

MALAWI UNIVERSITY OF SCIENCE AND TECHNOLOGY

NDATA SCHOOL OF CLIMATE AND EARTH SCIENCE

DEPARTMENT OF EARTH SCIENCES

ASSESSING ENVIRONMENTAL IMPACTS OF ARTISANAL AND SMALL-SCALE GOLD MINING IN NATHENJE, LILONGWE

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ESC/006/20

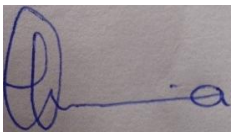
DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE BACHELOR OF SCIENCE DEGREE IN EARTH SCIENCES (GEOLOGY)

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DATE: 29th April 2025

DECLARATION

I Frank Chakomba declare that this research project represents my work and that it has never been submitted to this institution or any other institution for any academic purpose. All sources of information have been appropriately acknowledged.

SIGNATURE 

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ABSTRACT

The study was conducted in the Lumwira Village, T.A. Mazengera, Nathenje where villagers are extracting gold from their land illegally. It was aimed at assessing the environmental impacts of these activities through three specific objectives which were assessing water quality through three physical parameter (turbidity, Total Suspended Solids (TSS) and Total Dissolved Solids (TDS)). The second specific objective was assessing soil quality by looking at physical characteristic (soil texture) which is one of the factors that determines the productivity of the soil. Lastly it looked at land use and land cover changes in the areas. The study employed both qualitative and quantitative methodology by reviewing existing data, sampling of water and soils that later undergoes laboratory analysis to examine the impacts of mining activities in the area through these samples. Remote sensing data was also used to determine land use and land cover change. The findings revealed that mining activities affect water quality by contributing to significantly higher levels of turbidity (r=.998) and Total Suspended Solids (TSS) (r=999) with 5% level of significance and Total Dissolved Solids was not really affected as the levels are below recommendations. It further revealed that the soil textures at the mining site are sandy loam and loamy sand with high proportion of sand particles and little in silt and clay proportions due to the exposure of the land to erosional agents like surface runoff water. These soils at mining site are not productive to agricultural purposes. It has also noticed that the land use and land cover changes due to many factors with mining contributing to increased bare land and decreasing vegetation. It then recommended that appropriate steps should put in place such as formalization of ASMs through implementing the ASMs licences to corporate groups, community engagement and sensitization on the environmental implications of ASMs and monitoring of ASM sites by responsible authorities to make sure miners are abiding by the laws and regulations to protect the environment. This is to avoid further destruction of other environmental resources through inadequate awareness campaign and sensitization of the community about the negative impacts of the ASMs and to put environment into consideration whenever they are mining.

ACKNOWLEDGEMENT

I firstly thank God for keeping me alive up to this far His unwavering grace and mercy throughout my academic life cannot remain unappreciated.

Secondly, I extend my warm heart gratitude to my supervisor Mr. Richard Mvula for his invaluable support and guidance throughout my research journey, which started at developing a topic up to completion of the project.

I also thank my friends and classmates for their supports and encouragement whenever I feel down in my mind throughout the academic journey.

I lastly thank my family, my father, my mom and my brothers for their encouraging words. Their advice, support and motivation gave me strength to work hard in my academics and to pass through hard times I have been encountering throughout the academic journey.

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LIST OF ABBREVIATIONS

ABBREVIATION	WHAT IT STANDS FOR
ASM	Artisanal and Small-scale Mining
ASGM	Artisanal and Small-scale Gold Mining
ATM	Agriculture, Tourism and Mining
ArcMap/ArcGIS	Geographical Information System software
SDGs	Sustainable Development Goals
WHO	World Health Organization
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
GDP	Global Domestic Products
LULC	Land Use Land Cover
FAO	Food and Agriculture Organization
USGS	United States Geological Survey
NTU	Nethrometric Unit
USDA	United States Department of Agriculture
MUST	Malawi University of Science and Technology

CHAPTER ONE: BACKGROUND AND INTRODUCTION

1.0. Introduction

As Malawi is looking forward to achieving Vision 2063, there are number of areas that needs to be looked at when working to achieve Sustainable Development Goals (SDGs). One of the areas that needs much effort is the idea of ATM, which is Agriculture, Tourism and Mining as one of the pillars that will bring a change in the country economy when implemented. As mining sector is one of the pillars of SDGs it needs much attention as it affects the environment badly if not managed well (Mensah et al, 2015). The mining sector includes both large-scale, medium, small-scale and artisanal mining. With increasing discovery of mineral deposits in Malawi, Nathenje as one of the areas where it is believed to host placer gold (Haundi et al, 2021). This has attracted many artisanal and small-scale miners to flood the area to extract the mineral. This has brought to my attention the idea to assess the environmental impacts of these ASM activities in Nathenje with Lumwila village being the target where many villagers are extracting gold.

1.1. Background

Not all mining is done by large companies deep below ground or with expensive machinery in large open pits. Worldwide, millions of people labour with primitive tools, like picks, shovels, and pans to extract valuable resources from the Earth. This workforce of artisanal and small-scale miners is commonly itinerant, without much education or training. Many of the small-scale miners are earning their living through extraction of valuable resources like gold, diamonds and other gemstones include usable commodities for example, sand, coal and mica (Franklin W. et al., 2021). The socioeconomic importance of artisanal and small-scale mining (ASM) for precious minerals has been widely acknowledged by researchers. ASM provides employment, supports the livelihoods of impoverished rural communities, and contributes to national economies through taxes, exports, and the supply of raw materials to local industries (Hilson, 2016). According to the World Bank (2013), around 100 million people globally rely on ASM for their livelihood.

Although ASM have economic benefits, it also has environmental consequences, including mercury pollution, land degradation, and threats to biodiversity (Bansal et al., 2018). Additional concerns include water pollution, damage to landscapes, and public health risks due to inadequate sanitation (Anyona & Rop, 2022). The environmental impacts of artisanal and small-scale gold mining (ASGM) are currently a major issue globally. There is cause for concern given the rapid loss of forest resources and pollution of water bodies through contamination with heavy metals like cyanide, arsenic, and mercury (Cudjoe et al., 2023). The environmental and socio-economic effects of ASM are enormous, as a wide range of biophysical and socio-economic components of the environment are affected. ASM activities produce massive solid wastes and pits which cause environmental degradation. Thus, ASM contributes to river siltation, deforestation, loss of biodiversity, soil erosion; pollution of sources of drinking water (Liman et al, 2021). A study by Bansal et al. (2018) in the Bonsa River in Western Ghana found that water quality was severely impacted by turbidity, as well as elevated levels of manganese and iron from ASM activities, causing the water quality index to exceed the safe limits for drinking by at least 500%.

There are number of factors that leads to the increase in artisanal and small-scale mining globally. In many of the developing countries, ASMs are poverty driven with the involvement of people of different sex, age and other social groups in ASM operations to generate income (Ahmed & Oruonye, 2016). In Malawi, the growth of artisanal small-scale mining has been driven by the discovery of various mineral resources such as gold and gemstones across the country (Malawi-Mining and Minerals, 2024). It has also been noticed that poverty among people living in rural areas like Nathenje has contributed a lot to the growth of ASM activities in the area. Lilongwe is one of the districts experiencing an increase in ASM activities, with people extracting resources like gold, providing a source of income for both seasonal and permanent miners (Haundi et al., 2021; Dakalira et al., 2017).

However, these mining activities often lead to significant environmental damage in the areas where they occur (Fritz et al., 2018). Lilongwe, located in Central Malawi, is known for its widespread ASM activities, particularly gold extraction, alongside other districts such as Mangochi, Balaka, and Kasungu (Haundi et al., 2021). In the district,

especially the Nathenje area, is rich in valuable minerals, including gold, which attracts many artisanal miners (villagers) and other individuals (Malawi-Mining and Minerals, 2024). The villagers in the area are engaged artisanal gold mining, without considering the environment this increases environmental damage. This study aims to explore the environmental impacts of ASM activities in the Nathenje area, focusing on Lumwila village and Talira River in Group Villagehead Mdzeka, Traditional Authority Mazengela.

1.1.1. Background of ASMs in Nathenje

Artisanal and small-scale mining Nathanje started 10 to 15 years back and seen booming around 2015 to 2020. Mines and Minerals Act 2023-Part XI section 192 gives authority and power to Local Government to grant and regulate artisanal mining permits and make by-laws for this purpose. Section 196 of Mines and Minerals Act 2023 says artisanal mining permit may only be granted to mine minerals used in local area construction provided that among others, artisanal mining will not have significant impacts on the environment. Mining in Nathenje as with the case in other area where gold is extracted, it done illegally as the gold which is supposed to be extracted under small-scale as of Part X of Mines and Minerals Act, is not local construction mineral (Mines and Minerals Act, 2023). The government's stop order came after three Lilongwe women lost their lives along Nathenje Riverbank following collapsing of the land where the three were extracting gold (). It was discovered that by 2018 Makanjira in Mangochi, Lisungwi in Balaka and Nathenje in Lilongwe has over 5,000 gold miners (illegal). These miners were given a deadline of 28th July 2020 to vacate the land which proven not working as of year 2021, over 50 gold illegal buyers were noticed in Nathenje (Mining and Trade, 2018). Mines and Minerals Act 2023 elaborated that any mining activity needs to have its corresponding mining permit, but this has been failing to be implemented due to the poor funding of the sector leading to the increased number of illegal artisanal and small-scale miners in the country.

1.2. Problem Statement

Mensah et al., (2015) assessed the environmental impacts of mining in Prestea Huni-Valley District in the Western Region of Ghana, and the findings from the study showed that mining activities, especially that resulting from illegal small-scale mining deplete

environmental resources such as water, soil, the landscape, vegetation, among others. The findings further shows that the major rivers in the region have been heavily polluted, especially by illegal small-scale mining; land in areas surrounding mines has been rendered bare and susceptible to increased erosion and loss of viability for agricultural purposes and increased clearing of vegetation for mining areas.

The study aimed to evaluate the environmental and socio-economic impacts of SSM activities in the Atiwa East District of Ghana through three key objectives: analyzing mining methods, assessing waste generation and management practices, and examining environmental and socio-economic consequences revealed that mining activities predominantly occurred in forested areas, involving alluvial/surface and underground gold mining techniques. The primary waste products identified were overburden, gravel, and wastewater. The study was conducted across six Small-scale mining sites and documented 50 overburden heaps with a combined volume of 610,933.22 cubic feet and 49 gravel heaps totalling 75,784.43 cubic feet. The environmental impacts of SSM were significant, including the destruction of crops, soil infertility, and widespread pollution, such as contamination of the Birim River, with pollution levels exceeding WHO guidelines. (Mensah et al, 2025)

In Malawi, research has been carried out, with many of them focus on investigation of the socio-economic effects of ASM (Haundi et al., 2021; Hilson, 2016). In Mzimba district, the study focused on the influence of ASMs on livelihoods and other factors hindering ASM-related livelihood activities (Dakalira et al., 2017). A study by Chikanda et al. (2022) aimed at assessing the impacts of ASGM on the Lisungwi and Kaphamtengo rivers in Manondo where they evaluated the water quality of these rivers. Despite the increasing number of ASMs in Lilongwe more especially in Nathenje where people are mining gold, no studies have examined their environmental impacts to show whether these villager and other individuals who mine gold in the area put environment into consideration. This attracted my attention to assess the environmental impacts of these artisanal and small-scale mining activities in this project with Lumwila village in Nathenje, Lilongwe being my study area.

1.3. Main and Specific Objectives

This project was aimed at assessing the environmental impacts of artisanal and small-scale gold mining activities that are growing in Nathenje, Lilongwe with Lumwila village being sample area. This main objective was achieved through three specific objectives, which were;

I. To evaluate the effects of artisanal and small-scale gold mining (ASGM) on water quality physical parameters in Talira River.
II. To determine the impacts of ASGM on soil texture, which is one of the physical properties of soil that determines its productivity when it comes to agriculture productivity of the soil.
III. To conduct land use land cover change detection of an area to show how ASGM activities affect the land cover as these activities are increasing in Nathenje, Lilongwe.

1.4. Research Questions

This dissertation provides answers to several questions ensuring that environmental implications of artisanal and small-scale mining activities in the area are properly addressed. The following questions were answered by the dissertation.

On water quality, the following questions were answered.

I. Why water quality focussing on turbidity and total dissolved solids was assessed in relation to artisanal and small-scale mining activities in the area?
II. To what extent are the parameters (turbidity, total suspended solids and total dissolved solids) contaminating water in the Talira River that flows across the area?
III. By how much is the water quality differ from standards of portable water standards?

On soil, the following questions were answered.

I. Why soil texture, which is physical property of soil, was examined?
II. What is the relationship between ASGM activity and soil productivity in an area?
III. How ASGM affect the soil texture of the area?

On land use land cover, answers to the following questions were provided.

I. To what extent is the land use land cover changes in Nathenje over time due to the ASGM activity?
II. How ASGM contributed to changes in vegetative cover, agricultural land, water bodies and land uses?
III. Are the changes directly or indirectly related to ASGM activities in Nathenje area?

1.5. Significance of the Study

This research based on its finding, it has given an overview on how people living in villages around Group Village Headman Mdzeka, which is one of the areas where these ASGM activities are taking place have been affected. Upon the review of these findings, the environmental factors will be considered, and conservation measures will be guided whenever we are engaging in ASM activities since environment and ASM activities are interlinked and some of the impacts have been shown through this project.

Through this project, the impacts of ASGM on water as well as land have been shown in the villages of Mafuta and Lumwira in the area of T.A. Mazengera. ASGM activities have led to increased rate of soil erosion as the dugout soils are just left all over the area as well as sedimentation and contamination of Talira River. Therefore, this study has helped in giving the extent of these impacts for all the stakeholders to take appropriate measures to restore the land to its initial productivity as many of these lands where gold is extracted were initially used for agricultural purposes. Land cover changes that have been analysed in this project will help in land use planning and reclamation efforts in the area by adopting new measures that the miners should avoid further occurrence of the undesirable impacts.

Public health concerns will be addressed properly as this project through the observation made on the area, indicated that artisanal and small-scale mining activities in the area of study has leads to the creation of stagnant water bodies which are possible breeding grounds for disease vectors such as mosquitos that increases the spread of malaria. The study, therefore, will help in controlling vector borne diseases like malaria by advising the artisanal miners to find alternative ways of washing the soil rather accumulating waters around the sites.

As Malawi is focussed on achieving Sustainable Development Goals (SDGs) through Agriculture, Tourism and Mining (ATM) this project has contributed to the understanding of the environmental implications of ASM sector which is under the Mining Sector. This will help in the implementation of sustainable environmental practices by advising the miners to adhere to the Environmental Laws and Regulations when engaging in the ASMs to minimize environmental degradation and promoting well-being of people living in areas where there are these activities. Furthermore, this study has an ability to promote community awareness about the environmental and health impacts of ASM, fostering community engagement and support for environmentally sustainable practices.

CHAPTER TWO: LITERATURE REVIEW

2.0. Overview of Artisanal and Small-Scale Mining

In many resource-rich rural communities mostly in developing countries, artisanal and small-scale mining continues to grow. A recent study by IGF (2017) estimates the growth of ASMs and come out with population of people involved in ASMs. In 2017, 40.5 million people were directly engaged in ASM an increase from 30 million people in 2014. The population of people engaged in ASM was at 13 million and 6 million in 1999 and 1993, respectively. With reference to gold extraction in Ghana, Owusu et al. (2019) found that there was also an increase in production from 20,000 ounces (567.0 Kgs) in 1990 to 1.6 million ounces (45,359.2 Kgs) in 2016.

Artisanal and small-scale mining (ASM) is crucial globally, often employing as many people as large-scale mining. Artisanal and small-scale mining (ASM) plays a crucial role in socioeconomic empowerment to the rural and remote communities where people do not have many options for income generating activities (Hilson, 2009). In recent years, low technology, labour intensive mineral extraction and processing artisanal and small-scale mining has become income generating activity in hundreds of rural and semi urban communities across sub-Saharan Africa. Based on individual country estimates, ASM employs at least 20 million people in the region (Hilson et al., 2018). Several studies have characterized ASM by exploitation of small deposits, having poor capital, lacking standards to ensure health and safety, being labour intensive and having significant environmental impacts (Buxton, 2013) & (Girard et al., 2022). ASM significantly aids in poverty alleviation and rural development, as it provides the primary income source for many local individuals (Hentschel et al., 2002).

In some of the world's poorest countries, people use basic tools to mine valuable resources, facing numerous health risks such as accidents, dust inhalation, and toxic exposure (Schwartz et al., 2021). ASM provides livelihoods to 2 to 3% of world's population and about 60 million people in Africa depend on ASM to extract minerals (World Bank, 2020). ASM is both an important driver of economic development and a major driver of deforestation and environmental degradation (Girard et al., 2022) & (Mossa & James, 2013). Despite these disadvantages, ASM remains economically beneficial, supporting over 40 million people in developing countries, especially in

remote areas (World Bank, 2019). This underscores ASM's reliability as a livelihood despite its environmental impacts.

2.1. Artisanal and Small-Scale Mining Impacts on Environment

Artisanal and small-scale mining activities poses various environmental implications as most of them are illegally operated across the world. Mensah et al. (2015) discovered in their study that mineral exploration contributes economic growth and development in Ghana. Being second largest gold producer, mining contributes to about 5.7% of the country's GDP. However, mining activities both artisanal and small-scale and large-scale each contributes to varying impacts on the environment. The findings revealed that mining activities especially illegal small-scale mining deplete environmental resources such as water, soil, the landscape, vegetation, the ecosystem, among others. This was the cause of the concerns for both Ghanaian government and the residents in the mining community following the rapid loss of forest resources and pollution of water bodies through contamination of heavy metals such as cyanide, arsenic and mercury as other use these to extract gold (Cudjoe et al., 2023).

The environmental problems caused by the small-scale mining activities poses a challenge on sustainable development locally as well for international health and safety organizations. The environment provides support to human beings if it is well managed and sustainable measures are put in practice. To mitigate the negative impacts of ASM activities currently and future occurrences there is a need to make proper decisions considering the several alternative uses to achieve maximum benefits of the operations (Samuel, 2014). Even though small-scale and illegal mining have contributed to the growth of the economy in many parts of the world; its damaging effects on the environment has caused more harm than good (Boateng, 2018).

2.2. ASMs and Agriculture

The rapid growth of artisanal and small-scale mining activities has led to the extension of these activities to the territories where, traditionally, agricultural activities may be present. Considering the destructive impacts of the ASM life cycle on the environment, it has been revealed that these activities have negative agricultural impacts. It has also been revealed that in some instances ASM and agriculture complement each other with

beneficial consequences (Kamlongera, 2011). Hilson, (2016) reported that ASM is one the sources of income in rural African families and become a key part of many rural economies in sub-Saharan Africa. Since agriculture is done seasonally, many people switch between mining and agriculture throughout the year. For example, close to 30% of people engaged in ASM in the townships of Niassa and Manica in Mozambique use incomes from ASM in implementing growing seasonally crops in their farms. In Liberia, many rural residents use rice meant for food production attract to work in their mining sites to increase the mining production.

The study by Cartier L.E., Bürge M. (2011), showed that artisanal mining and small-scale agriculture are not alternatives for their livelihood but rather complements. They further continued with analysis that 46% of the GDP is coming from agriculture and contributes to 25% of the Sierra Leone's export earnings. Food insecurity is still problem in rural areas in the southern part of Sierra Leone this left many individuals with no choice but to engage themselves in artisanal gold or diamond mining to enhance food security and generate income for their living. This is not mainly because of artisanal mining activities rather it is influenced by number of factors. Maconachie & Hilson, (2011) also added on the same saying, small-scale mining like artisanal diamond mining complements the activities of the agriculture cycle. They also observed that during dry season many people flock to mining activities for two reason first being, during dry season less work is required in their farms and again during rainy season mining activities seizes due to high cost of mining since the pits usually gets filled with water. Therefore, farmers are mining, and miners are farmers that is their seasonal shift in occupation.

However, there is high competition between rural farmers and artisanal and small-scale miners over the available land, labour and water resources, which negatively impact agriculture production. The more sustainable of the two industries, agricultural productive lands can be employed to generate alternate crops, on the contrary minerals resources are non-renewable and depletable (Badeeb et al., 2017). Land degradation by miners reduces availability of agricultural land which leads to food insecurity, microeconomic effects through food price inflation (ACET, 2017b). Over a prolonged

period, this has adverse impacts when thinking other alternatives to bring food in the community to eradicate hunger.

Nevertheless, being highly informal type of mining, ASM activities can as well have negative impacts on agriculture through three mechanisms: land degradation and farm invasions, water and mercury pollution and change of the mind of people from agriculture sector to the ASM sector since most of the operations takes place in rural communities where agriculture is the main source of livelihood (Ofosu et al., 2020). Nukpezah et al., (2017) assessed the impacts of small-scale mining on irrigation water quality in Asante Akim Central Municipality of Ghana where they found that in many mining communities, ASM activities possess the threat on water resources and agricultural activities. Findings from the selected sites along rivers showed that physico-chemical parameters of water such as turbidity, TDS, conductivity and heavy metals were higher than Food and Agriculture Organization (FAO) limits for irrigation water with ASM activities being a major cause.

2.3. Artisanal and Small-Scale Mining and Socio-Economic Growth

Regardless of the adverse impacts of ASM on the environment, many rural mining communities are sustaining their lives through the same activities. ASM is an important activity in most rural communities endowed with mineral resources. For example, in Mambilla plateau of Taraba State, Nigeria, artisanal and small-scale miners informally carryout mining activities to extract gemstones without consideration of environment and other mining regulations. Due to increased demand for gemstones and unattractive nature of agriculture in rural areas, people opt for mining to generate income to sustain their living standards (Ahmed & Oruonye, 2016).

Idris-Nda et al (2018) assessed the importance of ASM in Niger state, central Nigeria which is known by its abundance in gold occurrence in addition to other gemstones. The state is highly populated with artisanal and small-scale miners who seek to start the search of the minerals and extracting them. Being cost effective though labour intensive the mined materials are washed in open waterways and rivers and streams hence maximizing the profits from the mined materials. The activity contributes to poverty

reduction among rural people hence the effort to eradicate the activity failed in the state. ASM has contributed to the development of the area by providing employment, introduction of local businesses and other economic activities.

A study by Yaaba & Ato, (2015), was aimed at assessing the impacts of ASM on sustainable livelihoods in the Tarkwa-Nsuaem Municipality of Ghana. The findings indicated that despite improved livelihoods of people by generating income after selling the mined products, land has been unproductive due to the failure of the miners to reclaim the land after extraction. Again, the workers are exposed to cyanide and mercury making them vulnerable to other health risks. This affects the sustainability of the mining activities and increased rate of environmental degradation and health concerns.

ASMs therefore, has both positive and negative impacts to both humans and environment. Despite providing the needs for the families living in rural mining communities, it also poses a risk to human health, gender-based violence in mining sites and child labour, among others. Upon following reclamation and closure procedure, mining activities helps to rebuild the environment and becomes productive even better that before. However, this is not the case with many artisanal and small-scale miners who most often left the environment at stake by leaving the land destroyed and in unproductive state (Bansah et al., 2018).

2.4. Artisanal and Small-Scale Mining in Malawi

In Malawi, artisanal and small-scale mining (ASM) is growing rapidly, primarily extracting gemstones, limestone, quarry stone, and other industrial minerals (Haundi et al., 2021). The study shows that ASGM is characterized by people with low literacy levels, who use traditional tools (low-tech) and use methods fueled by lack of capital, and deficiency of basic knowledge of mining and geology. Many are mining gemstones but recently there has been a rise in small-scale gold mining in districts like Mangochi, Balaka, and Lilongwe, despite government efforts to curb the practice (Haundi et al., 2021).

ASM is crucial for development and poverty alleviation in Malawi and other developing countries, providing economic opportunities for local communities with low education levels. ASM supports between 13,500 and 40,000 people in Malawi. Artisanal and small-scale mining is highly characterized by social, economic, environmental and health problems to both miners and surrounding communities in Malawi and other countries in sub-Saharan Africa. Dakalira et al. (2017) assessed the impacts of ASM on rural households in Mzimba. The findings from the study showed that mining is a source of livelihood for the respondents involved. They found among the respondents that 34% are fulltime miners who rely greatly on mining and 66% considered themselves as part time miners. It was also found that all the respondents take mining as a compliment for their agricultural activities. On top of mining, fulltime miners are also involved in other small business to supplement the income from mining. According to (Stephens, 2015) ASM in Malawi is generally carried through labour intensive methods for limestone which is used for lime production for both construction and agriculture, rock aggregate for quarry stone, river and dambo sand for construction etc. The government acknowledges ASM's role in economic growth and poverty reduction, focusing on industrial minerals, gemstones, and quarry materials in the 2015/16 financial year.

The Government of Malawi is looking to implement formalization of the ASM sector trying to prevent these problems and maximize the benefits of ASM. Though Malawi laws indicates that artisanal and small-scale miners need to obtain mining licenses to operate, this is not the case in many rural communities as they continue operating informally (Etter-Phoya, 2015).

2.5. Artisanal and Small-Scale Mining Impacts on Water Quality

Clean water is one of the key areas of focus in the transformative promise of vision 2063 under SDGs agendas. Studies on the impacts of ASM on water quality have revealed that ASM activities can lead to significant contamination of surface and groundwater with mercury and other chemical used in mining for both extraction and processing (Macháček, 2019). A study by Karikari et al. (2020) on the Ankobra, Tano, and Pra rivers in Ghana show that ASM significantly pollutes water bodies due to sector expansion. Analysis of 35 river samples revealed high levels of iron (Fe) and copper

(Cu), with extreme turbidity (mean = 488 NTU) and total dissolved solids (TDS) (mean = 382 mg/L). Similar studies on the Bonsa River in Ghana's Western Region found high turbidity and objectionable colour, attributed to mining activities like gravel crushing and sediment washing (Bansal et al., 2018).

Darko et al., (2021) discovered that in Ghana, small-scale mining has been carried out for many years, generating income and employment to the people in both rural and semi urban communities but illegal artisanal and small-scale mining has impacted environment negatively through land degradation and water pollution. This prompted the government of Ghana to put a ban on both legal small-scale mining and illegal ASM activities in March 2017. The results of the study revealed that the rivers were high in total suspended solids (TSS), turbidity and color with the inflow of wastewater from mining sites being a main cause. When they compared the finding of this study which was carried out after a ban to the results of previous studies the found that there was improvement of the water quality on the rivers.

Rivers are essential for fish farming as well as the main source of clean drinking water. Artisanal and small-scale mining usually occurs near streams and rivers to be close to the source of water for processing and even waste discharge. In artisanal and small-scale gold mining, people use small quantity of mercury to extract gold (Cudjoe et al., 2023). Again, ASGM also releases significant amount of sediment along with metals and other contaminants into water bodies thereby increasing the environmental damage and put human health at risk. The detailed study in Ahafo, Ghana on water quality of the Surow River indicated that many sites associated with ASGM activities contains water with its quality does not meet Ghanaian national standards for drinking water with particularly high concentration of manganese and other metals (Macdonald et al., 2015).

The effects of turbidity and suspended solids are described by some researchers (Alabaster & Lloyd Steven, 2013) and (Tychsen et al., 2018), some of which include increased cost of water treatment, decline in fishery resources and serious ecological degradation of aquatic environments. The ASM activities leads to the negative impacts on physical, chemical and biological composition of river water as they mostly located near water sources. The socioeconomic benefits of ASMs are always outweighed by

unfavorable environmental costs and impacts (Mujere & Isidro, 2016). In Malawi, research on the Lisungwi and Kaphamtengo Rivers in Manondo area where residents settled following the discovery of gold in basement rocks of the region, was carried to investigate the impacts of ASGM on water quality. The assessment of ASM gold mining impacts on water quality focussed on the turbidity, pH and other physicochemical parameters, showed that the water quality is not directly affected by the activity rather the regional geology has the influence on water chemistry, the results showed that mining activities left the water on and along the rivers uncontaminated (Chikanda et al., 2022).

2.6. ASM Impacts on Land and Soil

Mineral deposits occurs either on the earth's surface, near surface or at depth in underground. Extraction of these minerals requires the removal of top materials such as soil to reach the desired minerals. Mining activities, including artisanal and small-scale mining (ASM), significantly alter the earth's surface. According to Macháček (2019), the impact on land varies with the type and extent of ASM operations. ASM activities often result in changes in land cover, soil degradation, and water pollution. Byizigiro et al. (2020) highlight that visible feature like quarries, pits, trenches, and waste piles are prominent, creating significant geomorphic changes. These features have been seen in different mining sites regardless of the scale of the mine. Landscape of abandoned unstable piles of soil/rock, excavated pits and bare land due to excessive removal of vegetation, are common features in informal ASM sites. This is because the informal ASM workers tend to mine quickly and run away from security forces leaving the mine openings unreclaim. These mining pits serves as breeding place for mosquitos, which causes malaria not only that, but these pits also become fall traps for both farmers and other land users (Bansah et al., 2018).

The mining sector consist of both small-scale, medium and large scale as well as artisanal mining. Each of these categories has varying environmental impacts. The study in Prestea, Ghana revealed that mining activities more especially illegal artisanal and small-scale mining destroy environmental resources such as water, soil, the landscape, vegetation, among others. It further explains that land in areas surrounding the mines have left bare and at high risk of erosion and loss of its productivity for agricultural

purposes. Due to clearance of vegetation, important soil organisms have been destroyed and stable soil aggregates have been disrupted. These led to the loss of the quality of soil by reducing the soil organic matter content and low levels of macronutrients and soil fertility necessary for plant growth and crop production in the western region of Ghana (Mensah et al., 2015). In most mining sites number of microbial organisms that fixes nutrients in soils is always lower than in the control plots and soil types are predominantly sandy loam and loamy sand (Asare et al., 2024) with high silt to clay ratio.

In Taita Taveta County, ASM leads to deforestation, with indigenous trees like acacia and baobab being cleared and not replanted, causing soil erosion and loss of soil nutrients during rainy seasons (Anyona & Rop, 2015). A study by Essandoh et al., (2021) assessed how ASM activities influenced the distribution of some physico-chemical properties and heavy metals in soil Ghana by collecting samples from both the mined and unmined areas. They found that the concentrations of mercury, electrical conductivity, magnesium, potassium, sodium, copper and other elements were higher in the soils of mined sites. They concluded that ASM affected the quality of the soil supporting vegetation growth.

Furthermore, a study by Eludoyin et al. (2017) in Nigeria, was carried out to investigate whether active and abandoned mines, adjacent farmlands, and relatively undisturbed forest regrowth areas differed significantly in their soil's physical and chemical characteristics. They hypothesized that areas with artisanal and small-scale gold mining (ASGM) activities would have higher concentrations of toxic metals than farmlands and forests. Soil samples were analysed for parameters such as pH and heavy metals like mercury, manganese, and lead. The results showed that active and abandoned mine sites had significantly higher levels of heavy metals, but lower concentrations of soil nutrients compared to farmlands and undisturbed areas.

2.7. ASM Impacts on Land Use Land Cover

Artisanal and small-scale mining (ASM) activities have significantly altered land use and land cover in Niger State, Nigeria. Liman et al. (2021) conducted a study using satellite imagery from Landsat TM and EMT+ for the years 1994, 2004, and 2014 to evaluate

these changes. In 1994, 33.4% of the land was degraded due to mining, with settlements covering 3.7% and vegetation at 59.2%. By 2004, land degradation decreased to 21.1%, but vegetation cover also decreased to 30.9%. In 2014, land degradation rose to 47.36%, settlements expanded to 16.06%, vegetation cover dropped to 24.22%, and water bodies occupied 12.37% of the mining sites. Over the study period, the mining sites increased from 30,000 km² (33%) to 48,000 km² (45%), highlighting the severe impact of ASM activities.

A similar study by Madaki et al., (2021) assessed the effects of artisanal and small-scale mining on land use and land over (LULC) in Awe, Nasarawa State. It involved time series between 1986, 1996 and 2006 using LandSat 4 TM, LandSat 7 ETM+ and LandSat8 (OLI). They used major land use classes such as built-up area, vegetation, farmlands, mining pits and water bodies to determine changes in land use land cover. The results showed that major changes were observed in the built-up area, mining area and farmland land use and land cover types. Findings showed an upward trend in built-up areas from 157km^2 (6.3%) in 1986 to 371 km^2 (14%) in 1996, 413 km^2 (16%) in 2006 and 616.5 km^2 (24%) in 2016. Similarly, mining areas increased from 5.23km^2 (0.21%) in 1986 to 18.15km^2 (0.71%) in 1996, 34.191km^2 (34.2%) in 2006 and 105.3km^2 (4.1%) in 2016. However, farmlands declined consistently from 1445.5km^2 (57%) in 1986, 1002.5km^2 (37%) in 1996, 954km^2 (37%) in 2006 and 751.8492km^2 (29.3%) in 2016. It is concluded that land use and land cover changes as well as uncontrolled mining activities contribute to the existing environmental deterioration in the study area.

Cudjoe et al. (2023) discovered in Akango mining, Nzema East Municipality, Western Region, Ghana that between 2008 and 2022 mining area and subsequent settlement expanded with decreasing water bodies and vegetation. For instance, they discovered that mining area and size of the settlement increased by 1279.77% and 41.72% respectively between 2008 and 2015 in the study area. On the other hand, size of the water bodies decreased by 4.58% between the study periods. Accounting for the decline in the water body, 38.4% and 10.02% of the water body were converted into mining and bare land, respectively. The water bodies suffered great loss while

vegetation showed little change over the study period. This was so because many artisanal and small-scale miners they target alluvial and placer deposits in rivers.

CHAPTER THREE: METHODOLOGY

3.0. Study Area

This study was done in Lumwila village, Group Village Head Mdzeka, Traditional Authority Mazengera in Nathenje, Lilongwe. The mining sites where all the data collection were done are located about 2 km NWW of Matapila Trading Centre about 15km from Mazengera Turnoff that branches from M1 road between Nathenje and Nkhoma Trading Centres. Lumwila village is accessible through motorcycle operators that operates at Mazengera Turnoff along Lilongwe-Dedza M1 road as it is well known with its artisanal gold mining activities. Other villages where ASGM activities are taking place such as Ntenthera Village were approached but the miners denied the access to carry out the data collection stressing that the findings of the project might affect them negatively therefore, Lumwila Village was selected for its accessibility.

3.0.1. Geology of the Nathenje

Geology of Lilongwe is underlain by gneisses, granulites and schists assigned to the Basement Complex and forming part of the Malawi Province of the Mozambique Belt (Bulletin No. 26). In the southern part of Lilongwe with areas like Nanjiri, Nathenje, Nkhoma among others, it was intruded by minor intrusions of Chilwa Alkaline Province after it was subjected to faulting and folding (Bloomfield, 1961). There is no direct finding that described the occurrence of gold deposit in Nathenje but its presence as placer mineral is attached to some of activities the area subjected to in the past. The faulting of the southern Lilongwe created a room for hydrothermal activities that led to the deposition of different minerals. Some gold minerals originate from quartz veins, sulphide bands, which associates with hydrothermal activity and outcrop of calcsilicate granulites or skarns and in paragneisses and carbonised schists (Ministry of Ernegy and Mines, 2009). These structures can be some of the sources of gold in Nathenje. Weathering of these rocks releases gold into surrounding environment where it gets eroded and transported to stream valleys and some remain concentrated in soils from where villages and other small-scale miners extract it. Gold mineralization in Lilongwe can also be attached to processes of gold mineralization in Mangochi-Makanjira in the southern Malawi. In terms of mineral deposits, it has been noted that Malawi's geology has not been mapped in detail and there are no detailed geological and structural

assessments in relation to gold mineralization. Mangochi-Makanjira area in southern Malawi is one of the areas known with abundant gold mineral resources (Haundi et al., 2021) but there is a scarcity of precise knowledge on the structures that control primary mineralization of gold in Mangochi-Makanjira (Chisambi, 2023). With the of geophysical method, Chisambi 2023 discovered that the dominant linear trends present in the area are faults, dykes, and deep-level basement shear zones as structures responsible for fluid flow and gold mineralization in the area. Gold in Mangochi-Makanjira is structurally controlled by N-S structures that were derived during the Pan-African orogeny and it is during this event that the area got mineralized. It was concluded that these fractures and faults served as channel ways for hydrothermal solutions, resulting in the emplacement of gold mineralization within the fractures. Therefore, gold mineralization in Lilongwe-Nathenje can be linked to the same processes due to available information and field observation made on rock exposures.

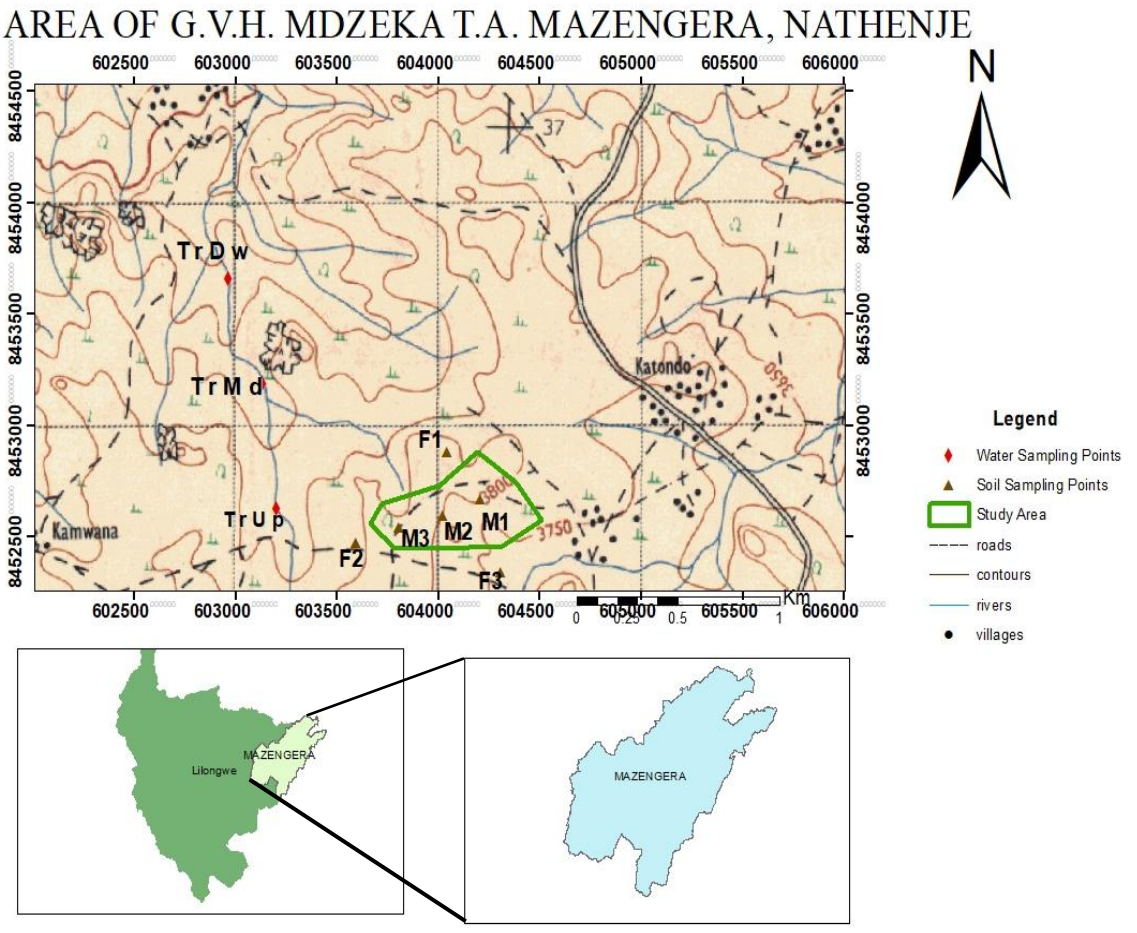


Figure 1: Topographic Map of Study Area Showing Mining Sites and Sampling Points

3.1. Research Design

The research employed both quantitative and qualitative methodological approach that involved a comprehensive review of existing literature, field observations which helped to have an overview of the methods that these miners are using, sampling of soils and water and remote sensing techniques to analyse land use of the area. Relevant literature on the impacts of ASM on the environment were reviewed to have an insight on general impacts of ASM activities on environment.

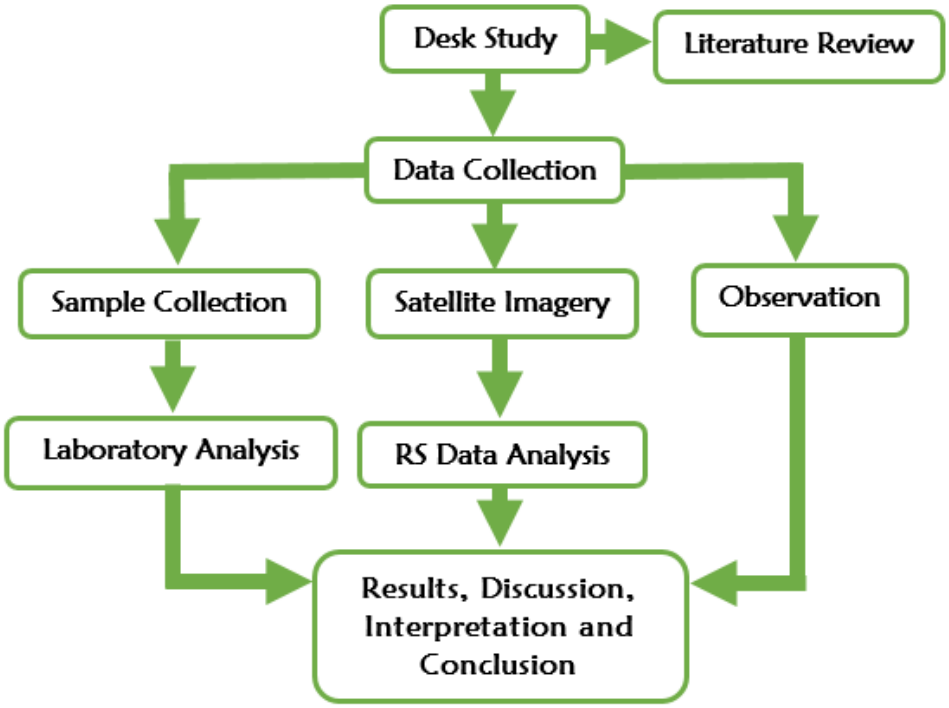


Figure 2: Showing a Flow Chart of Research Methodological Design Employed

3.2. Materials and Instruments

Materials that were used include: sampling bags, six 500 ml plastic bottles, handheld Garmin GPS, auger, ArcGis software, IBM SPSS statistical software, six beakers, 30 cm ruler, water, dish wash detergent, spatula, soil triangle chart and stop watch/timer.

3.3. Sample Collection

3.3.1. Water Sampling

To obtain water samples for the study, strategic sampling points were designated along the course of the Talira River, a river that crosses the mining site owned by villagers

from Lumwila Village. Three distinct sampling points were determined with 200m gap along the river as shown on a map of study area: one situated at upstream before the river reaches the mining sites, another at middlestream when the river joined by water way (tributary) from first mining site, and the third at downstream where the river joined by water way (tributary) that passes through second mining site. Two phase sampling of water was done following the activities that occurs at both sites. Miners dug soils for three days and come fourth day to wash the soils to extract the mineral.

Phase one involved collection of water samples from the designated points first day of digging the soils. During this three-day period, no mine water was draining into the main river (Talira River). The samples were sent to Lilongwe Water Board Laboratory the same day of collection for comprehensive testing. To facilitate easy identification, specific sampling codes were allocated to each sampling point, namely TrUp for Talira Upstream, TrMd for Talira Middlestream and TrDw for Talira Downstream.

Phase two sampling involved collection of water samples from the same designated points in the afternoon hours the day that mines came to wash the soils they dug. During this day all mine waters were drained into a water way that drains into Talira River. The samples were again sent to Lilongwe Water Board Laboratory the same day of collection for comprehensive testing. Specific sampling codes allocated to each sampling point were the same.

The collected water samples of Talira River on both phases were sent to the laboratory the same to mitigating any potential source of contamination and ensuring the integrity of the collected samples. It happened by chance that the rain had not been falling the week I collected samples and already one week was gone without rainfall in the area. This was to my advantage that other factors like runoff of rainwater did not contaminate the water in the river. Before collection, the sampling containers underwent preparation process, including thorough washing and dried on the sun. Subsequently, water samples from the Talira River were collected using 500 ml plastic bottles, selected for their suitability. To preserve the collected samples, they were sent to the laboratory on the same day. Each plastic container utilized for water sampling was labeled, clearly indicating the sample phase type and the precise sampling location. The bottles were labelled P1,TrUp, P1,TrMd and P1Dw for phase one sampling at

Upstream, Middlestream and Downstream respectively and P2TrUp, P2,TrMd and P2,TrDw for phase two sampling at upstream, Middlestream and Downstream respectively. Collection of the water samples involved submerging the necks of the bottles into the surface of the river, ensuring proper orientation to align with the flow of the river.

3.3.2. Soil Sampling

Two mining sites were selected both owned by villagers of Lumwira Village. Three sampling points were determined within the premises of the mining sites and other three were determined in the nearby agricultural field where the maize is grown near the mining sites as indicated on the study area map. The access to soil sampling was given to an abandoned sides of the mining sites of which it was to my advantage since the abandoned sites gives good insight into the impacts of ASMs on soil. Sampling on adjacent agricultural field was determined and used as control. Sampling points were labelled F1, F2 and F3 for sample points on adjacent agricultural land with distance of 100 m from the mine site and M1, M2 and M3 for sample points within the mining sites.

Using auger, the soil samples were collected considerably at 15 cm depth at each sampling point. In total six sample were collected, bagged and labelled such that Field Sample 1, Field Sample 2 and Field Sample 3 were for samples obtained from agricultural land soil (controls) sampling points. Site Sample 1, Site Sample 2 and Site Sample 3 labeling was for samples obtained from abandoned sides of the mining sites. The samples were taken to Earth Science (Geology) Laboratory at Malawi University of Science and Technology (MUST) campus for testing and measurements.

3.4. Satellite Imagery Processing

Free satellite images were used to determine the types of land use and land cover and how they changed over a ten-year period. The United States Geological Survey (USGS)'s Earth Explorer (https://earthexplorer.usgs.gov) provided the Landsat images. The two-year multitemporal 30m resolution Landsat 8 satellite imagery from 2014 and 2024, with spacing ten years, made up the remote sensor data. Then layer stacking was used to create a composite of individual image from the various spectral bands for each year that were imported onto the ArcMap. Bands 1 to 3 were layered in this study since they

will be used in subsequent analyses. The 2014 and 2024 single raster datasets were created from their respective multiple bands using the Arc Toolbox's Data Management Tool Composite Bands.

Classification of Images

To extract valuable thematic information, image classification aims to assign each pixel in a particular image to a Land Use and Land Cover (LU&LC) class (Madaki et al., 2021). Since the goal was to create clusters based on comparable spectral properties present in the image files, multivariate unsupervised classification using ArcGIS was recommended. A technique for examining multivariate images, where the image coordinates are location and variable number, is called multivariate image analysis (MIA). In order to provide additional information that is helpful for examining images and categorising different regions within them, MIA focusses on the correlation of structures between the variables. The images were classified using the Spatial Analyst Tool's Iso Cluster Unsupervised Classification. Using the Iso Cluster and Maximum Likelihood Classification tools, the Iso Cluster classifies a set of input raster bands.

Reclassification

Classification was done without supervision. Four major LU&LC class categories were found for reclassification and additional study. There are four categories:

I. The actual mining site, or the location where mining operations are conducted.
II. Seasonal agriculture, or regions utilised for farming.
III. Bare land
IV. Vegetation (trees, shrubs, and bushes)

The research area's training samples for the aforementioned classes were converted from Google Earth images to KML files. The training samples were digitised from images that contained the corresponding LU&LC class in 2014 and 2024 to prevent bias or inaccuracy. The KML files were then transformed into GIS shapefiles, each of which represented one of the four classes, using the Conversion Tools' from KML feature. To classify the smoothened images, the four training shapefile classes were superimposed on the categorised image. To do that, a new field named Class was added to the categorised and smoothed image's characteristics table. The Reclassify tool from Spatial Analysts was employed. The newly generated field (Class) was used as the Value Field,

and the images were reclassified using unique values to determine the LU&LC classes of the study area.

3.5. Data Analysis

3.5.0. Laboratory Analysis for Water Samples

Water samples were analysed in Lilongwe at the laboratory of Lilongwe Water Board. The testing encompasses water quality physical parameters namely, turbidity, total suspended solids (TSS), and total dissolved solids (TDS) and the results were recorded in the table of results. The results were further correlated (statistical analysis) using SPSS statistical software to show the strength of the relationship between mining activity and water physical parameters as well as the direction of the relationship. Null hypothesis that was required to reject or accept after the analysis was that mining activities does not affect the water quality physical parameters. The alternative hypothesis was that mining activities affect the water quality physical parameters. The aim was to provide a comprehensive assessment of water quality and evaluation of the levels of pollution of water resources as a result of ASMs (BOQU, 2023. Results from the laboratory are shown in the table below.

Sample Location	Turbidity (NTU)	Total Suspended Solids (TSS) (mg/l)	Total Dissolved Solids (TDS) (mg/l)
P1,TrUp	20	540	41
P1,TrMd	32	612	48
P1,TrDw	31	615	48.6

Table 1: Phase One Water Sampling Results

Sample Location	Turbidity (NTU)	Total Suspended Solids (TSS) (mg/l)	Total Dissolved Solids (TDS) (mg/l)
P2,TrUp	26	580	42.5
P2,TrMd	51	1740	52.0
P2,TrDw	53	1834	53.4

Table 2: Phase Two Water Sampling Results

3.5.1. Laboratory Analysis for Soil Samples

The soil samples were prepared by drying them on the sun for six hours to remove water from the sample and for easy grinding and removal of large particles. Six beakers were set in the laboratory and were labelled Field Sample 1 to Field Sample 3 for agricultural land samples (controls) and Site Sample 1 to Site Sample 3 for mine site samples. Each sample was put in its respective beaker up to 250 ml mark and 300 ml of water was added in each beaker. In each beaker, one spatula of dish wash detergent was added and the contents were shaked for 10 seconds. The dish wash detergent was added to enhance the separation of different sizes particles (Sand, Silt and Clay). The contents were left to settle for 48 hours allow complete settling of particles. Total depth of soil was measure as well as depths of each soil particles (Sand, Silt and Clay) and recorded in the table of results. The percentages of soil depth of soil particles were calculated using the formula:

$$\% \text{ Particle Layer} = \frac{\text{Depth of Particles Layer}}{\text{Total Depth of Soil}} \times 100$$

and recorded in the table as shown in table 3. The textural class of the soils was determined using the USDA textural triangle (Yang et al., 2015). Soil samples were analysed in the Geology laboratory at Malawi University of Science and Technology and all the necessary parameters were recorded accordingly. The results of the soil from mining sites were compared with the results of nearby farmland soils to determine the impact of ASM on soil texture (Bauder, 2020).

3.5.2. Remote Sensing Data Analysis

The LU&LC maps produced were subjected to a descriptive analysis. Over a 10-year period (2014-2024), Landsat satellite images were acquired and analysed to detect changes in land cover. The areas covered by different classes were analysed using MS Excel to show the areas on bar graphs. ArcGIS 10.8 was used to analyse the satellite images datasets.

CHAPTER FOUR: RESULTS, DISCUSSION AND INTERPRETATION

4.0. Results

4.0.1. Results on Water Quality

From the statistical analysis of the water physical parameter results, it has noted that in both phases there is a very strong positive relation between mining activity and physical parameters of water quality (Turbidity, TDS and TSS). The correlation of Phase One results is statistically significance at *p-value* values for both parameters below 0.05 (5%) conventional level. Correlation of Turbidity and TSS for Phase Two is statistically significant at lower values of *p*-value but it is not statistically significant with TDS as the *p-value* for Phase Two TDS is above 0.05 conventional level. The strength of the correlation shows that as the mining activity increases, the impacts on water physical parameters also tends to increase. This has proven by strong positive relationship between mining activity and water physical parameters both with Pearson Correlation Coefficients of around 0.9. The *p-values* of phase two results are lower for turbidity and TSS than *p-value* of phase one results showing that the evidence to reject the null hypothesis (Mining activities does not affect water physical parameters) are strong from the phase two results. The statistical results are shown in figures 3 and 4 below.

Phase One Statistical Correlation Results			
Variables		Significance (2-tailed)	p-value
Mining	Turbidity	0.997	0.048
Mining	TSS	0.998	0.043
Mining	TDS	0.997	0.045

Table 3: Statistical Correlation Results for Phase One

Phase Two Statistical Correlation Results			
Variables		Significance (2-tailed)	p-value
Mining	Turbidity	0.998	0.042
Mining	TSS	0.999	0.022
Mining	TDS	0.992	0.08

Table 4: Statistical Correlation Results for Phase Two

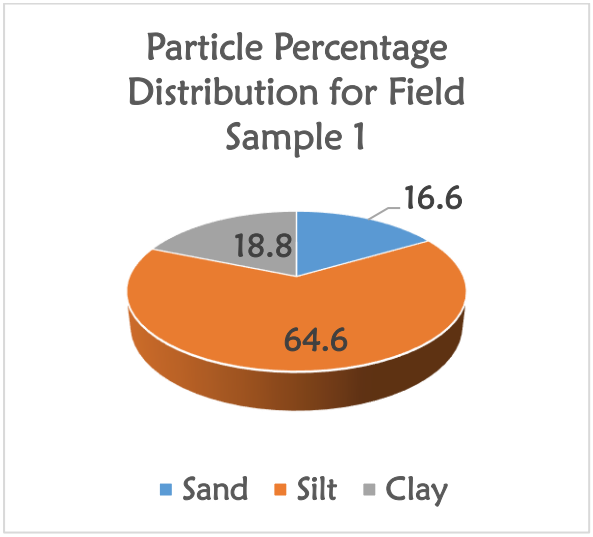
4.0.2. Results of Soil Textural Classes

The physical characteristics (soil texture) of the soils from the sites (mined and control) were determined by analyzing percentages of constituent particles (sand, silt and clay) and presented in Table 3. The soil type was determined from the percentages of particles using USDA Textural Classification. At both mining sites, the textural classes are sandy loam and loamy sand, with a greater distribution of sand fractions. Agricultural land is characterized by silt loam soils with silt dominating distribution. Percentage of sand was significantly higher in the mined plots than in the control agricultural fields as shown in the figures 5 to 10.

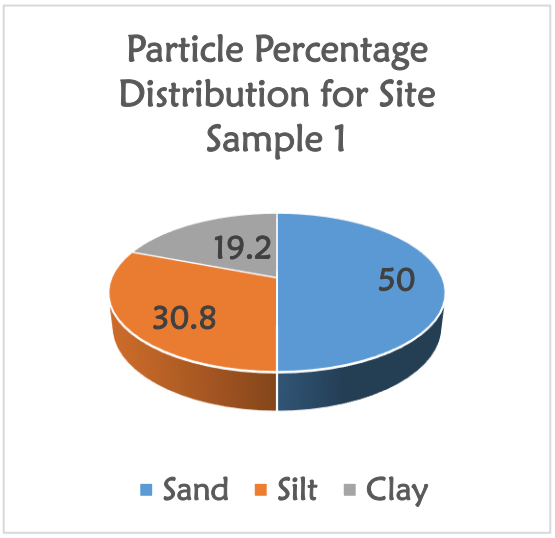
Sample type	Total Soil Depth (cm)	Sand Layer Depth (cm)	Silt Layer Depth (cm)	Clay Layer Depth (cm)	% Sand	% Silt	% Clay	Soil Type
Field Sample1	4.9	0.8	3.1	0.9	16.7	64.6	18.8	Silt Loam
Field Sample2	5.1	0.4	3.8	0.9	7.8	74.5	17.6	Silt Loam
Field Sample3	5.7	0.5	4.5	0.7	8.8	78.9	12.3	Silt Loam
Site Sample1	5.2	2.6	1.6	1	50	30.8	19.2	Sandy Loam
Site Sample2	4.9	2.9	1.3	0.7	59.2	26.5	14.3	Sandy Loam
Site Sample3	4.6	4	0.4	0.2	87.0	8.7	4.3	Loamy Sand

Table 5: Showing Soil Particles Distribution and Soil Type

The comparison of soil types between mined site and its adjacent control (agricultural field) are shown by the following pair of figures 3 and 4, 5 and 6, 7 and 8.

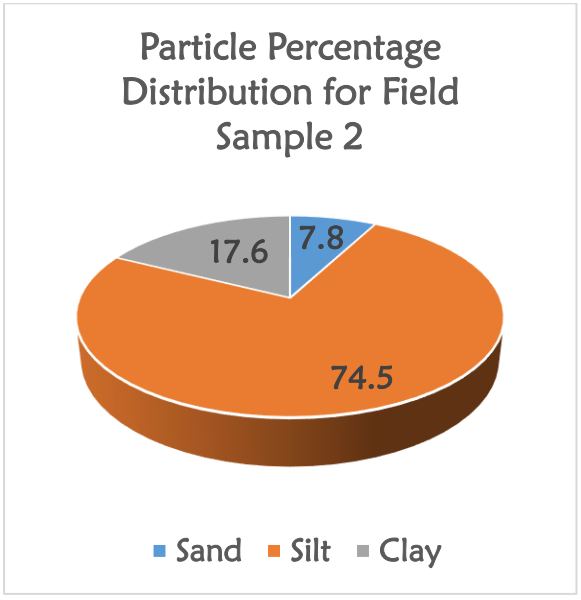


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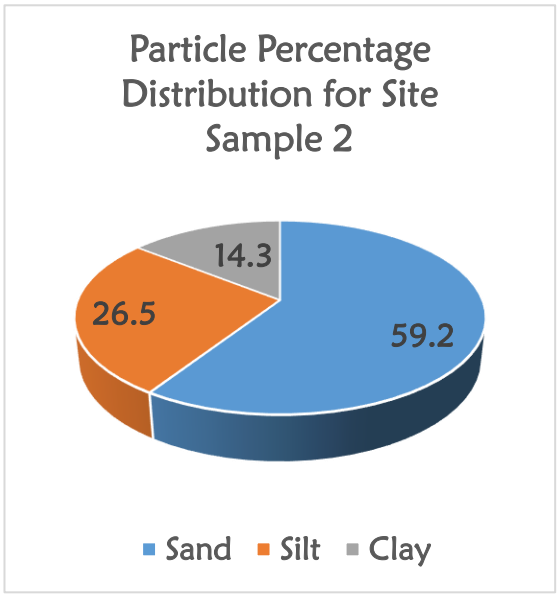


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Figure 3 and 4: Comparison of Soil Particle Distribution in Percentage Between Field Sample 1 (Agricultural Site) (3) and Site Sample 1 (Mined Site) (4).

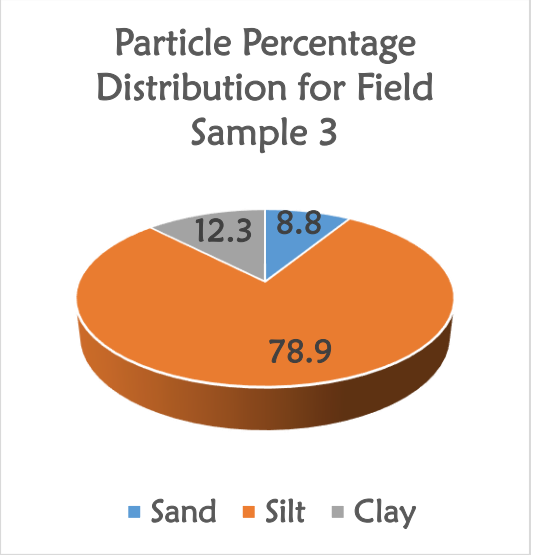


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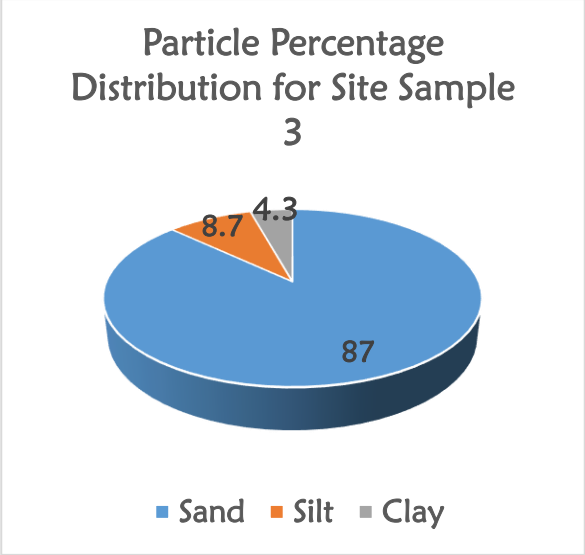


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Figure 5 and 6: Comparison of Soil Particles Distribution in Percentage Between Field Sample 2 (Agricultural Site) (5) and Site Sample 2 (Mined Site) (6).



7



8

Figure 7 and 8: Comparison of Soil Particles Distribution in Percentage Between Field Sample 3 (Agricultural Site) (7) and Site Sample 3 (Mined Site) (8).

4.0.3. Results for Land Use Land Cover Change Detection

Four land use and land cover (LU&LC) types and their dynamics were discriminated as actual mining site, bare land, vegetation and seasonal agricultural as shown on a land use and land cover maps (Figures 12 and 14). By 2014, bare land has increased from 3,055.2 square acres to 3,868.29 square acres by 2024. Vegetation has decreased from 5,336.61 square acres in 2014 to 919.82 square acres in 2024. The agricultural land increased from 15,052.56 in 2014 to 20,057 square acres in 2024. Vegetation suffered great lose as it was covering large part of the study area which decreased. Vegetation has depleted by 2024 while agricultural land increased. The bare land and actual mining site have also grown by 2024 as shown in figure 14.

LULC Class	2014 Area Coverage (sq. ac)	2024 Area Coverage (sq. ac)	% Increase	% Decrease
Bare Land	3,055.2	3,868.29	26.6	
Vegetation	5,336.61	919.82		82.8
Seasonal Agriculture	15,052.56	20,057	33.2	

Table 6: Showing Area Covered by LULC Classes in 2014 and 2024

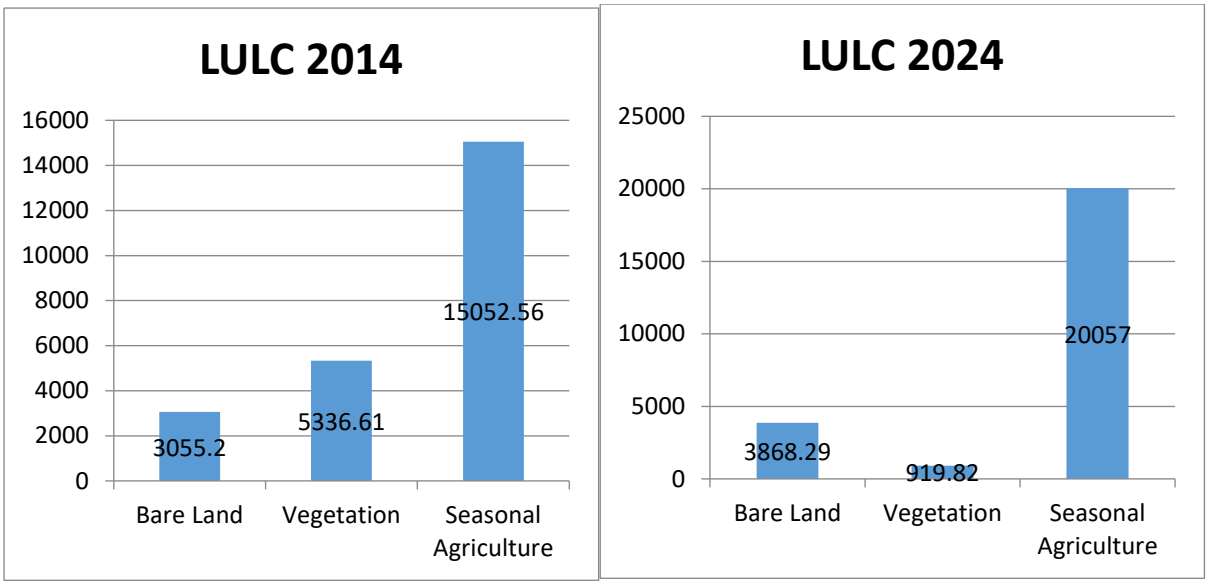


Figure 9 and 10: Showing areas covered by LULC classes in 2014 and 2024

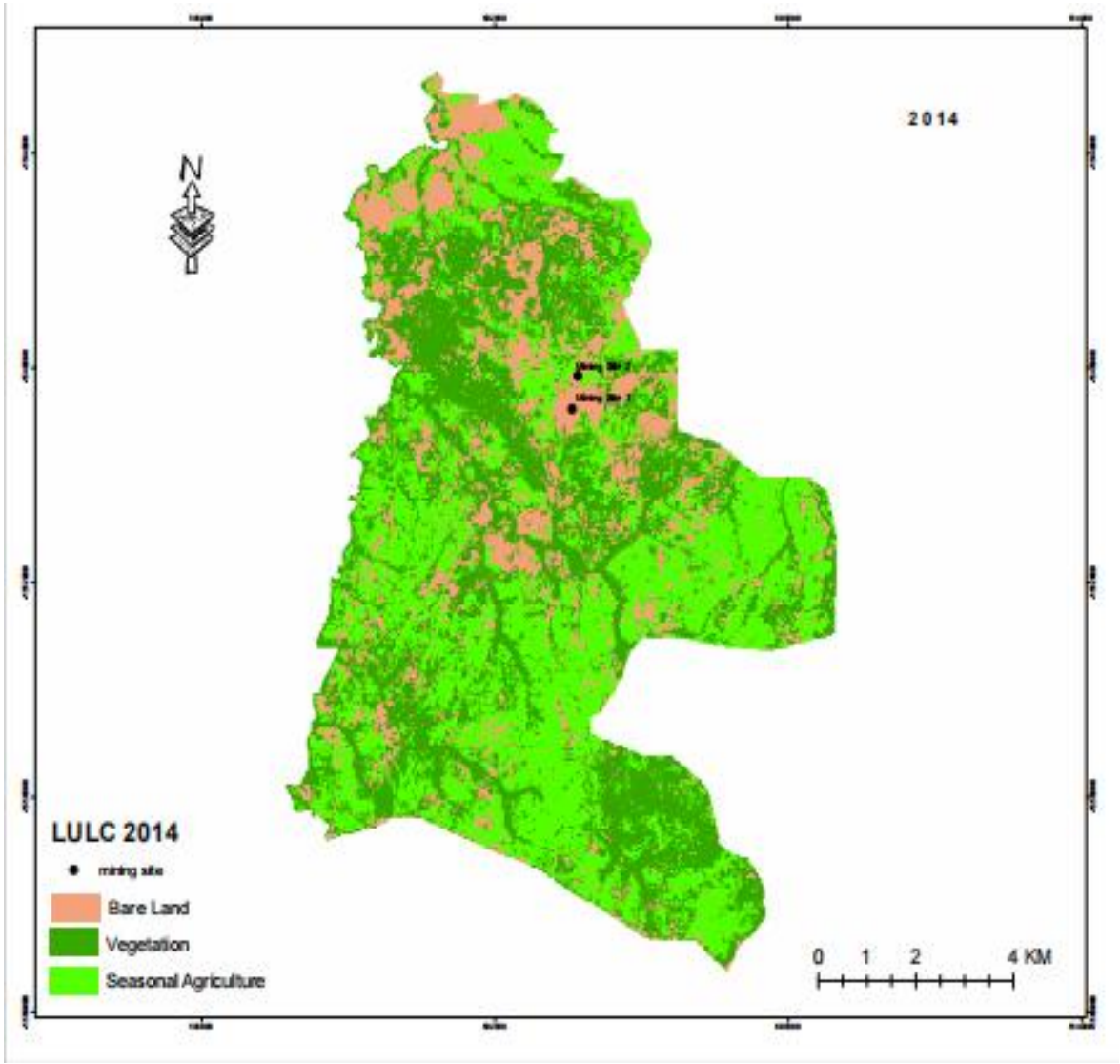


Figure 11: Land Use and Land Cover Map for 2014

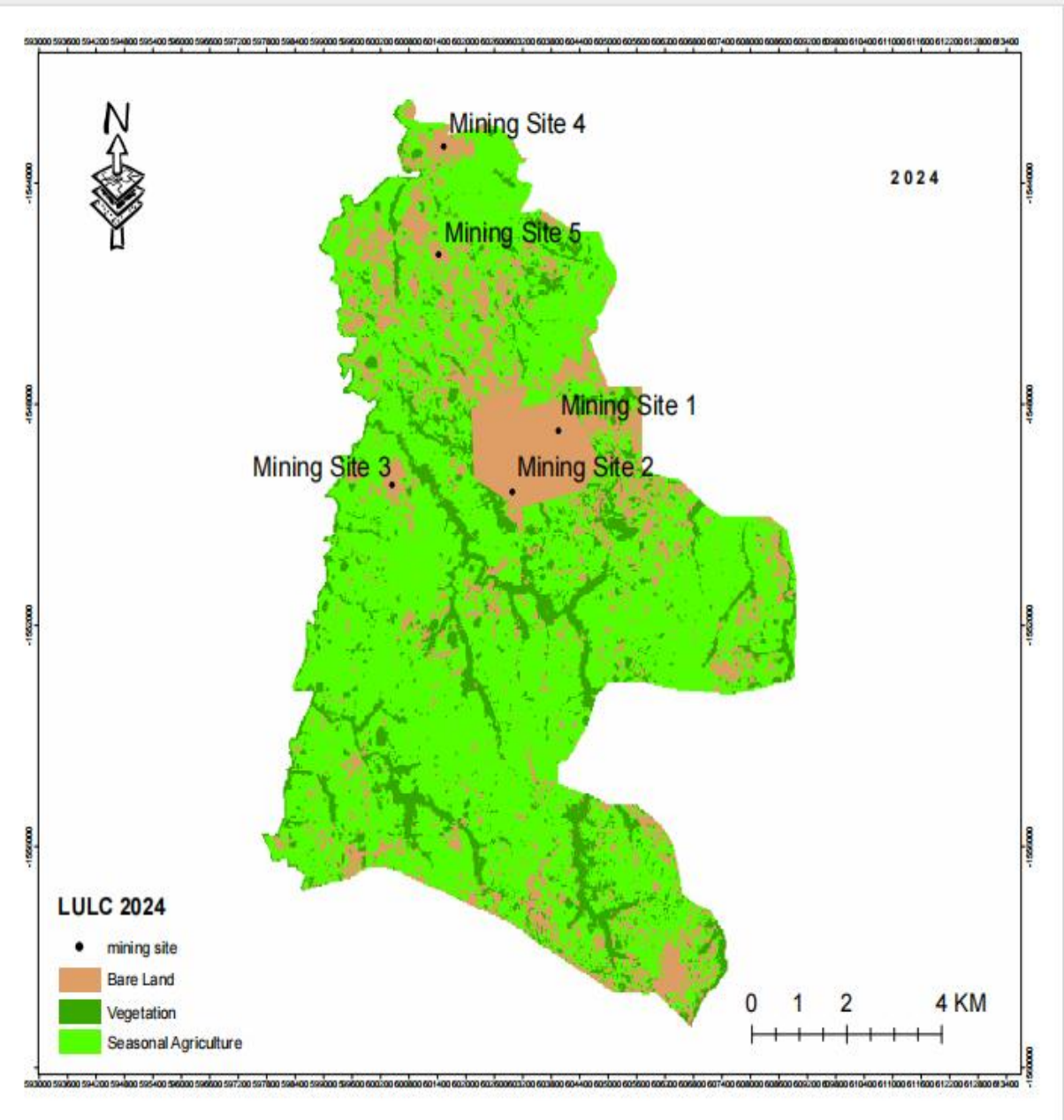


Figure 12: Land Use and Land Cover Map for 2024

4.1. Discussion

4.1.1. Water Quality

Water is essential in everyday life regardless of the source as it supports different activities such as agriculture and other domestic use. Turbidity of water ranges from fairly turbid (15-25 NTU), rather turbid (25-35 NTU), turbid (35-50 NTU) and very turbid (>50 NTU) (Azis et al., 2015). Correlation between mining and turbidity shows Pearson correlation coefficient of 0.997 and 0.998 for phase one and phase two respectively with *p-values* of 0.048 and 0.042 for phase one and phase two

respectively. This indicates very strong positive relationship between mining and turbidity so as mining increases, turbidity also tends to increase. The evidence for this is given by lower *p-value* for phase two, so the lower the value the stronger the evidence against null hypothesis (Henseler et al., 2014). Phase two gave strong evidence because during this period more mine water is released into the river as miners wash their soils to extract gold from it since they are using sluicing method. The miners drain water into the river while others wash the soils directly into river leading to increased levels of turbidity and the water becomes polluted. Water in the upstream (control) in both phase one and phase two is fairly turbid and rather turbid (20 NTU and 26 NTU respectively). This is because of absence of mining activities in the upstream of the river and was assigned zero when correlated showing no mine. Turbidity of water in the phase one at middlestram and downstream of the river falls under turbid range as shown in table 1. This shows that the water in the middlestream and downstream of the river is not as cloudier during soil excavation/ digging period, but the readings are higher than those of upstream showing that there are still impacts of mining on turbidity being within the mining sites. The correlation coefficient shows that though miners were not washing the soils, there is still positive relationship between mining activity and impacts on water quality physical parameter as the as the correlation is still significant at 0.048. When miners are cultivating the soils, the water in Talira River can be used for other agricultural purposes as the readings are below 25 NTU of Malawi Bureau of Standards but it becomes unfavourable when miners wash the soils, and the water becomes very turbid (over 50 NTU) as shown in table 2.

Total suspended solids as one of the determinants of water quality is another physical parameter that investigated in this project. This tells the amount of non-settleable solid particles both organic and inorganic that remain suspended in water after gravity settling (Pungsang, 2016). Correlation on Total Suspended Solids (TSS) on water indicated that there is very strong positive relationship between mining and total suspended solids parameter (0.998 and 0.999 Pearson Correlation coefficient) for both phases. The *p-values* for both phases indicate that the correlation was significant at 0.043 and 0.022 for phase one and phase two respectively. Lower *p*-value of phase two gives strong evidence that mining activities affect the TSS of water in the Talira River. This proved that water becomes highly polluted with suspended particles during

the period when miners wash their soils. Phase one results show that there is impact of mining on TSS which is worsen when extraction of gold started by draining wastewater into the river. This has shown by increased levels of TSS on the middlestream and downstream samples of water in phase two that those in phase one. The upstream result in both phases is within usable ranges for irrigating cereals crops as per Food and Agriculture Organisation (FAO). The cloudiness of water in the upstream is complemented by lower values of the turbidity. TSS in the middlestream and downstream of phase one water are below 1000 mg/l which is different from TSS of the phase two water samples in the similar locations as it registers 258.9 % and 298.2 % increment at middlestream and downstream of the river, respectively. The increased measurements of TSS in the phase two waters in middlestream and downstream is directly linked to wastewaters from the mining activities that contains high amount of sediments, silt content, clays other solid particles (Kumar et al., 2020).

The Total Dissolved Solids of in both phase one and phase two sampling in all the stages of the Talira River are below the WHO and Malawi Standards (MS733:2005), which are 1000 mg/l for WHO and 2000mg/l for Malawi Bureau of Standards. Though the correlation showed strong positive relationship between mining and TDS, the correlation was not significant as the *p*-value is greater that 0.05 (Diedenhofen & Much, 2015). This suggests that there should be other variables that affect the TDS of water rather than mining alone. This was proved by the observations made during the field work as the miners do not involve any use of chemicals when mining since chemicals and salts are major sources of dissolved solids hence the lower values of TDS below the standard limits are for drinking water. This shows that the TDS of water in the river is still under the recommended limit. However, the presence of little dissolved solids in the river can still linked to ASGM activities, which expose loose soil particles carried into the Talira River hence requiring further studies on the chemical analysis of exposed rocks and river water.

4.1.2. Soil Physical Characteristics

Results of the soil samples shows that the soil types on the mined land are sandy loam and loamy sand. As shown in figures 8, 10 and 12 the soils at mine site have higher proportion of sand than silt and clay. This makes the land not suitable for agriculture in its current state as sandy loam and loamy sand soils drains water very quickly and

does not retain the much water to the plants needed for growth (Baritoesaen & Jas, 2024). The soils at the mine sites due to high proportion of sand can lose nutrients easily through leaching, the nutrients are easily washed away in these types of soil.

Soil type on the agricultural land, which was control in this project is silt loam different from mined land soils. Due the balanced mix of sand, silt and clay with silt being the dominant particles as shown in figure 7, 9 and 11, makes the silt loam sand agricultural productive. The soils from all the sampling point in the agricultural field shows that it is rich in nutrients and humus content as it was proved by floating of organic sediments at the top of beakers during the setup of laboratory testing. The nutrient content makes silt loam soils fertile as witnessed during the field observations that there were crops such as maize and groundnuts grown on these fields. The soil type at mine sites is because of the excavation of soils to extract minerals that left the soil disturbed (Asare et al., 2024).

4.1.3. Land Cover and Land Use

It has discovered that bare land increased from 2014 to 2024 by 26.6 %. This is the case because the mining sites are left uncovered and unrehabilitated after the mineral depleted or finished. Increase in number of mining sites by 2024 as shown by LULC 2024 map has led to the clearance of land to mine the mineral which is left bare after the mining seized. The miners do not return the land to its initial productivity by reclaiming the land since the pits are left unfilled and heap of the waste soils are over the abandoned area as shown in the appendix. Seasonal agriculture land increased from 2014 to 2024 by 33.2 %. Both increased bare land and seasonal agricultural land has contributed to the decrease of vegetation by 82.8% from 2014 to 2024. Since miners sought to move to other new potential mining area after previous ones became unprofitable, the land is cleared. Mostly artisanal miners start mining at their own agricultural field and move to vegetated land as an option to continue the activity when the mineral depleted at their land. This has led to decrease in agricultural land that intern let to further clearance of vegetation to open new farms. Vegetation is cleared even more as villagers need to increase agricultural land to meet the demand from increased population as the area attracts more residents due to the presence of gold. Whenever miners feel they have finished the mineral, they left the land unfilled and unvegetated hence the decrease in vegetation by 2024. The actual mining site started

in Lumwira village in 2013 with two sites and neighbouring villages of Chisambo, Chimtengo, Chisaliko and Chiwamba followed the suit by 2024.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.0. Conclusion

Artisanal and small-scale mining pollute water resources as it is mostly done illegally without any monitoring of the environment (Nukpezah et al., 2017). This study, therefore, concluded that the quality of the water in Talira River is polluted due to the mining activities that are taking place in Lumwira Vilage. The water in the river is mostly affected during the period when the miners wash soils to extract gold minerals. This has shown by increasing levels of turbidity and Total Suspended Solids (TSS) of samples obtained during this period in the middlestream and downstream of the Talira River (significance 0.042 for turbidity and 0.022 for TSS) compared to turbidity and TSS of water from the same in the same sampling locations during excavation days (significance 0.048 for turbidity and 0.043 for TSS). The turbidity and TSS increased as the miners drain mine water into the river while other wash the soils direct into a river. The increase in mining activities, increases water quality physical parameters making it unfavourable for domestic purposes.

It also concluded that due to absence of chemical such as mercury and cyanides for gold extraction (Cudjoe et al., 2023), TDS is not highly affected by the mining activities as it shown with low levels as compared to recommended ones. This is because the mining activities in the area are done manually, no involvement of machinery and chemicals that can lead to the concentrated water with dissolved solids or salts.

Soil degradation is another serious issue with illegal artisanal and small-scale mining activities (Byizigiro et al. 2020). It has revealed from this study that ASG mining sites are abandoned without following rehabilitation or reclamation strategies when the mineral depleted. It has noted that villagers in Lumwira do not refill the pits, levelling the heaps of soils made when digging to find gold concentrated soils. This exposed the soil to erosion makes it lose its quality for agricultural purposes. The soils become loamy sand and sandy loam with very high proportion of sand particles making loose and easily carried away by surface runoff water during rainy season.

Mining is one of the factors that contribute to the change in land cover and land use in the area. It has revealed that mining contributes to increased bare land because of the attitude of miners that flock to new land without returning the previous one to its initial state. This attitude makes vegetation to be cleared in search of the gold concentrated

soils hence the severe decrease in vegetation. All the classes of land cover and land use shows the changes with time.

The research has contributed to a body of knowledge on how mining activities that are taking place in Nathenje are affecting environmental resources such as land and water.

5.1. Limitations

This research did not cover all mining sites in Nathenje to examines their environmental implications as there are many ASMs sites. This was so because of the financial problems since the projects were not funded so increasing number of mining sites in this research would mean more money needed. Land use land cover change detection was done for 10 years period (2014 and 2024), this did not include other activities that were happening in the area within this time period. It did not also provide mineral composition of the rocks in the area to have an insight into the occurrence of gold minerals in the area. Therefore, future work in the area shall be done covering as many mining sites as possible to have a broader overview of the impacts in of ASMs in the whole Nathenje area. Again, it shall also investigate rock mineralisation and other geological structures associated with the area to have the information on the occurrence of gold.

5.2. Recommendations

Formalization of Artisanal and Small-Scale Mining: Miners needs to form corporate groups so that government through Department of Mines should reach them out. Authorities needs to educate people on the importance of the formalization of the mining activities and how they can obtain mining licences as a group since these activities are done illegally. This can help to make them answerable in every damage caused to the environment. As mining sector is increasing with emerging number of ASMs across the country, its impacts need to be properly addressed.

Education and Training: Miners needs to be trained and educated through community engagement and sensitization and awareness campaign to put environment on consideration whenever the mining starts. When the corporate groups seek to start mining, they should consult the government and get trained in the process. The Government of Malawi through Inspectorate Department under Ministry of Mining should work hand in hand with environmental experts to the miners so that they should

be aware of environmental challenges of the mining activities. They need to be told on how they can protect the environment and manage the mine wastes while sustaining their livelihoods from the mining. People needs to be sensitized through awareness campaign in rural mining communities on the adverse impacts of ASM on environment if not managed well and how they make mining environmentally friendly.

Monitoring of All ASM Activity: After formalizing and training the miners on the environmental issues, all areas where people are mining minerals as artisanal and small-scale, the relevant authorities need to monitor all those sites and make sure that the miners are following what they taught concerning the environment. Reclamation of the land whenever the miners feel the mineral has depleted has to be done by refilling the open pits, revegetating the land in order to bring the land back to its initial productivity. The group that fails to meet the requirement must be answerable and punishable accordingly.

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APPENDIX

Field Observations Made from Two Different Site in Lumwira Village Mine Site





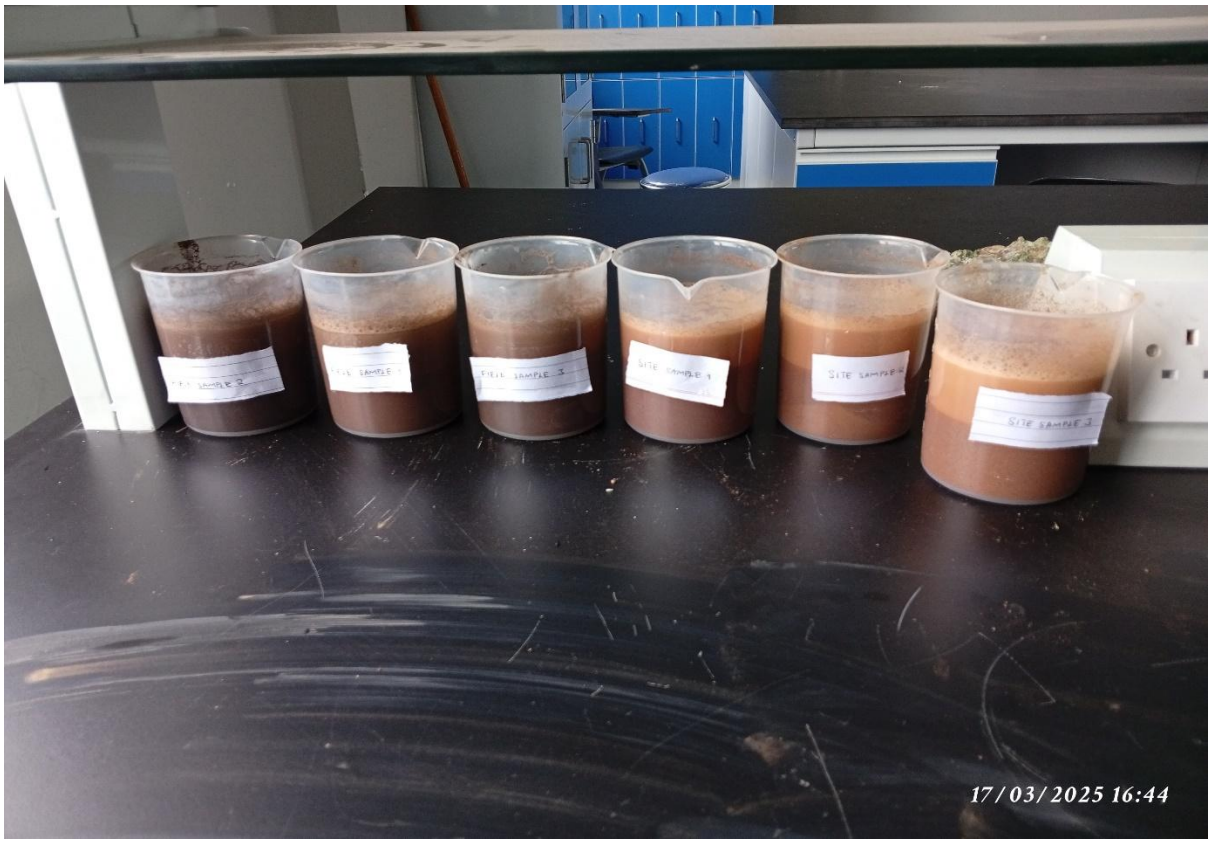








Laboratory Work for Soil Samples





USDA Soil Texture Triangle

