OCCUPATIONAL HEALTH RISK ASSESSMENT IN ARTISANAL AND SMALL-SCALE GOLD MINING IN KAKAMEGA AND MIGORI, REGIONS, KENYA

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Occupational Health Risk Assessment in Artisanal and Small-Scale Gold Mining in Kakamega and Migori, Regions, Kenya

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DECLARATION

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

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DEDICATION

This research work is dedicated to my dear wife Jescah, N. W. my son Paul, my daughters Mercy and Yvonne and also to my parents who dearly supported and gave me all that I needed to carry out this study.

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ACRONYMS AND ABBREVIATIONS

ACGIH	American Council of Government Industrial Hygienists
ACIH	American Conference of Industrial Hygienists
ASM	Artisanal and Small-scale Mining
ASGM	Artisanal and Small-scale Gold Mining
AS/NZS	Australian/ New Zealand Standards
COP	Code of Practice
dB (A)	Decibels (A)
DOSHS	Directorate of Occupational Safety and Health Services
GOK	Government of Kenya
HAV	Hand-arm Vibrations
HAVS	Hand-arm Vibrations Syndrome
IEET	Institute of Energy and Environmental Technology
ILO	International Labour Organization
ISO	International Organization for Standardization
JKUAT	Jomo Kenyatta University of Agriculture and Technology
MORTA	Management Oversight and Risk Tree Analysis
MSDS	Musculoskeletal Disorders
NIOSH	National Institute for Occupational Safety and Health
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Act, 2007 Kenya
OSHMS	Occupational Safety and Health Management System
PPE	Personal Protective Equipment
SOPs	Standard Operating Procedures
USA	United States of America
USDA	United states Department of Agriculture
WHO	World Health Organization

ABSTRACT

Due to the nature of activities associated with artisanal gold mining, there is an increase in mortalities and physical injuries among gold miners. This study sought to assess the occupational health risk in artisanal gold miners in Rosterman village-Isulu and Ikolamani-Liranda corridor in Kakamega County and Francis-Suna-East and Masara-Suna west in Migori County. Stratified random sampling was used to gather empirical data from miners, foremen, supervisors and mine owners using questionnaires and interviews. A total population of 770 participants from which 260 were selected as follows: Ikolomani – 40, Rosterman – 85, Masara West – 35, Francis – Suna East – 100. From each stratum, the selected participants were issued with the research instruments. From the empirical study, 77.5% of the respondents were male while 22.5 % were female aged between 19 - 60 years with 72.5% being of the age 19-35 years, 2.5% of these respondents had no formal education, 88.7% had basic education and 8.8% had higher education qualifications. 93.3% of these respondents used personal protective equipment (PPEs), 6.7% did not use PPEs, whereas 8.3% rarely used PPEs. The concentration of $PM_{2.5}$, which was measured using a low-cost purple air PA-II-SD sensor, ranged between 2.06 – 150.63 µg/m^3way above WHO guidelines. Ionizing radiation at selected mines were established using Geiger- Muller tube, PHYWE model detection while a Thermolumiscence dosimeter (TLD) badges was provided to respondents. It was observed that average radiation exposures for skin, eye and body were 0.197±0.40-.399±0.09, 0.197±0.31 - 0.547±0.14 and 0.186±0.30 - 0.405±0.10 millisieverts per month (mSv/m) respectively ($p>0.05$) way below threshold levels. Furthermore, female respondents exhibited higher levels of skin radiation (mean rank=38.93) and eye radiation (mean rank=37.24) as compared to male ($p<0.0001$) respondents. However, no statistically significant difference was observed in body radiation exposure by gender (U=379.00, p=0.392). Noise was measured using integrating sound level meter (LA220) 2 Meters (M) from noise emitting machine that were identified through survey. The noise levels ranged between 83.98 ± 15.5 to 96.97± 9.21 dB (A) way above OSHA 2007 standards which could easily cause hearing loss ($p<0.05$). To evaluate the concentration of heavy metal to which miners were exposed too, sediments samples (dry ore, wet tailings, personal hair and nails) were subjected to Atomic Absorption Spectrophotometric (AAS-6200 Shimadzu) analysis after digestion. The heavy metals in dry were lead (3.15 ± 0.1 - 5.48 ± 0.5), Cadmium (0.37 ± 0.05 – 1.46 ± 0.3), Mercury (0.01 ± 0.002 – 0.63 ± 0.05) and Arsenic (0.8 ± 0.18 to 2.02 ± 0.37) mg/kg. While wet samples had Lead (0.75± 0.11 – 3.64 ± 0.53), Cadmium (0.48 ± 0,03 – 1.57 ± 0.65), mercury (0.03 ± 0.003 - 1.44 ± 0.07) and Arsenic (0.56 ± 0.38 - 1.81± 0.06). Mini-tab analysis was used to assess carcinogenic health risk using the hazard quotient (HQ). There were high hazard quotient (HQ) values in wet samples ingested from Rosterman, Ikolomani, Masara and Francis and dermal dry samples from Rosterman that ranged between $1x10^{-2}$ - $1x10^{-4}$, indicating high risk of developing cancer. The gold miners in the study areas were exposed to radiations, noise, particulate matter, and heavy metals. Hence, there is need for adoption of health policies,

continuous risk assessment and provision of PPEs to reduce the exposure to these hazards.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Artisanal and small-scale gold mining (ASGM) refer to mining by individuals, groups or cooperatives with minimal or no mechanization (Cheng et al., 2023; Grynberg & Singogo, 2021). Often in the informal sector of the market, an important economic activity in many developing countries across Africa, Asia and South America (Cheng et al., 2023; Ismarulyusda et al., 2015; Kahhat et al., 2019; Le Tourneau, 2021). An estimated 40.5 million people were directly engaged in ASM in 2017, up from 30 million in 2014, 13 million in 1999 and 6 million in 1993. That compares with only 7 million people working in industrial mining in 2013 (IFMM, 2018). The process accounts for a quarter of the world's gold output. It is estimated that globally, 13 million people depend on ASM for their livelihood, majority of who are in developing countries. Women and children comprise of approximately 30% of these miners, with 40-50% of those coming from Africa (Cheng et al., 2023; Grynberg & Singogo, 2021). Small-scale gold mining occurs near the surface and within unconsolidated rock. The most frequent being deposits contained in riverbed alluvium, colluviums and altered upper portions of quartz veins (Odumo *et al*., 2018).

Gold mining in Kenya has been going on for close to a century and currently carried out primarily by the artisanal miners. There are several gold deposits present in Kenya, which include; Migori (Kuria west-Keleseha, Karasi) (Odumo *et al*. 2018). and Kakamega (Ikolomani- Liranda corridor) There has also been a renewed attempt by different companies to explore gold deposits in other areas Nyanza and Western regions of Kenya (Tampushi *et al.*, 2022). The gold deposits in these regions are considered to be embedded in the Lake Victoria greenstone belt which runs into both Kenya and Tanzania, hence contributing to gold mining ventures in adjoining Tanzania (Odumo *et al*., 2018). ASM in these regions employ traditional techniques for mineral extraction and thus they always operate under hazardous, labour intensive and highly disorganized environments (Tampushi *et al*., 2022).

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 (Achina-Obeng & Aram, 2022; Bugmann et al., 2022; Cheng et al., 2023; Grynberg & Singogo, 2021; Meutia et al., 2022). The amalgam is cleaned using 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 (Ignatavičius et al., 2022). An estimated 300 tons of mercury are volatilized directly to the atmosphere per annum, while 700 tons are discharged in mine activities into soil, rivers and lakes (Ignatavičius et al., 2022).

Mercury was considered by World Health Organization as one of the top ten chemicals of major public health concern (WHO, 2014). Exposures to mercury, even in small quantities, are associated with serious health problems including complications during fetal and early life (Mut & Ono, 2016; WHO, 2018). Elemental (inorganic) and methyl (organic) mercury are toxic to the central and peripheral nervous system, causing harmful effects on the nerves (WHO, 2010: NEDES, 2019), the toxicity can also affect other organs including digestive and immune system, lungs and kidneys (WHO, 2010: NEDES, 2019). The elemental mercury released to the environment may be converted by microbial activity to organic forms of mercury, like methyl-mercury, a potent neurotoxin, which damage the central nervous system and is especially toxic to foetuses (WHO, 2016). Children exposed to methyl-mercury while still in the womb may suffer from loss or reduction in cognitive thinking memory concentration speech and visual impairment (Mut & Ono, 2016). Consumption of mercury contaminated aquatic foods is a threat to both humans and other fish-eating animals as methyl mercury has protein binding properties, making it readily bio-accumulate and bio-magnify in aquatic food chains (WHO, 2014, 2016; Basu *et al*., 2023). An example is 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 (Mut & Ono, 2016; Basu *et al.*, 2023).

Methyl mercury and arsenic, which is part of the smelter dust from gold, end up in water collection points used by humans and other animals through leaching (Achina-Obeng & Aram, 2022; Bugmann et al., 2022). These two compounds are associated with diseases like impairment of the peripheral vision, sensations, movement coordination, speech and hearing as well as walking and muscle weaknesses, peeling off of skin, kidney failures, respiratory failure and eventually death (WHO, 2016). Besides poisoning associated with mercury and arsenic, artisanal mining has other environmental impacts, which include diversion of rivers, water siltation, landscape degradation, deforestation, destruction of aquatic life habitat and widespread mercury pollution (Mut & Ono, 2016). The environment degradation caused by mining occurs mainly as a result of inappropriate and wasteful working practices and poor rehabilitation measures (WHO, 2016) which include restrained plant growth due to acid mine from toxic compounds and metals that are leached to the environment (Odumo *et al.*, 2018 Basu *et al*., 2023).

Artisanal gold mining harms the physical and social environment during the different stages of mining (exploration, exploitation, processing and closure) through mercuric pollution and 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 (Amallia et al., 2024; Cheng et al., 2023; Espin & Perz, 2021; Meutia et al., 2022). The miners who lack awareness of risks, especially risks of chronic occupational disease (such as dust, vibrations, nitrous gases, mercury) that stem from inadequately implemented education and training bring about frequent injuries and illness in mining communities (WHO, 2016).

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 (Amallia et al., 2024; Meutia et al., 2022; Mut & Ono, 2016). 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, 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 (Achina-Obeng & Aram, 2022; Bugmann et al., 2022; Lèbre et al., 2020). 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. Implications associated several health with mining activities. Blasting of rocks that lead to air and noise pollution that affect the people within the surrounding areas is a common phenomenon at mining sites (Adator et al., 2023; Le Tourneau, 2021; Lèbre et al., 2020; Malone et al., 2023). 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(Adator et al., 2023; Le Tourneau, 2021; Lèbre et al., 2020; Malone et al., 2023).

The negative environmental and health impacts of mining activities are so immense that they call for urgent interventions. These was achieved through careful determination of concentrations of As, Pb, Cd, Hg and inhalable particulate in water bodies and sediments in the study area (Adator et al., 2023; Le Tourneau, 2021; Lèbre et al., 2020; Malone et al., 2023). To evaluate human health and environmental risks to Artisanal and Small-scale Gold Mining (ASGM) miners associated with exposure to these contaminants through ingestion, inhalation and dermal contact with water and sediment in the study area. Research study assessed and recommended carcinogenic health risk assessment exposures to heavy metal from dry ore and wet tailings to artisanal goldmine population at selected study sites.

1.2 Statement of the Problem

Artisanal and Small-Scale Gold Mining is associated with pollution of rivers resulting from increase in sedimentation, deforestation and acid rock drainage. Miners are also exposed to dust and noise that bring about occupational health problems such as silicosis, hearing loss and cancer among other health problem (Chanda & MoH-Zambia, Landrigan *et al*., 2022a; 2020; Richard *et al*., 2014). Recent reports show that ASGM mining communities in Nyanza and Western Kenya are exposed to chemical and physical hazards in high proportions with Injury rates estimated at 44.7 injuries per 100 person per year (Rabera Makokha *et al.*, 2020). It is reported that close to 50 people work underground, all at the same time, causing commotion which makes the mine a source of diseases such as dust poisoning and infectious diseases such as tuberculosis (Landrigan *et al*., 2022b). Gold mining involve use of chemicals such as mercury, which is toxic, noise, radiation, and dust from crushed stones. There has been reported cases of ill health and injuries in ASGM (Doumo et al., 2022; Mlewa et al., 2023; Omondi et al., 2023; Ondayo et al., 2023a; Opakas, 2023; Sharma & Tyagi, 2013; Thiombane et al., 2023). The situation is not different in Kenya (Auma *et al.*, 2023). It is noted that there have been some isolated reports from media, Kakamega and Migori County's environment and natural resources department that focus mainly on fatalities because of tunnel collapses and cave-ins. of mines. There is a potential for ASGM activities to harm the health of Artisanal gold Miners who are occupationally exposed and inadvertently harm the health of surrounding.

1.3 Justification of the Study

The rising cases of cancer and lung diseases and the financial burden associated with managing these diseases necessitates the need to evaluate occupational hazards associated with mining activities in the country. To date even though there are mining companies operating legally in the country a vast majority of them are operating illegally hence they do not follow the laid down OSH requirements for mining. In such instances a vast number of miner working in such industries are often left exposed to the occupational hazards associated with artisanal gold mining activities thereby putting them at risk of acquiring life changing ailments. Moreover, while personal protective gear are readily available, a majority of miners are not aware of their importance in the human health protection hence they rarely take precautions to protect themselves during artisanal gold mining operations.

Table 1.1: Justification for the Need for Current Studies

Previous studies	GAP
Lack awareness of risks of associated with vibrations, and contact with chemical used in gold mining (WHO, 2016)	Levels of noise levels and particulate matter in the atmosphere around artisanal gold mines not measured
Inadequately implemented education and training on OHS Standards amongst miners (WHO, 2016).	Up take of OHS recommendations amongst miners
identify responses and policy options associated with mining in Ghana leading to improved environmental quality and human health (Emmanuel *et al.*, 2018).	Concentration of heavy metal in gold effluent and sediments not measured
Reported on trace and major elements in soil, sediment and water samples from 19 ASGM villages in Kakamega and Vihiga counties (Auma *et al.,* 2023).	Limited sampling region Particulate matter and noise pollution not measured. Respondent demography and exposure profile to pollutants not measured
Framework for organizations to manage risks and improve OH&S performance (ISO 45001;2018).	Lack of adoption of risk thinking at workplaces including artisanal gold mines. Proactive identification and management of hazards before they happen.

1.4 Hypotheses

1. Artisanal Gold mining activities do not pose any risks to workers
2. Levels of noise, radiation, Respirable dust airborne particles in ASGM do not exceed safe limits sets by OSHA.
3. There are no significant differences between OSH risks and exposures among gold mines in Kakamega and Migori.

1.5 Objectives

1.5.1 Main Objective

The main objective of the study was to conduct an Occupational health risk assessment in artisanal and small-scale gold mining in Kakamega and Migori regions of Kenya

1.5.2 Specific Objectives

1. To evaluate the occupational hazards in artisanal gold mining in selected sites in Kakamega and Migori regions, Kenya.
2. To determine the exposure to respirable particulate matter in artisanal gold mines in Kakamega and Migori region, Kenya
3. To assess the exposure to radiation and noise in artisanal gold mines in Kakamega and Migori regions, Kenya.
4. To determine the concentrations of Mercury, Cadmium, Arsenic, and Lead in dry (Ore extract), Wet sample (sediment tailings), hair and nails samples in Kakamega and Migori regions, Kenya
5. To assess the occupational health risk and provide remedial strategies in artisanal gold mines in Kakamega and Migori Kenya

1.6 Scope of the Research

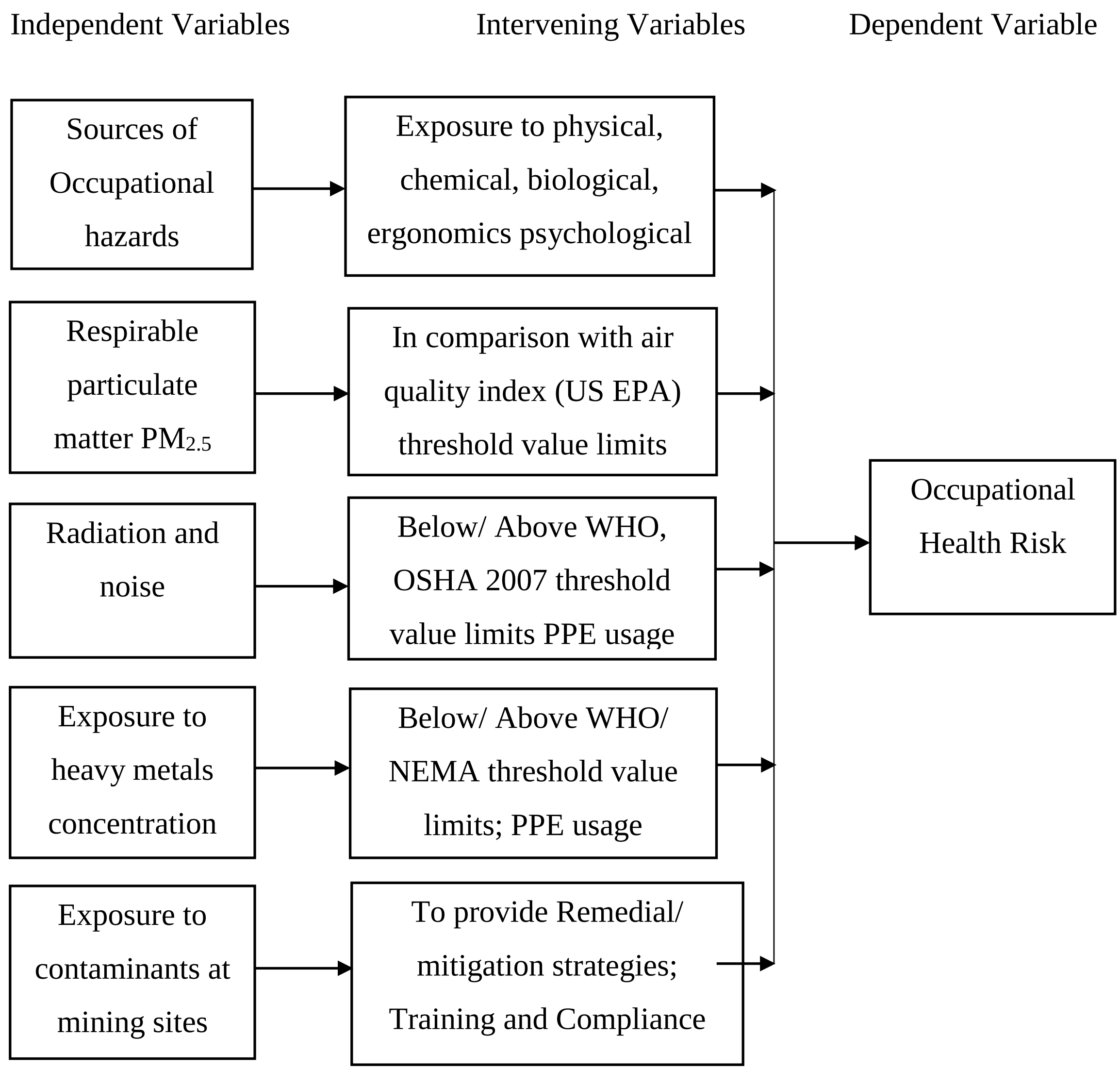
The study was conducted at Ikolomani and Rosterman mines, in Kakamega County and Francis and Masara mines, in Migori County. Sites were chosen based on high extractive activities in those areas with limiting factors such as underage group (children) present at sites (Appendix I). The study was conducted between the months of January and December 2021.

1.7 Significance of the Study

Precious metals such as gold are important, as they are a source of livelihood to many people in Kakamega and Migori Counties. Gold mining uses heavy metals such as Arsenic, Mercury and lead that are toxic and a threat not only to miners but also to the ecosystems and local population. The gold ore also contains Sulphur, which forms Sulphuric acid when it reacts with water during washing process and hence increasing acidity in soil and water bodies. The study is significant because it captures the levels of toxic elements (lead, mercury, cadmium and arsenic), and compares 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 hazards and their health effect were determined through statistical modeling associated with artisanal mining activities and environmental issues determined and compared against accepted International Standard toxic levels. The data from research formed a basis for further research and enable policy makers to come up with better policies that protect artisan gold miners and the adjacent environment.

1.8 The Conceptual Framework

The conceptual framework (Figure 1.1), consisted of identifying sources of occupational hazards in artisanal gold mines with a focus on OSH practices as independent variable for the study. The dependent variable was occupational health risks associated with artisanal gold mining activities while the independent variables were exposure to chemical, physical, biological, and ergonomic health hazards. The moderating /intervening variable of the study was drawn from threshold limits set by U.S Environmental protection Agency (EPA), World Health Organization (WHO), Occupational Safety and Health Act (OSHA, 2007) to assess hazardous concentration, duration or frequency of exposures. Further, the intervening variables provide the mitigating strategies for reducing the identified risks and hazards in the gold mining sites.



1.1: Conceptual Framework

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews literature on practices in artisanal gold mining worldwide and focuses on Western and Nyanza regions, Kenya.

2.1 Theoretical Principles

This section discuses theoretical principles governing artisanal gold mining globally, regionally, nationally and locally. The research study was guided by three theories. First the Social learning theory that highlights the importance of promoting open communication and foster safety culture in artisanal gold mines (De Haan *et al.,* 2020). Then, the Resource dependency theory that focuses on how artisanal gold mining sector can rely on knowledge expertise, technology and regulatory compliances to manage and address safety concern in the workplace (Geenen, 2015). Lastly the Goal- setting theory that enhances safety-performance improvement outcome at workplaces (Scientific, 2023)

2.1.1 The Artisanal Gold Mining Practice

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. The first known cases of gold mining using amalgamation method occurred as early as 700 BC in Spain, with Romans subsequently using the method (Aluko *et al*., 2018). The first documented case of mercury poisoning also occurred in Spain in the same period (Jimenez *et al*.,2020). 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 (Beth, 2018). The waste from gold mines contains toxic elements and the minerals, which when released to the environment, pollute soils, rivers and large water bodies (Techane *et al.*, 2023).

2.1.2 Gold Extraction Process

In artisanal gold mining, gold extraction is done mainly from alluvial deposits along rivers, waterways and terrestrial soils (Ondayo et al., 2023b) 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 alluvial 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 (Mutono, 2016). The second phase involves the use of mercury, which was mixed into the concentrate, forming a mercury-gold amalgam as captured in Appendix II. 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(Calao-Ramos *et al.*, 2021). Metallic mercury discharged into the environment can be transformed by microorganisms into methyl mercury, which is easily transferred to the foetus, with effects ranging from sterility, spontaneous abortion and from mild to severe neurological symptoms (Schoneveld *et al.*, 2017). 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 as captured in Appendix III 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(Calao-Ramos *et al.*, 2021).

The generalized flow sheet of gold mining and processing is as shown below (Figure 2.1).

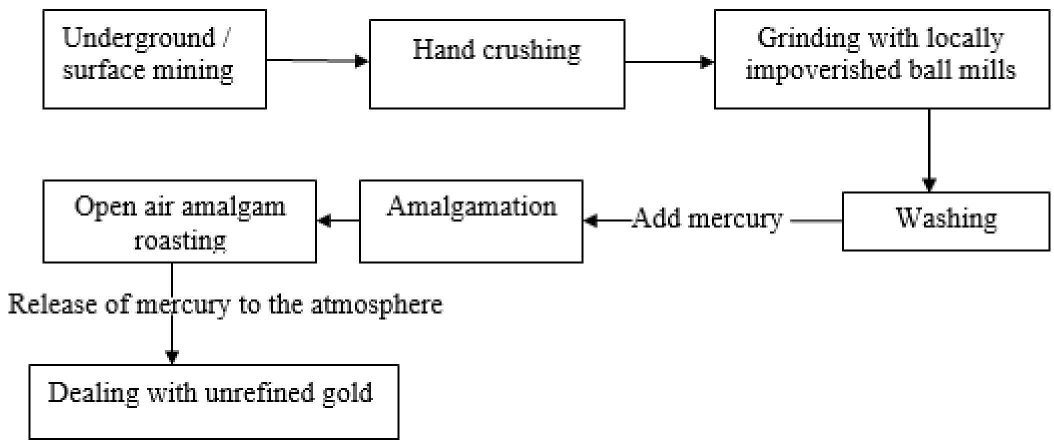


Figure 2.1: Generalized Flow Sheet of Gold Mining and Processing

Source: (Asamoah et al., 2014; Kale, 2019)

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 (Keane *et al.*, 2023) These activities have a high potential for the immediate and direct impacts on human health and the environment (such as waste rock placement, erosion, dust). They also involve the use of water and the use of anthropogenic ally introduced mercury as well as the disposal of process-contaminated waste (WHO, 2016). 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(Calao-Ramos *et al.*, 2021). Most gold fields in Migori County contain sulphide minerals associated with gold (Ngure et al., 2014a). 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 was 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 such as effluent form processing industries which affects ecological zones with contamination of heavy metals (Bisekwa *et al*., 2021). This also poses a threat to children who play in the streams as well as unborn through use of water from the contaminated rivers (Ngure et al., 2014a).

2.1.3 Health Effects of Artisanal Mining

2.1.3.1 Mercury

In most developing countries, mercury is imported through legal channels for permitted uses, such as dental amalgamation, but in many cases, it is then diverted to artisan mining operations. Mercury exists in both organic and inorganic compounds. Methylation of inorganic mercury into organic mercury is by microorganisms under anaerobic conditions, for example in under water sediments (Luo *et al*., 2023). 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 (Luo *et al.*, 2023).

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 (WHO, 2016). It also leads to organ failure, miscarriages and minamata disease, (which was first detected in Japan) among the adults (Kumari & Chand, 2023). The foetuses 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 (WHO, 2016). High mercury concentrations have also been reported in people who carry out amalgamation and amalgam burning in Tanzania (Kaishwa *et al*., 2020).

2.1.3.2 Cadmium

Cadmium is a naturally occurring toxic heavy metal with common exposure in workplaces, plant soils, and from smoking. The buildup of cadmium levels in the water, air, and soil has been occurring particularly in industrial areas. Environmental exposure to cadmium has been problematic in Japan, where many people have consumed rice that was grown in cadmium contaminated irrigation water. This phenomenon is known as *itai itai* diseases. The general population of people living near hazardous waste sites may be exposed to cadmium in contaminated food, dust or water from unregulated or accident releases (Khatun *et al*., 2022).

2.1.3.3 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 foetus, infants and young children resulting in lowering of intelligence quotient, growth abnormalities and anemia. It may also increase the risk of cancer, heart diseases, infertility and anemia among adults (Collin *et al*., 2022).

2.1.3.4 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 (Garcia & Cebrian, 2023). 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 (Minnaar, 2020). 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 Migori and Liranda corridor-Ikolomani in Migori County show orange coloration and the water is acidic, depicting chemical pollution.

2.1.4 Environmental Effects of Artisanal 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 (Achina & Aram, 2022). 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 (Odumo *et al.*, 2018). 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(Adator et al., 2023; Kahhat et al., 2019). 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*., 2018).

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 (Schoneveld *et al*., 2017). 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 (Cheng et al., 2023; Espin & Perz, 2021; Lèbre et al., 2020). 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 (Biswas *et al*., 2021). 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 (Greg *et al*., 2018).

2.1.5 Hazards in Artisanal Mining

In order to prevent a worker or any person in artisanal mining work place from being affected by workplace injuries and ill health, it is important to identify and recognize the principle hazards, the anticipated injuries, diseases, ill health and incidents(Bugmann et al., 2022; Cheng et al., 2023; Le Tourneau, 2021). Artisanal and small-scale miners are usually exposed to physical hazards, especially accidents, airborne dust, and noise. Accidents are reported to be the main hazards for miners since they lack protective equipment and safety trainings and regulations are lacking (Achina-Obeng & Aram, 2022; Amallia et al., 2024). Some of the hazards encountered include; physical hazards (extreme temperatures, noise, vibration, Slips, trips and falls); skin and eye contact with chemical hazards (exposure to dust); biological hazard agents (animals, bacteria, parasites); ergonomic hazards (manual handling, repetitive work, tools poorly designed for the intended task) (Beth, 2018). Frequent or common injuries in artisanal mining include; cuts or laceration, burns and scalds, contusion and abrasion, eye infections, skin problem, fever and headaches caused by excessive heat or by exposure in mining- pit/ extraction process (Beth, 2018). In hard rock ASM mines silica exposure tend to increase as a result of silica – laden dust which increases respiratory diseases such as lung cancer, silicosis, tuberculosis, and COVID-19. Besides, noise levels in ASM are normally far above the acceptable limits due to uncontrolled use of dynamite and heavy machinery. Long-term exposure to loud noises can impair cognitive and behavioral functioning as well as cause hearing loss. The COVID-19 pandemic disproportionately affects ASM miners and their communities because there are rarely hand washing stations, face masks, or safeguards for physical separation. The immune system is weakened by silica exposure, which is common in ASM, making people more susceptible to illnesses like COVID-19 and tuberculosis. Due to the absence of hygiene and sanitation facilities in the mines and inadequate access to clean water and food, enteric disease rates are high. HIV/AIDS and other sexually transmitted diseases are frequent among money-making mobile men miners (Grandgirard *et al*., 2002; Landrigan *et al*., 2022b).

2.1.5.1 Micro-climate

In artisanal mining, the safety and health professional are concerned with high temperature exposure to the workers especially in mining shafts and long exposure to sun radiations. It is of significance to note that there is a range of temperature that a worker can be exposed to without experiencing heat strain or any other adverse effect. Heat stress is the net heat load that a worker is exposed from combined contribution of metabolic cost of work, environmental factors (air temperature, humidity, air movement and radiant heat exchange) and clothing requirements. The micro-climate in artisanal mining site can vary widely depending on the nature and design of work methods required. Micro-climate associated with gold mining processes and heat radiation are factors that can cause certain occupational diseases such as cataracts and pathological conditions of the alimentary tract and blood circulatory system. Protective measures, such as shielding, medical surveillance, rest periods, protective clothing and correct body liquid and salt balance are necessary (Rofhiwa *et al*., 2017).

2.1.5.2 Heat Exhaustion

This disorder is caused by loss of salt and water from the body through excessive sweating in gold mine. It usually develops gradually and often affects people who are not acclimatized to hot/humid condition. People who are unwell especially those with illness that cause vomiting and diarrhea are more susceptible than others to developing heat exhaustion. A dangerous and common cause of heat exhaustion occurs when the body produces more heat than it can cope with Warm environment, becoming overheated and dehydrated. These effects can lead to heatstroke or even death in mine shafts (Meshi *et al.*, 2018).

2.1.5.3 Heatstroke

This condition is caused by failure of ‘thermostat’ in the brain which regulates body temperature. The body becomes dangerously overheated usually due to high fever or prolonged exposure to heat. Heatstroke can also result from use or exposure to chemicals/dust. In some cases, heatstroke follows heat exhaustion when sweating ceases and the body then cannot be cooled by evaporation of sweat. Heatstroke can develop with little warning resulting into unconsciousness or feeling unwell to a casualty in gold mine shafts. Help administered to a casualty worker exposed to excessive heat in mine pits that may include the following strategies; Casualty to be moved to a cool shady place, encourage him to lie down and raise and support his legs. Give him plenty of water to drink; Oral hydration of salt or isotonic drinks can help or prevent the health condition or even call emergency (Glaser *et al.*, 2022).

2.1.6 Manual Handling and Lifting

Artisanal mining continues to be a source of musculoskeletal disorders and injuries. This is one of the most common injuries in the workplace. Manual handling is defined by current regulations as the transport or support of a load by hand or bodily force. This includes lifting, putting down, pushing, pulling, carrying, maneuvering or transporting. Automation and mechanization are the only way to reduce many of the traditional hazards associated with the handling of material as back- injuries problems continue to affect workers involved in artisanal mining. Very few of the back injuries are reported by the workers in artisanal activities. Training in proper lifting methods and the increased safe use of mechanical devices wherever available will decrease the number and severity of injuries due to handling of material for control of poor ergonomic issues (The Occupational Safety and Health Act, 2007, 2007).

2.1.7 (Achina-Obeng & Aram, 2022; Amallia et al., 2024)**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 (Ondayo *et al.*,2023). In accordance with the Environment Protection Agency (USA), the safe levels of arsenic in water are 0.010ppm. 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 < 0.01ppm respectively. Mercury exposure leads to relatively higher contamination of the 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 (Guney *et al.*, 2020).

2.1.8 Soil Pollution

In accordance to World Health Organization, the safe levels of mercury in soil are 70 (WHO, 2014)). The proposed safe levels of arsenic in soil by both the Environment Protection Agency (USA), and World Health Organization are 75ppm. The World Health Organization lead safe levels in soil are 107ppm (King et al., 2024; Mulaba-Bafubiandi et al., 2023; Thiombane et al., 2023). 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. 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. There are also arsenic concentrations in the soil profiles (Achina-Obeng & Aram, 2022; Amallia et al., 2024; Esdaile & Chalker, 2018; Kahhat et al., 2019). The mean value of mercury in the soils near the mining areas exceeds the US-EPA value by 19 times (Schoneveld *et al.*, 2017). 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 (Aluko *et al*., 2018).

2.1.9 Hazard Hierarchy Control Measures

Hazards and risks to artisanal gold mining workers' safety and health require identification and assessment on an ongoing basis. Preventive and protective measures are implemented in a hierarchical order (Nalule, 2023; Nuhu et al., 2023). Elimination of the hazards can be is achieved at the design stage through engineering controls. Hazards at source can be minimized through the use of engineering controls or organizational measures substitution of hazardous substance with less hazardous without compromising the product, isolation of the hazardous area through use of barriers; minimize the hazard by the design of safe work systems (Doumo et al., 2022; Mimba et al., 2023; Opakas, 2023). These include administrative control measures; Where residual hazards cannot be controlled by collective measures, the employer provides for appropriate personal protective equipment, including clothing, at no cost, and implement measures to ensure its use and maintenance (Barasa, 2014). Hazard prevention and control procedures or arrangements are established and adapted to the hazards and risks encountered by mining sector. They are reviewed and modified on regular basis in order comply with national laws and regulations considering the current state of knowledge, including information or reports from organizations. These may include labor inspectorates, occupational safety and health services, and other services as appropriate (ILO-OSH, 2001a). The impact on OSH of internal changes such as those in staffing or due to new processes, work procedures, organizational structures or acquisitions and of external changes. For example, because of amendments of national laws and regulations, organizational mergers, and developments in OSH knowledge and technology should be evaluated and appropriate preventive steps taken prior to the introduction of changes (ILO, 2004). A workplace hazard identification and risk assessment are carried out before any modification or introduction of new work methods, materials, processes or machinery are commissioned (Dodoo *et al.*, 2023). Such assessments are performed in consultation involving workers and their representatives; the safety and health committee, where appropriate. The implementation of a "decision to change" ensures that all affected members of the organization are properly informed and trained in

Emergency prevention, preparedness and response. These arrangements identify the potential for accidents and emergency situations and address the prevention of OSH risks associated with them. The arrangements are made according to the size and nature of activities of the organization for ensuring that the necessary information, internal communication and coordination are provided to protect all people in the event of an emergency at the worksite (Andreassen *et al*, 2020) .

2.1.10 Training of Workers

Safety frequently depends on individuals in a place like artisanal mining sector having the knowledge and skills to perform tasks safely. If safety training is to make contribution to the 90% improvement goal that Johnson and others working with management oversight and risk tree analysis (MORTA) see as attainable, safety training must integrate traditional and effective training methods with new. (Rivaldo & Nabella, 2023)

In training, an operation or activity is selected for which trainings is needed. This is done once hazards that is or may have an adverse effect have been identified. In the training effort, attention may be focused on the hazards that will be encountered during the performance (or non-performance) of the workers. The ultimate responsibility for successful implementation of training programs is with the top management (Laberge et al., 2014). Most studies on safety management have shown that full involvement of the top management is a very important factor. The top management aims to achieve and maintain high levels of safety through knowledge of the hazards, their effects and the techniques to counter those effects. The employer has a responsibility of ensuring that employees of all levels have correct knowledge and sound technical base about hazards encountered at work (Laberge et al., 2014). The provision of that knowledge through training, instruction and information constitutes a major contribution towards high safety performance.

In providing the training, account of the level of employee's knowledge must be taken into consideration. Among the applications of the general systems model to safety activities, one of the most useful activities due to its contribution to understanding of development of safety training is the risk management process. The risk management process is the systematic application of management policies, procedures and practices to the tasks of communicating, establishing the context, identifying, and analyzing, evaluating, treating, monitoring and reviewing risks (Srinivas, 2019).

Artisanal mining sector must have risk management process in order to safeguard the safety and health of workers. The gold mining workplace, like all other workplaces in Kenya must conduct risk assessment and the management to establish appropriate measures to mitigate hazards encountered at work (Wachira, 2016). Risk assessment can be defined as the characterization of the potential adverse health effects of human exposures to environment hazards. Four steps in the process of risk assessment as used in artisanal gold mining (Kamunda *et al*., 2016).

1. Hazard identification: determination of whether a particular hazard is casually linked to health effects.
2. Dose-response assessment: Determination of the relationship between the magnitude of exposure and the probability of occurrence of the health effects in question
3. Exposure assessment: Determination of human exposure before or after application of regulatory controls.
4. Risk characterization: description of the nature-and often the magnitude-of human risk, including attendant uncertainty.

2.1.11 Legal Framework

Mining license as provided in Government of Kenya (GoK), 2016). The Act expects mining operations to comply with laws on water rights and use the land in accordance with the terms of the permit or license. In addition to this, persons conferred with mineral rights are expected to comply with the Occupational Health and Safety Act. Before a person is granted a mining license, they are expected to obtain an Environmental Impact Assessment, Social Heritage Assessment and an Approved Environmental Management Plan (Government of Kenya (GoK, 2016). Most artisanal miners are not licensed and do not have access to knowledge of existing regulatory systems. 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 (Stanley, 2014). In order to encourage employers and employees to reduce workplace hazards and to implement safety and health program, Kenya has ratified ten out of fifty ILO conventions that are related to OSH (ILO, 2013).

2.1.12 Subsidiary OSH Laws in Artisanal Mining Activities

2.1.12.1 Factories and other Places of Work (Hazardous Substances) Rules, L.N. No. 60/2007

These rules apply to workplaces where workers are likely to be exposed to hazardous substances. They require the occupier to prevent employees from exposure to such substances by putting various control measures in place, or, where these are not reasonably practical, to ensure that personal protective equipment (PPE) is provided. They prescribe occupational exposure limits (OEL) for hazardous chemical substances, safe handling, use and disposal of hazardous substances. A hazardous substance is any material that poses a threat to human health and or environment. Typical hazardous substances found in artisanal mining process; mercury exposures during amalgamation and refinery of gold through heating/smelting process. Aerosols and dust exposures are common chemical hazards present from mine pits; storage and disposal of water pumped from the min pits to the surface which is poorly controlled; Waste rock/overburden is poorly disposed may generate fumes in environment. The fumes and dust in the smoke emitted from such process become air pollutants as they elevate surrounding temperatures that have possibility of contributing to ill health. The hazardous substances rules require that where in a workplace such as Artisanal mining unit materials used or process done could give rise to exposure to any hazardous substances such as dusts and fumes, appropriate safe work procedures should be written and the employee instructed on proper use of them. 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. An issue that may be considered to be one of the largest single occupational problems is airborne substances. Some toxic agents and potentially hazardous substances exposure in artisanal activities include Dust particles, aerosols (from mine pits) and fumes (from improper storage/control of excess water pumped from mine pits to the surface). These types of hazards not only affect the workers but also the surrounding community that may be having residential houses nearby. The organic pollutants have been known to contribute to respiratory problem and most seriously lung cancer, asbestosis, cancers of the stomach, mesothelioma (ILO, 2009).

2.1.12.2 The Factories (First Aid) Rules, L.N. No. 160/1977

These rules apply to workplaces, and require the occupier to put in place appropriate measures to ensure that those injured at work receive necessary medical attention. The rules specify the contents of the first-aid box in accordance with the number of workers, and the training of first-aiders.

2.1.12.3 The Factories (Eye Protection) Rules, L.N. No. 44/1978

These rules apply to workplaces, and require the occupier to protect their employees against exposure that is injurious to the eyes. The occupier is required to provide eye protectors and shields for the protection of persons employed in specific processes. Duties of the person provided with eye protector or shield is supposed to observe the following; Take care of them and avoid misuse, report for any loss or destruction, or any defect, make full and proper use of the provided fixed shield

These rules apply to the generation, transformation, conversion, switching, control, regulation, distribution and use of electrical energy in workplaces. They require the occupier to put appropriate measures in place to eliminate electrical hazards within their premises by the insulation of conductors, and by the provision of circuit breakers and personal protection.

These rules apply to workplaces with 20 or more regular employees. They require the occupier to set up safety and health committees with equal representation of management and workers. The functions of the committee include conducting safety and health inspections, investigating accidents, and making recommendations to the occupier on improvements for the promotion of a safe and healthy working environment. In order for workplaces to secure a safe work environment, cooperation of the management and workers through formation of Safety and Health Committees has been found to be necessary. An active safety and health committee is important in improving the safety of the workplace. The primary purpose of the safety and health committee is to enable management and workers to work together to monitor the work environment, prevent accidents and improve working conditions. Occupiers of artisanal mining are expected to establish their Health and Safety Committees. Among the duties of the safety and health committees are to advice on the adequacy of safety and health measures for hazardous activities in the artisanal mining operations. Safety and Health committee members are able to identify hazards in ASGM operations through awareness of occupational hazards (GoK, 2016). Hazard awareness in the workplace is achieved through training of workers to help in identifying occupational hazards and cases of ill health among workers in the workplace. Occupational hazards identified in the artisanal activities may sometimes require the employer to monitor and evaluate hazards and risks by more knowledgeable persons. Training as one of the educational activities on safety and health risks, raises awareness of both workers and employers about the need to of safety and health at work (Atakora & Stenberg, 2020)

These rules apply to workplaces where employees are engaged in occupations that expose them to hazards that might harm their health. They specify occupations requiring medical examinations, and the types of examination of employees at the employer’s cost. According to the medical examinations’ rules, workers in artisanal mining units are to undergo medical examinations if they are exposed to specific occupational health hazards for the purposes of preventing and controlling occupational diseases. Medical examinations are required for artisanal mining employees especially due to exposure to chemicals (dust) when mining processes is being carried out. Owners of artisanal mining activities are expected to seek the designated health practitioners to perform medical examinations as part of worker screening programs, for both predictive and preventive purposes. Pre-placement and medical surveillance are thus offered to comply with the occupational safety and health standards to ensure a worker is not affected by an Occupational hazard.

2.1.12.4 The Factories and other Places of Work (Noise Prevention and Control) Rules, L.N. No. 25/2005

These rules apply to workplaces where activities result in noise levels that could impair or damage employees' hearing ability. They specify the permissible levels of noise, and require the occupier to carry out noise measurements, develop a noise prevention program to reduce noise levels, and provide hearing protection. Occupational exposure to noise levels in excess of OSHA standards places workers to risk of noise being induced hearing loss (Reese, 2017). One of the ways of providing a safe workplace where noise is concerned is taking practicable steps to ensure Occupational Exposure limits of noise is not exceeded. The noise level exposure to workers is determined through a noise assessment to show where levels are exceeding exposure limits. (The Factories and Other Places of Work (Noise Prevention and Control) Rules Legal Notice No. 25, 2005) Where noise levels exposures in artisanal sections exceeds the continuous equivalent of eighty five decibels for eight hours, an effective noise control and hearing conservation program shall be developed. The program is to address noise measurement, education and training, hearing protection and hearing tests. Owners/management of artisanal mining unit are required to inform all workers in writing the results of any noise exposure measurements done. Rock crushing/mining Section operators are expected to ensure that all workers exposed to harmful noise levels are fully trained on the hazard, and are instructed in the measures available for prevention, control and protection against high level noise exposure. Before hearing protectors are given, employees require training in fitting, selection, use, care, and maintenance of appropriate hearing protectors (The Factories and Other Places of Work (Noise Prevention and Control) Rules Legal Notice No. 25, 2005). Noise levels in the industry should be measured to establish levels and duration of exposure to the workers and identify the sources of noise and exposed workers in order to come up with control measures. Harmful effects of noise can be categorized as exposure to high level over a significant period of time which may cause both temporary and permanent damage, noise that interferes with speech communication and warning signals that which interferes with work performance and the noise that interferes with relaxation and sleep (Themann *et al*., 2023). Stress causing noise may contribute to heart disease, ulcers and other stress related problems. Control or mitigating measures will be necessary where the exposure levels are above the statutory recommended standards. Sometimes it is important to put in place mitigating measures where the stipulated standards are not being exceeded (Themann *et al*., 2023). Mitigating or control measures will also require monitoring of the effectiveness of the control methods being implemented to ensure, Noise Induced Hearing Loss does not result either due to failure of Personal Protective Appliances in use or other modes of control in place (Themann *et al*., 2023). Control of noise can be done is various ways. The equipment in use can be changed or modified through engineering controls to reduce levels of noise being emitted by a process that can be insulated through glazing or use of silencers or the process itself can be isolated. These noise control methods can be applied where a large number of workers are being unnecessarily exposed. Well maintained machinery is known to be less noisy as compared to poorly maintained ones (Themann *et al*., 2023)

Vibration hazards are closely associated with noise hazards because tools that produce vibration typically also produce excessive levels of noise. The most common vibration-related problem is known as hand-arm vibration syndrome (HAV). The condition strikes an alarming number of workers who use vibrating power tools day in day out as part of their jobs (Themann *et al*., 2023).

2.1.12.5 The Factories and other Places of Work (Fire Risk Reduction) Rules, L.N. No. 59/2007

These rules apply to workplaces, and require the occupier to put appropriate measures in place to prevent the occurrence of fires within their premises. They address the safe handling, storage and transportation of flammable substances. They also require the occupier to provide means of evacuation, fire detection systems, firefighting equipment, and firefighting teams. The Rules prescribe annual fire safety audits, the formulation of a fire safety policy, and training of workers on fire safety issues.

2.1.12.6 Environmental Management and Co-ordination Act, 1999

At the onset of this environmental law, every company is required to carry out an environmental audit. The environmental audit looks at the management of solid waste, liquid waste and gaseous waste, from activities going on in the industry. Artisanal mining units are required to undertake their first Environmental audits using registered National Management Authority lead experts on environmental issues. Under the Environmental Management and Co-ordination (Environmental Management and Co-Ordination Act, 1999), all new projects or changes in existing projects are required to undergo an Environmental Impact Assessment. The Environmental Impact Assessment is supposed to address any significant impacts that are positive or negative due to the operations of an activity or project. Various hazards from artisanal mining are encountered which are known to impact negatively to the environment as well as to the health of employees. The environmental impact assessment is conducted by individual experts or firm of experts authorized on behalf of the Kenyan National Environmental Management Authority. The National Environmental management Authority in conjunction with other lead agency such as Directorate of Occupational Safety and Health Services in the Ministry of labor address among other matters reduction or minimization of risks to human health (Environmental Management and Co-ordination act (Environmental Management and Co-Ordination Act, 1999) .

Other Laws and regulations covering aspects related to OSH but issued under other Ministries include: The Bio safety Act, No. 2, 2009 with objective to ensure that potential adverse effects of genetically modified organism are addressed to protect human health and the environment when conducting contained use at workplace. The Public Health Act, Cap. 242 concerns the protection of public health in Kenya and lays down rules relative to food hygiene and protection of foodstuffs, keeping animals safe, protection of public water supplies, prevention and destruction of mosquitos and the abatement of nuisances including nuisances arising from sewerage. It also establishes and defines functions of health authorities in management of medical hazards at workplace. The Radiation and Protection Act, Cap. 243 provide guidelines for the protection of the public and radiation workers from the dangers arising from the use of devices or material capable of producing ionizing radiation and for connected purposes at workplaces.

2.2 Previous Related Studies

In a study on the Environmental and Health Impacts of Mining in Ghana Conducted by (Emmanuel *et al.*, 2018) reviewed the environmental and human health issues that arise from the mining of gold. The ultimate goal of the report was to identify responses and policy options associated with mining in Ghana leading to improved environmental quality and human health. The review was conducted in two stages. In the first stage, articles were retrieved via online Scopus database searching. The following combinations of keywords were used: Ghana, mining, community, health, environment, and impact. During the second stage, titles and abstracts of articles were independently reviewed to assess eligibility for inclusion. The study concluded that Mining is extremely important to the economy of Ghana and a major contributor to its GDP and the mining sector creates employment for many people. However, there are also many adverse effects of mining as outlined; The health impacts of mining on surrounding communities which included increased risk of malaria, skin diseases, diarrhea, fever, colds and cataract. Additional health impacts include contraction of HIV/AIDS by individuals who are involved in or associated with prostitution in mining communities

(Emmanuel *et al*., 2018). The environmental impacts included noise pollution (caused by heavy trucks from mining centers), pollution of water bodies by chemicals such as arsenic, mercury and cadmium from refining of mined minerals. Contamination of agricultural soils by heavy metals and other pollutants, resulting in the depletion of agricultural land, reduction in food productivity due to infertile land and depletion of wildlife due to clearing of forests that serve as habitat for many animal species (Emmanuel *et al.*, 2018).

In a study “impact of artisanal gold mining on human health and the environment in the Batouri gold district, Cameroon’’ revealed that miners are exposed to numerous health and safety risks inherent from artisanal gold mining ASGM activity. Questionnaire and interviews were used to collect the data; Blood samples were collected and analyzed for the presence of mercury and lead. Gold miners in Batouri are exposed to the risk of physical injuries, respiratory conditions, diarrheal conditions, psychotic disorders, dermatophyte infections, helminthic infestations, malaria and musculoskeletal problems. The most common health problems among miners are musculoskeletal disorders (35.6%), malaria (26.4%) and hernias (14.9%), while malaria (18.7%) and musculoskeletal disorders (15.4%) are common among stakeholders. The mean blood mercury and lead levels among miners is 2.27 ± 8.85 µg/L and 12.73 ± 32.73 µg/kg respectively, and 9.1% of them are chronically intoxicated with mercury, reporting ≥ 4 symptoms possibly related to mercury intoxication. The study pointed out the most common health condition being;, musculoskeletal disorder problems (Greg *et al*., 2018). Deforestation, land degradation, water pollution, air pollution and water logged pits were major environmental problems reported in Migori (Mutono, 2016). Conclusion drawn from the study pointed out that there was negative impact on human health and environmental sustainability. This information is in conjunction with the studies done in Batouri where the findings indicated that there was danger of physical injuries, respiratory problems, diarrheal problems, mental disorders, dermatophyte infections, helminthic infestations, malaria, and musculoskeletal issues for gold miners. Besides, hernias and musculoskeletal diseases were the three health issues that affected miners the most frequently, whereas malaria and musculoskeletal issues affected stakeholders more frequently. Miners had higher blood levels of lead and mercury, and 9.1% of them were chronically mercury-toxic, exhibiting four symptoms that may be related to mercury intoxication (Greg *et al*., 2018).

In the article “the mercury problem in artisanal and small-scale gold mining’’ indicate that artisanal-small scale gold mining ASGM is the largest source of mercury pollution on Earth. Mercury released from tailoring and vaporized mercury exceeds 1000 tons each year from ASGM. Effects of mercury to the health of people are dire ranging from neurological damage and other health issues (physical, mental disabilities and compromised development). Between 10-19 million people use mercury to mine gold in more than 70 countries making mercury pollution from ASGM global issue (Aluko *et al.*, 2018; Greg *et al*., 2018)

Communities around these mines are affected by mercury contaminations of water and soil and subsequent accumulation in food staples such as fish which is a major source e of dietary protein in many ASGM regions (Marie *et al*, 2017). In the article ‘‘Women and artisanal small-scale gold mining” articulate that artisanal gold mining involve the whole family survival; battling against starvation recognizing the substantial lessons of Minamata diseases; in particular the serious health and environmental effects from mercury pollution and the need to ensure proper management of mercury and the prevention of such event in future as recorded in Minimata convention (Marie & Fritz, 2017). The gold mining plant of Oman in Suhar area on the Al Batinah coast was set to assess the contribution of gold mining on the degree of heavy metals into different environmental media. Samples were collected from the gold mining plant area in tailings, stream waters, soils and crop plants. The collected samples were analyzed for 13 heavy metals including vanadium (V), chromium (Cr), manganese (Mn), nickel (Ni), copper (Cu), cadmium (Cd), cobalt (Co), lead (Pb), zinc (Zn), aluminium (Al), strontium (Sr), iron (Fe) and barium (Ba). The water in the acid evaporation pond showed a high concentration of Fe as well as residual quantities of Zn, V, and Al, whereas water from the citizens well showed concentrations of Al above those of Oman and WHO standards.

The desert plant species growing closed to the gold pit indicated high concentrations of heavy metals (Mn, Al, Ni, Fe, Cr, and V), while the similar plant species used as a control indicated lesser concentrations of all heavy metals. The results revealed that some of the toxic metals absorbed by plants indicated significant metal immobilization. The highest potential threat for the environment is mostly represented by mineralized rocks exposed in waste dumps and open pits. The water chemistry observed in the area, clearly showed that these materials, have a high capability for acid drainage generation and release of toxic or harmful elements (Pb, Cd, Co, Cr, Cu, Ni). Moreover, the acid, high- metal waters can cause contamination in the scarce local groundwater through the solubilization of toxic metals. Although the analysis done on the well water from the vicinity did not conform to the Oman and WHO Standards.

In order to understand the risk of heavy metal contamination in soil and water and their associated health problems among communities practicing artisanal gold mining, a cross-sectional study was carried out in the Macalder mines in Migori County, Western Kenya (Mutono, 2016)., A total of 150 soil samples and 150 water samples were randomly collected from the house- holds, the Macalder mines area and River Kuja. Data from the questionnaire survey and key informant interviews was analyzed using descriptive statistics. 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 Macalder mines had unacceptable levels of lead and arsenic in both soil and water samples, creating an occupational risk for the mine workers. 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. To allow safe mining processes, research recommended 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 are used in the mining process (Mutono, 2016).

Study of gold sites in the Migori Gold Belt, Kenya, revealed that the concentrations of heavy metals, mainly Hg, Pb and As were above acceptable levels (Ngure et al., 2014). Tailings at the panning sites recorded values of 6.5–510 mg kg^{-1} Pb, 0.06–76.0 mg kg^{-1} As and 0.46–1920 mg kg^{-1} Hg. Stream sediments had values of 3.0–11075 mg kg^{-1} Pb, 0.014^{-1}.87 mg kg^{-1} As and 0.28–348 mg kg^{-1} Hg. The highest metal contamination was recorded in sediments from the Macalder stream (11075 mg kg^{-1} Pb), Nairobi mine tailings (76.0 mg kg^{-1} As) and Mickey tailings (1920 mg kg^{-1} Hg). Mercury has a long residence time in the environment and this makes its emissions from artisan mining a threat to health. Inhaling large amounts of siliceous dust, careless handling of mercury during gold panning and Au/Hg amalgam processing, existence of water logged pits and trenches; and large number of miners sharing poor quality air in the mines are the major causes of health hazards among miners (Esdaile & Chalker, 2018). The amount of mercury used by miners for gold amalgamation during peak mining periods varies from 150 to 200 kg per month. Out of this, about 40% are lost during panning and 60% lost during heating Au/Hg amalgam. The use of pressure burners to weaken the reef is a deadly mining procedure as hot particles of Pb, As and other sulphide minerals burn the body. Burns become septic. This, apparently, leads to death within 2–3 years. On-site training of miners on safe mining practices met with enthusiasm and acceptance. The use of dust masks, air filters and heavy chemical gloves during mining and mineral processing were readily accepted. Miners were thus advised to purchase such protective gear, and to continue using them for the sake of their health. As a result of this, the Government considered setting up a clinic at Masara, which is one of the mining centres in the district to improve the health of the mining community (Esdaile & Chalker, 2018).

Particulate matter, Metals and metalloids such as inhalable dust, Cd, As, Pb and Hg are toxic to humans and produce multiple adverse health effects. The hazardous metals were analyzed using minitab, even at low concentrations via exposure to them in the environment (either through the food chain or oral, dermal and inhalation from contaminated environmental media such as water, dust sediment, soil or air). They also have the ability to bioaccumulation in human beings, organisms and in environmental media such as water, soil, sediment or food crops (Long *et al.*, 2015). For example, a strong linkage has been established that long term exposure to cadmium via inhalation route is known to cause lung cancer in human beings. However, other exposure routes for cadmium by human beings have been linked to prostate cancer, renal cancer, liver cancer and stomach cancer, although this linkage is very weak (Long *et al*., 2015). Exposure to lead has adverse effects on the renal and central nervous systems, haematopoiesis; Pb in its inorganic form is classified as a possible human carcinogen by the International Agency for Research on Cancer.

According to the World Health Organization (WHO) , arsenic metal has been classified as a class 1 human carcinogen, based on sufficient evidence from human epidemiological data that exposure to arsenic causes several forms of cancers (Long *et al.*, 2015). For instance, high cases of lung cancer mortality were observed in multiple human populations exposed to arsenic primarily through inhalation. Increased mortality from multiple internal organ cancers (liver, kidney, lung and bladder) and an increased incidence of skin cancer were observed in populations consuming drinking water high in inorganic arsenic. It has been noted that exposure to mercury is known to be a causative agent of neurological, nephrological, cardiac and reproductive disorders, as well as genetic damage and disrupting certain functions of the endocrine system. Dose-response assessment describes the degree, incidence, or likelihood of hazard associated with a particular dose of contaminant.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The global position system was used to map out sampling points in Migori (Suna West and East) in Nyanza- globally located at 1° 1' 59" S, 34° 19' 59" E) and Kakamega (Rosterman and Liranda corridor-Ikolomani) in Western Kenya globally located at 0˚17.569N, 34˚39.812E), which are major explored gold deposited regions (Figure 3.1).

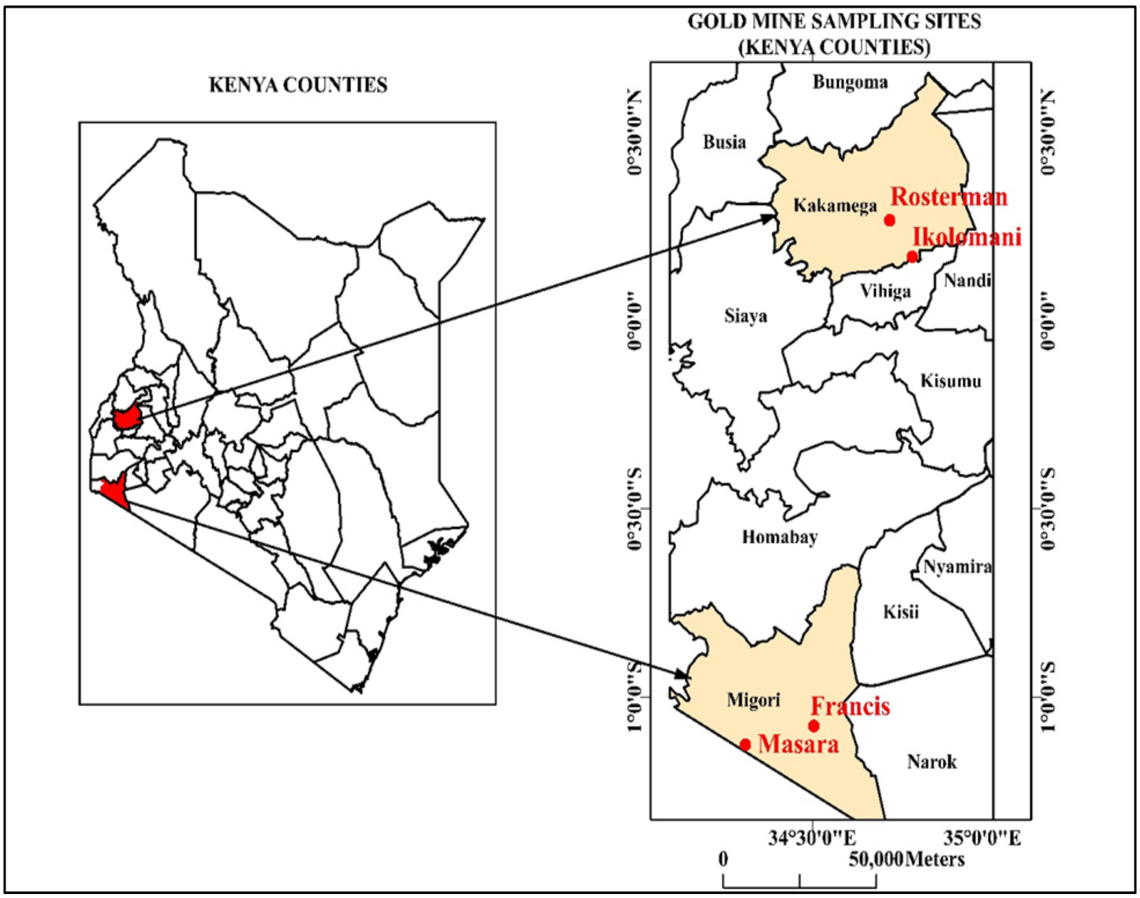


Figure 3.1: Masara and Francis- Migori and Corridor-Ikolomani and Rosterman-Kakamega

The main rivers in the area are Kuja, Migori and Riana. Other rivers included Ongoche, Oyani and Sare. These rivers have waterfalls and cataracts and are not conducive for water transport. At lower altitudes, there are frequent reports of flooding disasters. Lake Victoria, which lies on the Western border of the county, is a source of water and fish and serves as a tourist attraction (Kembenya *et al.*, 2022).

Rainfall patterns in the County range from 700 mm to 1800 mm annually, with the short rains occurring between March and May while the long rains experienced during the period of October to December. 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 (KCCRPS, 2015).

Migori County has a population of 907,499 of which 48.3% were male and 51.7% female. Nyatike Sub County has approximately a population of 162,857 People. Liranda corridor-Ikolomani-Kakamega has a population of 143,545 of which 68,477 (47.7%) were male and 75,068 (52.3%) female (KNBS, 2019).

3.2 Study Design

Geographic research techniques used in this study included various data collection methods such observations, interviews, surveys and they involved five steps; that is, ask acquire, examine, analyze and act. For empirical data, stratified random sampling that involved surveys, interviews, observations, photography was used for collection of these data with modifications to studies performed (Priya, 2021). This involved a subset representative of the total population at the four artisanal gold mining sites where data was collected at one specific point in time and no follow-up was contacted after completion of the study. Occupational Safety and Health (OSH) guidelines and independent variables were used to check the OSH status in the artisanal mining sites. Risk factors on miners' age, Gender, educational level of workers, work experience, equipment and machinery safety, use of personal protective equipment and good operational practices were evaluated and interventional recommendations proposed.

3.3 Study Population

The study entailed all miners working in the ASSGM.

3.3.1 Inclusion Criteria

All consenting property owners, supervisors and artisanal gold miners who were present at the four mining sites formed part of the study population.

3.3.2 Exclusion Criteria

All persons present at mining sites who did not own mining sites, non-workers or supervised mining activities were excluded from the study population

3.4 Sample Size Determination

Since the population was heterogeneous, the Cochran's formula for categorical data developed in 1960 was used (Nanjundeswaraswamy & Divakar, 2021). The sample size was calculated as follows;

$$SS_O = \frac{Z^2 x P x (1-P)}{c^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where: SSo is the sample size, *Z* = 1.96 for a confidence level of 95%, P is the standard deviation, fixed p at 0.5, C is confidence interval, fixed in 0.05, and P x (1-p) is the estimate of variance

Hence using the above formula, the sample size was;

$$SS_0 = \frac{1.96^2 x\ 0.5\ x\ (1-0.05)}{(0.05)^2} = 384 \text{……………………..} \quad (3.2)$$

When sample size exceeds 5% of the population, the formula is corrected in the following way;

$$SS_1 = \frac{SS_0}{1+\frac{SS_0}{POP}} \text{………………………………..….} \quad (3.3)$$

Where: SS_1 is the corrected sample, pop is the population, which in this case is represented by the total number of workers present at two mining workplaces. The required sample is thus;

$$SS_1 = \frac{384}{1+\frac{384}{770}} = 260 \text{…………………………………} \quad (3.4)$$

The sample size in each stratum was calculated using proportionate distribution, which generates more accurate primary data as follows:

$$\frac{Size\ of\ the\ strata}{Total\ population}\ x\ Required\ sample\ size \text{…………} \quad (3.5)$$

Table 3.1 presents sampling frame for data collection from the various gold mines.

Table 3.1: Sampling Frame for Data Collection

ASGM Sites	Population size	Sample size	Sample size percentage
Ikolomani Liranda (Kakamega county)	120	40	15
Rosterman village (Kakamega county)	250	85	33
Masara-suna West (Migori	100	35	14

county)			
Francis-Suna- East (Migori county)	300	100	38
Total	**770**	**260**	**100**

From the Table 3.1, random sampling technique was employed to select study participants from each of ASGM site. In total, 260 study participants from the ASGM workforce was selected. For miners, the head of the household was selected within the mining site in accordance to the sample frame for data collection. The same number of questionnaires was distributed as (Table 3.1) for comparison study for exposed group to mining activities.

3.5 Sampling

A simple random sampling technique was used to collect data on $PM_{2.5}$, noise levels, ionization radiation, and sediment samples from each strata in the selected mine. Measurement of $PM_{2.5}$ was done using purple Air PA-II-SD Low cost sensors, noise measurement using Integrating sound level meter (LA220) and Environmental ionizing radiation using Geiger- Muller tube, PHYWE detector and dosimeter badges to collect individual dosage-data at defined sites. Samples from Dry (Ore extract) and wet sample (sediment tailings) at mining sites were collected (1kg) each randomly using soil auger, rapped into plastic paper for laboratory analysis to quantify heavy metal concentration levels using AAS (AA-6200 Shimadzu).

3.6 Data Collection Methods

A combination of interviews, questionnaires, measurements and participant observations tools were used to acquire primary data in ASGM. Cameras were used to capture photographs (Plates), questionnaires for gold mine workers (Appendix 1 and II), workplace observation checklist (Appendix III) and measurement to be carried out using (AAS, Integrating Sound level meter (LA220) and GM-tube model PHYWE as ionizing radiation detector and dosimeter were used to collect the required data. The questionnaires were hand delivered to the workers and supervisors of artisanal mining sites who were responsible for implementation of safety and health management systems. A checklist (Appendix II) was used at the four gold artisanal mining sites with the help of research assistants. Fig 3.2 shows the data collection procedures.

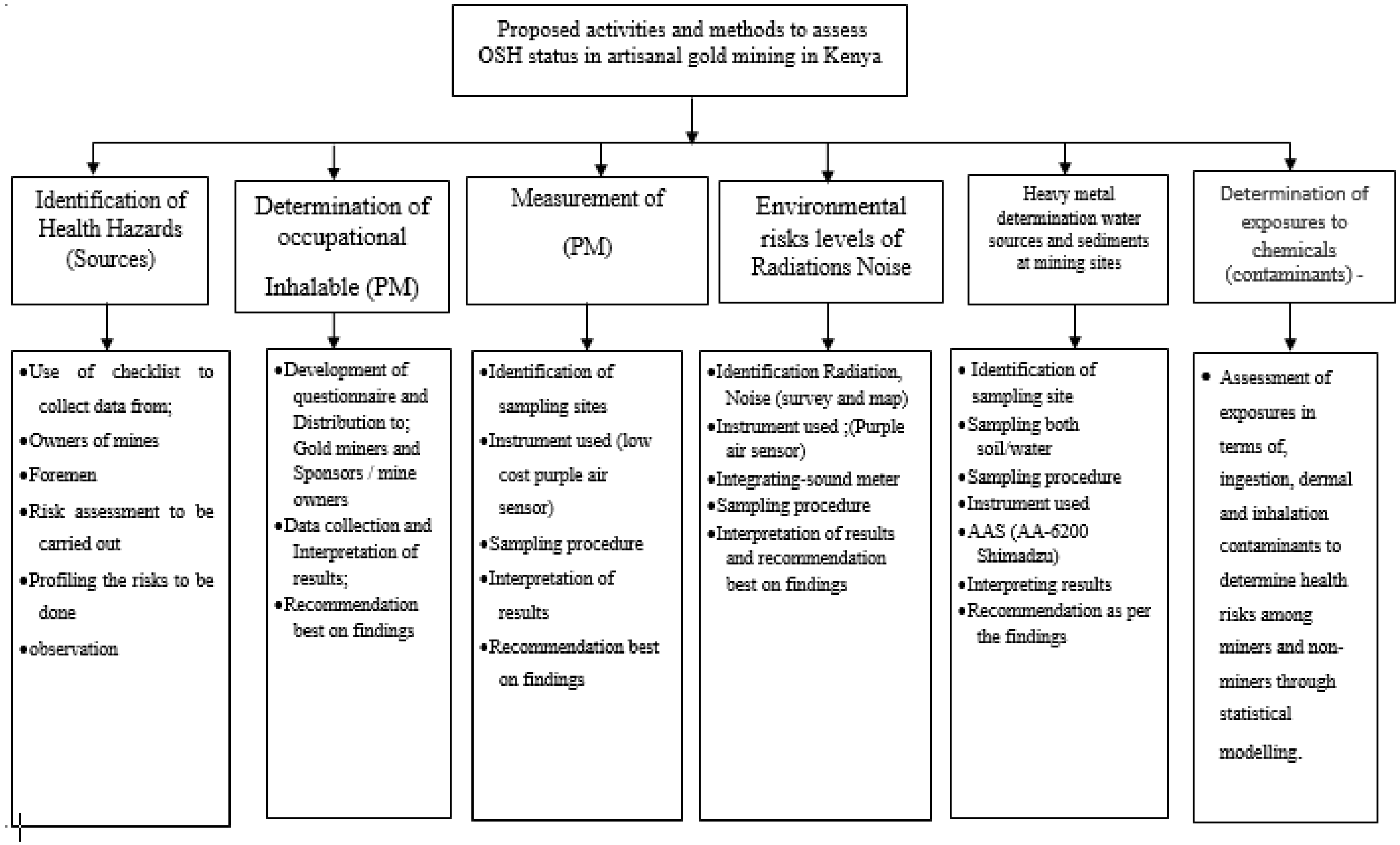


Figure 3.2: Data Collection Procedures

The study involved six (6) broad areas under a major classification of comparative type of design for four sites.

3.6.1 Assessing Sources of Health Hazards

Sources of health hazards were identified through observations, personal interviews and administration of questionnaires from artisanal gold miners and landlords/owners of mines prior to preliminary site assessment that was done to evaluate sources of Occupational Health Hazards.

3.6.2 Determination of Health Risks of Respirable Fraction of Inhalable Particulate Matter

It involved administration of a questionnaire to the miners. Data was collected from miners/supervisors and surrounding community.

3.6.2.1 Determination of Respirable Fraction of Inhalable Particulate Matter

The sampling points were carefully chosen from four sampling sites based on where the artisanal mining activities were highly concentrated and the sensors mounted 2M above the ground, at breathing zone of miners. Monitoring of $PM_{2.5}$ was undertaken using portable purple air sensors that selects particles of interest (2.5 µm) from ambient air between 06:30 hrs and 14:30 hrs local time, for five non-consecutive weekdays, which are the normal working hours for most miners (Barkjohn *et al*., 2022). Data was recorded using sensors at an interval of 24-hour cycle in a month (Appendix IV)

3.6.2.2 Ionizing Radiations Levels

Ionizing radiation levels were measured using Geiger Muller (GM)-tube, PHYWE model probe radiation detector, calibrated as captured in Appendix (XXIV) and equipped with clarity to display the real value. The GM–tube was used by the researcher to measure radioactive atoms that decayed every second. The measurements were performed in counts per minute (Appendix XIX)

Dosimeters (badges) as captured in **(**Appendix XVII) were provided randomly to miners to determine exposure levels of miners to ionizing radiation on skin, eye and body. Supervisors and artisan gold miners that had worked at site for 1 year and above were recruited in the study, given two badges to wear for a period of one month and later one badge was collected and taken to d-orbital company for interpretation and recording of data using Thermo-luminescence Dosimeter reader (TLD) . Assessment of eye, skin and body ionizing radiation exposure data recorded was then compared to As Low As Reasonably Achievable (ALARA) threshold value of approximately 1.67 mSv/month .The process was repeated for a period of six months Appendix V).

3.6.2.3 Noise Levels

Noise levels in the mining sites were determined using the standard integrating sound level meter (LA220, model). The instrument was set at an average hearing height of a worker and 1 to 2 M from the noise emitting machines/tools with the start point source along the wind direction. Noise measurement was done at 08:30hrs, 12:30hrs and 17:30hrs. Kenyan time, for five consecutive weekdays. The measurements were recorded by direct reading from integrating sound level meter (ISLM) at arm's length position along the wind at an average height of the ear of a worker for six-month period (Appendix XIV).

3.6.3 Determination of Heavy Metals in Sentiment Tailings within Goldmines (Dry and Wet) Samples

Analysis of lead mercury, cadmium and arsenic was done using the standard procedures by (APHA, 1999) standard methods. To determine the level of heavy metals (Pb, Cd, As, Hg), the soil Ore dry sediments) and wet sample tailing was collected at mining sites, air dried at room temperature for 5 days to a constant weight and then sieved through a 125μm stainless steel mesh wire (Ngure & Obwanga, 2017). 1g of the sample was weighed to the nearest 0.001 g and transferred to a round-bottomed flask then 10 ml of 50 % (v/v) HNO_3 was added to the sample. The flask containing the mixture was covered with a watch glass. The sample was heated to 95 ^{0}C and then refluxed for 10 to 15 minutes without boiling. The sample was allowed to cool to room temperature. Upon cooling, 5ml of concentrated HNO_3 was added. The cover was replaced followed by refluxing for 30 minutes. This step was repeated three times until there was no further formation of the brown fumes due to oxidation of the sample. The resulting solution was heated at 95^{0}C without boiling for two hours. The sample was cooled and then 2 ml of water and 3ml of 30% H_2O_2 was be added to the solution. The vessel was covered using a watch glass and returned to the heat source for warming to start the peroxide reaction. The sample was heated until the effervescence subsided after which the vessel was cooled. One ml aliquots of 30% H_2O_2 was added continuously with warming until the sample appearance remained unchanged. The sample was covered using an allihn condenser to recover the vapor. The acid – peroxide digest was left heating until the volume reduced to approximately 5ml. 10ml concentrated HCl was added to the sample digested. The sample was placed in the heating source and refluxed at 95^{0}C for 15 minutes, by covering with a watch glass and allowing the vapors to cool on the glass and return to solution. The resulting digested was filtered through Whatman filter paper No. 41 and the filtrate transferred into a 100ml volumetric flask and distilled water added to 100ml. The solutions were aspirated into the AAS, Shimadzu AA-6200.

3.6.3.1 Determination of Heavy Metals in Human Samples (Hair and Nails)

The concentration of heavy metals in hair and nail samples was determined by first digesting the samples at 80^{o}C in a beaker using concentrated HNO_3 (Ismarulyusda *et al.*, 2015). The collected hair and nail samples were cleaned in solvent mixture consisting of 50% distilled water and 50% acetone, and then coded and stored. To enable a representative subsample of the hair specimens, the stored samples were then cut into roughly 0.3cm pieces, combined, and washed again. In a 50mL beaker 0.1065 g of hair sample and 8ml of concentrated HNO_3 was placed, covered with a watch glass and digested on a hot plate at 80°C for 25 minutes. Each sample was added 1 ml of 30% H_2O_2 after it had cooled to ambient temperature inside the fume hood. The samples were then heated once again on the hot plate at the lowest setting of 42°C only until bubbling stopped. Then, heat was increased to around 80°C after the volume was decreased to approximately 2.5ml. quantitatively, the contents of each beaker were transferred to a 100mL volumetric flask that had been cleaned and dried. The digesting vessel was put to the volumetric flask and filled to volume with deionized distilled water after being cleaned three times with 1.5mL each of deionized distilled water. It was then moved to a thoroughly cleaned sample bottle, corked, clearly labelled, and refrigerated before analysis. Standard solutions were prepared using concentration ranges of 1–20mg/kg for all the elements under investigation.

3.6.3.2 Elemental Analysis of Heavy Metal Contents in Hair and Nail Samples

The contents of the heavy metals were analyzed using the method of atomic absorption spectrometry - (AAS). The instrument was calibrated with standard solutions (1000 mg/l).

Table 3.2: Atomic Absorption Spectrophotometer Conditions

Element	Wavelength (nm)	Fuel gas flow	Lamp Current (mA)	Slit with (nm)
Lead	283.3	2.0	10	0.7
Cadmium	228.8	1.8	8	0.7
Arsenic	193.7	0.2	10	0.5
Mercury	253.7	0.2	10	0.5

3.6.3.3 Digestion of Samples for Selected Heavy Metals Toxicants in Dry Ore and Wet Sediment Tailings.

Analysis of lead, mercury, cadmium and arsenic was done using the standard procedures by (APHA, 1999). In the laboratory, the acidified water samples (wet samples) were filtered through Whitman filter paper No. 41. For the determination of As and Cd, 5ml each of concentrated H_2SO_4 and concentrated

HNO_3 was added to acidified filtered water samples (100ml). In the case of Pb, concentrated HNO_3 (5ml) was added to 100ml of the collected water sample. The mixtures were heated on a hot plate until the volume was reduced to about 15–20ml. The digested samples were allowed to cool to room temperature and then filtered through Whatman filter paper. The final volume was adjusted to 100ml with distilled water and the samples stored for analysis. In the digestion of Hg for 100ml sample preparation, concentrated H_2SO_4 (5ml) and concentrated HNO_3 (2.5ml) was added, followed by additional 5% (w/w) of $KMnO_4$ (15ml). The mixture was heated in a water bath for 2hrs at 95^0C. It was then removed and allowed to cool to room temperature, before 12% (w/w) hydroxylamine hydrochloride (6ml) was added to reduce the excess permanganate and the mixture filtered through a 0.45 µm filter paper into a 50 mL volumetric flask and stored for analysis. Blank solutions were prepared for each of the heavy metals was used to calibrate the machine before the analysis of the samples for that particular toxicant was done.

3.6.3.4 Analysis of Arsenic (As) and Mercury (Hg)

Analysis of As and Hg was performed using Atomic Absorption Spectrophotometer Hydride Vapor Generator (P/N 206-17143) Shimadzu model;

Sample preparation for Arsenic analysis was performed using previous methods where the samples and standards for arsenic analysis were pre-reduced (As^{+5} to As^{+3}). A reducing solution containing 5% (w/v) KI and 5% (w/v) ascorbic acid was used to achieve this. A suitable volume of standard or sample analyte of 10ml was placed in a 50 ml polypropylene auto sampler tube, then 1ml of the reducing solution and 5ml of concentrated HCl were added to this sample prior to analysis. The treated samples or standards were stored at room temperature for 30-60 minutes. Thereafter deionized water was added to fill the tube to the 50 ml mark. Arsenic analysis was then carried out at 193.7nm wavelength.

Analysis of mercury was performed using previously developed methods. In brief, 10ml of sample solution was placed in the reaction flask, topped to 50ml with distilled water after addition of 5ml of 10% HCl acid. Argon gas was allowed to flow in the presence of stannous chloride, the calibration curve was developed and sample analysis carried out at 253.7nm wavelength.

3.6.4 Determination of Carcinogenic Health Risks of Heavy Metal Exposure of Artisanal Gold Miners

3.6.4.1 Exposure Assessment

The exposure routes evaluated include oral, dermal and inhalation routes for the contaminants in dry sediments, wet tailings and dust samples. Ingestion, dermal and inhalation contact with dust, dry sediment, wet tailings was considered as appropriate exposure routes through which ASGM miners are exposed to, As, Cd, Pb and Hg. This is due to the fact that, the ASGM workers carry out their activities (washing of the gold ores or dredge the water bodies for the alluvial gold) in highly dusty and turbid water bodies often with or without protective clothes (Ngure & Obwanga, 2017).

This study evaluated carcinogenic health hazards which refer to harm that can do to the central nervous system as well as other adverse health effect due to exposure to the aforementioned dust, metals and metalloids based on both CTE parameter and (RME) methods developed by US. EPA guidelines used in this study. It assumes that ASGM workers have Central Tendency Exposure (CTE) and Reasonable Maximum Exposure of fifty percent (50%) of the mean concentrations of particulate matter, dust, As, Cd, Hg and Pb while the RME parameters assume ASGM workers are exposed to ninety-five (95%) of the mean concentrations of the particulate matter, dust, metals and metalloids (Mpanza & Adam, 2020).

3.6.4.1.1 Ingestion of Sediment

ASGM miners working outdoors in contaminated water bodies may ingest sediment through incidental contact of the mouth with hands and clothing. In this study, intake of As, Cd, Pb and Hg in ingested sediments by ASGM miners was expressed as average daily dose (ADD) which was calculated as follows (Long *et al* 2015).

$$ADD = \left[\frac{(EPC\ x\ IR\ x\ AAF_{SO}\ x\ ED\ x\ EF\ x\ 10^{-6})}{(BW\ x\ AT)}\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.1)$$

Where: ADD = Average daily dose, mg/kg-day; EPC = Exposure Point Concentration, i.e., concentration of As, Cd, Pb and Hg in sediment (mg/kg) to be impacted upon by ASGM miners.

IR = Sediment ingestion rate (mg/day); AAF_{SO} = Oral-sediment absorption adjustment factor (mg/mg); ED = Exposure Duration (years). It is assumed that the ASGM miners work on an average 8hrs a day for CTE parameters and 12hrs a day for the RME parameters; EF = Exposure Frequency (events/year); BW = Body weight (kg); AT = Averaging Time, which is equal to the life expectancy of a resident Kenyan. With the exception of EPC, ED, and BW, the rest were default values in the Risk Integrated Software for clean-up of hazardous waste sites (RISC 4.02) developed by BP for the Superfund sites (Long *et al*., 2015). U.S. EPA does not endorse the use of this software or others). Bodyweight of 60.7kg was used for resident adults, in line with data from the African Statistical Service. The average life expectancy for resident adults in Kenya is 66.7 years (i.e., 64.4 years for men and 68.9 years for women). However, in this study, an average lifetime expectancy of 70 years was used as life expectancy for ASGM miners in Migori (Nyatike and Masara–Suna west) and Kakamega (Rosterman village-isulu and Ikolamani–Liranda corridor) (Mut & Ono, 2016).

3.6.4.1.2 Dermal Contact with Sediment

For ASGM miners in the study area, some sediment contaminants may be absorbed across the skin into the bloodstream. The absorption rate was obtained depending on the volume of water in contact with the skin, the concentration of chemicals in the water, the skin surface area exposed, and the potential for the chemical to be absorbed across skin. Equation (4) as published by US. EPA, was used in calculating the uptake of the toxicants in water bodies via dermal exposure pathway;

$$ADD = \left[\frac{(EPC\ x\ SA\ x\ AAF_{sd}\ x\ AF\ x\ FS\ x\ EF\ X\ ED\ x\ 10^{-6})}{(BW\ x\ AT)}\right] \quad (3.2)$$

Where: ADD = Average daily dosage mg/kg-day, SA = Total skin surface area exposed to the sediment (cm^2); AA_{sd} = Dermal-sediment absorption adjustment factor (mg/mg); AF = Sediment-to-skin adherence factor (mg/cm^2 /event). FS = Fraction of skin area exposed to the sediment (unit less). The other variables were as defined in Equation (1).

3.6.4.1.3 Ingestion of Wet Samples at Four Artisanal Gold Mining Sites

ASGM miners working outdoors in the contaminated water bodies may ingest water through drinking or incidental drinking or contact of the mouth with hands contaminated with such water bodies. The average daily dose for each of the toxic metals (i.e., As, Pb, Cd and Hg) ingested in the water bodies by the ASGM mine workers was calculated using Equation (3) below:

$$ADD = \left[\frac{(EPC\ x\ IR\ x\ AAF_{wo}\ x\ EF\ x\ ED\ x\ 10^{-6})}{(BW\ x\ AT)}\right] \quad (3.3)$$

Where EPC = exposure point concentration of a metal in the drinking water (µg/L), IR = water ingestion rate per unit time (L/day); AAF_{WO} = Oral-water adjustment factor (µg/L). Other variables were defined in Equations (1) and (2) above.

3.6.4.1.4 Inhalation Exposure

Inhalation may be through the nose or the mouth as possible routes for particulate matter. For those cases where the average daily dose (ADD) needs to be estimated, the general equation is:

$$ADD = [(C\ x\ IR\ x\ ED)/(BW x\ AT)] \ldots\ldots\ldots\ldots\ldots \text{(3.4)}$$

ADD average daily dosage (mg/kg-day);

C contaminant concentration in inhaled air (g/m^3);

IR inhalable rate (m^3/day);

ED exposure duration (days);

BW body weight (kg); and

AT averaging time (days), for carcinogenic effects At = ED, for carcinogenic or chronic effects AT=70 years or 25.550 days (lifetime)

The average daily dose is the rate averaged over a pathway-specific period of exposure expressed as a daily dose on a per-unit-body-weight basis. The ADD is used for exposure with chemicals with carcinogenic or non-chronic effects. For compounds with carcinogenic or chronic effects, the lifetime average daily dose (LADD) is used. The LADD is the dose rate averaged over a lifetime. The contaminant concentration refers to the concentration of contaminants in inhaled air. Exposure duration refers to the total time an individual is exposed to an air pollution.

3.6.4.2 Hazard Identification and Dose-Response Assessment

Particulate matter, Metals and metalloids such as inhalable dust, Cd, As, Pb and Hg are toxic to humans and produce multiple adverse health effects. The hazardous metals were analyzed using minitab. Data was collected, cleaned, coated and exported to the minitab for analysis, even at low concentrations via exposure to them in the environment either through the food chain or oral, dermal and inhalation from contaminated environmental media such as water, dust sediment, soil or air.

Dose-response assessment describes the degree, incidence, or likelihood of hazard associated with a particular dose of contaminant. Estimating the magnitude of adverse health effects on human exposures to the artisanal gold mining environmental hazards.

3.6.4.3 Calculation of Carcinogenic Health Risk

The likelihood or incidence of hazard estimated for ASGM miners under different exposure scenarios routes is part of the risk characterization of this population. In order to assess the carcinogenic and non-carcinogenic health risk of ASGM miners from dermal, oral and inhalation exposure through water and sediments, the average daily dose calculated from Equations (3.1) – (3.5) above was used. As is recommended in U.S. EPA guidance documents, the non-carcinogenic health risk faced by ASGM miners from exposure to the toxicants in the water and sediment samples via oral dermal and inhalation contact based on both CTE and RME parameters are expressed in terms of the hazard quotient (HQ). The hazard quotient for an individual chemical and individual exposure route is calculated by:

$$HQ = \frac{ADD}{RfD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

where ADD = the average daily dose ASGM miner is exposed to inhalable dust, As, Pb, Cd and Hg in water and sediment via inhalation, oral and dermal exposure routes respectively (mg/kg—day); RfD = the reference dose for each metal or metalloid for each exposure route. The RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of a daily inhalation, oral or dermal exposure to the human population (Long *et al*., 2015).

If HQ < 1, signifies no adverse effects but where HQ > 1, signifies adverse effects.

Risk value < 10^{-6} represents no carcinogenic risk from any contaminant.

Risk value >10^{-4} denotes high risk of developing cancer.

A risk value of contaminant ranging from $1x10^{-6}$ – $1x10^{-4}$ signifies an acceptable risk to human health (U.S. EPA Exposure factor book).

3.7 Data Processing and Analysis

Statistical Package for Social Scientists (SPSS) Program was used to analyze questionnaires from respondents, edited to completeness, relevance and accuracy. The data was then coded to enable the responses to be grouped into categories for both closed and open-ended questions. The statistical analysis and mode (descriptive statistics); bar charts, Tables and frequencies were included and Inferential analysis (measure of dispersion) was conducted for goodness of fit and contingency analysis. A test for significance at p =0.05 for the measured and analyzed data obtained from (AAS, & Integrating sound meter and GM-tube radiation detector) supported surveillance description of occupational health hazard and risk at the four gold artisanal sites.

3.8 Ethical Considerations

Institutional approval was sought from JKUAT ethical committee as indicated in Appendix VI , county executive committee member; (water, environment and natural resource/ Regional County director artisanal mining activities) as captured in Appendix VII; at all levels, participants were briefed on the study objectives and their consent received before administering the instruments. Confidentiality of all information was upheld.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Response Rate

In total, 260 questionnaires were distributed. Of these, 244 questionnaires were returned among which 4 questionnaire were not appropriately filled and were therefore not considered for analysis representing a response rate of 92.3% which was acceptable according to Mugenda & Mugenda, (2003).

4.2 Profile of the Artisanal Gold Miners

The general profile of gender; age and education level of artisanal Gold miners in four selected mines in western and Nyanza sites. The characteristics of miners are presented in Table 4.1. From the Table 4.1, majority (77.5%) of the respondents were male. More than seventy-two percent (72.5%) of the respondents were aged between 19 and 35 years, followed by 46-60 years, 12.9%. In terms of education level, more than half (52.5%) of the respondents indicated having primary education. From the observation, it is clear that most of the respondents involved in ASGM have little or low level of education. This could be due to a lack of employable skills, resulting in the lack of alternative livelihood options other than ASGM. Such people get employed in ASGM particularly those in rural areas, because it does not require any special skills (Arthur *et al*., 2016; Mensah *et al*., 2022). Such results in lack of understanding of the environmental impact of their mining activities. This is because the majority of respondents with a primary level of education do not believe that gold mining had a negative impact on the environment. The lack of education among most artisanal and small-scale miners prevents them from understanding the environmental impact of their activities. The study established that artisanal gold mining brings about environmental harm that causes widespread environmental degradation due to poor mining practices. Although some respondents believed that the activities did not result in environmental harm, the study found that many excavations had resulted in land dereliction due to gaping holes and ground subsidence in some areas, rendering the land unproductive for agriculture and unworthy for building construction (Alwang'a *et al*., 2020).

Table 4.1: Composition of Characteristic of Miners

Characteristic		**Percent (%) N=240**
Gender of respondents	Male	77.5
	Female	22.5
Age of respondents	Below 18 years	2.5
	19-35 years	72.5
	36-45 years	12.1
	46-60 years	12.9
Education level of respondents	No formal education	2.5
	Basic Education	88.7
	Post-Secondary	8.8

4.2.1 Gold Mining Activities

This section presents the activities and the number of years that the miners were involved in mining sites as presented in Table 4.2. As indicated in Table 4.2 below, 48.6% had engaged in gold mining activities between 5 to 10 years for 5-10 years. All the adult men who participated in the study had engaged in gold mining activities. The research indicated that 81% engage in gold mining activities and 29% of the rest of the respondents (King et al., 2024; Mulaba-Bafubiandi et al., 2023; Opakas, 2023). Approximately eighty-six percent, (86.1%) of the study participants reported that the persons engaging in gold mining activities adhered to health and environmental protection laws of Kenya. Regarding the type of gold preferred, 94.0% of the respondents preferred yellow gold. Majority (80.8%) of the respondents stated that less than 0.5 grams of gold was mined in a day. Based on the responses from the amount earned from gold per gram, more than three quarters (77.6%) of respondents earned Ksh. 2001- 4000. Further, most of the respondents, 86.1% were of the opinion that the persons engaged in gold mining activities adhered to health and environmental protection laws of Kenya, 13.95 indicated that the dominant people do not work within the laws of Kenya ,similarly as case reported in ASGM, Ghana (Mensah *et al*., 2022).

This indicates that the respondents chosen for the study had at least some years of experience in ASGM operations and could provide necessary information for the study. It also indicated that the majority of respondents engaged in illegal ASGM activities. The Environmental Protection Agency (EPA) is the institution in charge of issuing license to persons who have m*et al*l requirements in order to obtain a license for ASGM operations. However, the observation indicated that the legislation, in particular, appeared reluctant in establishing of long-term and equitable environmental protection in the small scale mining centers (Mensah *et al.*, 2022).

Regarding the type of gold preferred, 94.0% of the respondents preferred yellow gold, 4.2% preferred brown gold and 1.7% preferred alluvial gold. Majority of the respondents, 80.8% specified that less than 0.5 grams of gold was mined in a day; 12.3% indicated 10 grams of gold is mined in a day while 6.8% demonstrated that more than 10 grams of gold is mined in one day. Based on the respondents from the amount earned from gold per gram, 77.6% indicated earnings Ksh. 2001 – 4000, 12.2% indicated earnings Ksh. 0 -2000, 6.1 % indicated earning above Ksh. 6000 while 4.1% earnings Ksh. 4001 – 6000 per month. These indicated the low level of income that the miners have. The amount of income earned from gold only but encourages them continuously to take part in ASGM. The small amount of gold mined a day and the preference of color of gold is an indication of the desperate status of life that people are living. This indicates poverty levels and shows that mining was a secondary source of income for them that helps them support their families. Most of the miners are not satisfied as they do not receive adequate compensation even after investing a lot of time, energy, and even risking their lives for the sake of mining (Mulele *et al.*, 2019).

Table 4.2: Demographic Characteristics of Respondents in Artisinal Gold Mining

Activities/Response		Percent (%)
Duration engaged in gold mining activities	Below 5 years	32.4
	5-10 years	48.6
	11-19 years	13.5
	20-30 years	1.4
	Above 30 years	4.1
Category of gold miners	Adult Men	100.0
	Adult Women	83.1
	Children	46.4
Adherence to health and environmental protection laws in Kenya	Adherent	86.1
	Non-adherent	13.9
Type of gold preferred	Yellow	94.0
	Brown	4.2
	Alluvial	1.7
Color of gold mined	Yellow	100.0
Amount of gold mined in a day	Less than 0.5 grams	80.8
	10 grams	12.3
	More than 10 grams	6.8
Monthly Amount earned from gold (in Kshs)	0-2000	12.2
	2001-4000	77.6
	4001-6000	4.1
	Above 6000	6.1

4.3 Hazards Generated by ASGM Equipment/Tools in Kakamega and Migori Region, Kenya

Artisanal and small-scale Gold Mining (ASGM) is generally a repetitive occupation with varied degree of hazard exposure. In the current study, the physical hazards in ASGM were evaluated. On Equipment and tools used in the gold sites jaw crushers/hammers was commonly used at 93.2% followed by jikos at 81.1% while spiral classifies utilization was at 14.9% and shaking tables were at 12.20% although they were the safest of equipment used in ASGM (Figure 4.1).

4.3.1 Types and Sources of Physical Hazard among ASGM

This section presents types and sources of physical hazards in ASGM. The respondents' perception is that equipment and tools used in Artisanal gold mining causes physical hazards. Figure 4.1 Equipment and tools used in artisanal gold mining sites at four-selected study sites.

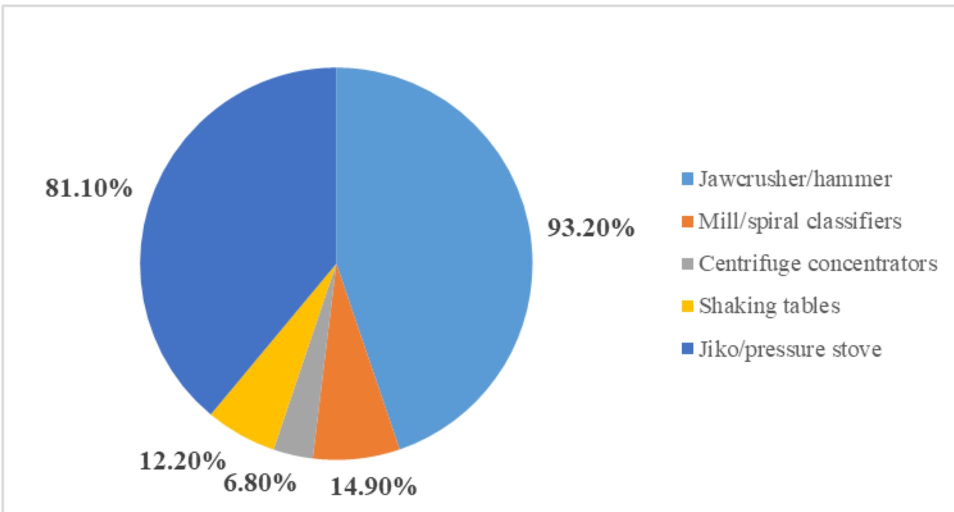


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Figure 4.1: Equipment and Tools Used in Artisanal Gold Miming

The research found out the machines that were used in extracting, processing and refining raw gold ore materials in selected study sites acted as sources of occupational health hazards in ASGMs if not handled or maintained properly (Mensah *et al*., 2022). Jaw/ball Crusher (Plate 4.1) was used to grind large ore particles into fine powder. The ore extracted may be in big sizes which need to be reduced to small sizes to increase surface area for maximum extraction of the product (gold) which exposes artisanal gold miners to physical hazards (injuries), supported by study carried out in Ghana (Long *et al*., 2015)

Plate 4.1: Sample Jaw/Ball Crusher in One of the Sites

Source: (Author, 2020)

Used a jaw crusher, hammer, Jiko, a pressure stove. Besides, the sites also had a miller, centrifuge concentrators, and shaking tables. The physical hazards were attributed to machines and equipment used in ASGM operations which were major sources of excessive noise. Over ninety percent (93.2%) of the respondents indicated using jaw/ball crusher or hammer in their mining activities (Figure 4.1). In addition, the miners were exposed to high level of noise during blasting, drilling, milling and other operational activities that involve the use of power plants and heavy equipment (Plate 4.1). Noise is a major issue in artisanal mining as a result of use of heavy machines for drilling, blasting, transferring, sorting and crushing of ore (Alwang'a *et al.*, 2020). The miners were also exposed to dust at work place due to working without proper usage of personal protective equipment. Jikos or pressure stoves (Plate 4.1) were in high usage as supported by 81.1% of the respondents, they were used to provide heat directly to heat amalgam with increased emissions of particulate matter which is toxic to miners. Release of mercury vapors into the environment with continued confined room mining had a possibility of concentrating the heavy metal amount to toxic exposure to miners. Utilization of these equipment and tools as well as machines indicates the poor mining methods since most of the mining takes place in small – scale and does not necessitate more sophisticated equipment. This study agrees with other studies reported that found out that small-scale gold mining was associated with inefficient equipment (Mwakwambirwa, 2015). it has been reported that small-scale mining in most developing countries is still largely informal and unregulated, and as a result, most small-scale miners rely heavily on relatively outdated, low-cost, and mostly polluting technologies with high risks to human health and the environment, resulting in a direct bearing on human health and the environment (Mcmahon & Moreira, 2014). Table 4.3 presents methods employed to mine gold at four selected study sites.

Table 4.3: Popular Methods Used to Mine Gold

		Percent (%) (N=240)
Method used to mine gold	Underground only	79.2%
	Open surface (pit) only	20.4%
	In-situ leach mining	4.6%

From the Table 4.3, majority of the miners (79.2%) used underground method in gold mining. When the ore body is too deep to be mined profitably by open pit, underground mining is a viable option. This method provides means of obtaining ore deposits that are deep, when ore body is steep, and when the grade is high enough to exceed costs. This mainly entails the form of deposit, dimensions of deposit, strength of the ore and host rocks, geological conditioning, content and distribution of the ore deposit work agrees with (Harraz, 2016; Khaboushan & Osanloo, 2020). The ore body's grades or quality are high enough to cover expenses. Compared to open pit mining, underground mining has a smaller environmental impact. However, the devastation of land, surface, abandoned shafts, sizable surface spoil heaps, mine explosions, collapses, and flooding are risks associated with underground mining. That excludes the steep price tag associated with subterranean mining.

The depth in meters that the miners worked underground and working on surface Table 4.4.

Table 4.4: Underground Depths in Gold Mining

	Depth from the surface	Frequency	Percent (%)
Meters respondents work at depths	1-500 Meters	126	54.5%
	501-1000 Meters	45	19.5%
	(Working on surface)	60	26.0%

From the Table 4.4, it was observed that slightly more than half of the respondents, 54.5% (126) indicated working 1-500 meters underground; 26.0% (60) indicated working on surface and 19.5% (45) worked 501-1000 meters underground. The underground working areas had limited lighting and ventilation systems (Plate 4.2). Common mining practices involve underground mining which is accomplished through the excavation of pits with tools such as pick axes and sledgehammers which range in depth from 70 to 150 feet or deeper, depending on the level of mechanization (Khaboushan & Osanloo, 2020). The four sites researched agree with these mining practices.

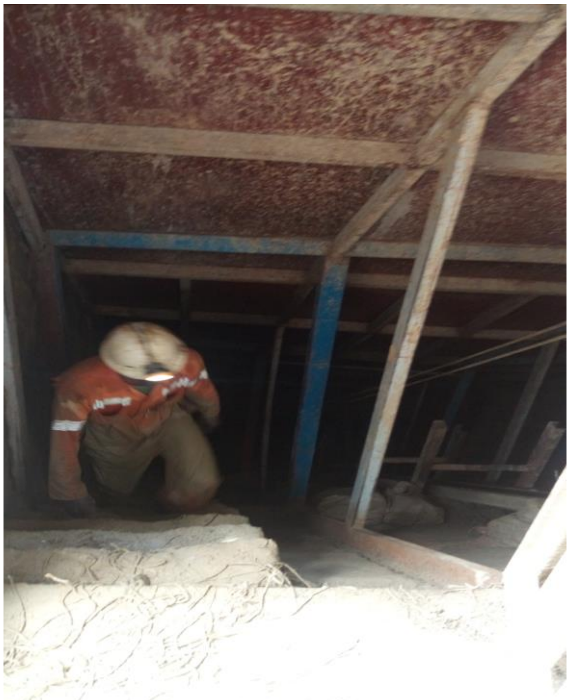

Plate 4.2: Working Underground with Limited Lighting Using Torches and Ventilation Systems

Miner’s reported having experienced falls when ascending or descending into a pit or walking around a pit that has not been fenced and easily cave-in was experienced due to inadequate ground support as indicated by the site survey in Plate 4.3; Guardrail systems erected around such like artisan gold mine reduces such falls, slips and cave-in structure (Mansdorf, 2019). Plate 4.3 presents a very poor construction of underground mines. ASGM extract ore from underground through such like opening. The materials used to construct mine pit made of wood which can easily cave-in as it is not durable and at the same time not fenced as captured in Appendix VIII

Plate 4.3: Construction of Underground Mine

Mining sites are exposed to physical hazards, chemicals and ergonomic hazards in ASGM operations. They are also exposed to health hazards due to contamination of larger environment by chemicals. Occupational work place are also exposed to water runoffs which causes landslides and subsistence. The main primary effect of ASGM operations is leachate of mine tailings that contaminates ground water. The whole ground water systems are heavily polluted with water and heavy metals that is applied during mineral separations and some waste materials the is released as indicated in Plate 4.4 which was also captured in Appendix XIX.

Plate 4.4: Physical Destruction/Degradation of land at Mining Site

The major primary effect of operations is leachate of mine tailings that contaminates ground water, the whole ground water system is heavily polluted with heavy and toxic metals that applied during mineral separation and same waste materials that is released. Slips, drips and collapse of mines are common incidents/accidents in the mines (Plate 4.4)

4.3.2 Types and Sources of Chemical Hazard

The main chemical used in ASGM were diesel grease, mercury, fumes and dust. Refining amalgam with heat in confined rooms acts as source of both physical and chemical hazards to miners (exposure to extreme high temperatures and fumes) (Fig 4.5). The health risk of working with mercury occurs when mercury vapor is inhaled during the preparation of amalgam or smelting processes. The study also identified accumulation of smoke emitted by diesel-operated equipment such as jaw/ball crusher as a major source of chemical hazard to miners in ASGM. The miners were also exposed to dust which when inhaled due to the fact that they spend more time at mining sites and this poses threat to their health.

Sample pressure stove used to refine sponge like raw gold. The process involves exposing sponge like gold to high temperatures to remove impurities. Artisanal gold miners are exposed to high temperatures and fumes as presented by Plate 4.5 (chemical hazards) and captured in Appendix XVI

Plate 4.5: Sample Pressure Stove in a Congested Room, which Generates Fumes

4.3.3 Types and Sources of Biological Hazards

Artisanal gold miners work in wet condition (26.3%) with no protection. They are exposed to animal or insect bite, fungus, bacteria and virus as source of biological hazard in mines. This is supported by appendix XII. The exposure to excessive heat from the sun during the day and underground heat from mines is presented in Table 4.5.

Table 4.5: Exposure to Excessive Heat from the Sun during the Day and Underground Heat from Mines

Environment/Frequency of Working	Safety	Percent (%)
Type of environment worked in (N=240)	Extremely dry	25.4
	Normal (safe)	48.3
	Extremely wet	26.3
Frequency of working in extremely dry or wet conditions (N=124)	Always	90.3
	Rarely	9.7

From the Table 4.5, it was found that miners were exposed to biological hazards especially during blasting, transportation of ore, crushing and in washing of ore without protection or barefooted. Miners often suffered from fungal infection and got exposed to mosquitoes' bites due to presence of stagnant water and remote location of sites. The mining activities are associated with sources of biological hazards as a result of poor working environment as such limbs exposed to biological hazards such as snake bites and injuries, exposure to bacteria, viruses, fungi and blood- borne pathogens that have adverse effects on the health and safety of artisan miners. More than a quarter of the respondents (26.3%) reported working in extremely wet environment.

These findings agrees with a study on assessing the safety and health practices in the artisanal an small-scale gold mining sector of Ghana, (Mensah *et al*., 2022). Types and Sources Ergonomic Hazards at the Studied Mining Sites. Table 4.6 presents lifting of objects in the mining sites.

Table 4.6: Lifting of Objects in Artisanal Gold Mining

		Percent (%)
Lifting of heavy loads by respondents during gold mining (N=240)	Yes	93.7
	No	6.3
Heavy objects lifted	Rocks (N=133)	4.9
	Stones (N=150)	86.0
	Mud/Soil (N=156)	69.2
	Machines (N=135)	35.6
	Tools (N=124)	92.1
Approximate weight of objects lifted (N=180)	1 - 50 Kgs	43.3
	51 - 100 Kgs	50.0
	101 - 150 Kgs	6.7

The proportions of respondents who lifted any weight and the nature of the weight handled and how it was handled are shown in Table 4.6. From majority of the respondents, 93.7% gold mining in the study area involved lifting of heavy loads; 6.3% indicated not lifting heavy loads in the course of gold mining. Among the heavy objects that were lifted included stones (86.0%), mud/soil (69.2%) and tools (92.1%). Further, the weight of the objects according to 50.0%, 43.3% and 6.7% of the respondents was 51-100 Kg, 1-50 Kgs and 101-150 Kg, respectively. Lifting of heavy loads is an Ergonomic hazard that is very often encountered by miners when materials are lifted unaided (Mensah *et al*., 2022). About seventy-two percent (72.1) % of the respondents reported that the lifting of the heavy objects was done manually, by pulling with ropes (Table 4.7).

Table 4.7: Methods of Lifting Objects in Artisanal Gold Mining

Method of lifting the objects	Percent (%) (N=240)
Manually	72.1
Mechanized	27.9
Total	**100.0**

Miners were involved in lifting of heavy loads (Plate 4.6) and manually (72.1%) were likely to suffer injuries and or disorder in the knees, shoulders, waist and back. Miners suffer other forms of injury such as knee, shoulder, waist and back pains as well as awkward working posture in ASGM activities (Beth, 2018; Mensah *et al*., 2022).

Plate 4.6: Manual Carrying of the Extracted Ore

Awkward working postures and lifting heavy loads which were observed by the researcher during operations as indicated by the site Plate 4.6 act as source of ergonomic hazard workplace to artisanal gold miners. Prolonged digging, sitting in awkward positions, bending over, carrying heavy loads for great distances could all result in severe and persistent injuries and pains in the back (Mensah *et al*., 2022). Locally constructed pulley and winch pulling are popular common methods practiced at four sites to extract ore from underground as presented in Plate 4.7 and 4.8.

Plate 4.7: Locally Constructed Pulley for Extraction of Ore from Underground

Use of non-mechanized constructed pulleys for extraction of underground ore exposed Gold miners to physical injuries such as muscular skeletal disorder condition (Plate 4.7).

Plate 4.8: Winch Pulling of Ore Extraction

The was no prescribed standards on maximum weight that one can lift by both men and women in Kenya, UK, or even USA but the national institute of occupational safety and health (Andrews & O'Connor, 2020)of USA has since developed a formula that can be adopted by employers while carrying out a lifting risk assessment (Centres for Disease Control and Prevention Kenya, 2018; The Health and Safety Executive United Kingdom, 2022). NIOSH lifting equation/formula estimate the risk of lifting related injuries based on factors like load weight, lifting frequency, distance lifted and lifting technique (postures). According to this formula, the recommended weight limit for lifting loads under ideal condition is 51pounds (23 kilograms) for men and 31pounds (14 kilograms) for women.

Sources Psychological Hazards

Due to long working hours and the intense manual work, the artisanal gold miners were exposed to psychological hazards appendix X111. This was supported by 60% of the respondents from interviews and observations recorded from artisanal gold miners at sites. The findings agreed with a study on safety and health practices in the artisanal and small-scale gold mining sector of Ghana (Mensah *et al*., 2022) which also indicated 60% prevalence of psychological hazards at gold mining sites. Awareness and Use of Personal Protective Equipment (PPEs)

Common PPEs used by artisanal gold miners (Plate 4.9) were as follows; gloves 73.3%, helmet 85.5%, gumboots 75.0%, overall/aprons 25.0%, spectacles/eye shields 14.6% and masks 19.2% as displayed in Figure 4.2.

Plate 4.9: Activities at Artisan Gold Mining Sites

Plate A; Working with grinder with no protection to dust exposure, Plate B; Using fabricated pulley with no protection, standing for long time in open sun, and Plate C; In mine pit with partial protection, wearing helmet only and Plate D, E & C. Bending and handling sponge-like gold with no protection, exposing artisanal gold miners to health risk.

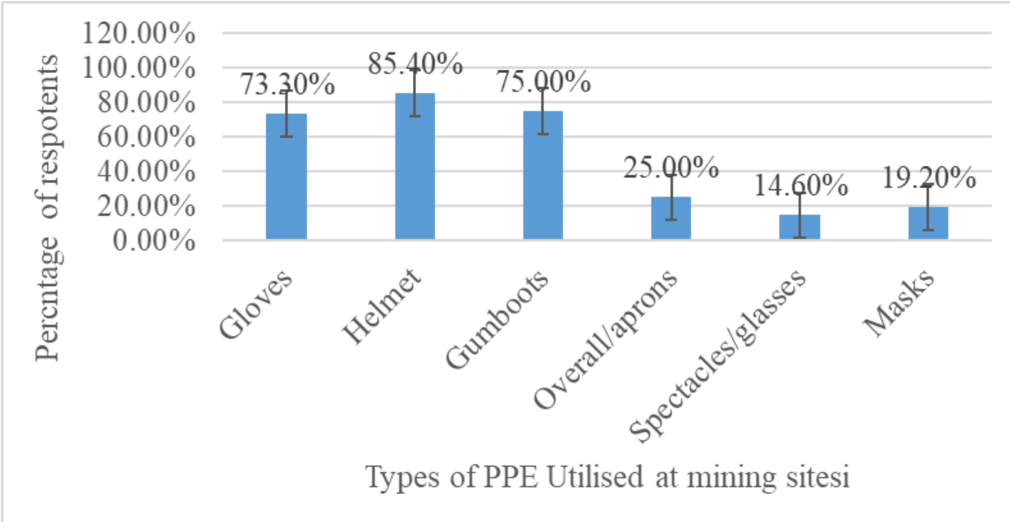

Figure 4.2: Percentage of Miners Working without or with PPEs

With respect to the awareness of the Personal Protective Equipment (PPEs) used in artisanal mining, 85.4% of the respondents were aware of helmets, 73.3 gloves, and 75.0% gumboots (Figure 4.2). More than ninety percent (93.3%) of the respondents reported using the personal protective equipment with majority (90.4%) using the personal protective equipment at all times (90.4%). However, contrary to the reports, an observation of the artisanal gold miners when working at the sites demonstrated partial or no usage of personal protective equipment, thus exposing them to various hazards related to gold mining in the study which agrees with Appendix I. Table 4.8 shows the data for the usage of PPEs in selected sites (ASGM).

Table 4.8: PPEs Used in ASGM

		Frequency	Percent (%)
Usage of personal protective equipment	Usage	224	93.3%
	No usage	16	6.7%
Frequency of using personal protective equipment by respondents	Always	217	90.4%
	Rarely	20	8.3%
	Never	3	1.3%
Personnel maintaining personal protective equipment	Self	102	42.5%
	Store Keeper	98	40.8%
	Management/supervisor	40	16.7%

The maintenance of the PPEs was mostly carried out by the users themselves followed by the storekeepers. PPEs are supposed to be procured, stored and maintained by employer (The Factories and Other Places of Work (Hazardous Substances) Rules, 2007) (The Occupational Safety and Health Act, 2007, 2007).

4.4 Levels of Respirable $PM_{2.5}$ in Artisanal Gold Mining in the Study Sites

In order to understand the contribution of PPEs, the study measured the value of $PM_{2.5}$. This was compared to WHO threshold value limits as indicated in Table 4.9. This section presents trends and analysis of inhalable particulate matter ($PM_{2.5}$) using purple air sensors as captured in Appendix XIII.

Table 4.9: Ranges of $PM_{2.5}$ in ASGM

Goldmine Sites	Respirable Fraction of Inhalable Particulate Matter ($PM_{2.5}$) from Air Purple Sensor Output	
	(Ranges ($\mu g/m^3$))	Comments
Rosterman	2.06 - 121.90	>Threshold Value Limits
Ikolomani	10.70 - 135.80	>Threshold Value Limits
Masara	20.85 - 140.65	>Threshold Value Limits
Francis	15.84 - 150.65	>Threshold Value Limits
Control	12.0 – 25.0 for 24-hr cycle	<Threshold Value Limits

Table 4.10 presents the percentage analysis of the levels of PMs in the sites. Further analysis was carried out on air quality index (Table 4.10) referring to the obtained data.

Table 4.10: Air Quality Index Analysis of $PM_{2.5}$ Levels

$PM_{2.5}$ Levels	Good (0-50) (%)	Moderate (51-100) (%)	Unhealthy for Sensitive Groups (101-150) (%)	Unhealthy (151-200) (%)	Very Unhealthy (201-300) (%)	Hazardous (>300) (%)
Rosterman Site	84.0	9.7	3.7	2.7	0.0	0.0
Rosterman Control	52.7	47.3	0.0	0.0	0.0	0.0
Ikolomani Site	82.3	17.7	0.0	0.0	0.0	0.0
Ikolomani Control	72.0	19.7	8.3	0.0	0.0	0.0
Masara Site	98.0	1.7	0.3	0.0	0.0	0.0
Masara Control	83.3	11.3	4.0	1.3	0.0	0.0
Francis Site	77.7	8.3	3.3	3.3	4.0	3.3
Francis Control	95.7	4.3	0.0	0.0	0.0	0.0

The findings on air quality levels ($PM_{2.5}$) revealed that 84.0% of the measurements taken in Rosterman were good, 9.7% were moderate while 3.7% were categorized as unhealthy for sensitive groups. At the Roster Man Control site, 52.7% of the $PM_{2.5}$ measurements were good while 47.3% were moderate. The measurements for $PM_{2.5}$ at Ikolomani gold mining site revealed 82.3% of the $PM_{2.5}$ levels as being good; 17.7% were moderate. For Ikolomani control site, 72.0% of the $PM_{2.5}$ levels were categorized as good, 19.7% were moderate and 8.3% were unhealthy for sensitive groups. The $PM_{2.5}$ measurements for Masara gold mining site were categorized as 98.0% being good, 1.7% being moderate and 0.3% being unhealthy for sensitive groups. For the control site at Masara, 83.3% of $PM_{2.5}$ levels were good, 11.3% were moderate, 4.0% were unhealthy for sensitive groups and 1.3% were unhealthy. The results demonstrated that $PM_{2.5}$ levels for Francis mining site to be categorized as 77.7% being good, 8.3% moderate, 3.3% were unhealthy for sensitive groups, another 3.3% unhealthy and 4.0% being very unhealthy. The $PM_{2.5}$ levels at the Francis control site revealed 95.7% of the measurements being good and 4.3% being moderate. An analysis of the time series plots for the four sites revealed some $PM_{2.5}$ values exceeding the recommended WHO air quality guideline value of 25 $\mu g/m^3$ 24-hour mean. The health consequences of these

dusts depend on the level of exposure, the duration of exposure, the frequency of exposure, and the chemical and mineral composition of the inhaled particle. Since miners were dressed in ripped clothes and lacked personal protection equipment such as a hard hat, coveralls, nose and ear muffs, they were at high health risk. Researchers discovered that when miners are exposed to silica dust over a long period of time, there is always the possibility that these miners will contract silicosis, lung cancer, or tuberculosis (Armah, Adedeji, & Boafo, 2021).

Figure 4.3 presents Purple air sensor output for $PM_{2.5}$ at the four artisanal gold mining sites. For the four ASGM sites, variation output on $PM_{2.5}$ was established as shown in Figure 4.3. As indicated, Ikolomani had the highest at 82% indicating high variation, which was statistically significant as shown in Table 4.11.

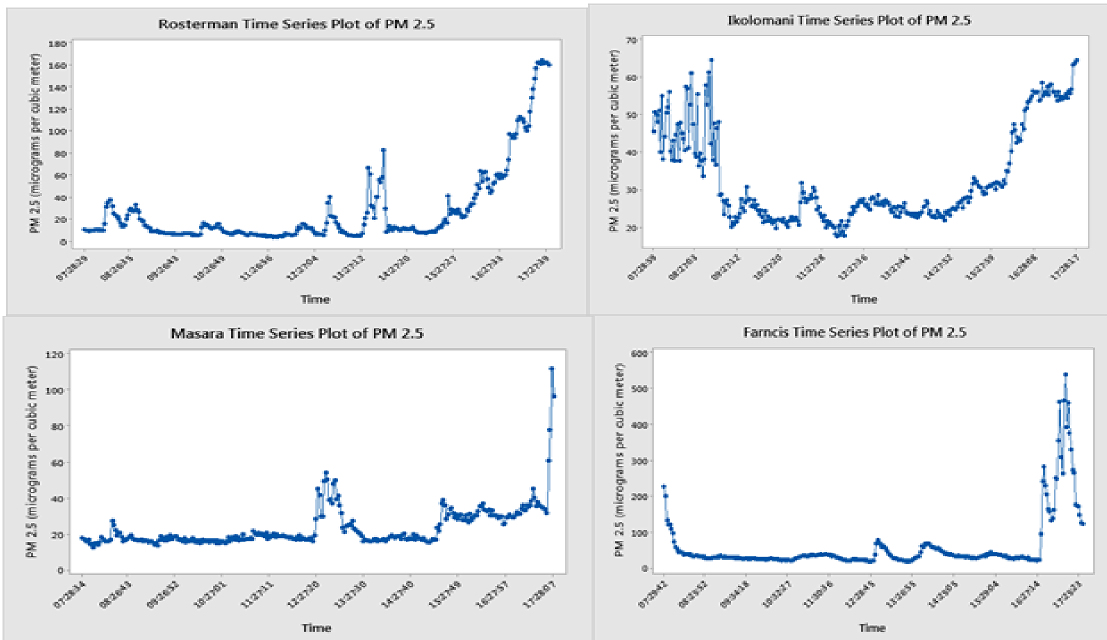

Figure 4.3: Purple Air Sensor Output for $PM_{2.5}$ at the Four Artisanal Gold Mining Sites

From the output of purple air sensor $PM_{2.5}$ levels for the four mining sites was significant (all the $p < 0.05$). Therefore, $PM_{2.5}$ exposures from artisanal gold mines equally health concern. The 24-cycle variation output of $PM_{2.5}$ in mining sites was high which is supported by work done by (Otieno *et al*., 2022)

Table 4.11 presents the statistical output for $PM_{2.5}$ at the mining sites and control. The research found that $PM_{2.5}$ at the mining sites and their controls was statistically significant as shown in Table 4.11.

Table 4.11: Statistical Output for $PM_{2.5}$ at the Main Sites and Control

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	**df**	**Sig.**	**Statistic**	**Df**	**Sig.**
$PM_{2.5}$ (Rosterman)	0.194	179	0.000	0.780	179	0.000
$PM_{2.5}$ (Rosterman Control)	0.084	179	0.004	0.954	179	0.000
$PM_{2.5}$ (Ikolomani)	0.262	179	0.000	0.807	179	0.000
$PM_{2.5}$ (Ikolomani Control)	0.351	179	0.000	0.632	179	0.000
$PM_{2.5}$ (Masara)	0.287	179	0.000	0.607	179	0.000
$PM_{2.5}$ (Masara Control)	0.233	179	0.000	0.694	179	0.000
$PM_{2.5}$ (Francis)	0.300	179	0.000	0.492	179	0.000
$PM_{2.5}$ (Francis Control)	0.138	179	0.000	0.925	179	0.000

a. Lilliefors Significance Correction

The Mann-Whitney U test (the non-parametric equivalent of the independent samples t-test) was used to evaluate whether significant differences existed between the artisanal gold mining sites and the respective control sites. The mean rank and test statistics columns indicates that $PM_{2.5}$ levels were statistically significantly higher in the control sites for Rosterman (mean rank=400.83, p-<0.0001), Ikolomani (mean rank=386.12, p<0.0001) and Masara (mean rank=351.77, p<0.0001) as compared to the corresponding main sites (Table 4.12). The results also show that $PM_{2.5}$ levels were statistically significantly higher for the main site for Francis (mean rank=325.79, p<0.0001) as compared to the corresponding control site which is a public health concern that requires intervention. This was attributed to the dust emission from the site and diesel engines (Armah *et al.*, 2021; Luo *et al.*, 2021). Table 4.12 shows the mean ranking of $PM_{2.5}$ at the sites and control.

Table 4.12: Mean Ranking of $PM_{2.5}$ at the Sites and Control

	Location of site	N	Mean Rank	Sum of Ranks	Test Statistics
Rosterman	Site	300	200.17	60051.00	U=14901.00, p-value<0.0001
	Control	300	400.83	120249.00	
Ikolomani	Site	300	214.88	64463.00	U=19313.00, p-value<0.0001
	Control	300	386.12	115837.00	
Masara	Site	300	249.23	74768.00	
	Control	300	351.77	105532.00	U=29618.00, p-value<0.0001
Francis	Site	300	325.79	97735.50	U=37414.50, p-value<0.0001
	Control	300	275.22	82564.50	

Through the use of the Kruskal Wallis Test, an analysis was conducted to assess whether there were significant differences in $PM_{2.5}$ levels among the four artisanal gold mining sites. From the Kruskal Wallis test, statistically significant differences exist in $PM_{2.5}$ levels among the four artisanal gold mining sites, Chi-Square (df = 3) = 301.84 and p-value<0.0001 (Table 4.13). The mean rank results show that $PM_{2.5}$ levels are highest in Francis followed by Ikolomani, then Masara and Rosterman has the lowest.

Table 4.13: Statistical Significance of $PM_{2.5}$ at the Sites and Control

	Mining site	N	Mean Rank	Test Statistics
Levels of $PM_{2.5}$	Rosterman	300	380.14	Chi-Square=301.84, df=3, p-value<0.0001S
	Ikolomani	300	740.36	
	Masara	300	479.50	
	Francis	300	802.01	
	Total	**1200**		

The mean rank results can easily be attributed to high variation distribution $PM_{2.5}$ particles at mining sites that was in agreement with study on PM_{10} and $PM_{2.5}$ that recorded high concentrations (respirable particulate matter) above the permissible levels by EPA and EMCA, as the main causal factors of $PM_{2.5}$ untreated industrial or artisanal emissions such as ambient air samples in Nairobi city, Kenya (Evagelopoulos *et al.*, 2022). Figure 4.4 presents weather consideration at the mining sites in the two counties under study.

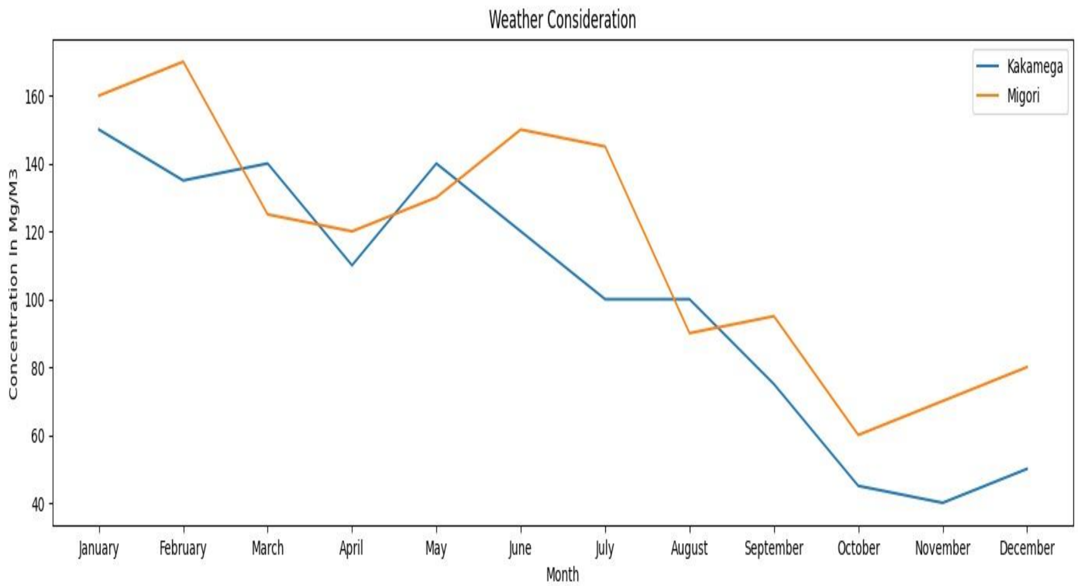

Figure 4.4: Represents Variation in $PM_{2.5}$ Output During Dry and Wet Season

From Figure 4.4, during the dry seasons (January to March) more of particulate matter are dislodged into the air hence higher concentration of particulate matter in the air. The trend of the concentration particulate matter decreased during wet season (April to June). There was also a further decrease in $PM_{2.5}$ in wet seasons. During wet seasons, particulate matter is not dislodged into the air due to sedimentation as a result of interacting with rain water in the atmosphere which is significant at two counties leading to wet deposition ($P < 0.004$, $\alpha = 0.05$). Weather consideration is key factor to reduce / minimize dust exposures at artisanal gold mining sites(Shepherd *et al.*, 2018)

4.5 Environmental Risk Levels of Radiation and Noise

In order to establish the magnitude of exposure to external environmental energies to miners (physical hazard), the research sort to establish radiation dosage and noise level exposures in artisanal small-scale gold mining sites

4.5.1 The Ranges of Radiation Dosage Exposure in ASGM Sites to Skin, Eye and Body

The section presents exposure to radiation in artisanal gold mines in Western and Nyanza regions, Kenya are displayed in Table 4.14.

Table 4.14: The Ranges of Radiation Dosage Exposure in ASGM Sites to Skin, Eye and Body

	Range	Minimum	Maximum	Mean	Std. Deviation
Skin	.202	.197	.399	.30367	.097914
Eye	.350	.197	.547	.30533	.137545
body	.219	.186	.405	.30433	.104974

The minimum and maximum exposure dosage ranged from (.197-.399) mSv/month with average of .30367±.097914 mSv for the skin, (.197-.547) mSv/month with average of .30533±.137545 mSv for the eye and (.186-.405) mSv/month with average of .30433±.104974mSv for the body ($p>0.05$). ALARA threshold levels are captured as follows; maximum dosage limit is 20 mSv/year (approximately 1.67 mSv/month; maximum dosage limit is .08mSv/month (for expectant mother during all 9 months of expectancy). The radiation exposure to gold miners do not cause any serious harm as presented by the results (Table 4.14).

Table 4.15 presents statistical significance of radiation exposure of skin, eye, and body in ASGM.

Table 4.15: Statistical Significance of Radiation Exposure of Skin, Eye, and Body in SSGM

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	**Df**	**Sig.**	**Statistic**	**Df**	**Sig.**
Skin radiation	.298	59	.000	.669	59	.000
Eye radiation	.371	59	.000	.695	59	.000
Body radiation	.308	59	.000	.726	59	.000

a. Lilliefors Significance Correction

The Kruskal Wallis Test was used to evaluate if there was any statistically significant difference in radiation exposure by body parts. From the results, Chi-Square (df=2) = 8.179 and p = 0.017, an =73.64) as shown in Table 4.16. Skin, eye and body are equally exposed to radiation to miners at artisanal mining sites.

Table 4.16: Statistical Ranking of Radiation Exposure to Skin, Eye, and Body in ASGM

	Body organ	N	Mean Rank	Test Statistic
Level of Exposure to body organs	Skin	59	98.75	Chi-Square=8.179, df=2, p-value=.017
	Eye	59	94.60	
	Body	59	73.64	
	Total	177		

For skin radiation, there were significant differences in skin radiation among the 4 sites, Chi-Square (df=3) = 37.554 and p<0.0001 (Table 4.17). The mean rank results show that Francis had the highest skin radiation (mean rank=45.00). For eye radiation, statistically significant differences were observed in eye radiation, Chi-Square (df=3) = 42.655 and p<0.0001. From the mean rank results, Francis had the highest eye radiation (mean rank=48.50). For the body radiation, statistically significant differences were observed among the 4 sites, Chi-Square (df=3) = 36.87, p<0.0001. Francis had the highest body radiation with mean rank 48.50. Table 4.17 shows the findings for the mean rank difference of radiation exposure to body organ and ASGM Sites.

Table 4.17: Mean Rank Difference of Radiation Exposure to Body Organ and ASGM Sites

	Site	N	Mean Rank	Test Statistic
Skin radiation	Rosterman	15	8.00	Chi-Square=37.554, df=3, p-value<0.0001
	Ikolomani	15	33.27	
	Masara	15	34.73	
	Francis	14	45.00	
	Total	59		
Eye radiation	Rosterman	15	8.00	Chi-Square=42.655, df=3, p-value<0.0001
	Ikolomani	15	30.00	
	Masara	15	34.73	
	Francis	14	48.50	
	Total	59		
Body radiation	Rosterman	15	15.00	Chi-Square=36.87, df=3, p-value<0.0001
	Ikolomani	15	19.73	
	Masara	15	38.00	
	Francis	14	48.50	
	Total	59		

Table 4.18 presents the radiation exposure to body parts organs and gender. There was statistically significant difference in skin radiation by gender, U=176.00 and p-value<0.0001, with females exhibiting higher levels of skin radiation (mean rank=38.93) as compared to males. Similarly, statistically significant difference was observed in eye radiation by gender, U=225.00 and p-value<0.0001, with females exhibiting higher levels of eye radiation (mean rank=37.24) (Table 4.18). However, no statistically significant difference was observed in body radiation by gender (U=379.00, p-value=0.392). Women are equally exposed to radiation as they use less or no protection gear while working at artisanal gold mining sites (Mensah *et al*., 2022; Speranskaya *et al*., 2017) (Appendix X1II).

Table 4.18: Radiation Exposure to Body Organs and Gender

	Gender of participants	N	Mean Rank	Sum of Ranks	Test Statistic
Skin radiation	Male	30	21.37	641.00	U=176.00, p-value<0.0001
	Female	29	38.93	1129.00	
	Total	59			
Eye radiation	Male	30	23.00	690.00	U=225.00, p-value<0.0001
	Female	29	37.24	1080.00	
	Total	59			
Body radiation	Male	30	28.13	844.00	U=379.00, p-value=.392
	Female	29	31.93	926.00	
	Total	59			

From the findings, statistically significant differences were observed in radiation between the body parts and their respective controls (all the p-values were less than 0.05). Further, the control radiations had higher mean ranks as compared to the radiation measures collected for each body part at the sites, implying that the control radiation measures were higher (Table 4.19). Dosimeter badges detects ionizing radiation that enter the individual only. Control badges pick out/ detect sources of radiation at workplace in totality giving rise to higher levels of radiation as compared to that of individual. Table 4.19 presents the radiation exposure to body parts compared to control.

Table 4.19: Radiation Exposure to Body Parts (Skin, Eye and Body) Compared to Control

	Exposure to organ	N	Mean Rank	Sum of Ranks	Test Statistic
Exposure to Skin	Main Body Part	59	45.00	2655.00	U=885.00, p-value<0.0001
	Control	59	74.00	4366.00	
	Total	118			
Exposure to Eye	Main Body Part	59	45.00	2655.00	U=885.00, p-value<0.0001
	Control	59	74.00	4366.00	
	Total	118			
Exposure to Body	Main Body Part	59	45.00	2655.00	U=885.00, p-value<0.0001
	Control	59	74.00	4366.00	
	Total	118			

Through the use of descriptive statistics, that is, the minimum and maximum values, the radiation measure for each body part were compared with As Low As Reasonably Achievable (ALARA) threshold levels which indicated that the maximum dose limit is approximately 1.67 mSv/month (Chinangwa *et al*., 2017). Skin exposure to radiation, had a minimum radiation of 0.197 and the maximum was 0.803. Eye exposure to radiation, had a minimum radiation of 0.197 while the maximum was 0.547 and the minimum exposure of body to radiation was 0.186 and the maximum radiation was 0.405. This demonstrates that the radiation levels are within the recommended radiation exposures threshold levels that should not exceed maximum dose limit of 1.67 mSv/month.

4.5.2 The Ranges of Noise Level Exposure in ASGM Sites

Noise measured range levels from the source was measured and data presented in Table 4.20 and Figure 4.5, which were well demonstrated by researcher in Appendix XI

Table 4.20: Statistical Analysis of Noise Exposure at Sites as Compared with Control

	N	Mean	Std. Deviation	Minimum	Maximum
Rosterman	12	83.98	15.50	56.00	103.20
Rosterman Control	12	58.48	9.39	43.00	73.20
Ikolomani	12	86.01	10.66	74.00	110.00
Ikolomani Control	12	45.37	7.99	38.10	62.80
Masara	12	96.97	9.21	84.00	113.60
Masara Control	12	62.99	7.56	53.40	77.90
Francis	12	89.38	11.86	75.00	106.50
Francis Control	12	54.39	11.12	40.00	71.50

The descriptive statistics shows that mean noise levels for Rosterman was 83.98±15.50) with minimum and maximum noise levels being 56.00 dB(A) and 103.20 dB(A). The mean noise levels for Ikolomani was 86.01±10.66 dB(A) with minimum and maximum noise levels being 74.00 dB(A) and 110.00 dB(A). In Masara, the mean noise levels recorded was 96.97±9.21 dB(A) with minimum and maximum levels being 84.00 dB(A) and 113.60 dB(A) respectively. The mean noise levels recorded for Francis was 89.38±11.86 dB(A) with minimum and maximum noise levels being 75.00 dB(A) and 106.50 dB(A) respectively. Despite the data following normal distribution, some values were outside the required noise threshold levels of 85 dB(A) and 90 dB(A).

Control sites showed that Rosterman Control site had mean noise levels 58.48±9.39 dB(A) with minimum and maximum noise levels 43.00 dB(A) and 73.20 dB(A) respectively. Ikolomani Control site mean noise levels was 45.37±7.99 dB(A) with minimum and maximum noise levels were 38.10 dB(A) and 62.80 dB(A) respectively. For Masara Control site, mean noise levels was 62.99 dB(A) (standard deviation=7.56), minimum and maximum noise levels 53.40 dB(A) and 77.90 dB(A) respectively. In Francis Control site, the mean noise level was 54.39±11.12 dB(A) with minimum and maximum noise levels of 40.00 dB(A) and 71.50 dB(A) respectively. The noise levels for the control sites fell within the 85 dB(A) and 90 dB(A) threshold levels. Figure 4.5 shows data for measured noise levels against distance meters (m)

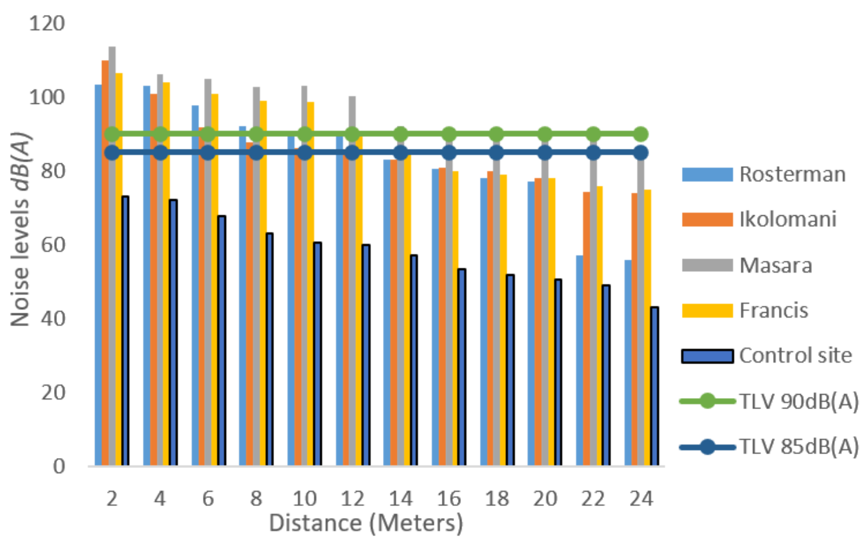

Figure 4.5: Data for Measured Noise Levels against Distance Meters (m)

Table 4.21: Statistical Analysis of Noise Levels in ASGM

Sites	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	Df	Sig.
Rosterman	.160	12	.200*	.915	12	.245
Ikolomani	.187	12	.200*	.901	12	.162
Masara	.205	12	.174	.917	12	.260
Francis	.203	12	.185	.884	12	.097

*. Lower bound of the true significance.

One-Way ANOVA was used to test whether there were differences in noise levels among the sites. From the ANOVA table, p-value=0.057, greater than 0.05, an indication that there were no statistically significant differences in noise levels among the sites (Table 4.22). This reveals that noise levels remain high due to excavation, drilling, bogging, crushing, and hauling activities at mining sites (Armah *et al*., 2021). Table 4.22 shows statistical significance of noise level analysis at the mining sites.

Table 4.22: Statistical Significance of Noise Level Analysis at the Sites

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1172.431	3	390.810	2.698	.057
Within Groups	6373.149	44	144.844		
Total	**7545.580**	**47**			

At gold mining sites, there is geometric spreading of noise because of the expansion of the wave front from noise emitting Machines and tools. It is a spherical spreading of noise with distance in meters as presented in the Figure 4.6.

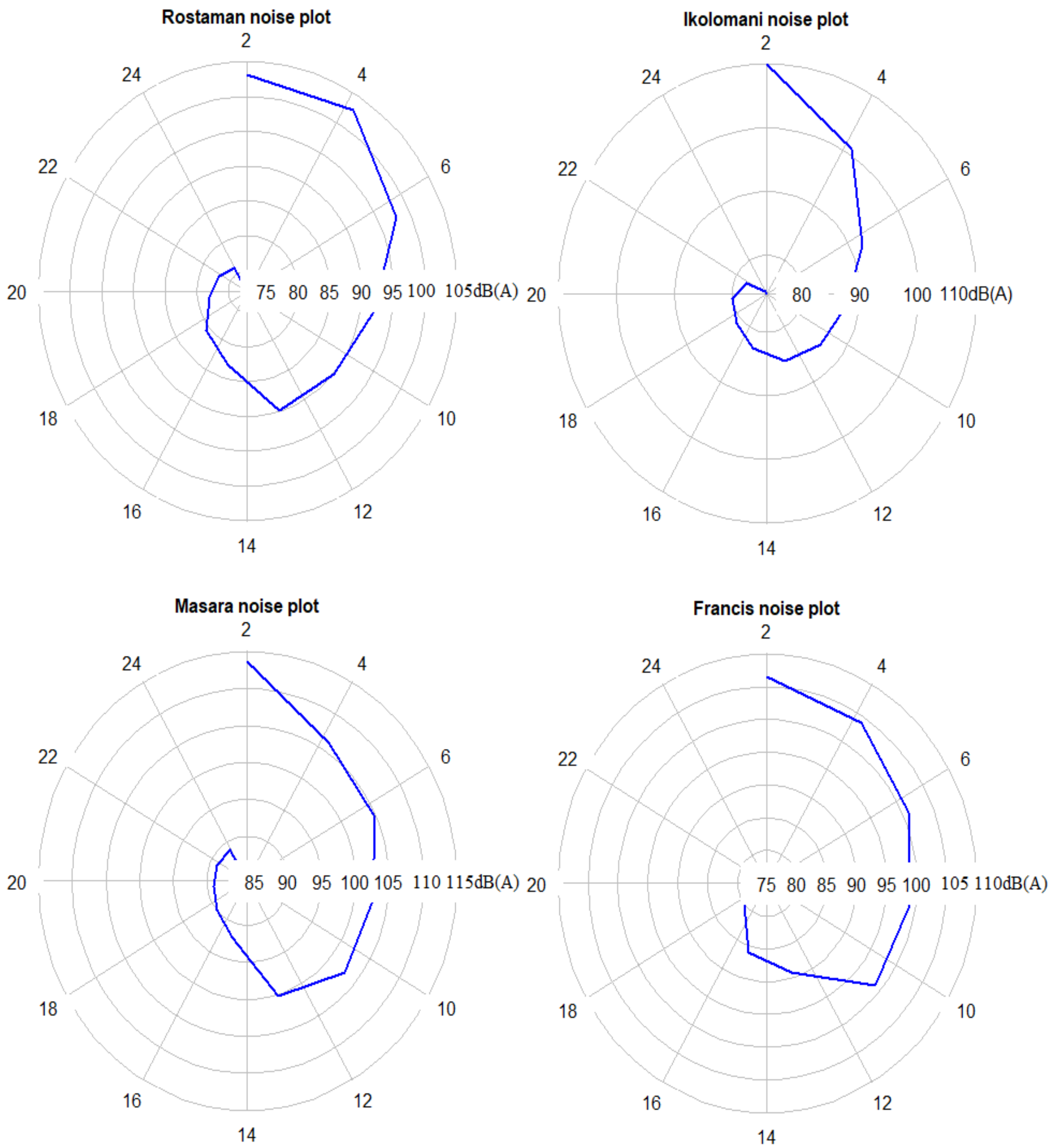

Figure 4.6: Noise Survey Map

Observations were made for noise attenuation for the control site as shown in the Figure 4.5. The work sites of ASGM are sources of noise pollution to miners as indicated by noise survey maps. The average noise levels above acceptable limits of 90 dB(A) were recorded as follows; Rosterman (13%), Ikolomani (18%), Masara (21%) and Francis

(16%) whereas noise levels within acceptable limits were recorded in control areas being below the limit set.

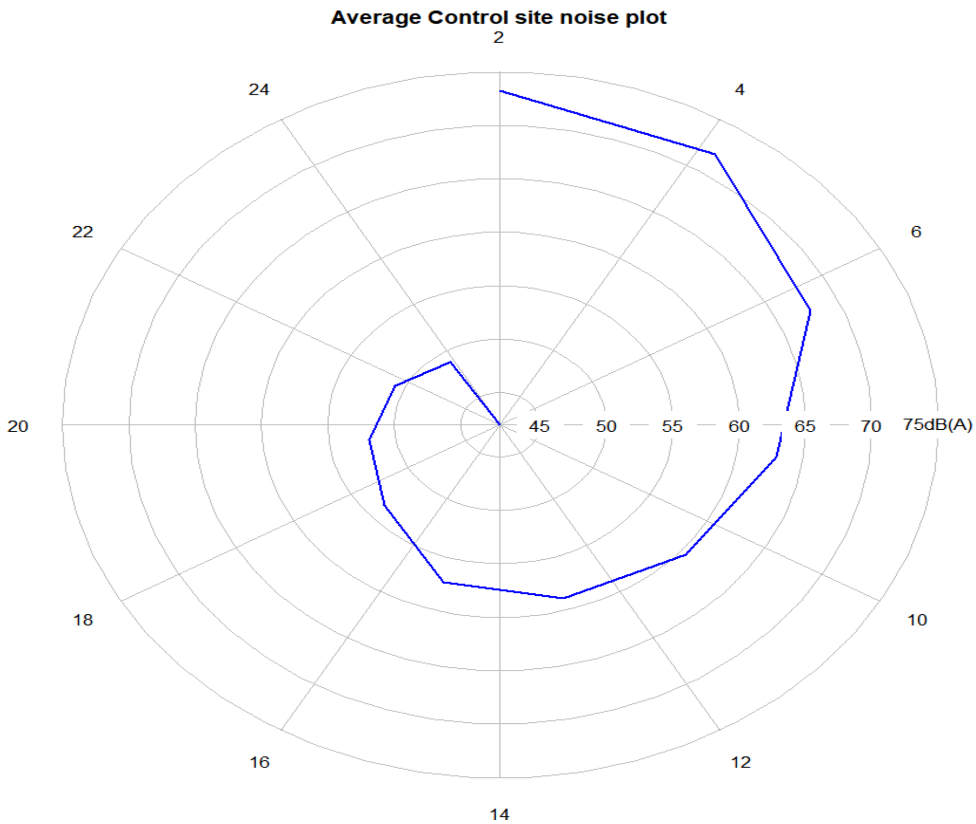

Figure 4.7: Distance from Noise Emitting Machines in Relation to Exposure

The average noise levels at control site was below occupational exposure threshold limit value of 85 dB (A). Artisanal and small-scale gold mining sites exposes workers to hazardous noise levels. Noise conservation program me is necessary at work sites in order to prevent, protect and preserve health of miners from induced hearing loss.

4.6 Concentrations of Mercury (Hg), Cadmium (Cd), Arsenic (As), and Lead (Pb) in dry samples (Ore extract) and Wet samples (Sediment tailings)

The current research study presents analysis of heavy metal concentrations in soil and human samples, compared with each referenced threshold value standards (Chemical hazard Exposure). Figure 4.8 represents the concentration of Pb, Cd, Hg and As in the wet and dry samples against the WHO limits for the heavy metals from the four selected artisanal gold mining sites. There is evidence that heavy metals are distributed in troposphere in different concentration as per the activities carried out as indicated by the research of (Mutua *et al.*, 2021).

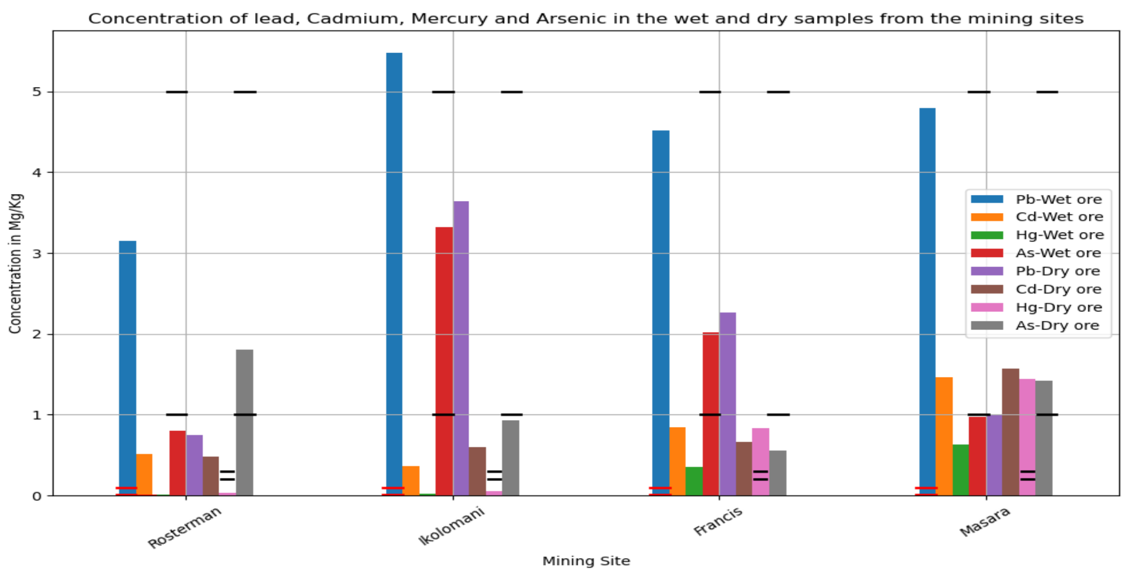

Figure 4.8: Concentration of Pb, Cd, Hg and as in the Wet and Dry Samples against the WHO Limits for the Selected Heavy Metals from the Various Mining Sites

Table 4.24 presents the concentration of lead, cadmium, mercury, and Arsenic in the wet and dry samples from the mining sites. When the concentrations of contaminant exceed agreed threshold, limits indicate adverse health condition exposures. The intervention is sort for either prevention, preservation or treatment against such like risk factors.

Table 4.23: Concentration of Pb, Cd, Hg and as in the Wet and Dry Samples from the Mining Sites

Mining Site	Dry ore (Average mean mg/kg)				Wet Ore (Average mean mg/kg)			
	Pb	**Cd**	**Hg**	**As**	**Pb**	**Cd**	**Hg**	**As**
Rosterman	3.15±0.01	0.51±0.01	0.01±0.002	0.80±0.18	0.75±0.11	0.48±0.03	0.03±0.003	1.81±0.06
Ikolomani	5.48±0.51	0.37±0.05	0.02±0.01	3.32±0.61	3.64±0.53	0.60±0.09	0.05±0.006	0.93±0.24
Francis	4.52±0.41	0.85±0.09	0.35±0.07	2.02±0.37	2.26±0.30	0.66±0.05	0.83±0.04	0.56±0.38
Masara	4.79±0.69	1.46±0.30	0.63±0.05	0.97±0.01	0.99±0.20	1.57±0.65	1.44±0.07	1.42±0.35
Total	**4.49±0.96**	**0.80±0.46**	**0.25±0.27**	**1.77±1.10**	**1.91±1.12**	**0.83±0.53**	**0.59±0.62**	**1.18±0.55**

From Table 4.24, it was found that the average mean of lead (Pb) concentration in Dry Ore ranged from 3.15±0.01mg/kg to 5.48±0.51mg/kg in Rosterman and Ikolomani respectively. Lead Metal concentration in Wet Ore ranged from 0.75±0.11mg/kg to 3.64±0.53mg/kg in Rosterman and Ikolomani respectively(Mlewa et al., 2023; Omondi et al., 2023). The trend is that heavy metal of lead concentration was higher in Dry Ore as compared to Wet sediment tailings. Leaching of the metal might have occurred during mining processes (Doumo et al., 2022; Mimba et al., 2023; Mulaba-Bafubiandi et al., 2023; Thiombane et al., 2023). The high concentration of lead in dry ore could be attributed to types and location of rocks at mining sites. Sources of lead might have come from transportation means, storm water and dust in the environment at the sites. There was exposure of lead heavy metal contaminants to artisanal gold miners at all mining sites.

The average mean of Cadmium (Cd) concentration in Dry Ore ranged from 0.37±0.05mg/kg to 1.46±0.30mg/kg at Ikolomani and Masara respectively. Cadmium (Cd) concentration in Wet Ore ranged from 0.48±0.03mg/kg to 1.57±0.65mg/kg at Rosterman and Masara. Cadmium as a heavy metal at artisanal gold mining showed high concentration in Wet tailings than in Dry Ore. This was attributed to the anthropogenic activities and location of the site. Sources of Cd metal at mining site may have been as a result of polluted storm water and the transportation activities such as the use of diesel engines and petrol products at the site.

Concentration of Mercury (Hg) ranged from an average mean of 0.01±0.002mg/kg to 0.63±0.05mg/kg in Dry Ore and from 0.03±0.003mg/kg to 1.44±0.07mg/kg in Wet tailings at Rosterman and Masara respectively (Table 4.24). Results showed that there was low level of concentration of Mercury heavy metal contaminant was high in wet tailings concentrations as compared to in Dry Ore. This could be attribute to the activities of the mining of gold processes where Mercury was used to extract gold.

The concentration of Arsenic heavy metals ranged from average mean of 0.80±0.18 to 3.32±0.61 mg/kg in dry ore at Rosternan and Ikolomani respectively and from 0.56±0.38

to 1.81±0.06 mg/kg in wet tailings at Rosterman and Francis. Results showed that there was high level of concentration of Arsenic heavy metals in wet tailings than in dry ore extract. There was a reduction of arsenic metal concentration contaminant at Ikolomani (3.32±0.61 - 0.93±0.24 mg/kg) and Francis (2.02±0.37 - 0.56±0.3 mg/kg) sites in Wet tailing conditions as compared to dry Ore extracts. The reduction might have been attributed to leaching of the heavy metals taking place at the sites or retention of the arsenic metal in an ore that was not detected. There was an increase in arsenic metal concentration at Rosterman (0.80±0.18 - 1.81±0.06 mg/kg) and Masala (0.97±0.01 - 1.42±0.35 mg/kg) in Wet tailings as compared to dry Ore extracts. The increase might have been attributed to activities of refining gold during extraction processes.

Table 4.24: Statistical Comparison of Heavy Metals as per the Sites

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Pb Concentration	Between Groups	21.25	3	7.08	6.84	.001
	Within Groups	45.54	44	1.04		
	Total	**66.79**	**47**			
Cd Concentration	Between Groups	4.22	3	1.41	50.18	.000
	Within Groups	1.22	44	.03		
	Total	**5.43**	**47**			
Hg Concentration	Between Groups	4.26	3	1.42	45.77	.000
	Within Groups	1.38	44	.03		
	Total	**5.64**	**47**			
As Concentration	Between Groups	2.35	3	0.78	2.25	.095
	Within Groups	15.32	44	.35		
	Total	**17.67**	**47**			

The Tukey post hoc test revealed significant differences in Pb concentration between Rosterman and Ikolomani ($p=0.033$). Significant differences were also observed in Cd concentration between Rosterman and Masara ($P<0.0001$), Ikolomani and Masara ($P<0.0001$), Francis and Masara ($P<0.0001$). Significant differences in Hg concentration was found between Rosterman and Francis ($p<0.007$), Rosterman and Masara (p-value<0.0001), Ikolomani and Francis ($P<0.009$), Ikolomani and Masara (p-value<0.0001), Francis and Masara ($P<0.009$) (Table 4.25). Geological parent material as a natural source of heavy metals should not be underestimated as a precise determination of the source of the heavy metals; lead, cadmium, arsenic and mercury. The findings indicate that the miners in the selected sites are at high risk of contamination, which could have serious consequences for their health and future generations. For example, lead poisoning has serious consequences for the children and persons who had been exposed. Lead poisoning, among other health risks, interferes with the normal formation of blood affecting oxygen transportation in humans. The findings also revealed that gold mining activities in the selected sites have resulted in the dispersion of elevated levels of the metals studied in comparison to background levels in the surrounding areas (Ngure & Obwanga, 2017). Concentration of heavy metals among the sites at $p<0.05$ signifies that there are exposure levels to these contaminants as follows; Cd<Hg<Pb<As as indicated by Table 4.26. Artisanal gold miners have a likelihood to get exposure to these heavy metals. The trends are also the same within the sites.

Table 4.25: Presents Significance Difference Levels of Heavy Metals as per the Sites

						95% Ci			
		N	**Mean**	**Std. Dev**	**Std. Error**	**Lower Bound**	**Upper Bound**	**Minimum**	**Maximum**
Pb concentration	Rosterman	3	3.03	.15	.09	2.65	3.41	2.90	3.20
	Ikolomani	3	2.77	.15	.09	2.39	3.15	2.60	2.90
	Francis	3	2.67	.25	.15	2.04	3.29	2.40	2.90
	Masara	3	4.30	.26	.15	3.64	4.96	4.10	4.60
	Total	12	3.19	.70	.20	2.74	3.64	2.40	4.60
Cd concentration	Rosterman	3	.02	.006	.003	.009	.04	.02	.03
	Ikolomani	3	.03	.02	.009	-.005	.07	.02	.05
	Francis	3	.02	.01	.006	-.005	.04	.01	.03
	Masara	3	.19	.02	.009	.15	.22	.17	.20
	Total	12	.0658	.07	.021	.02	.11	.01	.20
Hg concentration	Rosterman	3	.08	.04	.03	-.03	.19	.05	.13
	Ikolomani	3	.13	.05	.03	.02	.25	.08	.17
	Francis	3	.27	.02	.01	.22	.32	.25	.29
	Masara	3	.28	.01	.01	.26	.30	.27	.29
	Total	12	.19	.09	.03	.13	.25	.05	.29
As concentration	Rosterman	3	1.60	.10	.06	1.35	1.85	1.50	1.70
	Ikolomani	3	2.93	.40	.23	1.93	3.94	2.50	3.30
	Francis	3	1.80	.10	.06	1.55	2.05	1.70	1.90
	Masara	3	3.13	.61	.35	1.62	4.65	2.60	3.80
	Total	12	2.37	.77	.22	1.88	2.86	1.50	3.80

** ci Confidence interval for the mean

To check whether there was significant difference in Pb, Hg, Cd and As concentration among the four sites, ANOVA was conducted. Statistically significant differences were observed in Pb, Cd, Hg and As concentrations in the four sites (all the $p<0.0001$) (Table 4.27). This shows that the level of occurrence of these metals in the mining sites is in close ranges. These can cause a synergistic health effect to miners.

Table 4.26: ANOVA of Levels of Heavy Metals within the Study Sites

		Sum of Squares	df	Mean Square	F	Sig.
Pb concentration	Between Groups	5.129	3	1.710	37.994	.000
	Within Groups	.360	8	.045		
	Total	**5.489**	**11**			
Cd concentration	Between Groups	.059	3	.020	130.426	.000
	Within Groups	.001	8	.000		
	Total	**.060**	**11**			
Hg concentration	Between Groups	.089	3	.030	25.734	.000
	Within Groups	.009	8	.001		
	Total	**.099**	**11**			
As concentration	Between Groups	5.453	3	1.818	13.062	.002
	Within Groups	1.113	8	.139		
	Total	**6.567**	**11**			

From the post hoc Tukey tests, statistically significant pairwise differences were found in Pb concentration between Rosterman and Masara ($p<0.0001$), Ikolomani and Masara ($p<0.0001$), and Francis and Masara ($p<0.0001$). Similarly, statistically significant differences were found in Cd concentration between Rosterman and Masara ($p<0.0001$), Ikolomani and Masara ($p<0.0001$), and Francis and Masara ($p<0.0001$). Pairwise Tukey test also revealed statistically significant differences in Hg concentration between Rosterman and Francis ($p<0.001$), Rosterman and Masara ($p<0.0001$), Ikolomani and Francis ($p<0.005$), Ikolomani and Masara ($p<0.003$). Pairwise statistically significant differences were found in as concentration between Rosterman and Ikolomani ($p<0.01$), Rosterman and Masara ($p<0.004$), Ikolomani and Francis ($p<0.024$), Francis and Masara (p<0.01). This study showed that the concentration of these heavy metals in the sites are contributed majorly by the anthropogenic activities that take place at the site.

Multi -variate Analysis Output for Significance Difference of levels of heavy metals as per the sites; Table 4.28. The contaminants of heavy metals were analyzed against selected artisanal gold mining sites significant at 0.05 level (Table 4.28) at the same time well captured in Appendix XII

Table 4.27: Statistical Comparison Levels of Heavy Metals as per the Sites

Dependent Variable	(I) site	(J) site	Mean Difference (I-J)	Std. Error	Sig.	95% CI	
						Lower Bound	Upper Bound
Pb concentration	Rosterman	Ikolomani	.27	.17	.460	-.29	.82
		Francis	.37	.17	.227	-.19	.92
		Masara	-1.27*	.17	.000	-1.82	-.71
	Ikolomani	Rosterman	-.27	.17	.460	-.82	.29
		Francis	.10	.17	.936	-.45	.65
		Masara	-1.53*	.17	.000	-2.09	-.98
	Francis	Rosterman	-.37	.17	.227	-.92	.19
		Ikolomani	-.10	.17	.936	-.65	.45
		Masara	-1.63*	.17	.000	-2.19	-1.08
	Masara	Rosterman	1.27*	.17	.000	.71	1.82
		Ikolomani	1.53*	.17	.000	.98	2.09
		Francis	1.63*	.17	.000	1.08	2.19
Cd concentration	Rosterman	Ikolomani	-.01	.01	.754	-.04	.02
		Francis	.003	.01	.986	-.03	.04
		Masara	-.16*	.01	.000	-.20	-.13
	Ikolomani	Rosterman	.01	.01	.754	-.02	.04
		Francis	.01	.01	.569	-.02	.05
		Masara	-.15*	.01	.000	-.19	-.12
	Francis	Rosterman	-.003	.01	.986	-.04	.03
		Ikolomani	-.01	.01	.569	-.05	.02
		Masara	-.17*	.01	.000	-.20	-.13
	Masara	Rosterman	.16*	.01	.000	.13	.20
		Ikolomani	.15*	.01	.000	.12	.19
		Francis	.17*	.01	.000	.13	.20
Hg concentration	Rosterman	Ikolomani	-.05	.03	.293	-.14	.04
		Francis	-.19*	.03	.001	-.28	-.10
		Masara	-.20*	.03	.000	-.30	-.11
	Ikolomani	Rosterman	.05	.03	.293	-.04	.14

Dependent Variable	(I) site	(J) site	Mean Difference (I-J)	Std. Error	Sig.	95% CI	
						Lower Bound	Upper Bound
		Francis	-.14*	.03	.005	-.23	-.05
		Masara	-.15*	.03	.003	-.24	-.06
	Francis	Rosterman	.19*	.03	.001	.10	.28
		Ikolomani	.14*	.03	.005	.05	.23
		Masara	-.01	.03	.983	-.10	.08
	Masara	Rosterman	.20*	.03	.000	.11	.29
		Ikolomani	.15*	.03	.003	.06	.24
		Francis	.01	.03	.983	-.08	.10
As concentration	Rosterman	Ikolomani	-1.33*	.30	.010	-2.31	-.36
		Francis	-.20	.30	.910	-1.18	.78
		Masara	-1.53*	.30	.004	-2.51	-.56
	Ikolomani	Rosterman	1.33*	.30	.010	.36	2.31
		Francis	1.13*	.30	.024	.158	2.11
		Masara	-.20	.30	.910	-1.18	.78
	Francis	Rosterman	.20	.30	.910	-.78	1.18
		Ikolomani	-1.13*	.30	.024	-2.11	-.16
		Masara	-1.33*	.30	.010	-2.31	-.36
	Masara	Rosterman	1.53*	.30	.004	.56	2.51
		Ikolomani	.20	.30	.910	-.78	1.18
		Francis	1.33*	.30	.010	.36	2.31

*. The mean difference is significant at the 0.05 level. CI Confidence interval

At $p<0.05$, Lead as heavy metal contaminant Levels was significant in selected sites; Ikolomani, Masara and Francis, Cadmium was significant at all artisanal sites which include; Rosterman, Ikolomani, Masara and Francis, and Mercury and Arsenic were significant at all artisanal gold mining sites. This means that there is a significant exposure to these heavy metals from the mining sites.

Figure 4.9 gives the average heavy metal concentrations in hair samples at the four Artisanal Gold Mining Sites as bio-indicator for accumulation of heavy metal due to exposures to contaminant at artisanal gold mining sites.

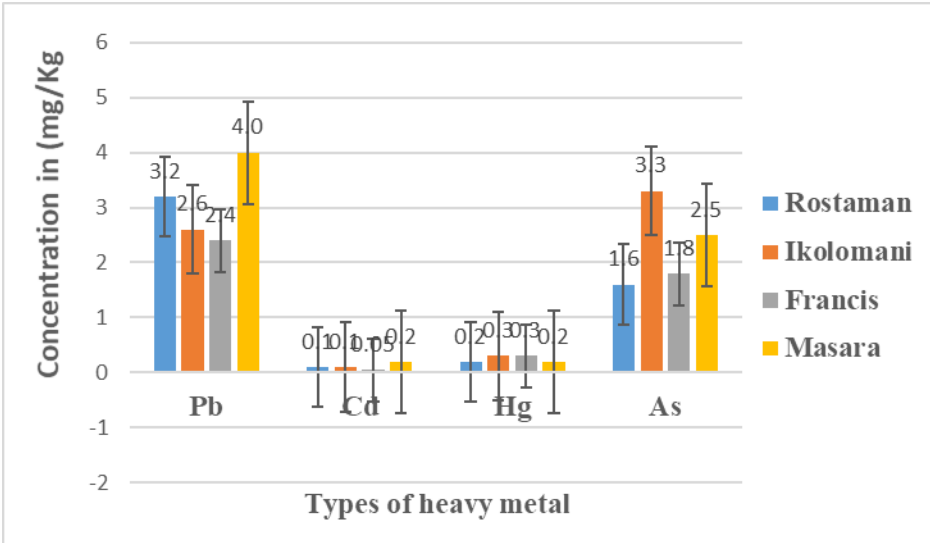

Figure 4.9: Average Heavy Metal Concentrations in Human Hair Samples at Four Artisanal Gold Mining Sites

From the Figure 4.9 it was observed that the concentration of lead accumulated in hair samples was considerably high in all the four sites (Rosterman, Ikolomani, Francis, and Masara being 3.1±0.42, 2.6±0.13, 2.4±0.13, and 4.1±.08 mg/kg, respectively) with high concentration in Masara (4.1±.08 mg/kg). The concentration of Arsenic was also high in all the four sites; Rosterman, Ikolomani, Francis, and Masara being 1.6±0.08, 3.4±0.08, 1.8±0.21, and 2.6±0.08 mg/kg, respectively with the highest in Ikolomani and Masara. However, the accumulation of cadmium and mercury were low at (Rosterman, Ikolomani, Francis, and Masara with averages of 0.051±0.02, 0.04±0.0.06, 0.03±0.03, and 0.07, and 0.21±0.04, 0.18±0.04, 0.19±0.002, and 0.20±0.04 mg/kg, respectively. The World Health Organization (WHO) recommends 0.2 $mgkg^{-1}$ of lead for healthy people. In this study, the obtained values of lead were higher than the limit value. Presence of lead concentrations was high in all samples of hair and nails from the workers in the mining sites. Cd concentration was within ranged as reported in other studies (Shimo *et al.*, 2023). The high levels of lead and arsenic in the hair samples shows a high risk to carcinogens.

Figure 4.10 shows the average concentration of heavy metals contaminants in composite nail sample at artisanal gold mining.

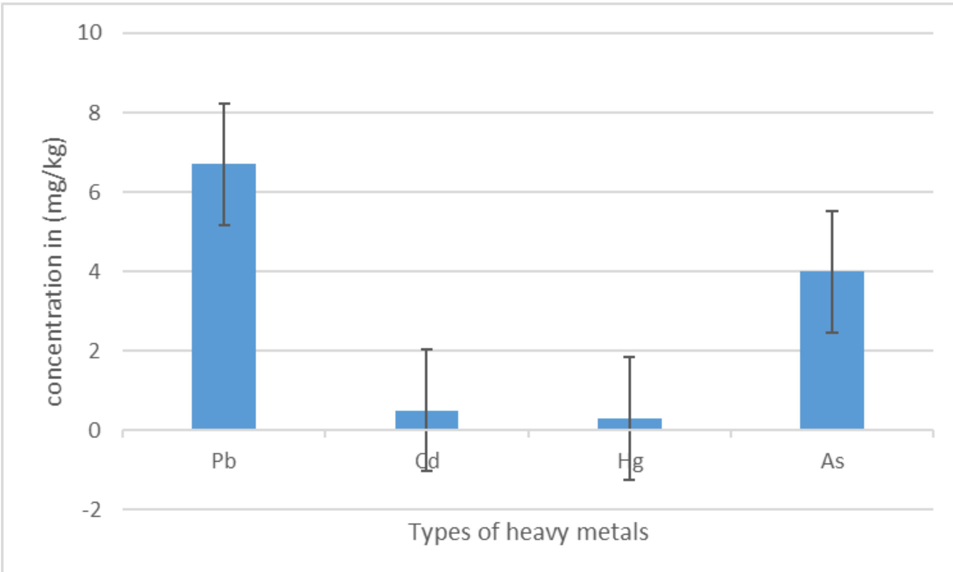

Figure 4.10: Average Concentration of Heavy Metals Contaminants in Nail Sample

The bioaccumulation of Pb and As in the nails was high with Cd and Hg very low. The concentration of lead and arsenic were found high in the nails also, with averages of 6.15± and 3.62±0.12 ppm, respectively. The concentrations of Cd and As were found to be 0.3± and 0.26± ppm, respectively. The high concentration of lead in the hair and in the nails is attributed to gold ore /rock occurrence in the form of galena (PbS) which is found when the ore's sulphide concentration that is high. The high arsenic concentration in hair and nails is due to the fact that arsenic occurs in gold bearing rock as arsenopyrite [FeSAs], realgar [As_2S_2], and orpiment [As_2S_3] (Fashola *et al*., 2016). This suggests that metal exposure at work affects the amounts of metals in the body. Besides, the high concentrations in the nail samples indicate carcinogenic effect that the miners may have.

4.7 Carcinogenic Health Risk Assessment of Heavy Metal Exposure

The current study adopted Mini-tab Technology for statistical analysis to assess Carcinogenic health risk in order to determine hazard quotient (HQ) based on occupational analysis of health risk from heavy metal exposure. The HQ values for dermal contact with wet samples shown in the table 4.29 were all less than 1 (< 1) for both (CTE and RME), signifying no adverse effects to the health of artisanal gold miners exposed to miners in such like pathways (dermal contact).

Table 4.28: Dermal Contact with Dry (Ore Extract) and Wet (Sediment Tailings) Samples

	CTE			RME		
	As	**Cd**	**Hg**	**As**	**Cd**	**Hg**
HQ-Dermal contact with water Rosterman wet	$9.40x10^{-3}$	$2.49x10^{-3}$	$2.76x10^{-4}$	$3.426x10^{-1}$	$9.088x10^{-1}$	$1.005x10^{-2}$
HQ-Dermal contact with water Rosterman dry	$4.14x10^{-3}$	$2.63x10^{-3}$	$1.15x10^{-4}$	$1.509x10^{-1}$	$9.510x10^{-2}$	$4.187x10^{-3}$
HQ-Dermal contact with water Ikolomani wet	$4.81x10^{-3}$	$3.12x10^{-3}$	$4.85x10^{-4}$	$1.750x10^{-1}$	$1.136x10^{-1}$	$1.768x10^{-2}$
HQ-Dermal contact with water Ikolomani dry	$1.73x10^{-2}$	$1.94x10^{-3}$	$2.15x10^{-4}$	$6.298x10^{-1}$	$7.072x10^{-2}$	$7.826x10^{-3}$
HQ-Dermal contact with water Masara wet	$2.89x10^{-3}$	3.4310^{-3}	7.3310^{-4}	$1.055x10^{-1}$	$1.250x10^{-1}$	$2.673x10^{-1}$
HQ-Dermal contact with water Masara dry	$1.05x10^{-2}$	4.4410^{-3}	$3.06x10^{-3}$	$3.820x10^{-1}$	$1.617x10^{-1}$	$1.117x10^{-4}$
HQ-Dermal contact with water Francis wet	$7.36x10^{-3}$	8.1410^{-3}	$1.275x10^{-2}$	$2.684x10^{-1}$	$2.968x10^{-1}$	$4.649x10^{-1}$
HQ-Dermal contact with water Francis dry	$5.02x10^{-3}$	7.5910^{-3}	$5.54x10^{-3}$	$1.831x10^{-1}$	$2.767x10^{-1}$	$2.018x10^{-1}$

It was found that the HQ values were all less than 1, signifying no adverse effects (Table 4.29)

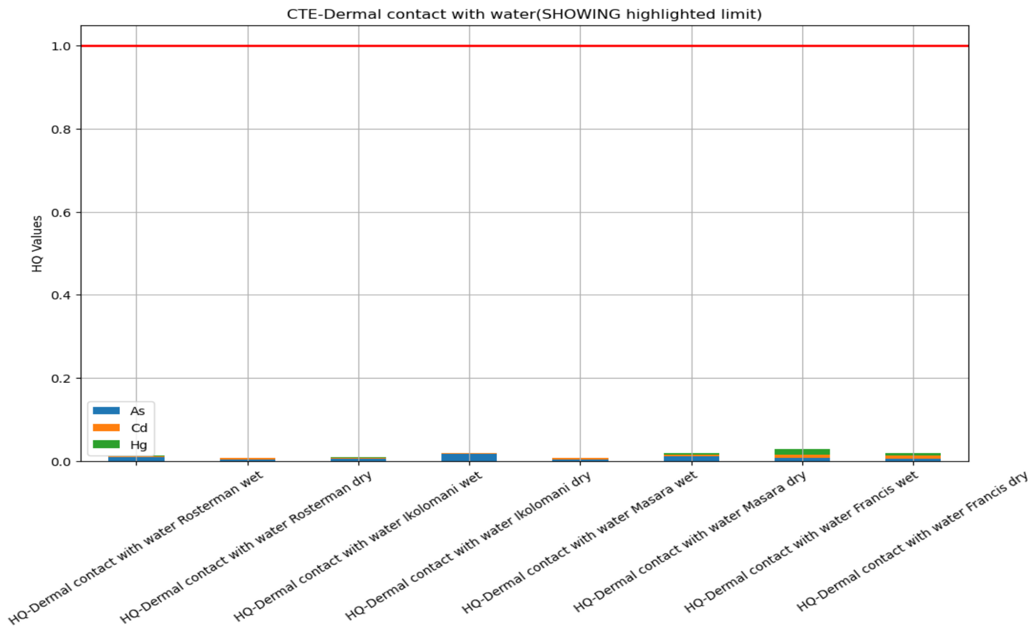

Figure 4.11: CTE-Dermal Contact with Water against the Maximum Limits

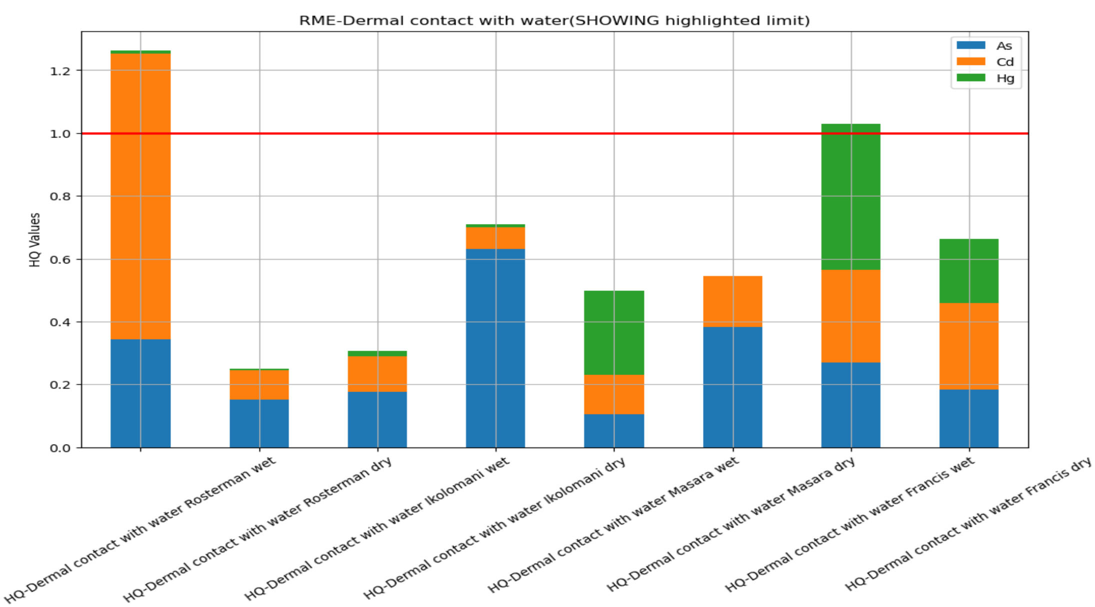

Figure 4.12: RME-Dermal Contact with Water against the Maximum Limits

Key: **X – Axis -** RME (Reasonable Maximum exposure) and – CTE

(Central tendency exposure)

Y – Axis - HQ (Hazard Quotient)

The HQ values for ingestion of sediments samples and the results are shown in the Table 4.30. They were all less than 1, signifying no adverse effects to the health of artisan gold miners at four selected sites.

Table 4.29: Ingestion of Sediment

	CTE				RME			
	As	**Cd**	**Pb**	**Hg**	**As**	**Cd**	**Pb**	**Hg**
HQ-Ingestion of sediment (Rosterman wet)	$2.043x10^{-1}$	$5.419x10^{-3}$	$8.51x10^{-3}$	$3.520x10^{-4}$	1.4895	$3.951x10^{-4}$	$6.205x10^{-4}$	$2.570x10^{-4}$
HQ-Ingestion of sediment (Rosterman (dry)	$9.000x10^{-3}$	$5.724x10^{-3}$	$3.5585x10^{-2}$	$1.470x10^{-4}$	$6.563x10^{-4}$	$4.174x10^{-4}$	$2.595x10^{-4}$	$1.071x10^{-4}$
HQ-Ingestion of sediment Ikolomani (wet)	$1.046x10^{-2}$	$6.775x10^{-3}$	$4.1083x10^{-2}$	$6.200x10^{-4}$	$7.628x10^{-1}$	$4.939x10^{-4}$	$2.996x10^{-4}$	$4.522x10^{-2}$
HQ-Ingestion of sediment Ikolomani (dry)	$3.751x10^{-2}$	$4.217x10^{-3}$	$6.1944x10^{-2}$	$2.750x10^{-4}$	2.735	$3.075x10^{-4}$	$4.517x10^{-4}$	$2.002x10^{-2}$
HQ-Ingestion of sediment Masara (Wet)	$6.289x10^{-2}$	$7.456x10^{-3}$	$2.5531x10^{-2}$	$9.376x10^{-3}$	$4.586x10^{-1}$	$5.437x10^{-4}$	$1.862x10^{-4}$	$6.837x10^{-1}$
HQ-Ingestion of sediment Masara (dry)	$2.278x10^{-2}$	$9.640x10^{-3}$	$5.1099x10^{-2}$	$3.917x10^{-3}$	1.661	$7.029x10^{-4}$	$3.726x10^{-4}$	$2.85585x10^{-1}$
HQ-Ingestion of sediment Francis (wet)	$1.600x10^{-2}$	$1.769x10^{-2}$	$1.1147x10^{-2}$	$1.631x10^{-2}$	1.167	$1.291x10^{-4}$	$8.127x10^{-4}$	1.189
HQ-Ingestion of sediment Francis (dry)	$1.092x10^{-2}$	$1.649x10^{-2}$	$5.4112x10^{-2}$	$7.080x10^{-3}$	$7.960x10^{-4}$	$1.203x10^{-4}$	$3.946x10^{-4}$	$5.162x10^{-1}$

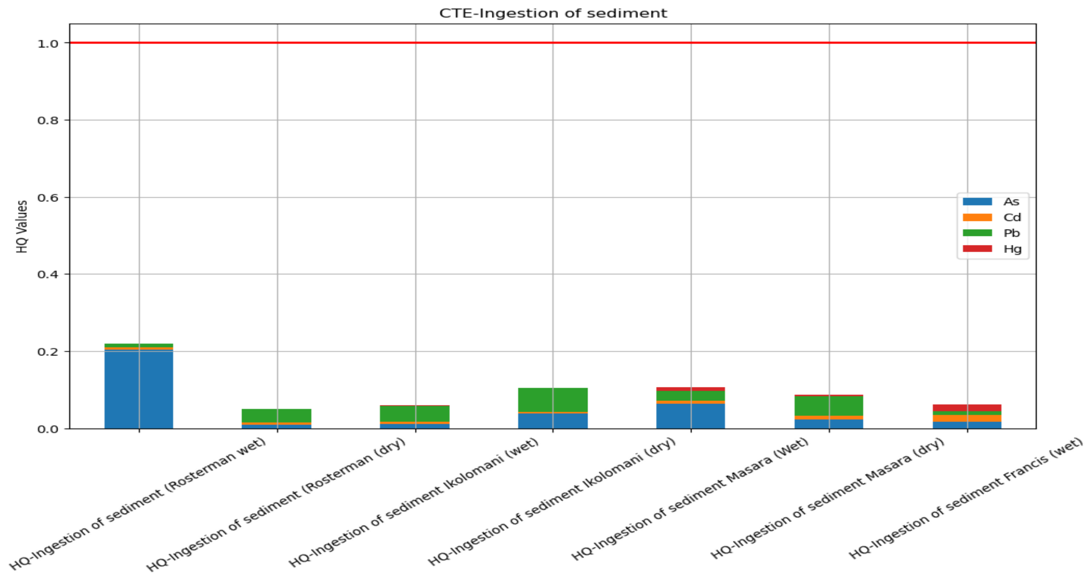

Figure 4.13: CTE-Ingestion Sediment against the Maximum Limits

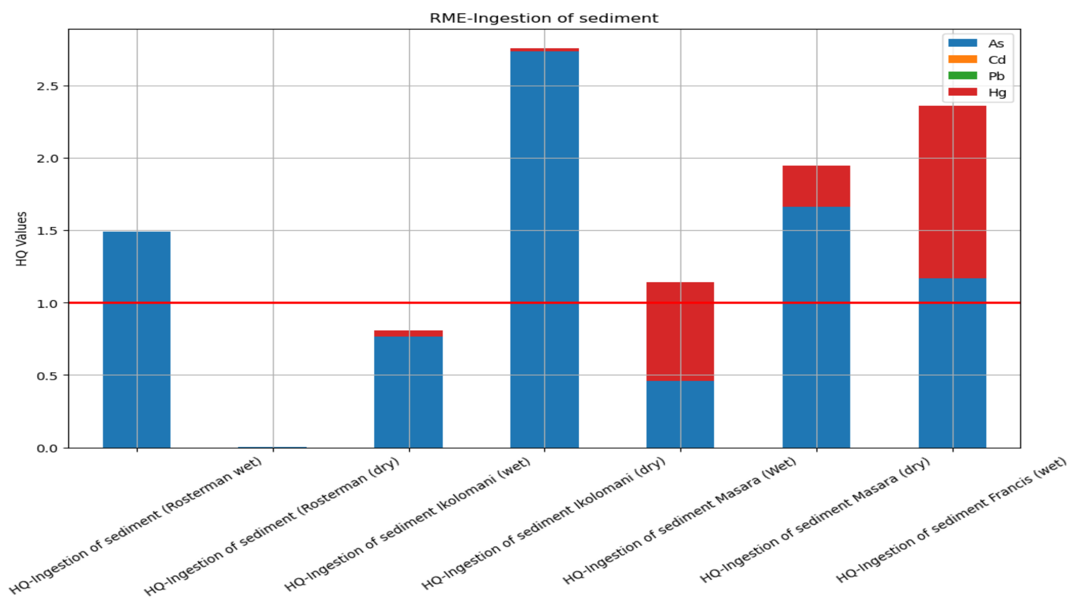

Figure 4.14: RME-Ingestion sediment against the maximum limits

The results for HQ values for ingestion of sediment revealed some values greater than 1, especially for RME (Figure 4.13 and 4.14). This signifies presence of adverse health effects that is likely occur among artisanal gold miners. Agrees with work done on

Assessing the safety and health practices in the artisanal and small-scale gold mining sector of Ghana: A case of Ntotroso (Mensah *et al*., 2022).

Table 4.31 presents HQ values for dermal contact with sediment dry ore.

Table 4.30: Dermal Contact with Sediment Dry Ore

	CTE				RME			
	As	**Cd**	**Pb**	**Hg**	**As**	**Cd**	**Pb**	**Hg**
HQ-Dermal contact with sediment Rosterman wet	6.202 x10^{-3}	5.48x 10-^{5}	8.610 x10^{-4}	3.57 x10^{-3}	5.14x 10^{-1}	4.54x 10^{-3}	7.14x 10^{-2}	2.96 x10^{-2}
HQ-Dermal contact with sediment Rosterman dry	2.732 x10^{-3}	5.79x 10^{-5}	3.601 x10^{-3}	1.44 x10^{-4}	2.26x 10^{-1}	4.80x 10^{-4}	2.984 x10^{-1}	1.23 x10^{-2}
HQ-Dermal contact with sediment Ikolomani wet	3.176 x10^{-4}	6.86x 10^{-5}	4.158 x10^{-3}	6.28 x10^{-4}	2.63x 10^{-1}	5.68x 10^{-3}	3.445 x10^{-1}	5.20 x10^{-2}
HQ-Dermal contact with sediment Ikolomani dry	1.139 x10^{-2}	4.27x 10^{-5}	6.269 x10^{-3}	2.78 x10^{-4}	9.445 x10^{-1}	3.546 x10^{-3}	5.194 x10^{-1}	2.30 x10^{-2}
HQ-Dermal contact with sediment Masara wet	1.909 x10^{-3}	7.55x 10^{-5}	2.584 x10^{-3}	9.49 x10^{-3}	1.58x 10^{-1}	6.25x 10^{-3}	2.141 x10^{-1}	7.86 x10^{-1}
HQ-Dermal contact with sediment Masara dry	6.917 x10^{-3}	9.76x 10^{-5}	5.171 x10^{-3}	3.96 x10^{-3}	5.731 x10^{-1}	8.083 x10^{-3}	4.285 x10^{-1}	3.28 x10^{-1}
HQ-Dermal contact with sediment Francis wet	4.859 x10^{-3}	1.790 x10^{-4}	1.128 x10^{-3}	1.65 x10^{-2}	4.026 x10^{-1}	1.484 x10^{-2}	9.346 x10^{-2}	1.36 7
HQ-Dermal contact with sediment Francis dry	3.314 x10^{-3}	1.670 x10^{-4}	5.476 x10^{-3}	7.17 x10^{-3}	2.746 x10^{-1}	1.383 x10^{-2}	4.537 x10^{-1}	5.94 x10^{-1}

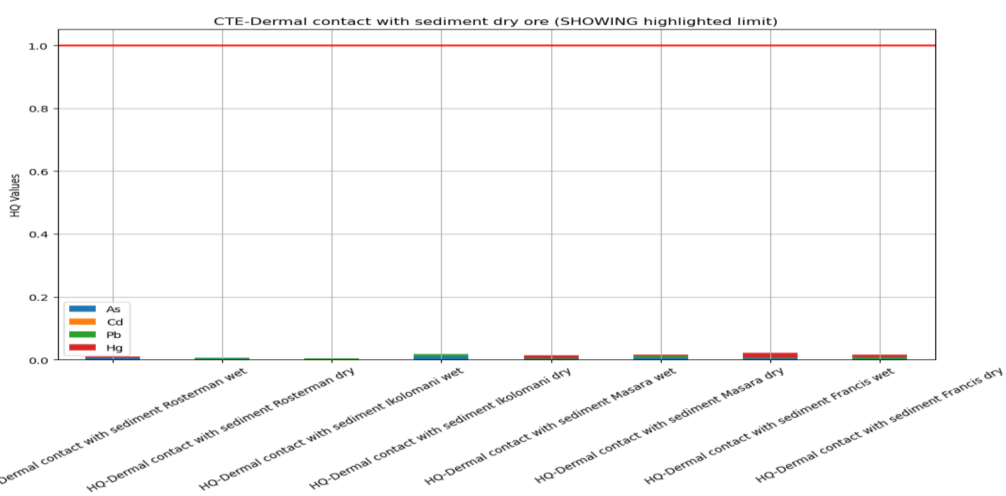

Figure 4.15: CTE-Dermal Contact with Sediment Dry Ore against the Maximum Limits

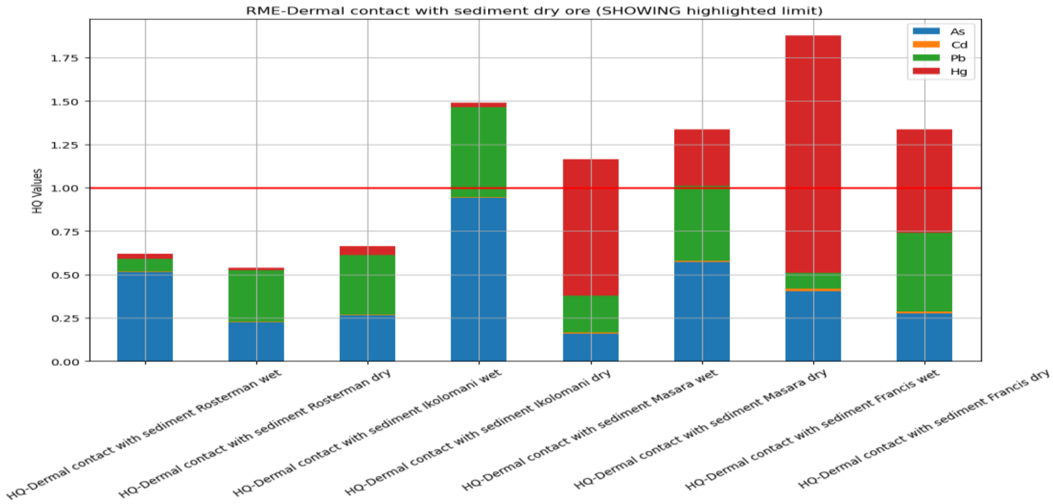

Figure 4.16: RME-Dermal Contact with Sediment Dry Ore against the Maximum Limits

The finding for HQ values for dermal contact with sediment revealed value exceeding 1. The findings indicate that there was likelihood of adverse health effect among artisanal gold mining at selected sites as indicated in Figure 4.15 and 4.16.

Table 4.31: Ingestion Dry Ore

	CTE				RME			
	As	**Cd**	**Pb**	**Hg**	**As**	**Cd**	**Pb**	**Hg**
HQ-Ingestion of water Rosterman wet	$2.540x10^{-5}$	$6.770x10^{-6}$	$1.060x10^{-5}$	$4.410x10^{-7}$	$2.550x10^{-4}$	$6.770x10^{-5}$	$1.060x10^{-4}$	$4.410x10^{-6}$
HQ-Ingestion of water Rosterman dry	$1.125x10^{-5}$	$7.160x10^{-6}$	$4.450x10^{-5}$	$1.840x10^{-7}$	$1.125x10^{-5}$	$7.160x10^{-5}$	$4.450x10^{-4}$	$1.840x10^{-6}$
HQ-Ingestion of water Ikolomani wet	$1.308x10^{-5}$	$8.470x10^{-6}$	$5.140x10^{-5}$	$7.750x10^{-7}$	$1.308x10^{-5}$	$8.470x10^{-5}$	$5.140x10^{-4}$	$7.750x10^{-6}$
HQ-Ingestion of water Ikolomani dry	$4.688x10^{-5}$	$5.270x10^{-6}$	$7.740x10^{-5}$	$3.430x10^{-5}$	$4.688x10^{-4}$	$5.270x10^{-5}$	$7.740x10^{-4}$	$3.430x10^{-5}$
HQ-Ingestion of water Masara wet	$7.861x10^{-6}$	$9.320x10^{-6}$	$3.190x10^{-5}$	$1.170x10^{-5}$	$7.861x10^{-4}$	$9.320x10^{-5}$	$3.190x10^{-4}$	$1.170x10^{-4}$
HQ-Ingestion of water Masara dry	$2.848x10^{-5}$	$1.200x10^{-5}$	$6.390x10^{-5}$	$4.900x10^{-6}$	$2.848x10^{-4}$	$1.200x10^{-5}$	$6.390x10^{-4}$	$4.900x10^{-5}$
HQ-Ingestion of water Francis wet	$2.001x10^{-5}$	$2.210x10^{-5}$	$1.390x10^{-5}$	$2.040x10^{-5}$	$2.001x10^{-4}$	$2.210x10^{-4}$	$1.390x10^{-5}$	$2.040x10^{-5}$
HQ-Ingestion of water Francis dry	$1.365x10^{-5}$	$2.060x10^{-5}$	$6.760x10^{-5}$	$8.85 x10^{-6}$	$1.365x10^{-4}$	$2.060x10^{-5}$	$6.760x10^{-4}$	$8.850x10^{-5}$

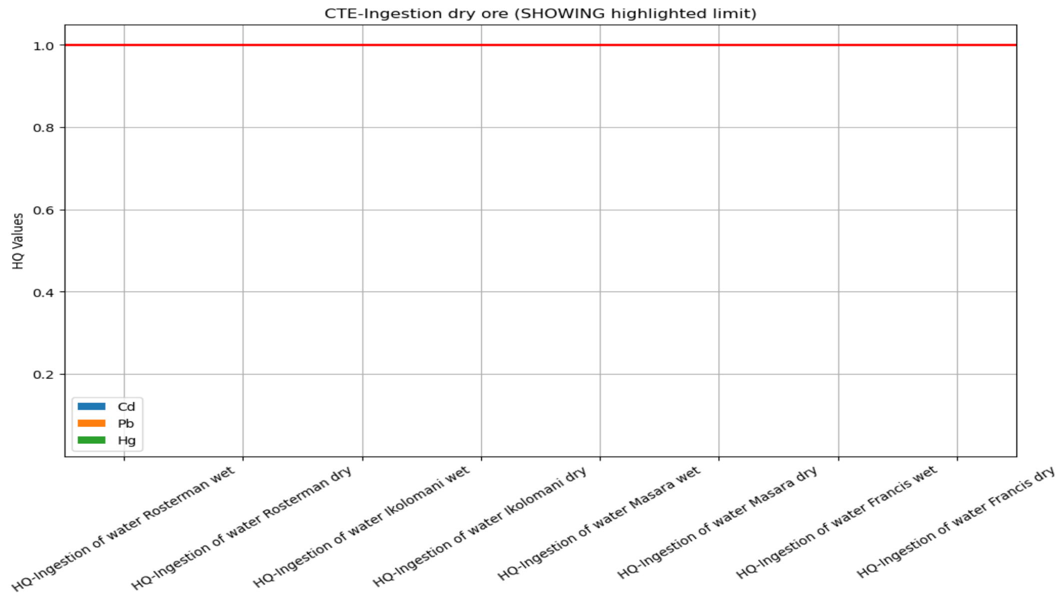

Figure 4.17: CTE-Ingestion Dry Ore against the Maximum Limits

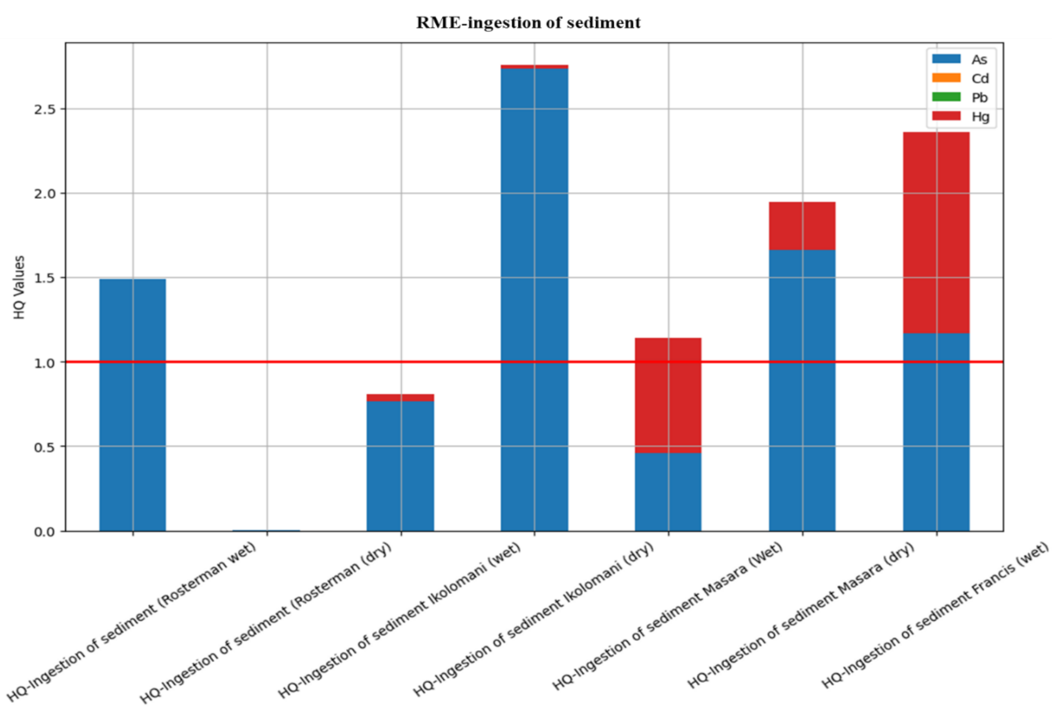

Figure 4.18: RME-Ingestion Dry Ore against the Maximum Limits

The HQ values for ingestion of water (wet sample) revealed no value exceeded one (1), signifying no adverse health effects of exposure to heavy metal contaminant to artisanal gold miners (Figure 4.17). The findings agreed with what was done on Intervention model that presented Human Health Risk Assessment of Artisanal Miners Exposed to Toxic Chemicals in Water and Sediments in the Prestea Huni Valley District of Ghana (Obiri *et al*., 2016). The results for HQ values for ingestion of sediment revealed some values greater than 1, especially for RME (Figure 4.18). This signifies presence of adverse health effects to artisanal gold miners. Study finding agreed with work done on Assessing the safety and health practices in the artisanal and small-scale gold mining sector of Ghana: A case of Ntotroso (Mensah *et al*., 2022). Human health risk assessment: the average intake of the selected heavy metals in the samples via three pathways (ingestion, dermal, and inhalation) indicated in Table 4.29 – 4.32. In Rosterman, Ikolomani, Francis and Masara.

Lead as contaminant in dermal contact pathway was not detected. It was detected in ingestion of sediment. Both CTE and RME were below the levels posing no health risk to miners. The sum of quotient for individual heavy metal at sites CTE = 0.012; RME = 0.444; HIb = 0.456 for wet sample. The results depicted that the total average daily intake of the metals was low since HQ < 1. However, metal intake and the effects they cause originated from the dermal contact, inhalation, and ingestion, which is as a result of the HQ values obtained. The daily intake through the pathways could cumulatively cause adverse health effects to the artisanal gold miners and may lead to carcinogenic effects. Non-carcinogenic assessment: the results depicted in hazard quotient for the presented exposure pathways are presented in Tables 4.29 – 4.32, respectively. The results show that HQ values greater than 1 of the selected metals implied that the metals posed a carcinogenic health effect

Cancer risk assessment: From the tables above there is possibility of carcinogenic risk of ingestion, inhalation, and dermal pathway because of the values that were recorded. These values were found to be higher than the safety limit of 10^{-6} to 10^{-4} that is according to US Environmental Protection Agency. Therefore, the selected metals collectively pose a health risk to the miners Olujimi *et al*. (2015) and Kamunda *et al*., (2016).

4.8 Risk Assessment Proposed at Mine study Site

The current research study has since proposed strategies and remedial action for hazard control at artisanal gold mining sites.

Figure 4.19 shows the proposed strategies/ remedial for human risk assessment at artisanal gold mining site.

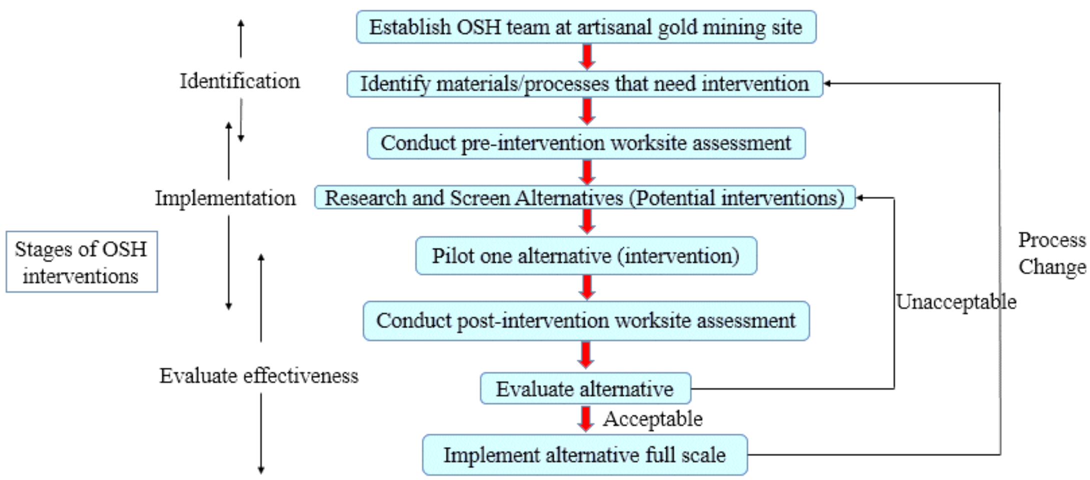

Figure 4.19: Human Risk Assessment Recommendation at Mine Site

Steps to be put in place at workplace in order to manage proactively occupational health hazards at artisanal gold mining site through formulation of safety committees, which is in line with (The Occupational Safety and Health Act, 2007, 2007). The Safety Committee team is mandated to identify, implement and evaluate effectiveness of occupational health and safety interventions at artisanal gold mining activities and implement the same to other selected gold mining worksites in reference to International occupational safety and health standard (International Organization for Standardisation, 2018).

The stages of occupational safety and health interventions at work sites was to be mapped out by the Safety committee to assess toxic exposure to workers, workplace conditions, and work practices vis-a-vis the current OSH- Environmental related laws and policies (Granadillos & Parafina, 2020).

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This chapter presents the conclusions based on the result of study

The first and second null hypotheses (Ho) were rejected at ($P<0.0001$), which was significant at $\alpha = 0.05$, leading to the acceptance that artisanal gold miners are exposed to health risks. Sources of occupational health hazards in artisanal gold mining include physical hazards (machinery/tools and workplace conditions), chemical hazards (exposure to dust and mercury fumes in confined spaces), ergonomic hazards (lifting/pushing heavy loads, prolonged standing, awkward working postures), and biological hazards (standing barefoot in stagnant water for extended periods). Miners are also exposed to varying levels of $P.M_{2.5}$ concentrations; with 24-hour exposure, exceeding the WHO recommended limits of 12.0 to 25.0 $\mu g/m^3$. Additionally, miners face different radiation and noise levels determined by the type and maintenance of machinery used and the process of extracting ore to the surface. Heavy metals such as lead, cadmium, arsenic, and mercury are present in wet sediment tailings and dry ore extracts, with mercury, arsenic, and cadmium concentrations exceeding WHO exposure limits. Furthermore, there is a carcinogenic risk from mercury and arsenic exposure via ingestion and dermal contact among miners in Kakamega and Migori, primarily due to mercury use in gold extraction and resulting environmental contamination.

5.2 **Recommendations**

1. The County government in conjunction with national government should consider registering mines and to train miners on identifying sources of occupational health hazards at artisanal gold mining working site using developed OSH- mining plan manual.

2. Initiating industrial hygiene methods and formulation of risk policy on artisanal gold mining activities using developed OSH-mining plan manual.
3. There should be continuous monitoring of chemicals and other hazardous materials, control and improvement by vetting of Gold miners at artisanal gold mining sites.

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APPENDICES

Appendix I: Study Information Sheet

TITLE OF STUDY

Assessment of Workplace Safety, Health Practices and Provide Intervention in Artisanal Gold Mining in Kakamega and Migori Regions, Kenya

PURPOSE OF STUDY

I would like to invite you to take part in a research study. Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully. Ask questions if anything you need is not clear or would like more information. Take time to decide whether or not to take part. The purpose of this study is to assess occupational safety and health issues in artisanal Gold mining. There was testing and development of an intervention model with aim to protect the healthiness of the population (miners & non-miners) and environment.

VOLUNTARY PARTICIPATION

Taking part in the research is entirely voluntary. You have been selected randomly. I request you to participate freely. The study was described and go through the information sheet, which we will give to you. We will then ask you to sign a consent form to show you agreed to take part. You are free to withdraw at any time, without giving a reason.

STUDY PROCEDURES

I will ask participants who agree to be interviewed questions above and effects of sources of hazards at artisanal gold mining sites. I will also collect samples of sediment tailings and water at mining sites. I will take them to the Laboratory for analysis to determine contaminant concentration levels at four mining sites and compare with accepted standards. Respondents will be involved in answering questionnaire or participating in an interview for approximately 1 hour.

RISKS

There are no foreseeable risks, discomfort or inconvenience arising from participating in this study. However, if an issue is sensitive to you, kindly let me know.

HARM

No participant is anticipated to be harmed in the study.

BENEFITS

No benefits will accrue directly to the participants. However, study results will be shared and are likely to improve workplace practices regarding use of hazardous processes and chemicals.

CONFIDENTIALITY

All information which is collected during the course of the research will be kept strictly confidential.

I will endeavour to preserve participant confidentiality by doing the following:

- Assigning code names/numbers for participants that will be used on all research notes and documents
- Keeping notes in (JKUAT Research Logbook), interview transcriptions, and any other identifying participant information in a locked file cabinet in the personal possession of the researcher.
- Data from participants will be compiled and analysed to answer research questions
- If you withdraw from study, we shall still keep your information securely and dispose after 2 years
- Interview data /questionnaires will be destroyed after 2 years
- The results of the research study will be published and relevant county Governments informed accordingly.

CONTACT INFORMATION

If you have questions at any time about this study, or you experience adverse effects as the result of participating in this study, you may contact the researcher whose contact information is provided below:

Investigator Charles Wafula Buyela

JKUAT

P.O BOX 62000 NRB

O722508563

Supervisor Dr. Paul Njogu

JKUAT, Kenya

0723538887

JKUAT IERC Secretariat, JKUAT, P.O. box 62000-00200 NRB

CONSENT

I have read and I understand the provided information and have had the opportunity to ask questions. I understand that my participation is voluntary and without cost. I understand that I will be given a copy of this consent form. I voluntarily agree to take part in this study.

Participant’s signature __________________________Date_______________________

Investigators signature _________________________ Date_______________________

Appendix II: Miners Individual Interview Questionnaires

Questionnaire number…………… **Mining site**………………………………………….

A. Profile of minors

1. Enter the gender of the respondent	Male [ ] Female [ ]

I would like to ask some personal information; (Tick appropriate answer)

2. Indicate your age	Below18 years [ ] 19-35 [ ] 36-45 [ ] 46-60 [ ] Above 60 [ ]
3. What is the highest level of Education you attained	No Formal Education [ ] Basic Education [ ]

	Post-Secondary [ ]
4. How long have you been engaged in gold mining work activities	Below 5 years [ ] 5-10 [ ] 11-19 [ ] 20-30 [ ] Above 30years [ ]
5. Rank and indicate the most dominant category of people involved in gold mining (1,2,and 3)	1.Men [ ] 2.Women [ ] 3.Children [ ]
6. Does the dominant category people work within OSHA, 2007 act and environmental protection laws in Kenya?	Yes [ ] No [ ]
7. What is the types/color of gold mined	(i) Type of gold………………. (ii) Color of gold mined………..

8. Which type of gold is preferred and why?	………………………………… ……………………………………..
9. How much gold do you mine in one day?	Less than 0.5grams [ ] 10grams [ ] More than 10grams [ ] Other, specify……………………….
10.Does it vary by day ,week ,or month?	………………………………..
11. How much do you earn from mined gold per gram.	Specify……………………………………
12.Indicate the machine/tools that you use in mining gold	Jaw crusher/hammer [ ] Mill/spiral classifiers [ ] Centrifuge concentrators [ ] Shaking tables [ ] Jiko/ pressure stove [ ] Others [specify]……………………….

13. Which type of method do you use to mine gold?	Underground [ ] Open surface (pit) [ ] Any other (specify)------------------------
14. Why is the method most preferred to the miner and why the method is popular?	………………………………………
15. Do you in the course of your work lift heavy objects?	Yes [ ] No [ ]
16. If yes, which ones?	…………………………………..
17. What is the approximate weight?	……………………….
18. How do you lift them	…………………………
19. Do you know ways of proper lifting?	………………………
20. Which type of personal protective equipment do you know?	List them………………………………… ……………………………………….
21.Do you use these personal protective equipment	1.Yes [ ] 2. No [ ]
22. If yes, how often do you use them?	Always [ ] Rarely [ ]

	Never [ ]
23. Who maintains your personal protective equipment?	…………………..
24. What kind of environment do you work in?	……………………………
25. How often do you work in dry or wet condition	Always [ ] Rarely [ ] Never [ ]
21.What are the challenges you experience while working in dry or wet condition	………………………….
22. How many metres do you work at depths	………………………………….
23. What challenges do you face when working at depths	……………………………………
24. Indicate if the following are present or near gold mining sites.	Rivers [ ] Wells [ ] Forest[ ] Wild animals [ ]

Insects [ ]

25.If present, how was it before 5 years ago? ……………………………………..

Appendix III: Hazards/Sources Recording Checklist

Activity	**Hazard identified**	**Remarks**

Appendix IV: Measurement of inhalable particulate matter at mining sites

Particulate matter	**Concentration**	**Remarks**
At $PM_{2.5}$		

Appendix V: Measurement of levels of radiation/Noise at mining sites

Radiation measurement	**Level (Concentration)**	**Remarks**
At point A (inside mine shaft)		
At point B (outside mine shaft)		

Appendix VI: Measurement of Heavy Metals at Mining Sites

Heavy metals	Sediments				Water bodies			
	Wet Season		Dry Season		Upstream		Downstream	
	Top layer	Bottom Layer	Top layer	Bottom layer	Wet Season	Dry Season	Wet Season	Dry Season
Mercury (Hg)								
Cadmium (Cd)								
Arsenic (As)								
Lead (Pb)								

Appendix VII: OSH Knowledge and Practices at Mining Sites

Tick the most appropriate answer to the following questions

5- Strongly Agree, 4- Agree, 3- Neither agree nor disagree, 2- Disagree, 1- Strongly disagree

	5	4	3	2	1
1. There is a law in Kenya that protect workers from hazards associated with mining activities					
2. Inhalable particulate matter can easily cause ill heath among miners					
3. Levels of noise and radiation that exceeds laid down limits by Hazardous rule (OSHA 2007), causes ill health among miners					
4. Exposures to contaminants of heavy metals (Pb, Hg, As and Cd) can easily cause illness among miners and the community surrounding mining activities					
5. Miners who do not use personal protective equipment (PPE) while handling chemicals (Mercury) stand a high chance of developing ill health					

Name any type of (PPE) used while working;-------------------------------

----

6. It is important to read chemical labels before handling them					
7. Work in an environment full of dust is likely to cause diseases					

8. Lifting heavy loads is likely to cause ill health

9.Personal protective equipment are available in local shops

10.Personal protective equipment are affordable

11. I have been trained on safe work practices

12. I have been trained on the need to wear personal protective equipment

13. Mine owners/sponsors conduct training on safe use of chemicals(mercury)

14. Miners are advised on types of gold extractive/process to be used

15. Maintenance of machines and tools reduces the risks of accidents

16. Tools/machinery are sources of injuries in mining activities

17. Landslides are source of injuries in mining activities

18. Chemical exposure in mining activities are sources of ill-health to miners

Appendix VIII: Questionnaire for Health Conditions Attributable to Mining Activities (for miners)

18. Are you or any member of your family involved in mining activities?	Yes [ ] No [ ]
19. If yes which one?	-----------------------------
19. Do you remember any illness in your family which was as a result of gold mining activities?	Yes [ ] No [ ] Can't remember…………………….
20. If yes, how were you then treated?	Bought pain killer [ ] End patient in hospital [ ] Admitted in hospital [ ]
21. For how long were you sick?	A few hours [ ] One day [ ] More than 3 days [ ] More than one moth [ ]
22. What were the symptoms?	Headache [ ] Dizziness [ ] Sneezing [ ]

	Vomiting [ ] Loss of sleep [ ] Breathing problems [ ] Skin Rashes [ ] Others [ ] ……………………………..
23. Have you ever been injured while working?	Yes [ ] No [ ]
24. What caused the injury?	Machine [ ] Tools [ ] Lifting load [ ] Fall from heights [ ] Others [ ]
25. Which part of the body was injured?	Hand [ ] Leg [ ] Back [ ] Head [ ] Others [ ]
26. How long were you i	1day [ ]

njured?	1-2 days [ ] More than 3 days [ ]
27. Where did you get treated?	In hospital [ ] At home [ ] Admitted in hospital [ ]
28. How much did it cost for treatment?	……………………….
29. Have you ever been attacked by wild animals while working?	Yes [ ] No [ ]
. If yes, where were you get treated?	In hospital [ ] At home [ ]
30. Have you ever suffered from Malaria attack?	Yes [ ] No [ ]
31. If yes, how long were you sick?	1 day [ ] 1-2 days [ ] 3 days and above [ ]
32. Where did you get treated?	In hospital [ ] At home [ ] Admitted in hospital [ ]
32. What are the challenges of working underground?	-----------------------------
33. Do you feel pain in the body that may be related to the work that you do	Yes [ ]

	No [ ]
34. If yes, which part of the body aches	Arm [ ] Hand [ ] Shoulder [ ] Back [ ] Neck [ ] Lower back [ ] Legs [ ] Others [ ]……………………………………..
35. Did it lead to disability?	Yes [ ] No [ ]
36. Within the last 12 months, have you been admitted to hospital	Yes [ ] No [ ]
39. What was the nature of your ailment?	Malaria [ ] Bilharzia [ ] Typhoid [ ] Back pain [ ] Aching bones [ ]

	Flue [ ] Pneumonia [ ] Others [specify]…………………………….
40. How long were you treated?	1 day [ ] 1-2 days [ ] 3 days and above [ ]
41. Name of the hospital/heath center attended	……………………………..
42. Type of the hospital/heath center	Government [ ] Private [ ]
43. Distance of the hospital/from your home	…………………….(Km)
44. Within the last 12 months have you been sick or injured but not admitted in hospital?	Yes [ ] No [ ]
45. If yes, state the nature of illness and period you were sick?	………………………………..

Appendix IX: Questionnaire for Health Conditions Attributable to Gold Mining Activities (non-miners)

1. Do you have any member of your family involved in gold mining activities?	Yes [ ] No [ ]
2. If yes which mining activity?	………………………
3.Which health conditions do you associate to mining activity?	Breathing problems Skin rashes Persistent headaches Persistent sneezing Eye –vision impairment Excess sweating Backache
Did you seek treatment?	Yes [ ] No [ ]
If yes, where?	,,
If not, why?	,,,
What was the cost of treatment?	
3. How long were they sick?	A few hours One day

	More than 3 days More than one month
4. Have you ever had any family member injured while mining gold?	Yes [ ] No [ ]
5. If yes indicate what caused the injury?	Machines [ ] Tools [ ] Lifting load [ ] Fall from depths [ ] Exposure to dust [ ] Attack from a wild animal [ ]
6. Which part of the body was injured?	Head [ ] Neck [ ] Back [ ] Shoulder [ ] Leg [ ]
7. Where did they treat injury while mining?	Private hospital [ ] Government hospital [ ]
9.Did it lead to disability?	Yes [ ] No [ ]
10. What was the nature of their ailment?	Back pain [ ] Aching bones [ ] Pneumonia [ ]

	Impaired vision [ ] Others,,,,,,,,,,,,,,,,,,,,,,,,,
11. How long were they treated?	1 day [ ] 1-2 days [ ] 3 days and above [ ] Admitted
12 Where did they get treated?	Private hospital [ ] Government hospital [ ]
13. What was the cost of treatment?	………………………..
14. Indicate the distance of the hospital from gold mining site?	
15. Within the last 12 months have you ever been sick or injured but not admitted in the hospital?	Yes [ ] No [ ]

Appendix X: Questionnaire to Mine Sponsors /landlord, Officers in Charge of Mining Sites

1. Name of the county……………………………………………………………………….

2. Name of the sub-county………………………………………………………………

3. Position/ title of the officer………………………………………………………………….

4. Area represented

i) location--- ii)Size of land------------------------

5. Type/ color of gold mined……………………………………………………………..

6. Do mine owners/ landlords organize trainings on sources of occupational hazards?

Yes [ ] No [ ]

7. Do mine owners/sponsors organize training on safe handling of chemicals (mercury?)

Yes [ ] No [ ]

a. If yes, when was the last training………………………………
b. What training methods were used……………………………………
c. If No, who is responsible for organization of mining site………………….

d. Does your department advice on approved chemicals for use?........................

e. Do you provide personal protective equipment to workers?,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,

f. Is your department satisfied with the use personal protective equipment by miners...

g. In your own opinion, why do miners not apply good occupational safety and health practices in their work …………………………………………………………………

h. What do you do when there is an injury? ……………………………………………

i. Is there any place to report/handle work place injuries?

j. List the challenges you face.-- --- --- ------------------------------

Appendix XI: Sluicing Process in Gold Extraction at Rosterman Mine Taken 2020

Appendix XII: Ikolomani Artisanal Gold Mining Activities Taking Place Captured as of 2020.

Appendix XIII: Amalgamation Process in Gold Extraction Being Executed by a Woman in Ikolomani

Appendix XIV: Noise Meter

Appendix XV: Noise and Radiation Measurement by Researcher at Rosterman Mining Site, 2020

Appendix XVI: Roasting of Gold at Francis Mining Site, Migori, 2020

Appendix XVII: TLD Dosimeter Badge

Appendix XVIII: Purpleair Sensor for Measurement of P.M2.5

Appendix XIX: Geiger Muller Tube

Appendix XX: Women Working at Rosterman Artisinal Mines, 2020.

Appendix XXI: Abandoned Open Mine Pit at Masara Mining Site, Migori, 2020

Appendix XXII: Ethical Approval Letter

JOMO KENYATTA UNIVERSITY
OF
AGRICULTURE AND TECHNOLOGY
P. O. Box 62000-00200 Nairobi, Kenya Tel 0675870225 OR Extn 3209
Institutional Ethics Review Committee

September 20th, 2019

REF: JKU/2/4/896B

Charles Wafula Buyela,
Institute of Energy and Environmental Technology,

Dear Mr. Buyela,

RE: ASSESSMENT OF WORKPLACE SAFETY, HEALTH PRACTICES AND DEVELOPMENT OF INTERVENTION MODEL IN ARTISANAL MINING IN KENYA

The JKUAT Institutional Ethics Review Committee has reviewed your responses to issues raised regarding your application to conduct the above mentioned study with you as the Principal Investigator.

The is to inform you that the IERC has approved your protocol. The approval period is from September 20th 2019 to September 20th 2020 and is subject to compliance with the following requirements:

a) Only approved documents (informed consent, study instruments, study protocol, etc.) will be used.
b) All changes (amendments, deviations, violations, etc.) must be submitted for review and approval by the JKUAT IERC before implementation.
c) Death and life threatening problems and severe adverse events (SAEs) or unexpected adverse events whether related or unrelated to the study must be reported to the IERC immediately.
d) Any changes, anticipated or otherwise that may increase the risks to or affect the welfare of study participants and others or affect the integrity of the study must be reported immediately.
e) Should you require an extension of the approval period, kindly submit a request for extension 60 days prior to the expiry of the current approval period and attach supporting documentation.
f) Clearance for export of data or specimens must be obtained from the JKUAT IERC as well as the relevant government agencies for each consignment for export.
g) The IERC requires a copy of the final report for record to reduce chances for duplication of similar studies.

Should you require clarification, kindly contact the JKUAT IERC Secretariat.

Yours Sincerely,

DR. PATRICK MBINDYO
SECRETARY, IERC

INSTITUTIONAL ETHICS REVIEW COMMITTEE
20 SEP 2019
APPROVED
P.O. Box 62000-00200
NAIROBI
JKUAT

JKUAT is ISO 9001:2015 and ISO 14001:2015 Certified
Setting Trends in Higher Education, Research, Innovation and Entrepreneurship

Appendix XXIII: Ministry of Mines Recommendation Letter

HARAMBEE

REPUBLIC OF KENYA

MINISTRY OF PETROLEUM AND MINING
STATE DEPARTMENT FOR MINING

Ministry of Petroleum and Mining, State Department for Mining,
Kakamega
P.O. Box 1983 – 50100,
KAKAMEGA

5th September 2020.

To Whom It May Concern

RECCOMENDATION FOR WAFULA BUYELA

Mr. Wafula is undertaking a research work on Occupational Health Risk Analysis and Surveillance in Artisanal and Small Scale Mining in Western Region. This is in alignment with the ongoing formalization and registration of the artisanal mines. His research work will help to inform on key priority areas during our planning which will further address the persistent challenges especially in his area of research.

Any assistance accorded him will be highly appreciated.

REGIONAL INSPECTOR OF MINES
05 SEP 2020
SIGN:
P.O. Box 1983-50100, KAKAMEGA

JACOB MUTUA
INSPECTOR OF MINES
KAKAMEGA REGION

Appendix XXIV: KEBS Calibration Certificate

ORIGINAL

Kenya Bureau of Standards
P.O Box 54974–00200
NAIROBI
Tel:(+254 020) 6948000
info.metrology@kebs.org
Website: www.kebs.org

KEBS
CALIBRATION MARK

Calibration Certificate

Page...1..of..2..pages

REQUESTED BY	:	WAFULA CHARLES
ADDRESS	:	P.O. BOX 62000 - 00200, NAIROBI
EQUIPMENT	:	GEIGER- MULLER COUNTER
TYPE/MODEL	:	N/A
SERIAL NO.	:	09028-00
LABORATORY	:	RADIATION DOSIMETRY LAB.
MANUFACTURER	:	PHYWE
DATE	:	2019-12-11
CERTIFICATE NO.	:	BS/MET/16/3/439
STICKER NO.	:	51755

1.0 **STANDARD EQUIPMENT USED**

Cesium – 137 gamma irradiator source, calibrated using ionization chamber LSOI S/No TW32002-00349 calibrated at PTB *(Physikalisch-Technische Bundesanstalt)*.

2.0 **PRECALIBRATION CHECKS**

2.1 Batteries performance- okay
2.2 Mechanical integrity- okay
2.3 Speaker/audio- okay
2.4 Check source response-okay
2.5 GM Voltage set to 500V
2.6 Reference of the detector tube taken at marker

3.0 **CALIBRATION METHOD**

3.1 The survey meter was calibrated according to procedure *MET-LP-19/17- Cs: Gamma Calibration procedure and Quality control.*

3.2 The detector of survey meter was irradiated in the horizontal position alo the central axis beam facing the source.

Prepared by: ***Collins Omondi*** Date: ***2019-12-11***

Checked by: Grace Ateka Date: 2019-12-17

Appendix XXV: Statistical Comparison Levels of Heavy Metals as per the Sites

Dependent Variable	(I) Mining site	(J) Mining site	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Pb Concentration	Rosterman	Ikolomani	-2.61*	.87	.033	-5.05	-.17
		Francis	-1.44	.87	.373	-3.88	.998
		Masara	-.94	.87	.708	-3.38	1.50
	Ikolomani	Rosterman	2.61*	.87	.033	.17	5.05
		Francis	1.17	.87	.549	-1.27	3.61
		Masara	1.67	.87	.252	-.77	4.11
	Francis	Rosterman	1.44	.87	.373	-.998	3.88
		Ikolomani	-1.17	.87	.549	-3.61	1.27
		Masara	.50	.87	.938	-1.94	2.94
	Masara	Rosterman	.94	.87	.708	-1.50	3.38
		Ikolomani	-1.67	.87	.252	-4.11	.77
		Francis	-.50	.87	.938	-2.94	1.94
Cd Concentration	Rosterman	Ikolomani	.007	.14	1.000	-.39	.41
		Francis	-.26	.14	.281	-.66	.14
		Masara	-1.02*	.14	.000	-1.42	-.62
	Ikolomani	Rosterman	-.007	.14	1.000	-.41	.39
		Francis	-.27	.14	.261	-.67	.13
		Masara	-1.03*	.14	.000	-1.43	-.63
	Francis	Rosterman	.26	.14	.281	-.14	.66
		Ikolomani	.27	.14	.261	-.13	.67
		Masara	-.76*	.14	.000	-1.16	-.36
	Masara	Rosterman	1.02*	.14	.000	.62	1.42
		Ikolomani	1.03*	.14	.000	.63	1.43
		Francis	.76*	.14	.000	.36	1.16
Hg Concentration	Rosterman	Ikolomani	-.02	.15	.999	-.44	.41
		Francis	-.57*	.15	.007	-.99	-.14
		Masara	-1.01*	.15	.000	-1.44	-.59
	Ikolomani	Rosterman	.02	.15	.999	-.41	.44
		Francis	-.55*	.15	.009	-.97	-.12
		Masara	-.995*	.15	.000	-1.42	-.57
	Francis	Rosterman	.57*	.15	.007	.142	.99
		Ikolomani	.55*	.15	.009	.12	.97
		Masara	-.45*	.15	.037	-.87	-.02
	Masara	Rosterman	1.01*	.15	.000	.59	1.44
		Ikolomani	.995*	.15	.000	.57	1.42
		Francis	.45*	.15	.037	.02	.87

*. The mean difference is significant at the 0.05 level.