UNIVERSITY OF NAIROBI

COLLEGE OF AGRICULTURE AND VETERINARY SCIENCES

WANGARI MAATHAI INSTITUTE FOR PEACE AND ENVIRONMENTAL STUDIES

ENVIRONMENTAL AND HEALTH PROBLEMS ASSOCIATED WITH ARTISANAL MINING IN KENYA: A CASE STUDY OF MACALDER MINES IN MIGORI.

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A60/67837/2013

A thesis submitted to the University of Nairobi in partial fulfillment of the award of Masters of the degree of Masters of Science in Environmental Governance

2016

Declaration

This thesis is my original work and has not been presented for a degree in any other university.

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Acknowledgement

I sincerely thank my supervisors, Dr. Thuita Thenya and Dr. Thumbi Mwangi for the great effort they put in guiding me throughout my work.

I am also grateful to my parents for funding my research project and their encouragement without which I would not have completed this study.

I greatly thank all members of Wangari Maathai institute and the technical staff at the Institute of Nuclear Science and Technology, University of Nairobi for their support and positive criticisms during my study period.

I am really grateful to the people of Migori for being so helpful and supportive during my data collection. I also appreciate Mr. Albert Otota who guided me during my stay there and Grace Kinyori, for her immense assistance during my data collection.

Last but not least, I thank God for enabling me reach this far.

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List of acronyms

NEMA- National Environmental Management Authority

EIA- Environmental Impact Assessment

PPE- Personal Protective Equipment

WHO- World Health Organization

FAO- Food and Agriculture Organization

AEO- Agricultural Extension Officer

XRF-X-ray fluorescence

PPM- Parts per million

US-EPA- United States Environment Protection Agency

µL- microliter

Abstract

In order to understand the risk of heavy metal contamination in soil and water and their association with health problems among communities practicing artisanal gold mining, a cross-sectional study was carried out in the Macalder mines in Migori County, Western Kenya. In order to collect information on heavy metal concentration in the soils and water in mines and surrounding area, a total of 150 soil samples and 150 water samples were randomly collected from the households, the Macalder mines area and River Kuja which was the main source of drinking water for most of the study respondents. Data from the questionnaire survey and key informant interviews was analyzed using descriptive statistics. An elemental analysis for mercury, lead and arsenic was carried out using the X-ray fluorescence spectrometry (XRF) technique. The household surveys showed the average household size was 7 people, and 50% of the respondents reported artisanal mining as their main source of livelihood. The binomial tests proved that there is no relationship between occupation and illness as the results of the logistic regression were all tending towards the probability of 1 (Chest infections-0.9907, miscarriages- 0.993, tuberculosis-0.991, anaemia 0.405, malaria-0.0144). The miners and non-miners had minimal knowledge on the dangers associated with the use of mercury or any illnesses linked to mercury. None of the miners reported using any personal protective equipment. The levels of mercury, lead and arsenic in soil and water study samples were compared against the acceptable safe levels recommended by the World Health Organization and United States Environment Protection Agency. The levels of lead and arsenic were highest in soil samples from River Kuja and the Macalder mines, with lead quantities being 1.05 and

5200 times, and arsenic quantities being 1.97 and 7300 times above the WHO/US-EPA acceptable levels respectively. The levels of mercury, lead and arsenic in soil and water study samples were compared against the acceptable safe levels recommended by the World Health Organization and United States Environment Protection Agency. Levels of arsenic, lead and mercury from the household were either within the WHO and US-EPA acceptable levels or undetectable. Levels of lead in River Kuja were above acceptable levels in both soil and water samples. Arsenic had acceptable levels in the water but unsafe levels in the soil samples. The Macalder mines had unacceptable levels of lead and arsenic in both soil and water samples, creating an occupational risk for the mineworkers. It is interesting to note that mercury, which is the main input for the amalgamation process was undetectable in all the soil and water samples. The data shows an increased risk of exposure to the heavy metals among the miners in Macalder mines and River Kuja compared to exposure acquired at the households.

To allow safe mining processes, there should be precautionary steps such as rehabilitation of the mines, use of personal protective equipment and education on the dangers of exposure to toxic elements like mercury, which is used, in the mining process. Also, artisan-mining policies that have well organized laws of operation to reduce the occupational risks should be implemented.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Artisanal and small-scale mining, defined as mining by individuals, groups or co-operatives with minimal or no mechanization often in the informal sector of the market, is an important economic activity in many developing countries across Africa, Asia and South America. The process accounts for a quarter of the world's gold output (Donkor & Nartey, 2006). It is estimated that globally, 13 million people depend on artisanal mining for their livelihood, majority of who are in developing countries (Spiegel & Veiga, 2010). Women and children comprise of approximately thirty percent of these miners, with 40-50% of these coming from Africa (Hinton *et al*. 2003).

Small-scale gold mining occurs near the surface and within unconsolidated rocks, the most frequent being deposits contained in riverbed alluvium and colluviums and altered upper portions of quartz veins (Odumo *et al.* 2011). The small-scale miners employ traditional techniques for mineral extraction and usually operate under hazardous, labor intensive, highly disorganized and illegal conditions (Hinton *et al*. 2003). In order to free gold particles, the miners add mercury to the ore forming a mercury-gold amalgam; a process referred to as the amalgamation method. The amalgam is then cleaned with water and later roasted in high temperatures to release the gold from the mercury. This process of amalgamation is estimated to globally discharge to the environment up to 1000 tons of mercury per annum, accounting for one third of all global anthropogenic mercury pollution (Spiegel & Veiga, 2010). An estimated 300 tons of mercury are volatilized directly to the atmosphere per annum, while 700 tons are discharged in mine tailings into soil, rivers and lakes (Spiegel & Veiga, 2010).

Mercury is considered by World Health Organization as one of the top ten chemicals of major public health concern (WHO, 1996). Exposures to mercury, even in small quantities, are associated with serious health problems including complications during fetal and early life (Tchounwou *et al.* 2003). Elemental and methyl mercury are toxic to the central and peripheral nervous system, causing harmful effects on the nervous, digestive and immune system, lungs and kidneys (WHO 2007). The inorganic mercury released to the environment may be converted by microbial activity to organic forms of mercury, like methyl-mercury, a potent neurotoxin, which damages the central nervous system and is especially toxic to fetuses (International Finance Corporation & World Bank, 2010). Impacts on cognitive thinking, memory, attention, language and fine motor and visual spatial skills are seen in children exposed to methyl-mercury in the womb (Tchounwou *et al.* 2003). Consumption of mercury contaminated aquatic foods is a threat to both humans (Hruschka *et al.* 2002) and other fish-eating animals as methyl mercury has protein binding properties, making it readily bio-accumulate and bio-magnify in aquatic food chains (Donkor & Nartey 2006). This is illustrated by the mass mercury poisoning in Minamata Bay and Agano River in Japan where organic mercury was high in marine animals that were part of the staple diet of the local population (Tchounwou *et al.* 2003).

Methyl mercury and arsenic, which is part of the smelter dust from gold, end up in water collection points used for human and animal use. These two compounds are associated with diseases like impairment of the peripheral vision, disturbances in sensations, lack of movement coordination, impairments of speech, hearing, walking and muscle weaknesses, peeling of skin, kidney failures, respiratory failure and death (International Finance Corporation & World Bank, 2010).

Besides poisoning associated with mercury and arsenic, artisanal mining has environmental impacts, which include diversion of rivers, water siltation, landscape degradation, deforestation, destruction of aquatic life habitat and widespread mercury pollution (Kitula 2006). The environment degradation caused by mining occurs mainly as a result of inappropriate and wasteful working practices and rehabilitation measures (Hentschel *et al.* 2003)which include restrained plant growth due to acid mine because of toxic compounds and metals that are leached to the environment (Ogola *et al*. 2002)

1.2 Statement of the research problem

The number of people involved in artisan mining activities may range from 30,000 during the peak periods and 10,000 during off peak times and the practice is associated with pollution of rivers through increase in sedimentation, deforestation, acid rock drainage, use of mercury and other chemicals and other poor environmental practices, negative occupational health issues which include silicosis, noise-reduced hearing loss among others (International Finance Corporation & World Bank, 2010).

Gold mining in Kenya has been going on for close to a century and is now being carried out primarily by the artisanal miners. There are several gold deposits present in Kenya, which include Macalder, Masara, Osiri, Nyalapa and Nyatworo and Mikei mines in Macalder division; Nairobi, Kisumu, Ahero and Komito in

Rongo Division and Shinyanga in Suna West division (Ogola *et al.* 2002). Of late there has been a renewed attempt by different companies to explore gold in Southwestern Kenya. The major regions in focus have been Lolgorian in Trans-mara County and Macalder division in Migori County. The gold in this region is considered to be embedded in the Lake Victoria greenstone belt, which is also responsible for gold mining ventures in adjoining Tanzania (Odumo *et al.* 2011).

Artisan gold mining is practiced in Migori County where there is limited resources and training, and the availability of cheap but potentially dangerous method of extraction and processing of minerals which can cause potential risks to both miners and the environment (Ogola *et al*. 2002). The miners, who use mercury, are constantly exposed through the amalgamation process as they hold the mercury with their bare hands (Odumo *et al.* 2011). The mercury tailings end up in the rivers and soils due to poor disposal of the mercury once the miners use it, affecting the aquatic life. The rocks have sulphur minerals, which, when they react with water, produce sulphuric acid which increases the acidity in soil and water bodies, causing aquatic life to die. The sulphuric acid also reacts with the sulphur minerals to produce lead and arsenic (Ogola *et al*. 2002) which are both toxic elements (WHO 1996a). Gold mining in Migori incorporates both open-cut and underground operations which enhance environment degradation due to high uncontrolled excavation in search of gold (Ogola *et al*. 2002). This study determines the levels of heavy (lead, arsenic and mercury) metal contamination in soils and waters at different areas (mines, river, and household) in Migori mining region and finds the relationship between the reported health of the population and main livelihood occupation, and examines the environmental impacts of artisanal mining. This data will be useful in highlighting data gaps and providing data that can influence policies that protect the artisan miners and the environment.

1.2.1 General objective

To determine the levels of heavy (lead, arsenic and mercury) metal contamination in soils and waters at different areas (mines, river, and household) in Migori mining region and determine the relationship between the reported health of the population and main livelihood occupation, and examines the environmental impacts of artisanal mining.

1.2.2 Specific objectives

The specific objectives of the study included:

- To determine the levels of mercury, lead and arsenic in soil and water in Macalder Mines area
- To determine the main human health problems among the population living within the Macalder gold mines
- To determine the association between health events in the Macalder mines population, occupation and levels of mercury, lead and arsenic in the soil and water samples

1.2.3 Hypothesis

SO1: H_0 The levels of mercury, lead and arsenic in soil and water from Macalder mines are within the WHO acceptable levels.

SO2: H_0 The human health problems among the people living near the Macalder mines are similar to the control area.

S03: H_0 There is no association between health events, occupation and mercury levels in the soil and water samples among the population in Macalder mines

1.2.4 Justification of the study

Precious metals are important as they are a source of livelihood to many people in the Migori County and they also increase the Gross Domestic Product. Minimal research has been done in the Macalder mines that are a source of income for many artisan miners who use mercury in the amalgamation process. Mercury is a heavy metal, which causes both environment and health effects. The mineral ore also contains sulphur, which forms sulphuric acid when it reacts with water, increasing acidity in soil and water bodies. The sulphuric acid formed further reacts with the sulphur minerals to produce arsenic and lead which are toxic elements according to the World Health Organization. The study is significant because it will capture the levels of toxic elements (lead, mercury and arsenic), and compare them against the safe levels of international bodies like World Health Organization (WHO) and Environment Protection Agency of United States of America (US-EPA). The occupational health problems associated with artisanal mining and the association of health and environment issues will also be discussed. This data will influence more detailed research and enable policy makers to come up with better policies that protect artisan miners and the environment.

1.3 Scope and limitations of the study

- The study design was cross sectional and the data can only demonstrate associations but not causation.

- Data collection on the health events experienced by families living around the Macalder mines is subject to recall bias.
- Levels of heavy metal contamination were not measured in humans to make a stronger connection between pollution and potential health problems

CHAPTER TWO: LITERATURE REVIEW

2.1 The artisanal gold mining process.

Artisanal gold mining employs about 15 million people and provides a source of livelihood for over 100 million, majority of whom are in developing countries (International Finance Corporation & World Bank, 2010). The first known cases of gold mining using amalgamation method occurred as early as 700 BC in Spain, with Romans subsequently using the process (Donkor & Nartey 2006). The first documented case of mercury poisoning also occurred in Spain in the same period (Donkor & Nartey 2006). Artisanal gold mines generate high quantities of waste for each gram of gold recovered. It is estimated that for every 5-8g of gold recovered, there is a potential waste material amounting to 1 ton of ore disposed into the environment (Kitula 2006). The waste contains toxic elements and minerals, which when released to the environment pollute soils, rivers and large water bodies (Kitula 2006).

Gold extraction process

In artisanal gold mining, gold extraction is done mainly from alluvial deposits along rivers, waterways and terrestrial soils (Donkor & Nartey 2006). The process of artisanal gold mining is divided into two phases. The first phase includes activities related to the actual mining of gold deposits, in this case shallow underground mining of primary reef gold and near surface mining of eluvial and supergene gold accumulations. Here, the miners crush and grind the extracted gold bearing ores, resulting in the recovery of heavy concentrates using gravity separation techniques (Hruschka *et al*. 2002).

The second phase involves the use of mercury, which is mixed into the concentrate, forming a mercury-gold amalgam. This ‘raw gold’ is recovered through the process of amalgam roasting. During this process, the amalgam is roasted in an open fire, potentially exposing the miners to mercury that may accumulate in their lungs and kidneys (Hruschka et al. 2002). Metallic mercury discharged into the environment can be transformed by microorganisms into methyl mercury, which is easily transferred to the fetus, with effects ranging from sterility, spontaneous abortion and from mild to severe neurological symptoms (Kitula 2006). The final refinement of the gold is normally carried out away from the small-scale gold mining sites, at dealers’ places in towns and in goldsmiths’ shops.

Another common practice is to amalgamate the whole ore, by either spreading mercury on the riffled concentration sluices or by using the old copper plate amalgamation method. When alluvial or ground ore flows over a copper plate covered with mercury, gold is eventually trapped forming a solid amalgam. Because of water, copper oxidation occurs, causing the mercury to lose its amalgamation ability. This causes the miners to burn the plates to remove mercury and clean the copper plate with cyanide to re-amalgamate it, exposing them to high levels of mercury vapor as the emissions are inhaled by the miners (Veiga et al. 2006)

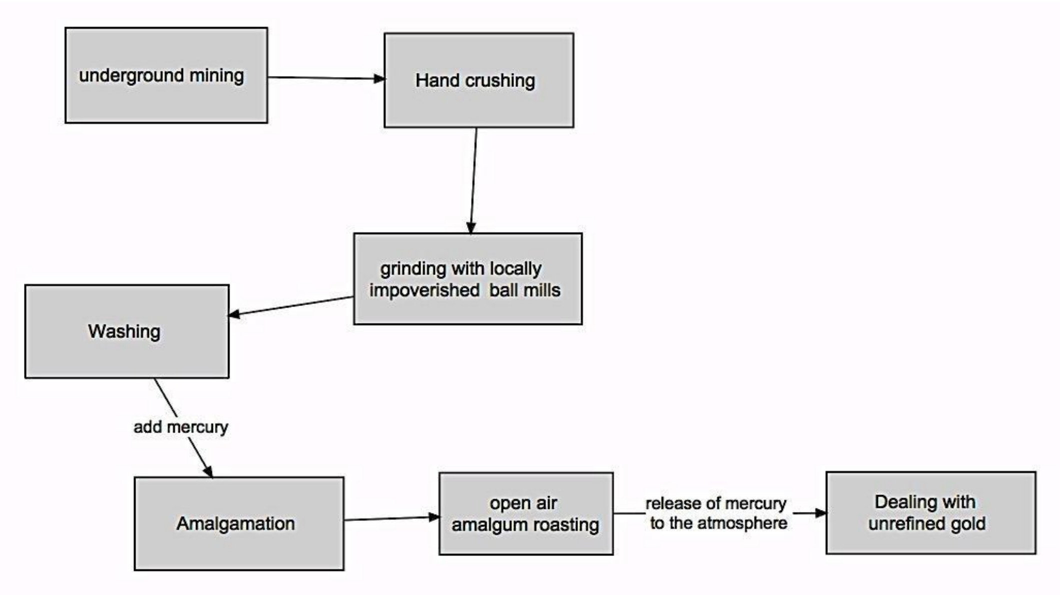

Figure 1 Generalized flow sheet of gold mining and processing (Van Strateen 2000)

Physical contact with metallic mercury occurs during the amalgamation process as miners use bare hands to mix the mercury and the concentrate. Long-term damage to human health through inhalation of volatized mercury can happen during the second phase where miners roast the amalgam at a close distance and without donning personal protection (Hentschel *et al*. 2003). These activities have a high potential for the immediate and direct impacts on human health and the environment (waste rock placement, erosion, dust etc.). They also involve the use of water and the use of anthropogenically introduced mercury as well as the disposal of process-contaminated waste (Kitula 2006). Cyanide and mercury leakage or spillage, and improper disposal of mine wastes, can be deadly to humans and can poison ground water, farming land and the resources in water bodies which the livelihood of the majority depend on for their survival (Veiga et al. 2006).

Most gold fields in Migori County contain sulphide minerals associated with gold (Ogola *et al*. 2002). After gold extraction, the decomposition of sulphide minerals releases acid waters in the form of acid mine drainage. This drainage can contaminate nearby streams and ground water for centuries after a mine has closed. Evidence of river pollution includes siltation and coloration. Sulphuric acid, which is produced through oxidation of the sulphide minerals, gives the strong acidic property in the rivers, killing aquatic life. The sulphuric acid attacks other sulphide minerals, breaking them down to release metals such as lead, arsenic among others (Ogola *et al.* 2002). This also poses a threat to children who play in the streams and also the fetuses through use of water from the contaminated rivers (Ogola *et al.* 2002)

2.2 Health effects of artisanal mining.

Mercury

In most developing countries, mercury is initially imported through legal channels for permitted uses, such as dental amalgamation, but in many cases, it is then diverted to artisan mining operations (Veiga *et al.* 2006). Mercury exists in both organic and inorganic compounds. Methylation of inorganic mercury into organic mercury is by microorganisms under anaerobic conditions, for example in underwater sediments (Hruschka *et al*. 2002). Organic mercury is highly poisonous and is easily absorbed by the gastric and intestinal organs, and carried by blood into the brain, liver, kidney and fetus in pregnant women (Tchounwou *et al*. 2003).

Mercury in the central nervous system leads to numbness and unsteadiness in the legs and hands, awkward movements, tiredness, ringing in the ears, narrowing of the field of vision, loss of hearing, slurred speech, loss of sense of smell and taste and forgetfulness (Tchounwou *et al*. 2003). It also leads to organ failure, miscarriages and minamata disease, (which was first detected in Japan) among the adults. The fetuses and growing children experience nervous system failure, mental illnesses and slow brain formation, slurred speech and visual impairments. Minamata disease was associated with eating large quantities of aquatic life, which was contaminated by industrial discharges of mercury compounds. Similar situations have been experienced in Sweden in a population that fed on fish contaminated with an organic mercury compound used as a pesticide (Tchounwou *et al*. 2003). High mercury concentrations have also been reported in people who carry out amalgamation and amalgam burning in Tanzania (van Straaten 2000a).

Lead

Lead does not dissolve, but exposure to sunlight and water can change its minerals and compounds, enabling it to stick to soil particles and enter underground water where the water is acidic or soft. Exposure to lead occurs through drinking contaminated water, breathing polluted air or dust and eating foods grown on soils contaminated with high lead content. Even the lowest doses of lead can impair the nervous system and affect fetus, infants and young children resulting in lowering of intelligent quotient, growth abnormalities and anemia. It may also increase the risk of cancer, heart diseases, infertility and anemia among adults (Ogola *et al.* 2002)

Arsenic

Arsenic poisoning causes cancer, bronchitis, rhinitis and heart diseases among others. It can result in skin and lung cancer 20-30 years after the first occurrence of symptoms (Tchounwou *et al*. 2003). Research done on humans and aquatic life in areas where the water from the mining sites drain to lakes or water bodies found out that heavy metals often accumulate in the top layer of the soil and therefore, rain-washed into nearby streams and rivers (Donkor & Nartey 2006). Evidence of possible pollution includes siltation and water colorations due to chemical reactions, resulting in the formation of sulphuric acid and ferrous hydroxide. The streams near Macalder mines in Migori County show orange coloration and the water is acidic, depicting chemical pollution (Ogola *et al*. 2002).

2.3 Environmental effects of artisan mining.

Recent increase in gold mining in Kenya has had a positive impact on unemployment through being a source of livelihood for many artisan miners, but at the same time has a plethora of environmental implications, causing significant damage to the landscapes (Odumo *et al*. 2011). The environment implications in the mining regions include pollution of water sources from mercury and cyanide, dust, cracking and collapse of mine pits. At the local level, the uncontrolled digging and abandoning of pits has caused destruction of land beyond economic and technical reclamation (Ogola *et al*. 2002). Mine pits not only make land unfavorable for agricultural activities following closure but also adversely impact livestock and wildlife resources, which in turn, affects locals, who depend on power and animal manure.

Continuous disposal of mine wastes contributes to air and water contamination, which are detrimental to human health, livestock and wildlife biodiversity and have serious effects on the welfare of the mining communities, especially groups of women and children (Odumo *et al.* 2011)

Forty percent of the mercury lost during amalgamation is released directly into the soil, streams and rivers, as inorganic mercury, which later converts into organic mercury (Hentschel *et al*. 2003). The remaining sixty percent of mercury is released to the atmosphere when the gold amalgam is heated during the purification process and is often inhaled. Heavy metals are also seen to affect the microorganisms as resistant genes are known to develop in the bacteria as a result of continued exposure of these bacteria to heavy metal pollution to the environment leads to increased antibiotic resistance (Ndungi Raphael 2011). Aquatic life is also affected as they accumulate toxins in their body through eating planktons, which absorb mercury and in the long run, the animals suffer the risk of poisoning from these heavy metals (Hentschel *et al.* 2003).

Water pollution

According to the United States Agency for Toxic Substances and Disease Registry, arsenic, lead and mercury top the priority list of hazardous substances. The main input in artisanal gold mining during the amalgamation process is mercury, which has safe levels of 0.002 parts per million in water (EPA-US 2015). In accordance with the Environment Protection Agency (USA), the safe levels of arsenic in water are 0.010 parts per million. This is the same as the World Health Organization recommended levels of arsenic levels in water. The proposed safe levels of lead in water by the US Environment Protection Agency and World Health Organization are < 0.015 and < 0.01 parts per million respectively. Mercury exposure leads to relatively higher contamination of environment in the gold mining areas through the tailings and this leads to exposure to the households in the area as they end up using water from the contaminated rivers and grow crops in the contaminated soils (Donkor & Nartey 2006)

Soil pollution

In accordance to World Health Organization, the safe levels of mercury in soil are 70 parts per million in the soil (WHO 1996b). The proposed safe levels of arsenic in soil by both the Environment Protection Agency (USA), and World Health Organization are 75 parts per million. The World Health Organization lead safe levels in soil are 107 parts per million. Lead poisoning has been reported among residents of Owino Uhuru slums in Mombasa Kenya with resultant impotency in adults and lowered the children's Intelligence Quotient and their immune system (Benards 2012).

In the results of the soil analysis of gold mines in Northern Tanzania showed that between 20 and 30% of mercury is lost in tailings, soils and waters (van Straaten 2000a).There are also arsenic concentrations in the soil profiles. The mean value of mercury in the soils near the mining areas exceeds the US-EPA value by 19 times (van Straaten 2000b). It is also seen that green leafy vegetables absorb most of the mercury from the soil, as compared to other crops like cassava, maize and rice, among others (Taylor et al. 2005).

Mining license

Also, most artisanal miners are not licensed and do not have access to knowledge of existing regulatory systems (Spiegel & Veiga 2010). The miners who are crucially driven by poverty, have limited economic abilities and limited or no conventional technical training on methods to mitigate the long-term impacts of their mining activities on environmental and on their health (Hruschka *et al*. 2002)

2.4 Theoretical and Conceptual framework.

Artisanal mining harms the physical and social environment during the different stages of mining (exploration, exploitation, processing and closure) through mercury pollution, cyanide pollution, direct dumping of tailings and effluents into rivers, improperly constructed tailings dams, acid rock drainage, river siltation, erosion damage and deforestation, landscape destruction among others. The miners who lack awareness of risks, especially risks of chronic occupational disease (dust, vibrations, nitrous gases, mercury etc.) that stem from inadequately implemented education and training (Hentschel *et al*. 2003). Unsustainable development associated with mining activities resultant from the compounding environmental and health effects and damages of mining activities far outweighing their economic and social benefits (Hilson & Pardie 2006).

The conceptual framework used for the study shows the environmental and health impacts of mining activities.

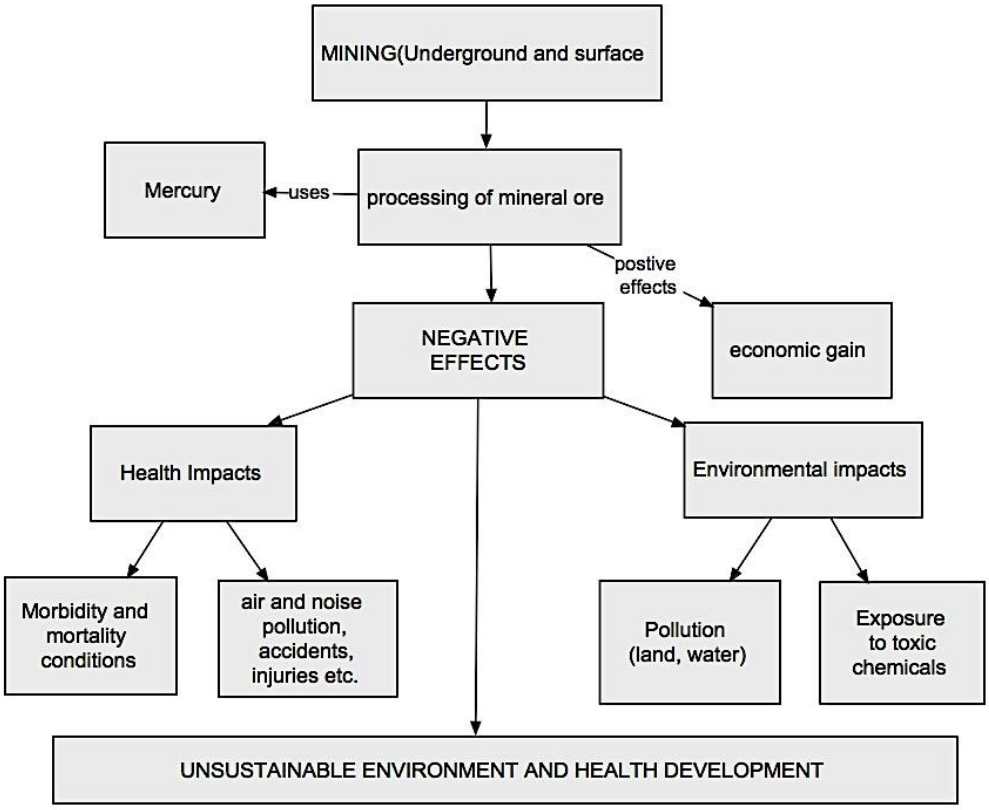

Figure 2 Conceptual framework showing the effects of traditional mining on the health and environment

The conceptual framework shows the impact of mining on the environment and the health of people. This is based on the review of the available literature. Mining methods on the land can either be underground (deep shaft) or surface mining. With any of these methods, there are positive and negative effects. Positive effects include economic gains and source of livelihood for the miners. Negative effects include environmental and health impacts. The impact of mining activities on the environment is very remarkable. First of all, mining activities require acquisition of large tracts of land. Both deep and surface mining degrade the land surface since there is destruction of the entire forest. Consequently, land for farming and other agricultural purposes is lost. Furthermore, spillages of toxic elements such as mercury, lead and arsenic and other toxic materials into the nearby streams cause water pollution, destroying water bodies and aquatic life. Exposures of such toxic elements are also harmful to human health.

On health, several health implications are associated with mining activities. Mining activities such as blasting of rocks lead to air and noise pollution that affect the people within the surrounding areas. This sometimes leads to increased incidence of upper respiratory tract infections and cancer. There are also incidences of malaria, diarrhea, acute conjunctivitis and accidents all of which result in increased morbidity and mortality among populations living in the mining areas. The negative environmental and health impacts of mining activities are so immense that they call for urgent interventions.

CHAPTER THREE: STUDY AREA

The study was conducted at Macalder Mines, which are located in Nyatike Sub County, Migori County (latitude 0°40’ and 0° South and longitude 34° and 34°50’ East) in Western Kenya. Migori County borders Homa-Bay, Kisii and Narok counties.

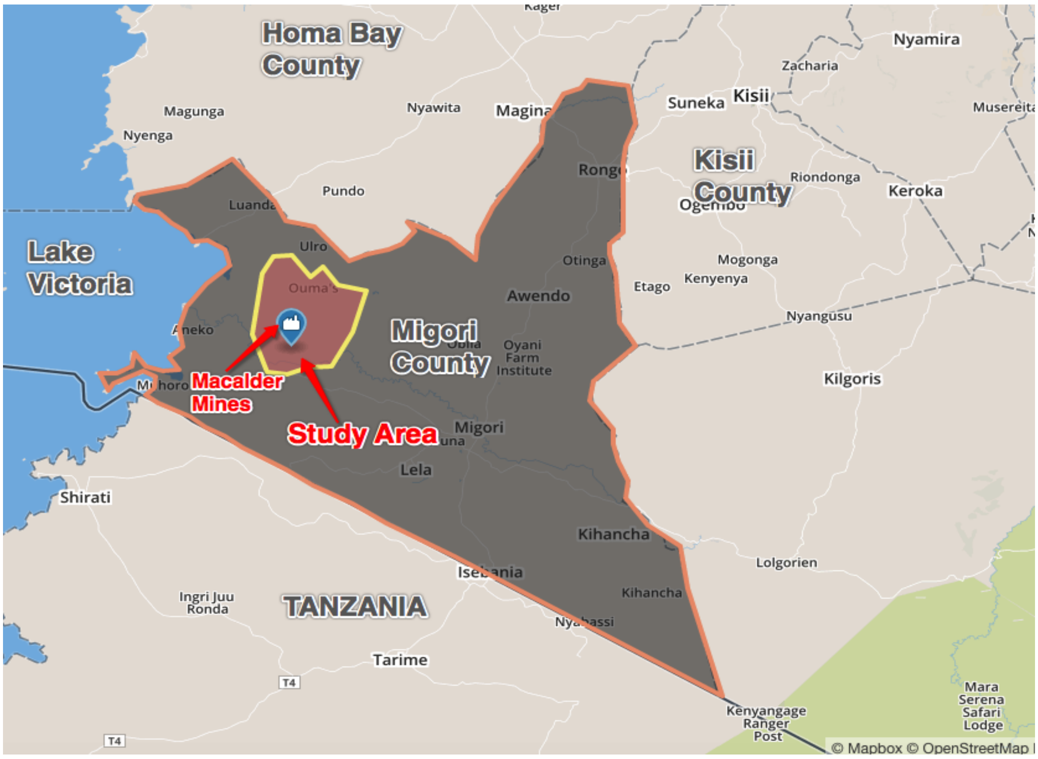

Figure 3 Macalder mines in Migori County

3.1 Biophysical characteristics

The main rivers in the area are Kuja, Migori and Riana. Other rivers include the Ongoche, Oyani and Sare. These rivers have waterfalls and cataracts and are not conducive for transport. At lower attitudes, there are frequent reports of flooding disasters. Lake Victoria, which lies on the Western border of the county, is a source of water, fish and serves as a tourist attraction (Ministry of Planning and Development 2002).

Climate

Rainfall patterns in the County range from 700mm to 1800mm annually, with the short rains occurring between March and May while the long rains experienced during the period of October to December (Ministry of Planning and Development 2002).

Climate is of a mild inland equatorial type that is modified by relief, altitude and proximity to the lake. It favors the cultivation of sugarcane, which is the county's main industrial crop, and tobacco, cotton, maize and cassava (Ministry of Planning and Development 2002).

3.2 Demographic characteristics

Migori County has a population of 907, 499 with 48.3% being male and the rest being female. Nyatike Sub County where the Macalder mines are located has a population of 143,545 with 68,477(47.7%) male and 75,068 (52.3%) female (KNBS & SID 2013). The total dependency ratio is a measure of the pressure on productive force of those not in the labor force (dependent) and those in the labor force (productive) in an area. In the sub county, the total dependency ratio is 1.108 (KNBS & SID 2013). The Gini Coefficient of Nyatike sub county, which is a measure of inequality of the income distribution of a country's residents, is 0.416. This is slightly lower than average of Migori County, which has a Gini Coefficient of 0.464 (KNBS & SID 2013)

3.3 Energy, water and sanitation

Eighty percent of the population in Migori county use firewood and seventeen percent use charcoal as the main source of fuel (KNBS & SID 2013).The rest use paraffin (2%) and liquefied Petroleum Gas (1%). Twenty eight percent of the residents use improved sources of water which include protected spring, protected well, borehole, piped water and collected rainwater while the rest rely on unimproved sources of water including pond, dam, lake, stream/river, unprotected spring, unprotected well, water vendor and others (Ministry of Planning and Development 2002). Fifty two percent of the residents in Migori County use improved sanitation (adequate sewage disposal) while the rest use unimproved sanitation. Use of improved sanitation is slightly higher in households headed by men, which is at 54% as compared to female-headed households at 48% (KNBS & SID 2013). The improved water per household as at 2009 was 47.8%, having the County ranked at number 39 out of 47 counties in the country while the improved sanitation was at 66.8% as at 2009 (Commission of Revenue Allocation 2012).

3.4 Education levels

Fifteen percent of Migori County residents have secondary level education while 65% of the residents have primary level education. The rest have no formal education. This is also similar to the statistics of the Nyatike sub county (KNBS & SID, 2013).

3.5 Farm characteristics

The average size of farms per household is 5 acres with 2.3 acres planted maize and 1.1 acres planted tobacco (Ojala *et al.* 2014). The farms can be as low as 0.3 acres, demonstrating how land is a scarce resource in the country and continues to experience more pressures from the escalating population. The average number of animals per household was 2 bullocks, 1 local breed of sheep, 1 local breed of goat, 3 cows and 12 layers (Ojala *et al.* 2014).

CHAPTER FOUR: MATERIALS AND METHODS

4.1 Sampling design and approach

Stratified random sampling formed the study design. The strata were sampled as separate entities and results from each stratum combined to give overall results. Stratification was aimed as reducing variability in the population samples thus increasing the precision results. Water and soil samples for determination of heavy element concentration were collected randomly from Macalder mines, River Kuja and households. Questionnaires were administered randomly from miners and non-miners households. The various sample collection methods of water samples, soil samples and questionnaires are described below.

4.1.1 Collection of soil samples

The soil samples were taken following the Food and Agriculture Organization soil sampling guidelines (FAO 2006). Three soil samples were taken moving in a zigzag manner in the selected sampling area, mixed together and one subsample taken from that and stored in a cool dry place. Thirty soil samples were taken in Macalder mines and the surrounding areas of River Kuja while one hundred and twenty samples were taken in 120 households where questionnaires were administered. Total number of samples taken was one hundred and fifty. Soil sampling in the Macalder mines was taken from the center of the mine and after every half a kilometer. Three samples were taken in a zigzag manner and mixed in a plastic bag then transferred to a 15ml falcon tube for transportation and storage. Soil sampling in the households was taken from the respondents' farms. The date, location and GPS Co-ordinates of the point where each sample was collected, was recorded.

4.1.2 Collection of water samples

This was done following the World Health Organization Guidelines (WHO 2006). Thirty water samples were taken in the Macalder mines and the surrounding areas of River Kuja while one hundred and twenty samples were taken in different households. Water sampling in the Macalder mines was taken from the center of the mine and every water point after every half a kilometer in a circular manner. Water samples in the households were taken from the household drinking water. The date and location of the area was recorded while a water sample was being taken. Total number of samples taken was one hundred and fifty.

4.1.3 Questionnaire sample size determination

The questionnaires were administered after consent from both the administrative officer and the interviewees. Stratified random sampling technique was used among the miners and the non-miners. The questionnaires were limited to the head of the households as the respondents. The selection of households of miners and non-miners, which was a 50:50 selection, was made through the help of the area administrator.

4.2 Data collection

Enumerators from the local community who had a secondary school minimum education and who knew the language and area very well were engaged in administering questionnaires.

The enumerators underwent a one-day training, which ensured there is correct interpretation of the questions and minimize errors during data collection. The use of local community interviewers helped reduce suspicion among respondents given the interviewers are well known to them, and also ensured an understanding of the questions. The principal researcher conducted the training. A pilot questionnaire was done on the enumerators so as to ensure the questions were relevant and not infringing on any person’s rights. The questionnaire had both open ended and closed-ended questions. All closed-ended questions were homogeneous and all open-ended questions were designed to give the respondent freedom to respond. Photography and observations on what is naturally occurring enhanced primary data collection. Secondary sources of information for this study included published documents and maps. Emphasis was given to studies on use of amalgamation methods for gold mining and the impacts of gold mining to the environment and health.

4.3 Key Informant interviews.

The people interviewed included the sub county administrator, agricultural extension officer, NEMA representative and the clinical officer of Macalder level 4 hospital. Each interview took approximately 45 minutes where the interviewer asked a series of questions and responses recorded. The interview took place at the interviewee’s place of work. The interviewees focused on either mining practice in the area or effects of mining as per their line of expertise.

4.4 Reconnaissance of Macalder Mines and surrounding area

In order to gain an overview of the topography, rivers and mining sites in the area, the researcher, with the assistance of a guide, walked around the Macalder mines and the surrounding villages before data collection could start. This helped establish a rapport with the study population, as well as identifying the areas where soil and water sampling would be conducted. The main data collection method was observation, and asking a few questions to the villagers and miners so as to gain a better understanding of the area and taking photographs.

Community structure

The people live in villages, where everyone has their own house and grazing land is communal. The villagers keep animals including cows, goats, hen and donkeys. The donkeys are used as the main mode of transport in the mines as they carry the rocks from the mining hole to the crusher. Water siltation, dust, collapsed mine pits; uncontrolled digging and abandoned pits were all observed. The streams near Macalder mines also had an orange coloration, depicting chemical pollution. Also, evidence of rocks corrosion due to sulphuric acid was seen.

4.5 Soil and water Sample analysis

The soil and water samples were taken to the University of Nairobi's Institute of nuclear science and technology laboratory. One gram of each sample was weighed into a clean triplicate and 5 millimeters of double distilled water and 10 millimeters of concentrated nitric acid were added. The samples were digested using a microwave digester for forty minutes at 200°C. After cooling, they were transferred into clean vials and distilled water added to top up the solution to 50 millimeters. Ten millimeters of each sample were then measured into clean vials and 20µL of 1000ppm Gallium stock solution was added. The resulting concentration of Gallium solution is 2ppm in each sample.

Each sample was homogenized using a vortex mixer for one minute. Aliquots of 10µL of each sample were pipetted onto a clean quartz carrier using a micropipette. Triplicate sub-samples were prepared for each sample. The carriers were then dried in an oven to evaporate the liquid. Each sample carrier was irradiated for 1000 seconds using a S2 PICOFOX TXRF spectrometer, which was operated at 50-kilo volts and a current of 1000µA. The spectrometer uses a molybdenum node. Evaluation of the measured spectra was done using S2 PICOFOX software on the basis of the chosen elements. The concentrations were calculated based on the net intensities of the analyte peak elements as per the following formula (Hagen Stoshnach 2007):

$$Cx = \frac{Nx / Sx}{Nis / Sis} x Cis$$

Where, Cx ---- Concentration of the analyte

Cis ---- Concentration of the internal standard

Nx----- Net intensity of the analyte

Nis-----Net intensity of the internal standard

Sx------Relative sensitivity of analyte

Sis------Relative sensitivity of internal standard

4.6 Data analysis

A questionnaire was pre-coded to facilitate data analysis and to reduce time needed in data entry. The statistical data was analyzed using R statistics program. Proportion tests and logistic regression analysis were performed to test for any significant differences in the parameters on both temporal and spatial scales. Effects of the explanatory variables in logistic regression analysis were separated through multivariate tests. The differences were considered significant at $P<0.05$ or at 95% Confidence Levels.

CHAPTER FIVE: RESULTS

5.1 Household characteristics

5.1.1 Miners

Among the 120 respondents, fifty percent had their main source of livelihood from mining and they ranged between 25 years and 70 years. Forty four percent of the miners were female and 56% male. The average household size in this group was seven persons. Approximately 30% of the respondents in this group did not have any formal education, 40% had primary school education and the rest (30%) had attained secondary school education.

5.1.2 Non-miners

Among the 120 respondents, fifty percent had their main source of livelihood from non-mining activities and they ranged from 28 years to 65 years. Twenty six percent were female and 74% male. Approximately 24% did not have any formal education, 34% had primary school education, 36% had secondary school education, 14% had diploma level education and 3% had attained university level.

Demographic structure of the family members included:

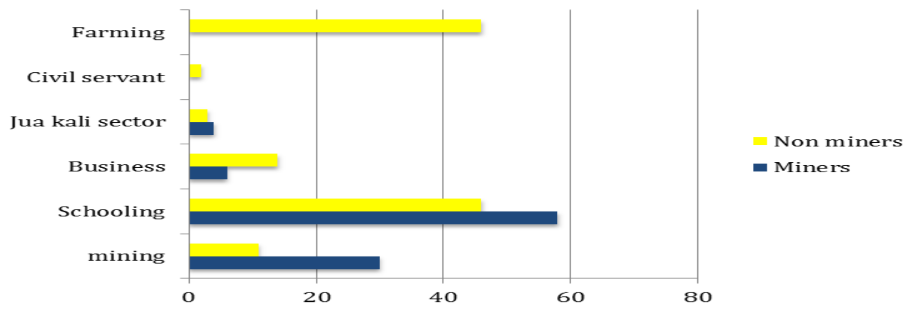

Figure 1 Different occupation among the respondents' family members

Among the respondents, households that were led by miners had mining as the main source of livelihood and most of the members of their families attended school (schooling) while non-miners were involved in other activities like farming and business. Miners were not engaged in farming and did not have civil servants in their households. Non-miners also had people involved in mining activities although it was not the main source of livelihood for the families.

5.1.3 Water sources and farming activities

According to the respondents, seventy eight percent got their water for domestic purposes from river Kuja and the rest got their water from River Migori. Nineteen percent of the non-mining farmers got their farming and drinking water from River Migori while the rest got water from River Kuja. The miner respondents got most of their family drinking water from River Kuja.

Interview with the agriculture and livestock extension officer revealed that most of the farming land is owned individually and whereas the grazing land is communal. The main constraints of livestock keeping in the area were tick borne diseases, tsetse flies and insufficient grazing areas due to increasing population sizes. The officer mentioned observing high mortality rates among animals drinking water from the mining area. Mining also affects the cropping system in the area because most people prefer mining, which is a relatively quick money generating occupation as compared to farming. The agricultural and livestock extension officer also informed that some of the tailings from the mines end up in the farms, affecting the farm production because the tailings are contaminated and not favorable for crops.

5.1.4 Policy and awareness

According to the information from the sub county administrator, there are 15 villages around the mines. The Macalder mines, which have 20 mining holes, cover a total area of 22.4 square kilometers. The mining structure is open cast mining where the miners dig holes supported by timber. Since obtaining individual mining permits is expensive, the miners have formed cooperative organizations, which they use to jointly seek for these permits. The cooperative organizations also make it easier for mining taxes to be regulated. Each miner regularly contributes a small amount as payment to the cooperative organization. None of the respondents knew about the dangers associated with use of mercury or any illnesses linked to mercury therefore, they did not know how to minimize the risks associated with mercury. Also, none of the miners reported using any personal protective equipment. There was no awareness on the matter as most admitted to never having attended any workshop on environmental and health effects of artisanal mining using toxic elements.

National Environment Management Authority (NEMA) is mandated with conducting Environment Impact Assessments in mining areas, as well as guaranteeing environmental compliance and environment law enforcement. According to the mining policy, mining in Macalder mines is illegal and therefore the artisan miners are considered to be mining illegally. No environment impact assessment has been conducted in the Macalder mines since mining started there before the environment policy on Environment Impact Assessment was written. NEMA faces staff shortage as only two of NEMA officials have been deployed to cover the whole of Migori County. They also lack working equipment like water and soil sampling tools. NEMA is advising on afforestation in the area as Migori County lies on the lowlands, making it prone to flooding hence the contaminated water from the mines finds its way to the rivers during the rainy season. NEMA is also pushing for a legal mining policy implementation in the Macalder mines.

5.2 Health issues affecting artisanal gold miners.

Majority of the respondents sought health care at Macalder Level 4 hospital. Among the miners households interviewed, they all reported at least a family member who had fallen ill in the last three months. Among the non-miner households, seventy three percent of them had at least a family member who had fallen ill in the three months preceding the interview. According to the proportional tests done on the results, there was no statistical difference between miner and non-miner illnesses in the 3 months period prior to my interview as the proportions were 0.993 on miners and 0.989 on non-miners. The common diseases reported among miners and non-miners are shown in the graph below (Figure 4 below). The most common diseases among miners were chest infections and tuberculosis (42.4%) followed by malaria (22.4%) and anemia and miscarriages (17.6%). However, the non-miners did not have cases of chest infections and tuberculosis. The most common diseases were cholera, pneumonia and typhoid (63.4%) followed by malaria (29.5%). The proportional tests carried out to find out if there are any statistical differences between miners and non-miners in different diseases showed that there is no difference as the probability of non-miners when it came to chest infections was 0.9907, 0.0144 on malaria and 0.991 for tuberculosis. Also, sixteen percent of the miners stated that a female in their household had failed to bring a pregnancy to term while no miscarriage was reported among the non-miners. However, the proportional test for miscarriages was 0.993 for non-miners showing no statistical difference.

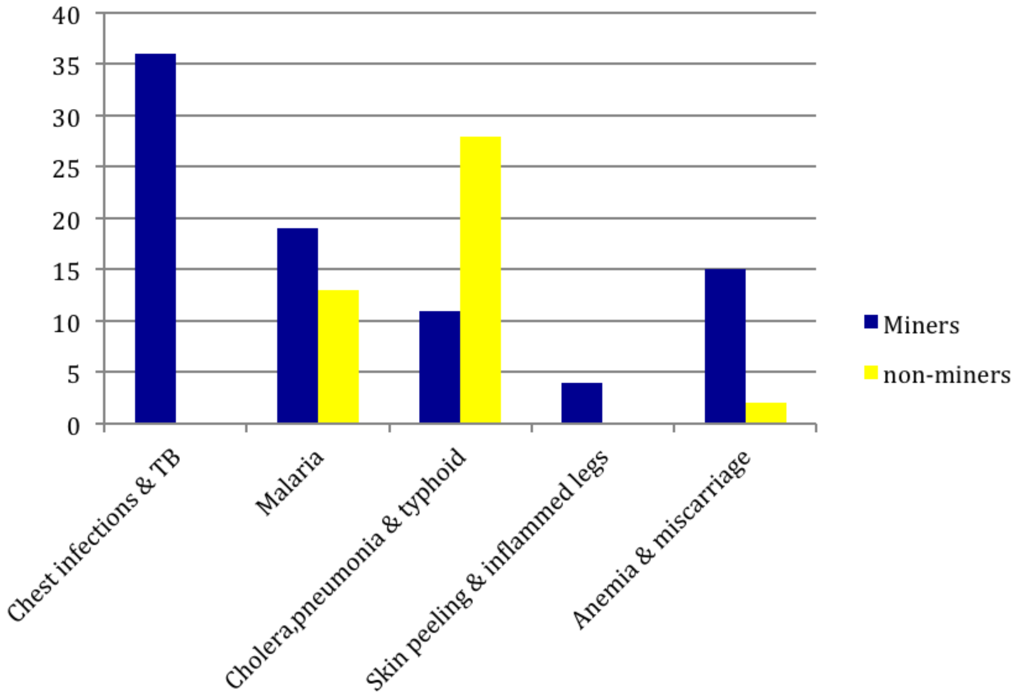

Figure 4 Common diseases reported in the study households in Macalder mines and its environs, aggregated by whether they are miners and non-miners

The logistic regression results show that chest infection, miscarriages, tuberculosis, anaemia and malaria do not have a significant difference between miners and non-miners, as the probability is more than 0.005. (Chest infections-0.9907, miscarriages- 0.993, tuberculosis-0.991, anaemia 0.405, malaria-0.0144)

According to the health officer in Macalder level 4 hospital, estimated about (75%) of the miners suffered from chest infections and silico-tuberculosis which was caused by the dust in the mining site. The health officer also reported observing increased risk of death during the rainy seasons and associated that with mining pits collapsing on the miners when flooded or suffocation caused by the fumes from use of diesel water pumps which were used to remove water from the flooded pits. Review of the hospital records in the Macalder level 4 hospital, which serves the people of Nyatike, revealed high cases of typhoid, anemia, pneumonia and rheumatism, joint points, cholera, silico-tuberculosis and chest infections. The 2013 hospital records had three hundred cases of chest infections, four hundred cases of Malaria, two hundred cases of silico tuberculosis and fifteen cases of miscarriages with ninety percent of cases of silico tuberculosis and chest infections being from artisan miners. Seventy five percent of both inpatients and outpatients in the hospital were miners. Complicated cases, of which most of the patients had a history of mining, were transferred to the Migori Hospital hence it was not able to determine the chronic illnesses. Also, the health officer pointed out that approximately 90% of the miners who came to the hospital had peeling skin, which to them was not a cause of alarm. The district health officers treated patients and carried outreach services, which included health immunization and health education.

5.3 Environment impact

There was water siltation at River Kuja, landscape degradation associated with uncontrolled excavation and abandoned mine pits that were not rehabilitated. Land management risks occurred when mining pits collapsed and/or suffocation inside the mining pits especially during the rainy season. There was also observation of sulphuric acid corroding with rocks and silt coloration due to sulphuric acid, as seen in the images below.

Figure 4 Sulphuric acid corrosion with rocks

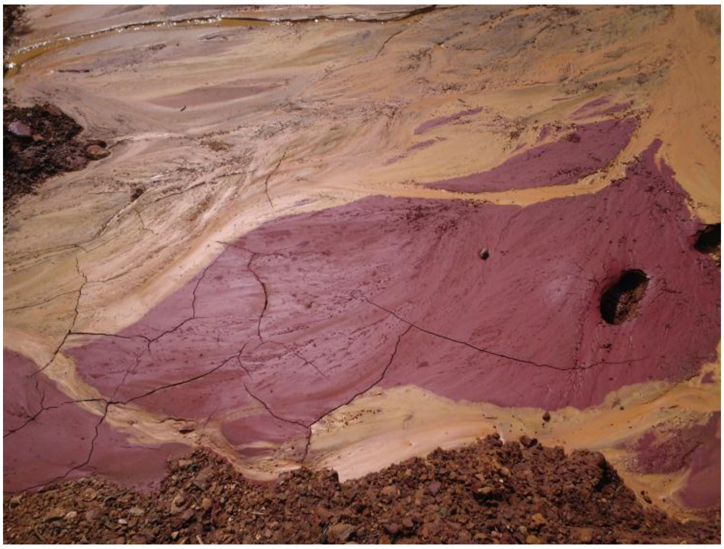

Figure 5 Silt coloration due to sulphuric acid

According to the NEMA officer, environment reports of the area, which were done by Environment officers from National Environment Management Authority

(NEMA), gave recommendations of the future of the mines. It was also observed that where the tailings were deposited into land, all plant life died and this was seen in the farms near the Macalder mines, where the maize farms were really vulnerable. According to the agricultural extension officer, tick borne diseases, tsetse flies were common diseases among the livestock.

5.4 Soil samples elemental concentration

The graph below (figure 5) shows the heavy metal concentration in the study area. Arsenic and lead, which are always associated with gold mining (Odumo et al. 2011) and are toxic, were the two heavy metals detectable in most of the soil samples.

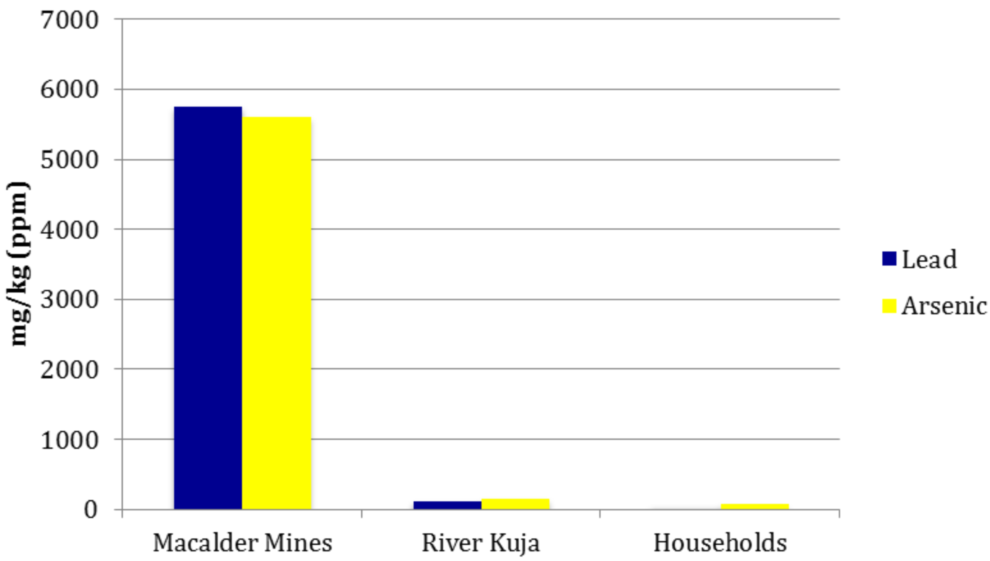

Figure 5 heavy metal concentrations in the soil samples collected from River Kuja, Macalder mines and households near the Macalder mines in Nyatike sub-county, Migori County.

The World Health Organization safe levels of lead and arsenic are 107mg/kg and 75mg/kg respectively (WHO 1996b). The households had safe levels of 48mg/kg of lead and 70mg/kg of arsenic in their soil samples. The banks of River Kuja had 112 mg/kg of lead and 148 mg/kg of arsenic in their soil samples, which was 5% and 100% respectively more than the World Health Organization recommended values. The Macalder mines, which had the highest concentrations, had 5,760 mg/kg of lead and 5,616 mg/kg of arsenic, which was 5300% and 7400% respectively more than the recommended levels of the World Health Organization. This raises a lot of concern for the miners working at Macalder mines since the highest levels of the toxic elements were recoded at the Macalder mines.

5.5 Water samples elemental concentrations and discussions.

The graph below (figure 6) shows the heavy metal concentrations in the water samples collected from the study area. The levels of some heavy elements including arsenic and lead were detectable in all the samples.

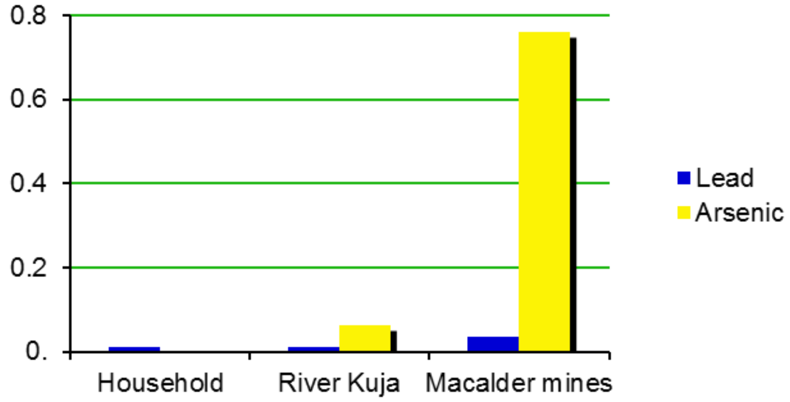

Figure 6 Heavy metal concentration in the water samples collected from River Kuja

The World Health Organization and Environment Protection Agency of the United States of America recommended levels of lead and arsenic are both 0.01 mg/kg (WHO 1996b) (EPA-US 2015). The households had safe levels of lead (0.01mg/kg) and undetectable levels of arsenic in their water samples. The banks of River Kuja had safe levels of lead (0.01 mg/kg) and 0.063 mg/kg of arsenic, which was 500% more than the recommended levels. The Macalder mines, which had the highest concentrations, had 300% more than the recommended safe levels of lead (0.037 mg/kg) and 7500% more than the recommended levels of arsenic (0.76 mg/kg).

5.6 Spatial distribution of study area

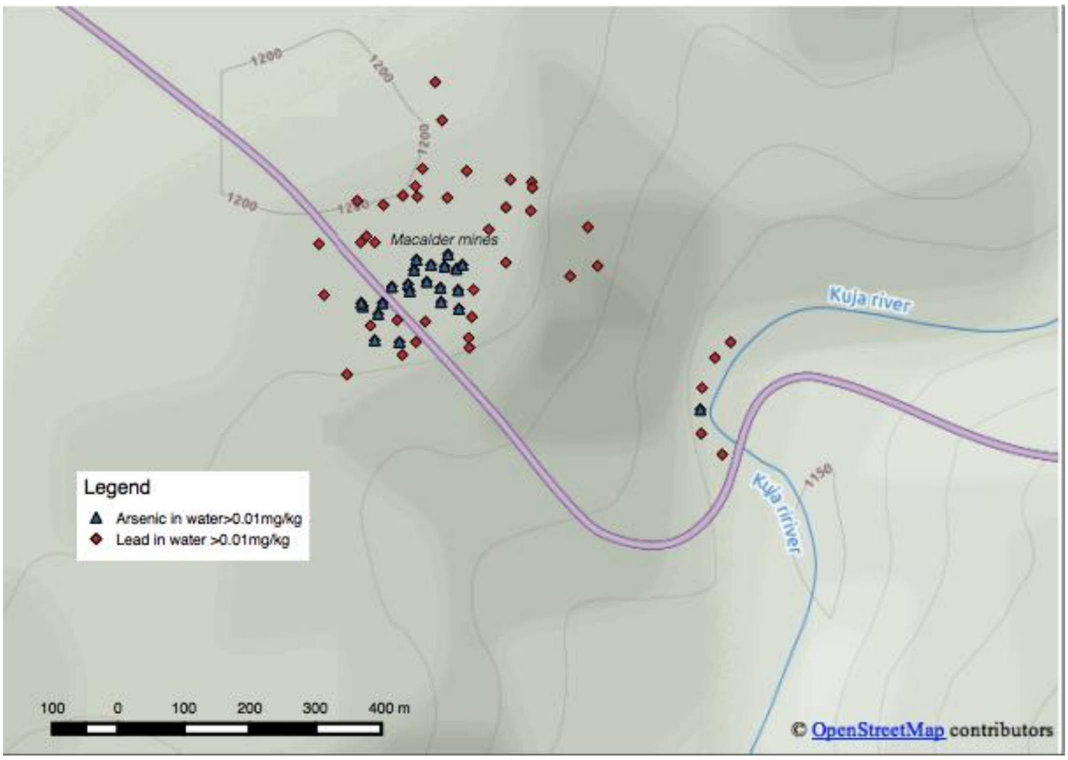

Figure 7 spatial distributions of unsafe levels of lead and arsenic in the water samples of Macalder mines and its environs

Figure 7 above, shows spatial distribution of the unsafe levels of lead and arsenic in the water samples. The recommended safe levels of both lead and arsenic in water by the WHO and USA-EPA bodies was 0.01 parts per million. However, the mining area, which is named, and the areas near it, had the highest unsafe levels of toxic elements. The River Kuja also had unsafe levels of lead and arsenic. The contours show that the mining site is at a higher level as compared to the River Kuja because the mining site is shown to be at a contour of between 1200m and 1190m. However, River Kuja is at a contour of 1150m. This shows that the river is at a risk of water pollution from the heavy metals and acidity from the corrosion of water with the sulphur minerals during the rainy season when the water pans in the mining site overflow and drain into River Kuja, which is the main source of water among the residents.

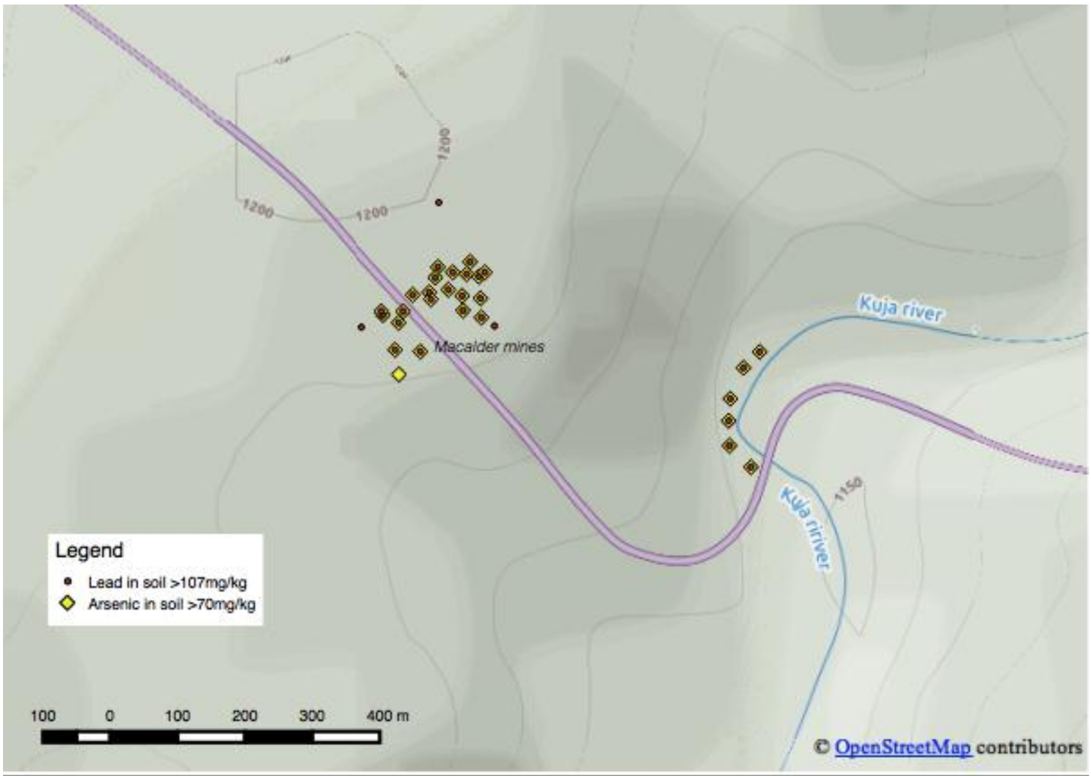

Figure 8 spatial distributions of unsafe levels of arsenic and lead in the soils of Macalder mines and its environs

In figure eight, we are able to see that the unsafe levels of arsenic and lead were more in the mines and the surrounding area and also in River Kuja. As also seen in figure seven above, the river is at a relatively low lying area as compared to the mines. The toxic elements may move from upstream to downstream during the rainy season and this might cause a potential risk for the residents living in the downstream areas.

From figure 7 and 8 above, we are able to see that the Macalder mines had unsafe levels of heavy metals. The contours show that Macalder mines is at 1200m and the land slopes slightly up until River kuja, which is at 1150 meters. The slope plays a key role during rainy season where the water flows from the upstream to the downstream. The water pans at the Macalder mines get flooded and the polluted water finds its way to River Kuja. Also, sulphuric acid which is formed when water corrodes with the sulphite mineral ores streams downstream posing a potential risk to the households which leave downstream and which rely on River Kuja for their source of water.

CHAPTER SIX: DISCUSSIONS

6.1 Soil elemental concentration

According to the World Health Organization (WHO) and the Environment protection Agency-USA (EPA-USA), the safe levels of lead and arsenic in soils are 107mg/kg and 75mg/kg respectively. However, in the soil samples of Macalder mines and River Kuja, the results were above the safe levels. Lead and arsenic were more than the safe levels by 5300% and 7400% respectively in Macalder mines while 5% and 100% respectively in River Kuja. The same findings were reported by Ogola *et al.* 2002 in Macalder mines and River Kuja. He recorded 282 mg/kg of lead in River Kuja and 11075 mg/kg of arsenic in the tailings of Macalder mines. This was 60% and 10300% respectively. The same findings were recorded by Odumo *et al.* 2011 in the Macalder mines. He recorded 3199mg/kg of arsenic and 7375mg/kg of lead. This had surpassed the safe levels by 4165% and 5800% respectively. This raises a lot of concern on the health of the miners who work at Macalder mines. These levels are much higher than levels registered in other mines in the East African region. Van Straaten 2000 recorded 168.4 mg/kg of arsenic in the soils of Mwakitolyo site in Tanzania and 404mg/kg of arsenic in Tafuna site in Zimbabwe. this had surpassed the safe level by 100% and 440% respectively.

Mercury, which was not detected in the soil, was also undetectable in the findings of both Odumo *et al.* (2011) and Ogola *et al*. (2002) in Macalder mines. The high density of mercury makes the sediments to be washed away while allowing the gold and gold amalgam to sink to the bottom of the panning pond or river (Alpers, *et.al.* 2005). This shows environment contamination that is caused by artisanal mining process.

6.2 Water elemental concentration

In accordance to the World Health Organization (WHO) and the Environment protection Agency-USA (EPA-USA), the safe levels of lead and arsenic in water are both 0.01 mg/kg. However, in the water samples of Macalder mines, both arsenic and lead were above the safe levels and also the arsenic levels of River Kuja were above safe levels. In the Macalder mines, lead and arsenic were recorded at 0.037mg/kg and 0.76mg/kg respectively. This was 300% and 1500% above the safe levels of lead and arsenic respectively. River Kuja recorded 0.063mg/kg of arsenic, which was 500% more than the safe levels. The same findings were reported by Ogola *et al.* 2002 in Macalder mines and River Kuja. He recorded 7 mg/kg of lead and 0.08 mg/kg of arsenic in River Kuja and13.75mg/kg of lead in Macalder mines. This was 700% more than the safe levels of arsenic in River Kuja, 10300% more than the safe levels of lead in River Kuja and 1400% more than the safe levels of lead in Macalder mines. This raises a lot of concern on the health of the miners who work at Macalder mines.

Mercury, which is highly used in the amalgamation process, was undetectable in the water samples. It was also undetectable in the findings of both Odumo *et al.* (2011) and Ogola *et al.* (2002) in Macalder mines and (Taylor *et al*. 2005) in Rwamagasa artisanal gold mine in Tanzania.

6.3 Health problems associated with mining

The logistic regression probability of health issues based on occupation, as shown in the table below, is tending towards 1, showing that there is no difference between a miner and a non-miner. However, the probability of occurrence of heavy metals based on the area (household, River Kuja, Macalder mines) shows that Macalder mines has heavy metal concentration as compared to the households and River Kuja. This may pose an occupational hazard to the miners who work in Macalder Mines on a daily basis.

Logistic regression on the probability of health issues based on occupation	
	Occupation (miner vs non-miner
Anaemia	0.405
Chest infections	0.9907
Malaria	0.993
Miscarriages	0.993
Tuberculosis	0.991

6.4 Policy and awareness of mining

There was minimal awareness of the dangers of using mercury with bare hands and the use of personal protective equipment during mining. Similar observations were also made by Veiga *et al.* (2006) in Tanzania where artisanal miners had less awareness hence they were resistant to embrace new techniques. Donkor & Nartey (2006) also observed the lack of awareness in using mercury among artisan miners in Ghana, which was posing a serious environment threat. There was also lack of awareness in the Masara, Mikei and Osiri mines in Kenya, which have artisanal miners who are using the mercury amalgamation method (Odumo *et al*. 2011, Ogola *et al*. 2002). In Ghana, the artisan miners who do not wear protective equipment also 'suck amalgam' to remove excess mercury prior to roasting by putting the amalgam in a handkerchief and sucking the excess mercury which may be reused (Hilson & Pardie 2006). There was high occupational risk of the miners as they handled mercury with their bare hands and also breathed in the dust from the mines during the crushing process. Van Straaten (2000a) also recorded high occupation risks of miners who handled mercury in his research in Northern Tanzania and Zimbabwe.

There is no international legal framework specific to artisanal mining but there are a number of mining conventions that are relevant. The International Council on Mining and Metals has principles, which are based in the mining issues. Some of the principles include seeking continual improvement of the health, safety and environment performance, facilitating and encouraging responsible product use, reuse, recycle and disposal of the product, among others. The mining policy draft of Kenya recognizes small-scale miners and finds it difficult to regulate artisan mining as it often takes place outside the mainstream industry. However, the policy calls for promotion of healthier and more environmentally compliant operations and enhancement of an investment environment for large-scale mining through the elimination of some of the dangers caused by artisanal mining, which is informal. According to the National Environment Management Authority library on environment impact assessments, there has not been any Environment Impact Assessment done in the Macalder mines as it was in operation long before the environment policy and the environment management act of Kenya came to place.

Major efforts were made during the 1980s under the advocacy of the United Nations to coordinate international conferences for the aim of reaching a uniform industry policy (Hilson & Pardie 2006). Even though it turned futile, a pattern emerged where the poorest mineral-rich countries had the largest and least-skilled artisan miners which has given rise to a poverty-driven industry label as experts attribute poor policy, inefficient equipment and an inability to diversify income earning activities as the main driving forces behind the impoverishment(Hilson & Pardie 2006)

6.5 Environment impact

The Macalder mines which have sulphur ores produce sulphuric acid when the rock comes into contact with water. The stone ore corrosion with water is seen in the Macalder mines and also, observed by Ogola *et al* (2002) in the Macalder mines. This is seen by the orange coloration of the tailings, where the sulphide minerals, mainly phyrite (FeS_2) which when exposed to oxygen and water oxidizes forming sulphuric acid and ferrous hydroxide as shown below:

$$2FeS_2 + 6H_2 + 7O_2 \rightarrow 4H_2SO_4 + 2Fe(OH)_2$$

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Artisanal mining, which is an informal mining sector in Kenyan, is associated with environment and health problems. There is land degradation, which is posing an occupational threat to the miners as the mines are collapsing and / or occupational related illnesses due to poor working conditions like chest infections due to the high levels of dust in the mines. Also, unsafe levels of heavy metal contamination (lead, arsenic) were recorded in the mining areas and also in the River Kuja, which is the main source of water for the mining activities and the households, posing a threat to the health of the residents in the area.

7.2 Recommendations

Based on the results and conclusions drawn from this study, the following are recommended:

7.2.1 Policy

- The government should come up with an artisanal mining policy that will have well-organized laws of operation to reduce the occupational risks.
- Comprehensible policies on mining that pay detailed attention to the mining effects of the environment and health of the miners should be structured.

7.2.2 Management

- The County government should take precautionary steps such as use of personal protective clothing among the miners since the level of dust in the crushing sites is high and handling mercury with bare hands is common.

- The Macalder mines need to be rehabilitated by the County Government and emphasis should be made on the responsibility of the miners in terms of environment pollution both during and after mining.

- The amounts of toxic elements like arsenic and lead in the mines are very high consequently the miners may need to take precaution and decrease possible exposure pathways from the mines through management initiatives from the SACCOs.

- Public access to the mines and mine tailings should be minimized to avert the exposure to heavy metal contamination and injuries caused due to environment degradation like collapse of mines.

- The miners should also be sensitized on the dangers of mining through workshops and eco-friendly solutions should be provided to ensure green economy in the mining sector.

7.2.3 Research

- Further research should be carried out to affirm the exact levels of dust emissions from the mines and its effect on human health.

- More soil and water samples should be collected at different times of the year for analysis in order to have a more representative result. In as much as contamination of the rivers by toxic elements in the area had been done by Ogola *et al.* (2002), a research of the concentration of the elements further downstream should be done in order to determine their levels because these water from the mining areas flows to the rivers.

- A potential case- control study could be done that monitors the health of miners and non-miners concurrently to determine the heath problems associated with mining.

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Appendix A: Key Informant semi-structured interview with sub-county administrator

Introduction.

- Doing introduction and outline scope of the study
- I have a number of questions on the mining area and would like to take about half an hour of your time.

Mining and village characteristics

- What is the population of the area/ number people in the villages?
- How many villages are in the area?
- How many mines are in the area and what is the size of the area covered by each mine?
- What are the mining structures and any licenses?
- What mining processes do the miners use (mechanized vs. artisanal)?
- What are the common inputs used in the mining process?
- Where are the inputs sourced?
- What kinds of minerals are found in the Macalder mines?
- What are the main sources of water for the miners?
- What happens to the water used in the mining?

- How much gold is mined and how much is it processed and marketed?

Ask for map of the households that have miners and non-miners in the sub county.

Equipment: Interview guide, notebook, pen, camera

Appendix B: Key Informant semi-structured interview with the Agricultural extension officer

Introduction.

- Doing introduction and outline scope of the study
- I have a number of questions on the mining area and would like to take about half an hour of your time.

Cropping system.

- What cash crops are most frequently grown and the seasons of planting?
- Which are the main land tenures in the village and which persons are associated with each?
- What are the main constraints to livestock keeping in the area?
- How is the mining affecting the cropping system in the area?
- What are the main sources of water for agricultural processes in the area?

Time: 30 minutes

Equipment: Interview guide, notebook, pen.

Appendix C: Key informant semi-structured interview with NEMA representative.

Introduction

1. Doing introduction and outline scope of the study

1. I have a number of questions on the mining area and would like to take about half an hour of your time.

Environment and mining characteristics

1. What is the role of NEMA in terms of mining?

1. What are the common inputs used in the mining process?

1. Where are the inputs sourced from?

1. Does NEMA issue any licenses to the miners?

1. What are the constraints facing NEMA with regards to mining?

1. What are the future plans of NEMA on Migori County?

Time: 30-45 minutes

Equipment: Interview guide, notebook, pen

Appendix D: Key Informant semi-structured interview with District health officer and Representative from Ministry of Health.

Introduction

1. Doing introduction and outline scope of the study

1. I have a number of questions on the mining area and would like to take about half an hour of your time.

1. Ensure that the data will be kept confidential

Introduction of the informant(s)

1. What is your role in the community?

1. Can you tell me more about the health services in the village/ area?(approximately number of patients seen in a day).

Characteristics of the villagers

1. How many hospitals serve residents of the villages around the mines?

1. Minimum patients that come in the hospital are from which occupation?

1. Are there any differences observed in illnesses based on occupation of patients? Are there any differences between miners and non-miners?

1. Number of deaths recorded in a month?

1. Do you think there are any occupation illnesses among the miners?

1. Is the government working together with the hospital to reduce occupation illnesses among the miners?

Ask for statistics of the hospital illnesses per occupation.

Approximate time: 30-45 minutes hour

Equipment: Interview guide, notebook, pen.

Appendix E: Transect Walk

This will involve the villages near the Macalder mines and the Macalder mine it-self.

Things to note

1. Ensure we observe the mines (how big)
1. Sources of water used for mining and flow of waste water from the mines
1. Take GPS co-ordinates of mines, rivers and features(if possible)
1. Observe the different miners- gender and age
1. What is the community structure?
1. What other livelihood practices do the villagers engage in?
1. Where do they get the water from?(for both farming and drinking)
1. Do they have any animals?

Also, tick if any of the below are observed:

Diversion of Rivers	Water Siltation	Landscape Degradation
Deforestation	Dust	Collapsed mine pits
Uncontrolled digging	Abandoned pits	

Note: Be sure to map the mines, distance to water bodies, community structures and distance to hospitals.

Approximate time: 2 hours

*Equipmen*t: interview guide, notebook, pen, camera, GPS

Considerations: I am aware that the selection of the area I will be presented to rely on what the informants find relevant for my objectives. It is therefore important to state the purpose clearly before the beginning of the transect walk.

Appendix F: Questionnaire.

Questionnaire Number:	Interviewer:
Date: Time:	Household Number:
Picture Number:	GPS Co ordinates

(If you find that a family has both husband and wife present, you can interview them both)

Introduction

1. Full Name: 2. Gender:

1. Age/ Year Born: 4. Highest education level:

1. Marital status: 6. Occupation:

Household and mining characteristics

1. How many people are in your household?

2. What is the occupation of the different people in your household?(keep in mind that the children may also be engaged in mining)

3. What is the main source of livelihood?

4. Do you use any Personal Protective Equipment(PPE) while mining(If they are not miners, skip the question)?

5. Do you have a farm? (If yes, who farms?)

1. Where do you get water for farming from?

2. Where do you get your family drinking water from?

Human health characteristics

3. Which hospital do you visit as a family?

4. In the last 3 months, have any members fallen sick?

5. What are the common diseases?

6. Common diseases (tick if mentioned)

Peeling of skin	Walking and muscle weakness	Inflamed legs
Speech impairment	Lack of co-ordination	Chest infections
Miscarriages	Forgetfulness	School performance
Anemia(blood level)	Cancer	Tuberculosis

1. Has any mother in the household failed to bring a pregnancy to term?

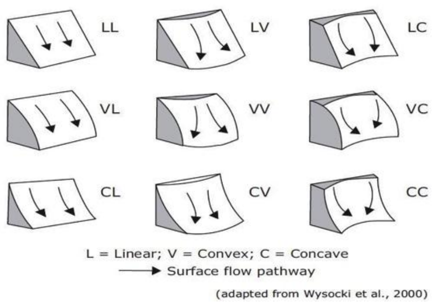
2. Do you know about dangers of mercury?

3. Do you know any diseases associated with mercury?

4. Do you know how to minimize the risks?

Approximate time: 30 minutes

Appendix G: Soil sampling and analysis

Soil Survey Site Indication Number:	Person describing the soil:
Date (MM/DD/YY)	Photo numbers:
Climate: (Sunny/ clear-SU, partly cloudy- PU/ Overcast-OV, rain-RA, Hail- HL)	
Location: (co-ordinates if possible)	
Slope:	
	
Land cover:	
Comments on the soil analysis:	

Approximate Time: 2-3 hours.

Equipment: Sampling rings, measuring tape, plastic bags, shovel, knife, soil description sheet, soil color chart.

Considerations: the famers and miners were asked for permission.

Appendix H: Water sampling and analysis

Sample Number:	
Locality	
Sample site (GPS Coordinates)	
Place	
Source	
Sender	
Date and time col- lected:	
Date and time of analysis	
Results:	

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