable for drinking.
- **Mercury:** Mercury enters water through pesticides, fungicides, batteries, paints, and electrical wastes. Mercury can cause vision and hearing loss, intellectual deterioration and many other health effects if found in high concentration. It should be present at a concentration below 0.001mg/L.

Chapter Three: Research Methodology

Sampling

To obtain the desired representative samples, sampling was carried out. These samples mirrored the environment and surrounding conditions in which they are present that is, in the surrounding area the concentration were similar to that of the samples taken. The water bodies from which samples are taken were within confines of the concession area near the Port of Buchanan and not isolated. I perceived the collected samples were handled carefully to avoid any significant changes taken place between the time the samples were collected and analyzed in laboratory.

Sample Collection

The researcher used quantitative method in gathering and analyzing the research data. Five samples were collected from River Savage and nearby water (Motown Creek), around the stockpile in Buchanan, Grand Bassa County. These samples were analyzed with a HORIBA Multi-Parameter Water Quality Analyzer.

Table 2: Sample name and respective locations

BUCHANAN SURFACE WATER	OLD SAMPLE ID	NEW SAMPLE ID	LOCATION DESCRIPTION
Savage River old channel	BUC1	SW81	River
Savage River Bridge	BUC2	SW82	River
Savage River Lagoon	BUC3	SW83	Lagoon
Motown Creek	BUC4	SW84	Creek
Junction to Hospital	BUC5	SW85	Water Stream

Observation

Water quality can be measured by analyzing it for different physical and chemical parameters. Different parameters have different methods of analysis. Each parameter is compared with the standards specified by different agencies to determine whether the water is suitable for use or not. Table 3 presents the data gathered from the analysis of all five samples collected from various sections of River Savage covering the chemical analysis of inorganics, dissolved metals, unfiltered metals, phenols and minerals oils.

Table 3: Some Chemical Parameters of Data Collected From Samples

Test/Analysis	Method	Units	LOD	SW-81	SW-82	SW-83	SW-84	SW-85
Inorganics								
Conductivity @ 20 deg.C	TM120	mS/cm	<0.005	0.0187	0.294	0.0367	1.22	0.0497
Fluoride	TM104	mg/l	<0.5	<0.5	<0.5	<0.5	<0.5	0.736
Nitrite as NO2	TM184	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
pH	TM256	pH Units	<1	6.94	7.16	6.5	6.67	6.72
Sulphate	TM184	mg/l	<2	<2	11.9	<2	57.5	<2
Surfactants, Anionic (MBAS)	TM249	mg/l	<0.05	<0.05	<0.05	<0.05	0.0681	<0.05
Chloride	TM184	mg/l	<2	<2	71.8	7.9	362	<2
Ammoniacal Nitrogen as NH3	TM099	mg/l	<0.2	<0.2	0.293	<0.2	<0.2	<0.2
Cyanide, Total	TM227	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Phosphate (ortho) as PO4	TM184	mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Dissolved solids, Total (gravimetri	TM021	mg/l	<10	16	167	30	745	40
Nitrate as NO3	TM184	mg/l	<0.3	0.301	<0.3	<0.3	0.72	<0.3
BOD, unfiltered	TM045	mg/l	<1	-	-	-	<1	-
Suspended solids, Total	TM022	mg/l	<2	7	5	14.5	<2	11.5
Filtered (Dissolved) Metals								
Chromium, Hexavalent	TM241	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Chromium, Trivalent	TM152	mg/l	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Silver (diss.filt)	TM283	µg/l	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
Boron (diss.filt)	TM152	µg/l	<9.4	<9.4	37.5	9.53	115	9.63
Chromium (diss.filt)	TM152	µg/l	<0.22	0.335	0.323	0.537	0.878	0.703
Manganese (diss.filt)	TM152	µg/l	<0.04	1.58	174	21.1	131	78
Vanadium (diss.filt)	TM152	µg/l	<0.24	<0.24	<0.24	<0.24	<0.24	<0.24
Unfiltered (Total) Metals								
Mercury (tot.unfilt)	TM183	µg/l	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Arsenic (tot.unfilt)	TM191	µg/l	<2	<2	<2	<2	<2	<2
Iron (tot.unfilt)	TM228	mg/l	<0.024	1.54	1.93	1.48	0.704	5.38
Cadmium (tot.unfilt)	TM191	µg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Chromium (tot.unfilt)	TM191	µg/l	<3	<3	<3	<3	<3	<3
Copper (tot.unfilt)	TM191	µg/l	<4	<4	<4	<4	<4	<4
Hardness, Total as CaCO3 unfilte	TM228	mg/l	<0.35	5.63	69.6	8.05	180	32.1
Nickel (tot.unfilt)	TM191	µg/l	<0.5	<0.5	<0.5	<0.5	0.773	<0.5
Lead (tot.unfilt)	TM191	µg/l	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Zinc (tot.unfilt)	TM191	µg/l	<3	<3	<3	<3	<3	<3
Phenols								
Phenol	TM259	mg/l	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Cresols	TM259	mg/l	<0.006	<0.006	<0.006	<0.006	<0.006	<0.006
Xylenols	TM259	mg/l	<0.008	<0.008	<0.008	<0.008	<0.008	<0.008
Phenols, Total Detected monohyd	TM259	mg/l	<0.016	<0.016	<0.016	<0.016	<0.016	<0.016
Mineral Oil / Oils & Greases								
TPH / Oil & Greases	TM235	mg/l	<1	-	-	-	<1	-

Water Quality Standards

Water quality standards describe the quality parameters set for the various classes of water. The locally approved and accepted international standard for drinking water in Liberia is provided in Table 4 and Table 5 follow by ArcelorMittal Liberia Limits of Detection (LOD).

Table 4: Interpretation of the Various Classes of Water in Liberia

mg	Milligram
L	Liter
n	Count
n.d.	Not detectable
Water classification	Water can be used as
Class I	Drinking water for population, water supply for industry requiring drinking water
Class II	For fisheries, cultivated fisheries, organized public bath, recreational water sport
Class III	Industry supply except for industry requiring drinking water, irrigation of agricultural land

Table 5: Prescribed Liberian Water Quality Standards

EXISTING LIBERIAN WATER QUALITY STANDARDS					
Parameter	Unit	WHO	Class I	Class II	Class III
pH	-logH	-	6.5- 8.0	6.0-9.0	5.5-9.0
Chloride	mg Cl/L	350	≤ 250.0	≤ 350.0	≤ 450.0
Sulphate	mg SO_4/L	250	≤ 150.0	≤ 200.0	≤ 250.0
Hardness	$CaCO_3$ mg/L	100-500	≤ 190.0	≤ 300.0	≤ 600.0
Iron Total	Fe mg/L	0.1	≤ 0.1	≤ 1.5	≤ 2.0
Manganese	Mn mg/L	0.1	≤ 0.1	≤ 0.3	≤ 0.8
Zinc Total	Zn mg/L	5	≤ 1.0	≤ 2.0	≤ 5.0
Coliform Bacteria	n/mL	0	0	0	≤ 5
Bacteria Total	n/mL	0	0	≤ 10	≤ 50
Dissolved Substance	mg/L	500	≤ 500.0	≤ 1000.0	≤ 1200.0
Suspended Solids	mg/L	-	≤ 10.0	≤ 30.0	≤ 50.0
Ammonia	mg NH_4/L	0.5	≤ 1.0	≤ 3.0	≤ 6.0
Nitrate	mg NO_3/L	50	≤ 40.0	≤ 60.0	≤ 80.0
Nitrite	mg NO_2/L	-	≤ 0.1	≤ 0.5	≤ 1.0
Phosphate	mg PO_4/L	-	≤ 0.01	≤ 0.02	≤ 0.05
Phenols	mg/L	0.001	≤ 0.001	≤ 0.02	≤ 0.05
Detergents	mg/L	-	≤ 1.0	≤ 2.0	≤ 3.0
Fluoride	F mg/L	1.5	≤ 1.5	≤ 1.5	≤ 2.0
Cyanide	Cn mg/L	0.05	≤ n.d.	≤ 0.02	≤ 0.05
Lead	Pb mg/L	0.1	≤ 0.1	≤ 0.1	≤ 0.1
Mercury	Hg mg/L	0.01	≤ n.d.	≤ 0.005	≤ 0.01
Copper	Cu mg/L	0.05	≤ 0.01	≤ 0.01	≤ 0.02
Cadmium	Cd mg/L	0.01	≤ n.d.	≤ 0.001	≤ 0.01
Chromium Trivalent	Cr mg/L	-	≤ 0.5	≤ 0.5	≤ 0.8
Chromium Hexavalent	Cr mg/L	0.05	≤ 0.05	≤ 0.1	≤ 0.1
Nickel	Ni mg/L	-	≤ 1.0	≤ 1.0	≤ 0.1
Silver	Ag mg/L	0.05	≤	≤	≤
Vanadium	V mg/L	-	≤ 1.0	≤ 1.0	≤ 1.0
Boron	B mg/L	-	≤ 1.0	≤ 1.0	≤ 1.0
Arsenic	As mg/L	0.05	≤0.05	≤0.05	≤ 0.02

Table 6: ArcelorMittal Liberia Control Limit of Detection (Standards)

ArcelorMittal Liberia (AL) Standards ALcontrol limits of detection			
Analysis	**Unit**	**LOD**	**Max.**
Inorganics			
Ammoniacal Nitrogen as NH3	mg/l	0.2	6
BOD, unfiltered	mg/l	1	50
Chloride	mg/l	2	450
Conductivity @ 20 deg.C	mS/cm	0.005	
Cyanide, Total	mg/l	0.05	0.05
Dissolved solids, Total (gravimetric)	mg/l	10	1200
Fluoride	mg/l	0.5	2
Nitrate as NO3	mg/l	0.3	80
Nitrite as NO2	mg/l	0.05	1
pH	pH Units	1	6.0-9.0
Phosphate (ortho) as PO4	mg/l	0.05	0.05
Sulphate	mg/l	2	250
Surfactants, Anionic (MBAS)	mg/l	0.05	
Suspended solids, Total	mg/l	2	50
Filtered (Dissolved) Metals			
Boron (diss.filt)	µg/l	9.4	1000
Chromium (diss.filt)	µg/l	0.22	
Chromium, Hexavalent	mg/l	0.03	0.1
Chromium, Trivalent	mg/l	0.03	0.8
Hardness, Total as CaCO3	mg/l	0.35	600
Manganese (diss.filt)	µg/l	0.04	800
Silver (diss.filt)	µg/l	1.5	10
Vanadium (diss.filt)	µg/l	0.24	1000
Unfiltered (Total) Metals			
Arsenic (tot.unfilt)	µg/l	2	200
Cadmium (tot.unfilt)	µg/l	0.5	10
Chromium (tot.unfilt)	µg/l	3	1000
Copper (tot.unfilt)	µg/l	4	200
Iron (tot.unfilt)	mg/l	0.024	2
Lead (tot.unfilt)	µg/l	0.5	100
Mercury (tot.unfilt)	µg/l	0.02	2
Nickel (tot.unfilt)	µg/l	0.5	500
Zinc (tot.unfilt)	µg/l	3	1000
Phenols			
Cresols (low level)	µg/l	0.006	
Phenol (low level)	µg/l	0.002	50
Sum of Detected Monohydric Phenol	µg/l	0.016	
Xylenols (low level)	µg/l	0.008	
Mineral Oil / Oils & Greases			
TPH / Oil & Greases	mg/l	1	20

Chapter Four: Discussion of Findings

Findings

Though mining is extractive in nature and always has adverse effects on the environment, it is important for the mining firms to look after the impacts that the mining activities pose on the environment and try to curb these impacts as much as possible, making mining eco-friendly.

As seen from the results, most of the parameters are found outside the permissible limits. The main findings are as follows.

- The entire total unfiltered metals including Iron, Mercury, and Arsenic, Chromium, Copper, Lead, Nickel and Zinc concentrations in the rivers were generally higher than the limit of Liberian Standard and WHO standards.
- Concentration levels of all other toxicologically relevant dissolved filtered metals, including Chromium, Chromium trivalent, Chromium hexavalent and Vanadium were either below the limit of detection or lower than the standard set by WHO for drinking water which is a plus, except for Boron and Manganese that were above the Liberian and WHO Standards.
- Relatively high levels of Chloride (especially for Sample SW-84), Cyanide and Dissolved Solid were found in all river samples due to probably the effect of salt water from the sea.

Chapter Five: Conclusion

It is clear from the results that mining activities have resulted in some environmental anomalies particularly in surrounding water sources. Low pH, high chromium and iron content are some irregularities to support this.

However, ArcelorMittal has done a good job at keeping the concentration of some of parameters within the permissible limits. River Savage water sample were found to be of average good water quality satisfying basically Class III water quality standards for Liberia. However, they have to look after their pollution control methodologies as some of the parameters are still outside the permissible limit, which affects the quality of well. All the water samples were found to be above the WHO and Class I (drinking water) of the Liberian Standard which may be due to run-off from their stockpile into the river, or previous operations carried out by the Liberian American-Swedish Mineral Company (LAMCO). Proper measures must be taken to curb this. Water must be properly treated before allowing it to drain into nearby creeks or ocean.

Chapter Six: Recommendation

It is advisable that proper management of water pollution, like recycling of decanted effluents before discharging into nearby waters can be adopted for iron ore washing plants and building efficient stockpile facilities to help avoid run-off water or seepages from contaminating river savage. It will cause less consumption of raw water and less surface water pollution due to less discharge in the natural bodies. There is a need of improvement in environment monitoring process of mining operations by the require agencies and ministries to avoid such unevenness and help build a safe and clean environment for all Liberians.

I will like to also recommend to the Ministry of Mines and Energy and Environment Protection Agency to partner with University of Liberia to ensure students conduct periodic field visits and enable research proceedings in various disciplines that are pertinent to the colleges at the University of Liberia.

Chapter Six: References

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Appendix

Figure 1: Map of Liberia showing location of ArcelorMittal concession area (Source: Hadden, 2006)

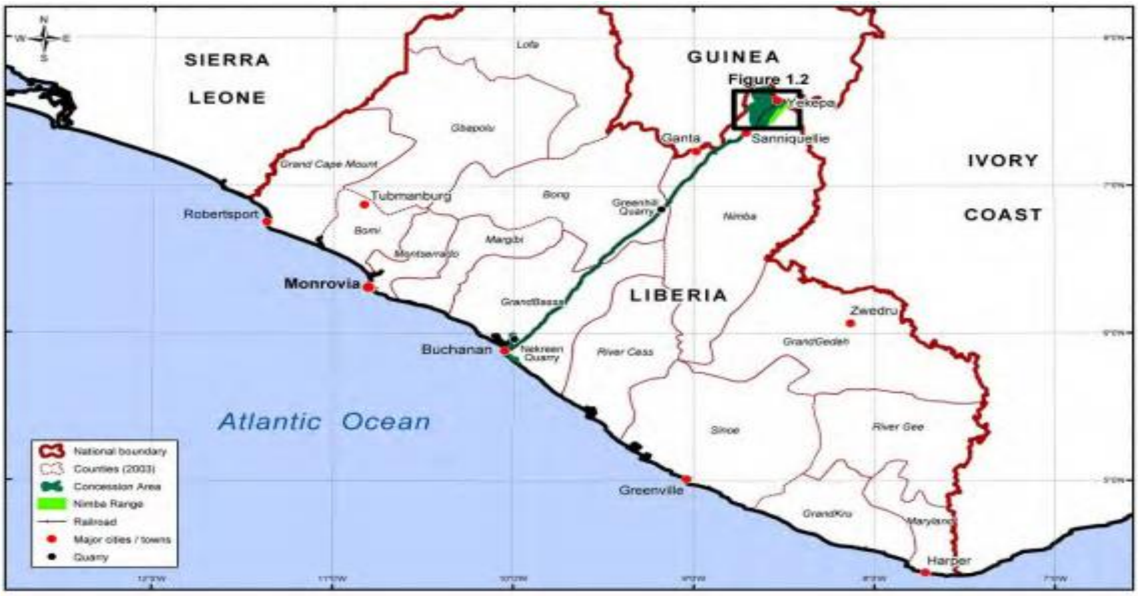

Figure 2: Map of Liberia Showing locations of past four major iron ore mining companies (Source: Van der Kraaij, 2010)

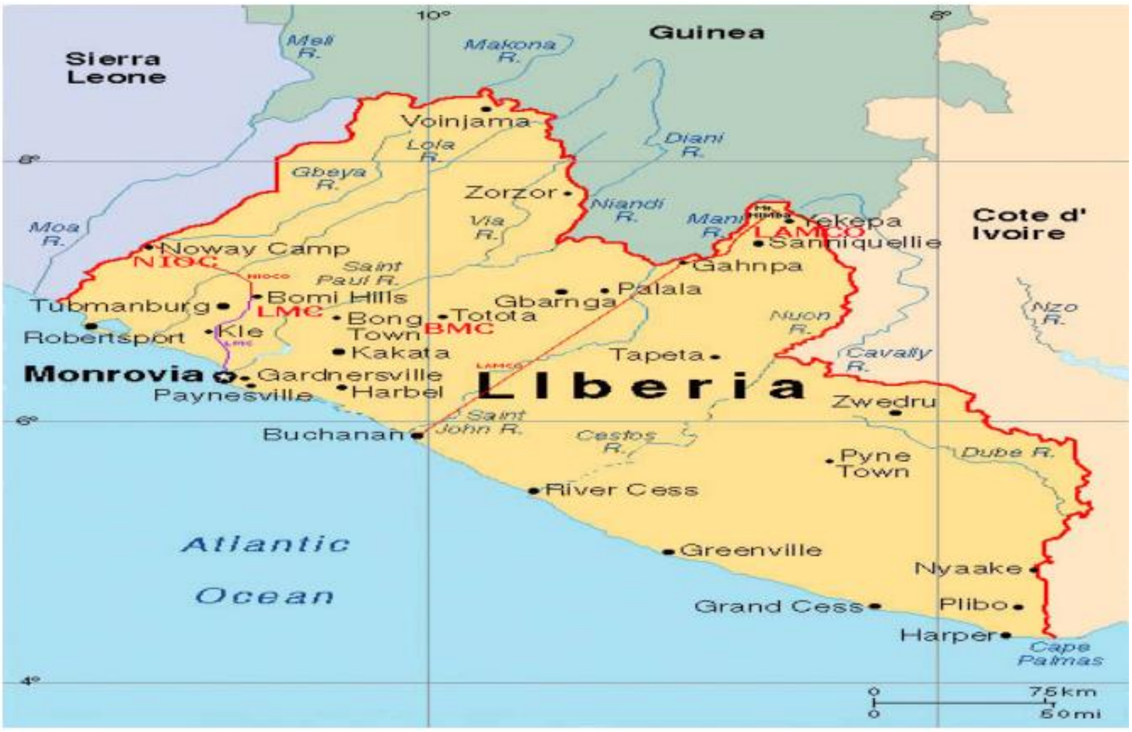

Figure 3: Acid Mine Drainage (Source: SOSBlueWater.org)

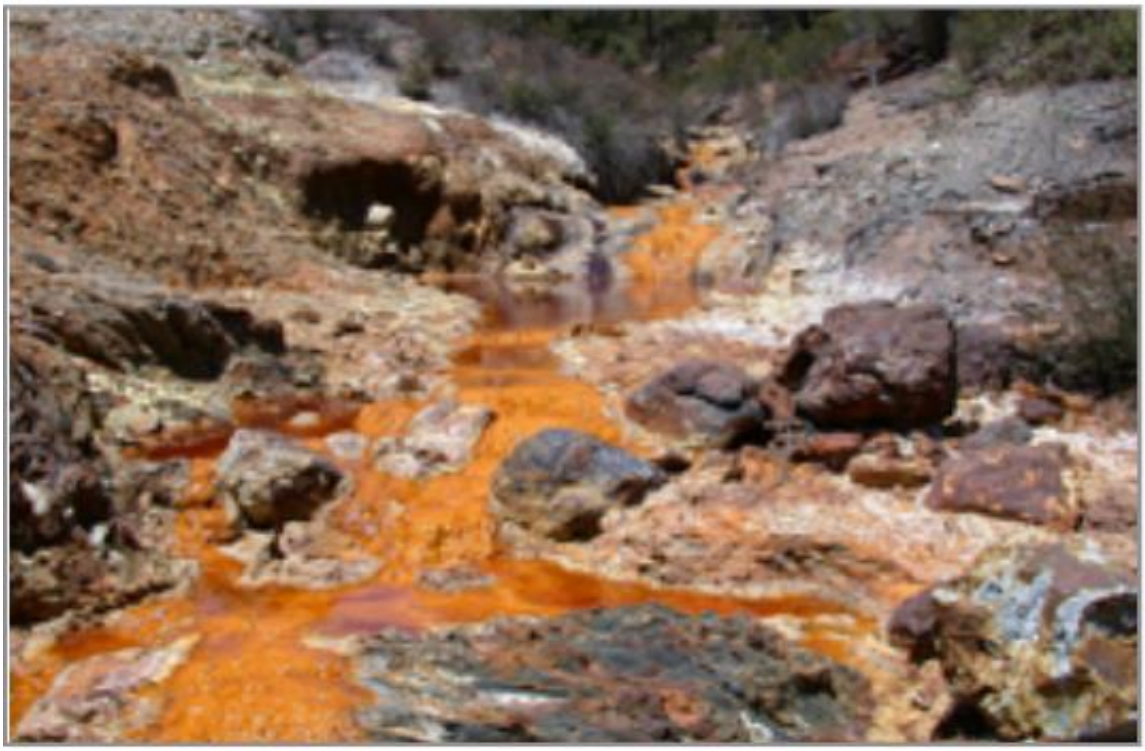

Figure 4: Overburden Drainage at an Australian Mine (Source: Peripitus)