ENVIRONMENTAL EFFECTS OF ARTISANAL GOLD MINING AT ABANDONED ROSTERMAN MINE AND ITS SURROUNDING, KAKAMEGA COUNTY, KENYA

BY

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DECLARATION

Declaration by the student

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DEDICATION

This thesis is dedicated to my wife Anne J. Sigilai as well as my daughters Shanny, Shadney and Shaween for their tender love and inspiration during my study.

ABSTRACT

Rosterman mine is an abandoned gold mine located in Kakamega County, of Western Kenya. The mine was started in 1935 and was abandoned without rehabilitation in 1952 with deep open excavations and huge amount of tailings due to non enforcement of rehabilitation policy during the time. Locals have been panning the tailings for gold remains, unaware of the impacts of the leached elements. Water form the nearby stream is used for domestic purposes. Water that has ponded in the abandoned mine pits has been dangerous to both people and animals that drown in it. To enable future rehabilitation there was need to establish the quality of the mine water. The study aimed at assessing the concentration of the leached elements in the abandoned mine water and their influence on the soil pH, salinity and runoff to nearby streams. Samples of mine and the stream water were analysed for various selected total elements (Iron (Fe), Manganese (Mg), Zinc (Zn), Copper (Cu), Lead (Pb), Cadmium (Cd), and Chromium (Cr)) concentrations during the period of October, 2006 to March, 2007. Topographical map Sheets of the area at scale 1:50,000 were used as a base map to plot the sampling sites. The locations sites were geo referenced using a global positioning system (GPS) in Universal Transverse Mercator. Photographs of the sampled areas were also taken. The results showed that the average concentrations of the selected trace elements in stream water were generally higher that in the mine water. However, concentrations Pb, and Cd in both waters were found to exceed the recommended WHO limits of 0.005 ppm, for drinking water and the applies to Fe, which exceeded the 0.3 ppm limit recommended. The results also indicated that the waters' pH lies between 6.48 and 7.48 which were within the neutral range under neutral range. Partial correlation revealed low correlation between heavy metals and sulphates under the field pH conditions. At 95% confidence level, there was found no variation between levels of heavy metals in the mine waters and the streams suggesting possible other sources of heavy metals into the steams. Recommendations for further studies on the sources of heavy metals to the streams waters were made.

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ACRONYMS USED

AMD	-Acid Mine Drainage
C	- Shichinji Sampling Station
CMW	- Shichinji Mine Water
CSW	- Shichinji Stream Water
DNA	- Deoxyribonucleic Acid
K	- Khayega Sampling Site
KMW	- Khayega Mine Water
KSW	- Khayega Stream Water
L	- Lirhembe Sampling Site
LMW	- Lirhembe Mine Water
LSW	- Lirhembe Stream Water
M	- Mutaho Sampling Site
MMW	- Mutaho Mine Water
MS	- Metal Sulphides
MSW	- Mutaho Stream Water
R	- Rosterman Sampling Site
RMW	- Rosterman Mine Water
RSW	- Rosterman Stream water
S	- Sigalagala Sampling Site
SMW	- Sigalagala Mine Water
SSW	- Sigalagala Stream Water
UNIDO	-United Nations Industrial Development Organizations
WHO	- World Health Organization
NTU	-Nephelometric Turbidity Units

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Artisanal mining is termed the ‘informal' sector of the mining industry, and refers to people, often individuals or families, working with simple tools and equipment outside a legal and regulatory framework. Artisanal gold mining is fundamentally driven by global economic inequality and is an employment choice influenced by poverty. In many developing countries and rural regions economic alternatives are critically limited and the lack of viable employment opportunities impels people into the gold mining sector (UNIDO, 2005). Artisanal gold mining activities are often unplanned and undertaken by workers with little technical understanding of the long term impacts their mining activities have on the environment. Consequently, their methods for gold extraction result in large scale environmental, health and social problems.

Since the modern "gold rush" in developing countries began in the 1980s, millions of people have become artisanal miners, despite the risks of working in small tunnels or on steep hills and being exposed to mercury spilling mills, toxic vapours and explosives (UNIDO, 2005).

An estimated 13 million people work as artisanal miners in at least 30 countries in Latin America, Africa and Asia, extracting a broad range of minerals. Gold is the main substance chosen for extraction as it has the advantage of being simple to extract, refine, and transport, with an average 6 million people mining between 300 and 500 tonnes annually (ILO, 1999). While it is thought that at least a quarter of the world's total gold output comes from artisanal gold mining, World Bank reports acknowledge that in some countries as much as three-quarters of all the gold produced goes unreported (ILO, 1999). Cycles of floods and drought, and political instability has driven many farmers to give up subsistence farming for artisanal gold mining, and the informality and illegal aspects of these activities, such as child labour, makes the full extent of this industry difficult to determine.

Artisanal gold mining activities are frequently accompanied by extensive environmental degradation and deplorable socio-economic conditions, both during operations and well after mining activities have ceased. Typical environmental impacts caused by disorganised artisanal gold mining are diversion of rivers, water siltation, landscape degradation, deforestation, destruction of aquatic life habitat, and widespread mercury poisoning. The miners, many of whom are mining illegally, often follow a ‘hit and run' strategy, thus abandoning a deposit prematurely and causing significant large-scale environmental damage (Mol and Ouberter, 2004).

UNEP 1991 have identified Hg, As, Pb, Cd, Cr, Ni, Zn, Cu Mn among metals and metalloids of concern for potentially harmful effects in the environment in many mining areas. These heavy metals are naturally present in the environment in low quantities, and under any degree of environmental pollution; may sufficiently accumulate in plants and animals. In this study Fe, Pb, Cd, Cr, Zn, Cu and Mn were investigated.

1.2 STATEMENT OF THE PROBLEM

Scavenging through the tailings and opening of new sites by the small scale miners has resulted in mine water ponds, open pits and decreased vegetation cover. In the study area, artisanal mining is unsupervised and uncontrolled, thus can have adverse environmental effects through water dispersion (UNEP, 1991). Previous studies on river waters within Migori gold belt have shown that some metal contaminants of Pb and Hg (Ogola *et al.*, 2002). The community members are at risk using contaminated stream or mine waters.

The study was to investigate levels of contamination caused by the tested elements (metals) on the environment in the said waters. The study was also based on WHO (1996) and WHO (1984) standards.

1.3 GENERAL OBJECTIVE

The general objective was to determine the environmental effects of artisanal gold mining at abandoned Rosterman mine and it's surrounding for the selected heavy elements in water mine and stream water.

1.4 SPECIFIC OBJECTIVES

The specific objectives were:

1. To determine the pH and sulphate (SO_4^{2-}) in the stream waters and mine waters.

2. To analyse the water samples from various mines and their neighbouring streams for Fe, Mn, Zn, Cu, Pb, Cd and Cr.
3. To infer the environmental implications of 1 and 2 above.

1.5 HYPOTHESIS

(i) There is no variation in the element concentration in mine and stream waters

(ii) There is no variation in pH of the mine and stream waters.

1.6 JUSTIFICATION

The long existence of the artisanal gold mining in several parts of the country has been considered a small – scale activity with insignificant impacts. With increasing population and poverty in the country, mining is now a significant economic activity to supplement rural income (Ogola, 1995). This may lead to increased adverse environmental degradation and health effects. Studies elsewhere show that low pH values are associated with effluents from sulphide rich ores commonly associated with gold ores, and leads to release of toxic metals (Foster, 1993). The contamination levels of available water sources needed to be established to safeguard environment and human health. Deep geological environments are exposed to air, oxidizing the reduced minerals ending up reacting and dissolved into water. The resulting water solution may be hazardous for both domestic and industrial use and equally to riparian aquatic life.

1.7 SCOPE OF THE STUDY

The study aims at investigating the concentration levels of the selected trace elements in mine waters and the neighbouring streams during September, 2006 to March, 2007 around abandoned Rosterman gold mine and its surrounding areas. The study does not cover the social economic and physical aspects. These are months with the lowest rainfall.

1.8 AREA

1.8.1 Location and Size

The total area under study in Kakamega County is 1,394.8 km^2. The county lies between longitudes $34^0$32’0’’and $34^0$57’30” E of the prime meridian and latitudes $0^0$07’30” and $0^0$15’0’’ N (Figure 1.1).

1.8.2 Topography

The county has a varying topography with altitudes ranging from 1,250 m to 2,000 m above sea level. It can be divided into two main physiographic units, namely the southern hills made up of rugged peneplain with remnants of denudation of Kakamega and Kambiri hills. The Nandi Escarpment forms a prominent feature on the County’s eastern border with its main scarp rising from the general elevation of 1,600 m to 2,000 m. The flat topography in the southern parts of the district coupled with heavy rainfall and well drained soils provide a good potential for irrigation (GOK, 2002)

Figure 1.1: Location of the larger Kakamega County

Figure 1.1: Location of the larger Kakamega County (Source: GOK, 2002)

One of the main rivers found in the district is Yala, which originates from the Nandi Hills, east of Kakamega County. It flows westwards through Kakamega forest and in the south part of the county. The Nandi escarpment forms the catchment zone for the streams such as the Shitiya, Kabkalet, and Nurungo, which follows westwards to form the Isiukhu River. The two rivers form the larger Lusumu, which flows westward to join the River Nzoia. Several small streams form tributaries to these main rivers, exhibiting dendritic drainage patterns dissecting the peneplain surface often with steep erosional valley. Only the northern part of the distict to the north of Mumias is swampy due to low gradient and poor drainage (GOK, 2002, Huddlestone, 2007).

1.8.3 Geology

The general geology of the county has formation belonging to the Nyanzian volcanic and the Kavirondian sediments (Figure 1.2). The Nyanzian System is associated with gold bearing auriferous quartz veins, e.g. at the abandoned Rosteman mines and along river beds) and placer deposits. It is associated with base metals and massive sulphide mineralization. Quartz porphyries are intrusive in both systems (Huddlestone, 2007). Other intrusives include the Maragoli granite in the south and the Mumias granites to the north. The Kavirondian rocks have a wide distribution in the central portion of the area between the Maragoli and Mumias granites, which are intrusive to them. At the abandoned Rosterman gold mine, the gold bearing quartz veins occurs mainly from the underground geology. The veins occur in a series of marginal tension cracks along the diorites (Huddlestone, 2007).

1.8.4 Climate

The district has high temperatures all the year round with slight variations in the mean maximum and minimum range of 28^0C to 32^0C and 11^0C to 13^0C, respectively. Low temperatures are usually recorded at night while the very high temperatures are recorded during the day. The mean annual evaporation ranges from 1,600 – 2,100 mm with high humidity and low evaporation rates. It is only a few low lying parts of the district that receive annual average evaporation of more than 1,800 mm (GOK, 2002).

There are two rain seasons in the district, the long and short rains. The long rains start in March and end in June, with the peak in May. The short rains commence in July and end in September and peak in August. The driest Months are December, January and February. Generally rainfall varies from 1,000 mm per annum in northern parts of the county to 2,400 mm per annum in the southern parts. Most rainfall received in the county comes in form of heavy afternoon showers with occasional thunderstorms.

1.8.5 Economic Activities

The economic activities undertaken include maize farming, tea growing and livestock rearing (GOK, 2002). In the municipality, there exists few small scale industries coupled with business. In addition, artisanal mining is also becoming a common venture (Ogola, 1995).

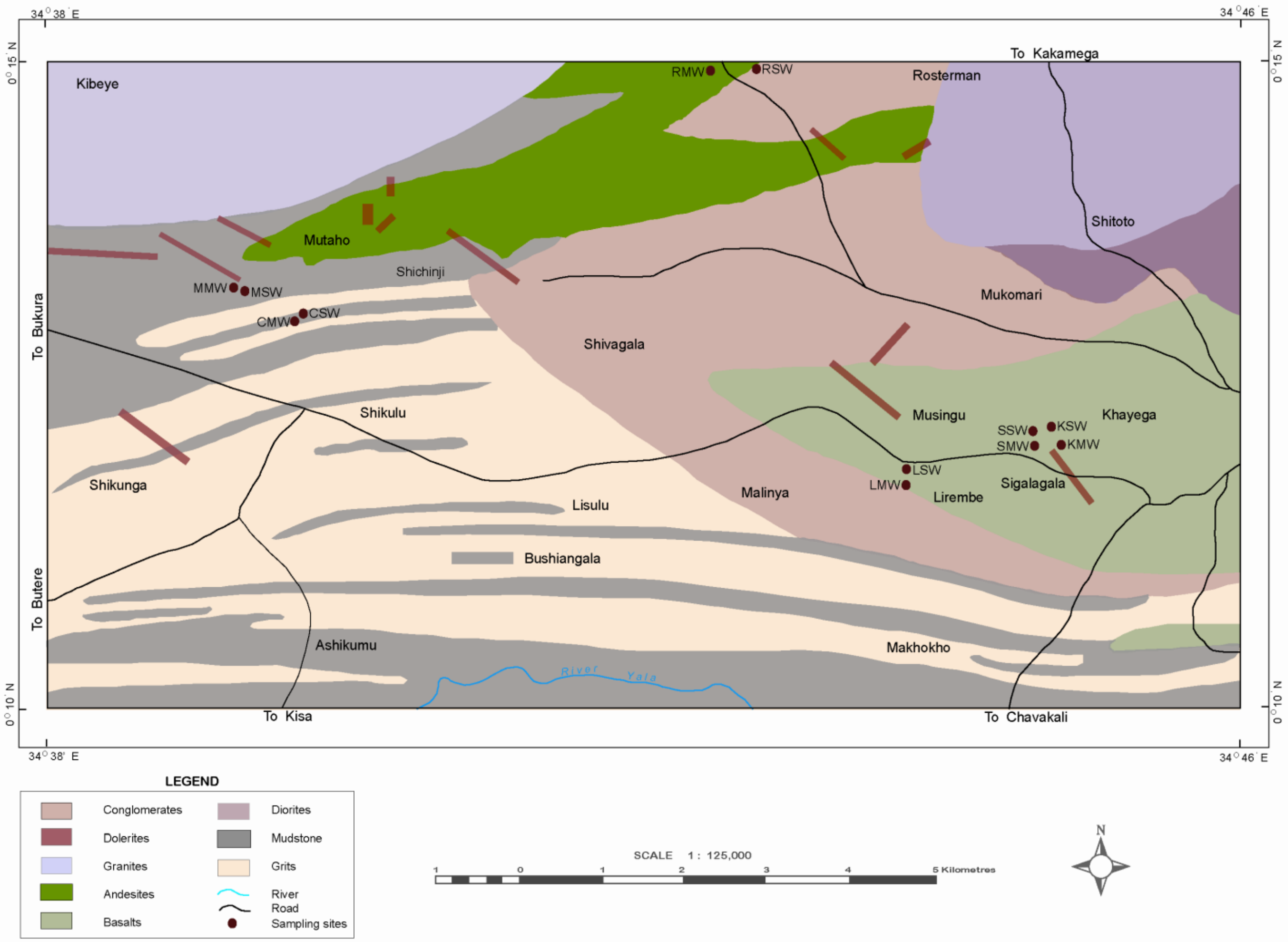

Figure 1.2: Geological Map of the Study Area (Huddlestone, 2007)
(Kavirondian System comprises conglomerates, mudstone and grits. Nyanzian system comprises andesites and basalts. Major intrusives are granites and diorites. Minor intrusives are dolerites).

1.8.6 Population Density

Kakamega County population stood at 603,422 as recorded from 1999 population and housing census report. It was projected to reach 1,514,597 in 2002 with a density of 502 persons/km^2 Major urban centres in the district include Kakamega and Malava town ships. The Ikolomani Division in which Rosterman mine is found, has a high population of 680 persons per km^2 (GOK, 2002).

CHAPTER TWO

LITERATURE REVIEW

2.1 BACKGROUND INFORMATION ON GOLD

From ancient times, gold has been used in jewellery and coinage. For both purposes it is usually alloyed with copper or silver to increase its hardness and resistance to wear. The purity of gold is usually expressed in carats. Pure gold is said to be 24 carats. When alloyed with another metal the proportion of gold clearly diminishes. For example 22 carat gold consists of a mixture of 22 parts of gold to 2 parts of copper or brass. Gold occurs vary widely in nature, chiefly in free or natural state, but invariably alloyed in some silver or copper (UNEP, 1991).

There are conflicting reports concerning the date when gold was first discovered in Kenya. A speck of gold was found at Jombo area of the Kenyan coast in 1893 but this has never risen more than historical interest. One report mentions gold being found at Lolgorian, Trans Mara District, as early as 1892 and at Kavirondo in 1904 (Du Bois and Walsh, 1970). However, the government Geologist in 1909 reported widespread occurrence of gold in stream and rivers in western Kenya but failed to locate any payable bodies and considered that the gold originated from low grade disseminations in the country rocks. Between 1922 and 1933 there was a minor gold rush in the country lying south and south-east of Kisii. In 1942 the government commissioned the geological examination of nearly 25,889 square kilometres of Nyanza Province and recommended the division of the province into mining areas, some of which were considered suitable for exploitation by large mining companies and the remainder by small miners (workers) (Du Bois and Walsh, 1970).

There has been a rapid expansion of the intensive prospecting from 1932 onward for the gold- bearing Nyanzian and Kavirondian rocks (Du bois and Walsh, 1970). By 2006 there were about six major Companies prospecting for gold in western Kenya (i.e. B & M Mining Company, the Mid-Migori Mining Co., AfriOre (Barbados) Ltd., Sebimu Mining and Prospecting Ltd., East African Pure Gold Company Ltd.) and many artisanal miners (Mines and Geology Department, Kenya, 2006). The gold source is predominantly in strata veins within altered quartzite (Foster, 1993). It is often associated with iron and copper sulphides and other base metal. The nature of the deposit primarily determines the mining methods. Thus the impact of gold mining on environment necessarily depends on the composition extension and the mining method(s) employed.

2.2 SULPHATES (SO_4^{2-})

2.2.1 Occurrences

(i) Natural Sources

Sulphur is a non-metallic element that occurs naturally in numerous minerals, including barite ($BaSO_4$), epsomite ($MgSO_4{\cdot}7H_2O$), and gypsum ($CaSO_4{\cdot}2\ H_2O$). Hexavalent sulphur combines with oxygen to form the divalent sulphate ion (SO_4^{2-}). The reversible reaction between sulphide and sulphate in the natural environment is often referred to as the "sulphur cycle." Natural sources of sulphur include volcanoes, decomposition and combustion of organic matter and from sea salt over the oceans. Particles of sea salt formed by the breaking of myriads of bubbles are an important source of atmospheric sulphate. The atmosphere is the main vehicle for transport of sulphur from various sources (Nehb and Vydra, 2006).

(ii) Anthropogenic Sources

Sulphates are discharged into the aquatic environment in wastes from industries that use sulphates and sulphuric acid, such as mining and smelting operations, kraft pulp and paper mills, textile mills and tanneries. Iron pyrite (FeS) may be leached from abandoned coal mines and the sulphide ions converted in surface waters to sulphates. Sulphates are also released during blasting and the deposition of waste rock in dumps at metal mines. This is a significant source of sulphate generation in British Columbia (Jarman, personal communication). The burning of fossil fuels is also a major source of sulphur to the atmosphere. Most of man's emissions of sulphur to the atmosphere (about 95%) are in the form of SO_2. Sulphate fertilizers are identified as a major source of sulphate to ambient waters (Nehb and Vydra, 2006).

Mining allows the introduction of oxygen to the deep geological environment and thus the oxidation of the minerals which are in reduced state. The same occurs when reduced minerals are brought to the surface and deposited in spoil tip (Wiggering, 1993 a,b). The family of such minerals are the sulphides. Unlike most geochemical weathering processes, the oxidation of some sulphides (of the type MS_2) leads to the production rather than the consumption of protons (acid). The reactions involved in the breakdown of pyrite in the presence of water and oxygen to yield sulphuric acid are well known (Zodrow, 2005).

FeS_2(s) + 7/2 O_2 (g) + H_2O (l) $\longrightarrow$ Fe^{2+} (aq) + $2SO_4^{2+}$ (aq) +$2H_{+}$ aq) ----------- 1

Fe^{2+} (aq) + ¼ O_2 (s)+ H^{+} (aq) $\longrightarrow$ Fe^{3+} (aq) + ½ H_2O (l) ----------------------- 2

Fe^{3+} (aq) + $3H_2O$ (l) $\longrightarrow$ Fe $(OH)_2$(s) + $3H^{+}_{(}$(aq) -------------------------------- 3

FeS_2(s) + Fe^{3+} (aq) + H_2O (l) $\longrightarrow$ 12 F^{2+} (aq) + SO_4^{2+}(aq) + 16 H^{+}(aq) --------- 4

Other sulphide minerals will oxidise similarly to pyrite, releasing heavy metal and sulphide. Oxidation of common sulphides (of the type MS) does not in itself release acid. For example sphalerite, ZnS:

ZnS (s) + $2O_2$ (g) $\longrightarrow$ Zn^{2+} (aq) + SO_4^{2-} (aq) ---------------------------------- 5

Subsequent hydrolysis of metal ions release proton; but equilibrium modelling of sphalirite oxidation in dissolution indicates that pH is unlikely to be depressed below 5.5 due to partial hydrolysis of zinc ions (Blodau, 2006).

The buffering reaction only results in a significant depressed pH in the mine water when it exceeds the alkalinity available in the system. Such alkalinity may be available as bicarbonates in ground water by normal weathering or reduction processes or in the form of mineral phases. The most mineral sources of alkalinity are common calcite and dolomite (Nilsen and Grammelt, 1983).

2.2.2 Environmental and Health Effects

Sulphate is a substance that occurs naturally in drinking water. Diarrhea occurs when switching abruptly from drinking water with low sulphate to drinking water with high sulphate concentrations (USEPA, 1999). Humans are able to adapt to higher concentrations with time (USEPA, 1985).Dehydration has also been reported as a common side-effect in humans following the ingestion of large amounts of $MgSO_4$ or Na_2SO_4 (Fingl, 1980).

McKee and Wolf (1963) reported that water containing less than 0.5 ppm sulphate will not support the growth of algae. An elevated sulphate levels can stimulate large sulphur bacteria growths which can cover creek beds and result in significant changes to the macro invertebrate community.

2.2.3 Sulphate Oxidation

The overflowing mine system with saturated opportunities for bacterially catalysed sulphate reduction may occur, generating metal sulphides and / or hydrogen sulphide and alkalinity (Younger and Bradley, 1994, Younger, 1995). The pH of the water is thus elevated.

The oxidation of pyrite in the acid mine drainage water is catalysed by the action of acidophilic sulphide – oxidizing bacteria in particular *Thiobacillus Ferooxidans*, which thrives at a pH range of 1.5 – 3.0. The bacteria *chemoautotroph,* derives energy for its metabolic processes from the oxidation of reduced sulphur and Iron Compounds and utilises carbon dioxide as a carbon source. By catalysing the oxidation of ferrous sulphide for ferric sulphate, this bacterium greatly accelerates the chemical oxidation of iron sulphate (Mielke *et al.*, 2003).

2.3 ACID MINE DRAINAGE

Acid Mine Drainage (AMD) can be defined as inorganic chemical water pollution resulting from oxidation of sulphide- containing minerals and takes places both during the operational and closure of the mine (UNEP, 1991). Potential sources of AMD at the mine sites include (a) drainage from underground workings and runoff from open pit workings; (b) crunching/ mill tailings; (c) waste rock pile from underground mining; and (d) ore stock piles. The quality of mine water and its volume depends on the type of mining operations, the geochemistry and hydrology. AMD can continue for year after closure of the mine. In this study therefore, was to also establish whether AMD was caused by drainage from underground workings and runoff from open pit workings.The mechanism of AMD formation is mainly pyrite being primarily oxidized by air (reaction 1) or by ferric iron (reaction 2) significant at pH below 2.5 (Zodrow, 2005).

FeS_2(s) + 7/2 O_2 (g) + H_2O (l) $\longrightarrow$ Fe^{2+} (aq) + 2SO_4^{2+} (aq) +2H_+ aq) ------------ 1

FeS_2(s) + Fe^{3+} (aq) + H_2O (l) $\longrightarrow$ 12 F^{2+} (aq) + SO_4^{2+}(aq) + 16 H^+(aq) --------- 2

2.3.1 Environmental Impact of Acid Mine Drainage

Acid mine drainage affects organisms living in water in numerous and interactive ways. This results in multiple pressures, both direct and indirect on the organism comprising the community structure of the ecosystem. These effects can be loosely categorized as chemical, physical, biological and ecological, although the overall impact on the community structure is the elimination of species simplifying the food chain and so significantly reducing ecological stability (Walles and Jennings, 2001).

(i) Chemical effects

The effects range from increased acidity, reduction in pH, destruction of bicarbonate buffering system, increase in soluble metal concentrations and increase in particulate metals (Nordstrom *et al.*, 2000).

(ii) Physical effects

The effects ranges from substrate modification for example increase in stream velocity, turbidity, sedimentation, adsorption of metal and sediments reduction in turbulence due to sedimentation increasing laminar flow, and decrease in light penetration (Nordstrom *et al.*, 2000).

(iii) Biological effects

The effects are the behavioural, respiratory reproduction, osmoregulation, acute and chronic toxicity, death of sensitive species and base balance, failure in organisms and migration or avoidance (Nordstrom *et al.*, 2000).

(iv) Ecological Effects

The effects are adverse. It varies from habitat modification, niche loss, Bioaccumulation within food chain, loss of food source of prey, elimination of sensitive species, reduction of primary productivity and modification of food chain.

In essence ecological stability increases with food chain complexity as this complexity allows loti communities in particular to cope with pollutants (e.g. organic matter, solids deposition and degradation, temperature, etc.) and to recover once the pollution impact has ceased or has been either biologically degraded or removed by physico-chemical processes. However, the effects of AMD are so multifarious that community structure collapses rapidly and totally, even though very often no single pollutant on its own would have caused such severe ecological impact. Recovery is suppressed due to habitat elimination, niche reduction, substrate modification, the toxic nature of sediments and bioaccumulation of metals in the flora and fauna (Mielke *et al.*, 2003).

Acid mine drainage is recognized as a multi- factor pollutant and the importance of each factor varies within and between affected systems. The main factors are the acidity itself, salinization, and metal toxicity and sedimentation progresses (Foster, 1993). The overall impact is very largely controlled, not so much by the nature of the leachate draining from the mine adits, but the buffering capacity of the receiving water and available dilution. Soft, poorly buffered rivers are more severely affected than hard, well buffered systems where the impact may be more reprinted with sedimentation being the major mode of impact (Barnes & Romberger, 1968).

The impact of AMD is very difficult to predict due to the variability of discharge from adits. The composition which varies seasonally, the effect of surface runoff from exposed areas of the mines during heavy rainfall and the effect of the catchments discharge characteristics affecting dilution and the concentration of organic matter in the water chelating soluble metals present. Assessment is also difficult due to the complexity of the impacts, although diversity and abundance are key variable for biotic evaluation. There are no specific indicator species for AMD in affected rivers although fish movement and migration is useful indicator. Toxicity of key metals or the degree of substrate modification caused by iron precipitation, directly linked to pH (Gray, 1996), may prove to be more useful in understanding AMD impacts and predicting them.

2.4 TYPES OF MINING

Mining is defined as wining of minerals and include any operations necessary for the purpose (GOK, (1987).

2.4.1 Surface Mine (Open Excavation)

Surface mining activities observed at Rosterman mine and artisanal mines consist of open pit mining. Open pit mining is practical when a large, three- dimensional ore body is located near the surface (Montgomery, 1989). Most of the material in the pit is valuable commodity and is extracted for processing. Thus this procedure permanently changes the topography, leaving a large hole in its wake. The exposed rock may begin to weather and depending on the nature of the ore body, may release pollutants into the surface runoff water.

Strip mining is commonly applied when the material of interest occurs in a layer near and approximately parallel to the surface. This underlying soil and rocks are stripped off and the waste is dumped back in a series of spoil banks. The broken up materials of the spoil banks, with its high surface area, is susceptible to both erosion and chemical weathering (Montgomery, 1989).

2.4.2 Underground mines

Underground mines are generally much less apparent than surface mines. They disturb a relatively small area of the land's surface close to the principal shaft(s) waste rock dug out of the mine and may be piled close to the mine's entrance. The tunnels follow the ore body as closely as possible to minimise the amount of non-ore rock to be removed and thus mining costs.

When mining activities are complete, the shafts can be sealed and the area often returned very nearly to its pre-mining condition. However, near- surface underground mines occasionally have collapsed years after abandonment when supporting timber have rotted away or ground water has enlarged the underground cavities through solution (UNEP, 1991).

2.6 HEAVY METALS (ELEMENTS)

2.6.1 Iron

(i) Occurrences

Most of this iron is found in various iron oxides, such as the minerals hematite, magnetite, siderite and taconite. The earth’s core is believed to consist largely of a metallic iron-nickel alloy. It is a hard, silver-grey metallic element. Iron is essential to almost living things, from micro-organisms to humans.

Iron can be found in meat, whole meal products, potatoes and vegetables. The human body absorbs iron in animal products faster than iron in plant products. Iron is an essential part of haemoglobin; the red colouring agent of the blood that transports oxygen through our bodies (Williams, 2001).

(ii) Environmental and Health Effects

Iron may cause conjunctivitis, choroiditis, and retinitis if it contacts and remains in the tissues. Chronic inhalation of excessive concentrations of iron oxide fumes or dusts may result in development of siderosis. No physical impairment of lung function has been associated with siderosis. Inhalation of excessive concentrations of iron oxide may enhance the risk of lung cancer development in workers exposed to pulmonary carcinogens (Strahler and Strahler, 1973). A more common problem for humans is iron deficiency, which leads to anaemia.

Dissolved iron is mainly present as $Fe(OH)_2^+$ (aq) under acidic and neutral, oxygen-rich conditions. Under oxygen-poor conditions it mainly occurs as binary iron. Iron is part of many organic and inorganic chelating complexes that are generally water soluble Weathering processes release the element into waters. Both mineral water and drinking water contain iron carbonate. Iron is a dietary requirement for most organisms, and plays an important role in natural processes in binary and tertiary form. Oxidized tertiary iron cannot be applied by organisms freely, except at very low pH values. Still, iron usually occurs in this generally water insoluble form (Williams, 2001).

Adding soluble iron may rapidly increase productivity in oceanic surface layers. It might then play an important role in the carbon cycle. Iron is essential for nitrogen binding and nitrate reduction, and it may be a limiting factor for phytoplankton growth. Solubility in salt water is extremely low. The iron cycle means reduction of tertiary iron by organic ligands (a process that is photo catalysed in surface waters), and oxidation of binary iron. Iron forms chelating complexes that often play an important role in nature, such as haemoglobin, a red colouring agent in blood that binds and releases oxygen in breathing processes. Organisms take up higher amounts of binary iron than of tertiary iron, and uptake mainly depends on the degree of saturation of physical iron reserves. Iron is often a limiting factor for water organisms in surface layers. When chelating ligands are absent, water insoluble tertiary iron hydroxides precipitate. This is not thought to be hazardous for aquatic life, because not much is known about hazards of water borne iron (Suvlivan *et a.l*, 1995).

Green plants use iron for energy transformation processes. Plants that are used as animal feed may contain up to 1000 ppm of iron, but this amount is much lower in plants used for human consumption. Generally plants contain between 20 and 300 ppm iron (dry mass), but lichens may consist up to 5.5% of iron. When soils contain little iron or little water soluble iron, plants may experience growth problems. Plant uptake capacity strongly varies, and it does not only depend on soil iron concentrations, but also upon pH values, phosphate concentrations and competition between iron and other heavy metals. Lime soils are often iron deficit, even when sufficient amounts of iron are present. This is because of the generally high pH value, which leads to iron precipitation (Thomson &Turk, 1993).

Iron usually occurs in soils in tertiary form, but in water saturated soils it is converted to binary iron, thereby enabling plant iron uptake. Plants may take up water insoluble iron compounds by releasing H^+ ions, causing it to dissolve. Micro organisms release iron siderochrome, which can be directly taken up by plants. A number of bacteria take up iron particles and convert them to magnetite, to apply this as a magnetic compass for orientation. Iron compounds may cause a much more serious environmental and health impacts than the element itself (Vander *et a.l*, 1990). Iron dust may cause lung disease.

2.6.2 Manganese

(i) Occurrences

Manganese occurs principally as pyrolusite (MnO_2), and to a lesser extent as rhodochrosite ($MnCO_3$). Manganese is a very common compound that can be found everywhere on earth. Manganese is an essential element for all species. Some organisms, such as diatoms, molluscs and sponges, accumulate manganese (Van Ioon, 1985).

(ii) Environmental and Health Effects

Manganese compounds exist naturally in the environment as solids in the soils and in small particles in the water. Manganese particles in air are present in dust particles (WHO, 1996). These usually settle to earth within a few days.

Manganese that derives from human sources can also enter surface water, groundwater and sewage water. Through the application of manganese pesticides, manganese will enter soils. Manganese can cause both toxicity and deficiency symptoms in plants at above 0.5 ppm and below 0.1 ppm in soils. When the pH of the soil is low, manganese toxicities are more common (Taiz and Zeiger, 2002).

Manganese is an essential trace element, but it is also toxic when too high concentrations are present in a human body. Its deficiency, i.e. below the recommended daily allowances can also cause health effects (Manahan, 1991). Chronic manganese poisoning may result from prolonged inhalation of dust and fume of Manganese compounds. The central nervous system is the chief site of damage from the disease, which may result in permanent disability. Symptoms include languor, sleepiness, weakness, emotional disturbances, spastic gait, recurring leg cramps, and paralysis. A high incidence of pneumonia and other upper respiratory infections has been found in workers exposed to dust or fume of Manganese compounds.

2.6.3 Zinc

(i) Occurrences

Zinc is a very common substance that occurs naturally. The most significant zinc ores include sphalerite (ZnS) and smithsonite ($ZnCO_3$). Many foodstuffs contain certain concentrations of zinc. Drinking water also contains certain amounts of zinc, which may be higher when it is stored in metal tanks. Industrial sources or toxic waste sites may cause the zinc amounts in drinking water to reach levels that can cause health problems (WHO, 1996).

Zinc occurs naturally in air, water and soil, but zinc concentrations are rising unnaturally, due to addition of zinc through human activities. Most zinc is added during industrial activities, such as mining, coal and waste combustion and steel processing. Some soils are heavily contaminated with zinc, and these are to be found in areas where zinc has to be mined or refined, or where sewage sludge from industrial areas has been used as fertilizer.

(ii) Environmental and Health Effects

The world's zinc production is rising and this basically means that more and more zinc ends up in the environment from mining activities (Weber and Zsack, 2007).

Water is polluted with zinc, due to the presence of large quantities of zinc in the wastewater of industrial plants. This wastewater is not purified satisfactorily. One of the consequences is that rivers are depositing zinc-polluted sludge on their banks. Zinc may also increase the acidity of waters (Keller, 1988).

Some fish can accumulate zinc in their bodies, when they live in zinc-contaminated waterways. When zinc enters the bodies of these fish it is able to bio magnify up the food chain (Vinikour *et al.*, 1980).

Large quantities of zinc can be found in soils. When the soils of farmland are polluted with zinc, animals will absorb concentrations that are damaging to their health. Water-soluble zinc that is located in soils can contaminate groundwater. On zinc-rich soils only a limited number of plants have a chance of survival. That is why there is not much plant diversity near zinc-disposing factories. Due to the effects upon plants zinc is a serious threat to production of farmlands. Despite this, zinc-containing manures are still applied. Finally, zinc can interrupt the activity in soils, as it negatively influences the activity of micro organisms and earthworms. The breakdown of organic matter may seriously slow down because of this.

Elemental zinc does not react with water molecules. The ion does form a protective, water insoluble zinc hydroxide ($Zn(OH)_2$) layer with dissolved hydroxide ions, according to the following reaction mechanism (Upor, 1985):

$Zn^{2+} (aq) + 2OH^{-} (aq) \longrightarrow Zn (OH)_2 (s)$

Zinc reacts with H^+ ions, according to the following reaction mechanism:

$Zn(s) + 2H^{+} (aq) \longrightarrow Zn^{2+}(aq) + H_2(g)$

This reaction releases hydrogen, which reacts with oxygen explosively.

Zinc salts cause a milky turbidity in water in higher concentrations. Additionally, zinc may add an unwanted flavour to water. This occurs at concentrations of about 2 mg Zn^{2+}/ l. The solubility of zinc depends on temperature and pH of the water in question. When the pH is fairly neutral, zinc is water insoluble. Solubility increases with increasing acidity. Above pH 11, solubility also increases. Zinc dissolves in water as $ZnOH^+$ (aq) or

Zn^{2+} (aq). Anionic $ZnCO_3$ has a solubility of 0.21 g/l (Wright, 2003). Examples of solubility of zinc compounds are: zinc chloride ($ZnCl_2$) 4320 g/l, and zinc oxide (ZnO) or zinc vitriol ($ZnSO_4$. $7H_2O$) 580 g/l.

The human body uses zinc mainly for enzymatic processes and DNA replication. The human hormone insulin contains zinc, and it plays an important role in sexual development. Minimum daily intake is 2.3 g; this prevents deficiencies. The human body only absorbs 20-30% of zinc present in food (WHO, 1996); consequently many people drink mineral water rich in zinc. Symptoms of zinc deficiencies are tastelessness and loss of appetite. Children's immune systems and enzyme systems may be affected. Higher zinc application appears to protect people from cadmium poisoning (WHO, 1996).

One may also absorb zinc overdoses. This does not occur very regularly. Symptoms include nausea, vomiting, dizziness, fevers and diarrhoea and mostly occur after intake of 4.8 g of zinc. Intake of 2 g of zinc sulphate at once will cause acute toxicity leading to stomach aches and vomiting. Strikingly, zinc belongs to the same elemental group in the periodic chart as cadmium and mercury, which are both toxic (Nyambok and Davies, 1993).

2.6.4 Copper

(i) Occurrences

Copper is a very common substance that occurs naturally in the environment and spreads through the environment through natural phenomena. Humans widely use copper. For instance it is applied in the industries and in agriculture. The production of copper has increased over the last decades and due to this, copper quantities in the environment have expanded.

The world's copper production is still rising (Weber and Zsack, 2007). This basically means that more and more copper ends up in the environment. Rivers are depositing sludge on their banks that is contaminated with copper, due to the disposal of copper-containing wastewater. Copper enters the air, mainly through release during the combustion of fossil fuels. Copper in air will remain there for an eminent period of time, before it settles when it starts to rain. It will than end up mainly in soils. As a result soils may also contain large quantities of copper after copper from the air has settled (Raiswell, 1980).

Copper can be released into the environment by both natural sources and human activities (Manahan, 1991). Examples of natural sources are wind-blown dust, decaying vegetation, forest fires and sea spray. A few examples of human activities that contribute to copper release have already been named. Other examples are mining, metal production, wood production and phosphate fertilizer production.

Because copper is released both naturally and through human activity, it is very widespread in the environment. Copper is often found near mines, industrial settings, landfills and waste disposals.

Most copper compounds will settle and be bound to either water sediment or soil particles. Soluble copper compounds form the largest threat to human health. Usually water-soluble copper compounds occur in the environment after release through application in agriculture.

(ii) Environmental and Health Effects

When copper ends up in soil it strongly attaches to organic matter and minerals. As a result it does not travel very far after release and it hardly ever enters groundwater. In surface water copper can travel great distances, either suspended on sludge particles or as free ions (Lide, 1998).

Copper can accumulate in plants and animals when it is found in soils. On copper-rich soils only a limited number of plants has a chance of survival. That is why there is not much plant diversity near copper-disposing factories. Due to the effects upon plants copper is a serious threat to the productions of farmlands. Copper can seriously influence the proceedings of certain farmlands, depending upon the acidity of the soil and the presence of organic matter. Despite this, copper-containing manures are still applied (Sullivan and Krieger, 2001).

Copper can interrupt the activity in soils, as it negatively influences the activity of microorganisms and earthworms. The decomposition of organic matter may seriously slow down because of this (Lide, 1998).

When the soils of farmland are polluted with copper, animals will absorb concentrations that are damaging to their health. Mainly sheep suffer a great deal from copper poisoning, because the effects of copper are manifested at fairly low concentrations (Bodgen & Klevay, 2000).

Copper can be found in many kinds of food, in drinking water and in air (WHO, 1994). Because of that we absorb large quantities of copper each day by eating, drinking and breathing. The absorption of copper is necessary, because copper is a trace element that is essential for human health. Although humans can handle proportionally large concentrations of copper, too much copper exceeding 1.3 ppm can still cause more health problems (USEPA, 1999).

Copper concentrations in air are usually quite low, so that exposure to copper through breathing is negligible. But people that live near smelters that process copper ore into metal do experience this kind of exposure (Sullivan and Krieger, 2001).

Long-term exposure to copper can cause irritation of the nose, mouth and eyes and it causes headaches, stomach aches, dizziness, vomiting and diarrhoea. Intentionally high uptakes of copper may cause liver and kidney damage and even death. Whether copper is carcinogenic has not been determined yet (USEPA, 1999).

Industrial exposure to copper fumes, dusts, or mists may result in metal fume fever with atrophic changes in nasal mucous membranes. Chronic copper poisoning results in Wilson’s disease; characterized by a hepatic cirrhosis, brain damage, demyelination, renal disease, and copper deposition in the cornea (Sullivan and Krieger, 2001).

2.6.5 Lead

(i) Occurrences

Native lead is rare in nature. Currently lead is usually found in ore with zinc, silver and copper and it is extracted together with these metals. The main lead mineral is Galena (PbS) and there are also deposits of cerussite and anglesite which are mined

Lead occurs naturally in the environment. However, most lead concentrations that are found in the environment are a result of human activities (Manahan, 1991).

(ii) Environmental and Health Effects

Lead and lead compounds are generally toxic pollutants. Lead (II) salts and organic lead compounds are most harmful ecotoxicologically. Lead salts are attributed to water hazard class 2, and consequently are harmful. The same applies to lead compounds such as lead acetate, lead oxide, lead nitrate, and lead carbonate (Foulkes, 1990).

Lead limits plant chlorophyll synthesis. Nevertheless, plants can take up high levels of lead up to 500 ppm from soils. Higher concentrations negatively influence plant growth. Lead accumulates in organisms, sediments and sludge (Daniels-Davis, 1996).

Lead removal from water may be accomplished by applying coagulation, sand filtration and ionic exchange. The full impact of lead on an ecosystem and its biota is also not well understood, although its toxic effects to all organisms are widely recognised. Although organisms can tolerate lead at the very low levels that occur naturally in the environment, lead has no beneficial role to organisms.

Lead fulfils no essential function in the human body, it can merely do harm after uptake from food, air or water. Lead can cause several unwanted effects, such as disruption of the biosynthesis of haemoglobin and anaemia, a rise in blood pressure, kidney damage, miscarriages and subtle abortions, disruption of nervous systems, brain damage, declined fertility of men through sperm damage, diminished learning abilities of children, behavioural disruptions of children, such as aggression, impulsive behaviour and hyperactivity. Lead can enter a foetus through the placenta of the mother. Because of this it can cause serious damage to the nervous system and the brains of unborn children (Pearce, 2007, USEPA, 1986).

Lead can end up in water and soils through corrosion of leaded pipelines in a water transporting system and through corrosion of leaded paints (Yu, 2005). It cannot be broken down; it can only be converted to other forms. Lead accumulates in the bodies of water organisms and soil organisms causing lead poisoning. Health effects on shellfish can take place even when only very small concentrations of lead are present. Body functions of phytoplankton can be disturbed when lead interferes. Phytoplankton is an important source of oxygen production in seas and many larger sea-animals eat it (Elinder, 1985). That is why we now begin to wonder whether lead pollution can influence global balances.

Soil functions are disturbed by lead intervention, especially near highways and farmlands, where extreme concentrations may be present. Soil organisms can suffer from lead poisoning too (Yu, 2005).

Lead is a particularly dangerous chemical, as it can accumulate in individual organisms, but also in entire food chains.

Under normal conditions lead does not react with water. However, when lead comes in contact with moist air, reactivity with water increases. A small lead oxide (PbO) layer forms at the surface of the metal. When both oxygen and water are present, metallic lead is converted to lead hydroxide ($Pb(OH)_2$) (Wiberg *et al*, 2001).

$$2Pb(s) + O_2(g) + 2H_2O(l) \longrightarrow 2\,Pb(OH)_2(s)$$

Elementary lead does not dissolve in water under normal conditions (20°C, and pressure = 1 bar). It may however occur dissolved in water as $PbCO_3$ or $Pb(CO_3)_2^{2-}$. A well-known example of a water soluble lead compound is lead sugar (lead (II) acetate), which derived its name from its sweet nature. Lead frequently binds to sulphur in sulphide form (SO_4^{2-}), or to phosphor in phosphate form (PO_4^{3-}). In these forms lead is extremely insoluble, and is present as immobile compounds in the environment. Lead compounds are generally soluble in soft, slightly acidic water (Needleman, 1992).

2.6.6 Cadmium

(i) Occurrences

Cadmium is an element that occurs naturally in the earth's crust. Pure cadmium is a soft, silver-white metal. Cadmium is not usually present in the environment as a pure metal, but as a mineral combined with other elements such as oxygen (cadmium oxide), chlorine (cadmium chloride), or sulphur (cadmium sulphate, cadmium sulphide). Cadmium is most often present in nature as complex oxides, sulphides, and carbonates in zinc, lead, and copper ores. It is rarely present in large quantities as the chlorides and sulphates. These different forms of cadmium compounds are solids that dissolve in water to varying degrees. The chlorides and sulphates are the forms that most easily dissolve in water.

Cadmium may change forms, but the cadmium metal itself does not disappear from the environment (Foulkes, 1990). Knowing the particular form of cadmium, however, is very important when determining the risk of potential adverse health effects.

(ii) Environmental and Health Effects

Cadmium is released to the environment each year, about half from the weathering of rocks into river water and then to the oceans. Forest fires and volcanoes also release some cadmium to the air, with major contributions from mining activities, and burning of fossil fuels (Manahan, 1991). Cadmium can enter the air from the burning of fossil fuels (e.g., coal fired electrical plants) and from the burning of household waste (Riley, 1960). Because of regulations, only small amounts currently enter water from the disposal of waste water from households or industries. Fertilizers often contain some cadmium that will enter the soil when fertilizers are applied to crops. Cadmium can also enter the soil or water from spills or leaks at hazardous waste sites if large amounts of dissolved cadmium are present at the site. The form of cadmium at these sites is important since many forms do not easily dissolve in water.

Cadmium that is in or attached to small particles can enter the air and travel a long way before coming down to earth as dust, or in rain or snow. The cadmium metal itself does not break down in the environment, but it can change into different forms (Elinder, 1985). Most forms of cadmium stay for a long time in the same place where they first entered the environment. Some forms of the cadmium that goes into the water will bind to soil, but some will remain in the water. Some forms of cadmium in soil can enter water or be taken up by plants. Fish, plants, and animals can take some forms of cadmium into their bodies from air, water, or food. Cadmium can change forms in the body, but it also stays in the body for a very long time (years) (Manahan, 1991).

Most of the cadmium that enters bodies goes to kidney and liver and can remain there for many years. A small portion of the cadmium that enters the body leaves slowly in urine and faeces. Bodies can change most cadmium to a form that is not harmful, but too much cadmium can overload the ability of liver and kidney to change the cadmium to a harmless form and the harmful form may damage one's health (Elinder, 1985). Most cadmium taken into the stomach and intestines passes through without being absorbed. At high enough levels, however, damage to the stomach and intestines can occur. A few studies in animals indicate that younger animals absorb more cadmium than adults. Animal studies also indicate that the young are more susceptible than adults to a loss of bone and decreased bone strength from exposure to cadmium. Animal studies also indicate that more cadmium is absorbed into the body from the diet if the diet is low in calcium, protein, or iron, or if the diet is high in fat (because fat slows down the passage of food in the gut and allows more time for absorption). Children who do not get enough iron, calcium, or protein may also absorb more cadmium (International Program Project Society, 1992).

2.6.7 Chromium

(i) Occurrences

Many chromium compounds are relatively water insoluble, therefore, found in trace amounts. Chromium (III) compounds are water insoluble because these are largely bound to floating particles in water. Chromium (III) oxide and chromium (III) hydroxide are the only water soluble compounds. Chromium (VI) oxide is an example of an excellently water soluble chromium compounds, solubility = 1680 g/l (Cox, 1991).

Chromium does not occur freely in nature. The main chromium mineral is chromite. Chromium (III) oxides are only slightly water soluble; therefore concentrations in natural waters are limited. Cr^{3+} ions are rarely present at pH values over 5, because hydrated chromium oxide ($Cr(OH)_3$) is hardly water soluble (Mason, 2002).

Chromium (VI) compounds are stable under aerobic conditions, but are reduced to chromium (III) compounds under anaerobic conditions. The reverse process is another possibility in an oxidizing environment. Chromium is largely bound to floating particles in water (Kota and Stasicka, 2000).

Chromium (VI) compounds are toxic at low concentrations for both plants and animals. The mechanism of toxicity is pH dependent. These compounds are more mobile in soils than chromium (III) compounds, but are usually reduced to chromium (III) compounds within a short period of time, reducing mobility. Soluble chromates are converted to insoluble chromium (III) salts and consequently, availability for plants decreases. This mechanism protects the food chain from high amounts of chromium. Chromate mobility in soils depends on both soil pH and soil sorption capacity, and on temperature (Katz and Salem, 1992).

(ii) Environmental and Health effects

There are several different kinds of chromium that differ in their effects upon organisms. Chromium enters the air, water and soil in the chromium (III) and chromium (VI) form through natural processes and human activities (Manahan, 1991).

The main human activities that increase the concentrations of chromium (III) are steal, leather and textile manufacturing. The main human activities that increase chromium (VI) concentrations are chemical, leather and textile manufacturing, electro painting and other chromium (VI) applications in the industry. These applications will mainly increase concentrations of chromium in water. Through coal combustion chromium will also end up in air and through waste disposal chromium will end up in soils (Manahan, 1991).

Most of the chromium in air will eventually settle and end up in waters or soils. Chromium in soils strongly attaches to soil particles and as a result it will not move towards groundwater. In water chromium will adsorb on sediment and become immobile. Only a small part of the chromium that ends up in water will eventually dissolve. Crops contain systems that arrange the chromium-uptake to be low enough not to cause any harm. But when the amount of chromium in the soil rises, this can still lead to higher concentrations in crops. Acidification of soil can also influence chromium uptake by crops. Plants usually absorb only chromium (III). This may be the essential kind of chromium, but when concentrations exceed a certain value, negative effects can still occur.

Chromium is known to be toxic at high concentrations in fish bodies. Disposal of metal products in surface waters, can damage the gills of fish that swim near the point of disposal. In animals chromium can cause respiratory problems, a lower ability to fight disease, birth defects, infertility and tumour formation (Langrrd, 1990).

People can be exposed to chromium through breathing, eating or drinking and through skin contact with chromium or chromium compounds. The level of chromium in air and water is generally low. In drinking water the level of chromium is usually low as well, but contaminated well water may contain the dangerous chromium(IV); hexavalent chromium. For most people eating food that contains chromium (III) is the main route of chromium uptake, as chromium (III) occurs naturally in many vegetables, fruits, meats, yeasts and grains. Various ways of food preparation and storage may alter the chromium contents of food. When food is stored in steel tanks or cans chromium concentrations may raise (Katz and Salem, 1992).

Chromium (III) is an essential nutrient for humans and shortages may cause heart conditions, disruptions of metabolisms and diabetes. But the uptake of too much chromium (III) can cause health effects as well, for instance skin rashes (Manahan, 1991).

Chromium (VI) is a danger to human health, mainly for people who work in the steel and textile industry. People who smoke tobacco also have a higher chance of exposure to chromium (Levy *et al.*, 2001).

Chromium (VI) is known to cause various health effects. When it is a compound in leather products, it can cause allergic reactions, such as skin rash. After breathing it in chromium (VI) can cause nose irritations and nosebleeds. Other health problems that are caused by chromium (VI) are skin rashes, upset stomachs and ulcers, respiratory problems, weakened immune systems, kidney and liver damage, alteration of genetic material, lung cancer and death (Dayan and Paine, 2001).

The WHO limits of the tested elements in drinking water is summarised as in table 2.1.

Table 2.1: Trace element limits in drinking water (WHO, 1984).

Element	**WHO limits mg/l (ppm) in drinking water**
Cadmium(Cd)	0.005
Copper (Cu)	1.0
Iron (Fe)	0.3
Lead (Pb)	0.05
Manganese (Mn)	0.1
Zinc (Zn)	5.0
Chromium (Cr)	0.05

2.7 PREVIOUS ENVIRONMENTAL STUDIES IN THE AREA

Ogola (1995) found that the gold belt is associated with silver and traces of schealite, pyrite, chalcopyrite, ansonopyrite, molybdenite , sphaherite and pentlandite. Cadmium, one of the top hazardous substances has been detected in spharelite, occurring as an isometric trace element (Ogola *et al*., 2002). Through long term pollution, cadmium may present problems in the belt.

Ogola (1986) reported the presenceof sulphides deposit in Macalder area, which is likely to cause acid mine drainage. Gold was found to occur with silver and copper sulphide deposits. Ogola *et al.*, 2002, found that the main health problems around mining areas include respiration ailments and indirectly associated malaria, which is a consequence of water logged pits and trenches. Ogola *et al*., 2002 also found out the concentrated of Arsenic (As), Mercury (Hg), and Lead (Pb) alarmingly above acceptable levels in migori mining belt with values at panning site as high as 6.5 – 510 mg/kg Pb, 0.06 – 76.0 mg/kg As and 0.14 – 120 mg/kg Hg. In terms of documented data, gaps still remain with regards to health impacts of these metals in the area.

Davies (2000) reported high levels of metals around the Macalder mine that is 0.0119 g/l Cd and 0.086 g/l Pb in water. Neyole (2005) reported 0.002 mg/l, 0.01 mg/l and 0.035 mg/l, for Cd, Pb and Cr, respectively from Isiukhu River in the study area.

CHAPTER THREE

METHODOLOGY

3.1 INTRODUCTION

This study involved collection of mine and stream water samples for laboratory analyses; and was conducted between September, 2006 and March, 2007 being the months reported to be with the lowest rainfall. The analysis of environmental determinants Fe, Mn, Zn, Cu, Pb, Cd, pH and (SO_4^{2-}) levels in both stream and mine waters was done. The results obtained were statistically analysed for possibility of association of the stream and mine waters and in the process predict possible AMD.

3.2 FIELD METHODS

3.1.1 Preliminary Survey

Reconnaissance of the area was done to identify the artisanal mine sites in the study area. The abandoned mines with water pools were marked for the study.

The specific study areas are the abandoned Rosterman mine in Kakamega Municipality, Sigalagala, Khayega, Lirembe, Shichinji, and Mutaho in Ikolomani division (**Figure 3.1**).

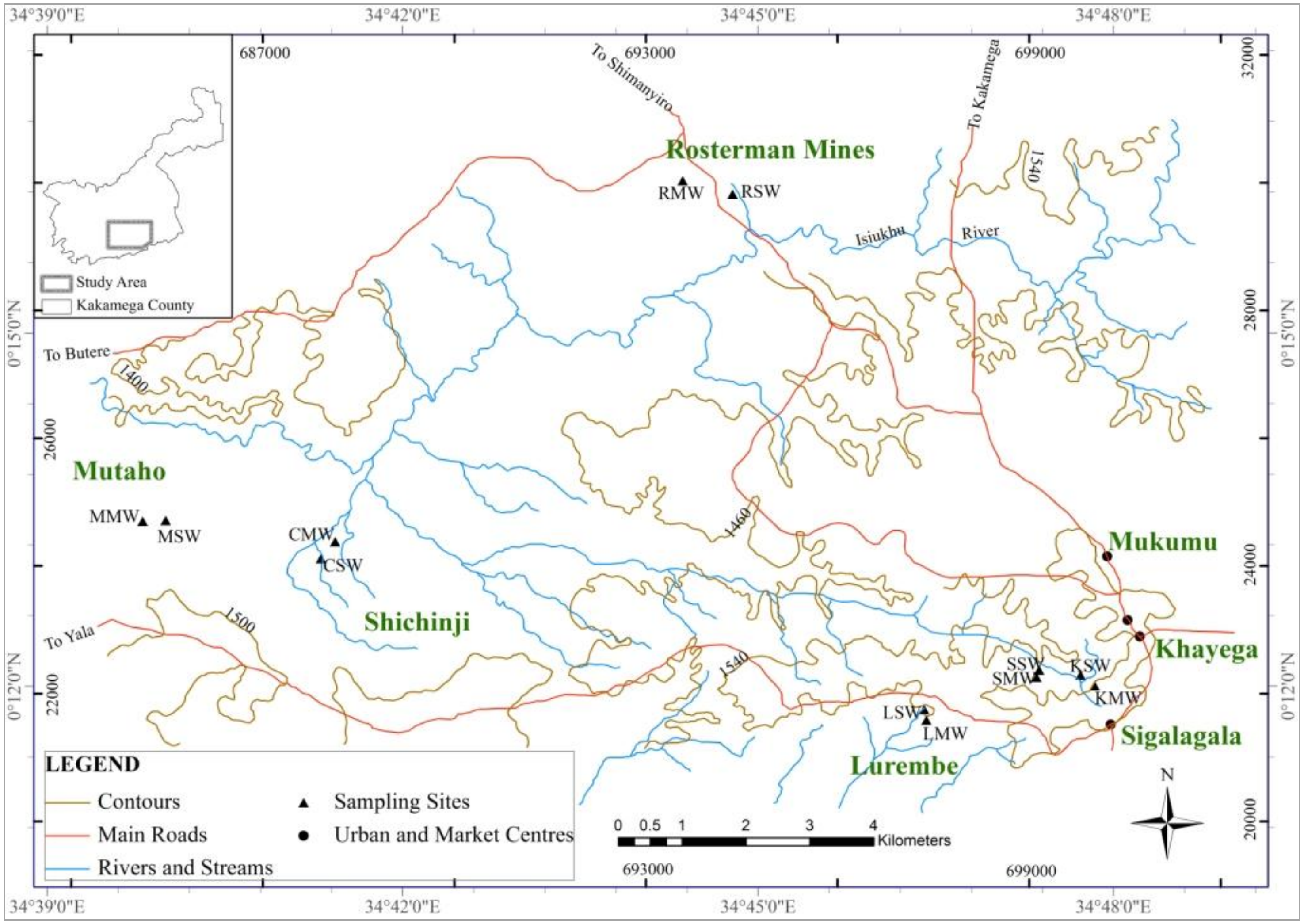

Figure 3:1 Location of the study area, Kakamega County.

The sampled stations were guided by reconnaissance survey and mapped out using the Global Positioning System (GPS). Table 3.1 shows the exact localities of the sampled mine waters and the nearest drinking streams waters. The coordinates were in Universal Transverse Mercator (UTM) in meters at zone 36 N.

Table 3.1: Coordinates of the sampled sites (Zone 36 N UTM)

Number	Sampling Sites	Easting	Northing
1.	RSW	0692018	0028773
2.	RMW	0691366	0028950
3.	KSW	0696240	0022350
4.	KMW	0696400	0022050
5.	LSW	0694498	0021834
6.	LMW	0694533	0021696
7.	SSW	0695948	0022372
8.	SMW	0695930	0022294
9.	MSW	0684507	0024351
10.	MMW	0684798	0024374
11.	CSW	0686957	0024077
12.	CMW	0686774	0023848

The positions were plotted in the **Figure 3.1** to clearly visualise the study sites. The sampling sites were photographed (**Appendix 1**) to observe the physical environment

3.1.2 Sampling and pH measurement

Reconnaissance survey established that there were several active artisanal gold mining sites during the time of the study. Communities use the stream water neighbouring the mine for drinking and other domestic uses. The small quantities of gold deposits were found underlying the rocky surfaces in these areas and this supported small scale gold mining activities. It was found that mining was carried out in privately owned land with consent of the land owner.

These observations guided selection of gold mining sites for sampling. All samples collected materials (sampling bottles) were rinsed with concentrated nitric acid and distilled water before use.

Mine waters and neighbouring stream waters were sampled in duplicates from the selected sampling sites at any particular visit, harmoniously mixed and pH measured then acidified with 5 ml of HNO_3 to 100 ml of well mixed sample and stored in plastic bottles. The acidified samples in the field (HNO_3 acidified samples) were then refrigerated in the potable ice fridge in readiness for transportation to the laboratory for analysis. The acid used to preserve water samples was stored and handled with care to avoid inhaling vapours or direct contact with skin, eyes, and clothing. Gloves and an apron were worn when working with these chemical preservatives. In the process, a total of seventy two (72) monthly samples were collected and analysed (Appendix 2). In the shallow and deeper mines, equal volumes were taken from a maximum of four sampling depths using a bottle tied with a rope, mixed, before being transferred to 0.5 litre polythene bottles for pH determination and preservation.

The pH measurement involved using a Mestohm Dogmat microprocessor model 5986-62 Automated pH Meter calibrated with two buffers according to manufacturers requirements at the sites before any acid was added for preservation. Record keeping was achieved by assigning each sample reference number. The samples were labelled by indicating location, date, time and type of sample.

3.2 LABORATORY METHODS

3.2.1 Analysis of Water Samples for Metals (Elements)

Procedure

The samples were first shaken well and a volume of 50 ml was pippeted into a conical flask followed by adding 5 ml of nitric acid. It was then evaporated / digested to almost dryness on a hot plate. The samples were filtered using 541 whatman filter papers and washed thoroughly using warm distilled water. The filtrate volume was made to 50 ml (top up to the mark) using distilled water. The sample was ready to be aspirated by atomic absorption spectrometer under the control using blank

Prepetition of Blank

50ml of distilled water was pippeted into a conical flask and 5ml of nitric was added. It was the evaporated / digested to almost dryness on a hot plate and filtered using 541 whatman filter papers and wash thoroughly using warm distilled water. The filtrate was allowed to cool and transferred into 50 ml volumetric flask and was topped up to the mark using distilled water. The sample was ready to be aspirated by atomic absorption spectrometer.

The samples were analyzed at Mines and Geology Department, Nairobi and Moi University Laboratory by aspiration method using AAS (Model Spectra AA10). The Varian Atomic Absorption Spectroscopy (AAS) was preferred because of its high precision and accuracy (Van Ioon, 1985; Christian, 1986). The detection limits being 0.005 ppm Fe, 0.003 ppm Mn, 0.002 ppm Zn, 0.003 ppm Cu, 0.02 ppm Pb, 0.006 ppm Cd and 0.005 ppm Cr. A five calibration standards were used to construct calibration curve (Figures 3.2 -3.8) for each analysed element. The dilution factor into the AAS equation has been presented for example in Odhiambo and Howard (2002)

(a) Iron (Fe) Standard Preparation

Procedure

1.000 g of iron metal strip was accurately weighed and dissolved in 1:1 HCL acid and was diluted using distilled water to a volume of 1000 ml to make 1000 ppm Fe. From

1000 ppm, dilution was made to give 100 ppm using dilution formula $C_1V_1=C_2V_2$ where C and V are concentration and volume, respectively. From this 100 ppm a series of dilution was done to give working standard; 0.000 ppm,0.50ppm,1.00 ppm,5.00 ppm and 10.00 ppm Fe using dilution formula $C_1V_1=C_2V_2$. The above prepared standards were used to calibrate the atomic absorption spectrometer (Table 3.2). A calibration curve was drawn (Appendix 2, Figure A).

Working Conditions

Lamp current = 8 mA, Wavelength = 248.3 nm, Slit width = 0.2 nm, Fuel = acetylene, and Oxidant = Air

Table 3.2: Iron Calibration

Standard	Concentration (ppm)	Absorbance
1	0.00	0.000
2	0.50	0.030
3	1.00	0.058
4	5.00	0.296
5	10.00	0.581

(b) Manganese (Mn) Standard Preparation

Procedure

1.000 g of lead metal strip was accurately weighed and dissolved in 1:1 HNO_3 acid and was diluted using distilled water to a volume of 1000 ml to make 1000 ppm manganese. From 1000 ppm, dilution was made to give 100 ppm using dilution formula $C_1V_1 = C_2V_2$ where C and V are concentration and volume, respectively. From this 100 ppm a series of dilution was done to give working standard; 0.00 ppm,0.50 ppm,1.00 ppm, 4.00 ppm and 8.00 ppm manganese using dilution formula $C_1V_1 = C_2V_2$. . The above prepared standards were used to calibrate atomic absorption spectrometer (Table 3.3). A calibration curve was drawn (Appendix 2, Figure B).

Working Conditions

Lamp current = 5.0 mA, Wavelength = 279.5 nm, Slit width = 0.2nm, Fuel = acetylene, and Oxidant = Air

Table 3.3: Manganese Calibration

Standard	Concentration (ppm)	Absorbance
1	0.00	0.00
2	0.500	0.060
3	1.000	0.123
4	4.000	0.488
5	8.000	0.976

(c) Zinc (Zn) Standard Preparation

Procedure

1.000 g of zinc metal strip was accurately weighed and dissolved in 1:1 HNO_3 acid and was diluted using distilled water to a volume of 1000 ml to make 1000 ppm zinc. From 1000 ppm, dilution was made to give 100 ppm using dilution formula $C_1V_1 = C_2V_2$ where C and V are concentration and volume, respectively. From this 100ppm a series of dilution was done to give working standard; 0.00 ppm, 0.50 ppm, 1.00 ppm, 3.00 ppm and 5.00 ppm zinc using dilution formula $C_1V_1 = C_2V_2$. . The above prepared standards were used to calibrate atomic absorption spectrometer (Table 3.4). A calibration curve was drawn (Appendix 2, Figure C).

Table 3.4: Zinc Calibration

Standard	Concentration (ppm)	Absorbance
1	0.00	0.000
2	0.50	0.266
3	1.00	0.533
4	3.00	1.601
5	5.00	2.640

Working Conditions

Lamp current = 3 mA, Wavelength = 213.9 nm, Slit width = 0.1nm, Fuel = acetylene and Oxidant = Air

(d) Copper (Cu) Standard Preparation

Procedure

1.000 g of copper metal strip was accurately weighed and dissolved in 1:1 HNO_3 acid and was diluted using distilled water to a volume of 1000 ml to make 1000 ppm copper. From 1000 ppm, dilution was made to give 100 ppm using dilution formula $C_1V_1 = C_2V_2$ where C and V are concentration and volume respectively. From this 100 ppm a series of dilution was done to give working standard; 0.00 ppm, 0.50 ppm, 1.00ppm, 3.00 ppm and 5.00 ppm copper using dilution formula $C_1V_1 = C_2V_2$. A calibration curve was drawn (Appendix 2, Figure D).

Working Conditions

Lamp current =3 mA, Wavelength = 327.4 nm, Slit width = 0.1nm, Fuel = acetylene and Oxidant = Air

Table 3.5: Copper Calibration

Standard	Concentration (ppm)	Absorbance
1	0.00	0.000
2	0.50	0.060
3	1.00	0.121
4	3.00	0.360
5	5.00	0.599

(e) Lead Standard Preparation

Procedure

1.000 g of lead metal strip was accurately weighed and dissolved in 1:1 HNO_3 acid and was diluted using distilled water to a volume of 1000 ml to make 1000 ppm lead. From 1000 ppm, dilution was made to give 100 ppm using dilution formula $C_1V_1 = C_2V_2$ where C and V are concentration and volume, respectively. From this 100 ppm a series of dilution was done to give working standard; 0.00 ppm, 0.10 ppm, 0.25 ppm, 0.50 ppm and 1.00 ppm lead using dilution formula $C_1V_1 = C_2V_2$. . The above prepared standards were used to calibrate atomic absorption spectrometer (Table 3.6). A calibration curve was drawn (Appendix 2, Figure E).

Working Conditions

Lamp current = 5mA, Wavelength = 217.0nm, Slit width = 1.0nm, Fuel = acetylene, and Oxidant = Air

Table 3.6: Lead Calibration

Standard	Concentration (ppm)	Absorbance
1	0.00	0.000
2	0.10	0.004
3	0.25	0.010
4	0.50	0.019
5	1.00	0.038

(f) Cadmium (Cd) Standard Preparation

Procedure

1 .000 g of cadmium metal strip was accurately weighed and dissolved in 1:1 HNO_3 acid and was diluted using distilled water to a volume of 1000 ml to make 1000 ppm cadmium. From 1000 ppm, dilution was made to give 100 ppm using dilution formula $C_1V_1 = C_2V_2$ where C and V are concentration and volume, respectively. From this 100 ppm a series of dilution was done to give working standards; 0.00 ppm, 0.50 ppm, 1.00

ppm, 1.50 ppm, 2.00 ppm and chromium using dilution formula $C_1V_1 = C_2V_2$. The above prepared standards were used to calibrate atomic absorption spectrometer (Table 3.7). A calibration curve was drawn (Appendix 2, Figure F).

Working Conditions

Lamp current = 8mA, Wavelength = 228.8 nm, Slit width = 0.5nm, Fuel = acetylene and Oxidant = Air

Table3.7: Cadmium (Cd) Calibration

Standard	Concentration	Absorbance
1	0.00	0.000
2	0.50	0.100
3	1.00	0.200
4	1.50	0.301
5	2.00	0.396

(g) Chromium (Cr) Standard Preparation

Procedure

1.000 g of chromium metal strip was accurately weighed and dissolved in 1:1 HNO_3 acid and was diluted using distilled water to a volume of 1000 ml to make 1000 ppm chromium. From 1000 ppm, dilution was made to give 100 ppm using dilution formula

$C_1V_1 = C_2V_2$ where C and V are concentration and volume, respectively. From this 100 ppm a series of dilution was done to give working standards; 0.00 ppm. 0.50 ppm, 1.00 ppm, 3.00 ppm and 5.0 0ppm chromium using dilution formula $C_1V_1 = C_2V_2$. . The above prepared standards were used to calibrate atomic absorption spectrometer (Table 3.8). A calibration curve was drawn (Appendix 2, Figure G).

Working Conditions

Lamp current = 7 mA, Wavelength = 425.4 nm, Slit width = 0.1 nm, Fuel = acetylene and Oxidant = Nitrous oxide

Table 3.8: Chromium Calibration

Standard	Concentration (ppm)	Absorbance
1	0.00	0.000
2	0.50	0.030
3	1.00	0.061
4	3.00	0.180
5	5.00	0.301

3.2.2 Determination of Sulphate (SO_4^{2-}) Concentrations

Apparatus used

Magnetic stirrer, turbid meter, stopwatch and measuring spoon- 0.2 to 0.3 ml

Reagents used

(a) Buffer solution preparation

30 g of magnesium chloride ($MgCl_2.6H_2O$), 5g sodium acetate ($CH_3COOH.3H_2O$), 1.0 g potassium nitrate (KNO3), and 20 ml acetic acid (CH_3COOH) (99%) was dissolved in 500 ml distilled water and was made to 1000 ml.

(b) Barium chloride ($BaCl_2$), crystal 20 to 30 mesh

(c) Standard sulphate Solution preparation

0.1479 g of anhydrous Na_2SO_4 in distilled water and diluted to 1000 ml to make 100 ppm SO_4^{2-}. Then a series of standards was made using the formulae $C_1V_1 = C_2V_2$ where C_1 was initial concentration, C_2 was final concentration, V_1 was initial volume and V_2 was final volume. For example, to make 10 ppm of SO_4^{2}, 10 ml was pippeted from the original concentration (100 ppm) and transferred into 100 ml volumetric flask and top up to the mark using distilled water (Christian, 1986). The standard made in the same way was 0.00 ppm, 1.00 ppm, 2.00 ppm, 6.00 ppm and 10.00 ppm SO_4^{2-} (Table 3.9).

Table 3.9: Turbidity readings for standards of Sulphates (SO_4^{2-})

Standard	Concentration(ppm)	Turbidity(NTU)
1	0.00	0.00
2	1.00	3.21
3	2.00	6.52
4	6.00	19.40
5	10.00	32.12

Procedure

The prepared series of standards (0.00 ppm, 1.00 ppm, 2,00 ppm, 6.00 pmm and 10.00 ppm SO_4^{2}) was transferred to 250 ml Erlenmeyer flasks and 20 ml buffer solution added and was then mixed using magnetic stirrer. While stirring, a spoonful of $BaCl_2$ crystals were added and timing began immediately, for 1 minute at constant speed and turbidity measurements were taken after 5 minutes. The turbidity meters of standards were used in order to prepare a calibration curve. A graph of concentration of standard versus turbidity measurement was plotted ((Appendix 2, Figure H)). The concentrations of sulphates were read from the generated graph and for some samples (RSW, LSW, MSW, RMW, SMM, and LMW) which had higher concentration than the highest standard (10.0 ppm) was diluted using a dilution factor of 5 that is 20 ml of original sample was pippeted and transferred into 100 ml volumetric flask and topped up to the mark using distilled water. Except for RSW – October and November, 2006 (Appendix 3) in which their dilution factor was 10 that was 10 ml of the original sample was pippeted and transferred into 100 ml volumetric flask and top up to the mark using distilled water.

3.3 DATA ANALYSIS

Descriptive statistics was used to describe the relationship between trace metal (elements), pH and SO_4^{2-}, variations for both the mine and stream waters. These included tabulation, graphical representation and measure of dependency (correlation).

Partial Correlation coefficients were determined between the trace metals and SO_4^{2-} under the observed pH conditions for both mine and stream waters to enable the degree of association between these variables to be described. To determine the pH, element and sulphate (SO_4^{2-}) relationship, Partial Correlation coefficients (Υ) between the three (3) variables sulphates (s), metal element (m) and pH (p) were calculated using the formula below while the pH was kept constant. Symbolically represented as $\Upsilon_{sm.p}$ and calculated using the formula below:-

$\Upsilon sm.p = (\Upsilon_{sm} – \Upsilon_{sp}(\Upsilon_{mp})) / \surd ((1- \Upsilon_{sp}^2)(1 – \Upsilon_{mp}^2))$ (Konthari, 2008).

The data obtained was interpreted based on the Pearson correlation where +1 indicate a perfect positive (increasing) linear relationship (correlation), −1 in the case of a perfect decreasing (negative) linear relationship (anticorrelation), and some value between −1 and 1 in all other cases, indicating the degree of linearity dependence between the variables. As it approaches zero there is less of a relationship (closer to uncorrelated). The closer the coefficient is to either −1 or 1, the stronger the correlation between the variables.

The F values were determined at 95% confidence interval with the assumption that the waters samples were from the same geological formation.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 GOLD PROCESSING

The processes involved were similar to the ones used in other areas of small scale gold mining in Kenya such as in Lolgorian, Transmara district and Malcalder, Migori District. Mining and processing techniques were divided into three separate phases.

The first phase included activities related to the excavation of primary gold bearing deposits. These were open pits, trenches and/or shallow underground adits that followed the gold bearing veins. The excavation techniques employed were crude and the level of mechanization was very low, much of the work being done manually. Wooded pillars are used to support the loose soils or rock faces on the mine walls. Most miners mainly tend to minimise the excavation cost. At other sites, generators are used to pump the mine water outside to the land surface.

The second phase involved the processes of separating gold particles from the ore. The ore – bearing quartz is crushed by using heavy mallets into a fine powder (Plate 4.1). Gravity separation technique is used to separate the higher density gold particles from the gangue. Sluice beds (Plate 4.2) and pans are used in this process where water is used as a medium to separate the particles of different densities. Gold concentrate from the above processes further concentrated by stirring (panning) and elemental mercury is added to amalgamate the gold particles. The amalgam so formed is placed in a piece of cloth where the excess mercury is squeezed out by fingers.

Plate 4.1: Fine grinding of gold ore (Source: Author, 2007).

Plate 4.2: Gravity separation using a sluice bed. Process involves use of stream water hence allowing only the heavier materials to build up behind the riffles (Source: Author, 2007).

In phase three, the bead of amalgam formed is heated in open charcoal where mercury was vaporized off into air, leaving gold grains which are sold to local dealers. The dealers too, did further refining and were exposed to elemental mercury vapours. The operations in this phase were done without use of any protective devices.

4.2 CONCENTRATION OF THE TRACE ELEMENTS IN STREAM AND MINE WATERS

The heavy metal concentration is an important indicator of a possible environmental hazard emanating from abandoned mines. Hence the presentation of the results focuses on the average tested heavy metals (**Appendix 4**). The average pH and SO_4^{2-} are summarized in Table 4.1. The detailed absolute results are shown in **Appendix 3**

The average pH for stream water sampled varied from 6.48 at CSW to 7.13 at SSW while that of the mine varied from 6.55 at SMM to 7.46 at RMM (Figures 4.3 and table 4.1). The mean pH value is 6.87 in stream water and 6.86 in mine water in the study area. Hence, both waters' pH lies within the neutral range. An indication, mine water runoff does therefore not effect significantly the environment. It was also observed that, the average SO_4^{2-} concentrations in the stream water varied from 4.76 ppm at SSW to 32.61 ppm at RSW while that of the mine varied from 0.75 ppm to 24.77 ppm at RMW (Figure 4.4). These values cannot support the growth of algae but easily stimulates bacterial growth (Mckee and Wolf, 1963).

Table 4.1: Comparison between average pH and SO_4^{2-} in stream waters and mine waters

Stream waters		
Sampling Sites	pH	SO_4^{2-} (ppm)
RSW	6.96	32.61
KSW	7.01	6.08
SSW	7.13	4.76
LSW	7.10	10.68
MSW	6.53	15.43
CSW	6.48	8.90
Mine waters		
RMW	7.46	24.77
KMW	6.66	0.75
SMM	6.55	13.15
LMW	6.58	13.58
MMW	6.70	4.03
CMW	7.21	1.65

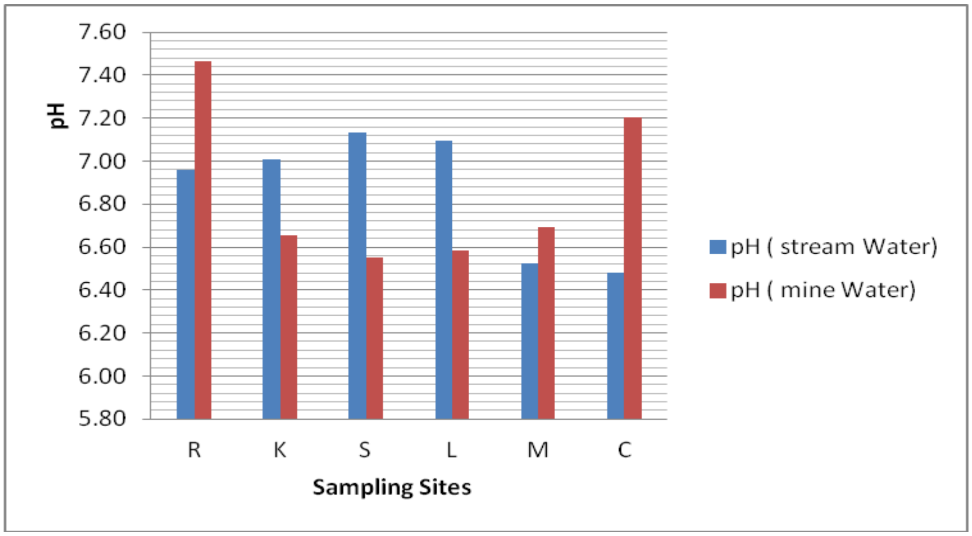

Figure 4.3: Average pH Concentrations at different sites (R = Rosterman Mine, K = Khayega, S = Sigalagala, L = Lirembe, M = Mutaho, C = Shichinji)

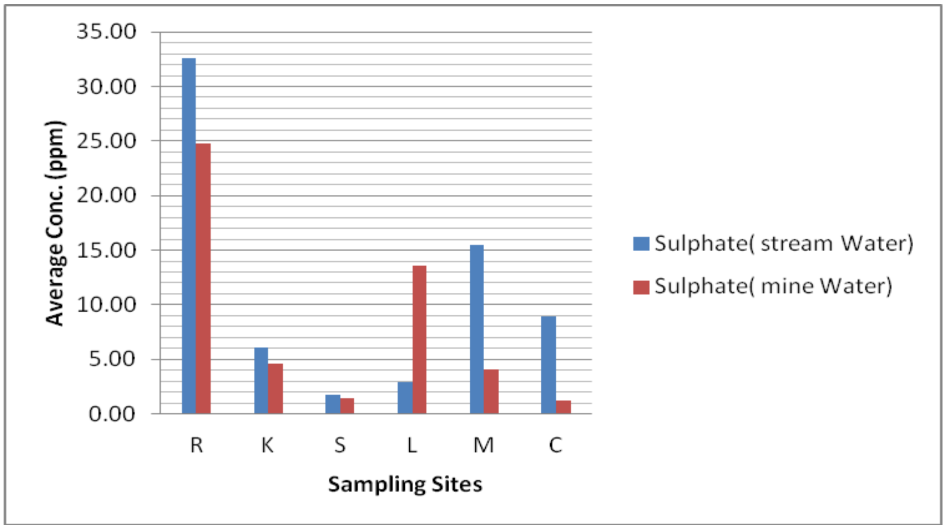

Figure 4.4: Average SO_4^{2-} Concentrations at different sites (R = Rosterman Mine, K = Khayega, S = Sigalagala, L = Lirembe, M = Mutaho, C = Shichinji)

The SO_4^{2-}mean value for mine and stream waters was 8.27 ppm and 11.29 ppm respectively. These levels shows that gold being mined are mostly embedded in quartzite rock with very low sulphide concentration.

The pH values obtained do not warren AMD in the tested mine and stream waters in the area of study. For this to occur, pH of less than 2.5 is required. Therefore, no strong AMD was established here. Further, the pH values variation between the mine and stream waters is also negligible.

Figure 4.5 shows Fe concentration level in stream water varied from 1.00 ppm at KSW to 5.37 ppm at CSW while in mine waters were 1.20 ppm at CMW to 4.58 ppm at KMW. The environment in the study area has high concentration of dissolved Fe in water. This therefore, indicates that soils and rocks in the area are rich in Fe which easily weathers.

Under the acidic and neutral range Fe is mainly present in $Fe(OH)_2^+$ (aq) hence the high values.

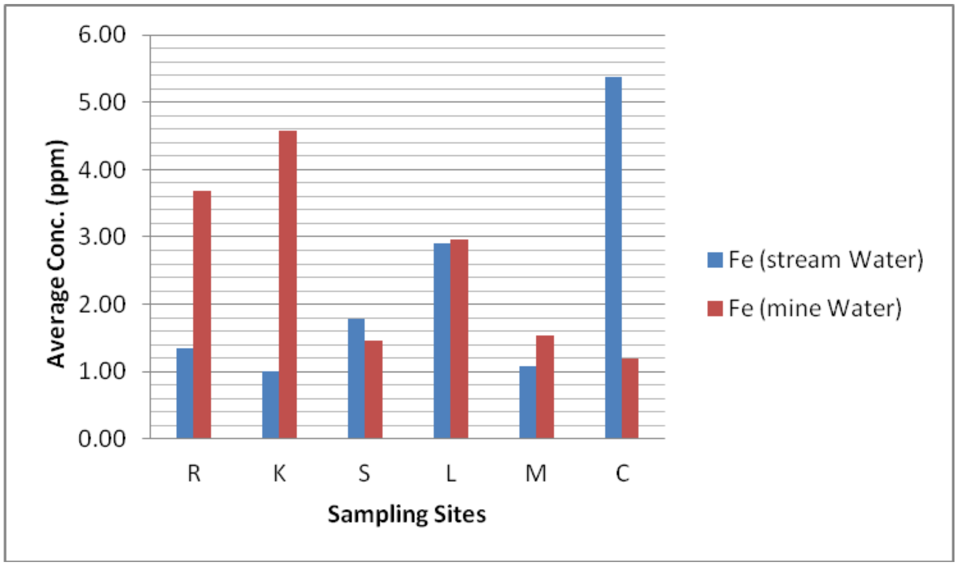

Figure 4.5: Average Fe Concentrations at different sites (R = Rosterman Mine, K = Khayega, S = Sigalagala, L = Lirembe, M = Mutaho, C = Shichinji)

In Figure 4.6, manganese average concentration in stream water varied from 0.48 ppm at RSM to 3.26 ppm at LSH while in mine waters were 0.12 ppm at CMW to 3.07 ppm at KMW. These values which lie between 0.5 – 1.0 ppm will affect plant growth and development at low pH (Taiz and Zeiger, 2002) the environment will be affected for having poor vegetation cover.

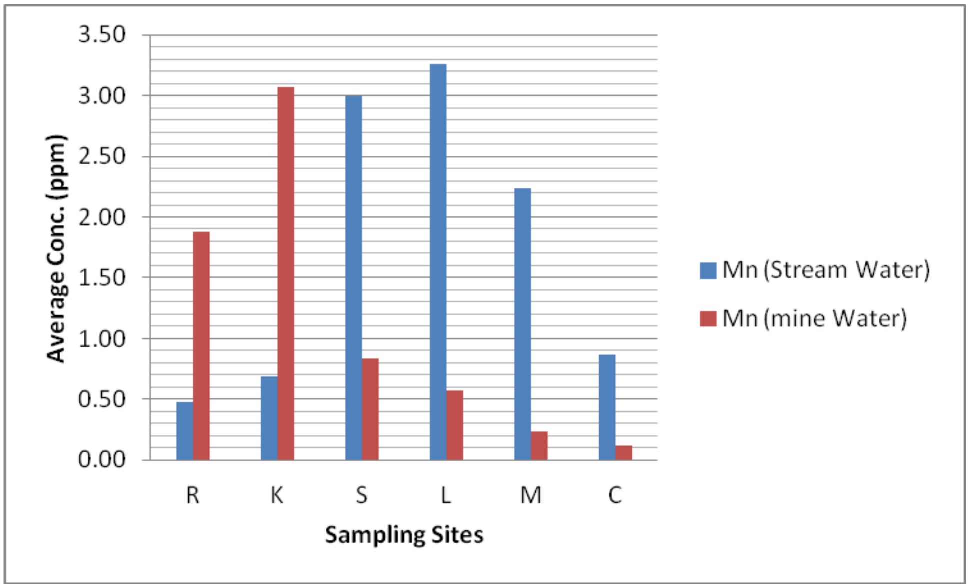

Figure 4.6: Average Mn Concentrations at different sites (R = Rosterman Mine, K = Khayega, S = Sigalagala, L = Lirembe, M = Mutaho, C = Shichinji)

The Zinc average concentration in stream water (Figure 4.7) varied from 0.04 ppm at KSW to 0.48 ppm at SSW while in mine waters were 0.02 ppm at CSW to 0.32 ppm at RMW. These low values do not increase acidity (Keller, 1988). Since also the pH lied between the neutral ranges, the solubility of Zn is very low (Wright, 2003).

The Copper average concentration in stream water (Figure 4.8) varied from 0.01 ppm at CSW to 0.13 ppm at LSW while in mine waters were 0.01 ppm at SMW to 0.43 ppm at RMW. This shows that Cu is readily available in Sludge particles as free ions. It is therefore in low concentrations in water and is expected to be in high concentration in soils of the study area since it is associated to gold mining.

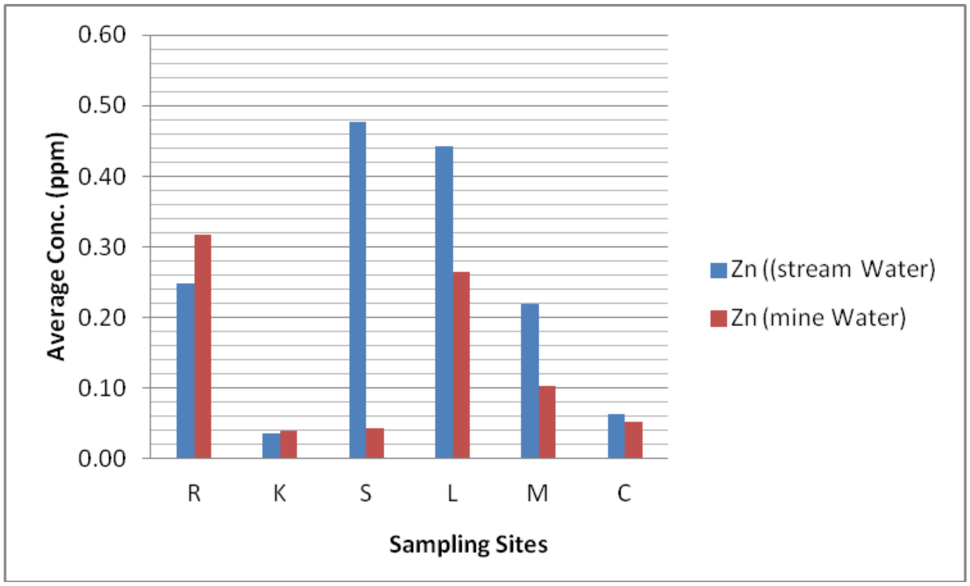

Figure 4.7: Average Zn Concentrations at different sites (R = Rosterman Mine, K = Khayega, S = Sigalagala, L = Lirembe, M = Mutaho, C = Shichinji)

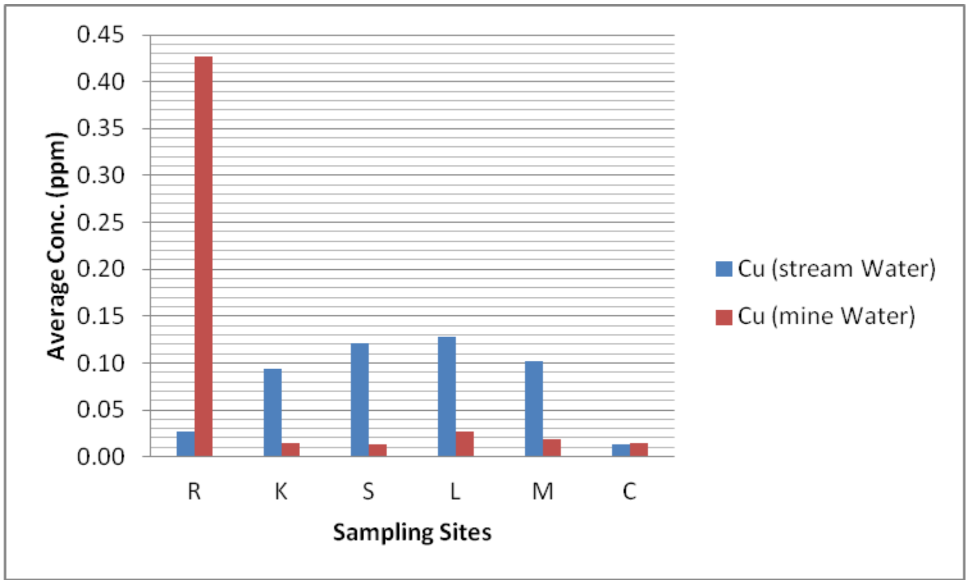

Figure 4.8: Average Cu Concentrations at different sites (R = Rosterman Mine, K = Khayega, S = Sigalagala, L = Lirembe, M = Mutaho, C = Shichinji)

Lead average concentration in stream water (Figure 4.9) varied from 0.09 ppm at CSW to 0.19 ppm at KSW while in mine waters were 0.06 ppm at CMW to 0.23 ppm at RMW. The highest concentration at RMW may be due to frequent reworking of the colonial - era tailings by the current small scale miners. Lead in stream water is higher than in the mine waters except in the case of RSM and RMW. This is tolerated at these low levels in the environment. However bioaccumulation can be experience in organisms in the study area.

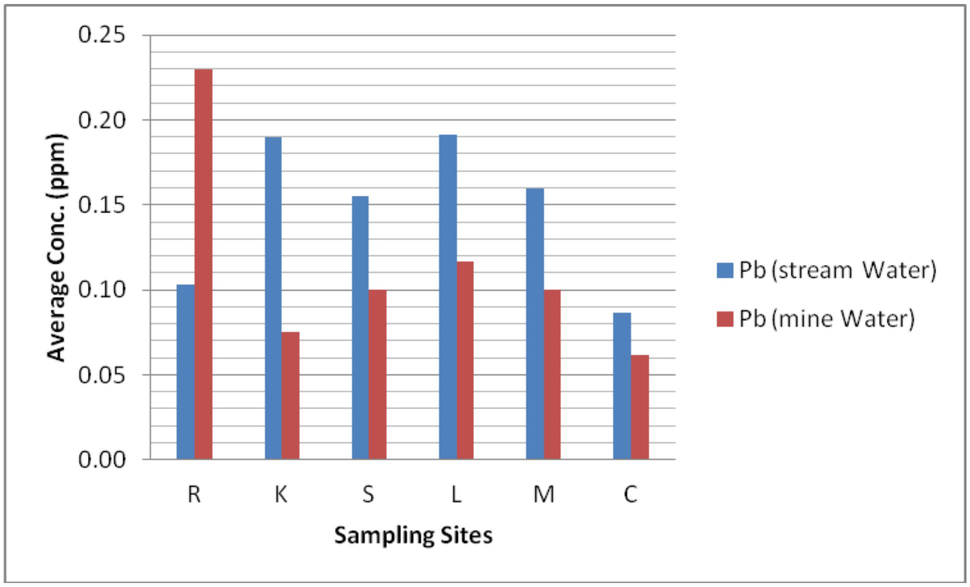

Figure 4.9: Average Pb Concentrations at different sites (R = Rosterman Mine, K = Khayega, S = Sigalagala, L = Lirembe, M = Mutaho, C = Shichinji)

The Cadmium average concentration in stream water varied from 0.00 ppm at RSM to 0.02 ppm at CSW while in mine waters were 0.00 ppm at CMW to 0.01 ppm at CMW (Figure 4.10). The study shows that there was high concentration in stream water. Cd is known to easily bind in soils in the mine. Its effects can therefore be easily being observed in the stream water than in mine water.

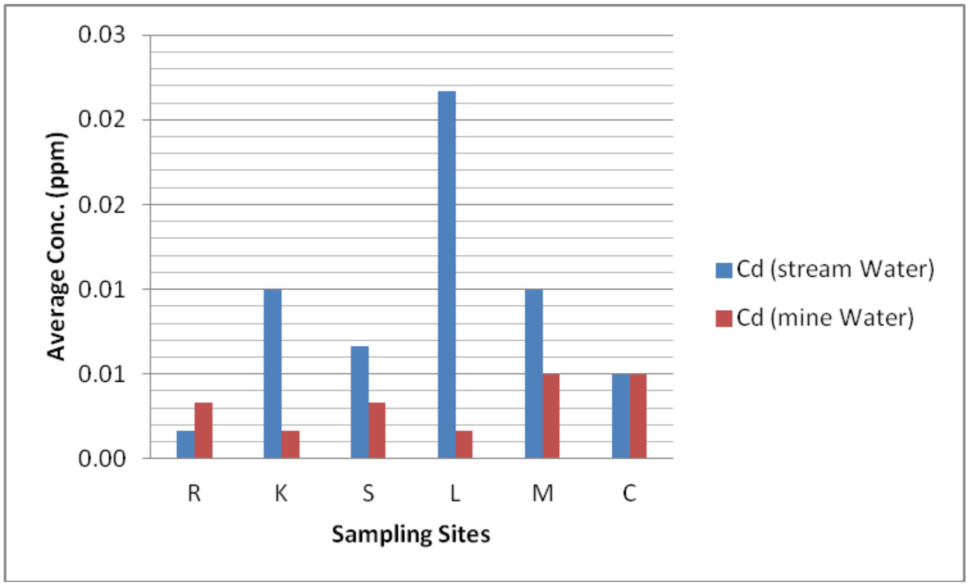

Figure 4.10: Average Cd Concentrations at different sites (R = Rosterman Mine, K = Khayega, S = Sigalagala, L = Lirembe, M = Mutaho, C = Shichinji)

Chromium average concentration in stream water (Figure 4.11) varied from 0.03 ppm at RSW to 0.54 ppm at LSW while in mine waters were 0.06 ppm at LSW to 0.70 ppm at RMW. The high concentration in mine water is as a result of the mining activity in the study area. The environment is therefore exposed to Cr contamination. Where artisanal miners have scavenged over tailings for quite a long period (Rosterman mine site) high value was observed.

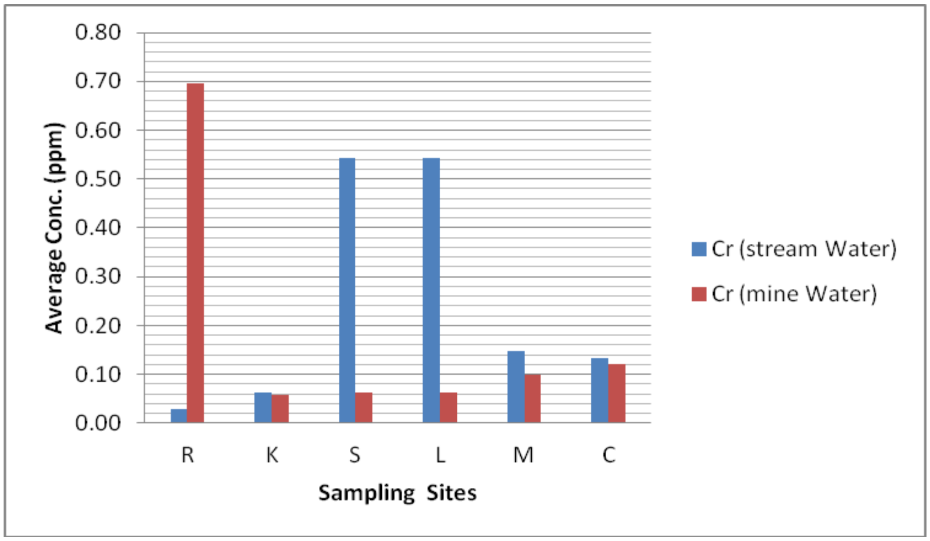

Figure 4.11: Average Cr Concentrations at different sites (R = Rosterman Mine, K = Khayega, S = Sigalagala, L = Lirembe, M = Mutaho, C = Shichinji)

The sampling sites verses concentration of respective elements was plotted (Figure 4.12 and 4.13) to clearly visualise their trends in the study area. It is observed that Sigalagala, Lirembe and Mutaho have the high element concentration in stream water. However, Fe was very high in all sampled mine water.

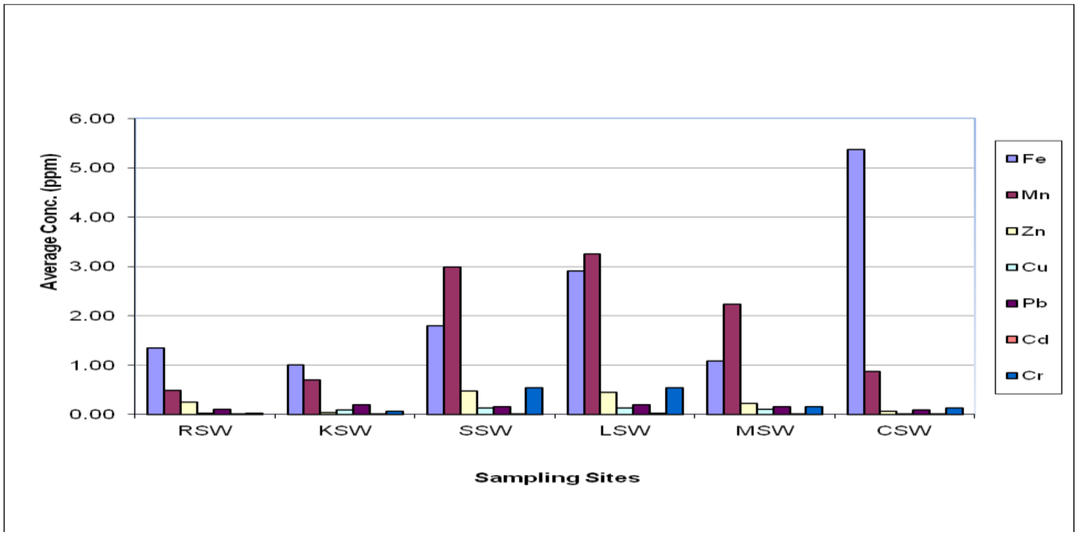

Figure 4.12: Comparisons of tested elements in stream waters

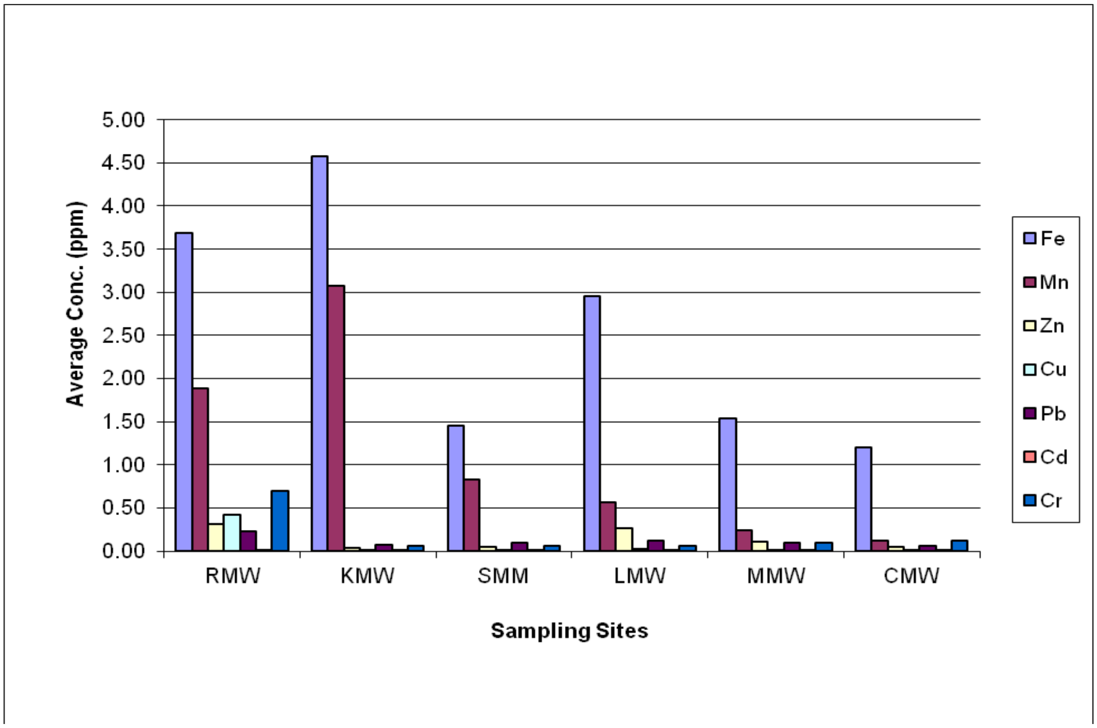

Figure 4.13: Comparisons of trace elements in mine waters

4.3: Discussion

The interpretation of the tested elements was tabulated based on F and P values (table 4.2) to determine the variation in stream and mine waters as stated in hypothesis (i).

Based on the table (F column) all the values are less than 3.9778 (F (1, 70) = 3.9778) and hence lies within the acceptable region. The hypothesis that there is no variation in element concentration in mine and stream water was accepted ($p > 0.05$). This implies that besides the mine waters, there are other sources of elements to in the stream water.

Table 4.2: Elements tested F and P Values Results

Element tested	**F – Value**	**Significant (P- Value)**	**Interpretation**
Fe	0.143	0.706	No reason to reject the Hypothesis (Ho)
Mn	0.889	0.349	No reason to reject the Hypothesis (Ho)
Zn	1.208	0.275	No reason to reject the Hypothesis (Ho)
Cu	3.228	0.077	No reason to reject the Hypothesis (Ho)
Pb	2.672	0.107	No reason to reject the Hypothesis (Ho)
Cd	3.370	0.071	No reason to reject the Hypothesis (Ho)
Cr	0.149	0.701	No reason to reject the Hypothesis (Ho)

Further test correlation was undertaken to determine the element tested and SO_4^{2-} dependency for each particular pH and tabulated in table 4.3. The results show that there was generally a low correlation in mine and stream water elements. Zn, Cd and Pb had a positive correlation in both waters unlike Fe, Mn and Cu had a negative correlation. However, Cr had a negative and positive correlation mine and stream water, respectively.

Table 4.3: Elements tested Partial Correlation Values Results

Element	Partial Correlation Between Elements and SO_4^{2-}. Keeping pH constant in Study Area	
	ϒsm.p Stream Water	ϒsm.p Mine Water
Fe	-0.202	-0.283
Mn	-0.023	-0.198
Zn	+0.018	+ 0.244
Cu	-0.003	-0.242
Pb	+0.033	+0.350
Cd	+0.303	-0.140
Cr	-0.097	+0.071

Since ϒsm.p $\neq 0$ in stream and mine waters, element and SO_4^{2-} are proven to be dependent on each other, the hypothesis that no variation in pH of mine and stream water is accepted in accordance with the already found results. Thus the pH varies from one sampled site to the other based on SO_4^{2-} concentration at any particular site.

The elements with positive correlation have their concentration values increases with SO_4^{2-} and likewise when the elements values decreases, the SO_4^{2-} also decreases. For negative correlation, these elements concentration values increases with decreased SO_4^{2-} and vice versa. These low correlation coefficients are an indication that there is a greater the uncertainty in the relationship to be useful enough.

CHAPTER FIVE

CONLUSION AND RECOMMENDATION

5.1 CONCLUSION

Mining and processing techniques were in three separate phase’s that is excavation of primary gold bearing deposits, crushing and amalgamation which is done near streams and ponds; where waste water from panning flows freely into the surrounding environment including surface water bodies. Results obtained from stream and mine waters shows a limited level of environmental pollution from gold mining activities. Most values for the tested elements concentration were within the natural range of sample materials, indicating a low range of contamination.

The results of the study have shown that the average` levels of trace elements investigated, except for lead, cadmium and chromium are within the WHO limits for drinking water. Except for zinc and chromium which are high in mine waters, the other trace elements investigated are higher in stream waters

The study has shown that artisanal gold miners around abandoned Rosterman Mine in Kakamega County are exposed to lead, cadmium, chromium and other related hazards at the working environment. Their mine workings at different sites also affected the environment uniquely with different elements concentration exposure. The test hypothesis that there is no variation in element concentration in mine and stream waters is true based on F and P values obtained. The element and SO_4^{2-} concentrations are proven to be independent on each other. Hence artisanal mining has a limited effect on the environmental geochemistry of the mine and stream waters in the study area

5.2 RECOMMENDATIONS

Artisanal gold mining is an important source of the livelihoods of the local miner. The study revealed the said environment encourages bacterial growth. It shows a localised pollution in some sites. The study therefore recommends base on its findings:

(i) Futher studies are necessary to identify other sources of elements in the stream water in the study area.

(ii) There is need for studies on impacts of artisanal gold mining on human health in the study area.

(iii) Monitoring of surface and ground water quality need to be done. In the process map all the existing and abandoned mines in line of their hazards and pollution problems.

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APPENDICES

APPENDIX I: Sampling Sites

Plate a. RSM Sampling point

Plate b. Sampling point

Plate c. MSW Sampling point

Plates a, b and c are unprotected stream sources (springs)

Plate d. KSW Sampling point

Plate e. LSW Sampling point

Plate f. CSW Sampling point

Plate d, e and f are cemented protected streams with drawing pipes

Plate g. RMW Sampling point

Plate g is a shallow(less than 7 M) mine with pools of water

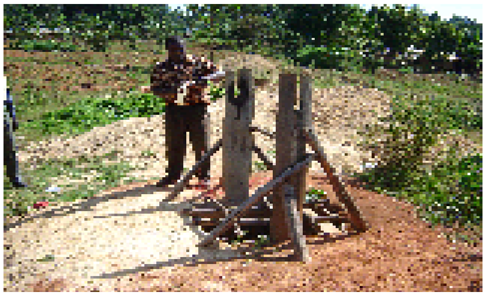

Plate h. SMW Sampling point

Plate i. KMW Sampling point

Plate j. MMW Sampling point

Plate k. LMW Sampling point

Plate l. CMW Sampling point

Plates h, i, j, k, and l are deep (greater than 7 M) open mines with wooden support on the surface where mine water was collected

<u>APPENDIX II:</u> Tested Elements Calibration Curve

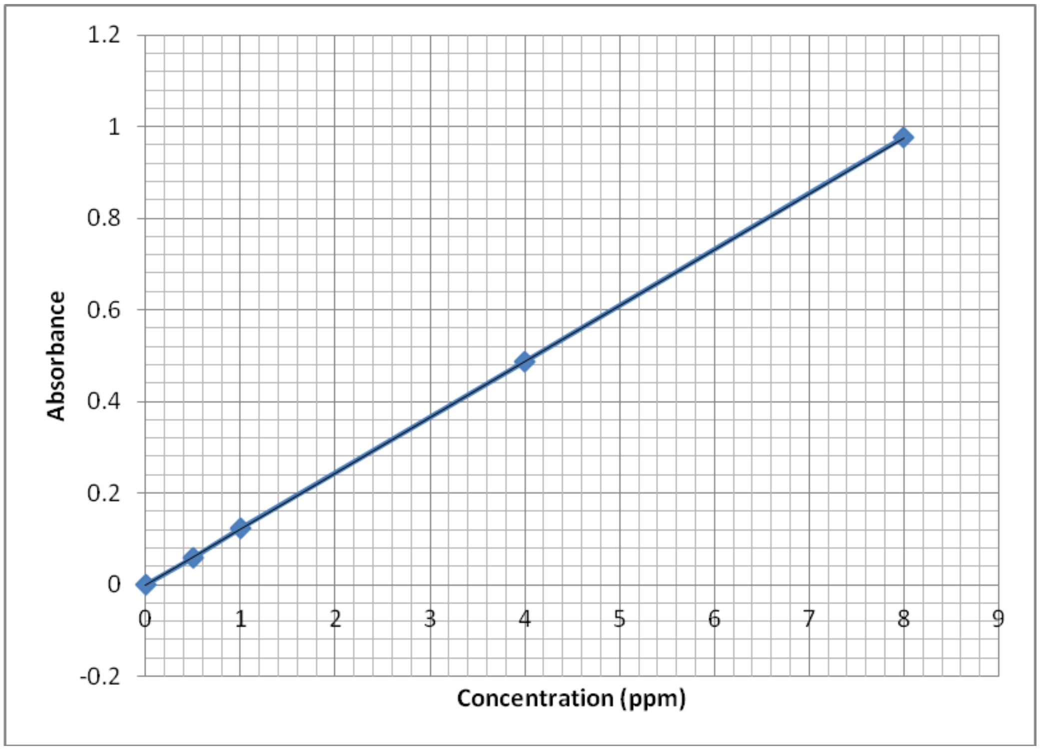

Figure A: Calibration curve for Iron

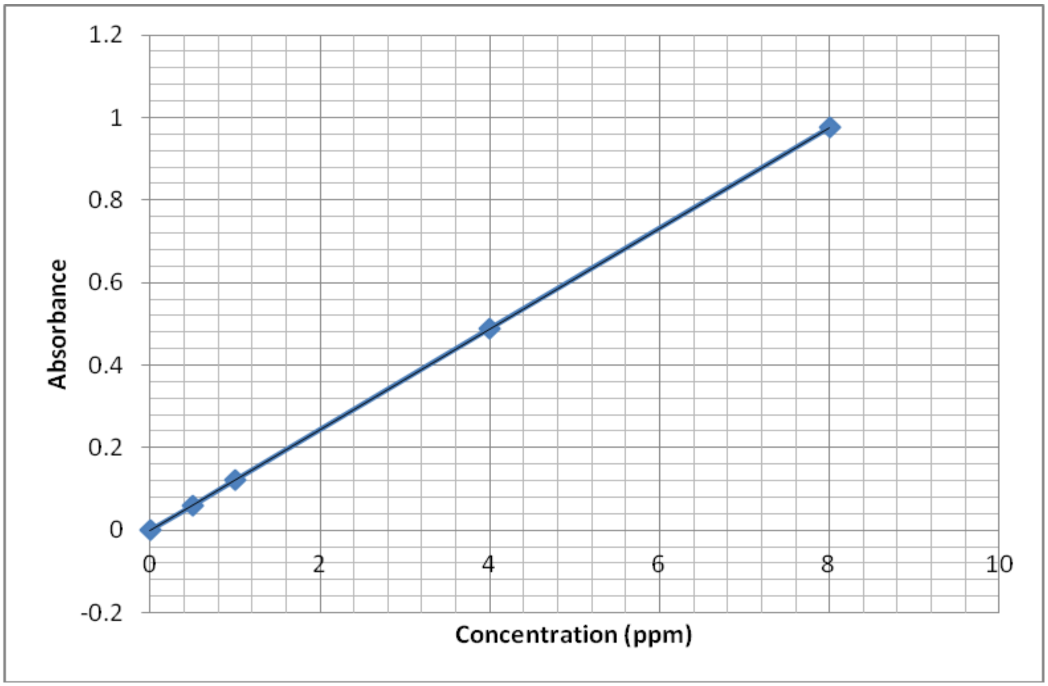

Figure B: Calibration curve for Manganese

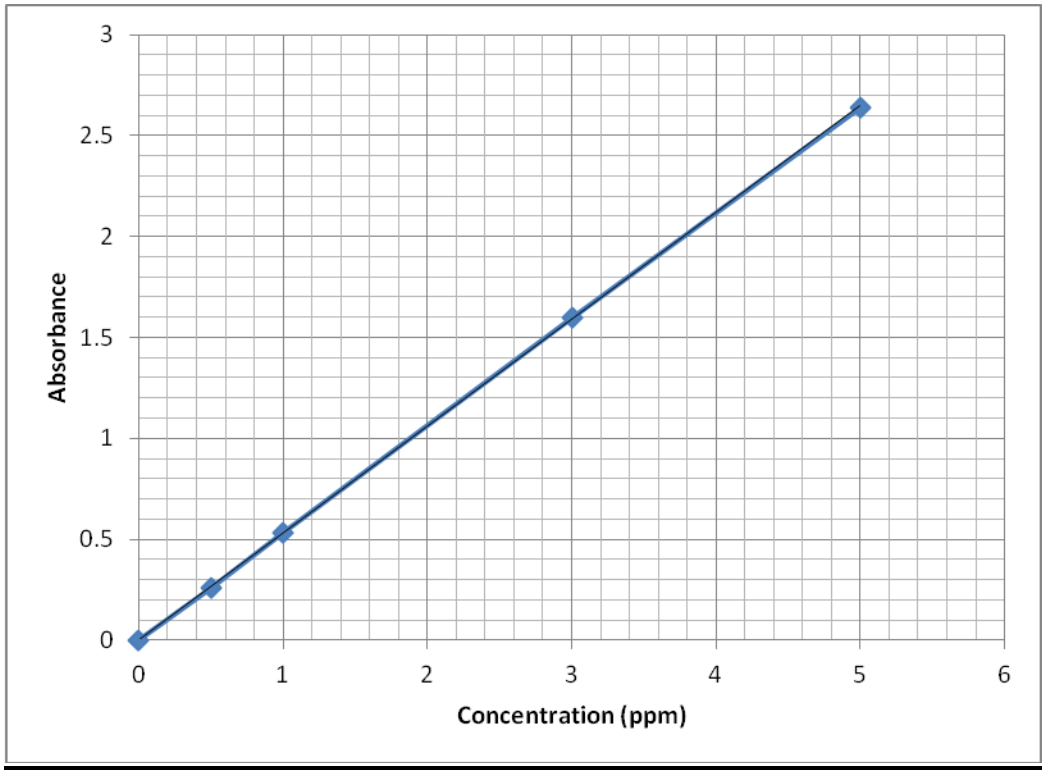

Figure C: Calibration curve for Zinc

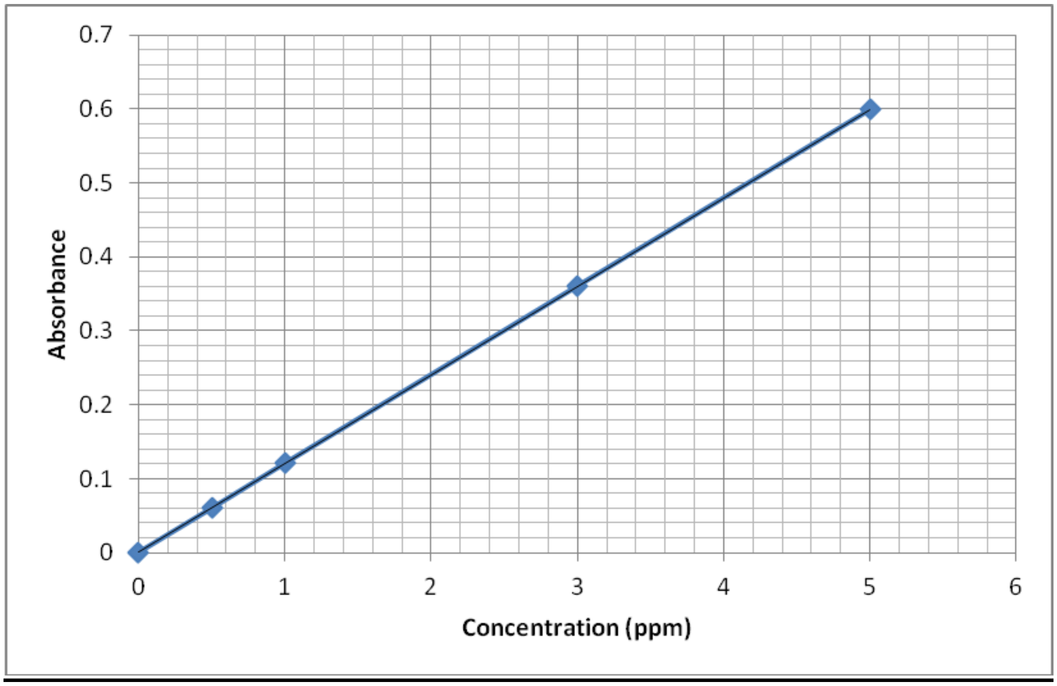

Figure D: Calibration curve for Copper

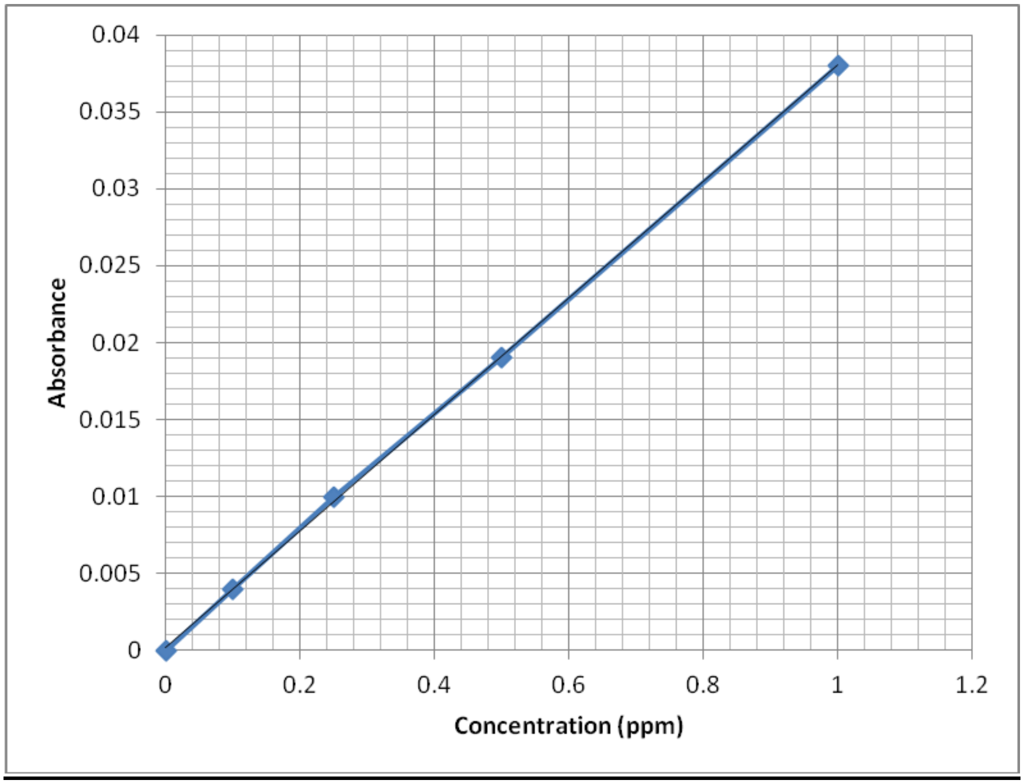

Figure E: Calibration curve for lead

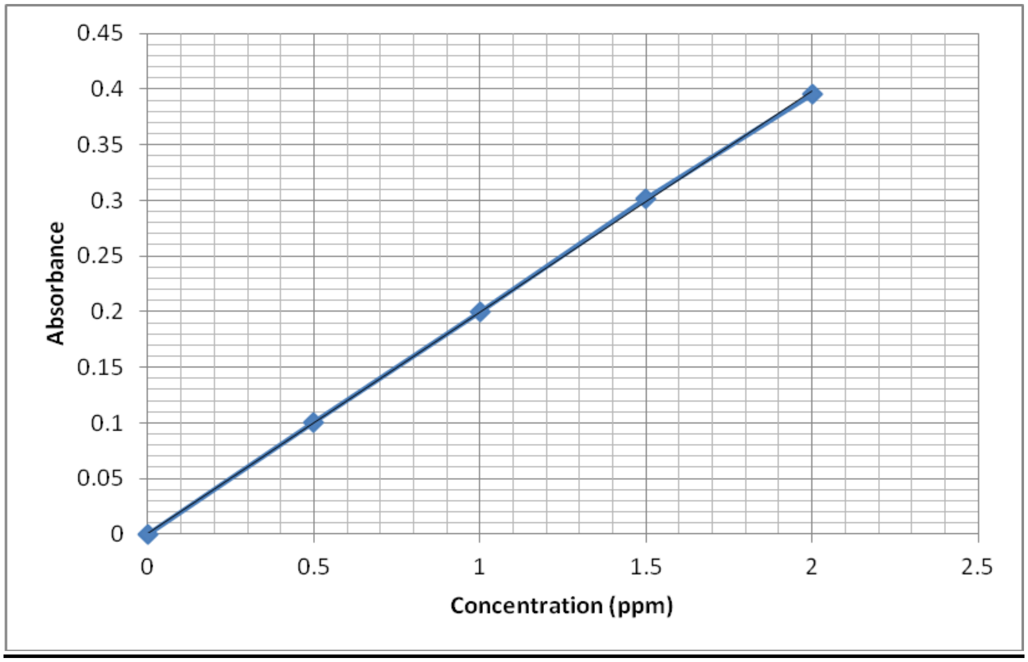

Figure F: Calibration curve for Cadmium

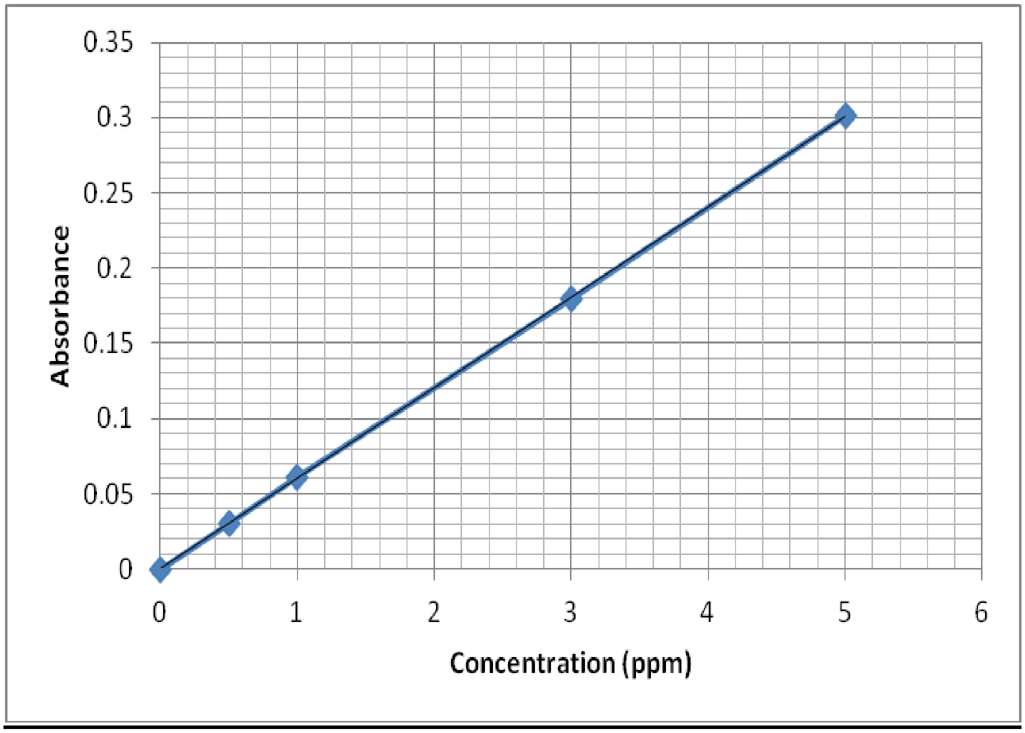

Figure G: Calibration curve for Chromium

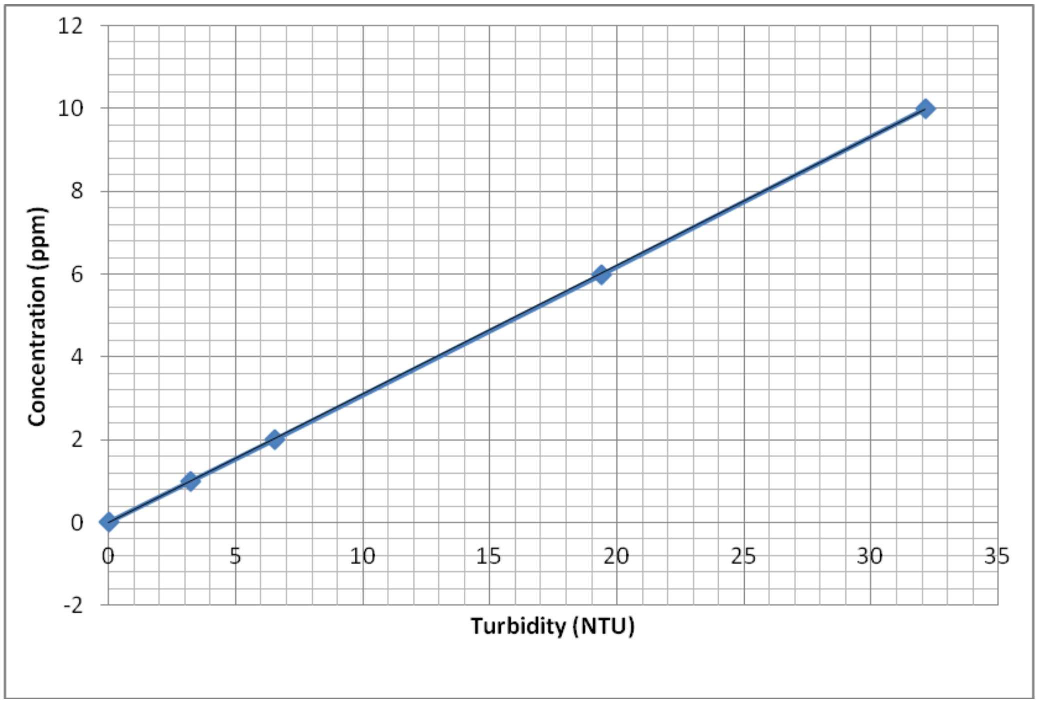

Figure H: SO_4^{2-} Calibration curve for concentration against turbidity of standards

<u>APPENDIX III:</u> Monthly Detailed Absolute results of element concentration in mine and the adjacent streams drinking water

Sampling Sites	**Month**	**pH**	**SO4^{2-} Mg/l**	**Fe (Total)**	**Mn (Total)**	**Zn (Total)**	**Cu (Total)**	**Pb (Total)**	**Cd (Total)**	**Cr (Total)**
	Oct.,06	5.48	63.7	1.77	0.09	0.06	0.03	0.19	0	0.17
RSW	Nov.,06	7.03	65	0.24	0.06	0.04	0	0.1	0	0
	Dec.,06	7.48	35.01	1.85	1.01	0.63	0	0.12	0	0
	Jan.,07	7.56	25.31	1.95	1.72	0.73	0	0.14	0.01	0
	Feb.,07	7.09	6.63	0.98	0	0.03	0.1	0.05	0	0
	March,07	7.12	0	1.31	0	0	0.03	0.02	0	0
	Mean	**6.96**	**32.61**	**1.35**	**0.48**	**0.25**	**0.03**	**0.10**	**0.00**	**0.03**
RMW	Oct.,06	7.09	45.2	3.66	2.44	0.65	1.2	0.43	0.01	1.28
	Nov.,06	7.88	45.4	0.09	0	0.04	0	0.14	0	0
	Dec.,06	7.71	40.3	0.72	0.15	0.05	0	0.11	0	0
	Jan.,07	7.56	15.83	1.42	0.2	0.06	0	0.1	0.01	0
	Feb.,07	7.52	1.58	8.1	0	0.1	0.03	0.12	0	0
	March	7.02	0.316	8.15	8.5	1	1.33	0.48	0	2.9
	Mean	**7.46**	**24.77**	**3.69**	**1.88**	**0.32**	**0.43**	**0.23**	**0.00**	**0.70**
KSW	Oct.,06	6.12	0	1.27	0	0.07	0.01	0	0.03	0.38
	Nov.,06	7.58	0.9	0	1.25	0.05	0	0.16	0	0
	Dec.,06	7.25	4.01	1.05	1.01	0	0	0.11	0	0
	Jan.,07	7.24	5.49	2.52	0.69	0	0.5	0.8	0.01	0
	Feb.,07	6.87	24.7	0.51	0.59	0.1	0.03	0.04	0.01	0
	March,07	6.99	1.385	0.63	0.61	0	0.02	0.03	0.01	0
	Mean	**7.01**	**6.08**	**1.00**	**0.69**	**0.04**	**0.09**	**0.19**	**0.01**	**0.06**
KMW	Oct.,06	6.39	2.4	5.07	0.4	0.11	0.02	0.1	0	0.34
	Nov.,06	5.05	0.3	0.97	3.18	0.02	0	0.13	0	0
	Dec.,06	6.41	0.5	0.61	2.05	0	0	0.08	0	0
	Jan.,07	7.98	0.86	0.41	0.69	0	0	0.06	0.01	0
	Feb.,07	7.55	0.42	7.02	5.3	0.01	0.02	0.03	0	0
	March,07	6.55	0	13.4	6.81	0.1	0.05	0.05	0	0
	Mean	**6.66**	**0.75**	**4.58**	**3.07**	**0.04**	**0.02**	**0.08**	**0.00**	**0.06**
SSW	Oct.,06	6.64	7.3	5.23	12.2	2.41	0.66	0.56	0.03	3.26
	Nov.,06	7.46	4	0.2	2.5	0.04	0	0.11	0	0
	Dec.,06	7.45	1.51	1.05	1.78	0.01	0	0.08	0	0
	Jan.,07	7.43	2.52	3.79	1.32	0	0	0.04	0.01	0

	Feb.,07	6.78	5.49	0.36	0.16	0.4	0.04	0.1	0	0
	March,07	7.03	7.73	0.12	0	0	0.03	0.04	0	0
	Mean	**7.13**	**4.76**	**1.79**	**2.99**	**0.48**	**0.12**	**0.16**	**0.01**	**0.54**
SMM	Oct.,06	6.46	27.6	1.93	0.16	0.09	0.01	0.07	0	0.37
	Nov.,06	5.52	29.9	0.03	0.45	0.04	0	0.15	0	0
	Dec.,06	6.05	12.3	0.2	0.31	0.02	0	0.14	0	0
	Jan.,07	6.94	7.27	0.53	0.23	0.01	0	0.13	0.01	0
	Feb.,07	7.35	0.86	4.96	2.78	0.1	0.03	0.11	0.01	0
	March,07	6.99	0.974	1.07	1.07	0	0.04	0	0	0
	Mean	**6.55**	**13.15**	**1.45**	**0.83**	**0.04**	**0.01**	**0.10**	**0.00**	**0.06**
LSW	Oct.,06	6.64	7.3	5.23	15.2	2.41	0.66	0.56	0.03	3.26
	Nov.,06	7.46	4	0.2	2.5	0.04	0	0.11	0	0
	Dec.,06	7.22	1.5	2.25	0.95	0	0	0.15	0	0
	Jan.,07	7.13	0.3	8.75	0.49	0	0	0.13	0	0
	Feb.,07	7.1	50.3	0.59	0.18	0.1	0.07	0.09	0.1	0
	March,07	7.03	0.68	0.42	0.21	0.1	0.04	0.11	0	0
	Mean	**7.10**	**10.68**	**2.91**	**3.26**	**0.44**	**0.13**	**0.19**	**0.02**	**0.54**
LMW	Oct.,06	6.46	27.6	1.93	0.16	0.09	0.01	0.07	0	0.37
	Nov.,06	6.52	29.9	0.03	0.45	0.64	0	0.15	0	0
	Dec.,06	6.62	20.5	0.75	0.25	0.4	0	0.19	0	0
	Jan.,07	7.34	2.47	2.38	0	0.06	0	0.13	0.01	0
	Feb.,07	6.17	1	5.51	1.31	0.3	0.11	0.08	0	0
	March,07	6.38	0	7.13	1.25	0.1	0.04	0.08	0	0
	Mean	**6.58**	**13.58**	**2.96**	**0.57**	**0.27**	**0.03**	**0.12**	**0.00**	**0.06**
MSW	Oct.,06	5.64	45.7	1.6	11.4	0.74	0.54	0.37	0.03	0.89
	Nov.,06	7.56	7.5	0.2	0.99	0.16	0	0.15	0	0
	Dec.,06	7.05	7.01	1.55	0.75	0.12	0	0.14	0.01	0
	Jan.,07	6.26	6.63	2.76	0.26	0.1	0	0.14	0.01	0
	Feb.,07	6.34	25.31	0.15	0	0.2	0.03	0.16	0.01	0
	March,07	6.31	0.4	0.26	0	0	0.04	0	0	0
	Mean	**6.53**	**15.43**	**1.09**	**2.23**	**0.22**	**0.10**	**0.16**	**0.01**	**0.15**
MMW	Oct.,06	5.83	2.7	0.67	0	0.17	0.01	0.04	0.02	0.6
	Nov.,06	7.51	1.4	0	0.05	0.05	0	0.12	0	0
	Dec.,06	6.81	1.51	0.01	0.01	0.08	0	0.14	0	0
	Jan.,07	6.5	1.58	0	0	0.12	0	0.14	0.01	0
	Feb.,07	6.67	15.83	0.12	0.68	0.1	0.05	0.12	0	0
	March,07	6.85	1.16	8.39	0.68	0.1	0.05	0.04	0	0
	Mean	**6.70**	**4.03**	**1.53**	**0.24**	**0.10**	**0.02**	**0.10**	**0.01**	**0.10**

CSW	Oct.,06	6.25	0.05	21.82	2.14	0.14	0.03	0	0.01	0.8
	Nov.,06	6.49	0	2.16	1.58	0.07	0	0.02	0	0
	Dec.,06	6.51	0.51	2.21	1.41	0.05	0.01	0.25	0.01	0
	Jan.,07	6.77	50.3	3.61	0.09	0.02	0	0.06	0.01	0
	Feb.,07	6.34	2.52	0.16	0	0.1	0.02	0.1	0	0
	March,07	6.51	0	2.27	0	0	0.02	0.09	0	0
	Mean	**6.48**	**8.90**	**5.37**	**0.87**	**0.06**	**0.01**	**0.09**	**0.01**	**0.13**
CMW	Oct.,06	6.26	0	0.68	0.01	0.06	0.02	0	0.01	0.73
	Nov.,06	6.8	0	0	0.07	0.03	0	0.09	0	0
	Dec.,06	7.21	1	0.81	0.05	0.03	0.01	0.07	0.01	0
	Jan.,07	8.54	1	0.14	0	0	0	0.05	0.01	0
	Feb.,07	7.14	7.27	3.35	0.45	0.1	0.03	0.08	0	0
	March,07	7.28	0.62	2.2	0.11	0.1	0.03	0.08	0	0
	Mean	**7.21**	**1.65**	**1.20**	**0.12**	**0.05**	**0.02**	**0.06**	**0.01**	**0.12**

APPENDIX IV: Average Trace Elements Concentration (ppm) for stream and mine waters

(A) Average Trace Elements Concentration (ppm) for stream waters

Sampling Sites	Average Trace Elements Concentration (ppm)						
	Fe	Mn	Zn	Cu	Pb	Cd	Cr
RSW	1.35	0.48	0.25	0.03	0.10	0.00	0.03
KSW	1.00	0.69	0.04	0.09	0.19	0.01	0.06
SSW	1.79	2.99	0.48	0.12	0.16	0.01	0.54
LSW	2.91	3.26	0.44	0.13	0.19	0.02	0.54
MSW	1.09	2.23	0.22	0.10	0.16	0.01	0.15
CSW	5.37	0.87	0.06	0.01	0.09	0.01	0.13

(B) Average Trace Elements Concentration (ppm) for mine waters

Sampling Sites	Average Trace Elements Concentration (ppm)						
	Fe	Mn	Zn	Cu	Pb	Cd	Cr
RMW	3.69	1.88	0.32	0.43	0.23	0.00	0.70
KMW	4.58	3.07	0.04	0.02	0.08	0.00	0.06
SMM	1.45	0.83	0.04	0.01	0.10	0.00	0.06
LMW	2.96	0.57	0.27	0.03	0.12	0.00	0.06
MMW	1.53	0.24	0.10	0.02	0.10	0.01	0.10
CMW	1.20	0.12	0.05	0.02	0.06	0.01	0.12