MERCURY LEVELS IN GROUNDWATER NEAR ARTISANAL SMALL-SCALE GOLD MINES IN MIGORI COUNTY, KENYA.

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DECLARATION

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

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DEDICATION

This thesis is dedicated to my father, my mother, brother, son and wife. An appreciation goes to Migori county residents and officers working for Migori County Government for their support, intuitive advice.

God Bless You.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS AND ACRONYMS

ANOVA - Analysis of variance

ASAL - Arid and Semi-Arid Lands

ASGM - Artisanal and small-scale gold mining

Au - Gold

CDC - Center for Disease Control

DNA - Deoxyribonucleic Acid

Hg - Mercury

Hg0 - Elemental mercury

Hg2+ - Inorganic mercury

ICP-MS - Inductively Coupled Plasma Mass Spectrometry

ICP-AES - Inductively Coupled Plasma Atomic Emission Spectroscopy

IQ - Intelligence Quotient

KEBS -Kenya Bureau of Standards

KEPHIS - Kenya Plant Health Inspectorate Service

KU-ERC - Kenyatta University Ethical Committee

LOD - Limit of Detection

LOQ - Limit of Quantification

Mg/L -Milligram per liter

PPM - Parts per million (ppm)

MDG - Millennium Development Goals

SDG - Sustainable development goal

NACOSTI - National Commission for Science, Technology and Innovation

NEMA - National Environment Management Authority

UNEP - United Nations Environment Programme

PPB - Parts per Billion

PPM - Parts per Million

USA – United States of America

US EPA – Environmental Protection Agency of the United States of America;

UNEP - United Nations Environment Programme

WASREB - Water Services Regulatory Board

WHO - World Health Organization

OPERATIONAL DEFINITION OF TERMS

Amalgamation	A process of obtaining gold from mine ore after mixing with mercury to get an amalgam. The gold is then recovered by removing the mercury**.**
Artisanal miner	A person who is working to obtain minerals by hand or inexpert skills of extracting minerals.
Artisanal small-scale gold mining	A process of using inexpert skills of extracting gold
Borehole	A hole bored into the ground to access water confined in an aquifer
Dry season	Period between January to February and June to September.
Groundwater	Water that is found below the surface of land between the rocks and soil
Season	Changes in weather patterns dividing the year
Pan-pond water	A pond that contains water that panning takes place to separate gold from soil
Pollution	Introduction of chemical that has harmful effects to the environment including human beings
Water service provider	An entity that is operated and mandated by regulating bodies to provide water services in a defined area
Wet season	Period between March to May and October to December experiencing rainfall patterns varying from 700mm to 1800mm.

ABSTRACT

In Migori County, Artisanal and small scale gold mining (ASGM) is an economic activity that uses mercury during the amalgamation process to obtain gold. The waste generated in form of soil tailings and pan-pond water contains mercury and is located close to community boreholes. The waste from the mines can lead to mercury contamination in groundwater. Boreholes are one of the most used sources of drinking water in Migori County. Ingestion of contaminated water is one of the ways mercury can get into the human body. A research done by Center of Environmental Justice and Development in 2017 showed that mercury is present in human hair from people around Masara mine, Migori County. Therefore, the study sought to establish the mercury levels in groundwater near Artisanal Small-Scale Gold Mines in Migori County. Specifically, the study determined mercury concentration in groundwater from boreholes, soil tailings and pan-pond water located near five mine sites during dry and wet seasons. The five mines were: -Masara, Osiri Matanda, Macalder, Kitere and Kehancha. The study used cross sectional-analytical study design. The research focused on boreholes found within a distance of 6 km from the five mines. Out of the 46 boreholes mapped, 15 (32% of 46) were proportionately sampled to obtain groundwater samples during dry and wet seasons. From the five mines targeted, 20 pan-pond water and soil tailings were collected in both dry and wet season as per respective sampling protocols applied. Mercury level from the samples was determined by use of Inductively Coupled Plasma –Mass Spectroscopy (7900 ICP-MS) at KEPHIS laboratory. Paired t-test was used to compare the means of the levels of mercury in groundwater obtained within the two different seasons. Measures of central tendency was used to describe the sets of data obtained after laboratory analysis of samples. The study established that during the dry season, all of the boreholes had groundwater mercury levels higher than the recommended limit by KEBS of 0.001 mg/L. There was a decrease in the levels of mercury in groundwater as distances from the mine increases. However, during the wet season, all of the boreholes had mercury levels below the limit of detection. The study established a significant difference on the levels of mercury in groundwater between wet and dry seasons at a 95% confidence level. In the mines, the study found that mercury levels in soil tailings and pan-pond water were above the NEMA effluents discharge standards of 0.05 mg/kg and 0.05 mg/L respectively in the dry season. During the wet season, all pan-pond water achieved the recommended mercury level of NEMA effluents discharge limits while the soil tailings had mercury levels above the recommended limit. This study recommends a need to implement mine waste remediation and, the borehole owners, licensed water service providers near the mines to continuously conduct groundwater heavy metal analysis during the dry season to protect their health. The county government to develop water related policies to ensure safe water services to the community.

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

Artisanal and Small-Scale Gold Mining (ASGM) uses inexpert skills of extracting minerals in the casual sector and it is practiced in over 70 emerging countries (UNEP, 2012). Worldwide, 15 million people are hired through such mining while people relying on it directly are estimated to range from 80 to 100 million. ASGM discharge mercury universally and it’s one of the most meaningful regarding pollution on water because it releases 37% of it (Esdaile & Chalker, 2018). Globally, it is estimated that 2,000 tonnes of mercury is generated from small scale artisanal mines to land, water and air directly (UNEP, 2012). The mercury convention held in Minamata as a global treaty urged the countries in support to reduce use of mercury in mining. This is was envisioned to protect the health and wellbeing of miners and promote environmental protection (IPEN, 2018).

Mercury exits in different forms naturally in soil, plants, atmosphere and animals. A form of mercury that easily evaporates into the air is elemental mercury. In the atmosphere, mercury reacts with other elements and settling. Sources of mercury in the environment are listed as geology of the soil, volcanic eruptions and ocean waters. The natural environment is associated with about half of mercury release (Erik, 2009).

Manmade activities lead to release of about 5,000 tons of mercury annually in the world. In the global context, the united states of America contribute an estimated 3 percent of mercury emissions worldwide because of its coal combustion industry. Other ways that generate mercury that finds its way to the environment include: use of fluorescent light bulbs, use of dry cell batteries. When these items are disposed of improperly, mercury may be released to the environment. In the past years, mercury was added to wood preservatives and fungicides to be effective. It is claimed that in the modern day, traces of mercury has been found in particular paints (Erik, 2009).

However, the industrial releases of mercury to the environment has been determined to reduce over time. It is good to note that mercury is volatile in its natural state. Atmospheric levels of mercury has been found to be ambient ranging from 10 to 20 ng/m^3. From the air, mercury finds its way on the land. From the mercury deposited on the land surface, only a small percentage finds its way to groundwater. Historically, mercury has been used for artisanal small scale gold mining which in turn makes its way to streams, rivers due to run off water. Rivers and streams are known recharge sources for groundwater (Erik, 2009). Conclusively, mercury is also known to exist naturally in groundwater at low levels. The low concentration is estimated at below 2 µg/L (Erik, 2009).

Mercury contamination adversely affects human life and can lead to mortality after chronic exposure (UNEP, 2013). Mine waste remediation can be able to reduce the risks; however, many ASGM activities do not practice it (UNEP, 2013). It has been research and found that mercury in both forms of elemental and methylmercury is lethal to the nervous system. One of the ways for mercury to enter the nervous and digestive system is through inhalation. Ingestion can also expose the immune systems leading to harmful effects or death to the individual. In inorganic state, mercury is corrosive to the kidney and other body parts. The level of exposure estimated at 20 µg/m3 for years can be shown in form of insomnia, headaches and motor dysfunction (Park, 2012).

Globally, the Minamata Convention focused on creating global policies, legislative frameworks on management of mercury use in developed nations urging implementation of phase out program. As part of mercury control strategy, developing counties were flagged for having little to no regulatory frameworks to curb mercury emissions. Nonetheless, monitoring systems of mercury emission globally indicate a decrease by up-to 50% as at the year 2020. The advanced technologies prioritized are pre-treatment and hardware rather than techniques used for recovery of mercury from manmade activities (Rhee, 2015).

In Africa, pollution of heavy metals in the previous decade has reached first time high levels. Therefore, human contact with heavy metals has developed into a great health threat attracting attention from the world and national organizations. The parts of the continent accused of being major sources of this pollution are the southern, east, west and north. Impacts on the human population are evident since toxic elements cause serious health hazards. 2.97 million Deaths of humans occur in Africa yearly due to environmental risk factors (Yabe & Umemura, 2010).

The Mining Act of 2016 in Kenya prohibited the use of mercury. However, poverty and unavailability of alternatives to mercury has made artisanal miner to have no choice (IPEN, 2018). In Kenya, apart from physical contact when mixing mercury and ore, the problem is exacerbated by amalgam which is a combination for mercury and gold in the same proportion. To recover gold, it is heated to evaporate mercury. During the panning process, over 40% of mercury applied is lost and 71% of the lost mercury is retained in soil and water wastes (UNEP, 2013).

ASGM in Migori County started in 1920, and it involves mercury usage in the mining procedure to obtain gold easily. As a result of climate change and rising poverty levels in the county over the past decade, ASGM has intensified (Barreto, 2016). Research done previously in the County in 2002 indicated mercury pollution in the mines (Ogola et al., 2002). A research conducted in one of the mines in Migori County on mercury, indicated that there was a reduced IQ of the people from the local community which is costing them billions of shillings estimated between 174 and 342 (CEJAD, 2017).

1.2 Problem statement

Mercury as a heavy metal is considered harmful to human health according to World Health Organization. During artisanal gold processing, mercury remains in waste soil tailings and pan-pond water (Yoshimura et al., 2021).Mercury accumulating in the mines can potentially lead to groundwater contamination. Boreholes are one of the most used sources of drinking water in Migori County (MoALFC, 2021).

A research done by Center of Environmental Justice and development in 2017 showed a presence of mercury in human hair from people around Masara mine, Migori County (CEJAD, 2017). Another research conducted in Mikie and masara mines revealed that 70% of the women involved in the study had mercury levels over 0.58 ppm. Mercury disposes them to developing neurological damage in the fetal development in times of pregnancy (IPEN, 2018). Therefore, this research sought to determine whether groundwater sources commonly used for drinking has presence of mercury during both dry and wet seasons following the research findings of IPEN.

1.3 Justification

The study has provided new information will assist the study participants make the safe decision of the source of water to drink during the dry season according to the acceptable levels. This study is supporting SDG 3 on healthy lives and well-being for all at all ages by making recommendations to decision makers. This information on groundwater contamination is vital because it can be used in the creation of water related policies to protect the health of borehole owners and community using the water for drinking.

1.4 Research questions

1. What are the levels of mercury in drinking water from boreholes located near artisanal mines in Migori County?

2. What are the levels of mercury in soil tailings and pan-pond water in artisanal mines in Migori County?

3. What influence does seasonal variation have on levels of mercury in groundwater located near artisanal mines in Migori County?

1.5 Hypothesis

Activities of artisanal small-scale gold mining have no effect on the mercury levels in groundwater near the mines in Migori County.

1.6 Objectives

1.6.1 Broad objective

To establish mercury levels in groundwater near Artisanal Small-Scale Gold Mines in Migori County.

1.6.2 Specific objectives of the study

1. To establish the levels of mercury in groundwater from boreholes located near artisanal mines in Migori County as compared to drinking water standards required by KEBS.

2. To establish the levels of mercury in soil tailings and pan-pond water in the artisanal mines in Migori County as compared to NEMA effluents discharge standards.

3. To determine the influence seasonal variation has on levels of mercury in groundwater from boreholes located near artisanal mines in Migori County.

1.7 Significance of the research

The study has provided new knowledge on the levels of mercury in groundwater during two seasons from boreholes near artisanal mines in Migori County. This information on groundwater contamination is vital because it can be used in the creation of county water and mining related policies. The county and national government will used the finding to justify promotion of alternative ways of extracting gold.

1.8 Limitation and Delimitation

1.8.1 Limitations

The study area has all-weather roads leading to the mines and boreholes, therefore, during wet seasons it was difficult to navigate through when collecting the samples. Parameters like temperature, pH and chemical factors that may influence levels of heavy metals were not within scope of the study.

1.8.2 Delimitations

The researchers adopted local transport methods to reach the mining sites and boreholes to manage time.

1.9 Conceptual Framework

Figure 1.1 shown below, shows how presence of mercury from artisanal mines impacted by several intervening variables influence the level of mercury in groundwater from boreholes.

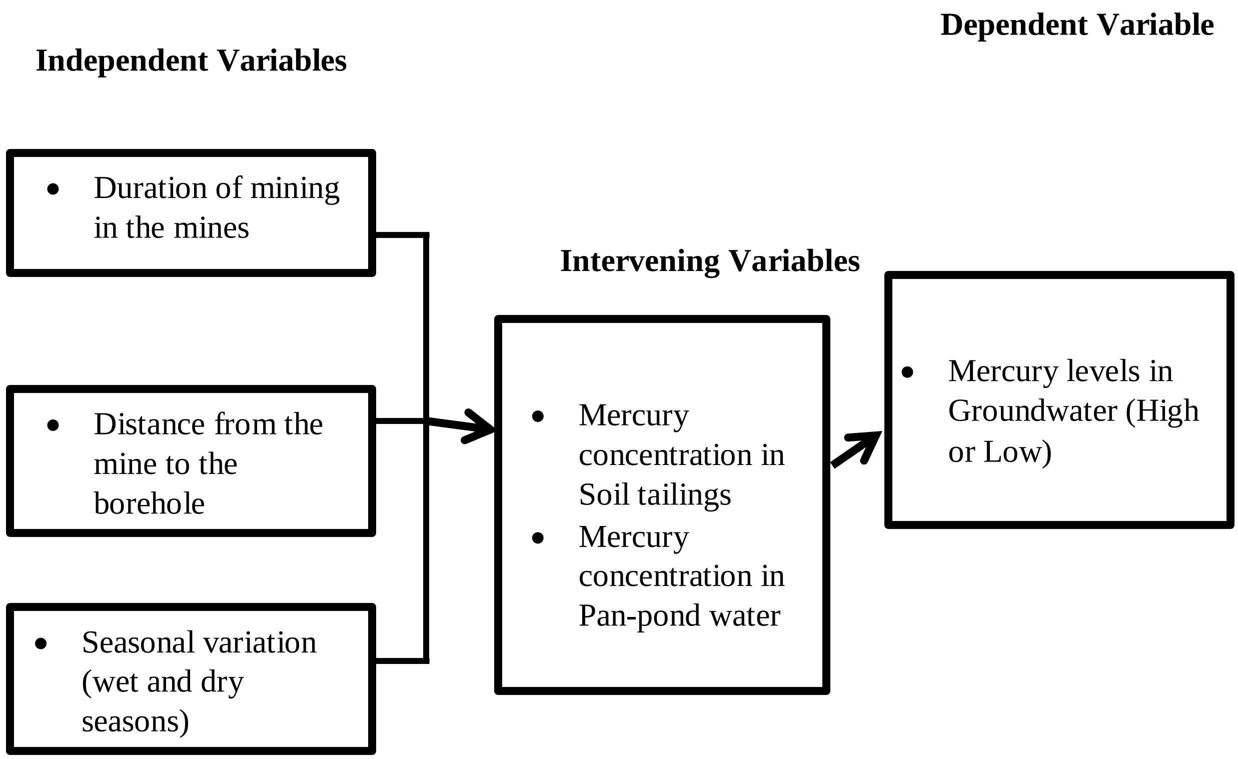

Figure 1.1: Conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviews information on mercury use in the Artisanal small-scale gold mines, the vulnerability of groundwater situated near artisanal small-scale mines, and how seasonal variation influences groundwater quality in regard to mercury levels near contaminated artisanal small-scale mines. It also highlights the importance of mercury to public health.

2.2 Mercury use in Artisanal Small-scale Gold Mining

Anthropogenic mercury discharge from the ASGM in a global context is approximated to be 17% of the spillage done directly into the environment. Naturally, mercury exists in water, air and soil in the environment (ATSDR, 1999). The mining process involves toxic elements and also unearths mineral components such as sulphuric compounds. The low pH on the water as a result of sulfide compounds increases the solubility of heavy metals such as mercury making wastewater contain high mercury levels. During gold mining and processing, mercury is added to form an amalgam which is then later heated to recover gold deposits. Mercury emission and distribution in the environment occur through natural and anthropoid activities (US EPA, 1997).

In artisanal small-scale gold mines, the frequency of amalgamation is influenced by the scale of mining activity. If there is more mining activity then more amalgamation processes will be repeatedly needed to extract as much gold as possible. The more the amalgamation process the more mercury is used. At the mines which are contaminated with mercury, the seasonal variation influences the amount of mercury that can be found on both soil tailings and wastewater. When it is raining then wastewater can flood and spread increasing absorption rate into the soil as opposed to when it's a dry season. This can influence the amount of mercury measured in the soil tailings and wastewater at any one point in time. Elemental mercury used in the amalgamation process during its movement environmental media, undertake complex chemical changes. Methyl-mercury is the most important while organic and ionic mercuric states also exist in the environment (US EPA, 1997).

Mining of gold by artisanal miners is separated into two stages. The first step involves mining of rocks containing the deposits of gold through shallow underground mining. The extracts are then crushed using rudimentary methods. Mercury is then introduced during the second step using plastic or metallic containers by constantly stirring to form an amalgam. The amalgam is composed of gold and mercury. To recover gold, the amalgam is roasted using fire to evaporate the mercury, therefore, causing air pollution with mercury. The process leads to potential mercury exposure to the miners and people living within the environment (Hruschka et al. 2002). Further refinement of gold is believed to be done in towns by gold dealers and gold smiths far away from the small-scale gold mining sites (Kitula, 2006).

The miners are encouraged to practice other technology such as borax technology due to poverty. There is normally no technical training or licensing to carry out these activities (Spiegel & Veiga, 2010). The lack of training affects miners ability to manage the use of mercury in preventing harm to the environment and human health (Spiegel & Veiga, 2010).

2.2.1 Pan-pond water use in Mines

Artisanal gold mining activities in Migori County are done using water near rivers and water sources. The wastewater generated from the process accumulates and leaches into the ground while waste ponds near rivers pollute it. The panning process is in most cases done by hand or makeshift tools and a small pond dug to drain the wastewater. Pan-pond water accumulates a lot of mercury due to the repeat amalgamation process on them (Ogola et al., 2002). The more accumulation of mercury the riskier it becomes (CDC, 2022). Recycling of waste from the mines and the cleaning procedures is not known to locals and economic capabilities are not adequate. An estimated 40% of mercury is lost in the pond water and tailings (Ogola et al., 2002). Rivers form part of the groundwater recharge system, hence, river Kuja is at high risk of pollution due to Macalder and Osiri mines situated near it. The research has hence, provided information on the level of mercury in waste (Ogola et al., 2002). The required amount of mercury allowed to be discharged in the environment is 0.05 mg/L and below (WASREB, 2008).

2.2.2 Soil tailings deposit in mines

Soil tailings from the small-scale gold mines are normally contaminated with mercury. The contamination happens because of amalgamation activities. Soil tailings are treated as waste soils after the recovery of amalgam which is a mixture of gold and mercury and is silver in color. The soil tailings are normally dumped in heaps at the mine sites exposed to the environment. The rainwater that leaches to the ground is contaminated by mercury from the soil tailings in the mines (UNEP, 2002). These concerns are further worsened by the continuous production of contaminated soil tailings from such artisanal mines. If conditions facilitate the formation of methyl-mercury from elemental mercury which the miners use then, health issues from contaminated water get worse due to the ability of methyl-mercury to bio-accumulate in the food chain. Mercury remains in soil tailings; wastewater is hazardous through erosion over time. In a global context, the only way to reduce the risk of mercury emission is to curb unauthorized release (UNEP, 2002). The required amount of mercury allowed to be discharged in the environment is 0.05 mg/kg and below as described by WASREB (WASREB, 2008).

2.3 Occurrence and movement of mercury in groundwater

Groundwater is naturally refilled from surface water from rainfall and rivers when they infiltrate into the ground. Groundwater is durable storage of the natural water cycle different from temporary water reservoirs such as the surface water and atmosphere. Aquifers have two different types which are based on physical characteristics described as follows: - i) A confined aquifer is when the saturated zone is enclosed between layers of impermeable rock ii) Unconfined aquifer is where there is no impermeable material directly above the saturated zone. Unconfined aquifer is susceptible to pollution by leachates that infiltrate the soil. The groundwater table is the section of the groundwater subjected to atmospheric pressure over the surface of the aquifer (Lenntech, 2019)

Groundwater contamination can occur when the boreholes are unprotected and toxic material released into them or if the source of the groundwater is contaminated. Mercury deposited near the boreholes can percolate into the unconfined aquifers and pollute the groundwater in the boreholes. The boreholes near suspected mines may be contaminated and water from them is still used by unsuspecting people which over time can cause adverse health effects. Hence, boreholes that are located near mines where wastes are produced are at risk and need to be tested for heavy metals such as mercury

(The Groundwater Foundation, 2018). The release of mercury in illegal ways has affected the Arctic even though; its distance is far from significant anthropologic activity (AMAP, 2003).

It is projected that about 5,000 tons of mercury are emanated into the ecosystem annually as a result of human activities (WHO, 2003). A small amount of mercury is percolated into groundwater due to the volatile nature of mercury on the land surface. However, in soils where this element exists, groundwater usually has low concentrations. In most cases, mining activities or past history of mining lead to increased concentrations. Normally, groundwater mercury concentration does not exceed 2 µg/L (WHO, 2003). The permissible mercury concentration in drinking water according to Environmental Protection Agency is below 0.001mg/l (WHO, 2019).

It is vital to comprehend the relationship linking regional topographical setting, low stratigraphy near the waste locations. In most cases, geographical settings do not significantly translate to low aquifers (about 20 m). The shallow aquifers are commonly the major routes for contaminant movement in the subsurface. However, local understanding reveals that there is reliance on the water supply from the aquifer (IAEA, 2001). The diagram in appendix IV comprises methods and knowledge used to predict how waste disposal activities pollute the groundwater system. It also involves directions of movements in the groundwater system (IAEA, 2001). In Migori County, geology research done in the area, however, indicates no mercury present in the natural soil characteristics. It is, therefore necessary to investigate the groundwater near polluted mines in the area (Ogola et al., 2002).

2.3.1 Groundwater Recharge and Hydrogeology

During groundwater recharge, water passes through soil and rocks after precipitation and this causes filtration. Water reacts with soil particles to form different compounds (Homsby, 1999). The organic material can be absorbed from the water. The ability of soil and rocks to absorb and retain pollutants such as chemicals is not steady (Vladimir, 2003). The amount of contaminants as a result of land use patterns can also affect soil filtration process. Therefore, contaminants from the land surface can be controlled by physical barriers reducing pollutant movement (Vegter, 1995).

In this context, Migori County has an aquifer with recharge patterns and quantities that is unknown. It is stated in the regional master plan that infiltration of water from rainfall is what contributes to recharge of the aquifer. The Nyanzian bedrock aquifer are is affected by lava and tuff layers which influence groundwater flow and storage (Regional Master Plan, 1974).

The rocks found in Migori County are known as granite-greenstone complex because their archaean age is estimated to be 2.8 billion years. It is the archean rocks that have traces of gold. In the Migori County, mercury doesn’t occur naturally. The mafic volcanic have quartz veins containing gold. Metabasalt, andesites, ironstone, and shales are the known host rocks in Migori County (Ogola, 2002).

Migori County has a hydrogeology that can be described as laterally and vertically heterogeneous. The hydrogeology is further influenced by availability of shallow weathered lateritic zone and sediments of alluvial nature (Africa Groundwater Atlas, 2019). The Migori Kehancha Regional Master plan (1974) assesses the catchments of Migori and Gucha documenting both land and water uses in the regions.

Hydrogeological reports collected from the Water Resources Authority located in Kisii Town (Lake Victoria South Catchment Area).Migori County has a geology that is categorized into: unconfined alluvial aquifer which is shallow, shallow laterite estimated at 10-50m with flexible permeability and a semi-confined aquifer estimated at 80–200 m comprising of nyanzian sedimentary rocks.

The approximated yield of the shallow unconfined aquifer is known as 3 l/sec based on information from boreholes dug in same alluvial aquifers in the county. It is believed that water stored within the unconsolidated alluvial aquifer recharges the semi confined aquifer below it. However, this is complicated by the many layers within the nyanzian sedimentary rocks. In this study, the aquifer located within the nyanzian sedimentary bedrock is the focus. There are cases of existence compartmentalized aquifer in the southern region of Migori County. According to the Regional Master Plan (1974), the nyanzian aquifer fracture is carried out from the depth of 50–60 m while before the depth, other groundwater aquifers are found.

Water from springs come from separated landscapes containing Migori Granite and rainfall is experienced more than other parts of Migori County. Migori Granite has both horizontal and vertical joints which is ideal for outflow of groundwater and recharge through infiltration. Regional Master Plan (1974). The shallow aquifer is the uppermost while less productive, while, the other one moderately to highly productive. It is indicated that 200m is the maximum depth of borehole recorded in the region and further beyond, indicates little to no groundwater because its rocks are not fractured (Regional Master Plan, 1974).

2.3.2 Groundwater Flow

Measurement of hydraulic head is required to develop maps showing water levels to enable determination of direction of groundwater flow within the respective aquifers. Groundwater system contains potential energy that is distributed. The developed maps show potentiometric surface and the contour can be defined as a hydraulic head. It is approximated that the direction of groundwater flow is from high to low hydraulic head. This is further explained by the gradient. This is typical of surface water which flows down a gradient. However, when the hydraulic conductivity of two directions differs, then water will flow in the direction of maximum gradient. The rate of groundwater flow can be explained by a potentiometric map because it depends on the hydraulic conductivity and hydraulic gradient. According to Darcy's law, (h1-h2)/L. is the formulae used to calculate head gradient or slope of potentiometric surface. Flow line is described as a constant line drawing the maximum gradient on a potentiometric map (Michael and Demian, 2022).

2.4 Seasonal Influence on Artisanal Small-scale Gold Mining activities and Groundwater

Migori region is known for its existence of gold deposits and artisanal gold mining practices. As part of western part of Kenya, it experiences two rainy seasons which is characterized by heavy rainfall. In 2020, adverse weather conditions was experienced which meteorological department sent advisories (County Government of Migori, 2018). The cautions were targeting the western, coastal and central parts of Kenya. In the wet seasons, artisanal mining operations normally get affected is the areas causing slowdowns. Artisanal gold mining uses amateur methods and unsafe methods to access the ores leading to potential fatal accidents (Macháček, 2019).

During the dry season, the conditions for agricultural practices becomes unconducive causing low farm produce and reduced incomes in households within Migori County. These conditions forces many residents to migrate to gold mining areas to survive. Therefore, it is the period of highest activity in the mines. An estimated 20,000 are said to be seek employment in these mines directly or indirectly to fend for themselves (Macháček, 2019).

In African countries like Zimbabwe where artisanal mining takes place, the gold mining operations reduce significantly during the rainy seasons. In the mine sites of Gankombol, gold mining operation intensify during the dry season because of less risks of accidents and easy accessibility of the ores. A research done on the mines by Edokpayi et al. (2016) revealed mercury levels in the mines were higher during the dry season compared to wet season. In the nearby River Lom, increase in mercury level was observed during the dry season because of low water levels and intensification of activities releasing mercury to the environment (Edokpayi et al., 2016).

In many parts of the world especially in ASAL, groundwater is the key water supply source. However, there is little research on the possible consequences of climate change. Rainfall, lakes, and rivers recharge aquifers through cracks, pores and penetrate through rocks and soil superimposing the water table. Recharge is changed if there is a rainfall change. There is normally what is called a recharge season and that is what will be altered. There is increased groundwater recharge during winter rainfall especially in mid-latitude regions (Singh & Kumar, 2010).

There are different ways in which aquifers are recharged. The key aquifers are confined and unconfined. Regional rainfall, rivers, and lakes recharge unconfined aquifers directly. Soil geology and permeability influence the recharge rate of groundwater and fissure and macro-pore recharge is the regular way. In regions where there are sinkholes and cracked soils, recharge occurs at a high rate. Mainly recharge occurs whenever it rains and can be important so changes in a seasonal cycle can affect it (Kumar, 2012).

Shallow boreholes drilled into an unconfined aquifer are normally boosted by seasonal rivers or watercourses and can be affected by vaporization. Hence, seasons in the environment have the ability to affect the amount of groundwater in combination with soil permeability. This indicates that the unconfined aquifer is delicate and vulnerable to microclimate and intrusion by seawater. The impact of vaporization in a region where there is a lot of sand is significantly lower. Nevertheless, it is correct to say that recharge is complex to be quantified due to varying weather patterns, aquifer properties, and soil geology. The confined aquifer is protected with impenetrable superimposing rocks; hence, it is not affected by the local climate. It is usually boosted from rainfall that happens even thousands of kilometers far away, lakes and rivers near a site. Generally, aquifers are influenced by climate change, soil geology, and aquifer media properties (Kumar, 2012).

2.5 Gaps identified in the literature review of the study objectives

Groundwater in Migori County is vulnerable as a result of long term mining activities conducted around it. The literature present shows the reason to periodically monitor potential mercury level in groundwater to protect public health. This research focusing on more than one mine and several boreholes at various distances in different seasons of

Migori County provided new information for licensed water service providers. The government agencies mandated to monitor safety of potable water will be empowered to develop relevant policies. The information on the mercury levels in pan pond water and soil tailings can be used to monitor the adherence to Minamata convention in route to sustainable mining practices.

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter describes study design and location of study, sampling methods, sample size determination, data analysis and presentation. This study carried out a pilot study was carried out keeping in mind the logistical and ethical considerations

3.2 Research Design

A cross-sectional analytical design was used in the research to measure the mercury levels during both wet and dry seasons. The study involved collection of water and soil samples from the artisanal mines and boreholes which were transported to a certified government laboratory for mercury analysis, and the results inferred to a specific point in time.

3.3 Variables

3.3.1 Dependent variable

In this study, mercury concentration in groundwater from boreholes was the dependent variable. This variable was measured quantitatively and the acceptable value for drinking water quality is placed at 0.001 mg/l according to WHO and KEBS (WASREB, 2008). Any concentration above the reference point was considered evidence of mercury contamination. So the quantitative results were further dichotomized into their compliant or non-complaint to depict contamination.

3.3.2 Independent variables

Independent variables independently or collectively used to explain the results observed on the dependent variable. In this research, the distance from mines to the boreholes, seasonal variation (wet and dry season) and, the duration of mining activity in the mine are the independent variables. They were thought to influence the level of mercury in groundwater used as a source of drinking water by residents. The distances of the mines to the boreholes were quantitatively measured in kilometers. The seasons in which the samples from the mines and groundwater were collected were both in dry and wet seasons. The mines chosen were based on the years of operation.

3.3.3 Intervening variables

Mercury concentration in soil tailings and pan-pond water were the intervening variables in this study. They are individually or collectively used to explain the relationship between dependent and independent variables. To achieve the measure of their influence, these intervening variables were measured quantitatively. The acceptable values for effluent discharge of mercury in pan-pond water and soil tailings is placed at 0.05 mg/1 and 0.05 mg/kg respectively by NEMA (WASREB, 2008). Any concentration above the reference point value was considered evidence of mercury pollution.

3.4 Location of Study

The study was carried at Macalder mines, Osiri matanda mine, Masara mine, Kehancha and Kitere mines located within Migori County. This county is situated in the western region of Kenya and covers an area of 2,596.5 km^2 with gps coordinates of 0.9366° S, 34.4198° E. It is divided into 10 sub-counties, with a total population of 917,170 (KPHC, 2019). The climate in Migori County, experiences its long rains between March to May while in October to December short rains, are experienced with rainfall patterns varying from 700mm to 1800mm. The average temperature every year is 21.2 °C (Climate-Data.org, 2018). The climate of the area supports the farming of sugarcane, tobacco, maize, and cotton (Ministry of Planning and Development, 2002). Migori County has granite-greenstone complex rocks. The study area has mafic volcanic with quartz veins containing gold. The host rocks in the areas are Metabasalt, andesite, ironstone, and shale. The soil geology has no natural existence of mercury (Ogola et al., 2002).

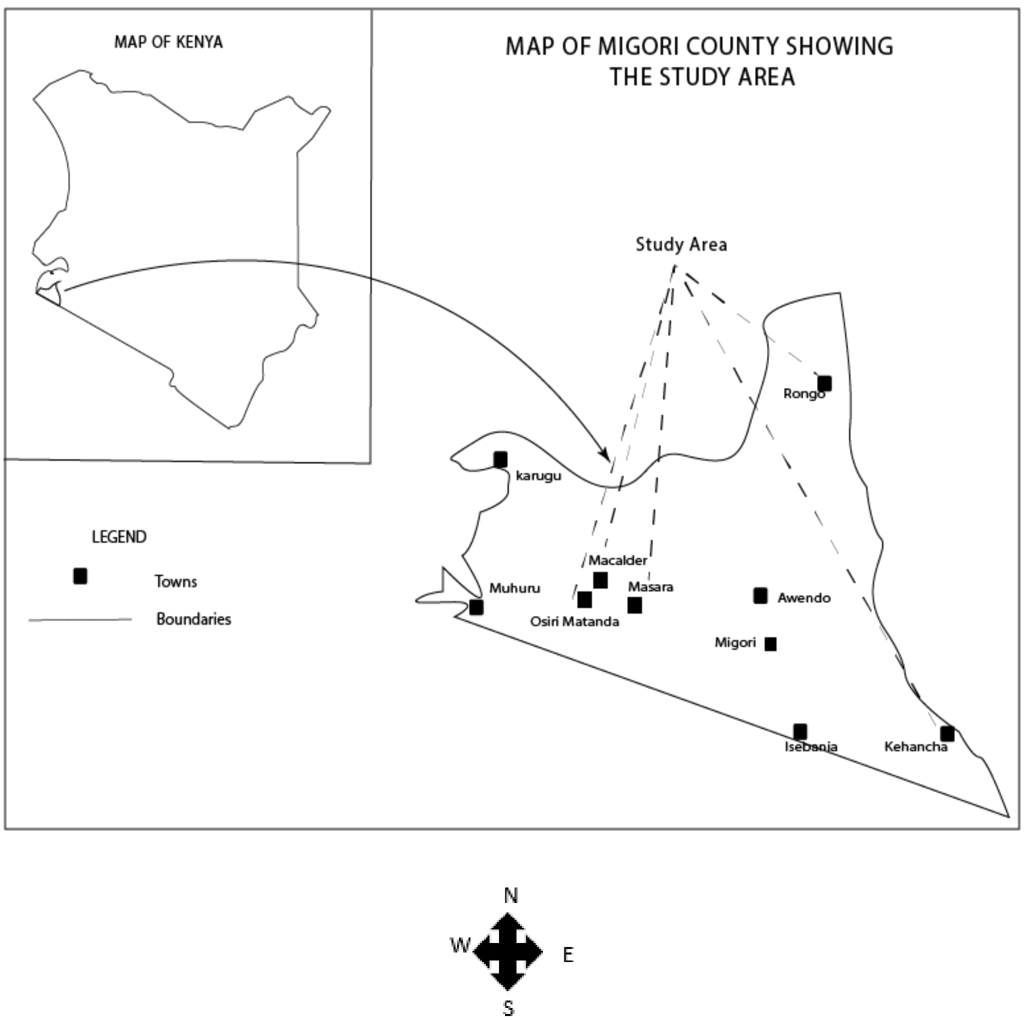

Figure 3.1: A map of location of the study

3.5 Study population

The study focused on artisanal small scale gold mining sites and boreholes within Migori County, Kenya.

3.5.1 Target population

Mines targeted for this study were: - Kitere (Rongo sub county), Osiri, Masara mine and Macalder mine (Nyatike sub county), Kehancha mine (Kuria sub-county).

In 2021, a total of 46 boreholes in use were mapped in collaboration with community resources persons within a distance of 6 kilometers from the five mines in Migori County. A distance of 6 km was preferred as used in a similar study by scientist El-Salam (El-Salam & Abu-Zuid, 2015; Hu et al., 2020). The depth of the boreholes targeted was between 80m-200m as estimated in the Regional Master Plan (1974).

3.5.1.1 Inclusion Criteria

- Soil and water samples from mines that have been operation for 10 years by the time of the study (Cossa et al., 2022).
- Groundwater from boreholes whose informed consent have been granted and located within a distance of 6 km from the five mines used in the study (Hu et al., 2020).
- Boreholes eligible were of 80m depth and deeper as verified by the owner (Migori Kehancha Regional Master Plan, 1974).

3.5.1.2 Exclusion Criteria

- Groundwater from boreholes which is being undertaken through water treatment before it is released for use.

3.6 Sample Size and Sampling Techniques

3.6.1 Sample Size Determination

Five water samples from pan-pond water and five soil tailings samples were collected during both the dry and wet season as per sampling protocols indicated in section 3.6.3 below. In this regard, 20 samples were to be collected in both seasons.

A sample size of 30% is a recommended minimum sample size acceptable to represent a population (Mugenda & Mugenda, 2008). Out of 46 boreholes mapped within 6km distance from the mines, 15 (32% of 46) in accordance with the sampling frame below were proportionately sampled.

3.6.2 Sampling of mines

The duration for artisanal gold mining activity was used to identify mines considered in the study. Similar to scientist Hermínio Cossa, 10 years was adopted to identify the mines to be monitored for mercury levels (Cossa et al., 2022). After consultation with the department of geology and mines in Migori County, five mines were noted for being in operation for 10 years by the time of the study. The five mines were: Macalder, Masara, Kehancha, Osiri and Kitere. This was confirmed by secondary information from previous research. Macalder, Masara and Kehancha mines started gold mining operations in the1930s and after independence, the artisanal mining has continued. It is estimated that by 1966, 4284 kg of gold had been mined from the ores (Ogola, 1993).

At independence, large-scale mining operations came to a halt and resumed with artisanal miners taking responsibility of exploiting the gold deposits. In Osiri mines, 1980s found the mines operational with several miners having been reported of experiencing fatal accidents (Ogola et al., 2002). Gold deposits were discovered in Kitere mines in 1953 and mining operations started (Ochieng, 2002).

3.6.3 Sampling of soil tailings and pan pond water

3.6.3.1 Soil tailings sampling

There was presence of numerous heaps of soil tailings at the five mine sites. To get composite soil samples, the mines sites were traversed in a zig-zag pattern during collection of 20 soil grab samples. Then, the soil samples of about 50 - 75 cm^3 /100g were mixed well and a stainless steel hand auger (3-inch) was used to scoop one kilogram of a soil sample. The procedure was repeated in each of the five mines. This was in line with sampling and analysis protocol outlined in Ontario Regulation 267/03 and in concurrence with protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners (Veiga & Baker, 2004).

3.6.3.2 Pan-pond water sampling

Water samples were collected from the pan ponds within the mines using a 500ml plastic container which was fixed on a wooden pole. It was pushed in the middle of pan pond water to approximately a depth of 10-25 cm, then pulled back to collect water along the depth to avoid unpredictable changes such as concentration. The samples collected were called depth-integrated samples as outlined in protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-

Scale Gold Miners (Veiga & Baker, 2004). The three depth-integrated samples obtained at one particular mine were mixed thoroughly in a large plastic container, and then a 500ml sample was taken in a plastic bottle (Breugtot et al., 2008).

3.6.4 Groundwater sampling

Groundwater was taken from boreholes identified for the study within 6 km distance (Loizidou, & Kapetanios, 1993). Since the boreholes were in constant use using water pumps, the water samples were collected from the outlet taps after using the water to rinse the collection plastic bottle (Jonathan, 2013) (Northern Territory, 2016). The samples collected from the boreholes were put in a 500 ml plastic bottle following water sampling procedures as described by US Environmental protection agency operating procedures (APHA, 1998). After water collection, 5 percent of concentrated nitric acid was added for preservation and to keep metal ions in the solution (Kar et al., 2008).

Table 3.1: Sampling Frame used for boreholes near the five mine sites

S/No.	Mine site	No. of Boreholes	Sample size of the boreholes near each mine site	N/n
1.	**Masara**	9	(9/46)*15=3	3
2.	**Osiri Matanda**	8	(8/46)*15=3	3
3.	**Macalder**	8	(8/46)*15=3	3
4.	**Kitere**	10	(10/46)*15=3	3
5.	**Kehancha**	11	(11/46)*15=3	4
	Total	**46**	**15**	

A total of 50 samples were collected during the dry season on 18th and 19th August, 2021, and on 11th and 12th December, 2021 for the wet season. Systematic sampling was used using calculated intervals (N/n) as displayed in the table above.

3.7 Pilot study

A pilot study was carried out in Komito mine which is not one of the mines intended for the research. The mine site was chosen to avoid pre-emptying the research to the artisanal miners and borehole owners. In this exercise, 10 samples were collected in both seasons. The samples consisted of two pan-pond water, two soil tailings samples from the mine and six groundwater samples. This represented 10% sample size recommended for a pilot study. The results of the pilot study, indicated that the sample collection and analysis techniques were accurate and needed to be replicated. However, the water collection forms needed to be amended by adding name of the mine associated with the sample apart from having the sample codes to avoid confusion.

3.7.1 Research Instruments

In this study, water sample collection tool was a vital instrument. A water sample collection form was developed and tailored to capture details of the samples like the date of collection, borehole code, and time of collection among others (WHO, 1997). This is presented in appendix IV.

3.7.2 Validity

The extent to which a study uses its instruments to measure its objectives is described as validity (Cooper & Schindler, 2006). Research assistants were adequately trained on sampling techniques and use of sample collection form to ensure relevant data collection. The contents of the water samples collection form were subjected to expert consultation to increase validity. In ensuring quality Control, the data analysis instruments were well calibrated. The (7900) ICP-MS used various standard series of 0, 10, 20, 30, 50, 100 ug/L to prepare a calibration that has a minimum of five points inclusive of the blank.

3.7.3 Reliability

The consistency of a study instrument or procedure is referred as reliability (Bryman, 2008). This study ensured reliability by carrying out similar procedures during sample collection and use of simple language when constructing questions in the water sample collection forms. Pretesting of research instruments before sample collection and laboratory testing practice.

3.8 Soil and water collection techniques

Soil samples of about 1kg were taken using soil augers from mining sites into a plastic container. A different hand auger was used for sampling in each collection points. Each sample was labeled with unique codes and samples not cleaned because of the risk of influencing mercury levels (UNEP, 2016).

Pan pond water samples were collected in 500ml plastic bottles. Thereafter, 5 percent of concentrated nitric acid was added for preservation and to keep metal ions in solution (Kar et al., 2008). This process was repeated in the other 5 sampling mine sites when collecting pan pond water samples.

Water samples from boreholes were collected in a standard 500ml plastic bottle. The bottle used for sampling were washed with water to be sampled first and then filled with sample water (APHA, 1998). 5 percent of concentrated nitric acid was added for preservation and to keep metal ions in the solution (Kar et al., 2008). The details of the borehole were captured as per the water collection form (see appendix IV).

3.9 Laboratory analysis of samples

A representative sample was weighted out into the ultra-clean and dry inert polymeric microwave vessels. 9+/- 0.5 mls of concentrated nitric acid were slowly added into each vessel. This was conducted under the fume extraction hood (Mangum, 2009). Gradually, Perchloric Acid was added followed by concentrated Hydrochloric Acid because the samples were for mercury analysis. After cooling, samples were quantitatively transferred into 250 ml volumetric flask and filled to the mark using de-ionized water (Mangum, 2009). The samples were analyzed analysis using the Inductively Coupled Plasma –Mass Spectroscopy (7900 ICP-MS) (Agilent, 2022). The samples were analyzed with suitable Certified Reference Material and samples or Spikes using secondary reference material for mercury and the values plotted in a control chart. The CRM results were plotted and a decision on method performance was derived from the plots as per Standard Operating Procedure on assuring of quality of analytical results (Mangum, 2009).

3.10 Data analysis

Data from the laboratory analysis was analyzed using Microsoft Excel (version 2016). This included data organization and summarization. Paired t-test was used to compare the means of the levels of mercury in groundwater obtained within the two different seasons. The sample size to be compared was less than 30 in number (Hsu &

Lachenbruch, 2014).Measures of central tendency were used to present findings of this research such as the mean. The distances from the mines to the boreholes were analysed using GIS software (ArcGIS 10.8.2).

For analysis purposes in this research, below limit of detection figures were replaced with 0.0000141421 mg/L. This replacement value was derived by dividing limit of detection by the square root of 2 (Croghan et al., 2003). The limit of detection of ICP-MS (7900) for mercury is stipulated as 0.01 ppb/0.00001 mg/L (Agilent.com, 2022).

3.11 Logistical and Ethical Considerations

An approval from graduate school and the department of Environmental and Occupational Health of Kenyatta University was obtained. Kenyatta University Ethical Review Committee (KU-ERC) also provided consent. The National Commission for Science, Technology, and Innovation (NACOSTI) authorized the study by providing a permit. The agreement to conduct the research was requested from department of mines and geology. The samples were collected with the mine representatives and the borehole owner's informed consent. Confidentiality of the boreholes was ensured through coding as per the water collection form.

CHAPTER FOUR: RESULTS

4.1 Introduction

This chapter outlines comprehensive analysis of data and presents a report of the results of the study. Graphs and tables are used to present the findings. Data analysis was done in line with the specific objectives guided by research questions.

4.2 Mercury concentration in groundwater from boreholes

The results of mercury levels in groundwater from boreholes during dry and wet season in Migori County are presented in Table 4.1 below. These results are disaggregated by season of the year. The dry season experienced in Migori County runs from July to September while wet seasons happen between the months of March to May and in October to December (County Government of Migori, 2018). The groundwater samples collected from the boreholes were not subjected to any form of treatment at the point of collection in this study.

From the results, it is observed that mercury was present in all groundwater samples during the dry season. The results were higher than the KEBS recommended levels of 0.001 mg/l for drinking water. This meant that the water might be a public health concern when used for drinking. However, during the wet season, mercury levels in groundwater were below limits of detection (Table 4.1). Therefore, indicating the water was safe because the mercury levels were below the maximum allowable limits when compared to KEBS recommended levels of 0.001 mg/l.

Table 4.1: The levels of mercury in groundwater from boreholes during dry and wet seasons

Mines	Borehole samples codes	Mercury levels in groundwater from boreholes		Distance from the mine (KM)
		dry season	wet season	
Osiri	OS11	0.19 mg/L	<LOD	**<1km**
	OS 12	0.13 mg/L	<LOD	**1km<2km**
	OS 13	0.17 mg/L	<LOD	**3km<6km**
Kitere	KIT 21	0.11 mg/L	<LOD	**<1km**
	KIT 22	0.21 mg/L	<LOD	**1km<2km**
	KIT 23	0.08 mg/L	<LOD	**3km<6km**
Masara	MAC 31	0.28 mg/L	<LOD	**<1km**
	MAC 32	0.35 mg/L	<LOD	**1km<2km**
	MAC 33	0.36 mg/L	<LOD	**3km<6km**
Macalder	MAC 42	0.76 mg/L	<LOD	**<1km**
	MAC 41	0.49 mg/L	<LOD	**1km<2km**
	MAC 43	0.46 mg/L	<LOD	**3km<6km**
Kehancha	KEH 51	0.12 mg/L	<LOD	**<1km**
	KEH 52	0.11 mg/L	<LOD	**1km<2km**
	KEH 53	0.10 mg/L	<LOD	**3km<6km**

<LOD ***means*** Below Limit of Detection

4.2.1 Influence of distance of mine to borehole on groundwater contamination

The results of mercury levels in groundwater were classified according to their distances. The distances of boreholes to the mines were a maximum of 6 km and mercury levels were measured in both dry and wet seasons. The contribution of distances of mines to boreholes when it comes to mercury levels in groundwater can be linked to gold mining activities (Michael & Demian, 2022).

From the results, the wet season values of mercury concentration in groundwater were constantly below the detection limit as distances from mine to boreholes increase (Figure 4.1). However, the dry season values showed a decrease in the levels of mercury in groundwater as distances from the mine increases. The mean values of mercury levels in the dry season ranged from 0.292 mg/L for <1km, 0.258 mg/L for 1km<2km, 0.234 mg/L for 3km<6km. Dry season values above KEBS recommended standards of 0.001 mg/L were a public health concern. Figure 4.1 below presents the levels of mercury in groundwater during the dry season against the distances of the boreholes to the mines.

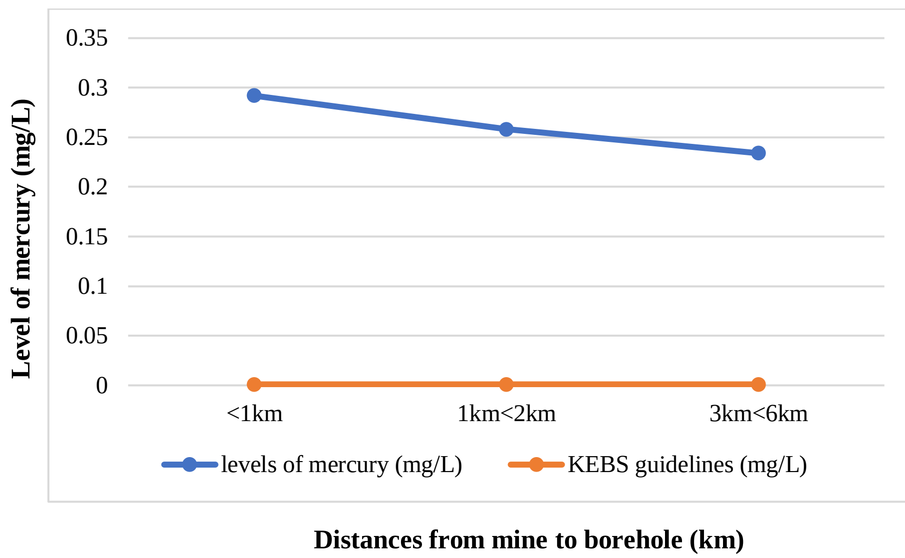

Figure 4.1: Levels of mercury in groundwater in relation to distances of the mines to borehole during the dry season

4.3 Mercury levels in soil tailings and pan pond water as a source of mercury to the Environment

The levels of mercury in soil and water from mines measured during the wet and dry seasons are displayed in table 4.3. The results were compared to NEMA effluents discharge into public sewers values of 0.05 mg/kg for soil and 0.05 mg/L for pan pond water. Despite the harmful effects of improper disposal of mercury to the environment, artisanal small scale gold miners have continued using it over years in the Migori gold belt. Mercury used in the mines might find themselves in the wastes generated from gold processing. Geology of Migori region do not have mercury naturally according to the Migori Kehancha Regional Master Plan (1974).

Table 4.2: Levels of mercury in water and soil samples from mine sites during wet and dry season

Mines	Samples		Mercury levels in seasons		
	State of Samples	**Codes of samples**	**Wet season**	**Dry season**	**Mean**
		Osiri Mine			
	Water samples	PPW 1	0.02 mg/L	2.08 mg/L	1.05 mg/L
	Soil samples	SS 1	2.81 mg/kg	9.08 mg/kg	5.945 mg/kg
		Kitere Mine			
	Water samples	PPW 2	0.01 mg/L	0.21 mg/L	0.11 mg/L
	Soil samples	SS 2	0.73 mg/kg	0.50 mg/kg	0.615 mg/kg
		Masara Mine			
	Water samples	PPW 3	0.01 mg/L	0.16 mg/L	0.085 mg/L
	Soil samples	SS 3	0.66 mg/kg	0.52 mg/kg	0.59 mg/kg
		Macalder Mine			
	Water samples	PPW 4	<LOD	0.17 mg/L	0.085mg/L
	Soil samples	SS 4	9.64 mg/kg	7.64 mg/kg	8.64 mg/kg
		Kehancha Mine			
	Water samples	PPW 5	0.04 mg/L	0.41 mg/L	0.225 mg/L
	Soil samples	SS 5	0.46 mg/kg	0.95 mg/kg	0.705 mg/kg’

Where,

PPW = Pan Pond Water

SS= Soil sediment

All the mercury concentration values obtained from soil tailings during the dry season were above the recommended NEMA effluents discharge value (0.05 mg/Kg). However, Masara and Macalder recorded lowest values at 0.52 mg/Kg and 0.50 mg/Kg respectively. The highest mercury concentration was as 9.08 mg/kg in Osiri Matanda mine (Table 4.3).

During the wet season, none of the mercury concentration values from the soil tailings were below the recommended NEMA effluents discharge value of 0.05 mg/Kg. The lowest mercury levels was recorded from Masara and kitere mines at 0.73 mg/Kg and 0.066 mg/Kg respectively. The highest mercury concentration was as 9.64 mg/kg in Macalder mine (Table 4.3).

Mercury concentration values of pan pond water samples collected from the study areas during the two seasons were compared. In the results, mercury concentrations during the wet season were not all above the recommended NEMA effluents discharge value of 0.05 mg/L. The range of levels of mercury determined were from 0.04 mg/L to <LOD (Table 4.5).

Similarly, mercury values determined in pan pond water during the dry season were all above the recommended NEMA effluents discharge value (0.05 mg/L).The highest levels of mercury measured was 2.08 mg/L while the lowest value was 0.16 mg/L (Table 4.2).

4.4 Seasonal influence on levels of mercury in groundwater from boreholes

Seasons are known to influence the recharge of groundwater and artisanal mining activities within the study area (Macháček, 2019). Reduction of groundwater volume is suggested to affect the concentration of pollutants according to previous studies (Dorleku et al., 2018). This study made comparisons of mercury levels in groundwater samples between wet and dry (table 4.3). A paired sample t-test was used to find out if there is differences in the means of mercury levels in boreholes during the two seasons. A probability figure of $p < 0.05$ was used to determine significant differences statistically. Table 4.2 below, shows a summary of paired sample t-test results.

Table 4.3: Paired sample t-Test results

t-Test: Paired Two Sample for Means

	0.19	*1.41421E-05*
Mean	0.266429	1.41421E-05
Variance	0.039302	1.23625E-41
Observations	14	14
Pearson Correlation	1.76E-16	
Hypothesized Mean Difference	0	
Df	13	
t Stat	5.028244	
P(T<=t) one-tail	0.000116	
t Critical one-tail	1.770933	
P(T<=t) two-tail	0.000231	
t Critical two-tail	2.160369	

From the calculations, it is observed that the P- value is less than 0.05 (0.000231). This means that the levels of mercury in groundwater in the two seasons are significantly different. This depicts a systematic variation in the mercury concentration in groundwater over the two seasons. Generally, it can be said that seasonal variation is capable of influencing mercury levels in groundwater from boreholes located near artisanal gold mines in Migori County.

4.5 Discussion of the study findings

4.5.1 The levels of mercury in groundwater from boreholes

Analysis of mercury levels in groundwater from boreholes during dry and wet season within the study area was carried out. It revealed that during the wet season, 100% the groundwater samples collected showed that there was a below limit of detection levels of mercury. Therefore, the water was considered safe for human consumption. However, the findings showed presence of mercury in 100% groundwater samples during the dry season. This concurs with a research conducted by Hathhorn and Yonge (1995) which attributed dilution of pollutants in groundwater to the groundwater recharge systems and increase of water quantity within the aquifers. It acknowledged that rainfall, soil surface and biological methods play a role (Hathhorn & Yonge, 1995). The rationale above explains the difference in findings between the two seasons.

When comparing the results of this study with other research in various parts of Africa, there was similarity in the levels of mercury in groundwater during the dry season. In this study, during the dry season, the results of all the groundwater samples were above 0.001 mg/L KEBS recommended limit for mercury levels in drinking water. Therefore, the water was deemed not fit for human consumption (table 4.1). Notably, the local communities in Migori County use groundwater from boreholes domestically without knowing whether it affected by nearby anthropogenic pollution or not (MoALFC, 2021).

The study also put into context the possibility of pollution by focusing on a distance of 6km from the five mines. In a study conducted on groundwater quality in the Wassa West District of Ghana, the water from wells sampled displayed mercury levels above the 0.001 mg l-1 recommended limit set by the WHO during the dry season. This was attributed to the characteristics of mining areas near the wells. Due to public health concern elicited by the findings, the study recommended reconsidering use of groundwater for drinking within the District (Obiri, 2007).This is similar to the findings of this study, with recommendations revolving around finding alternative sources of water for communities adjacent to the mines.

Scientist Kortatsi conducted a study focusing on concentration of heavy metals in boreholes within the Ankobra Basin in Ghana and found contrary findings. The dry season showed mercury levels below the detection limits while 60% of the groundwater showed presence of mercury higher than WHO recommended limit (0.001 mg l-1) during the wet season. This suggested the patterns of human activities as an origin of mercury potentially polluting the groundwater (Kortatsi, 2009).

In another related assessment, Palumbo-Roe et al, (2021) found that from the groundwater sampled within Mining areas of Migori county, all of them had mercury levels below the WHO recommended levels for human consumption of 6 μg/l. This study carried out samples collection during the dry season. However, there were varying figures when compared among the groundwater samples (Palumbo-Roe et al., 2021).

Lusilao-Makiese et al., (2014) agreed with the finding of this study that artisanal small scale mining may affect the mercury level in groundwater near the sites. This conclusion was arrived at when mercury level in the samples groundwater were found to be 3310 ng L^{-1} (Lusilao-Makiese et al., 2014).

4.6.1.1 Influence of distance on levels of mercury in groundwater from boreholes

Measurement of hydraulic head is required to develop maps showing water levels to enable determination of direction of groundwater flow within the respective aquifers. The flow then determines the direction of water within the aquifer. Groundwater system contains potential energy that is distributed. It is approximated that the direction of groundwater flow is from high to low hydraulic head. This is further explained by the gradient. The distance between the point of pollution and the possibility of contaminants travelling through the aquifer because of gradient is a key issue to be determined (Michael & Demian, 2022).

In this study distances between the mines and the boreholes were seen to influence the levels of mercury in groundwater (Figure 4.1). A decrease in the levels of mercury was observed in groundwater as distances from the mine increases during the dry season. This finding concurs with a study by Ochiba (2020) conducted in Kajiado County, Kenya, which stipulated that there was an indication of higher levels of heavy metals in boreholes closer to septic tanks in both dry and wet seasons. Proximity to the point of pollution and the season may have influenced the findings found (Ochiba, 2020)

It is important to determine the suspected point of pollution as true sources of mercury before attributing the contamination in groundwater. Table 4.2 confirms presence of mercury in both soil and pan pond water from the five mines in this study. Mantey et al. (2016) carried a study in the western region of Ghana and supports this narrative that artisanal gold mining areas discharge mercury into the environment (Mantey et al., 2016). This study is also in concurrence with the work of Gworek (2015) which reported on the spatial distribution of mercury in the environment around a municipal waste landfill Warsaw Plain. Gworek attributed municipal landfills to be polluting groundwater which in turn was causing mercury distribution. Groundwater pollution was reducing as distance to the landfill increased. However, only 50% of the samples recorded levels of mercury above the allowable limits of 0.001 mg/L by WHO (Gworek et al., 2015).

There have been several studies which sought to understand the level of heavy metals in groundwater adjacent to points of pollution. Udofia (2019) investigated the level of pollution on groundwater adjacent to dumpsites within Akwa Ibom State, Nigeria. In his results, he concluded that heavy metal presence in groundwater was influenced by distance to source of contamination. The findings of the study agreed with this research because the groundwater from borehole far away from mines as potential source of pollution showed lower contamination than the ones nearer (Udofia et al., 2019). Scientist Juma (2014) further hinted that there was a pathway to groundwater contamination after finding Coli forms hence poisoning risks to the population using the water for drinking purposes. This was recommended after dumpsites were suspected to pollute groundwater from boreholes in Kilifi County.

4.5.2 Levels of mercury in the Artisanal Small Scale Gold Mine sites

From the results, it was noted that mercury levels recorded during the dry seasons were higher than the values determined during the wet seasons with an exception of Malcalder mine, where pan pond water within the mines showed below limits of detection. The difference in the level of mercury in Macalder pan pond water can be attributed to two things. Firstly, pumping out of water from the mine pits and filing in the pan ponds even if they are over flowing was observed. Secondly, rainfall during the wet season fills pan ponds within the mines sites reducing their mercury concentration (Gonçalves et al., 2017).

Artisanal gold mining activities in Migori County are done using water near rivers and water sources. The panning process is in most cases done by hand or makeshift tools and a small pond dug to train the wastewater. Pan-pond water accumulates a lot of mercury due to the repeat amalgamation process on them (Ogola et al., 2002). Soil tailings are treated as waste soils after the recovery of amalgam which is a mixture of gold and mercury. The soil tailings are normally dumped in heaps at the mine sites exposed to the environment (UNEP, 2002). At the end of the processing mercury remains in pan pond water and soil tailings (Macháček, 2019).

Table 4.2 shows that pan pond water and soil tailings had mercury levels during both wet and dry season. Mercury levels in pan-pond water had a mean of 0.016 mg/L and 0.606 mg/L for wet and dry season respectively, while, mercury levels in soil tailings had a mean of 2.86 mg/kg and 3.738 mg/kg for wet and dry season respectively. Based on NEMA effluent discharge guideline for mercury in waste soils and water (0.05 mg/kg and 0.05 mg/1 respectively), the findings show that levels of mercury in soil tailing and pan pond water were comparatively high in both dry and wet season.

This study agrees with scientist Ogola et al., (2002), who also found high levels of mercury in soil tailings and pan pond water samples in Macalder Mine, Migori County. Another research conducted in nine mine sites in the western region of Ghana also found elevated mercury levels in soils obtained from the sites (Mantey et al., 2016).

Palumbo-Roe (2021) investigated the mercury levels in groundwater from boreholes within the artisanal gold mining areas of Migori County. It found mercury concentration of 1 μg/l in pan ponds of Osiri Mine during the rainy season. This finding also confirmed the use of mercury in creating amalgams. An environmental analysis done in three small-scale gold mining sites in Ghana found that there is widespread mercury presence in areas adjacent to them. In the analysis, water and soil samples from the mine sites were taken to a laboratory and the results compared to WHO safety guidelines (Abdul & Marikar, 2012).

A study was conducted in mines of Luku, Minna, North Central Nigeria to find out mercury level in soil samples within mine sites. It revealed presence of mercury (0.27 ppm). It further noted the risk of the element finding its way to surface and groundwater nearby. Therefore, making it unsafe for drinking by humans (Ako et al., 2014).

However, contrary to these findings, a research by Erik (2009), argues that mercury is more in the air than in the land surface within ranges of 10 to 20 ng/m^3. It adds that increased levels of mercury in groundwater can be as a result of artisanal mining, chemical spills or geological formations.

Githiria et al., (2020) also carried out a study in Kapsaos mine site. The observation made indicated presence of mercury found in the unregulated soil tailings. Mercury in uncontrolled soil tailings in the mines creates a risk of polluting groundwater located nearby. Therefore, affecting public health of the community (Githiria et al., 2020).

Detected level of mercury in the mines create a risk of spreading the poisonous element further into the environment and causing harm. Therefore, a study by Esdaile & Chalker

(2018) suggested an issue as a chemistry challenge. They advised scientists to come up with mercury free methods that require less technical skills to use to protect the health of communities worldwide. In addition, the methods are required to be affordable and easily accessible by the artisanal miners like Borax technology (Esdaile & Chalker, 2018).

It is hypothesized in many studies that artisanal small scale mining may lead to groundwater contamination in various ways. Some of the reasons are: leaks or disposal of pan pond water because it has been used before, contaminated run off from soil tailings and pan pond water. These can infiltrate the soils through open pits whose ore has been extracted (Palumbo-Roe et al., 2021). Therefore, the presence of mercury in the mines was thought to be a potential source of mercury pollution for groundwater. It is good to note that mercury is known to be carcinogenic and can lead to poisoning when ingested by human beings. Mercury is also associated with birth defects in unborn children (Solan & Lindow, 2014).

4.5.3 Seasonal variation influence on levels of mercury in groundwater from boreholes

As part of western part of Kenya, Migori experiences two rainy seasons which is characterized by two seasons of rainfall. In the wet seasons, artisanal mining operations normally get affected in the study area causing slowdowns. Artisanal gold mining uses amateur methods and unsafe methods to access the ores leading to potential fatal accidents (Macháček, 2019). During the dry season, the conditions for agricultural practices becomes unconducive causing low farm produce and reduced incomes in households within Migori County. These condition forces many residents to migrate to gold mining areas to survive. Therefore, it is the period of highest activity in the mines (Macháček, 2019).

In light of this, this study revealed a relationship between wet and dry seasons on the levels of mercury in groundwater near artisanal small scale mines of Migori County (Table 4.1). The groundwater from boreholes sampled during dry season had presence of mercury while the wet season had below detection limit values. Therefore, displaying a sharp contrast between the two seasons.

In a similar context, Dorleku et al., (2018) carried out a study in the Pra Basin of Ghana and suggested that wet season recordings of heavy metals in groundwater suggested less pollution in comparison to the dry season. The Pra Basin is known to have mercury in its soil geologically. He argued that increased rainfall and infiltration caused the aquifers to be diluted, therefore, influencing the recorded levels of mercury (Dorleku et al., 2018).Furthermore, another research conducted in Goa, India, established lower pollution values during wet seasons. Similarly, it also attributed the results to increased rainfall causing groundwater recharge (Singh & Kamal, 2015).

Ochiba (2020) conducted a study in Kenya to find out the mercury levels in groundwater from boreholes next to flower farms and slaughter houses within Ongata Rongai area. The results suggested that the groundwater sampled during the dry season had higher mercury concentrations compared to the wet season values. Additionally, the wet season concentrations were reported to be below the allowable limits by NEMA standards of 0.001 mg/L. The results was attributed to human activities such as presence of sources of pollution like slaughter houses and flower farms (Ochiba, 2020).

Ishaku (2012) made similar conclusions to the findings of this research by suggesting that prolonged artisanal gold mining operations may lead to groundwater pollution. The research further clarifies that the level of pollution can be influenced by season such as rainfall causing dissolution of pollutants (Ishaku, 2012).

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter outlines a summary of the research findings as per the set objectives. It also provides conclusions and recommendations in regard to the findings of the study.

5.2 Summary

In summary, in relation objective one, all the mercury concentration values recorded during the dry season in groundwater from the boreholes around the mines were above the KEBS standards. It's worrying that during the dry season, when water is required most, the levels of mercury in groundwater showed presence of mercury above the recommended standards. Mercury contamination in groundwater might be due to leachates from the mine sites. However, during the wet season, mercury levels in groundwater from boreholes displayed below detection limits. These values can be linked to increased rainfall and infiltration causing the aquifer to be diluted.

There was a decrease in the levels of mercury in groundwater as distances from the mine increases during the dry season. In concurrence with other studies, proximity to point of pollution presents risk for groundwater contamination. This indicates that there is a possibility that artisanal gold mining activity lead to mercury contamination in groundwater. Moreover, mercury is capable of traveling through a path way from the point of pollution. During the wet season, the recorded values of mercury concentration in groundwater from boreholes in the study areas maintained values below detection limit as distance increases. Generally, this might be due to rainfall infiltration affecting the aquifer which have the same characteristics as distances increase in the study area.

In the findings of objective two, levels of mercury in soil tailings and pan pond water within the mines were found to be higher than the NEMA effluents discharge standards for public sewers of 0.05 mg/L in both dry and wet seasons. The presence of mercury in the mines could be due to anthropogenic activities since they play a role of introducing mercury to the soil tailings and pan pond water. It can be argued that artisanal small scale mining operations can lead to contamination of groundwater adjacent to the mines sites.

Lastly, in the findings of objective three, the dry season mercury level values from groundwater were comparatively higher than wet season mercury values. A paired sample t- Test analysis was used to assess the means of mercury levels from the same boreholes during the wet and dry seasons, further, revealed that there was a significant difference (0.05> P- value). Seasonal variation can affect the levels of mercury in groundwater from boreholes.

5.3 Conclusion

From this research, the following are the conclusions drawn from the findings: -

1. Mercury levels in all groundwater samples were above KEBS recommended limits in dry season, however, all groundwater samples had levels of mercury below the limit of detection during the wet season. There was a decrease in the levels of mercury in groundwater as distances from the mine increases during the dry season.
2. The levels of mercury in soil tailings and pan pond water from the mines were higher than the NEMA effluents discharge standards in dry season, but during

the wet season, mercury levels in pan pond water was within the recommended standards while the soils tailings recorded mercury levels above the NEMA effluents discharge standards.

3. From the findings, the study interprets that mercury levels in groundwater during the dry season are significantly different from wet season values.

5.4 Recommendations

This study makes recommendations to different stakeholders with an aim of protecting public health that:

1. During the dry season, borehole owners using boreholes within 6km distances to the five mines need to routinely carry out heavy metal analysis.
2. Artisanal small-scale gold miners need to practise mine waste remediation and use alternative borax technology to reduce the levels of mercury in waste soil tailings and pan pond water. The county government of Migori and the national government should make initiatives to support miners to access the new technologies.
3. Licensed water service providers need to provide alternative sources of drinking water during the dry season to households drinking groundwater from around the five mines.

5.5 Recommendations for Further Study

Further research should seek to understand aquifer characteristics and vulnerability of groundwater in boreholes located within 6km from the five mines

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APPENDICES

APPENDIX I: CONSENT FORM

Part 1: Information sheet

I am George Omondi, a student from Kenyatta University. My research is titled '**MERCURY LEVELS IN GROUNDWATER NEAR ARTISANAL SMALL-SCALE GOLD MINES IN MIGORI COUNTY, KENYA'** I am humbly requesting you to participate in my research because the information will be used as a surveillance measure to determine if there is mercury pollution in groundwater as a result artisanal small scale gold mining using mercury in the area.

Procedures to be carried out.

Your participation in the study will be by allowing me to take a little amount of water sample (500 ml) from your borehole which I will take to a laboratory for analysis. The process to take the water sample will take about 5-10 minutes. After this short procedure, I will let you to use your borehole as usual.

Participant Selection

You have been chosen to be part of this research because you own a borehole that is near one of the selected artisanal mines in this research.

Voluntary Participation

Your participation is voluntary in this research. You can choose to participate or decline. In case you decide not to take part, there will be no consequences.

Benefits and Risks

There will be no direct gain. However, your participation will assist us to comprehend how the mining activities are affecting underground water near you. This is no risks involved in allowing us take water from your borehole as samples because all instruments to be used will be sterilized.

Confidentiality

I understand that this research in your community may attract attention. I will not share any information about you or your borehole. The samples that we take for this research will be confidential. Your information will be put in a form of random code and not your name. Your data will not be given to anyone except our research sponsors.

Reward

The knowledge that will be generated from this project will be given to you and your community before it is provided to the public. Every participant will have results summary. After the which, other stakeholders interested may access the research findings.

Contacts

Before your decision, and in case, when reading this agreement you still need further clarification, you may contact my supervisors: -

1. Dr Jackim Nyamari (Ph.D)
Phone number: 0722 589 335
Kenyatta University,
P.O Box 43884-00100, Nairobi-Kenya,

2. Dr. Judy Mugo (Ph.D)

Phone number: 0720 671286

Kenyatta University,

P.O Box 43884-00100, Nairobi-Kenya,

3. Chairman KUERC,

Kenyatta University,

P.O Box 43884-00100, Nairobi-Kenya.

chairman.kuerc@ku.ac.ke/secretary.kuerc@ku.ac.ke

Part II: Participant statement

The above information regarding my participation in the study is clear to me. I have been given a chance to ask questions and my questions have been answered to my satisfaction. My participation in this study is entirely voluntary. I understand that I will still get the same care or treatment whether I decide to leave the study or not and, my decision will not change the chances to access the information from the research after it's complete.

Code of participant…………………………………….

Signature or thumb print ……………………………………

Date ……………………

Investigator`s statement

I, the undersigned, I have explained to the volunteer in a language she/he understands, the procedures to be followed in the study and the risks and benefits involved.

Name of interviewer……………………………………..

Interviewer signature ………………………….

Date ………………………………….

APPENDIX II: RESEARCH PROPOSAL APPROVAL

KENYATTA UNIVERSITY
GRADUATE SCHOOL

E-mail: dean-graduate@ku.ac.ke
Website: www.ku.ac.ke

P.O. Box 43844, 00100
NAIROBI, KENYA
Tel. 020-8704150

Internal Memo

FROM: Dean, Graduate School

DATE: 22nd August, 2019

TO: Mr. George Zachary O. Omondi
C/o Department of Environmental & Occupational Health

REF: Q23/CTY/PT/37628/2016

SUBJECT: APPROVAL OF RESEARCH PROPOSAL

This is to inform you that Graduate School Board, at its meeting on **7th August, 2019**, approved your Research Proposal for the M.Sc. Degree entitled, **"Effects of Small-Scale Gold Mining on Mercury Levels in Groundwater in Migori County, Kenya."**

You may now proceed with your Data collection, subject to clearance with the Director General, National Commission for Science, Technology & Innovation.

As you embark on your data collection, please note that you will be required to submit to Graduate School completed Supervision Tracking Forms per semester. The form has been developed to replace the Progress Report Forms. The Supervision Tracking Forms are available at the University's Website under Graduate School webpage downloads.

Thank you.

JULIA GITU
FOR: DEAN, GRADUATE SCHOOL

CC. Chairman, Environmental & Occupational Health Department

Supervisors:

1. Dr. Daniel Akunga
   C/o Department of Environmental & Occupational Health
   Kenyatta University

2. Dr. Judy Mugo
   C/o Department of Population, Reproductive Health & CRM
   Kenyatta University

APPENDIX III: NACOSTI AUTHORIZATION AND PERMIT

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: **356754**

Date of Issue: **10/February/2020**

RESEARCH LICENSE

This is to Certify that Mr.. GEORGE ZACHARY OCHIENG OMONDI of Kenyatta University, has been licensed to conduct research in Migori on the topic: EFFECTS OF SMALL-SCALE GOLD MINING ON MERCURY LEVELS IN GROUNDWATER IN MIGORI COUNTY, KENYA. for the period ending : 10/February/2021.

License No: **NACOSTI/P/20/3626**

356754

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

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APPENDIX IV: ETHICS APPROVAL

KENYATTA UNIVERSITY
ETHICS REVIEW COMMITTEE

Fax: 8711242/8711575
Email: chairman.kuerc@ku.ac.ke

Website: www.ku.ac.ke

P. O. Box 43844,
Nairobi, 00100
Tel: 8710901/12

Our Ref: **KU/ERC/ EXEMPTION/VOL.1** (001)

Date: 4th December, 2019

George Zachary Omondi
P.0 Box 43844-00100
Nairobi

Dear Mr Omondi,

APPLICATION NUMBER PKU/2022/I1169: EFFECTS OF SMALL-SCALE GOLD MINING ON MERCURY LEVELS IN GROUNDWATER IN MIGORI COUNTY, KENYA

1. IDENTIFICATION OF PROTOCOL

The application before the committee is with a research topic **"Effects of Small-Scale Gold Mining on Mercury Levels in Groundwater in Migori County, Kenya"**. Received on 7th October, 2019 and discussed on 12th November, 2019

2. APPLICANT

George Zachary Omondi

3. SITE

Migori County, Kenya

4. DECISION

The committee has considered the research protocol in accordance with the Kenyatta University Research Policy (section 7.2.1.3) and the Kenyatta University Ethics Review Committee Guidelines and **EXEMPTED from having Ethical Clearance Letter from carrying his research.**

5. **ADVICE/CONDITIONS**

i. Progress reports are submitted to the KU-ERC every six months and a full report is submitted at the end of the study.
ii. Serious and unexpected adverse events related to the conduct of the study are reported to this committee immediately they occur.
iii. Notify the Kenyatta University Ethics Committee of any amendments to the protocol.
iv. Submit an electronic copy of the protocol to KUERC.

When replying, kindly quote the application number above.
If you accept the decision reached and advice and conditions given please sign in the space provided below and return to KU-ERC a copy of the letter.

PROF. JUDITH KIMIYWE
CHAIRMAN ETHICS REVIEW COMMITTEE

I ……………………………………accept the advice given and will fulfill the conditions therein.

Signature……………………………… Dated this day of…………………………….. 2019.

cc.
DVC-Research Innovation and Outreach

APPENDIX V: WATER SAMPLE COLLECTION FORM

Borehole Code…………………..

PART I: GENERAL INFORMATION OF SAMPLES

1. Name of related mine……………………………………………………….. …….

2. Date of Collection…………………………………………………………..........

3. Time of Collection………………………………………………………………….

4. Distance from the mine ……..…. <1km ………1km<2km

……..3km<6km

5. Depth of borehole……………………………………………………………………

6. Season of collection Wet …………………………

Dry……………………..

Signature of Field assistant ………………………
Date……………………….

Source: (partially informed by WHO, 1997)

THANK YOU!

APPENDIX VI: FIELD PICTURES

Plate 1 A photo of high-performance microwave digestion systems at KEPHIS Laboratory in Karen, Kenya

Plate 2 A photo of (7900) ICP-MS at KEPHIS Laboratory in Karen, Kenya

Plate 3: A photo of one of the many pan-ponds in Osiri mine during dry season