# ASSESSMENT OF HEAVY METAL POLLUTION IN SOIL AND SURFACE WATER IN MNG-GOLD, KOKOYA DISTRICT, BONG COUNTY, LIBERIA

**A THESIS PRESENTED TO THE DEPARTMENT OF MATERIAL SCIENCE AND ENGINEERING**

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**BY**

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**ASSESSMENT OF HEAVY METAL POLLUTION IN SOIL AND SURFACE WATER**

**IN MNG-GOLD MINE, KOKOYA, BONG COUNTY, LIBERIA**

By

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## DECLARATION

I, the undersigned, declare that this thesis is my personal work written under the direct supervision of my advisor, Professor Richard Kwasi Amankwah and has not been presented and published as a thesis for a degree in any other university. All relevant materials used or cited for this work have also been duly acknowledged for their contributions.

**ABSTRACT**

The presence of heavy metals in water and soil by metalliferous mining activities at MNG-Gold Mine was fully investigated. The extraction of gold in recent years, has led to the generation of huge quantities of solid and liquid wastes. During the course of the investigation, fourteen samples including surface water, groundwater and soil were collected and analyzed to determine physio-chemical parameters and heavy metal contents. Atomic Absorption spectrometer (AAS FS 240) was used to analyze iron (Fe), zinc (Zn), nickel (Ni), manganese (Mn) and lead (Pb) in samples from Adana, old TSF, new TSF and St. John River. Garmin 60 GPS was used during the field exercise to determine the coordinate points. The fourteen samples collected from water, soil and underground water were stored in 250 ml polyethylene bottle and kept at $19^0$ C before analysis was conducted. The findings revealed that the iron concentration in water and soil at certain places was extremely high as compared to other metals.

Out of 14 samples analyzed, five heavy metals such as Fe, Zn, Ni, Mn and Pb were detected in water at Adana, old TSF, new TSF and St. John River. The concentrations range from < 0.01 to 1.58, < 0.02 to 0.02, < 0.01 to 0.03, < 0.01 to 0.08 and < 0.01 to 0.02 ppm. Also, Fe, Zn, Ni, Mn and Pb were detected in sediment samples at Adana, old TSF, new TSF, Saprolite and St. John River and the concentrations range from 50,000-120,000 ppm, 15-55 ppm, 10-200 ppm, 50-1000 ppm and 5-20 ppm respectively. Except for iron, all the other metals were below the WHO maximum thresholds.

**Keywords** Heavy metals, soil, water, pH, Atomic Absorption Spectrometer, contaminants, GPS polyethylene bottle.

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appreciate you for the wonderful time together. You will always remain ingrained in my mind where ever I go.

## DEDICATION

I am deeply humbled and honored to dedicate this thesis to my beloved wife, daughter and my parents for their unconditional love, support and prayers offered during my sojourn in acquiring quality education.

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| | |
|---|---|
| **AAS** | **Atomic Absorption Spectrometer** |
| **AM** | **Arbuscular Mycorrhizal** |
| **AMD** | **Acid Mine Drainage** |
| **AMLIB** | **American Liberian** |
| **ARD** | **Acid Rock Drainage** |
| **ANFO** | **Ammonium Nitric Fuel Oil** |
| **ASM** | **Artisanal Small- Skill Mining** |
| **Au** | **Gold** |
| **BGM** | **Bureau De Geologie et Mine** |
| **BGS** | **British Geology Survey** |
| **BH** | **Borehole** |
| **BOD** | **Biological Oxygen Demand** |
| **Cd** | **Cadmium** |
| $CO_2$ | **Carbon dioxide** |
| **Cr** | **Chromium** |
| **CSZ** | **Cestos Shear Zone** |
| **Cu** | **Copper** |
| $CuSO_4$ | **Copper (II) sulphate** |
| **DO** | **Dissolved Oxygen** |
| **EC** | **Electrical Conductivity** |
| **EIAs** | **Environmental Impact assessments** |
| **EPA** | **Environmental Protection Agency** |
| **FAO** | **Food and Agricultural Organization** |
| $FeOH_3$ | **Ferric Hydroxide** |
| **Ga** | **Billion years ago,** |
| **GPS** | **Global Position System** |
| **HCL** | **Hydrochloric Acid** |
| **HF** | **Hydrofluoric Acid** |
| **HM** | **Heavy Metal** |
| $HCLO_4$ | **Perchloric Acid** |
| $HNO_3$ | **Nitric Acid** |
| **ICP-MS** | **Inductively Coupled Plasma Mass Spectrometer** |
| **ISO** | **International Standard Organization** |
| **KHY-LAB** | **Kokoyah Laboratory** |
| **LEITI** | **Liberia Extractive Industry Transparency Initiative** |
| **LGS** | **Liberia Geological Survey** |

| | |
|---|---|
| **Ma** | **Million Years Ago,** |
| **Mn** | **Manganese** |
| **Ni** | **Nickel** |
| **NE** | **Northeast** |
| **NW** | **Northwest** |
| **Pb** | **Lead** |
| **pH** | **Potential Hydrogen** |
| **Ppm** | **Part per millions** |
| **SD** | **Standard Deviation** |
| **SDWF** | **Safe Drinking water Foundation** |
| $Na_2S_2O_5$ | **Sodium metabisulfite** |
| **TDS** | **Total Dissolved Solid** |
| **TSF** | **Tailing Storage Facility** |
| **TTG** | **Tonalite-Trondhjemite-granodiorite** |
| **USGS** | **United States Geological Survey** |
| **WHO** | **World Health Organization** |
| **Zn** | **Zinc** |

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND TO THE STUDY

Mining and ore beneficiation processes, such as grinding, ore concentration processes and disposal of tailings provide obvious sources of contamination in the surface environment, along with mine and mill waste water [1]. Throughout history, mining in the world has been regarded as destructive due to its anthropogenic activities on the environment. The release of heavy metals is the major cause of environmental problems affecting communities where mining is done and steps must be taken to safeguard the environment against pollution such as water and soil pollution during and after mining.

Some of these metals are hazardous and carcinogenic and can cause serious health problems in humans if they are absorbed into the human body through the food chain. In recent history of mining, metal contamination has created potential environmental issues for the people and the environment. As a result of this, in some places where mining is done, the people have instigated violence against mining company due to their failure to control wastes emanating from processing plants. Sometimes untreated mining wastes are discharged directly into rivers or nearby streams [2].

These rivers are used by people either for irrigation purposes during the dry season or for domestic purposes. The presence of heavy metals in aquatic environments has contributed to a life-threatening situation to marine life. The sources of pollutants are industrial mining and ore beneficiation, domestic and agricultural wastes. Based on several investigations it has been established that, heavy metals concentrate in the sediment samples [3]. According to [4], sediments contain toxins that may accumulate in fish indirectly through the food web or indirectly from exposure due to re-suspended sediments. Low concentrations of some trace metals, such as Cu, Mn, Zn and Fe are good for all living organisms while some have been detected in biotas, sediments, and water [5]. Toxic metals can change many physiological processes and biochemical parameters in tissues including structural deformations in aquatic animals [6]. Being non-biodegradable, they can be concentrated along the food chain, producing their toxic effects at points often far away from the source of pollution [7]. In addition, with anthropogenic activities, ultimate disposal of treated and untreated waste effluents containing toxic metals as well as metal chelates [8] from different industries, e.g., tannery, steel plants, battery industries, thermal power plants, etc. and also the indiscriminate use of heavy metal-containing fertilizers and pesticide in agriculture results in deterioration of water quality, rendering serious environmental problems posing threat on human beings [9] and biodiversity [10]. Prolonged exposure to heavy metals such as cadmium, copper, lead, nickel, and zinc can cause deleterious health effects in human [11]. Previous studies revealed carcinogenic effects of several heavy metals such as cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg) and arsenic (As) [12].

The MNG-Gold is the Turkish company which has been mining gold in Liberia since 2015. It has a property ownership which stretches over 537 $km^2$ piece of concession land. The company is situated in the Kokoya district, Bong County, Liberia, approximately 50 km southeast of Gbarnga, the capital city of Bong County and some 170 km northeast of Monrovia, the capital city of Liberia as presented in Figure 1.1. According to the mineral potential map of Liberia, the mineral predominantly found and mined is gold. The mine established in this area is an open pit. It comprises of three open pits; namely, Arhavi, Istanbu and Adana respectively. The length, width and depth of the three open pit mines are presented in Table 1 and Figure 1.2. At the top of each pit consists of the saprolite zone and moving into formation of the soil are composed of hard competent rocks. Extending deep into the ground formation, there is major intrusion of the quartz and amphibolite into gold belt. The rock type is gneiss, amphibolite and quartzite associated with the gold. The climatic condition consists of both rainy and dry seasons. Each season has six-month period. The rainy season begins May and ends in October while the dry season kicks up November to April respectively. Prior to the coming of this multinational company, the people of Kokoya were engaged in artisanal and small-scale mining activities for their livelihood. They were also involved with subsistent farming which benefited them to some extent.


**Figure 1.1: Political Map of Liberia indicating major areas**

**Table 1: Dimensions of the Three open-pit Mine**

| Open Pit | Length(M) | Width(M) | Area($M^2$) | Depth(M) |
|---|---|---|---|---|
| Arhavi | 460 | 220 | 101200 | 120 |
| Istanbul | 170 | 165 | 28050 | 110 |
| Adana | 365 | 315 | 114975 | 95 |

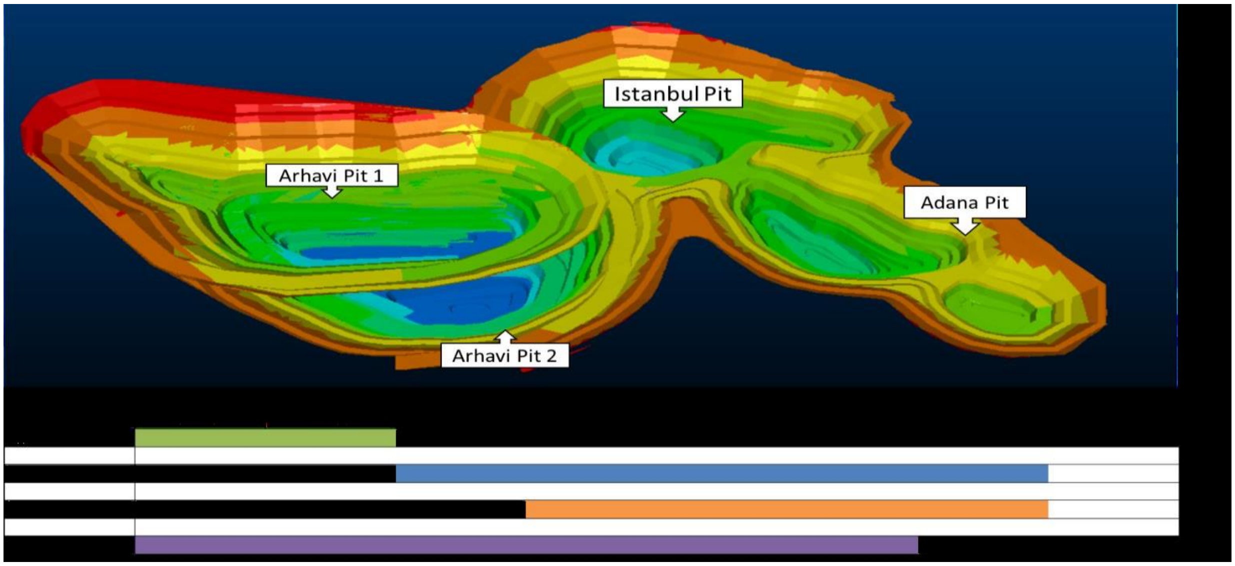


**Figure 1.2: The Mining Sequence of the 3D Print of The Open-Pit Mine, Kokoyah District**

## 1.2 STATEMENT OF THE PROBLEM

Liberia is blessed with abundant mineral resources such as gold, diamond and iron ore but many parts of the country are yet to be explored. Prior to the outbreak of the civil conflict in 1989, Liberia was among the leading exporters of iron ore in the world. In 2012, exploration activities were previously conducted by Amlib in Kokoya, Bong county on the shear zone at KleKle, now owned by MNG Gold, and several broad zones of gold mineralization have been defined [13]. Due to limited funds, the investment was later sold to MNG Gold.

Initially, the American Liberian (AMLIB) joint venture company did a resource estimate on the licensed property worth 380,000 oz of gold before being subsequently sold to MNG gold in 2014. As presented in Figure 1.3, MNG Gold project area is located in the central part of Liberia. It is situated between three counties of Liberia; namely, Bong, Nimba and Grand Bassa respectively. The area also has access to train track which runs from Yekepa, Nimba county to the port city of Buchanan, Grand Bassa county. It is the transport route for the iron ore being mined by Arcelor Mittal in Liberia. Subsequently, the project was later expanded to approximately 600,000 oz after being taken over by MNG. The project also has mineable underground potential. The reginal morphology of this area is mainly associated with Archaen

West African craton which comprises mainly Precambrian igneous and metamorphic rock types called the Liberia Age Province (2700Mya). The gold is embedded in quartz vein-deposit and strongly deformed in amphibolites and gneisses. The ore is extracted/mined by open pit method. In the mine, explosives such as Ammonium Nitrate and fuel oil (ANFO) are used to blast massive ore containing hard competent rocks. However, the blasting of the rocks sometimes releases dust in the environment, which eventually settle down in the river or nearby streams. As these rocks are fragmented into smaller boulders, they are transported by trucks from the run-off mine and then stockpiled. At the stockpile, separation of high grade from the low grade is considered. Subsequently, materials are fed into the grizzly hopper which is robustly built to accommodate materials about 1m in size to move into the jaw crusher. The jaw crusher which contains a movable jaw and fixed jaw, crushes the materials then transports through conveyed belts and delivers it to the grinding mill for ore beneficiation.

During the beneficiation process, several methods are employed to recover the gold. For example, cyanide is used to dissolve the gold in solution before it is adsorbed by activated carbon. The loaded carbon is subsequently removed from the circuit and sent to elution where the gold is stripped off the carbon back into solution, electrowon and smelted into bars. The remaining 'barren' solution is sent to detoxification tanks where sodium metabisulfite ($Na_2S_2O_5$) and copper (II) sulphate ($CuSO_4$) are added to destroy the cyanide. The waste materials from the processing units are then discharged into the tailing dams. According to the company regulation, the maximum allowed cyanide concentration that should be discharged into the dam is ±50 ppm (MNG gold, 2019). In some cases, the cyanide concentration exceeds the maximum allowable concentration. If such is observed, more copper sulfate and sodium metabisulfite is added to the detoxification tanks to avoid major pollution. Currently, the MNG gold has two dams. The first tailing dam constructed collapsed in 2018 due to structure failure. As a result of the collapsing of the dam, overflow of waste materials from the dam ran into surrounding swarms and streams which caused environmental problems. The next dam constructed in recent times also receive wastes from the processing plant and subsequently send them to another dam which is 2.5 km away from the new storage facility or tailing dam. At this dam, the waste is treated before discharging into the St. John River.

According to report by [14], metallic tastes of the contaminated water of the mine can stain the surfaces and cause an unpleasant water taste. Water pH also causes corrosion of metal components used in industry [15]. This can lead to grounding of machine tools.


**Figure1.3: Map of Liberia indicating MNG gold property, Kokoyah.**

**Source Available at AZOMining.com**

### 1.3 OBJECTIVE OF THE STUDY

The objectives of this research were to investigate the contamination level of heavy metals in water and soil along with their physio-chemical parameters (temperature, dissolved oxygen content, pH and electrical conductivity) collected from different locations in MNG gold, and to recommend the preventive mechanisms for the mitigations/remediations of pollution level of water and soil in the environment.

## 1.4 IMPORTANCE OF THE STUDY

Mining activities come with lot of social-economic benefits and consequences. This study is important for two reasons. Firstly, mining activities create potential economic investment in the country leading to employment opportunity for both unskilled and skilled workers. Secondly, the consequence is that, it creates environmental problems which may lead to land degradation, habitat alteration and water and air pollution. So, this research leads us to review the impacts of mining activities done on the environment in order to ensure a safe working environment. In so doing, mining companies may be compelled to treat wastes properly before releasing it into the environment.

## 1.5 THE RESEARCH QUESTIONS

The questions which arise during the research are as follows:

1.0 What is the mining method used to extract the gold from their bed?

2.0 Is there any hydrological challenge? If yes, how can it be solved?

3.0 What are the heavy metals and other chemicals released from the plant?

4.0 What is the source of water in the pit? (groundwater or rainwater)

As a result, the above questions are found in previous and subsequent chapters.

### 1.6 SCOPE AND LIMITATION OF THE RESEARCH

#### 1.6.1 Scope of the research

The research reviewed past works along with present ones on heavy metal concentration in soil and water. Information gathered from literature enabled us to conduct sampling. After collecting samples for both water and soil, they were sent to the KYH- lab-3602 to determine the heavy metal levels in both soils and waters. Other parameters assessed were pH, temperature, dissolved oxygen (DO) and electrical conductivity (EC).

#### 1.6.2 Limitation of the research

In the context of this research, tests were conducted on soil, surface and underground water samples to determine the pH, EC, temperature, DO and heavy metals respectively. However, the turbidity, salinity of water and compatibility test could not be determined.

## CHAPTER TWO

## LITERATURE SURVEY

In the past and the present, several works detailing heavy metal contents in both soil and water have been reviewed and published by many writers and publishers in mining journal and other significant documents [16]. Gold which has symbol Au and atomic weight 196.96 is a heavy metal. Although there is no precise definition of what a heavy metal is, density in most cases taken to be the defining factor. Heavy metals are thus commonly defined as those having atomic weight and specific density at least six times greater than that of water [17]. When heavy metals such as lead, cadmium, mercury and the metalloid arsenic are exposed to the environment in high concentrates, due to their multiple industrial, domestic, agricultural, medical and technological applications, there is wide distribution in the environment; raising concerns over their potential effects on human health and the environment. The presence of heavy metals in soil and water depends on several factors which include chemical species, the dose and amount of exposure. Also, the heavy metals such as, arsenic, cadmium, chromium, lead and mercury rank among the priority metals that are of public health concern. According to the U.S. Environmental Protection Agency, and the International Agency for Research on cancer [18] they consider heavy metals as systemic toxicants that damage human's organ, even at lower levels of exposure.

Also, prolonged and contaminated waste water that is subsequently used for irrigation may lead to the accumulation of heavy metals in soil and plant. Food poisoning and potential health risks cause most serious environmental problems [19]. At lower concentration, some of the heavy metals such as Zn, Mn, Ni and Cu behave as micro-nutrients; however, they become toxic at higher level. According to [20], health risks due to heavy metal pollution of soil has been widespread in mining activities. In comparison, crops and vegetables grown in contaminated soils with heavy metals have more accumulation of heavy metals than those grown in uncontaminated soil [21].

## 2.1 GEOLOGY OF LIBERIA

Liberia is a part of the West Africa Craton which constitutes two major features of the Archean to early Proterozoic terranes: The Man Shield and the Reguibat Shield. The Man Shield composed of the Archean basement of Liberian Age (3.0 to 2.5Ga) stretches across central and western Liberia and is characterized by TTG gneisses, locally migmatitic, which are folded with supracrustal metavolcanics and metasedimentary rocks and intruded by late-Archean granitoids dated at c. 2800Ma [22]. In the eastern and northern direction, the Man Shield is overlain by Birimian rocks of Paleoproterozoic age which is presented in (Figure 2.1).

The Archean Liberian-Age province is separated from eastern Birimian Ebumian- Age province by the regional, northeast trending Cestos shear Zone (CSZ). The Liberian province is described as a typical Archean granite- greenstone type terrane in that it can be subdivided into infracrustal rocks, supracrustal rocks and basic and ultrabasic igneous intrusion. Most of the rocks Baoule'- Mossi domain in Liberia, extending west from the Cote d'Ivoire border to Greenville, comprise tightly folded paragneiss, mimatite and amphibolite [23]. These rocks have been considered to be part of the Birimian sequence [24], but they are generally poorly known with little published modern research. Basically, there are three age province rocks formed in Liberia. These comprise of the Liberian Age province, the Pan African- Age rock and the Eburnean Age province (Figure 2.1). Liberian Age Province (2600-2700 million years) consists of granitic gneiss and granites which are mainly made up metasedimentary, containing schists, quartzites and iron formations. Eburnean Age province (2000 million years) composed of Paleoproterozoic which is an extension of the Baole-Mossi Domain of the Ivory Coast and contains less gneiss than the Liberian Age province [25] and underlain by isoclinally folded biotite- rich paragneiss. Pan African- Age Province (c. 550Ma) runs parallel to the coast, extends into northwest Liberia and consists of elongate and fault- bounded zone. Pan African province has a series of south- west dipping faults associated with intense zones of mylonite. It is formed along much of Liberia's coastline. They are associated with metasedimentary and mafic igneous rocks such as granitic and noritic.

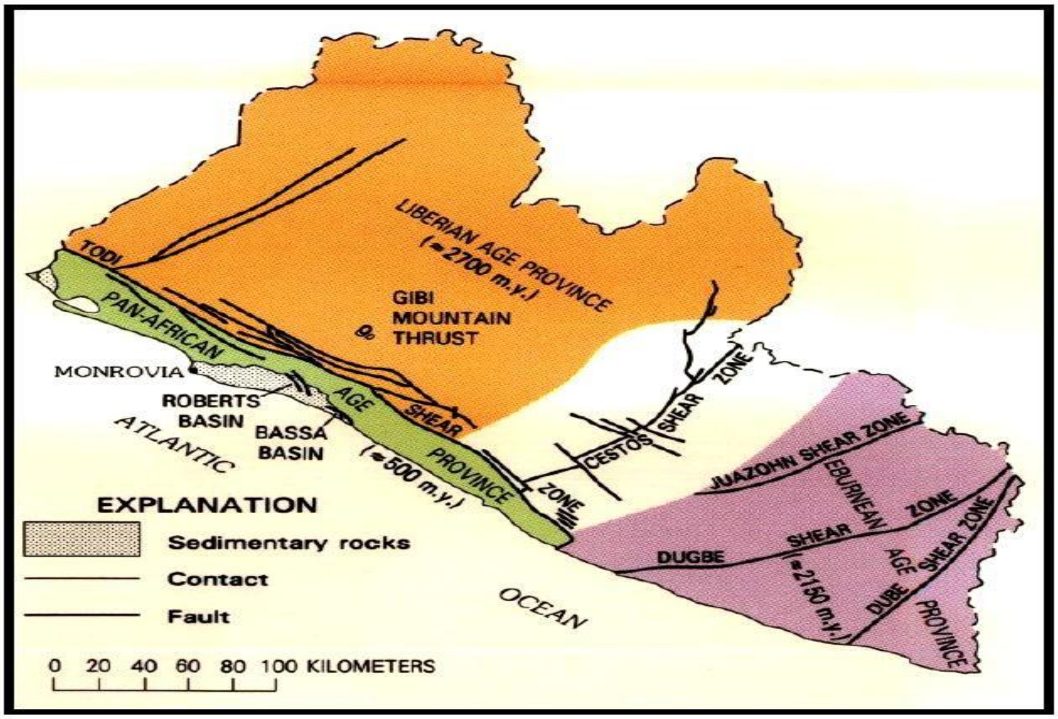


**Figure 2.1: Geologic Structural Unit of Liberia**

## 2.2 CLIMATE AND VEGETATION

Liberia is bounded on the west coast of Africa within the Mano river basin. It is bounded on the Atlantic Ocean in the south, Sierra Leone in the west, Guinea in the north and Ivory Coast in the east. Along the African continent, Liberia is located $6.4281^0$ N and $9.4295^0$ W which is characterized by predominantly tropical humid climate. It extends few degrees north above the equator and lies south of the Tropic of Cancer. The total land area of Liberia is estimated to be 111,370 $Km^2$. Out of the total number, 96,160 $km^2$ is covered by land while the remaining 15,210 $km^2$ is covered by water. The climatic condition in Liberia comprises of two seasons: the rainy and dry season. The rainy season begins May then reaches a maximum in July through September, and declines in October whereas the dry season kicks up in mid-October and ends in April. However, on the coastal plain, especially, Monrovia and Buchanan receive the highest number of rainfalls at the beginning of the rainy season. Also, they experienced a short period rainfall in October. This period is known as ''middle dries''. In the central part of the country as shown in Figure 2.2, the rainy season kicks off in April then continues for a period of three months and proceeds by a drier season for a maximum of three months. Between September to November, there is little bit of rainfalls which is sometimes refer to as ''middle dries. The short dry season has little effect on the people. This is because the Harmattan or cool Northeastern winds which sweep across the continent reaches Liberia in December and February cause intense amounts of dust with low cold temperature during the night. The average annual rainfall along the coast of Liberia is at least 4000mm and reduces to 1300mm extending to the northern part of Savannah belts [26]. The overall temperature of Liberia varies between $27^0$C to $32^0$C during the day while it ranges between $21^0$Cto $24^0$C during the night respectively. The minimum average rainfall temperature of Kokoya is $25.5^0$C, and the maximum precipitation is 2076mm. Along the coastal parts of Liberia, study has shown that the relative air humidity varies from 90% to 100% during the rainy season (July to August) and from 80% to 85% during the dry season (January to February).

The word vegetation means assemblages of plant species and ground covering the surface of the earth (Burrow, 1990) [27]. In Liberia, vegetation can be characterized into three main zones. They are: (Savannah woodland), northern Savannah and the tropical rainforest [28]. The Savanna vegetation is mainly caused by anthropogenic activities such as clearing of land to make farming. The northern Savanna region in Liberia is covered with elephant grass which are intermixed with scattered tress, woodland and patches of forest. These types of forest are mainly found in Lofa and Nimba counties. The third type of vegetation is the tropical rainforest. Over the years, this rainforest has been progressively reduced at the rate of 1.5% per annum. This is due to shifting cultivation and the felling of trees in the Liberian forest.


**Figure 2.2: The eighth Statutory districts of Bong county**

### 2.2.1 Gold formation

Liberia is endowed with many mineral resources but chief resources are gold, diamond and iron ore. 90 percent of Liberia lies within the Birimian and Archean which have most productive gold- bearing terranes in the world. Nearly 600 gold occurrences were recorded by USGS in Liberia, with the gold placer deposits accounting for almost 80 percent of the total [29].

Several 'gold belts' have been identified based on the distribution of alluvial placer deposits. These are located in Bukon Jedeh, Putu Range- Zwedru, Cestos River, St. John River-Kokoyah, Mano River-Wologizi Range, Masawo-ZoloWo- Zorzor, Bopolu-Wuesua-Tawalata and Bea Mountain. A good number of alluvial placer deposits are formed in some of these areas. The widespread occurrence of placer deposits indicates potential for bedrock-hosted gold mineralization. Bedrock gold deposits along the Archean and Proterozoic terranes in West Africa are highly mineralized shear zone and structurally-controlled quartz veins, greenstone-hosted gold mineralization.

Economically, the most important gold occurrences in the Archean greenstone belts are found in the north-west of Liberia. It is mainly associated with lineaments and shear zone. New Liberty Gold Mine is a shear zone-hosted gold deposit in Archean age rocks with greenstone belt. Another major gold occurrence occurs north- east of New Liberty gold. In addition, Weaju and Ndablama are currently undergoing significant exploration. Ndablama is hosted in the sheared ultramafic and mafic rocks intercalated in a gneiss sequence above a buried granitic body. In Ndablama, based on geology investigation, the mineral resource estimate including (indicated + inferred) consists of 901000 ounces of gold at grade of 1.6g/t Au.

In the Kpo Mountain Gbarpolu county, several mineralization was discovered due to recent exploration activities which identified major gold-bearing quartz veins. To the north of the Kpo Range, gold-bearing vein, are associated with hosted granitic gneiss. Also, this rock occurs in the lucky Hill (Gblita) area. Mineralization appears to be based on the lithological contact between granite and granitic gneiss

### 2.2.2 LOCAL GEOLOGY

Kokoya is situated within Liberia Age province. It constitutes the metamorphic rocks which compose mainly structural grains. Also, several deformations are recorded in the metamorphic rocks, comprising folding and faulting. Those metamorphic rocks found in kokoya are strongly deformed in amphibolite, gneiss and quartzite. Moreover, these metamorphic origins have undergone poly-phase deformation and display number of cross-cutting features. Several areas in Kokoyah have undergone high degrees of partial melting resulting in migmatitic textures. However, gold mineralization occurs along a series of broadly NE-trending, NW-dipping, shears and veins as shown in Figure 2.3. Table 2 shows the total mineral occurrences of Liberia.

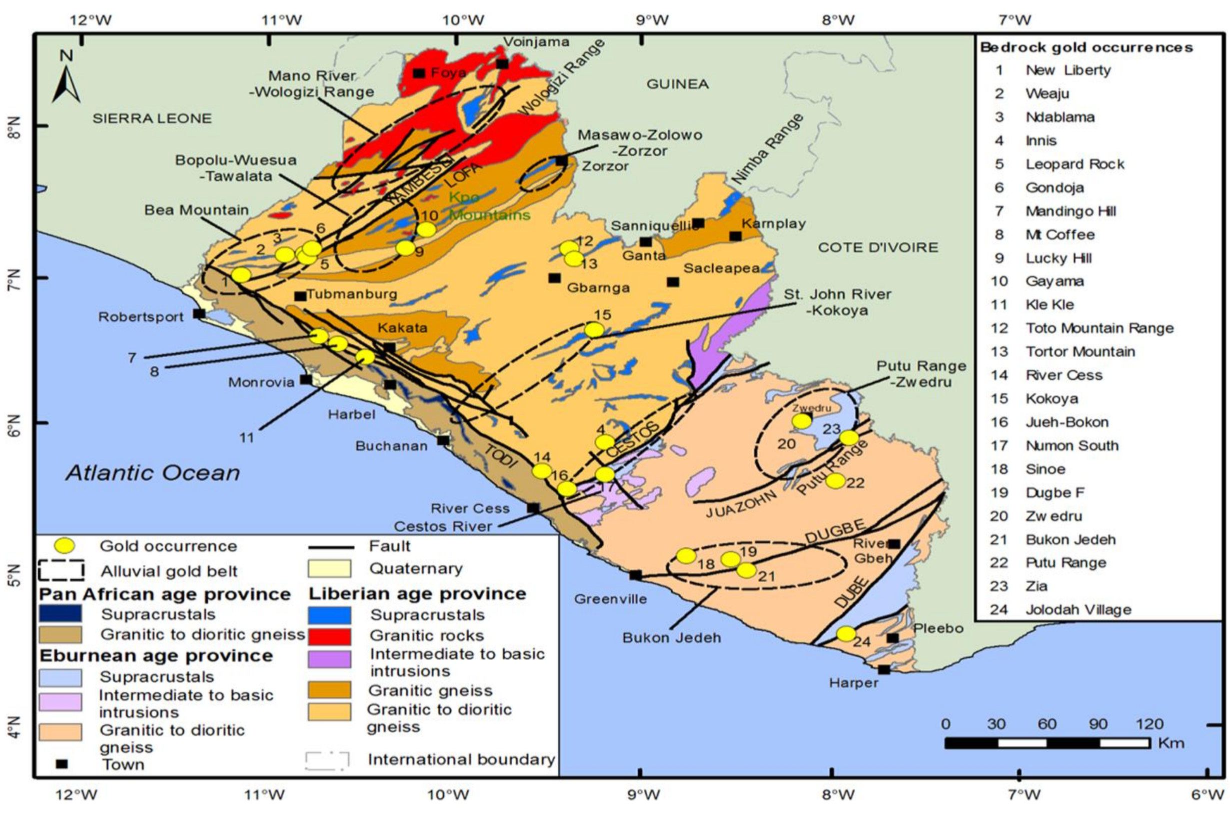


**Figure 2.3: the occurrences of gold in Liberia.**

**Source:** sciencedirect.com

**Table 2 Total Occurrences of Minerals in Liberia (LEIT, 2015)**

| No. | Ore type | Number of occurrences |
|---|---|---|
| 1 | Barite | 14 |
| 2 | Bauxite | 9 |
| 3 | Chromite | 12 |
| 4 | Copper | 14 |
| 5 | Corundum | 31 |
| 6 | Diamond | 158 |
| 7 | Gold | 258 |
| 8 | Heavy minerals | 19 |
| 9 | Iron | 172 |
| 10 | Kyanite | 5 |
| 11 | Vanadium | 5 |
| 12 | Manganese | 25 |
| 13 | Molybdenum | 4 |
| 14 | Nickel | 8 |
| 15 | Niobium, tantalum | 22 |
| 16 | Phosphorite | 2 |
| 17 | Platinum | 2 |
| 18 | Rutile | 94 |
| 19 | Sulfur | 3 |
| 20 | Tin | 10 |
| 21 | Titanium | 14 |
| 22 | Tungsten | 9 |
| 23 | Uranium | 3 |
| 24 | Wolframite | 2 |
| 25 | Zinc | 2 |
| Total | - | 897 |

## 2.3 THE HYDROGEOLOGICAL CONDITION OF MNG GOLD MINE

Following a thoroughly reviewed process of the local geology of MNG-gold, Kokoyah, it has been established that the hydrogeological condition of the area is challenged as a result of mining activities characterized by influx of both surface and groundwater into mine pit. The local geology describes in Section 2.2.2 indicates that gold is embedded in amphibolite, gneiss and quartzite respectively. At the northeast direction of the MNG gold, lies the St. John River which flows from the north of Guinea into Liberia. Much of the hydrogeological information about Liberia and its environs have not been studied in full details due to limited research capacity. However, the Bureau de Recherche Geologie et Mines (BRGM) has produced a hydrogeological map of Africa as part of Africa GIS network's ongoing project for mapping Africa resources. This map indicates that groundwaters in several parts of Africa are connected to small aquifer zones. The St. John River which is located approximately 2.5 km away from the mine site serves as a discharge point.

### 2.3.1 SURFACE WATER FLOW AND PIT DISCHARGE

Surface water is any water that collects on the surface of the earth. This includes oceans, seas, lakes, rivers or wetlands. The climatic condition of Liberia is categorized into two seasons. They are: the rainy and dry seasons. The dry season runs from November to April while the rainy season runs from May to October. During the rainy season, the mine is heavily flooded with water, sediment laden flood waters, rich in organic matter and nutrients which causes risks for operational activities, miners' safeties and environmental impact. Similarly, the problems of acid- mine drainage, excess inflow of rain water to mine pit affect the extraction processes of the metals. At the pick of the rainy season the mine gets flooded with water to the extent that it become inaccessible to mine. As a result, the Global water pump 8GHH and 4GSH with the capacities 605$m^3$/h and 313$m^3$/h are being installed to dewater the mine so that the extraction process can be effective and efficient.

### 2.3.2 Groundwater quality

Prior to investigating the groundwater quality in MNG, on September 24, 2018, a tailing storage facility containing slurry from MNG-gold's processing plants collapsed and ran in nearby Sien Creek and swarm. As a result of this incident, up to 30 people from the surrounding villages were hospitalized due to the effects of the spillage over of the slurry. The plant was shut down for a while to improve the environmental condition. In July 2019, water samples around the mine in Kokoyah were collected from five different locations.

### 2.3.3 General Concept of surface Mining

By definition, surface mining is the removal of soil and rock overlying the mineral deposit (the overburden) surface mining includes open-pit mining and strip mining. Both open-pit and strip-mining methods constitute more than 90% worldwide surface production. However, the major distinction between these two mining methods are the geographical location of the ore body and the mode of mechanical extraction. Strip mining (open cast mining) techniques involve the extraction of ore bodies that are near the surface and relatively flat or tabular in nature and mineral seams. In strip mining, equipment such as shovels, trucks, drag lines, bucket wheel excavators and scrapers are used. Most strip mines process non-hard rock deposits such as coal. Open-pit mining involves the removal of hard rock ore that is disseminated and/ or located in deep seems and is typically limited to extraction by shovel and truck equipment. For example, gold, silver and copper are mined by open pit method. Another surface mining method is quarrying mining. It is specialized open-pit mining technique wherein solid rock with a high degree of consolidation and density is extracted from localized deposits quarried materials are either crushed and broken to produce aggregate or building stone, such as dolomite and limestone, or combined with other chemical to produce cement and lime. Dimension stone such as flagstone, granite, limestone, marble, sandstone and slate represent a second class of quarried minerals. Sometimes it becomes very difficult to mine some ore bodies by strip or open pit methods due to its irregular size and shape. More advanced surgical method such as underground mining is employed to extract the ore. The factors that justify open pit mining includes: The terrain and elevation of the site and region, its remoteness, climate, infrastructure (roads, power and water supply, regulatory and environmental requirements, slope stability, overburden disposal and product transportation).

Production and equipment**:** mechanical drilling and blasting are the first steps in extracting ore from most developed open-pit mines and are the most common method used to remove hard rock overburden. Explosives are used. A commonly used hard rock explosive is ammonium nitrate, fuel oil and emulsifier. Also, drilling equipment is selected on the basis of the nature of the ore and the speed and depth of the holes necessary to fracture a specified tonnage of ore per day.

Loading: surface mining is now typically conducted utilizing table shovels, front- end loaders or hydraulic shovels. In open-pit mining, loading equipment is matched with haul trucks that can be loaded in three to five cycles or passes of the shovels; however, various factors determine the preference of loading equipment. Haulage**:** haulage in open- pit and strip mine is most commonly accomplished by haul trucks. The role of trucks in many surface mines is restricted to cycling between the loading zone and the transfer point such as an in- pit crushing station or conveyance system.

### 2.4 ENVIRONMENTAL IMPACT OF GOLD ON MINING ACTIVITIES

Keeping wastes for irrigation over long period may lead to the accumulation of heavy metals in agricultural soils and plants. Biological toxic effects of heavy metals depend upon the concentrations and oxidation states of metals, sources and mode of deposition [30]. Like other creatures, humans should make the environment clean and safe, otherwise they cannot live, but unlike the others, human should choose the type and amounts of these changes [31].

Heavy metals are naturally occurring elements that have atomic weight and a density greater than that of water. However, most environmental problems originate from heavy metals. It is also widespread by industries where mining is practiced. Metal contamination has received huge condemnation from rights group as a result of toxicity issues. Multiple industrial, domestic, agricultural, medical and technological applications have led to their wide distribution in the environment; raising concerns over their potential effect on human health and environment. Their toxicity depends on several factors including the dose, route of exposure and chemical species, as well as the age, gender, genetics and nutritional status of the exposed individuals in the gold mining areas. Because of their high degree of toxicity, arsenic, cadmium, chromium, lead and mercury rank among the priority metals that are of public health significance. The heavy metals are considered systemic toxicants that are known to induce multiple organs damage, even at lower level of exposure [32].

### 2.4.1 EFFECTS OF HEAVY METALS

Mining, mineral processing and metallurgical extraction are the three principal activities of gold mining industries which contribute to the production of large volume of wastes; especially when the metal contents in an ore is very low to process. Mineral processing also known as beneficiation aims to physically separate and concentrate the ore mineral(s) using physical, chemical and sometimes microbiological techniques. Metallurgical extraction breaks the crystallographic bonds in the ore mineral in order to recover the desire element or compound [33]. Large quantities of waste are produced during this activity particularly in gold mines which release over 99% of extracted ore as waste to the environment [34].

Tailings are the major waste produced from gold extraction and they contain high amounts of heavy metals (HM). These metals may be dispersed in an uncontrolled manner into surrounding environments on exposure to water or through dispersal by wind. The presence of elevated concentrations of Heavy metals in the environment is a serious health issue worldwide due to their non-degradative nature which makes them persistent and thereby exert long- term effects on the ecosystem [35]. Heavy metals affect the natural population of bacterial in soils. This leads to loss of bacterial species responsible for material cycling with a consequent negative effect on ecosystem functioning [36].

### 2.4.2 EFFECT OF HEAVY METALS ON SOIL

Soil contamination of heavy metals is the most important apprehension throughout the industrialized world [37]. Heavy metal population not only result in adverse effects on various parameters relating to plant quality and yield but also cause changes in the size, composition and activity of the microbial community [38]. Therefore, heavy metals are considered as one of the major sources of soil pollution. Heavy metal pollution is caused by various metals especially Cu, Ni, Cd, Zn, Cr, and Pb [39].

Heavy metals are present in industrial wastes, agricultural processes, domestic wastes and vehicles emission, and they are considered as one of the most serious pollutants as a result of their high toxicity [40]. Heavy metals exhibit toxic effects towards soil biota by affecting key microbial processes and decrease the number and activity of soil microorganisms. Conversely, long-term heavy metal effects can increase bacterial community tolerance as well as the tolerance of fungi such as Arbuscular mycorrhizal (AM) fungi, which can play an important role in the restoration of contaminated ecosystem [41]. Cu inhibits b-glucosidase activity more than cellulose activity. Pb decreases the activities of urease, catalase, invertase and acid phosphatase significantly. Cd contamination has a negative effect on the activities of protease, urease, alkaline phosphatase and arylsulfatase but no significant effect on that of invertase. Each soil enzyme exhibits a different sensitivity of heavy metals.

Mining is the major source of soil contamination. It destroys large areas of farming lands near mining project. According to a study commissioned by the European Union: ''Mining operations routinely modify the surrounding landscape by exposing previously undisturbed earthen materials. Finally, soils contaminated from chemical spills and residuals at mine sites may pose a direct contact risk when these materials are misused as fill materials, ornamental landscaping, or soil supplements [42].

### 2.4.3 WATER POLLUTION

To begin with, water is the most vital resource used for the existence of human beings and without which; human cannot survive. Orlaniran [43] defined water pollution to be the presence of excessive amounts of a hazard (pollutants) in water in such a way that it is no longer suitable for drinking, bathing, cooking or other uses. Pollution is the introduction of a contamination into the environment [44]. Generally, pollution may also be defined when natural or induced change affects the natural quality of water which renders it unstable or dangerous to food, human and animal health, industry, agriculture, fishing, etc.

Basically, water pollution is influenced by anthropogenic activities which cause pollutants to enter natural waters. Water pollution containing solid or liquid wastes discharge directly into river, sea or ocean. The wastes that contribute towards water pollution may be grouped into three: sewage, industrial and agricultural wastes respectively. It originates from domestic and commercial premises, land drains, some industrial plants and agricultural sites. Other industrial waste is discharged directly into rivers, canals and the sea and not into sewage systems. Furthermore, sewage treatment can be subdivided into three stages. They are preliminary, primary and secondary treatments. The preliminary treatment removes large suspended debris and solid particles by screen. The primary stage removes approximately 55% of settleable solids as sludge, and 35% reduction in biological oxygen demand (BOD) value. The sewage at this point contain suspended colloids, finely divided solids and dissolved solutes. Lastly, secondary stage activates sludge method which applies in the modern sewage treatment plants. Also, the primary effluent is agitated and aerated in large tanks, in the presence of flocculent suspension of activated sludge containing microorganisms**.** Industrial wastes are located near rivers or fresh water streams. These are responsible for discharging their untreated effluents into rivers like highly toxic heavy metals such as chromium, arsenic, lead, mercury, etc. along with hazardous organic and inorganic wastes (e.g., acids, alkalies, cyanides, chlorides, etc.). Agricultural wastes comprise of manure, fertilizers, pesticides, wastes form farms, poultry farms, salts and silt are drained as run-off from agricultural lands. Similarly, the expansion of human population, industrial and agricultural activities is the major causes of pollution in our environment [45].

### 2.4.4 SURFACE WATER POLLUTION

As pollutants enter stream, river or lake they give rise to surface water pollution. Surface water pollution is the major problem in the mining industry. Ore is washed or processed in its slurry form for enrichment and after the extraction of useful mineral, tailings are rejected and stored in big ponds. These ponds may overflow during the rainy season or they may even breach their banks, carrying huge quantities of suspended and dissolved solid into surrounding areas [46-47].

The silt may get deposited in water courses or agricultural lands. Such waters may become unfit for direct usage and to make this water fit for consumption, elaborate treatment has to be done at additional cost. The spill-over of toxic material like heavy metal is a major problem in the iron ore mining sites were water becomes turbid [48]. However, many aquatic organisms live in the sea and ocean. As the temperature level in the water increases, life become very inhospitable for aquatic organisms to survive. Furthermore, the increase in Earth's water temperature is caused by global warming. Global warming is the average global temperature increases due to the greenhouse effect. For example, gases from the mine, burning of fossil fuel releases greenhouse gases in the form of $CO_2$, into the atmosphere thus causing intense heat back in the earth's atmosphere.

### 2.4.5 GROUNDWATER POLLUTION

Groundwater pollution may occur from the top or below the water table. If a contaminant is spilled on the surface of the ground or injected into the ground above the water table, it may have to move through numerous layers of soil and underlying materials before it reaches the groundwater [49]. As the contaminants move through these layers, a number of processes come in operation, (e.g. filtration, dilution, oxidation and biological decay), that can lessen the eventual impact of the substances once it finally reaches the groundwater. The distance between the groundwater and place of contamination introduction and length of time affects the effectiveness of these processes [50].

Substances which contaminate groundwater can be divided into two basic categories, substances that occur naturally and substances produced or introduced by man's activities. Substances that occur naturally included minerals such as iron, calcium, selenium etc. and substances resulting from man's activities includes synthetic organic chemicals and hydrocarbons, pesticides, petroleum products etc.) landfill and pond leachates [51]. One of the significant sources of groundwater contamination is the surface impoundments used by municipalities and industries for disposing off variety of liquid wastes and wastewater [52].

Also, the percolation of toxic components from ore waste and storage yards in mining areas causes' groundwater pollution. As a result, land also gets polluted [53]. Drinking water from contaminated ground well can cause serious health problems. Diseases related to hepatitis and dysentery are caused by contamination from septic tank wastes, contaminated groundwater can affect the wildlife.

### 2.4.6 EFFECT OF MINE- WATER POLLUTION

Major water pollution emanates from mining activities. Basically, there are four main types of mine water pollution which adversely impact the water quality; they are: acid mine drainage (AMD), heavy metal contamination and leaching, processing chemical pollution and erosion and sedimentation respectively. Acid mine drainage or acid rock drainage (ARD) is one of the major problems affecting waters. According to [54], acid mine drainage is also characterized by high total dissolved solids (TDS), high sulphates and high levels of heavy metals, particularly iron, manganese, nickel and cobalt. As shown in table 2.1, such that, the presence of low pH, high electrical conductivity, iron, manganese and aluminum contribute to the existence of heavy metals. However, dark, reddish-brown water and pH as low as 2.5 persist at the site [55]. Acid mine drainage as shown in Figure 2.4, affects not only surface and groundwater but also destroy the soil and water quality [56]. Also, Table 2.2 shows the Environmental Protection Agency and World Health Organization standard for some heavy metals.

During mining operation, huge volume of rocks composed of sulphide minerals are mined from open pits, which reacts with water and oxygen if exposed, to produce sulphuric acid. As the water levels reaches acidic contents, Thiobacillus ferroxidans are found thereby accelerating the oxidation and acidification. As it shown in Figure 2.4, acid is transported and deposited into rivers or stream by means of rainy water and surface drainage.

Pollution of surface and ground water bodies are caused by leaching and heavy metals to the earth crust. They have particularly existed in mining communities for years as a major pollution [57]. Thirdly, processing chemical pollution occurs when chemical agent (such as cyanide or sulphuric acid used by mining companies to separate the target mineral from the ore) spill, leak, or leach from the mine site into nearby water bodies. These chemicals can be highly toxic to humans and wide life.

Lastly, mineral development poses major challenge to rock and soil. Rock and soil are used to maintain roads, open pits and waster impoundments. Adequate prevention and control strategies should be used to prevent soil and water erosion respectively.

**Table 2.1: Impact of Heavy Metals on Human Health and Waters**

| Heavy Metals | To Humans | To Waters |
|---|---|---|
| Lead | After the central and peripheral nervous systems; circulatory and digestive system | Acute toxicity to plants, animals and microorganisms |
| Mercury | Causes brain damage leading to blindness; mental abnormalities; acute intoxications affecting digestive system and kidneys death | Chronic effects |
| Cadmium | Induces respiratory and kidney disorders; cancer | Poisonous to flora and fauna decalcification bodies |
| Copper | Affects the liver, kidney and eyes; neurological disturbances | Toxic plants |
| Iron | Affects heart and liver; causes the diseases called siderosis | |
| Chromium | Is irritant to skin and mucous; induces circulatory disorders; allergic reactions; affects the nervous system; cancer | Poisonous to marine plankton and fish |
| Nickel | Induces allergic reaction; affects lung and kidney tissue; cancer | High toxicity to palamuru plants, approximately 8 times more toxic than zinc |
| Arsenic | Vomiting; cardiac dysfunction; skin cancer | Affects the plant growth |
| Zinc | Epigastric pains; affects the central nervous system, muscle cardiovascular system | Changes in physical and physiochemical properties reduces the biological |

| | | |
|---|---|---|
| | | activities |
| Manganese | Motor and mental disorders; Parkinson | |

Source: Jucan et al., 2016

**Figure 2.4: Acid- Mine Drainage of Rinto River (Zettler et al, 2003)**

**Table 2.2: EPA/WHO Standard of Heavy Metals in Water and Sediments**

| Heavy Metals | Common Range in Sediment (mg/kg) | Surface water quality (mg/l) |
|---|---|---|
| Iron (Fe) | 7,000-550,000 | 1.0 |
| Zinc (Zn) | 10-600 | 5.0 |
| Nickel (Ni) | 5-500 | 0.2 |
| Manganese (Mn) | 20-3,000 | 0.5 |
| Lead (Pb) | 2-200 | 0.1 |

Source: Everett Wilson and Carl Solomon, July 1995

### 2.4.7 Air Pollution

Car vehicular emissions, chemical from mining sites, factories, and dust are examples of pollution. Generally, it is a mixture of solid particles and gases which is released into the atmosphere. Mining and beneficiation processes in the minerals value chain generate gases that contaminate the environment. Ores are transported from the mining site to the processing unit by trucks and excavators. The equipment uses a lot of fossil fuels. However, the combustion of fossil fuel during mining operation produces sulfuric, carbonic and nitric acids and other volatile organic compounds and heavy metals that pollute the environment. At the mine, these gases react with water in the atmosphere in the form of acid rain and destroy limestone and marble.

## 2.5 IMPACTS ON PUBLIC HEALTH

In the developing countries such as Liberia, and Sierra Leone, mining project sometimes downplay the potential risks factored in the environmental impact assessments, (EIAs). However, hazardous substances and wastes in water, air and soil may cause serious public health. The

World Health Organization (WHO) defines health as a ''a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity [58]. 'Hazardous substances' include all substances which are harmful to people and the environment. Also, hazardous substances may cause an increase of mortality or further increase in human illness; pose a substantial health or environmental problem.

### 2.5.1 MITIGATING ENVIRONMENTAL IMPACT OF MINING

Mining in the past took place at a time when environmental impacts were not as well understood and not significant concerns. Now, mine closure is a major issue to be considered and a series of activities to remediate the impacts of mining are important part in mine planning and design of mineral development from the exploration phase through to closure.

Steps to mitigate environmental impacts are as follows: reclamation, soil treatment, water treatment and preventing acid rock drainage

- ✓ Reclamation: restoring the soil and vegetation back to its pre-mining state. After mining, the lands are destroyed. consequently, reclamation process is necessary and includes using sludge, ''biosolid'' from municipal waste water treatment processes as an organic soil amendment, and growing plant species that are more tolerant to acidic conditions.
- ✓ Soil treatment: elevated levels in sediments, not just acidity, can be harmful to plants, animals and people. Future remediations are needed to prevent soil pollution. This may include the use of chemical methods to stabilize metals in soils, use bacteriacides that prevent the bacterial growth, promotes the oxidation of pyrite and accompanying formation of sulfuric acid.
- ✓ Water treatment: lime is the most common treatment for acidic and metal-bearing in water. This ''active'' treatment process, causes the dissolved metals to precipitate from water but the process is very expensive. Some possible alternatives include wetland systems to treat metal-bearing water. This method is necessary because the volumes and acidity of water are not too great.
- ✓ Preventing Acid Rock Drainage: acid drainage presents challenges to water quality; however widespread occurrence of acid rock drainage is important to prevent its occurrence. Possible measures to reduce acid rock drainage include: flooding of old grounding mine, sealing exposed surfaces in grounding, backfilling mine and adding chemicals to the water flooded surface to prevent acid rock drainage.

## CHAPTER THREE

## MATERIAL AND METHODOLOGY

### 3.1 FIELD INVESTIGATION

In July 2019, the study was conducted on both soil and water to determine heavy metal concentration in a place, called MNG-Gold, which is situated in Kokoya district, 50 km southeast from Gbarnga, the capital city of Bong county. It is 170 km northeast from Monrovia, the capital city of Liberia. The road connecting Monrovia to Gbarnga is asphalted while from Gbarnga to Kokoya is of reddish soil and laterite. During the field investigation, composite Sampling was adopted for surface water whereas grab sampling was done on soil and groundwater. Four water grab samples, five soil samples and five groundwater samples were collected from different locations using Global Positioning System (GPS). For each of the sampling locations, the GPS coordinates was marked and recorded in the note pad. The collected samples for soils and waters were sent to KHY-lab-3602 to establish the heavy metals while electrical conductivity, dissolved oxygen, potential hydrogen and temperature were measured and recorded in the field. For groundwater, the physio-chemical parameters such as temperature, electrical conductivity, dissolved oxygen and water level of each well were determined.

### 3.2 STUDY AREA

The MNG- gold is located in Kokoyah district, Bong county, Republic of Liberia. Figure 3.1 shows the St. John River. The St. John River which has a source in Guinea flows through Bong county northwest of Nimba Mountains. The St. John River in Guinea is called the Mano River. The

MNG-gold, situated in Kokoya district, is characterized by tropical, hot and humid climate with the highest and lowest temperature ranges from $29^0$ C to $19^0$ C respectively. Moreover, the average annual precipitation is 2076 mm. Approximately, 178 to 453 mm of convectional rainfall occurs in the interior. This happens as a result of reduced in air moisture contents. The soil types are composed of latosols. Latosols are type of soil which is predominately in Kokoya, Bong county. It constitutes 18% of the total land in Liberia. It is rich in silica nutrients and humus. Also, this area has a very good vegetation. The vegetable is divided in an evergreen rain forest zone and the moist semi-deciduous forest zone. As the evergreen forest, it receives 453 mm of rain fall annually. However, for the semi-deciduous forest, the prolonged dry season causes the leaves to fall due to the present of less evaporation.

**Figure 3.1 Partial view of the St. John River Between Bong and Grand Bassa, Republic of Liberia**

**3.3 SITE SELECTION**

In selecting suitable site for soil and water samples, the primary objective was to clearly define the appropriate field for which the samples were collected. Figure 3.2 shows the site utilized.

Following that, the collected samples from the field were investigated, labeled, marked and sent to the laboratory for analysis. The results indicated that heavy metal concentrations and physio-chemical parameters for water and soil were reported and recorded. The water sample was conducted at four different sites and additional five groundwater samples collected from well. The surface water was collected 0.4 m below the water surface and less than 40 m away from the mine.

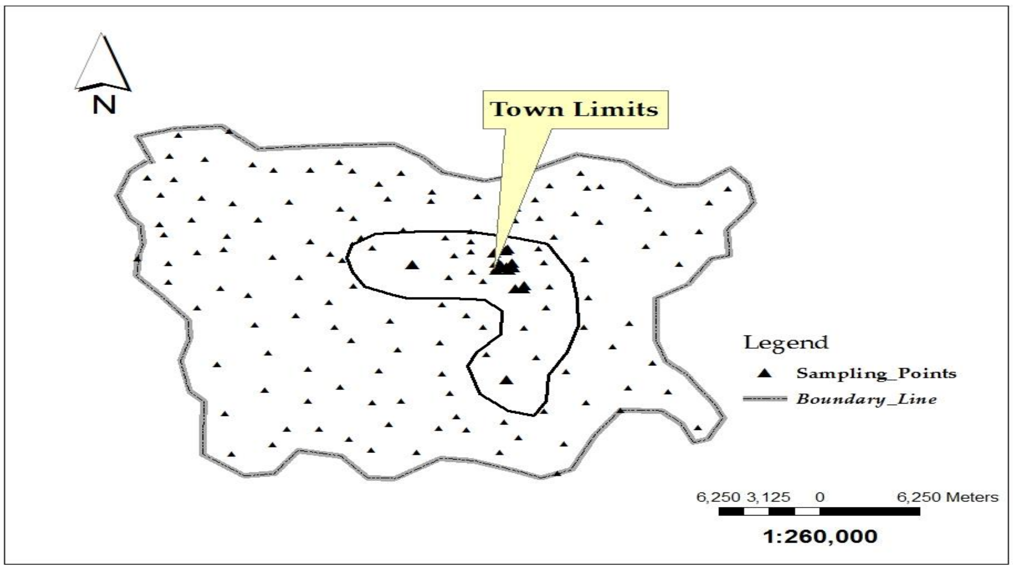


**Figure 3.2: surface water and soil sampling locations**

### 3.4 SAMPLING PROCEDURE AND SAMPLE MANAGEMENT

To begin with sampling procedure, it is important to understand what sampling procedure is? According to [59], sampling procedure means the technique adopted to sub-group an individual selected from largest group. The technique adopted for this work is as followed:

- Sampling point

Various sampling points were identified for sample collection. Sample containers such as density polyethylene bottles were washed at least three times with water from the specific site of sampling prior to taking the samples.

- Sampling tools

Sampling tools such as polypropylene, polyethylene, bucket and hoe were used during the sample procedure. For example, the hoe and digger were used to dig the ground 1 cm to 50 cm to take the soil sample and subsequently transfer into polyethylene bottle for laboratory tests. Similarly, water sample was also collected by the means of composite grab and as for ground water, the water level meter was also taken to know the depth of ground water condition.

- Cleanliness

Sampling materials and containers were thoroughly cleaned and at least three times in order to avoid contamination prior to sampling the materials.

- Field recordings

  All samples collected in the field, for example, sample name, (code), sampling site's name (code), an accurate position for the sample site, sampling data, environmental condition of the mine site such as temperature, pH, dissolved oxygen contents, depth of the groundwater and electrical conductivity were all recorded in the note pad.

- Labeling of soil and water samples

  After collecting the samples for both water and soil, water- resistant ink was used to label the name and code of the samples, the sampling date and sampling name respectively.

**3.5 SAMPLE ANALYSIS**

The sampling for water was done in a period of one month from July 1, 2019 to July 30, 2019 at four different locations and additional five different locations for groundwater. Groundwater, surface water, stream and tailing samples were collected from different points. However, water samples were collected 0.4 m below the water surface and less than 40m apart within the perimeter of the mining sites. The samples were stored in 250ml cleaned polyethylene bottles, and then acidified with concentrated nitric acid to pH less than 2. Also, pH, temperature, electric conductivity (EC) and dissolved oxygen (DO) were measured at the sampling sites while heavy metals such as Fe, Mn, Pb, Zn and Ni determination in water samples an air acetylene flame was analyzed using an atomic absorption spectrophotometers (AAS) FS 240.

Similarly, field surveys were conducted in July 2019. Five soil samples along with their geographical coordinates at different locations were recorded. During the laboratory analysis, 0.7 g dried, homogenized sediment samples were accurately weighed on an analytical balance and then transferred into a glass beaker. Three drops of distilled water plus 13 ml of nitric acid, $HNO_3$ were added to the solution in the beaker then heated on a hot plate till it was completely dried. The dried sample was allowed to cool for 45 min, after adding 8 ml of HF (%40w/w) and 8 ml of $HClO_4$ (%60w/w) respectively. The acid mixture was allowed to heat on a hot plate at 85$^{o}$C inside a fume hood until the dark color disappeared. At 120$^{o}$C, HF was subjected to boil and then the boiling temperature was not allowed to exceed 120$^{o}$C after final traces of HF and $HClO_4$ were expelled. The final residue was dissolved in 10 ml HCL then allowed to heat for thirty minutes. After cooling, the solution was transferred to a 50 ml volumetric flask. The AAS FS 240 was used to analyzed the concentration of Fe, Mn, Zn, Pb and Ni after the process was completed.

## CHAPTER FOUR

## RESULTS AND DISCUSSIONS

### 4.1 RESULTS

The graphs of total elemental concentration in water, relation of temperature, dissolved oxygen, and pH, conductivity and study areas, total elements of concentration in soil and groundwater depth are presented in Figure 4.1, Figure 4.2, Figure 4.3, Figure 4.4 and Figure 4.5 respectively. The raw data is presented in the Appendix. The heavy metal concentrations for iron in water was extremely high at 1.5 ppm, followed by manganese, nickel, zinc and lead which were all below 0.08 ppm. In Figure 4.2 and 4.3, Adana and new TSF reported high conductivity values. In Figure 4.4 and 4.5, the concentrations of iron and the depth of the BH-1 were reported high.

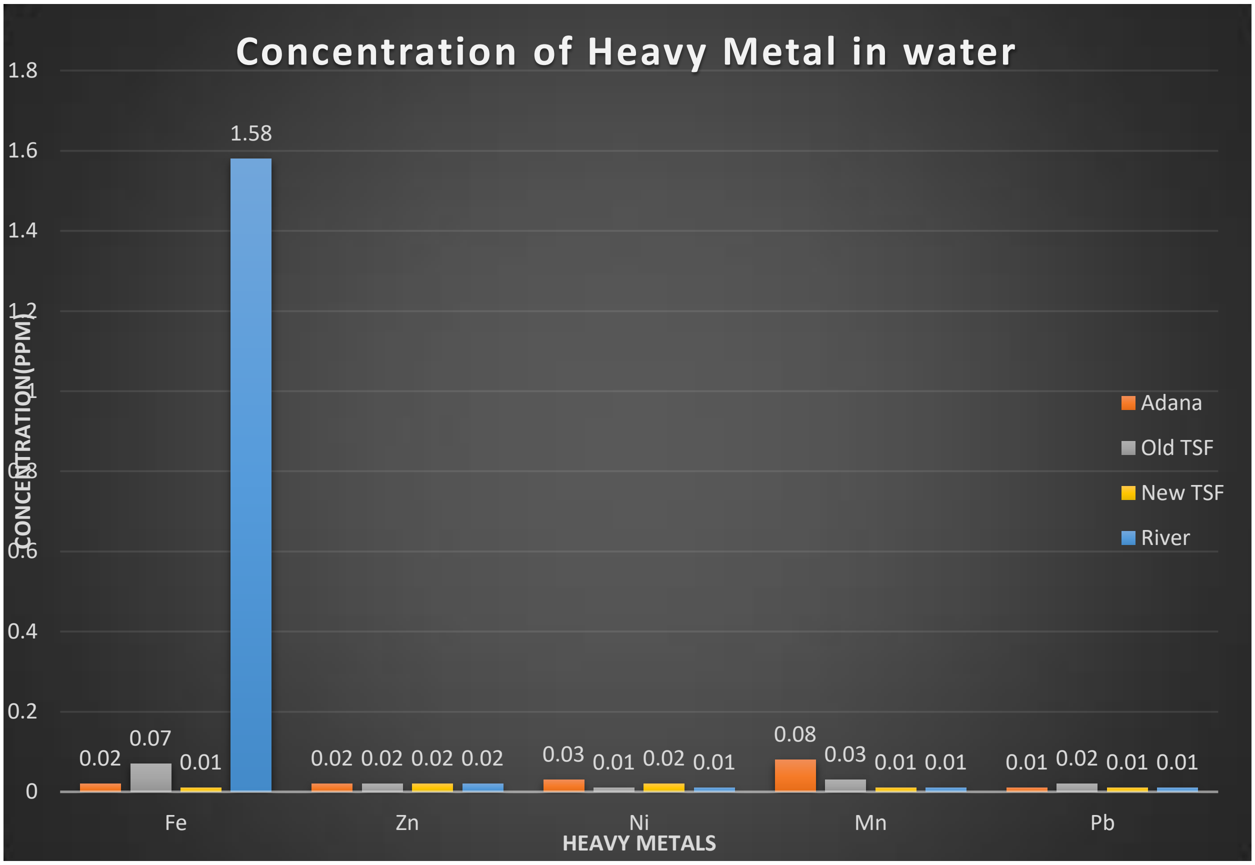


**Figure 4.1 Total Elementals (ppm) Concentrations in Water Samples against the Heavy metal element.**

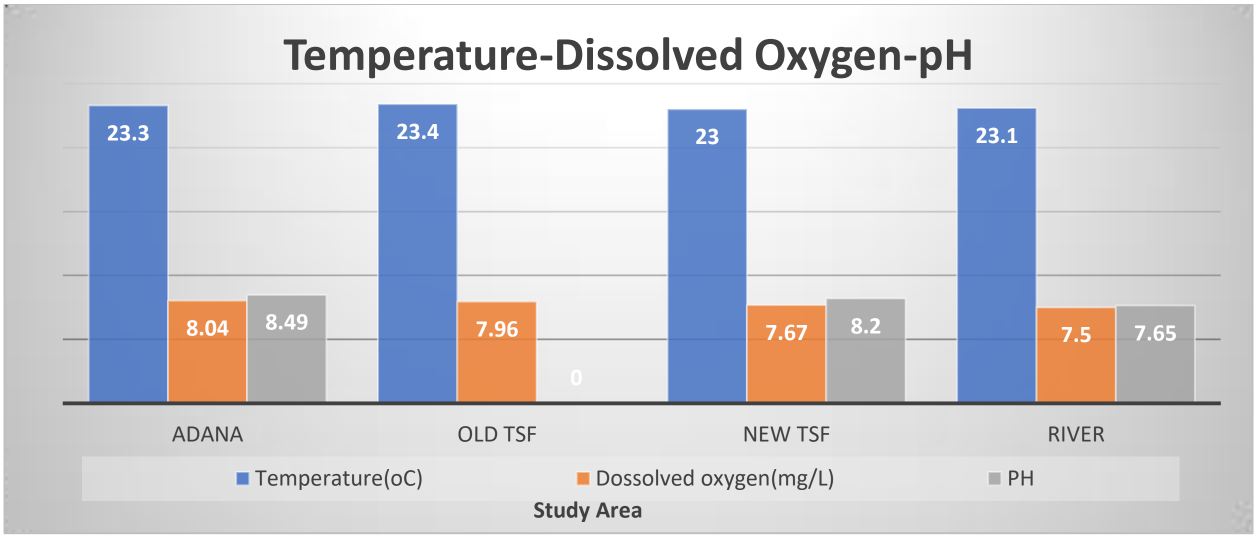


**Figure 4.2: Variation between temperature, dissolved oxygen and pH**

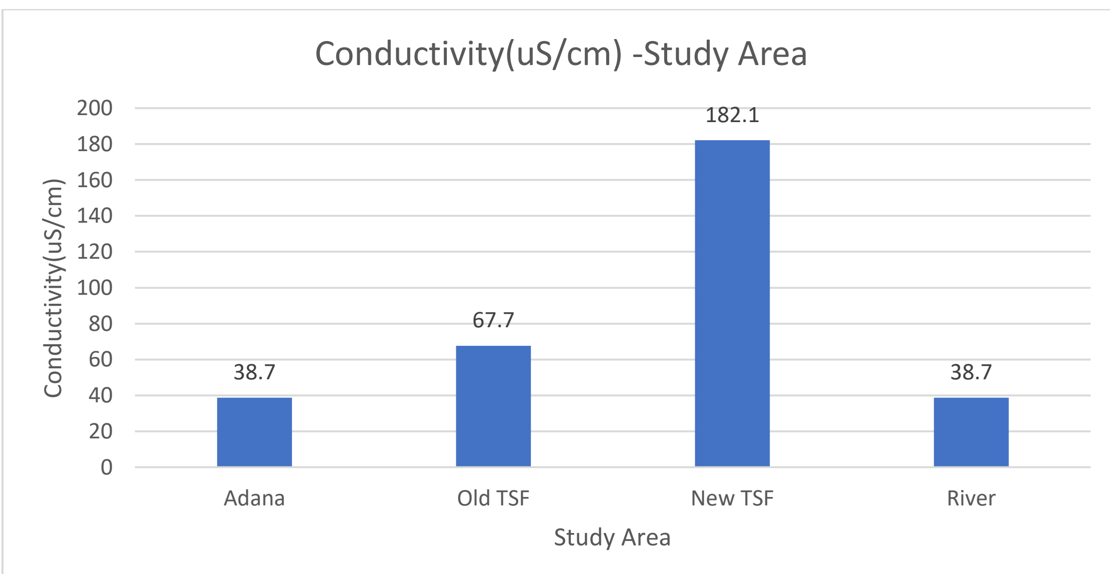


**Figure 4.3: Conductivity and study area relationship**

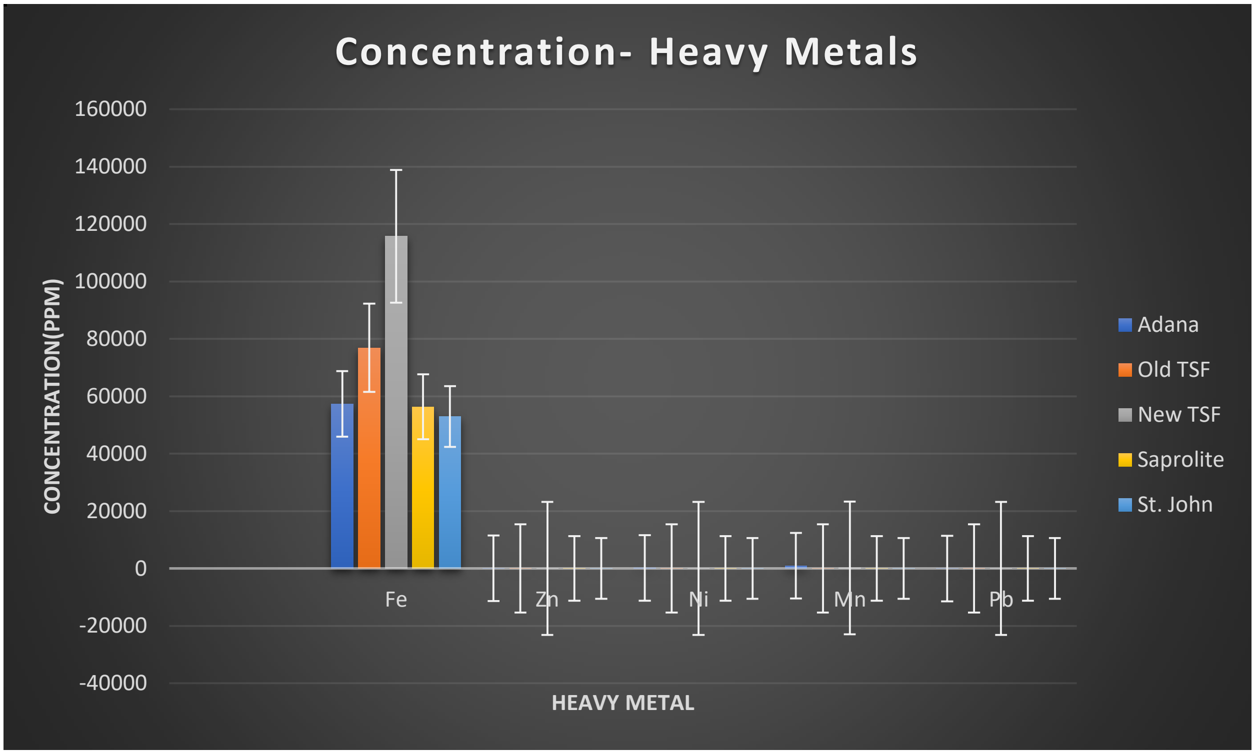


**Figure 4.4: Concentrations of selected heavy metals in soils**

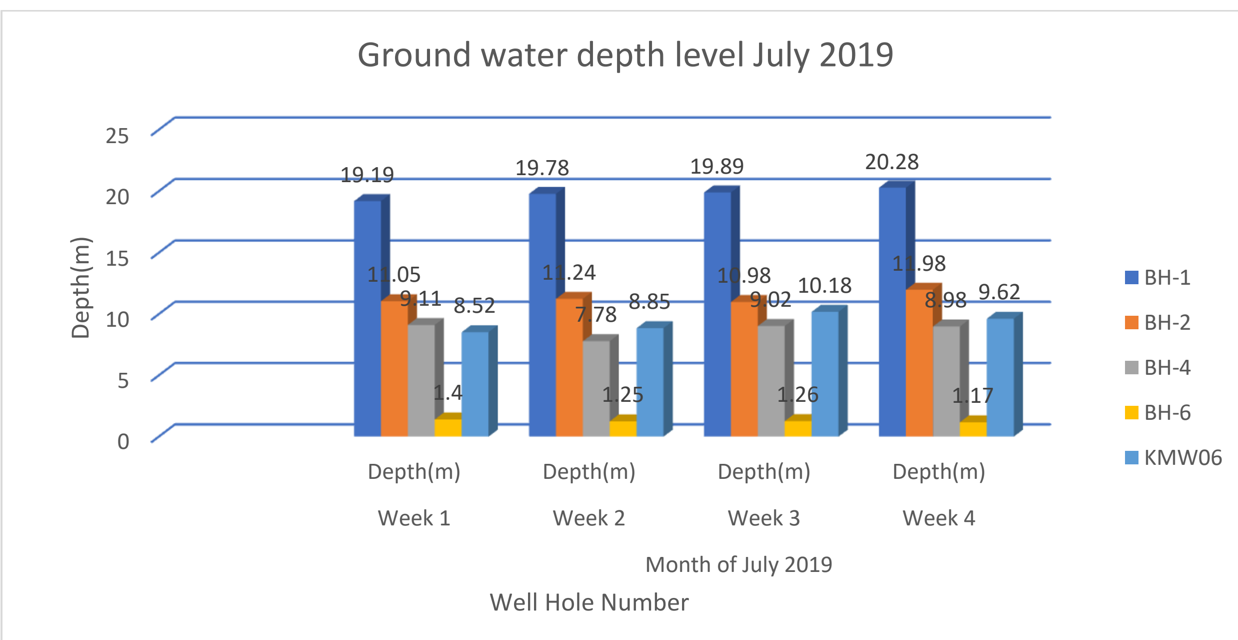


**Figure 4.5: Ground water depth level July 2019**

### 4.2 Discussion

Data analysis parameters such as standard deviation, mean concentrations were calculated. The statistical approach clearly indicates that the metal values for some heavy metals were below the detection limit especially in water sample except iron and manganese which exceeded the detection limit shown in Figure 4.1. As for the sediment samples, the concentrations of all metals were above the detection limit.

#### 4.2.1 Concentration of iron (Fe) in water and soil

Iron is one of the heavy metals which makes up at least 5 % of the earth's crust. It is one of the most abundant elements in the earth. Iron exists in water as soluble ferrous ($Fe^{2+}$) and insoluble ($Fe^{3+}$). Iron's concentration as low as 0.3 mg/L causes stains on tableware, fixtures and laundry that are very difficult to remove. Irons are formed when rainwater infiltrates the soil and dissolves the iron, causing it to seep into underground well. Although iron is not harmful to health, it is referred to as secondary contaminate. It is essential for good health and helps move oxygen in the blood. If more than 10 mg/kg of iron level exists in the human body, it causes increase of blood in the vessels. According to a report by [60] the maximum allowed concentration of iron present in drinking water is 1.0 mg/kg. As presented in Figure 4.1 water samples, the concentration level of iron was slightly above the permissible limit in the St. John River whereas it was below the limit in the remaining water samples. Sampling points closer the mining site, had higher concentrations of iron. The concentrations of iron can vary significantly as a result of source types and the presence of ferrous iron.

Based on statistics, it constitutes 4.6% of igneous rocks and 4.4% of sedimentary rocks. Investigation by [61] revealed that iron concentrations in soils range from (20,000 to 550,000 mg/kg) and concentration can also vary due to soil types and the presence of other sources. Iron can exist in either the divalent ($Fe^{2+}$) or trivalent ($Fe^{3+}$) states and the divalent state can be oxidized to the trivalent state which form oxide or hydroxide precipitates, and become unavailable to plants as micronutrient [62]. During mining, large amounts of iron are released into the environment as pyrite ($FeS_2$) which is found in coal seams, or sulphide minerals in general. When sulphide minerals are exposed to air and water, it is oxidized to sulphate by bacterial and chemical reactions. The reaction produces dissolved ferrous iron into mine drainage. When ferrous iron reacts with oxygen to form ferric iron, then hydrolyzes to form insoluble ferric hydroxide ($FeOH_3$). However, roots of some plants are able to reduce iron from ferric to the ferrous state, and allow iron uptake into the plant [63]. The iron concentration in all the soil samples collected from Adana, old TSF, New TSF, Saprolite and St. John as presented in Table 4.5 ranged 52,968 to 115,781 mg/kg. In all the soil samples concentration of iron was above the permissible limit set by WHO.

### 4.2.2 Concentration of Zinc (Zn) in water and Soil

Zinc is a heavy metal which is considered as a trace element in soil. It plays a major role in protein synthesis and is a metal showing fairly low concentration in surface water as a result of its restricted mobility from the weathering processes to deposition point. Higher concentration of zinc can cause more risk to an organism's survival.

The zinc concentration in water samples remained constant as presented in Table 4.1. According to WHO, the permissible limit of zinc in water is 5 mg/L. The zinc concentration in all the water samples collected from Adana, old TSF, new TSF, St. John River was recorded below the permissible limit. However, the zinc concentration in soil from old TSF, new TSF, saprolite and St. John River was also below the permissible limit except for Adana's soil sample which was slightly above 5 mg/L. The concentrations of zinc in soil samples ranged between 16.68 to 51.35 mg/kg.

### 4.2.3 Concentration of Nickel (Ni) in water and soil

Nickel (Ni) is one of the trace elements that is found in humans and animals. It is essential for human and animal health. It poses risk to human health if it is present in large quantities. As recommended by the WHO, the maximum permissible limit for nickel in water is 0.2 mg/L [64]. Nickel in water sample ranged between 0.01 to 0.03 mg/L which was below the permissible limit recommended by WHO. The permissible limit of nickel concentration presents in soil is 100 mg/kg [65-66]. As presented in Table 4.5, the value of Ni in all soil samples ranged between 17.55 and 186.49 mg/kg which was obtained from old TSF, new TSF, saprolite and St. John River. Nevertheless, in Adana soil sample, the value was recorded above the permissible limit of international standard. The variation of nickel in water and soil is based on the distance where the samples was collected in the mine. Nickel contamination of soil contributes high environmental impact.

### 4.2.4 Concentration of manganese (Mn) in water and Soil

Manganese is a heavy metal with symbol Mn and atomic number 25. As a free element in nature, it combines with iron. It also exists as a trace mineral which is present in the body in small amounts. When it is combined with calcium, zinc and copper, it supports bone formation. For water, the permissible limit of manganese is 0.5 mg/L [67]. Above this value, it is considered as risk to human health. As presented in Table 4.5, the concentrations of manganese in all water samples ranged between 0.01 to 0.08 mg/L in Adana, old TSF, new TSF, and St. John River which were recorded below the permissible WHO water standard. The permissible limit of Mn in soil is 12 mg/kg [68]. In soil, manganese ranged between 55.11 and 994.83 mg/kg which was recorded above the permissible limit of 12 mg/L.

### 4.2.5 Concentration of Lead (Pb) in water and Soil

Lead is a chemical element with the symbol Pb and atomic number 82. It is heavy metal that is denser than most materials. Lead is soft and malleable, and has a relatively low melting point. For water sample, the permissible limit of Pb is 0.05 mg/L. In all the water samples collected from Adana, old TSF, new TSF and St. John River, the concentration of lead was below the permissible limit since it ranged between 0.01 and 0.02 mg/L. However, the concentration of lead in soil samples was recorded to be ranged between 8.74 to 19.53 mg/kg. In all the collected soil samples from Adana, old TSF, new TSF and St. John River, the concentration was above the permissible limit set by WHO. Lead as a source of contaminant is considered as widespread issue; it accumulates with age bones aorta, and kidney, liver and spleen. It can enter human body through uptake of food (65%), water (20%) and air (15%). Lead mineral is naturally present in the soil.

#### 4.2.6 Physio-chemical Parameters of surface and groundwater quality, MNG-gold

Temperature and color of water are physical parameters while pH, dissolved oxygen contents, alkalinity, hardness and electrical conductivity belong to chemical parameters. Table 4.3 in Appendix I shows the results for pH, electrical conductivity and dissolved oxygen in water samples whereas Figure 4.2 shows temperature, dissolved oxygen-pH relationship. In Table 4.1, the composite water samples collected directly from the new tailing storage facility, (TSF) had higher electrical conductivity and less temperature than samples taken from the rest of the sampling points. This is because the wastewater from the processing unit which contains high concentration of ions are directly discharged into the new TSF.

According to WHO, the normal ranges for pH of drinking water is 6.5-8.5. pH of all the water collected from Adana, new TSF and St. John River was below the normal range except for pH value of old TSF which was not detected. Also, WHO normal range for electrical conductivity (EC) of water is 400-600$\mu$s/cm. In all the water samples collected from Adana, old TSF, new TSF and St. John River was recorded within the range. The temperature for the study area ranged between 23.0$^{o}$C to 23.4$^{o}$C. WHO normal range for hardness of water is 50-250mg/ml [69].

Electrical conductivity (EC) is a measure the ability of water to conduct an electric current which is associated to the amounts of dissolved minerals in water; however, it does not give indication of which element is present. Higher value of electrical conductivity is a perfect indicator of the presence of contaminants such as sodium, potassium, chloride or sulphate. Hardness is referred to as the measure of concentration of dissolved calcium and magnesium ions in water. Hardness is one of the most important properties of water such that it is significance for life processes. All these water parameters are very useful because their study is important for fish and human health.

**4.2.7 Means and Standard Deviation of Heavy Metals**

In Table 4.2, it is also indicated that the iron concentrations in sediment samples were extremely higher than the concentration levels of other metals. The heavy metal concentrations (mean ± SD) available in water samples are presented in Figure 4.4. From the above data, iron is the most predominate elements analyzed in the water samples in July 2019. However, the total concentrations of iron ranged from 0.42±0.64 ppm in July 2019. As presented, manganese is the second most abundant element in water samples with an estimated value of 0.04±0.03 in July 2019. The remaining heavy metals such as Zn, Ni and Pb were found under detention limit in July. In furtherance, the concentrations of zinc with value less than 0.02 ppm in all four samples were constant which was also less than the same amount as the detention limit of July 2019. Nickel further exhibited gradual reduction in July 2019 of the given water samples.

Similarly, the concentrations (mean ± SD) of heavy metals in soil are presented in Table 4.5 Appendix I. Again, iron concentrations in soil samples varied 71859±23507.54 ppm in July 2019. Nevertheless, the elemental iron concentration in the soil sample was extremely higher than the other heavy metals. Manganese is the second most predominate element in the soil sample with total mean concentration of 283.12 ppm. The concentration levels of heavy metal in soil were far higher than those of heavy metals in water. The heavy metals in sediment samples were all above the detention limit. The analysis presented in Table 4.3 and Table 4.5 Appendix I indicated that Fe, Zn, Ni, Mn and Pb in soil samples, varied hugely with water samples in July. In this work, manganese and iron concentration levels were recorded extremely high quantities in soil. However, lead, manganese, nickel and zinc in water samples were reported below the detention limit. Iron and manganese were considered to be the more concentrated metals in water samples. Similarly, the dissolved oxygen values varied from 7.50 mg/L to 8.04 mg/L and the electrical conductivity values changed from 38.7$\mu$S/cm to 182.1$\mu$S/cm.

## 4.3 Observation

In July 2019, after the water samples were collected and analyzed for heavy metals (Fe, Zn, Ni, Mn and Pb) using an atomic absorption spectrophotometer (AAS FS 240), it was observed that the concentrations of heavy metals such as iron were above the maximum permissible limit set by WHO while Zinc, Nickel and manganese were below the permissible limit in Adana, old TSF and new TSF respectively. The analysis of the study further revealed that the presence of heavy iron content in water at MNG-gold, Bong county, Liberia was beyond the permissible limit in St. John River. The pH value of all the water collected was in the permissible limit of WHO standard. Similarly, the soil samples, the concentration of all the heavy metals such as iron, lead, manganese and zinc were recorded above the permissible limit set by WHO. The concentration of nickel and zinc in Adana study area was recorded below the permissible limit set by WHO standard.

For the groundwater condition, it was clearly observed that electrical conductivity of BH-1, and BH-6 reported high electrical conductivity and temperature as compared to BH-2, BH-4 and KMW06. It was observed that people practiced open defecation along streams and beaches. In addition, industrial and sewage of the city and town were directly discharged into the river. This also contaminates the water making it unsafe for both aquatic and human life. Also using the affected water for the purpose of irrigation will further expose the soil and plants to heavy metals. Finally, it was observed that the heavy metal in soil was more than the value of heavy metals in water.

### 4.4 Future work

This research work provides a fundamental understanding of the presence of heavy metals in spaces close to and within the mining area due to open pit gold mining activities which has been taking place in Kokoya, Bong county Liberia since 2015. For detailed analysis of future work on soil and water quality in MNG-gold, regular monitoring system should be conducted on periodic basis to observe the contaminant levels of other heavy metals which were not discussed in the work. In so doing, the minimum time duration for such investigation should be at least one year in order to have more and accurate data that relate to the topic under discussion. In addition, sampling equipment should be designed to ensure easy collections of samples from sampling locations. Lithologies, bedrocks and another important feature need to be further analyzed by the use of scanning electron microscope to determine their mineralogical composition of the elements. Study on other heavy metals concentration should be investigated. The water and soil parameters should be analyzed in advanced, analytical techniques such as inductively coupled plasma-mass spectrometer (ICP-MS) in comparison to FAAS FS 240 (used in current study) due to high detection limits. Besides, the chemical and heavy metal analysis, radionuclides (radioactive materials such as uranium) should be analyzed using advanced techniques such as ICP-MS. The load of microorganisms (protozoa, parasite, algae, bacterial and virus) could also be assessed. This may not be from the mine but from the open defecation observed.

## CHAPTER FIVE

## CONCLUSIONS AND RECOMMENDATIONS

### 5.1 Conclusions

Mining and milling as well as tailing discharge into the environment led to accumulation of heavy metals in soil and water. The fundamental goal of this research work was to investigate the concentration level of some heavy metals and physio-chemical parameters such as temperature, electrical conductivity, dissolved oxygen and pH of surface water, groundwater and soil samples collected from MNG-Gold Kokoyah district, Bong county, Republic of Liberia. During the course of investigating soil, surface water and groundwater, a total of fourteen samples were collected and analyzed. It was reported in the research that five soil samples were collected and analyzed for heavy metals (Fe, Zn, Ni, Mn and Pb). Also, four water samples were collected and analyzed for the physio-chemical parameter ( temperature, electrical conductivity, dissolved oxygen and pH) and five heavy metals (Fe, Zn, Ni, Mn and Pb), while five groundwater samples were collected and analyzed for the three chemical parameters such as the electrical conductivity, dissolved oxygen and pH respectively.

In addition, the presence of heavy metal concentration varied from one location to another. Zinc, nickel, manganese and lead concentrations in surface water were less than or equal to 0.02 ppm, 0.03 ppm, 0.08 ppm and 0.02 ppm which are below the permissible limits set by WHO, whereas iron concentration of up to 1.5 ppm were above the permissible limit set by WHO in the St. John River. The presence of lead, manganese, nickel and zinc in soil were < 20 ppm, 1000 ppm, 200 ppm and 60 ppm respectively above the permissible limits set by WHO. However, in certain locations such as old TSF, new TSF, St. John River and saprolite, the concentrations of zinc and nickel in Adana remained relatively below the permissible limit set by WHO standard for soil. The increased levels of these heavy metals in sediments have the potential to endanger soil quality which is used for the agricultural processes. From the analysis of the investigation, the results showed that pH values of all the water samples were between 7.6 and 8.5 and within the permissible limits set by WHO, while the values of electrical conductivity of all the collected surface and groundwater samples below 200$\mu$s/cm far less than permissible limits set by the WHO. Similarly, dissolved oxygen of all collected surface water and groundwater samples was recorded to be less than permissible limits set by WHO. From the above studies of heavy metals and chemical parameter, it was found that the surface water at various locations of MNG-gold around kokoya district, Bong County are significantly rich in micronutrients (Zn, Mn and Pb) and have good pH and electrical conductivity for agricultural use. However, the iron concentration of the water samples exceeds the standard value for drinking water and irrigation as set by WHO and food and agriculture organization (FAO) and therefore, in terms of iron concentration, the surface water is not suitable for drinking and irrigation. Furthermore, proper treatment of the surface water containing elevated iron content should be carried out before use for drinking and irrigation; otherwise, it may lead to an overload which can cause hemochromatosis, diabetes, stomach problems, nausea and vomiting in human body when it is consumed as a result of drinking. The recommended level of iron in water is less than 0.3ppm. The best water treatment for iron removal is to install an iron water filter in private homes. It helps to removes iron, bacteria, sulfur and manganese from water, making it healthy enough to drink.

### 5.2 Recommendations

To address the problems of heavy metal concentration in water and soil at MNG-gold, it is absolutely necessary that the following considerations are made:

(i) Treatment of waste water before discharging into the environment should involve steps to remove metals causing risk to human health within the environment.

(ii) Waste water from the processing plants into the St. John River should be subjected to suitable chemicals for keeping Fe, Pb, Zinc, Mn and Ni within the permissible safe levels

(iii) Regular monitoring by the company should be put in place such that contaminations of heavy metal pollution would be avoided and reduce the health risk caused by taking contaminated vegetables grown in the area

(iv) Government in collaboration with Environmental Protection Agency (EPA) and the Ministry of lands, Mines and Energy should monitor, regulate and improve the water quality of MNG-gold and other environs which should also consider heavy metals such that water and soil are exposed to minimum amount of heavy metals

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## Appendix I:

### Tables of Findings

**Table 4.1: Total Elemental Concentrations (ppm) of Heavy Metal in Water Sample**

| Total Elemental Concentrations (mg/L) of Heavy Metal in Water Samples | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Laboratory Number | KYH-LAB-3602 | | | | | | | Recording | | | 5/8/2019 |
| Reference Number | POP 06/08 | | | | | | | Reporting | | | 9/8/2019 |
| | | | | | | | | | | | |
| Water Samples | Location / Description | GPS Coordinates | Conductivity(u/cm) | Temperature (OC) | LDO (mg/L) | PH | Fe | Zn | Ni | Mn | Pb |
| Adana | Open Pit | E0468963 N0733773 | 38.7 | 23.3 | 8.04 | 8.49 | <0.02 | <0.02 | 0.03 | 0.08 | <0.01 |
| Old TSF | Behind processing Plant | E0469721 N0732541 | 67.7 | 23.4 | 7.96 | nd | 0.07 | <0.02 | <0.01 | 0.03 | 0.02 |
| New TSF | Opposite Processing Plant | E0469138 N0732912 | 182.1 | 23 | 7.69 | 8.2 | 0.01 | <0.02 | 0.02 | <0.01 | <0.01 |
| River | St. John River 2.25km, NW of N | E0470666 N0730896 | 38.7 | 23.1 | 7.5 | 7.65 | 1.58 | <0.02 | <0.01 | <0.01 | <0.01 |
| | | | | | | | | | | | |
| **Detention Limit** | | | | | | | **<0.01** | 0.02 | 0.01 | 0.01 | 0.01 |
| **Units** | | | | | | | ppm | ppm | ppm | ppm | ppm |

Source: Fieldwork findings, July 2019

**Table: 4.2: Physio-chemical parameters of selected study area in MNG- gold Mine between July 1,2019 and July 30,2019.**

| **Study area** | **DO (mg/L)** | Temperature(oC) | **EC ($\mu$S/cm)** | **pH** |
|---|---|---|---|---|
| Adana | 8.04 | 23.3 | 38.7 | 8.49 |
| Old TSF | 7.96 | 23.4 | 67.7 | Nd |
| New TSF | 7.67 | 23.0 | 182.1 | 8.20 |

| | | | | |
|---|---|---|---|---|
| River | 7.50 | 23.1 | 38.7 | 7.65 |

**Nd: not detected**

Source: fieldwork finding, July 2019

**Table 4.3: Value of heavy metal contents (average ± standard deviation) summary in Water(ppm)**

| **HM** | **Concentrations** | | | | **Mean** | **SD** | **M±SD** |
|---|---|---|---|---|---|---|---|
| Fe | 0.02 | 0.07 | 0.01 | 1.58 | 0.42 | 0.64 | 0.42±0.64 |
| Zn | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 | 0.00 | 0.02±0.00 |
| Ni | 0.03 | 0.01 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01±0.02 |
| Mn | 0.08 | 0.03 | 0.01 | 0.01 | 0.04 | 0.03 | 0.04±0.03 |
| Pb | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.004 | 0.01±0.004 |

Source: fieldwork finding, 2019

**Table 4.4: Total Elemental Concentrations (ppm) of Heavy Metals in Soil Samples**

| Soil Samples | Descrptions | GPS Coordinates | Fe | Zn | Ni | Mn | Pb |
|---|---|---|---|---|---|---|---|
| Adana | Inside Adana Pit | E0463867 N0732762 | 57304 | 51.35 | 186.49 | 994.83 | 16.59 |
| Old TSF | Behind processing | E0470167 N0732480 | 76875 | 27.64 | 17.55 | 78.15 | 8.74 |
| New TSF | Opposite processing | E0469183 N0732967 | 115781 | 36.64 | 22.72 | 222.27 | 19.53 |
| Saprolite | Open Pit | E0469381 N0734129 | 56367 | 16.68 | 19.91 | 65.22 | 12.61 |
| St.John | 2.25km NW, new TSF | E0470261 N0730605 | 52968 | 26.24 | 18.35 | 55.11 | 17.03 |
| Detention Limits | | | 0.1 | 0.2 | 0.1 | 0.1 | 0.01 |
| Units | | | ppm | ppm | ppm | ppm | ppm |

Source: fieldwork finding, July 2019

**Table 4.5: Concentration of heavy metal in soil**

| Study Area | Fe | Zn | Ni | Mn | Pb |
|---|---|---|---|---|---|
| Adana | 57404 | 51.35 | 186.49 | 994.83 | 16.59 |
| Old TSF | 76875 | 27.65 | 17.55 | 78.15 | 8.74 |
| New TSF | 115781 | 36.64 | 22.72 | 222.27 | 19.53 |
| Saprolite | 56367 | 16.68 | 19.91 | 65.22 | 12.61 |
| St. John | 52968 | 26.24 | 18.35 | 55.11 | 17.03 |

Source: Fieldwork finding, July 2019

**Table 4.6: Value of heavy metal contents (Mean ± Standard Deviation) in soil.**

| HM | Concentrations | | | | | Mean | SD | M±SD |
|---|---|---|---|---|---|---|---|---|
| Fe | 57304 | 76875 | 115781 | 56367 | 52968 | 71859 | 23507.54 | 71859±23507.54 |
| Zn | 51.35 | 27.65 | 36.64 | 16.68 | 26.24 | 31.71 | 11.68 | 31.71±11.68 |
| Ni | 186.49 | 17.55 | 22.72 | 19.91 | 18.35 | 53 | 66.77 | 53.00±66.77 |
| Mn | 994.83 | 78.15 | 222.27 | 65.22 | 55.11 | 283.12 | 361.03 | 283.12±361.03 |
| Pb | 16.59 | 8.74 | 19.53 | 12.61 | 17.03 | 14.9 | 3.79 | 14.9±3.79 |

Source: fieldwork finding, July 2019

**Table 4.7: Parameters of Groundwater Condition, Kokoya District, MNG-gold**

| Study Area | Conductivity($\mu$S/cm) | Dissolved oxygen(mg/L) | Temperature($^{o}$C) | Water Level(m) |
|---|---|---|---|---|
| BH-1 | 24.87 | 2.41 | 26.49 | 19.97 |
| | 24.7 | 2.73 | 27.07 | 19.78 |
| | 26.81 | 2.59 | 26.47 | 19.89 |
| | 26.47 | 2.25 | 26.29 | 20.28 |
| BH-2 | 8.59 | 4.4 | 26.49 | 11.05 |
| | 8.69 | 4.45 | 27.02 | 11.24 |
| | 8.67 | 4.31 | 27.19 | 10.98 |
| | 8.48 | 4.36 | 32.22 | 11.98 |
| BH-4 | 8.3 | 2.86 | 26.97 | 9.11 |
| | 15.55 | 3.06 | 27.09 | 7.78 |
| | 8.59 | 2.68 | 26.59 | 9.02 |
| | 16.19 | 2.65 | 26.81 | 8.98 |
| BH-6 | 25.21 | 4.63 | 27.51 | 1.4 |
| | 24.34 | 5.41 | 27.96 | 1.25 |

| | | | | |
|---|---|---|---|---|
| | 25.22 | 5.98 | 27.93 | 1.26 |
| | 24.94 | 6 | 27.74 | 1.17 |
| KMW06 | 6.72 | 5.86 | 26.27 | 8.52 |
| | 7.03 | 5.57 | 26.49 | 8.85 |
| | 7.79 | 5.2 | 26.9 | 10.18 |
| | 8.43 | 6.08 | 26.72 | 9.62 |

Source: fieldwork finding, July 2019

**Table 4.8: Ground water level for July 2019**

| | Month of July 2019 | | | |
|---|---|---|---|---|
| | Week 1 | Week 2 | Week 3 | Week 4 |
| Well Hole Number | Depth(m) | Depth(m) | Depth(m) | Depth(m) |
| BH-1 | 19.19 | 19.78 | 19.89 | 20.28 |
| BH-2 | 11.05 | 11.24 | 10.98 | 11.98 |
| BH-4 | 9.11 | 7.78 | 9.02 | 8.98 |
| BH-6 | 1.4 | 1.25 | 1.26 | 1.17 |
| KMW06 | 8.52 | 8.85 | 10.18 | 9.62 |

Source: fieldwork finding, July 2019