INVESTIGATING SPATIAL VARIATION OF ARSENITE CONCENTRATIONS INTO RIVER AWOJA, PHYSIOGRAPHIC DETERMINANTS AND TREATMENT OPTIONS

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DECLARATION

I, Ecodu Michael, to the best of my knowledge declare that this dissertation work is entirely my work and free from previously publications by other authors or materials that have been accepted for the award of any other degree from the university or another higher education institution, with the exception of materials that has been properly acknowledged in the text and reference list.

Signature:……………………………… Date:…………………………………….

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APPROVAL

The undersigned hereby approve that he has read and recommend for submission to the Directorate of Research and Graduate Training, a research dissertation titled "Investigating spatial variation of Arsenite concentrations into River Awoja, physiographic determinants and treatment options".

Dr. Charles Onyutha (Main Supervisor)

Signature:…………………………………. Date:………………………………

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DEDICATION

This research dissertation is dedicated to my supportive family members and friends, whose unwavering belief in me has made this journey possible. I also extend my gratitude to Dr. Charles Onyutha, research supervisor, for his support throughout this process. Lastly, to my late father (may his soul rest in peace), whose passion for education inspired my pursuit of knowledge.

ABSTRACT

The 2030 agenda of the United Nations placed a high priority on addressing water quality challenges. Many towns and cities are supplied with water from rivers. Depending on the human activities on the catchment, the water from the river can be characterized by the presence of Arsinite. It is important to quantify Arsenite to guide in planning for the water treatment. In this study, several points were selected within River Awoja catchment. Rainfall runoff was sampled at selected locations and concentrations of Arsenite was determined from a laboratory. To explain the spatial variation of Arsenite concentrations, analysis of land categories was conducted. The potential of rice husk as Activated Carbon in removing Arsenite was investigated. The concentrations of Arsenite ranged from 20.21mg/L to 27.57mg/L against WHO standards of 0.01mg/L indicating the need to treat the water given the substantial level of pollution with Arsenite. The linear relationship between physiographic characteristics and Arsenite-based land categories of barren land, grassland, settlement, cropland, waterbody, wetland and woodland characterized in terms of coefficient of determination (R^2), yielding R^2 values of 0.80, 0.84, 0.86, 0.76, 0.62, 0.76 and 0.61, respectively. The efficiency of Arsenite removal using rice husks as Activated Carbon improves as dosage and contact time increase. This study demonstrated that Arsenite concentration at sampled points is higher than the WHO limit and that Activated Carbon has the potential to remove Arsenite with efficiency of about 78%.

Key words: Land use/Land cover change, River water quality, Activated Carbon, Atomic absorption spectrum.

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ABBREVIATIONS

EPA	Environmental Protection Agency
LULC	Land use land cover
MWE	Ministry of Water and Environment
NEMA	National Environment Management Authority
NPS	Non-Pollutant Sources
UN	United Nations
UNCED	United Nations Conference on Environment and Development
UNSDG	United Nations Sustainable Development Goals
UPHC	Uganda Population and Housing Census
WHO	World Health Organization

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Natural water of River Awoja is an essential resource for the survival of human communities who use and live near its catchment. The high population growth rate has led to increase in resource depletion in past half century (Pimentel et al., 2010). This resulted in an extraordinary drop in the availability of fresh water that has led to increasing freshwater shortages across the world. A number of studies have demonstrated that there is a growing global scarcity of fresh water Hassan, (2005); Leemans, (2009); Rockström et al., (2014), and Zhang et al., (2020). Global data indicates that both natural and human-caused events can account for a portion of precipitation that flows over the land surface into streams and rivers (Schwarzenbach et al., 2010).

Water pollution is a major problem in developed and developing countries (Chaudhry and Malik, 2017). In the twenty–first century water contamination causes 1.4 million deaths worldwide, primarily as a result of inadequate environmental management (Jury and Vaux, 2007). In Uganda, it’s estimated that 3,000 death occur annually due to water pollution and majority are the young children below 5 years of age (WHO, 2020; Bamuwamye M et al., 2017). Weathering of volcanic rocks, natural erosion, human activities on the ecosystem has likely contributed to Arsenite pollution on natural waters whenever they are released and not controlled Kapoor and Singh, (2021). World’s major rivers such as Ruak, Mekong, Ganges, Jie are now seriously polluted with Arsenite and depleted in form of its quality Yan Jin (2024). In Uganda some rivers including Nyamwamba in Kasese and Mpanga River and Rwiri in western Uganda with concentrations exceeding WHO permissible limits (Mukisa et al., 2020).

Severe inland, coastal and marine eutrophication is progressively brought on by increased nitrogen and phosphorus emissions from vehicles, industry, accumulation of anthropogenic activities and agriculture Kaydis and Kitsiou, (2019). Arsenite pollution has seriously weakened out our water resources as a result of human uses, ecological needs and recreational values (Adejumoke et al., 2018).

Effective water management strategies need to be proactive rather than reactive. Predictive knowledge of the movement of pollutants and nutrients through streams into water bodies is necessary for the prudent deployment of scarce resources for such treatments (Loucks, 2017). Water resource management is therefore essential for prevention or reduction of water pollution into the environment and it stabilizes the amount of good quality water which can be available for people and ecosystems.

The ecological health of River Awoja supports the growing population of 3 % per annum in their livelihood and social cultural such as fishing, swimming along the shores (Aben et al., 2018). There is therefore a need to ensure that water from the river is safe from heavy metals such as Arsenite. Given that Uganda is a developing country, there is a need for cheaper methods for water treatment. Activated carbon in some countries has shown some potential efficiency of removing both metallic and non-metallic water pollutants (Lewoyehu, 2021). However, potential of using Activated carbon in Uganda for removing Arsenite from the surface has not being comprehensively explored.

Over time, the physical and chemical breakdown of these rocks releases Arsenite into the surrounding environment and eventually into river Awoja. Therefore, gaps exists regarding the contributions of various activities to the overall Arsenite load into River Awoja. This research therefore prompted the need to investigate spatial variation of the concentrations of Arsenite into River Awoja, physiographic determinants and treatment options.

1.2 Statement of the Problem

Water pollution presents a major risk to the heath of Ugandan citizens and harms the environment. River Awoja just like other water bodies in Uganda faces many challenges, among which include increasing precipitation that flows over the land surface into streams and rivers due to land use practices, climate variability, high demographic rates, land degradation and deforestation resulting from increased human activities (Akello et al., 2016).

Development activities, animal grazing, subsistence agriculture, quarrying and population growth about 3% in the upstream of part of Karamoja and parts of North East Teso have caused changes in the water body ecosystem (Bakamanume, 2010; UBOS, 2014).

The Weathering of volcanic rocks into the river watershed has probably contributed to Arsenite pollution Wu et al., (2020). Over time, the physical and chemical breakdown of these rocks releases Arsenite into the surrounding environment and eventually into river waters. There are still gaps regarding the contributions of various activities to the overall Arsenite load into River Awoja. This study aimed at determining the prevalence of Arsenite by analyzing spatial variation in its concentrations into River Awoja and physiographic factors and treatment options.

1.3 General objective

To investigate spatial variation of Arsenite concentrations into River Awoja, establish the relationship of physiographic determinants and evaluate removal of Arsenite using Activated Carbon.

1.3.1 Specific objective

The specific objectives entailed;

i) Characterizing the land categories of River Awoja catchment.

ii) Determining the spatial variation of concentration of Arsinte entering River Awoja.

iii) Determining the relationship between Arsenite and physiographic characteristics, and

iv) Assessing the potential of Activated Carbon to treat Arsenite from surface water.

1.4 Research questions

i) What are current land categories in Awoja catchment?

ii) What are the various Arsenite loads entering River Awoja?

iii) What is the relationship of Arsenite and physiographic characteristics entering River Awoja?

iv) What is the potential of Activated Carbon in treating Arsenite from surface water?

1.5 Research Justification

Currently, approximately 2.2 billion people lack access to quality water globally posing health risks to the lives of people Sustainable Development Goals, (2015). The goal of Uganda Vision 2040 is to restore degraded areas, conserve flora and wildlife and create a green, clean environment free of water pollution. Africa Vision 2063 agenda, goal 7, emphasizes on environmentally sustainable and climate resilient economies and communities.

SDG 6(Target.3), which aims to improving the water quality by reducing pollution, requires data reporting and water quality monitoring systems, which will probably be very difficult for nations without a well-established monitoring program (Hering, 2017). Due to human activities like intense agriculture, livestock rearing and quarrying on the environment, Uganda's water resources are in danger of becoming polluted and unless its limited resources are managed in a sustainable way, a serious water crisis may occur (Clasen et al., 2007).

Data on Arsenite loadings helps the government to manage water resources properly. It will be essential to hydrologists, water resources engineers, supervisors and many policy makers to build the capacity of stakeholders on the adaptation measures to the effects of land use on hydrology.

1.6 Significance

Reducing water pollution will help achieve the healthy population and guarantees that people's health SDG 3, (2015). Goals 14 and 15 emphasizes the need of safeguarding our water and land to prevent contamination. Water quality is one of the targets in the 2030 agenda which recognizes the significant impact on future policies and strategies by international bodies to reduce water pollution. As the outcome, United Nations Development Program IV helps countries to achieve integrated equitable management of water resources through water governance, creating awareness about the contribution of Arsenite entering River Awoja as a result of land uses. Additionally, the effect of the land categories on water quality, influences decision making regarding management of River Awoja and exploring innovations in alternative methods of water treatment.

1.7 Scope of the study

The study covered River Awoja catchment which spans approximately 8,156 square kilometers and is situated in North Eastern Uganda at 33°40'E and 3°30'N and it is part of Lake Kyoga Watershed Management Zone. Rainfall – runoffs originating from up streams through a network of rivers, streams and swamps converge close to Awoja water body. Variation in concentration of Arsenite inflows have been considered in this study of River Awoja.

1.8 Conceptual framework

The independent variables for this research included human activities such as land use changes through subsistence agriculture, animal grazing, improper solid waste management and quarrying activities. The dependent variables were concentration of Arsenite in river Awoja.

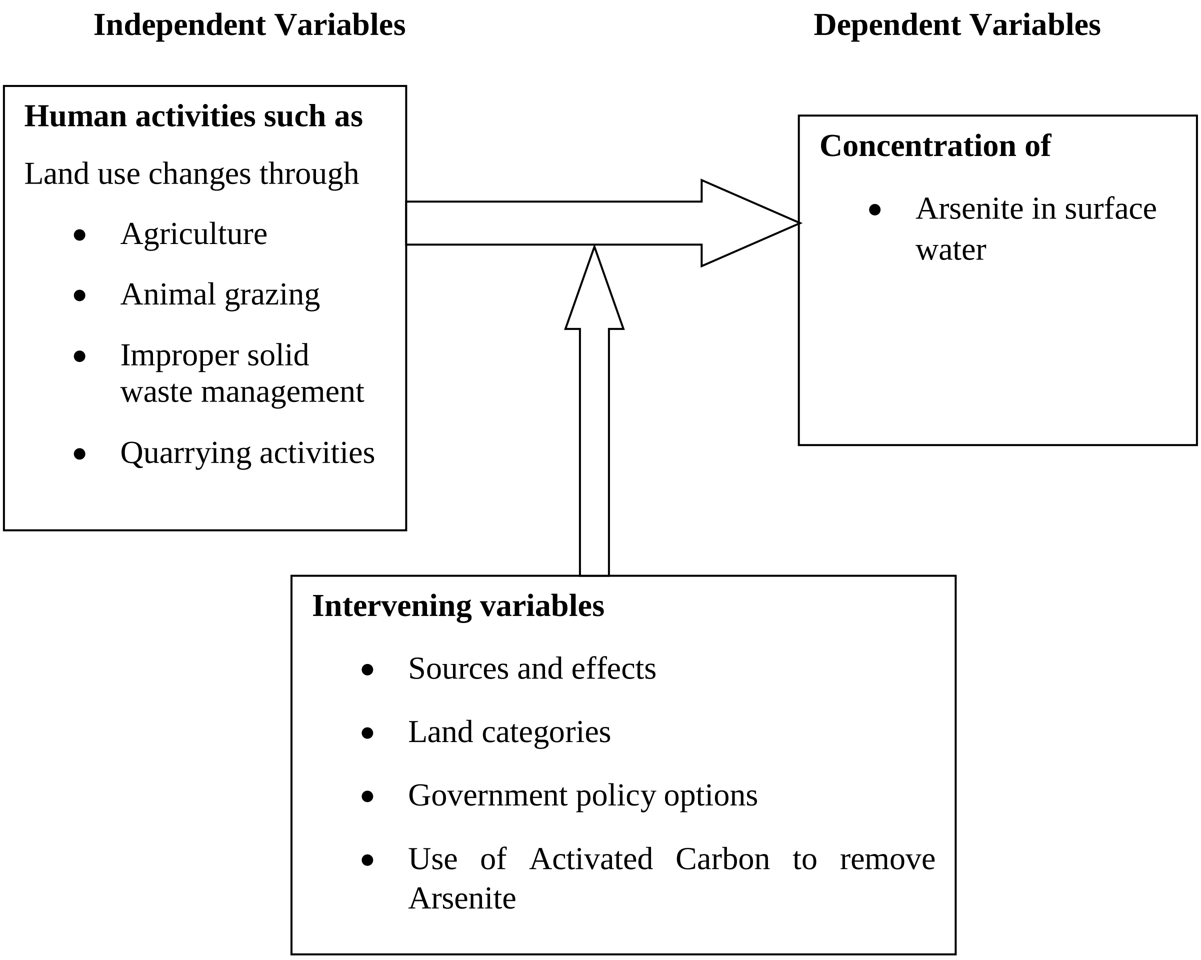


Figure 1.2: Conceptual framework

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviewed information on land categories and its changes, water pollution, Arsenite and methods of water treatment.

2.2 Land category changes

The issues of land categories use and climate change that the world is currently facing are affecting many different areas, such as water quality, land fragmentation, agricultural production and socioeconomic development. Largely populated rural areas in underdeveloped countries like Uganda that rely heavily on agriculture are the most affected (Obubu et al., 2022).

Changes in land categories are the outcome of biophysical and socioeconomic phenomena that depend on the size, location and current usage of the land. This can be understood in a number of ways. Historically, people have preferred to live close to bodies of water for fishing, forests for hunting and residential areas (Lambin et al., 2003). Analyzing changes in land categories is crucial to comprehending how humans and environment interact. Historical land-use change is predicated on the idea that past changes can be used to forecast future land use (Chughtai et al., 2021).

Synergistic factors such as resource scarcity that increase pressure on resources, changing opportunities, population growth, loss of adaptive capacity, changes in social organization and attitudes are what drive land-use change. Feedback on the drivers of land-use change is also a result of changes in ecosystem goods and services (Lambin et al, 2003).

Owners of land in catchment areas that extend to the banks of rivers use their land as they please, which results in the uncontrolled, spontaneous distribution of land use activities along the river, including sand mining, agriculture, urbanization, industrialization and forestry. The majority of these activities appear to degrade and impair the quality of the river water, as shown by siltation, the drying up of some river tributaries and changes in water color (Turyahabwe et al., 2020).

2.3 Land use category effects on runoff processes

The potential of land erosion increases when natural vegetation is removed for farming and the energy required to suspend or otherwise mobilize solids is mostly dictated by the length and intensity of significant hydrological events (Burt and Slattery, 2006). The water balance and the relative importance of the processes that control water quality are frequently changed due to human-induced changes in land categories. Similarly, the rate at which manure, inorganic fertilizers and other agrochemicals are applied has a major effect on the quality of surface and groundwater (Khan et al, 2018).

2.4 Water quality and land use in catchment

Due to an overdependence on basic resources, substantial changes in land use/cover occur in African nations now within a few decades and the continent also has the fastest rate of deforestation in the world (Namugize et al, 2018). In Africa, agricultural expansion, which results in the destruction of vegetation and forests, is the trajectory of land cover change that occurs most frequently. Although land use changes are typically brought on by the conversion of virgin forests to agricultural uses (deforestation) or the destruction of native vegetation due to overgrazing (desertification), they can also have this effect (Lambin et al., 2003).

Within a 10 km^2 size, the Awoja watershed in eastern Uganda's Kyoga Water Management Zone is a significant hotspot for watershed degradation. Its perceived degradation rate is 76%, compared to 63% for the Lake Victoria crescent and 41% for the country's south-western farmlands (Turyahabwe et al., 2013). Due to rapid population increase during the previous three decades, the land cover in the River Awoja watershed has undergone considerable changes (Akello et al., 2016).

2.5 Sources and types of water contamination

Water contamination can be classified into two categories: nonpoint sources and point sources. More diffuse sources of pollution, such as urban storm water runoff, agriculture and other land uses within the catchment, are known as nonpoint sources. Whereas point sources are from single source for example discharge from factories, sewage treatment plants. This leads heavy metals, organic contaminants, hazardous pollutants, nutrients and sediments (Davis and Hirji, 2003). Nonpoint Source pollution can have an equally detrimental effect of degrading water quality, harming aquatic life and disrupting ecological balance on the ecosystem even though their concentrations are often lower (EPA, 2002). Every country in the globe is seriously threatened by arsenite contamination, and it appears that no lake, river, or area of the ocean is totally pollution-free. Due to population expansion, urbanization, growing industrialization and poor land management, both pollutions generated by development and pollutions caused by lack of development get worse with time (Ankodia, 2021).

Despite water being the most important resource in the world, 80% of the population is at high risk from contamination by the presence of Arsenite. The freshwater supplies that are currently available have been steadily contaminated by human activity on the catchments (Kumar et al., 2012). A significant environmental problem that the world's population is currently dealing with is the rise in contaminants such as Arsinte in freshwater systems, which are mainly natural chemicals and organic materials. The discharge of Arsenite into water bodies endangers aquatic ecosystems and render the water unfit for human or domestic consumption (Nathanson, 2022).

Weathering and soil erosion are examples of natural processes that result in water pollution. Water pollution is a situation when the water has an unfavorable impact on the river as it gets contaminated when water's composition is changed, either directly or indirectly (Danquah, 2010). From my view water pollution is as consequence deliberate human activities around natural water bodies hence reducing its usefulness by contaminating.

Point sources are discrete and easily identifiable, making them relatively simple to monitor and regulate. The majority of these are industrial wastewaters and sewage, which are all released from point sources and primarily residential origin, which includes, among other things, human excreta (Emeka, 2015). Non-point sources are more difficult to control because it might be challenging to pinpoint their location and point of origin. This therefore leads to water contamination that originate from runoffs and large agricultural or urban catchments, which carry large amounts of nutrients and trash.

The increase in animal species with excreta is also posing high risks of pollution loading to the water catchment brought about by runoffs (WHO, 2012). Global human and agricultural sources of feacal pollution indicates that cattle accounts for 57% (FAO, 2007). Pesticide usage and its impacts on ecosystem statement recently being released showed that many are already on to the market and could damage water supplies (Sharma et al., 2019). The increased use of pesticides due to agricultural growth has an effect on environment (Tudi et al., 2021). Some chemicals, their effects, known and others not known on human life, yet not quantified (Prüss-Ustün et al., 2011).

Water supplies are becoming progressively contaminated by industrial and human activity (Johnson et al. 2009). Physical and chemical substances are the main environmental concerns that the world's population is currently facing and they are the reason behind the increasing contamination of water supplies. Pollution from human activities such as agriculture and manufacturing sectors, which has disastrous effects on freshwater ecosystems and affects fisheries, has a detrimental influence on people that depend on fish as a primary food source (Fuller et al., 2022).

In most parts of the world, water is seen as a valuable resource. According to a recent study, 80% of the world's population is exposed to high levels of threat from water insecurity (Tzanakakis et al, 2020). This is due to the world's population growth and the quickening pace of industrialization, which has increased demand for and supply of water. Water pollution is linked to some diseases like acute and chronic gastrointestinal diseases and mostly 70% diarrheal diseases (Rehman, 2021). Polluted water is linked to a range of poor sanitation and hygiene practices which causes diseases that affect human lives (Njambi et al., 2020). If alternative methods for supplying clean water cannot be developed, water scarcity in the future may cause social and political unrest, water wars and diseases. As a result of greater public awareness, governments and organizations all around the world have issued tough restrictions pertaining to water contamination. (Tzanakakis et al., 2020).

2.6 Water pollution-based disease burden and their trends

2.6.1. Disease burden

Poor sanitation and contaminated water are connected to a high burden of fatal diseases. The majority of the illness load resulting from fecal matter is thought to be caused by poor water, sanitation, and hygiene practices (Prüss et al., 2002). Unclean water sources, poor handwashing and inadequate sanitation all contribute to the disease burden caused by water pollution, which also causes numerous human fatalities (WHO, 2023; Wolf et al., 2023). Reducing the burden of sickness and preserving the quality of the water supply are key goals of member States of the United Nations (UN, 2015) to attain universal access to Water, Sanitation and Hygiene by 2030. At the UN Earth Summit in Rio de Janeiro, Brazil in 1992, environmental contamination was highlighted as a key concern for the world's natural resources. An increasing amount of waste and contaminants are entering the natural environment as a result of migration into metropolitan regions, urbanization and population growth.

The majority of women and children in developing countries experience the worst health effects from water-related illnesses and the deteriorated environment (WHO/UNICEF, 2003). These primary burdens are a result of insufficient sanitary facilities and drinking water sources, which exacerbates already existing environmental and health issues. The most vulnerable members of society have been particularly impacted by the repercussions. Families lack the means to maintain even a minimal degree of health when they lack access to food, clothing and shelter. Poverty can result in reduction of access to education, health care, nutrition, sanitation and impedes participation in legal and political processes (IMF Country Report 05/307, (2003)).

Environmental pollution has many facets and the resultant health risks that include disease that cause poor organ functioning system (Kjellstrom et al., 2006). The significance of water as a resource for just and peaceful societies as well as for sustainable development was emphasized during the 2001 United Nations water conference, underscoring the urgency of action in the developing world (Zehnder et al., 2003). Taking into account the aforementioned, Ugandan citizens are assured by their country's 1995 constitution that the government will improve water quality, management and intervention while lowering the unfavorable effects of water pollution on human health.

2.6.2. Trends of diseases due to water pollution

Several deaths were caused by various forms of water pollution during the early years of foreign developmental aid programs because different types of contamination commonly coexisted and overlapped one another (Botting et al., 2010). Environmental sustainability is guaranteed by Goal 7 of the 2015 United Nations Millennium Development Goals. This was expedited and integrated into the ideals and advancements of sustainability into national policies and initiatives. Due to lack of awareness, half of the world's population should have had access to sustainable supplies of drinkable water and sufficient facilities for basic sanitation. (Hutton, 2012). The Joint Monitoring Programme for Water Supply and Sanitation that was developed by WHO and UNICEF to monitor the indicators, indicates that the disease burden globally due to Arsenite is estimated at 922 disabilities – adjusted life years (DALYs) per 100,000 people. Sub – Saharan Africa bears the highest burden with 2,813 annual DALYs per 100,000 people, according to Health Metrics and Evaluation (HME, 2024)

The Sustainable Development Goals plan, whose objective is to ensure that everyone has access to sustainable management of water and sanitation was then developed. As a result, between 1990 and 2015, 2.6 billion people gained access to improved sources of drinking water and 2.1 billion people had access to better sanitation.

2.7. Water pollutants

Extensive wetlands are being progressively degraded by urbanization and agricultural growth. Almost 40% of Uganda's wetlands have disappeared since 1994, endangering biodiversity and lowering the capacity of wetlands to safeguard water quality in lakes and rivers (Crisman, 2001, Bulonza, 2015).

Wastewater produced by agricultural activities, containing a mix of pollutants from animal manure, pesticides, fertilizers and sediments cause eutrophication, algal blooms, invasive hyacinth outbreaks and prolonged anoxic dead zones reaching the lakes and rivers have detrimental effects on water quality and ecosystem (Awange and Ong’ang’a, 2006). Small scale gold mining has too polluted surface water with mercury, while industrial pollution contaminates groundwater sources near Kampala with heavy metals.

2.7.1 Emerging pesticides products

There has been a lot of documentation in recent years due to the presence of new pollutants, such as pesticides in wastewater, groundwater and surface waters (Naidu et al., 2016). Many of these products are now being used worldwide each year (Benbrook, 2016).

Some studies were conducted in Uganda to examine the occurrence and seasonal variation in emerging organic contaminants (EOCs) concentrations in shallow groundwater beneath two peri-urban areas, Bwaise (highly urbanized) and Wobulenzi (moderately urbanized) (Twinomucunguzi, 2021). The findings showed that the antibiotic and pesticide residues in the shallow groundwater beneath Bwaise and Wobulenzi could have harmful ecological effects when exposed over time.

2.7.2 Heavy metal (Lead, Cadmium, Nickel, Arsenite, Iron)

Among the most hazardous contaminants found in surface water are heavy metals (Pb, Ars (III), Ni, Fe, and Cd) (Mousavi et al., 2013, Ghorani-Azam et al., 2016, Luo et al. 2021). It has been discovered that anthropological activities upstream have an impact on the detrimental functions of wetlands in the catchments. (Muwanga et al., 2020). Arsenite (Ars(III)) and its ions are most frequently released onto the environment by natural weathering of arsenic rocks and by human activities, such waste disposal, petroleum refineries, fossil fuel power plants, and non-ferrous smelting, compared to other heavy metal Lead (Pb), Cadmium (Cd), Nickle (Ni), Manganese (Mn) and Iron (Fe). (Chutia et al., 2009).

In North Eastern part of Uganda, surface water harvesting is predominant in the study area. The recommended permissible limits for the discharge to surface as per National Environment Management Authority (NEMA, 2020) is 0.1mg/L. One of the largest threats to the public's health is Arsenite, a poisonous element. Arsenite exposure can come through the workplace, contaminated water and contaminated food. All the food, water and the environment can be contaminated by Arsenite. It is discussed as the "poison of kings" and king of poisons the, respectively (Gupta et al., 2021).

As per the Environmental Protection Agency EPA, (2000) a threshold of 5 ppb for Arsenite should be used as allowable permissible limits of drinking water as compared to 10 ppb which is above. The primary source of arsenite in groundwater is the dissolution of minerals in worn rocks and soils, as well as several types of associated bacteria (Raju, 2022). Sulfide minerals undergo natural weathering, oxidation and erosion releases arsenic into the environment (Wang and Mulligan, 2006). Arsenite may dissolve in water and can be found in very high amounts in soils formed by these sulfide minerals. Arsenite emissions into the atmosphere are thought to be produced by volcanoes, which account for about 25% of the total. All sources of released Arsenite mostly end up in soil and surface water.

The maximum amount of Arsenite allowed in drinking water was reduced from 50 micrograms per litre (ug/L) to 10 ug/L (US EPA, 2001). The drinking water regulation for Arsenite in some jurisdictions, like New Jersey, is as low as 5 ug/L. However, the National Environment Authority (2020) only permits 0.1 mg/L of discharge into surface water as the maximum allowed limits.

In view of the foregoing citation and it can be agreed that, because of the weathered rocks on the upstream of study area Arsenite substances be monitored through laboratory tests annually to ascertain its levels on surface water entering River Awoja.

2.7.3 Sedimentary heavy metals

One of the main environmental problems in catchments is sediment contamination since ecosystems act as both sources and sinks for pollutants. Determining the level of environmental pollution requires the use of sediment analysis (Mucha et al., 2003).

Numerous Arsenite concentrations in sediment form are of three orders of magnitude higher than those in the surrounding water. This is especially true of their graded particles, which serve as a transport agent in the water column. The interpretation of water quality is aided by the study of the concentrations of heavy metals in sediment samples (Heiny and Tate, 1997).

River flows carry Arsenite because of natural processes including weathering and soil erosion. The sediments are also used to find Arsenite when the amounts in the water cannot be found with the analytical methods available today (Soares et al., 1999).

One of the main goals of environmental research is the identification and speciation of Arsenite pollution. As a result, the detection of pollution that is lowering water quality is made possible by the study of Arsenite in sediments, which also offers information about the key water system locations (El Bouraie et al., 2010).

2.8 Past studies and gaps

2.8.1 River Awoja catchment

The five land use categories that included open water, wetland, tree cover, farming, and built-up area were investigated in the Awoja catchment under the heading of "Land use, land cover change, and watershed status in Eastern Uganda." (Akello et al., 2016). The findings revealed that the built-up area increased by five times to 154.27 km2, the open water area changed by 8.7 km2, the wetland area decreased by 1.0 km2, the tree cover increased by 48.07 km2, and the agricultural area increased by 11.4 km^2. According to the survey results, the main causes of deterioration include overpopulation, wetland encroachment, deforestation, and poor attitude. Despite the findings from the research, the extent of water pollution due to the fivefold increase in built up areas was not determined.

2.8.2 Studies on Lake Kyoga basin

Assessing the correlation between land category changes and the water quality status of a shallow Lake studies: An Example from Uganda's Lake Kyoga Basin (Obubu et al., 2021). The results demonstrate that activities related to land category uses in the catchments have a major impact on the water quality of the waterbodies.

2.8.3 Studies on River Mpanga in South West Uganda

Research from the River Mpanga that originates on the higher slope of Mount Rwenzori and its downstream flow over a 50-meter fall suggest that human activity is contributing to the river's increasing pollution. It also gradually flows into Lake George Ramsar site from the flanks of Queen Elizabeth National Park. However, reports indicate that within the past ten years, the River Mpanga's flows have drastically decreased (Businge et al., 2021).

The river's water quantity has decreased for a variety of reasons, including soil erosion, wetlands degradation, mining of sand and stones from the riverbanks, deforestation of mountain slopes, and the substitution of non-native tree species like eucalyptus, which has a high-water uptake. The issues with pollution from riparian settlements are also mentioned.

2.8.4 Heavy metal assessment in domestic water sources of Sikuda and Western Division Located in Busia District, Uganda.

Water supplies that are close to mining operations and agricultural areas run the risk of becoming contaminated and becoming unfit for human consumption. The study by Barakagira, A and Pule .S, (2022) sought to identify the economic activities that were conducted in the vicinity of the water sources in the Busia district, as well as to investigate the concentration and presence of arsenite in the water sources and the potential health risks that the district's residents would face from drinking water contaminated with heavy metals. The findings indicated that while copper, lead and mercury readings were within permissible bounds, arsenite values were beyond WHO and EAC standard limits (Pule and Barakagira, 2022).

2.8.5 Research work on treating water using Activated Carbon.

Some studies have shown effectiveness of treating surface water using Activated Carbon (Menya et al., 2020). Removal of Arsenite from surface water using the activated rice husks becomes effective based on its assembly, element composition and superficial area (Shukla, 2020). In his conclusion, the absorption of Arsenite by Activated Carbon showed a great improvement.

2.9 Development impacts of water pollution

2.9.1 Environmental impacts and contamination

Human beings can only be healthy in a healthy environment (Lumina, 2020). The African Human Rights Council of 2006 also stressed that people cannot live in isolation from the environments they inhabit, including the environments they breathe, drink, consume, and live in Jordaan, (2014). The majority of human activities have a significant negative impact on people's health. Sanitation systems in Uganda are crucial for waste treatment and disposal in order to reduce human impact and establish a sustainable ecosystem (Abdel-Shafy and Mansour, 2018). A number of health issues for humans and animals as well as environmental contamination, notably the tainting of surface and ground water supplies, can result from poor sanitation, poorly maintained facilities, and badly built systems (Okullo et al., 2017).

In light of the aforementioned, some faecal-oral illnesses are spread via unsanitary hands, during the preparation of food, and by the direct ingestion of contaminated water. In addition to the typical flora organisms that are already present in the feces, poorly kept areas provide an ideal habitat for numerous additional species that lead to human diseases. Stopping feces from coming into contact with or entering human bodies is a step toward breaking the cycle of infection. (Gerba, 2012)

Water pollution could have serious negative health effects since many of the infectious organisms are conveyed from hand to mouth or from hand to food to mouth rather than simply drinking contaminated water (Macy and Quick, 2009). Increasing public awareness of bettering hygiene habits and providing sanitation facilities may directly affect a variety of significant public health issues afflicting Uganda. Therefore, through public health communications, it helps to understand how infections are transferred and how to end the cycle of infection.

Public health incidents continue to be reported despite enormous efforts made in providing all Ugandans with access to clean water. However, where sanitation and the promotion of health and hygiene are not given enough consideration, the health impact of this investment is constrained. When people's fundamental requirements, particularly access to clean water, are addressed, improvements in sanitation along with the promotion of good health and hygiene have the biggest positive effects on people's health (Kulabako et al., 2010).

2.9.2 Impacts on different water uses

The water quality standards need to be fulfilled in order to meet the demands of different water users. For example, limits on the concentrations of toxic substances for drinking water use, or restrictions on temperature and pH ranges for water supporting invertebrate communities all pertain to the physical, chemical and biological characteristics that must be met for any given aquatic source (Franzén et al., 2015).

2.9.3 Impacts on agricultural use

Pollution reduces soil moisture, which has an impact on crop output. The greatest way to mitigate its effects on agriculture is to provide water for irrigation (Gadédjisso-Tossou et al., 2020). The primary objective of irrigation is to provide crops with timely and adequate watering so as to avoid crop losses caused by extended water stress during critical stages of crop growth. Water pollution impacts crops that are irrigated by several means, such as the buildup of salts in the root zone, the loss of soil permeability as a result of excessive sodium or calcium leaching, or the presence of pathogens or chemicals that are directly harmful to plants or their users (Machado and Serralheiro, 2017).

It is crucial to follow the requirements for irrigation water quality. The characteristics of crop resistance to salt, sodium content, and phytotoxic trace elements must also be carefully considered (Malakar et al., 2019). Crop production success is greatly influenced by the quality of the water. According to daily, seasonal, and climatic conditions, the quality of surface water is continuously changing over time (Ackah et al., 2011). It is thought that a comprehensive analysis and assessment of water resources is necessary for every productive agricultural endeavor. Therefore, knowledge of irrigation water quality is essential to identifying what management changes are needed for long-term productivity.

In light of the aforementioned, understanding of water quality is required at all levels for the River Awoja watershed if irrigation is to be conducted. For irrigation purposes, it is therefore imperative to ascertain the water quality in Uganda, particularly in the North - Eastern part of the study area. This is brought on by dwindling water supplies, growing population and water competition. Understanding the water quality required for good crop production practices that limit environmental pollution is necessary due to other development activities, such as domestic uses.

2.9.4 Impacts on fish use

Fish helps cleaning ecosystem and are of socio-economic importance to fishing community at Lake Victoria Uganda. Because of algae bloom, the ability of fish survivable is reduced and it can cause entire fish population to leave an area or die as a result of thick green muck (Reuter, 2014). Change in water quality due to human activities such as over fishing and grazing lead to loss of different fish species. The activities result into rapid algal bloom affecting ecosystem of river. Fish assist to improve bio system of River Awoja ecosystem and are the major source of food to the surrounding communities.

2.9.5 Impacts on potable water usage

The health of living things and issues related to national, regional and local development depend greatly on having access to clean and safe drinking water (Bwire et al., 2020). Depending on the country's health, conditions and economic situation, each country adheres to the World Health Organization's water quality standards (2006). The Millennium Development Goals and its associated indicators served as the guidelines for the standards.

Safe drinking water is defined by the WHO and UNICEF (2021) as the one which does not pose any substantial health risks over the course of a lifetime, including differentiable sensitivity that may arise at different periods of life. The Millennium Development Goals established national standards whose indicators were able to guide on this topic. The National Environment Management Authority (NEMA, 2020) has established several guidelines to maintain the Ugandan drinking water quality standards.

2.10 Methods of quantifying pollutant loads

Recently, consensus with scientists as well as policy makers on water quality problems must be addressed in an integrated manner where all the environmental, social and economic issues of natural waters are considered (Macleod et al., 2007). Utilizing published literature values, monitoring data, and watershed modeling are a few methods for calculating pollution loads (Hua et al., 2012).

2.10.1 Estimate water pollutant loads using figures from the literature

Calculating pollutant loads based on export coefficients for various watershed types and/or land uses is one of the simplest methods for doing so. The loading rates for a specific time period, or the load per unit of land per year, are commonly represented by export coefficients. Use of loading forecasts model based on published values vary sparingly if the basis of the coefficients is used and the conditions are not particularly close. Caution is therefore needed in their application due to the geographical and temporal averaging they reflect vs the dynamic spatial and/or temporal changes in environmental factors (Lin, 2004).

2.10.2 Watershed modelling as an approach to estimate pollutant loads

Models tend to be used for calculating pollution loads, predicting source loads, and assessing different treatment options (Pribak and Siegrist, 2015). A model is a collection of mathematical equations created to describe the natural and artificial processes that take place in a watershed system, including as precipitation, runoff, erosion, transport, loading, and land use and management techniques.

The equations are created by quantitatively analyzing the interactions between different variables in watershed and hydrologic processes. This allows for the employment of models to assess how one thing may affect other factors, as well as to predict potential future scenarios.

2.10.3. Digital Elevation Model (DEM)

A DEM for Central Region of Uganda at a resolution of 1 arc second (30 m × 30 m) was retrieved from the United States Geological Surveys (USGS) website (http://gdex.cr.usgs.gov/gdex/). The DEM was used for automatic delineation of the catchment and also to define the stream network and determine sub-basin parameters such as slope (Ghoraba, 2015). Therefore, Global Information Systems (GIS) are essential for monitoring the causes of eutrophication as well as evaluating the factors influencing changes in land use and cover and how they relate to the water quality of lakes, reservoirs, and rivers (Howarth et al., 2002).

Methods such conservative multivariate cluster analysis has been employed to examine how water contamination affects arable land in several German and Czech countries (Kändler et al., 2017). Principal component analysis (PCA) was performed in rivers to compare the effect of municipal effluent on the water quality.

Land usage and its cover are impacted by human activity in the catchment area surrounding urban centers and diffuse pollutants. The primary sources of nutrient loading into the lake could likely be activities like water deposition. Additionally, as the population grows, so do human activities that affect the catchment's water quality by influencing land use and cover. The water bodies are particularly vulnerable to water contamination due to the erodible effect caused by runoffs, deforestation, and the conversion of wetlands.

Statistics of Uganda's population is expected to expand by 3.0% annually, or 1,200,000 people, which has accelerated urbanization (UBOS, 2021). The main contributors of human activities on the land, environment and water resources are a number of socioeconomic and urbanization caused factors, which are rising at an accelerating rate.

2.10.4 Water quality monitoring

Water quality is monitored using Total Maximum Daily Load and pollutant loads are calculated using flow data. The quantities of items traveling through a particular monitoring site are represented by loads calculated from monitored data. To determine pollutant loads using monitoring data, numerous strategies, techniques, and computer systems have been created (Dressing et al., 2016)

Remote sensing and geographic information system (GIS) approaches were two of the various ways satellite data might be used to track water quality. The primary goal was to develop a mechanism for evaluating monitoring data in order to pinpoint areas within watersheds where discharges of heavy metals are lower than the national norm (Usali and Ismail, 2010).

The quality of water assessments can be used to analyze trends of water contamination in the catchment. Despite the necessity of assessing water quality, there are certain obstacles because of the spatial distribution of monitoring stations, the cost, the placement in relation to certain pollutant sources and the variability of the land (Zhang et al., 2022).

Geographic information systems are the most efficient method for monitoring landscapes that may be a contributing factor to poor water quality, claim various research (Usali and Ismail, 2010).

2.10.5 Laboratory analysis method

With time, weather changes and general environmental conditions, natural water quality, particularly river water, varies dramatically. These changes are usually undesirable and may be harmful to consumer health. Using laboratory analysis demands how safe the water is in that locality. Samples are passed through the laboratory and the parameters determined. The results are then analyzed and calculated to determine the pollutant quantities (Kelly et al., 2020)

2.10.6 Use of ANOVA to analyse the data

The association between a response variable and one or more independent variables was examined and described using analysis of variance (ANOVA). It is employed to establish the equality of more than two population means. The method determines if variability between and within each population is significantly different by using the F-distribution (probability distribution function), information about the variances of each inside, and grouping of populations between. When there are two or more independent variables in the design, the investigator can test mean hypotheses using the flexible data analytical technique known as factorial ANOVA. The analysis of the treatment effects and their interactions should be done using a factorial ANOVA (Larson, 2008).

2.10.7 Regression approach

The IBM SPSS version 25 software calculates the confidence level at 95% and shows a linear relationship between two or more changing land use and cover measures and water quality metrics. As a result, this investigates how dependent and independent variables are related.

2.10.8. Geographical information systems (GIS)

To characterize land usage / land changes of the earth's surfaces, factor analysis approaches (principal component analysis) and geographic information systems (GIS) can be employed. In reference to above methods of quantifying pollutant loads, the author used laboratory analysis to quantify pollutant loads in study area. Samples were collected stored at room temperature and run through the laboratory to determine atomic Absorption Spectrometer (AAS) parameter.

2.11 Land degradation

Land usage and its consequences on the development of water resources have affected many national agendas, policies, and signatories to major international accords on water resources (Scherr, 2019). As a result of the Dublin and Rio de Janeiro United Nations Commission on Economics and Development (UNCED) process (1992) on fresh water resources, the National Environment Management Act (1995) and Water Action Plan (1993) were created. The connection of water and land usage is emphasized.

In Uganda, land degradation has generated discussion, raised issues, and gained significant public acceptance. This led to the creation of numerous policies that aim to address problems with the sustainable use of land resources. Land deprivation, particularly soil erosion and nutrient depletion, has been linked to land use change, which has been made worse by population growth.

Removed forests has increased the amount of surface run-off that carried suspended particles into bodies of water (Turyahabwe et al., 2020). The issue with sediment movement is that it serves as a vehicle for pesticides, heavy metals, and nutrients that have a negative impact on water quality, particularly phosphate (Singh et al., 2017)

2.12 Water treatment

Water treatment is the process of removing all the substances, whether biological, chemical or physical, that are potentially harmful to the water supply for human and domestic use (Pakharuddin et al., 2021). This process makes the water acceptable, safe quality, sufficient quantity, portable and aesthetics. Thousands have lived without love but not without water (Granlund, 2021). This quote implies that water is life, it plays an important role in our lives, and nobody can survive without water. Water being a scarce resource, there is a need to manage it very well.

2.12.1 Methods of water treatment

Household water treatment

Household water treatment, or point-of-use water treatment, is a viable solution to reducing microbial risk levels in settings when access to safe drinking water is consistently limited. This is accomplished by treating tainted water that has been handled both domestically and at the source. Boiling, sedimentation, filtration, chlorination, and sun disinfection (SODIS) are the common home treatments for reducing water toxicity (Pichel et al., 2019). Some studies on household water treatment have recommended the use of products that provide filtration, solar disinfection (SODIS) and chlorination (Lantagne and Yates, 2018).

Conventional water treatment

The treatment process through the different processes which includes starting from raw water to finished water. These procedures, either by themselves or in conjunction with others, are included in treatment plans for community water supplies, depending on the quality of the raw water and the contaminants contained in it (Pakharuddin et al., 2021).

The destabilizing process used by aluminum sulphate to be added to raw water eliminates suspended particles. The particles settle and coagulate, or group together. Despite having access to safe and clean water, low-income people cannot afford this process. The existing water treatment techniques, which mainly rely on convectional systems including coagulation, fluctuation, sedimentation and disinfection, are expensive to deploy and ineffective to remove micro contaminants like heavy metals (Saravanan et al., 2021).

2.13 Natural zeolite

Organic zeolite, a volcanic rock with an ore grade gray-green tint, clinoptilolite is porous and has a sponge-like appearance. Zeolite has strong porosity in both water and soil, which allows it to absorb nutrients, gas smells and harmful substances from the air (Margeta et al., 2013). Zeolites are fairly stable under a wide variety of circumstances.

The presence of naturally occurring zeolites that were formed millions of years ago, as well as the current formation and persistence of enormous amounts of specific zeolites, particularly philipsite and clinoptilolite, which are found in shallow sediments on the ocean floor, serve as proof. Most zeolites are relatively stable and only slowly disintegrate at the pH range of natural surface water (pH 6–10) (Krstic, 2021).

2.13.1 Application of natural zeolite

The intrinsic properties of natural zeolites have led vast to applications such as absorbability, water purification, coagulation activity, membrane separation and antimicrobial activities. These are associated with their porosity and structural diversity their uniform pore size and shape, their mobility of cations and the hydrophilic and hydrophobic nature of the absorbents. Nowadays, zeolites continue to find various applications in solving environmental, scientifically and industrial problems (Margeta et al., 2013).

Previous studies revealed that the most effective natural zeolite is more effective in eliminating arsenite from surface water (Baskan,and Pala 2011). Natural zeolites are hydrated alluminosilicate materials with remarkable sorption and ion-exchange capabilities that are acceptable in both the economic and environmental domains. Their physical characteristics, which are closely related to their geological deposits, determine how successful they are in various technological processes (Margeta et. al, 2013). Further studies employing natural and modified zeolites to remove iron (Fe) and manganese (Mn) ions simultaneously from subsurface water samples have revealed that the clearance values of Fe and Mn for natural zeolite-clinoptilolite are 22–90% and 61–100%, respectively (Inglezakis et al., 2010)

2.13.2 Water treatment using electrochemical advanced oxidation processes

Arsenite removal from aqueous media is particularly difficult because the majority of current techniques don't show total Arsenite removal. The feasibility of extracting Arsenite from a water medium using advanced electrochemical oxidation techniques was examined in a few experiments. While the created Arsenite in the system could not be eliminated by anodic oxidation or electro-Fenton processes, they were successful in fully oxidizing Arsenite in its start to 1 mg/L and 10 mg/L (Nidheesh et al., 2020). The primary cause of Arsenite oxidation is in-situ produced hydroxyl radicals and hydrogen peroxide for anodic oxidation and electro-Fenton reactions. On the other hand, it was discovered that the peroxicoagulation technique worked effectively for both oxidizing Arsenite and eliminating arsenic from water. For a pH range of 3 to 11, the full elimination of arsenic was seen within 30 minutes of the electrolysis process.

2.13.3 Water treatment using Activated Carbon

Globally, rice husks are being used as adsorbents to remove both organic and inorganic impurities from liquid state (Lewoyehu, 2021). This is due to its exceptionally high surface area (ranges from 500 to 1500 $m^2\ g^{-1}$), well-developed internal micro porosity and wide spectrum of surface functional groups.

Numerous researches investigating the removal of Arsenite (Ars (III)) from surface water by absorption have used several carbons - based materials that include activated carbon, biochar, and iron – modified activated carbon. Other materials like activated alumina, iron oxide and manganese are also effective in removing Arsenite but they do not strictly fall under the of carbon surfaces (Sharma et al., 2022; Parlayici et al., 2024).

Sulfuration or nitrogenation can raise the basicity of the AC surface and encourage the adsorption of organic molecules. Increase of surface polarity improves the particular interaction with polar impurities to increase on the surface area of activated carbon. Researchers are studying alternate ways of treatments to have the potential AC surface area remove Arsenite (Bhavnagar et al., 2013). But research to date has largely focused on the use of these modified materials to remove heavy metals from water by complexes formation (Rivera – Utrilla et al., 2011).

2.13.3.1 Materials used for making Activated Carbon

Activated carbon can be obtained from the various materials which include the following rice hulls or husks, maize curbs, saw dust, cassava peels, lignite, coal, Chromium, wheat bran, coconut shells, wheat husks and tea wastes. These materials have received more attention for removing Arsenite due to their absorption efficiency, low expenditure and accessibility. One such material that has drawn more attention is rice husk, particularly in developing nations where over 96% of the world's rice husk production occurs. The creation of activated carbon from rice husks has been the subject of several studies, however the scientific data that is currently available is still dispersed extensively throughout the literature (Menya et al., 2018).

For this research, Rice husk (RH) has been considered because of it is abundance, availability, inexpensive agricultural surplus, its properties, such as structure, superficial adsorption, etc. (Viana, 2016). Rice husk has been extensively altered and utilized for a variety of purposes, such as boiler fuel, rubber fillers, animal feed, and as a source of various materials like carbon nanotubes and silica (Shukla, 2020). 'Morphology, structure, chemical composition and surface area are the basis for water purification efficacy, which draws scientists to innovate'. Biochar, activated carbon, silica, and hydrogels are a few of the rice husks derived materials being investigated for water purification, along with their advantages and disadvantages. This literature review discusses the rice husks as an adsorbent source and its use in removing different contaminants from wastewater and surface water in light of the aforementioned advancements.

2.14 Overview of water pollution management systems

The international community has now acknowledged the severity of the problems incurred by deteriorating water quality and agreed formally to take action to protect quality of freshwater resources. At the United Nations Conference on Environment and Development (UNCED), which took place in Rio de Janeiro, Brazil, from June 3–14, 1992, more than 178 governments adopted Agenda 21, the Rio Declaration on Environment and Development, and the Statement of Principles for the Sustainable Management of Forests.

2.15 Chapter summary

The literature review concentrated on the concentration of Arsenite as water contaminants in the watershed, their origins, the consequences of land usage and water quality. The reviews of the literature also addressed the trends in water pollution and Arsenite. The review also brought to light previous research and its shortcomings in the areas sorrounding Lake Victoria, the Lake Kyoga basin, the River Mpanga in South West Uganda, Arsenite assessment in domestic water sources and the River Awoja watershed. Lastly, reviews on surface water treatment with Activated Carbon were recorded.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This section describes the procedures used in the study to design, collect and analyze sources of data, data types and the location of the study area.

3.2 Study area

The study region is roughly bounded by longitudes 33° 44' East and 34° 8' East and latitudes 1° 44' North and 2° 8' North with an approximate area of 1,387,477 hectares. Runoffs originating from districts of Karamoja, through a network of streams and swamps converge close to this area. The variation in Arsenite pollutant concentrations entry into River Awoja have been considered in this study.

River Awoja catchment is dominated with various activities such as agriculture practices , waste disposal at downstream and mining, quarrying, volcanic weathering of aged rocks at the upstream that have formed a significant effect of the surrounding landscape. The river’s course can be affected by the terrain shaped by volcanic activities of Mount Moroto and the water quality may be influenced by minerals, heavy metals and sediments derived from volcanic rocks. In conclusion, above activities and rock weathering could have contributed to concentration of Arsenite into River Awoja. The scope of the study includes the locations of the water sampling points, types of land the years 2000, 2008, and 2017 which were classified as bush land, forestland, grassland, settlement, subsistence cropland, water body, wetland, and woodland.

River Awoja catchment area is characterized by relatively mild climate despite its location near equator and its attitude ranging from 940 to 3000 meters above sea level. It experiences a mean annual rainfall of 1103mm, with variations across different zones and main dry season being December to February. Significant portions of the catchment are well – watered supporting rain fed agriculture though spatial and seasonal variations in rainfall can lead to droughts (Metrological data,).

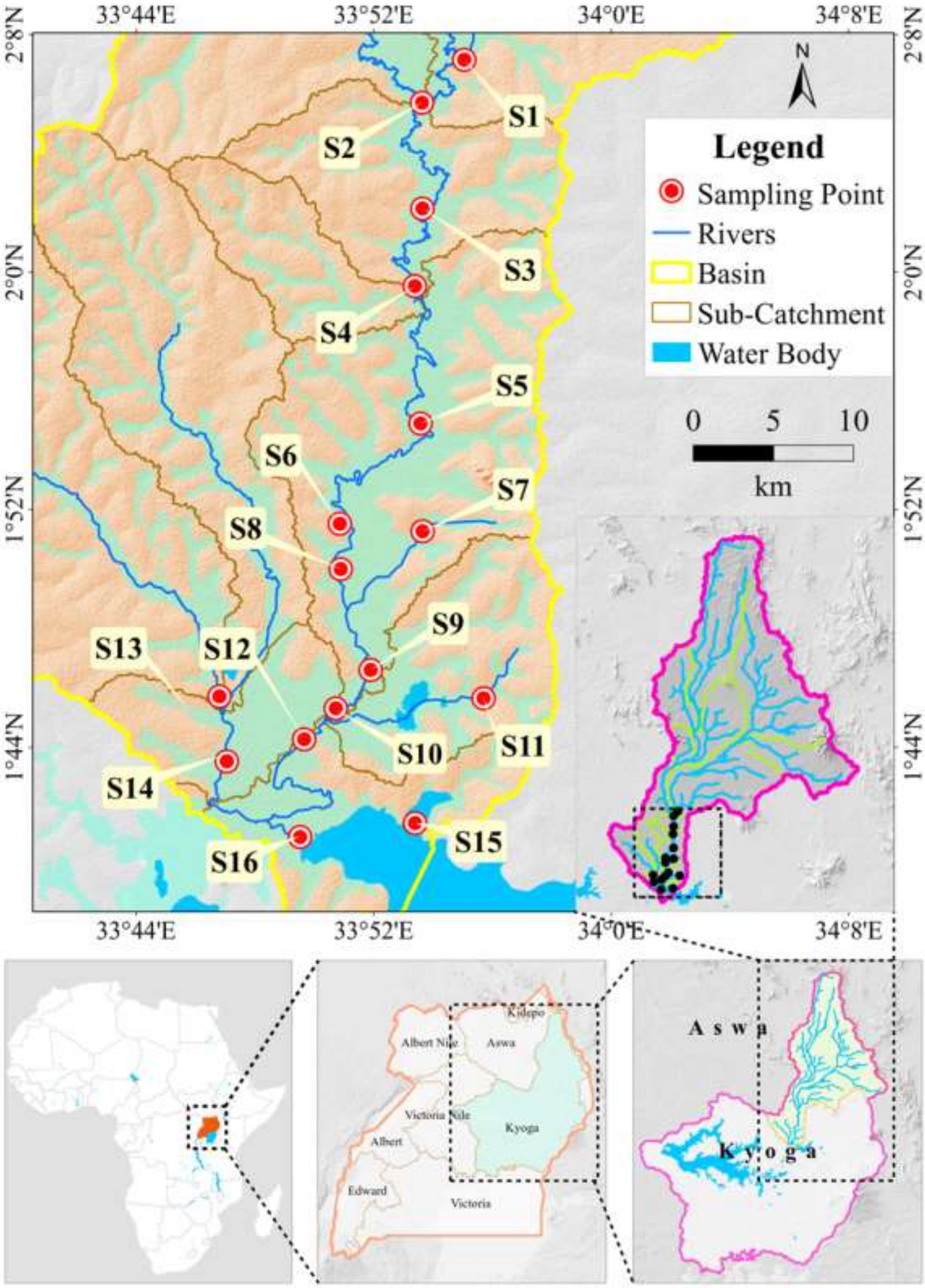


Figure 3. 1: Location of data sample points

3.3 Spatial data

Spatial data of the study area was obtained by using remote sensing – satellite imagery which detailed the land categories. With the resolution of 30 meters derived from satellite pictures, different land categories of barren land, built areas/ settlements, bush land, forest land, grass land, subsistence farmland, water body, wet land and woodland for the years 2000, 2008 and 2017 were obtained. The stream network, catchment boundaries and sub-basin metrics, such as the stream network, slope, aspect, size and distance downstream, were all established using DEM (Ghoraba, 2015). The nine land categories were created from the land photos, with a focus on the areas of each land category on a particular classed map. GIS analysis was used to partition the basin into watersheds to ascertain the relationship between the independent variable land use changes and the sampling locations for metals and non-metals. In this process, the quantitative relationship between water quality and land use was analyzed.

3.4 Data analysis and processing

The data for the study was gathered from the field that is visible as well as additional secondary sources. The standard field protocols for sampling, equipment calibration, sample bottle preparation and preservation were finished before the trip. Using 500 ml plastic bottles, unpreserved water samples were collected from each site on its coordinates. Streams, or point sources, were chosen based on where they were. Sterilized 500ml bottles were used to gather the samples, which were kept at a regulated room temperature.

A total of sixteen (16) sampled sources from the sub catchment were coordinates. Point samples, also known as instantaneous samples, were taken at a specific moment in time or for a short enough duration to be considered as capturing a discrete point in time. The study employed a snapshot technique, which involved gathering data at one time from multiple locations to monitor changes in the amounts of water pollutants over the course of that particular semi-dry weather period. At each location, the water pollutant considered included heavy metal Arsenite (Ars (III),). This array of pollutant was considered to allow investigation of whether the LULC types can be linked to Arsenite.

The calculation of land categories in square hectares was done using the global information system and manual method. The land categories included barren land, built areas/ settlements, bush land, forest land, grass land, crop land/ subsistence farmland, water body, wetland and wood land. The overall area of the study area, expressed in hectares, is obtained by adding the areas of each land category. The area in hectares of each land category is then divided by the total area in hectares, and the result is multiplied by 100 to determine the percentage proportion of each land use

3.5 Laboratory analysis

The samples collected from different point sources in different streams within the catchment were run through the laboratory for determination of different variation of concentrations of heavy metal pollutants entering River Awoja. Each water sample taken had to adhere to Science Biochemical laboratory of Makerere University. \and heavy metal tested was Arsenite (Photos attached)

3.5.1 Laboratory determination of concentration of Arsenite from surface water using Atomic Absorption Spectrum

The Atomic Absorption Spectrum with vapor generation assembly (AAS - VGA) method was used in laboratory to determine the presence of Arsenite. To accomplish this, the vapor generation assembly attached to AAS has acid channel filled with 30ml of Nitric acid (NNO_3) and the reduction channel with hydrogen peroxide (H_3O). In this system, Arsenite containing solution was pumped into a mixer and reacted with Nitric acid solution. Atomic absorption spectrometry therefore locates constituents in samples of surface water by utilizing certain wavelengths of electromagnetic radiation from a light source. Because every element absorbs wavelengths in a distinct way, standards were followed when measuring absorption. A spectrophotometric technique introduced measured Arsenite in surface water.

The Procedure included measuring 150ml of the sample which were was preserved under refrigeration at 25ºC., its then heat at 1000°C on the hot plate in the evacuator to 5ml . Concentration 30ml of Nitric acid (NNO3) was then added until the mixture is clear with no precipitates. Two drops of aqueous solution of hydrogen peroxide (H_3O) were added and to the sample and it's again heat. The heated sample is removed, cooled and filtered. Deionized water was added to the cooled sample up to a mark of to 25ml in the test tube and its then run in the atomic absorption spectrum. Results obtained were tabulated and analyzed for the concentrations of Arsenite in the specific sampled points The Beer-Lambert law explains the relationship between concentration and absorbance by linking a material's characteristics to light attenuation. According to Beer-Lambert's law, the concentration of a chemical solution and the amount of light it can absorb are inversely related. Because the concentration and absorbance of a solution are linearly connected, the concentration of a solution was determined by looking at its absorbance.

3.5.2 Laboratory preparation of Activated Carbon

The sample of rice husk was collected from Soroti Rice milling machine located in Soroti City, Eastern Uganda and passed through 1.6 mm sieve, its then carefully washed with purified water and dried in an oven (Oven-Thermostat DHG 9023A) from Kyambogo University laboratory at 105±30°C for 12 hours to a constant weight. The dried rice husk was then carbonized in a pyrolyzer (SK 2-2-12 TPA2, China) in the presence of nitrogen gas at 600°C for 3 hours, left to cool and stored in air-tight plastic bags. It’s then ground to its finest state using a mechanical grinder.

3.6 Water quality guidelines

The acceptable limitations for surface water categorization (such as drinking water supply, etc.) as shown in Table 3.1 are set by the National Environment and Management Authority (NEMA, 2020). These recommendations support resource agencies in locating and remediating harmed surface water systems and in warning the public of any possible health risks. Additionally, the guideline gives the maximum permissible limits for surface water quality standards that are acceptable and beneficial to the wellbeing of aquatic ecosystems and people. For Arsenite in which the study is based on, the allowable limit is 0.1mg/L.

Water laws may be put in place to safeguard human usage, but as these proposals show, they usually overlook the potential short and long-term ecological implications that water pollution may have on local and regional ecosystems.

Table 3. 1: Allowable discharge limits for wastewater containing inorganic compounds

Name of Pollutant	**Units**	**Allowable permissible limit**
Aluminum	mg/L	0.5
Antimony	mg/L	0.5
Arsenite	mg/L	0.1
Barium	mg/L	10
Beryllium	mg/L	0.1
Cadmium	mg/L	0.01
Calcium	mg/L	100
Chromium (Hexavalent)	mg/L	0.05
Chromium (Total)	mg/L	0.5
Copper	mg/L	0.5
Iron (Total)	mg/L	3.5
Lead	mg/L	0.1
Magnesium	mg/L	100
Manganese	mg/L	1
Mercury	mg/L	0.01
Nickel	mg/L	0.5
Selenium	mg/L	0.02
Silver	mg/L	0.5
Tin	mg/L	2
Vanadium	mg/L	1
Zinc	mg/L	2

(Source NEMA, 2020)

3.7 Analysis of water pollutants

This study establishes the association between the Arsenite loads for point locations and the physiographical characteristics of nine categories. Results from two-tailed tests were deemed statistically significant at *p*-values of $p < 0.01$ and $p < 0.05$. Therefore, the Pearson correlation coefficient was used to investigate the relationship between various land types and various water quality metrics.

Predicting water quality may be aided by the relationship between pollutant loads and physiographic parameters. In light of this, ANOVA method was utilized in the study to establish the *p*-values for predicting various land use patterns on water quality characteristics.

The relationship between physiographic parameters and water quality was assessed for the years 2000, 2008 and 2017. The importance of the association between land use and water quality indicators was examined by calculating the mean change percentage of LULC area and the mean water quality parameters using the Pearson correlation coefficient.

The degree of a linear link between two variables is gauged by the Pearson correlation. It ranges from -1 to 1, where a value of -1 indicates a completely negative linear correlation, a value of 0 indicates no correlation, and a value of + 1 indicates a completely positive correlation.

Variables that fall into the category of moderately correlated are indicated by correlation coefficients with magnitudes between 0.5 and 0.9. Reduced correlation is indicated by correlation coefficients with magnitudes between 0.3 and 0.5 for variables.

3.8 Calculation of cumulative areas in hectares of different land use

Using DEM, the areas of different land use for 2008, 2008 and 2017 are delineated cumulatively from the upstream to downstream to determine the relationship that exists between physiographic parameters and the water pollutants. The areas are therefore plotted against the concentration of the pollutants in that sub basin then the graphs are analyzed and results discussed.

3.9 Using Activated Carbon for treating Arsenite in surface water

Potential of using Activated Carbon from rice husk to remove the Arsenite from surface water with most substantial concentrations was investigated. Methodology for application of activated carbon vary with pollutants as described.

Arsenite (As (III)) concentration of 27.57 mg/L was found in the first laboratory results from the samples taken from catchment streams, which is higher above the 0.1 mg/L NEMA allowable limits. In laboratory setting of Kyambogo University Chemistry laboratory, stock solution was prepared by measuring 1.475g of arsenic Nitrate $As(NO_3)_3$ with 0.1M sodium hydroxide solution in de – ionized water to produce desired volume of 1,500ml synthetic arsenic nitrate effluent solution.

Crushed Activated Carbon was weighed in different grams of 0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 using a digital weighing scale and put into different flacons. Portions of 40 ml from the synthetic effluent solution was measured and pour it into different grams of 0.1, 0.2, 0.4, 0.6, 0.8, and 1.0 and left it to react for the designated amount of time. Different contact periods of 5, 10, 15, 20 and 25 minutes was considered. Using filter paper, the solution was filtered, then put each recorded filtrate into vials and run through a spectrometer ICPOES _ PAN ANALYTICAL from UNBS chemical laboratory of Bweyogerere, Kampala to determine the concentration of Arsenite and its percentage removal.

Percentage removal = $\left(\frac{C1 - C}{C1}\right) \times 100$, ……………………………….(4.1)

Where *C*1, overall effluent concentration, and *C* is concentration which remained after running the samples through spectrometer.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Introduction

The study's findings are presented this chapter. It also includes discussions and interpretation of the results.

4.2 Characterization of Land use and land cover of River Awoja

Table 4.1 describes the LULC types analyzed in the catchment including barren land, built areas/settlement, bush land, forest land, grassland, subsistence farmland, water body, wetland and woodland.

Table 4. 1: Description of Land categories

Class	Description
Barren land	These are areas whose formations are bare or rocky, it does not support the growth of vegetation
Built areas/ Settlement	Areas with structures such as semi-permanent or permanent houses both industries, roads, and buildings in cities, towns, trading centres and villages.
Bush land	These are remnant natural areas with savannah type which have not being disturbed for the agriculture purposes.
Forest land	These are places where there is a thick canopy of trees, with trees taller than two meters that can yield wood.
Grass land	Places where grass predominates and where semi-arid climates with little rainfall and frequent fires are common are prone to drought.
Subsistence farmland	This is land that can be used for both commercial and subsistence uses. It consists of recently planted crops as well as previously cleared ground that is ready to be planted. It fosters the growth of crops and livestock.
Water body	These are areas containing surface water with natural water open spaces, streams.
Wet land	Predominant or seasonal areas that are flooded or covered by saturated water.
Woodland	Areas that are characterized by of scattered trees of various heights and different grassland patches in between the trees.

Figure 4.1 show decrease in land usage and land cover between 2000 and 2017. Human activity on the catchment has caused forests to be reduced to woodland. This

result is consistent with Akello et al. (2016) analysis, which found that changes were mostly caused by overpopulation, wetland encroachment, deforestation and poor attitudes as a negative trend in land category changes.

Forest land in the Eastern part of Figure 4.1; 2000 (a), 2008 (b) have undergone depletion after a period of ten years into woodland characterized by scattered trees of various heights and different grassland patches in between the trees. The indication is that forests are being used for construction works and wood fuel for the communities around the catchment. This is therefore in agreement with the fact that uncontrolled degradation and conversion to other types of land use are threatening Ugandan forests due to the population pressure leading to loss of vegetation Kayanja and Byarugaba, (2001). Human demands for increased agricultural production by high conversion of grassland and forestland to cropland negatively affected environment leading to poor ecosystems. In the study area, forest cover may have been reduced due to seasonal burning for fresh grazing upstream of Karamoja, charcoal burning and wood fuel use, which resulted in highly erodible soils. Some of the services provided by forests like serving as carbon sink, reduction of water pollution, climate modification and ecological balance are not measurable to some people. A study on the decline of trees highlights that, deforestation is typically the result of the production of charcoal, which in turn results in substantial pollution and land bear overflow into water bodies (Chidumayo and Gumbo, 2013).

Other researches on the spatial variance in bushland conducted revealed that termite activity is the primary factor leading to bear soils, which cause runoff into river streams and contaminate the water Okullo et al. (2012). Concerns about overgrazing, uncontrolled browsing and other economic practices that contribute to biodiversity loss have been raised.

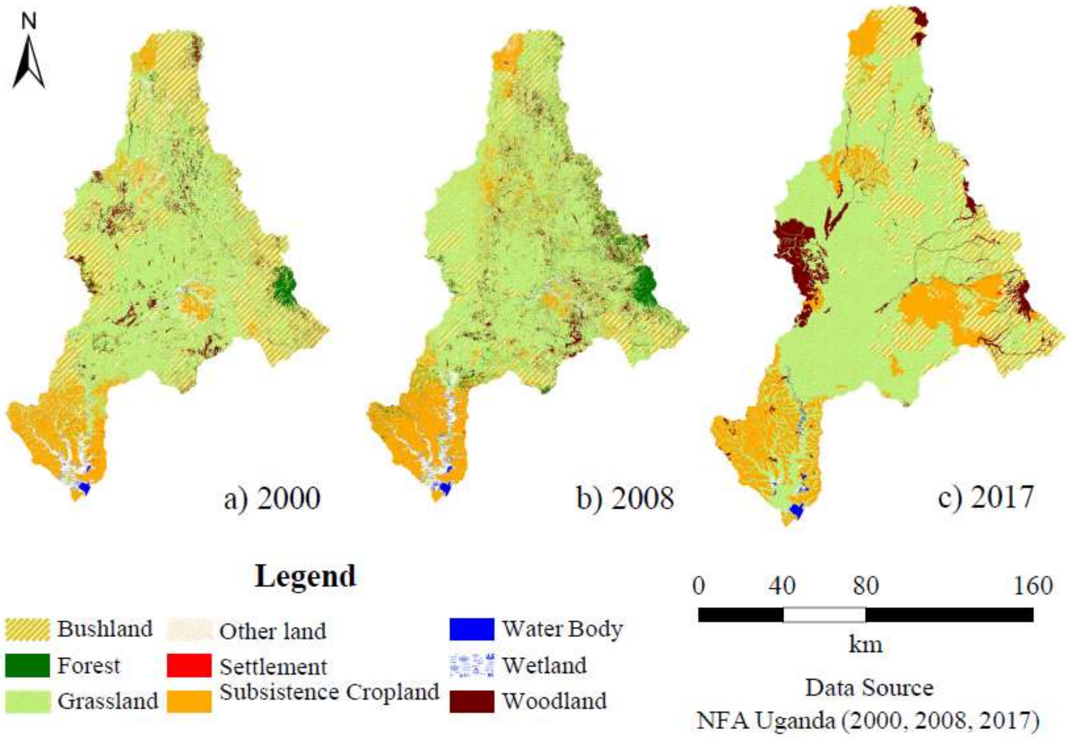


Figure 4. 1: Land category changes for River Awoja catchment

Table 4.2 shows the LULC types that included barren/rock, built-up areas, bushland, forest, grassland, open water, subsistence farming, swamps, and woodland.

In 2000, percentage coverage by built up areas, bushland, forestland, grassland, subsistence farmland, waterbody, wetland and woodland were 0.03%, 27.33%, 2.41%, 50.41%, 13.28%, 0.17%, 2.39% and 3.98% respectively. The corresponding percentages by 2017 became 0.04%, 19.89%, 0.00%, 56.31%, 17.09%, 0.32%, 0.28% and 6.06% respectively. Cropland increased from 13.28% (2000) to 17.09% (2017), while bushland decreased from 27.33% (2000) to 19.89% (2017). This indicates that cropland increased at the expense of bush land implying that there is increased subsistence farming as a major livelihood activity. The environmental impact of bushland to cropland conversion is significant because it is analogous to the impacts of forest loss, which results into bare land that increases the amount of erodible soil runoffs into water bodies. Similar findings in which cropland increased while bushland decreased can be found in the studies by Abera et al. (20200. The possible effects of converting wilderness to crops on the biophysical qualities of the surface have an impact on local climate changes. The Kenya Ministry of Forestry and Wildlife (2013), Zziwa et al. (2012), and Egeru et al. (2015) came to similar conclusions about changes in land usage. Changing land cover and it's use may have the effect of increasing the loads of pollutants in water bodies. When describing the LULC of the River Awoja, my findings is in agreement to Abera et al. (2020), there was a drop in bushland from 27.33% (2000) to 19.89% (2017) and an increase in cropland from 13.28% (2000) to 17.09% (2017).

Table 4. 2: Area of land use land and land cover types square hectares.

		2000		2008		2017	
ID	**LULC Type**	**Area (Ha)**	**Coverage (%)**	**Area (Ha)**	**Coverage (%)**	**Area (Ha)**	**Coverage (%)**
1	Barren land/ rocks	-	-	-	-	120	0.01
2	Build up areas	347	0.03	773	0.06	576	0.04
3	Bushland	378,065	27.33	438,366	31.69	275,109	19.89
4	Forestland	33,372	2.41	34,011	2.46	2	0.00
5	Grassland	697,422	50.41	606,662	43.85	779,086	56.31
6	Subsistence cropland	183,682	13.28	214,250	15.49	236,447	17.09
7	Water body	2,413	0.17	2,425	0.18	4,480	0.32
8	Wetland	33,126	2.39	28,008	2.02	3,858	0.28
9	Woodland	55,050	3.98	58,982	4.26	83,798	6.06
		1,383,477	**100.000**	**1,383,477**	**100.00**	**1,383,477**	**100.00**

Figure 4.2 (a, b and c) demonstrates average coverage in percentages for acreage of land categories. The land usage changed from 2000 to 2017. The forest cover reduced from 3% (2000) to 2% (2008) to 0.0% (2017) signifying that a lot of pressure was exerted on forest by human actions. Reduction in forest cover show grassland increase from 51% (2000) to 56% (2017), though in 2008, grassland reduced to 44% from 51% (2000), this is attributed to increase in bushland. Bushland, which is still a remnant of natural areas with savannah-type vegetation and a percentage of 32% as of 2017, has changed to 20% due to increased pastoralism and subsistence farming in the catchment. In other studies, by Muwanga et al. (2020) reported that stimulus of agro-pastoral activities had an effect on LULC in Karamoja. The change in land category is expected to negatively impact on water quality by exposing it to agents of erosion into water bodies. Changes seen is as a result of alterations on ecological systems for socio-economic gains, perhaps could have led to bushland decrease in hectares Maitima et al. (2010); Ebanyat, (2009).

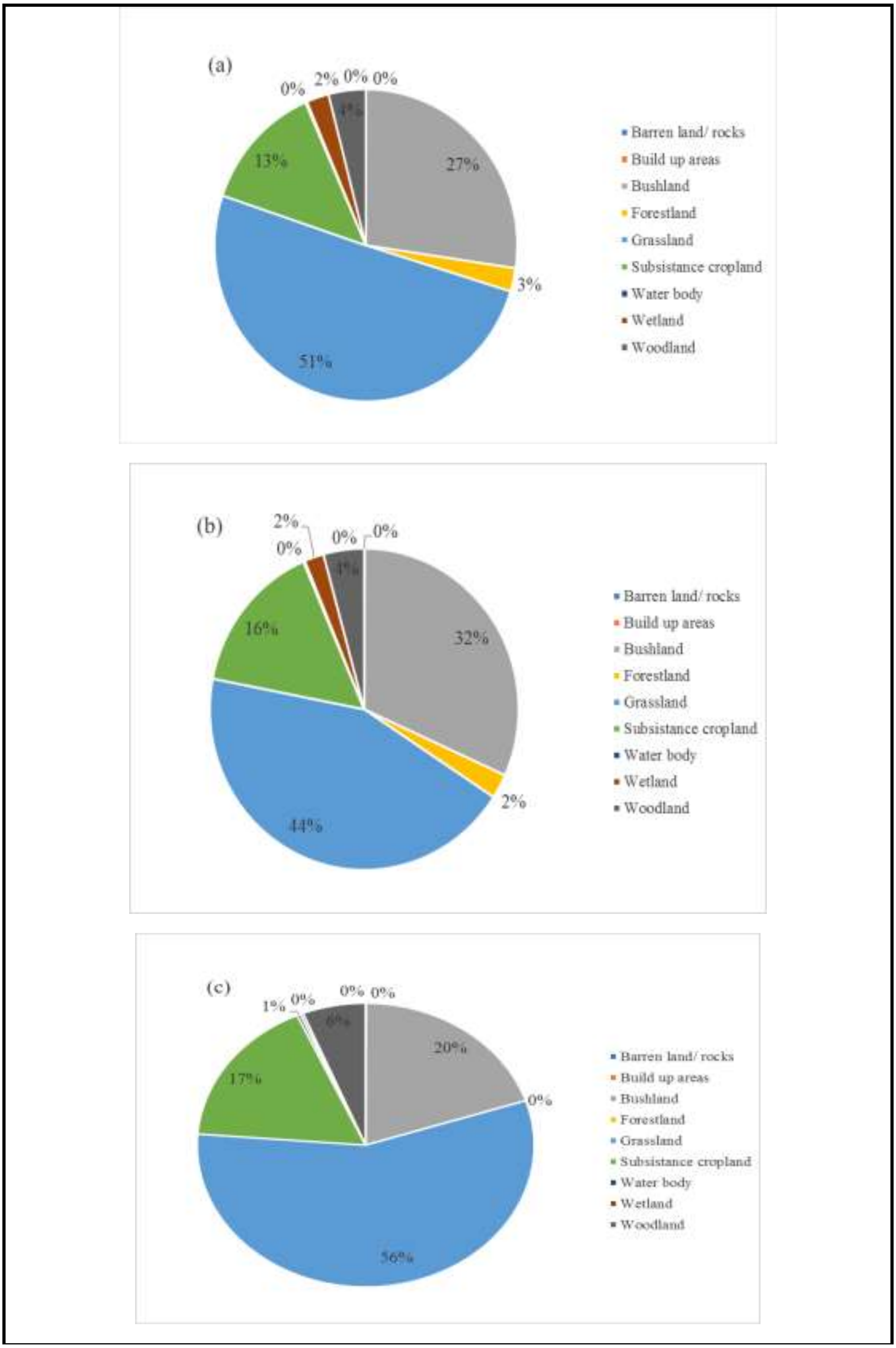


Figure 4. 2: (a) 2000, (b) 2008, (c) 2017 shows average LULC for different years

Table 4.3 describes the relationship that exists in the catchment in regards to elevation and slope from 2000 – 2017. The elevation affects the flow of the pollutants from the upstream to downstream, the steeper the elevation, the faster the flow leading to higher accumulations of pollutants (Arsenite) in to River Awoja and on the other hand the gentle the elevation the slower the flow leading to high deposition of the pollutant on the banks of the stream channels. Pollutants are too influenced by the slope of the area, the high the areas the higher the follow of the pollutants into the water body. In their study conducted ten years ago around Mount Elgon region of eastern Uganda, they estimated and compared soil erosion and found that the slope and elevation had an impact on the downstream flow of pollutants Ding et al. (2016). The quality of water at downstream is adversely affected by the pollutants discharged from major point sources upstream which agrees with research conducted by Chakraborti, (2021).

Table 4. 3: Distance between the sampling points, in terms of areas, elevations and the slope.

ID	Sampling Point	Distance between (km)	Area between (m^2)	Elevation Maximum (m)	Elevation Minimum (m)	Slope between (º)
1	0 - S1	0	0		1069	0
2	S1 - S2	9.02	1847.2	1069	1062	0.0776
3	S2 - S3	15.38	15771.2	1062	1058	0.0260
4	S3 - S4	13.24	15771.2	1058	1056	0.0151
5	S4 - S5	14.96	19372.6	1056	1054	0.0134
6	S5 - S6	15.86	10546.7	1054	1052	0.0126
7	S6 - S7	4.52	2426.3	1052	1051	0.0221
8	S7 - S9	3.81	1035.4	1051	1050	0.0262
9	S8 - S9	8.5	4301.6	1050	1049	0.0118
10	S9 - S10	8.79	2143.4	1050	1048	0.0228
11	S11- S10	12.53	13146.9	1049	1046	0.0239
12	S10 - S15	17.47	13919.1	1046	1044	0.0114
13	S12 - S13	7.3	8459.1	1046	1045	0.0137
14	S13 - S15	5.55	1192.6	1045	1044	0.0180
15	S14 - S16	7.5	0	1044	1044	0.0000

Figure 4.3 presents characteristics of DEM in form of slope, aspect, area and topographical information. Figure 4.3 (b) demonstrates a two-dimensional representation of the gradient of a surface, how steep or gentle a slope is at any given point. In this watershed, a slope of 63.52 degrees upstream indicates strong surface water runoffs to the downstream (slope of 0.75 degrees), which results in high deposition rates due to erodible soils and an accumulation of water pollutants. Surface water quality in catchments is influenced by anthropogenic variables including land use conversion, as well as natural geological and geographical elements (Sliva and Williams, 2001).

The topography of various structures in Figure 4.5 (a) establishes the accessibility of the places within the River Awoja watershed. In studies conducted in lake Kyoga, showed the correlation between land use transitions and soil erosion/sediment deposition, highlighting that topography aids the flow of water pollutants downstream Chasia et al. (2024). The catchment is flat in the southern section, which facilitates heavy deposition of water pollutants arriving from the northern part of the catchment through a network of streams, as shown in Figure 4.3 (c). In this findings, topography, slope and aspects have greater influence on the catchments' runoff and the stream's capacity to erode soil downstream to water body and this is concurring with Willgoose (1992).

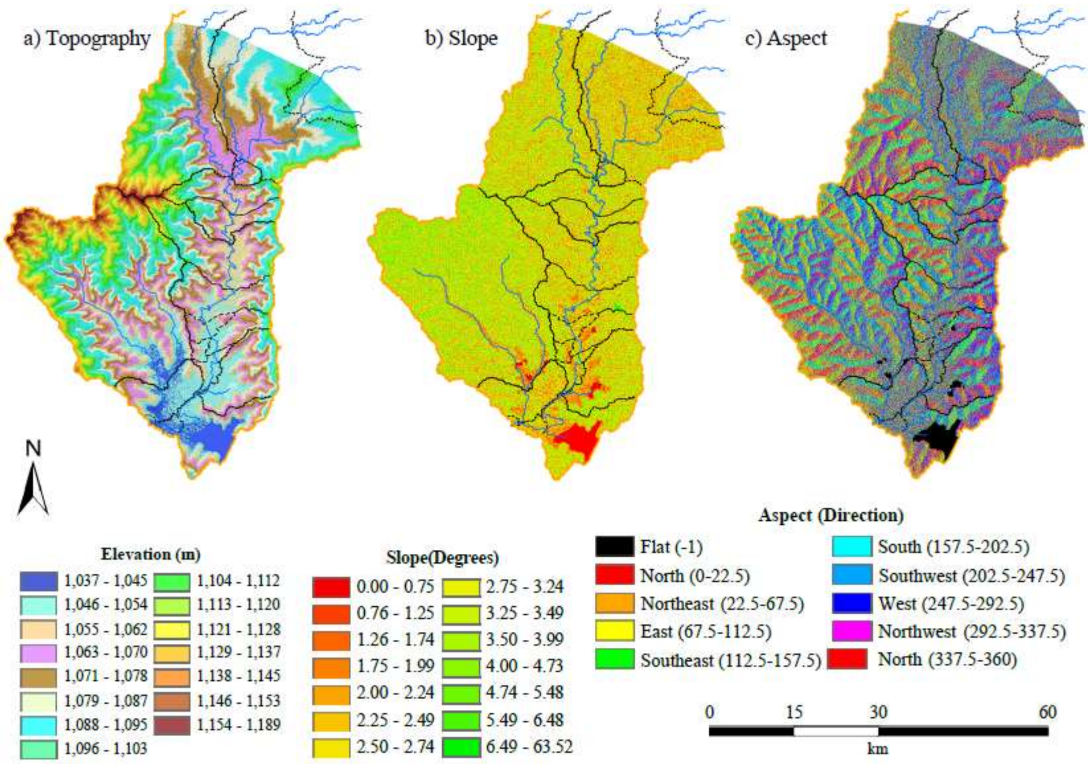


Figure 4. 3: a**)** Topography, b) slope, and c) aspect of the downstream section

4.3 Variation of concentration of pollutants entering River Awoja

This section presents, discusses the findings and interprets the results of variation in concentrations of Arsenite entering River Awoja.

Table 4.4 shows the laboratory analysis of the variations of Arsenite entering River Awoja. By analyzing its parameters of Arsenite, the test provided valuable information about the allowable standards of water in relation to World Health Organization, National Environment Management Authority and East African Standards permissible limits. At all the sampling locations, its observed that Ars(III) values (20.21 – 27.56mg/L) went beyond the standards (0.01mg/L), (0.1 mg/L) and (0.01mg/L) as compared with WHO, NEMA and EAS guidelines. It was also observed that the concentration of Ars (III) at sample point 9 is higher than entry point into the water body, this could be attributed by deposition of the Arsenite on the banks and meandering of the river as it flows downstream Malakar et al. (2021).

Table 4. 4: Laboratory results for Arsenite from the sampled points

Sample point	Distance between points	Cumulative distance	Ars (III)(mg/L)
S1	0.00	0.00	20.21
S2	9.02	9.02	23.37
S3	15.38	24.40	23.70
S4	13.24	37.64	20.43
S5	14.96	52.60	26.00
S6	15.86	68.46	21.66
S7	4.52	72.98	24.62
S8	3.81	76.79	24.72
S9	8.50	85.29	27.56
S10	8.79	94.08	25.15
S11	12.53	106.61	24.57
S12	17.47	124.08	24.04
S13	7.30	131.38	22.62
S14	5.55	136.93	24.04
S15	7.50	144.43	24.68
S16	12.00	156.43	26.78

Figure 4.4 shows the graphical representation of the concentration of Arsenite along the catchment. The results show that there is cumulative effect towards the downstream indicating the rate of change along the catchment. This can also be attributed to some of the natural processes such as mineral weathering, anthropogenic, agricultural and quarrying activities. The meandering of the river with bends could also regulate the flow by reducing the speed at the bends and increasing the turbulence at the straight points hence causing the variation of

deposition of Arsenite along the river. Because of the vegetation growth along the river, Arsenite can the trapped by the roots and the grass especially when the follow is slow.

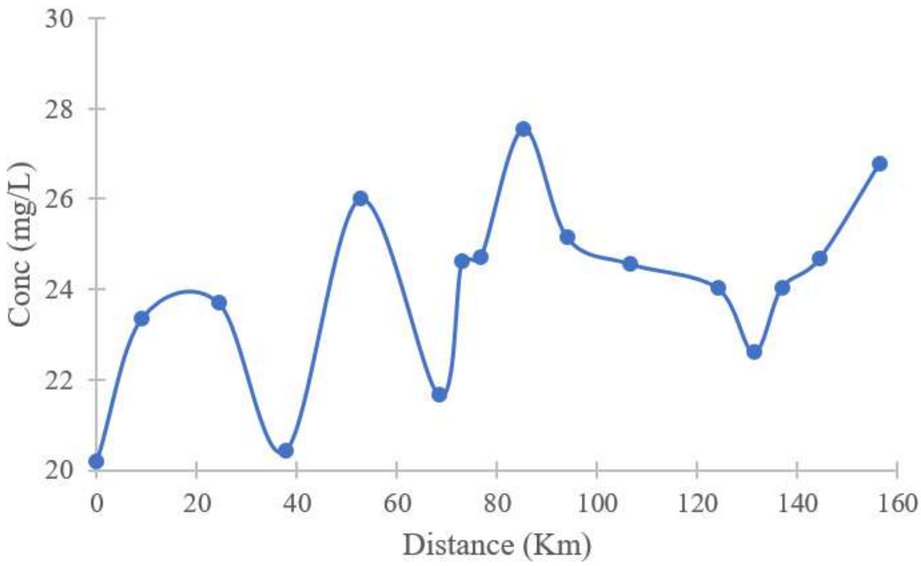


Figure 4. 4: Graphical representation of Arsenite along the catchment

In Table 4.5 shows permissible limits of the pollutants, the concentration of Ars (III) ranged from 20.21mg/L to 27.57mg/L as compared to WHO (2011), NEMA (2020) and EAS (2012) guidelines. The levels of Arsenite were higher than the allowable limit of 0.01 mg/L. The Earth's crust, which occasionally as a result of volcanic activity or other natural processes, causes high concentration of Arsenite. Additionally, quarrying activities on the mountainous parts and post mining upstream leads to high concentration of arsenite Nurcholis et al. (2017)

However, human activities at upstream such as overgrazing, subsistence farming and limestone quarrying could have led to increased concentrations of Ars (III) into surface water Malakar et al. (2021). Arsenite being one of the most toxic heavy metals enters waterways naturally through soil erosion, boulders, runoff, and waste streams. Exposure to modest amounts of Arsenite can result in diarrhea, nausea, stomach pain, and skin discoloration. WHO, (2020); Ratnaike (2003).

Table 4. 5: Permissible limits for Arsenite

			Permissible limits			
Parameter	**Max observed lab results (mg/L)**	**Min observed lab results (mg/L)**	**WHO (mg/L) , 2011**	**NEMA 2020 (mg/L)**	**UGANDA STANDARD - EAS 2012 (mg/L)**	**Method**
Arsenite (Ars(III))	27.57	20.21	0.01	0.1	0.01	AAS

4.4 Relationship between Arsenite and physiographic characteristics

This section presents and discusses the results for specific objective (iii) which was to determine the relationship between Arsenite concentrations from different land uses. The results were processed using single – factor ANOVA method of p – values ≤ 0.05. It also shows how the Arsenite is linked to catchment characteristics.

Table 4.6) shows that the F value is 68.51 and p - value is 2.209E-14 which is less than 0.05 implying its statistically significant, this analysis showed that the contribution of the distances between the sampling points cumulatively from the upstream to downstream influences the concentration of Arsenite in surface water. This therefore is assumed that Arsenite contamination in the study area might have been caused due to the anthropogenic activities along with the natural phenomenon which is in agreement with the study of Safiur Rahman et al. (2021). The distribution of the Arsenite contents and the physicochemical parameters in the surface water were greatly significantly different during the time the data was taken.

Table 4. 6: ANOVA for statistically significant variables and sampling points

Concentration of Arsenite

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample	16	136	8.5	22.667
Dist km	16	157.23	9.865	24.953
Ars(III) (mg/L)	16	384.15	24.00	4.159

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F critical*
Between Groups	2365.038	2	1182.51	68.512	2.209E-14	3.204
Within Groups	776.7012	45	17.26			
Total	3141.739	47				

Table 4.7 show statistical analysis of the effect of the slope on the concentration Arsenite in the catchment. The p values in Tables 4.6 and 4.7 are statistically significant, as indicated that they are less than 0.05. The finding seems to agree with the study of Perera and Gomes (2023) that showed that the cumulative pollutant load transported at time t and the total load from developed catchment depends on the slope.

Table 4. 7: ANOVA statistical analysis of the slope on Arsenite concentration

Effect of the slope on concentration of Arsenite

Groups	*Count*	*Sum*	*Average*	*Variance*
Sample	15	120	8	20
Slope Btn (º)	15	0.295	0.020	3.233E-04
As (III) (mg/L)	15	359.47	23.965	4.4223

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4459.603	2	2229.802	273.902	8.005E-25	3.220
Within Groups	341.917	42	8.141			
Total	4801.520	44				

Where SS is the sum of squares, df is degree of freedom, MS is mean squares, and F is factor ratio.

Table 4.8 shows how the cumulative areas of different land use for 2017 that have been delineated cumulatively from the upstream to downstream to determine the relationship that exists between physiographic parameters and the water pollutants. The cumulative areas have an effect on the land use land. Deforestation gets cumulated as more land is being opened for farming and grazing. Wetland on the other side is to being affected as its being encroached for farming purposes. In a study, by Cundy et al. (2003), increased heavy metal input into soils and natural waters is frequently as the result of agricultural practices and other anthropogenic activities.

Corresponding heavy water pollutant loads in the respective sub basin in Table 4.8 indicates that point S9 has a high Arsenite concentration of 27.56mg/L before entrance to the water body as compared to point S16 with 26.78mg/L. This is as a result of distance of cumulative areas that could have caused the deposition of part of the pollutant load. The occurrence, movement and transformation of Arsenite may be significantly impacted by the scenery patterns in a research area. Anthropological activities have the potential to worsen the situation and speed up contamination, particularly in peri-urban watersheds with a variety of land uses. On the other hand, some studies on Arsenite is caused by anthropogenic activities in the catchment (Marin et al., 2010).

Table 4. 8: Cumulative areas of different land characteristic from upstream to downstream

Sub-Basin	Barren land/rocks	Bushland	Forest	Grassland	Settlement	Subsistence Cropland	Water Body	Wetland	Woodland
1	113	274718	0.005	695259	352	129680	682	879	80385
2	113	274718	0.005	724831	365	145684	1041	1023	82195
3	113	274718	0.005	729099	383	149992	1352	1023	82244
4	113	274718	0.005	731883	389	153730	1631	1031	82244
5	113	274718	0.005	739540	415	164718	1829	1396	82383
6	119	274718	0.005	744520	442	169868	1829	1688	82476
7	119	274718	0.005	745848	442	170938	1829	1716	82476
9	119	274718	0.005	748540	442	173236	1829	2041	82499
11	119	274718	0.005	749134	477	175064	1829	2041	82499
16	120	275109	1.685	779086	576	236447.00	4479.94	3858.31	83798

Figure 4.5 shows variation of concentration of Arsenite with the various LULC types. The pattern shows an increase of the Arsenite downstream from upstream area into the water body through categories of land characteristics. The physiographic characteristics for the Arsenite showed the best relationship for grassland, settlement, cropland with the root square values of $R^2 = 0.84$, $R^2 = 0.86$, $R^2 = 0.76$, of the model's quality of fit for predictive significance and other land categories such as burren land, waterbody, wetland and woodland showed R^2 values of , $R^2 = 0.80$, $R^2 = 0.62$, $R^2 = 0.76$, $R^2 = 0.61$. However, the negative gradient in both bushland and forestland, with a negligible value of R2 = 0.29, suggests that LULC has no control over the amounts of Arsenite downstream. The study of Giri et al. (2018) considers effect of land use on water quality downstream. In this finding Arsenite increases downstream as it seems to agree with the study of Ishaq et al. (2013), Khan et al. (2013 and Zhang et al. (2022).

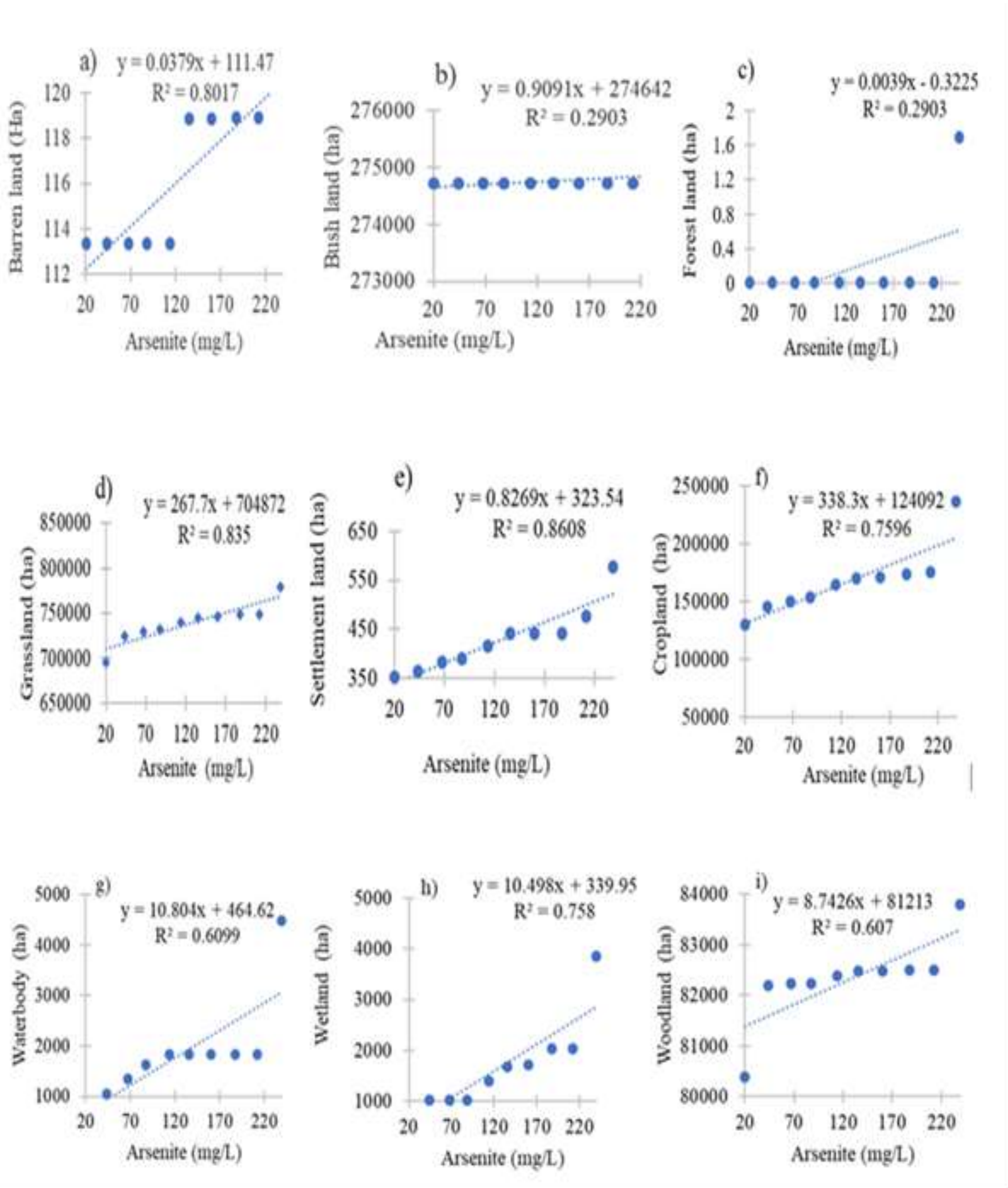


Figure 4. **5:** variation of Arsenite with a) barren land, b) bushland, c) forestland, d) grassland, e) settlement, f) cropland, g) waterbody, h) wetland, i) woodland

4.5 Potential of Activated Carbon to remove Arsenite from surface water

The results pertaining to the potential of activated carbon in eliminating Arsenite are presented and discussed in this part. This was done through laboratory analysis at different contact time and dosage of Activated Carbon. After determination of laboratory results of water quality parameters, Arsenite was detected having higher values of 20.21mg/L to 27.57mg/L as compared to permissible limits standards of 0.01mg/L by WHO (2011). In a study by Singh et al. (2010) found that heavy metals and metalloids can induce a variety of disorders that has a bearing on different human organs if left untreated Arsenite exposure, even at low levels, can have serious negative effects on health. This study demonstrates the necessity of eliminating Arsenite from surface water. Activated Carbon from rice husk was therefore used to reduce or treat the concentration of Arsenite in surface water. Study by Mondal and Garg (2017) showed that Activated Carbon cannot only reduce turbidity and chromaticity but also degrade ammonium, heavy metal cations and other cationic pollutants.

Table 4.9 shows the removal efficiency Arsenite from surface water by Activated Carbon. The findings demonstrate that the Arsenite removal efficiencies by Activated Carbon vary with different dosages and contact times, the variation is due to the large contact surface area and adsorption sites of ion concentration. Removal efficiencies are low at low dosages and contact times but increases with dosage and contact time Yao et al. (2014). Arsenite removal from water using Iron (iv) using activated carbon made from waste biomass, show that the particles were evenly distributed across the composite's surface, displaying a large surface area and pore volume for Arsenite absorption (Liu et al. 2010).

Table 4. 9: Removal efficiencies, corresponding Activated Carbon dosages and contact time

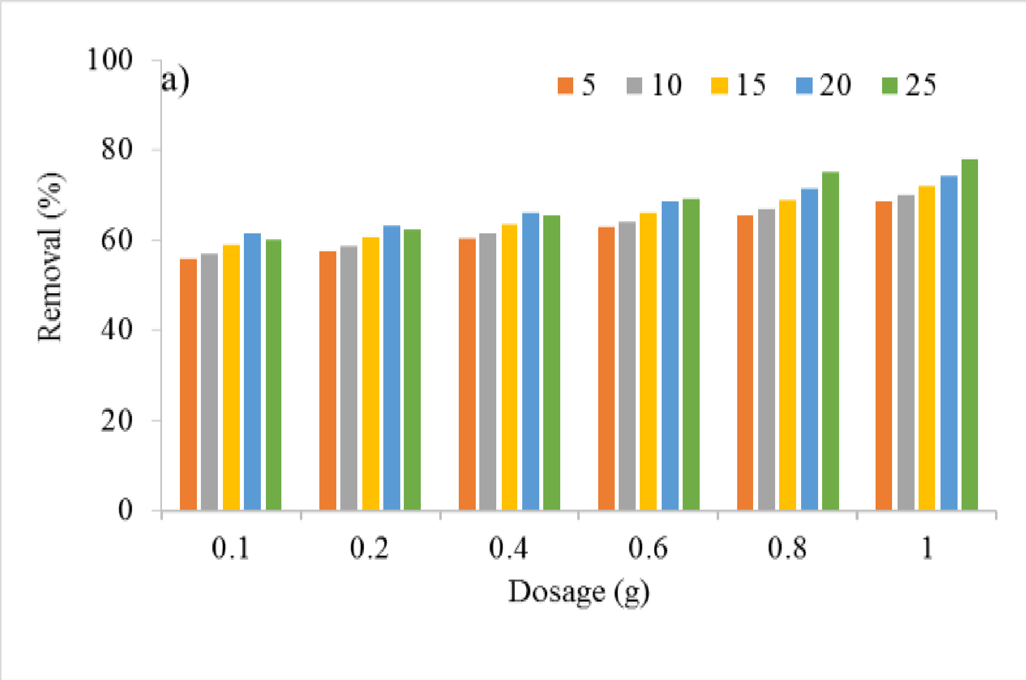
AC (g)	0.1	0.2	0.4	0.6	0.8	1.0
CT			**Percentage removal**			
5	55.76	57.39	60.28	62.91	65.56	68.64
10	57.02	58.66	61.54	64.17	66.82	69.90
15	59.01	60.65	63.53	66.16	68.81	71.89
20	61.50	63.13	66.02	68.65	71.30	74.38
25	60.06	62.24	65.33	69.24	75.09	78.01

Where CT is contact time and AC is activated carbon

Figure 4.6 a) demonstrates the effect of dosage of Activated Carbon in removing or treating water of higher Arsenite contaminants. The findings demonstrate that the removal efficiency of Arsenite considerably increased with the dosage. The increase in dosage from 0.1 to 1.0g resulted in an increase 55.76 to 78.01% in removal efficiency of Arsenite by Activated Carbon, 55.76% is the removal percentage efficiency at dosage of 0.1g of AC at contact time of 5min (the least efficiency) whereas 78.01% is the removal efficiency at dosage of 1.0g of AC at contact time of 25min (the more efficient). This increase could be as a result of availability of surface area at the high concentration of the absorbent. Also, on the other hand, the increase of the removal efficiency may be attributed to the fact that with an increase in the dosage, more absorption spots were available for the solute to be absorbed Kord Mostafapour et al. (2013). This result is consistent with research by Yao et al. (2014), which demonstrates that the concentration rate of absorption causes the percentage of arsenite removed from surface water to increase with dosage.

Contact time is one of the most important factors in the adsorption process. Figure 4.8 b) illustrated how contact time affected the Arsenite adsorption efficiency. As can be seen, during the adsorption stage (5 –25 min), the removal efficiency of Arsenite onto the composite adsorbent increases. An increase in Activated Carbon mass from 0.1 to 1g based on a 25-minute contact period resulted in a 60.06% increase in removal efficiency to 78.01%. At 25 minutes' time, the percentage removals of Arsenite from 0.1g, 0.2g, 0.4g, 0.6g, 8g and 1.0g samples were 60.06, 62.24, 65.33, 68.24, 75.09, 78.01 respectively, this showed that removal efficiency increases with increase in contact time and dosage. This is also seen with the rest of contact times of 5min, 10min, 15min and 20min with their respective Activated Carbon dosages. It can be explained as a result of surface area – the smaller the surface area of Arsenite, the effective is AC in removing efficiency. At the dosage of 1g of Activated Carbon with the contact time of 25mins, is more effective, removing 78.01% of Arsenite in surface water. Also, at contact time of 20mins with the same dosage of 1g saw effective removal of 74.38%. This finding is in line with research by Yao et al. (2014), Kord Mostafapour et al. (2013), and Gulnaz (2011) that showed how successful activated carbon was at removing Arsenite from drinking water under a variety of circumstances, including dosage and contact time. Additionally, observation by Nicomel et al. (2016) saw that persistent organic compounds such as Arsenite metal ions and microorganisms can also be removed from water by other technologies such as oxidation.

Therefore, as per the above discussions, contact time of 20mins and 25mins at dosage of 1.0g is recommended for effective removal of Arsenite using Activated Carbon from surface water.



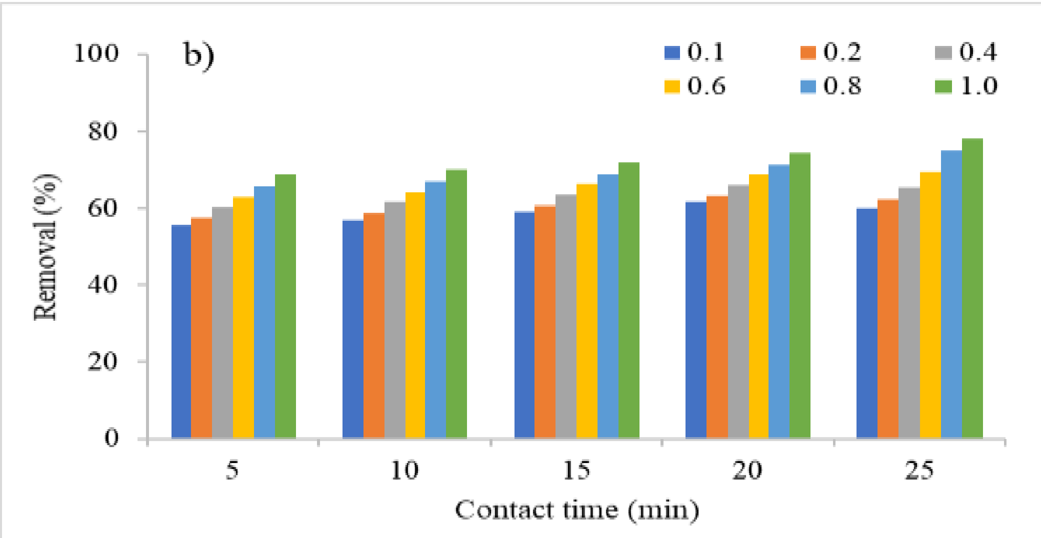


Figure 4. 6: Effectiveness of Activated Carbon with a) dosage, b) contact time in removing Arsenite in surface water

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This chapter presents the following conclusions of made based on the result findings from the specific objectives and research questions. The Arsenite results from surface water with concentration ranged from 20.21mg/L to 27.57mg/L above the permissible limits of 0.1mg/L by World Health Organization which prompted having a solution of removing it.

5.1.1 Characterization of LULC of River Awoja catchment

Built-up areas, bushland, forestland, grassland, subsistence agriculture, waterbody, wetland, and woodland made up the proportion of land cover in 2000, were 0.03%, 27.33%, 2.41%, 50.41%, 13.28%, 0.17%, 2.39%, and 3.98% respectively. With the corresponding LULC percentages by 2017 became 0.04%, 19.89%, 0.00%, 56.31%, 17.09%, 0.32%, 0.28% and 6.06% respectively. Cropland increased from 13.28% (2000) to 17.09% (2017), while bushland decreased from 27.33% (2000) to 19.89% (2017). This indicates that cropland increased at the expense of bush land implying that there is increased subsistence farming as a major livelihood activity.

5.1.2 Variation of concentrations of Arsenite entering River Awoja

Laboratory results of Arsenite (20.21 mg/L) in surface water entering the River Awoja have been discovered to have high concentrations values; that are greater than the recommended permissible values of 0.01 mg/L (NEMA, 2020) and 0.1 mg/L by WHO (2011) for discharge into water bodies. After the treatment with activated carbon the concentration of Arsenite reduced to 0.178g. This was calculated by determining the absorption capacity for Arsenite and apply to specific volume and initial concentration.

High concentration of Arsenite could be attributed to subsistence farming, overgrazing, deforestation and earth crush which could have led to increase of its concentrations in to water surface. This high concentration of Arsenite could cause infertility and miscarriages with women, skin disturbances, declined resistance to infections, heart disruptions and brain damage with both men and women leading into death.

5.1.3 Relationship between pollutant loads and physiographical characteristic

Statistical ANOVA test conducted showed that the concentration of Arsenite in relation to physiographic determinants is statistically significant with p – value of 2.209E-14 which is less than 0.05. Also, the physiographic characteristics for Arsenite showed the best relationship R2 > 0.5 between barren land, grassland, settlement, cropland, waterbody, wetland and woodland with the root square values of $R^2 = 0.80$, $R^2 = 0.84$, $R^2 = 0.86$, $R^2 = 0.76$, $R^2 = 0.62$, $R^2 = 0.76$, $R^2 = 0.61$ hence the quality model for predictive significance. Conversely, forestland has negative gradient with insignificant value of $R^2 = 0.2$, implying that LULC has no control on the quantities of Arsenite as it follows to downstream

5.1.4 Potential of Activated Carbon to remove the Arsenite from surface water

Activated Carbon mass of 1.0g based on the contact time of 25 minute more effective removing 78.01%. At 25 minutes' time, the percentage removals of Arsenite from 0.1g, 0.2g, 0.4g, 0.6g, 8g, 1.0g samples were 60.06%, 62.24%, 65.33%, 68.24%, 75.09%, 78.01% respectively, this showed that removal efficiency increases with increase in contact time and dosage. It has been explained as a result of surface area – the smaller the surface area of Arsenite, the effective is AC in removing efficiency.

5.2 Limitation and future actions

The study was based on investigating spatial variation in concentration of Arsenite entering River Awoja and therefore the research focused on the quality of water. The study does not look at the hydrological flow of the streams entering River Awoja ecosystem, including sediment deposition rate and bathymetry. The funding implications in doing the laboratory tests could not allow the researcher to test for the PH and conductivity.

5.3 Recommendations

5.3.1 Further research

Further research can be conducted in the following areas

i) How temperature and PH affect the elimination of arsenite.
ii) Potentials of other locally available materials such as avocado, tea wastes, cassava peels seeds, maize cobs, saw dust for removal of Arsenite from water.

5.3.2 Policy

The following recommendations have been made as result of this research;

i) The Ministry of Water and Environment to invest funds on data of Arsenite loads entering River Awoja in different climate conditions.

ii) Surface water is the main source of most people and animals, therefore, there is a need to monitor the concentration of Arsenite in water which is caused by rock weathering of some soil formations.

iii) Government with other stakeholder sensitize the communities' appropriate methods of catchment conservation of Awoja ecosystem.

iv) There is a need to strengthen National Environmental Management policy in addressing the issues of soil deforestation, loss of biodiversity, increasing pollution and environmentally related diseases on water catchment conservation areas.

v) Taxing and subsidizing can be used to reduce on Arsenite levels in point sources through creation of appropriate incentives.

In conclusion, the cost of feasibility study, additional monitoring and implementation of the findings can, for reasonableness, be based on the time when the activities can be conducted. Thus, an estimated cost in the current period may become unrealistic under future conditions. To be realistic, the cost of implementation, e.g. the cost of treatments of water polluted by Ars (III) can be determined in a separate comprehensive study.

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APPENDICES

APPENDIX I: PHOTOS




Sampling at coordinate point (1° 51´ 06" : 33° 50´ 52")



Sampling at coordinate 2° 02´ 12" N: 33° 53´ 35"E




Sampling at coordinate point (1° 45´ 13" : 33° 50´ 42")

Water analysis process for the heavy metals using Atomic Absorption Spectrum at Makerere – Chemical Laboratory.

Getting started in the laboratory to start analysis

Preparing the flacons, test tubes solution

preparation of synthetic Arsenic nitrate effluent

Weighing AC into the flacons

Taking records of all the samples weighted

Filtration process

Transferring the filtrate to vials to be taken for concentration tests

APPENDIX II: LABORATORY RESULTS FOR DATA CONCENTRATION OF ARSENITE

Laboratory results for data concentration of Arsenite before and filtration process from the overall concentration of mother solution of 250.8136g

Contact time (Min)	Dosage (g)	Concentration (g)	Removal eff (%)
5	0.1	110.96	55.75
5	0.2	106.86	57.39
5	0.4	99.64	60.28
5	0.6	93.03	62.91
5	0.8	86.39	65.56
5	1.0	78.66	68.64
10	0.1	107.79	57.02
10	0.2	103.70	58.66
10	0.4	96.49	61.54
10	0.6	89.86	64.17
10	0.8	83.22	66.82
10	1.0	75.49	69.90
15	0.1	102.80	59.01
15	0.2	98.70	60.65
15	0.4	91.46	63.53
15	0.6	84.87	66.16
15	0.8	78.23	68.81
15	1.0	70.50	71.89
20	0.1	96.56	61.50
20	0.2	92.47	63.13
20	0.4	85.24	66.02
20	0.6	78.63	68.65
20	0.8	71.99	71.30
20	1.0	64.26	74.38
25	0.1	100.18	60.06
25	0.2	94.70	62.24
25	0.4	86.96	65.33
25	0.6	77.17	69.24
25	0.8	62.48	75.09
25	1.0	55.16	78.01

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February 11, 2020

The Sub County Chief,
Amolo Sub County,
Amuria District
Kampala – Uganda.

Permission granted to conduct research as stated.

SENIOR ASSISTANT SECRETARY
AMOLO SUB-COUNTY
P.O. BOX 4, AMURIA DISTRICT
Date: 12th-03-2020

Dear Prof / Dr. / Sir / Madam

RE: INTRODUCTION LETTER FOR ECODU MICHAEL.

Mr. Ecodu Michael is a student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Building Engineering. He is conducting a research study on "Investigating spatial variation of Arsenite concentrations into River Awoja, physiographic determinants and treatment options". The research is being supervised by Dr. Charles Onyutha.

In his research, Ecodu Michael will require support on a number of occasions for the various specific objectives of the study (see next page). Both primary and secondary data shall be required for this research. The purpose of this letter is to request your office to assist the researcher with necessary information on Arsenite concentrations, physiographic determinants and allow him to collect water samples to be tested and analyzed for the research.

I shall be grateful for any assistance rendered to Mr. Ecodu Michael to allow him conduct his research study timely.

Yours sincerely,

THE HEAD OF DEPARTMENT
CIVIL AND BUILDING ENGINEERING
KYAMBOGO UNIVERSITY

Dr. Lawrence Muhwezi
Head of Department of Civil and Building Engineering

CC Dean, School of Graduate Studies, Kyambogo University
Dr. Charles Onyutha – Department of Civil and Building Engineering, Kyambogo University
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FACULTY OF SCIENCE
DEPARTMENT OF CHEMISTRY

7th May, 2024

Ecodu Micheal

Student of MSc. Water and Sanitation Engineering
Kyambogo University

Re: Laboratory report for analysis of arsenic in water samples

Header 1	Sample Name	Pb	As	Cd	Se	Ni	Cu	Zn	Mn	Cr	Fe	Mg	Al	Hg	As (mean)	Ba
Single	A1	< -0.008118	100.17549	< -0.001914	< -0.028615	0.000115	< -0.026467	< 0.059343	< -0.026467	< -0.120467	< -0.026467	> 26.439	< -0.120467	< -0.366867	—	> 0.013102
Single	A2	< -0.008118	94.7008	< -0.001914	< -0.028615	0.000115	< -0.026467	< 0.059343	< -0.026467	< -0.020467	< -0.026467	> 26.439	< -0.020467	< -0.366867	—	[illegible]
Single	A3	< 0.001000	86.9582	< 0.001000	< 0.008062	< 0.001000	[illegible]	0.327398	[illegible]	< 0.010000	[illegible]	9.257	< 0.100000	[illegible]	—	[illegible]
Single	A4	< 0.001000	77.16146	< 0.001000	< 0.008062	0.008505	[illegible]	[illegible]	[illegible]	< 0.100000	[illegible]	> 26.439	< 0.100000	[illegible]	—	[illegible]
Single	A5	< -0.003753	62.4771	< -0.002649	< -0.020787	< 0.003438	< -0.020388	0.91146	< -0.020388	< -0.020588	< -0.020588	7.81	< -0.020588	< -0.004225	—	[illegible]
Single	A5	< -0.003753	55.1586	< -0.002649	< -0.020787	< 0.003438	< -0.020388	0.91146	< -0.020388	< -0.020588	< -0.020588	7.81	< -0.020588	< -0.004225	—	> 0.002691
Single	B1	< -0.006118	96.5581300	< -0.001934	< -0.020615	0.008505	< -0.026467	[illegible]	< -0.026467	< -0.026467	[illegible]	> 26.439	< -0.026467	[illegible]	—	> 0.020712
Single	B2	[illegible]	92.4638300	[illegible]	[illegible]	[illegible]	< 0.000000	[illegible]	[illegible]	[illegible]	< 0.000000	7.81	[illegible]	[illegible]	—	[illegible]
Single	B3	[illegible]	85.2271500	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	—	[illegible]
Single	B4	[illegible]	78.0304300	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	> 31.830	[illegible]	[illegible]	—	[illegible]
Single	B5	[illegible]	71.9808300	[illegible]	[illegible]	[illegible]	< 0.000000	0.327398	[illegible]	< 0.000000	< 0.000000	9.257	[illegible]	[illegible]	—	[illegible]

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Single	B6	<0.001600	64.2085301	<0.001600	<0.058862	<0.086400	<0.008900	<0.000000	<0.008000	<0.008000	<0.008000	>35.850	<0.008000	<0.000000	—	>0.022974
Single	C1	<-0.001644	102.79708	<-0.000851	<-0.023626	0.043023	<-0.015762	3.886	<-0.015762	<-0.015762	<-0.015762	>13.727	<-0.015762	<-0.015103	—	>0.022974
Single	C2	<-0.001644	98.79438	<-0.000851	<-0.023626	0.043023	<-0.015762	3.886	<-0.015762	<-0.015762	<-0.015762	>13.727	<-0.015762	<-0.015103	—	>0.022974
Single	C3	<-0.000119	91.4757	<-0.001914	<-0.020615	0.008505	<-0.026467	<0.059343	<-0.026467	<-0.026467	<-0.026467	>26.439	<-0.026467	<-0.366867	—	>0.022974
Single	C4	<0.001600	84.86498	<0.001600	<0.008062	0.003323	<0.008000	5.886	<0.008000	<0.008000	<0.008000	>13.727	<0.008000	<0.000000	—	>0.022974
Single	C5	<-0.001991	78.22138	<-0.003318	<-0.020234	<-0.001283	<-0.023845	0.327389	<-0.023845	<-0.023845	<-0.023845	>9.257	<-0.023845	<0.003932	—	<-0.015698
Single	C6	<-0.001991	76.69988	<-0.003318	<-0.020234	<-0.001283	<-0.023845	0.327389	<-0.023845	<-0.023845	<-0.023845	>9.258	<-0.023845	<0.003932	—	<-0.019548
Single	D1	<-0.003753	107.79036	<-0.002649	<-0.026797	<0.003438	<-0.033188	0.91148	<-0.020988	<-0.020988	<-0.020548	>9.259	<-0.020988	<-0.034225	—	>0.012610
Single	D2	<-0.006118	107.69766	<-0.001914	<-0.020615	0.008585	<-0.026467	<0.059343	<-0.020467	<-0.020467	<-0.020467	>26.478	<-0.020457	<-0.366867	—	>0.029712
Single	D3	<0.001600	96.40808	<0.001600	<0.008062	<0.006400	<0.008000	0.91148	<0.008000	<0.008000	<0.008000	>5.81	<0.008000	<0.008000	...	>0.022974
Single	D4	<-0.003886	85.80226	<-0.002518	<-0.017636	<0.001318	<-0.028645	<0.077667	<-0.028645	<-0.028645	<-0.028645	>35.850	<-0.028645	<-0.312720	—	>0.022974
Single	D5	<-0.003886	83.21806	<-0.002518	<-0.017636	<0.001318	<-0.028645	<0.077667	<-0.028645	<-0.028645	<-0.028645	>35.850	<-0.028645	<-0.312720	...	>0.022974
Single	D6	<0.001600	75.49276	<0.001600	<0.008062	<0.206400	<0.008000	0.327389	<0.008000	<0.008000	<0.008000	9.257	<0.008000	<0.008000	—	>0.022974
Single	E1	<0.001600	110.9562	<0.001600	<0.008062	<0.206400	<0.008000	<0.008000	<0.008000	<0.008000	<0.008000	>35.850	<0.008000	<0.008000	—	>0.022974
Single	E2	<-0.001644	108.8623	<-0.000851	<-0.023020	0.043023	<-0.015762	3.886	<-0.015762	<-0.015762	<-0.015762	>13.727	<-0.015762	<-0.015103	—	>0.022974
Single	E3	<-0.001644	99.63482	<-0.000851	<-0.023020	0.043023	<-0.015762	3.886	<-0.015762	<-0.015762	<-0.015762	>13.727	<-0.015762	<-0.015103	—	>0.022974
Single	E4	<-0.006118	93.9281	<-0.001914	<-0.020615	0.008585	<-0.026467	<0.059343	<-0.026467	<-0.026467	<-0.026467	>26.439	<-0.026467	<-0.366867	—	>0.022974
Single	E5	<-0.006118	86.3845	<-0.001914	<-0.020615	0.008585	<-0.026467	<0.059343	<-0.026467	<-0.026467	<-0.026467	>26.439	<-0.026467	<-0.366867	—	>0.001502
Single	E6	<-0.006118	78.6582	<-0.001914	<-0.020615	0.008585	<-0.026467	<0.059343	<-0.026467	<-0.026467	<-0.026467	>26.439	<-0.026467	<-0.366867	—	>0.005988
Single	UT1	<-0.000981	250.8136	<-0.000818	<-0.020224	<-0.001283	<-0.023845	0.327389	<-0.023845	<-0.023845	<-0.023845	9.257	<-0.023845	<0.003932	—	<-0.025548

Analysed by: [signature]
Sign: ....
Date: 07/05/2024

Head of Chemistry Department
Sign: ....
Date: ....

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CHEMISTRY DEPARTMENT
P. O. BOX 1, KYAMBOGO

Header_1	DateTime	MethodName	ResultType	Sampl	Samp	Pb	As	Cd	Se	Ni	Cu	Zn	Mn	Cr	Fe	Mg	Al	Hg	Al (mon)	Ba
Single	07/05/24 11:10	Multielement 001	Concentration	5821	A1	< -0.006118	100.17548	< -0.001914	< -0.020615	0.008505	< -0.026467	< 0.099543	< -0.026467	< -0.026467	< -0.026467	> 26.439	< -0.026467	< -0.366867	—	> 0.011500
Single	07/05/24 11:12	Multielement 001	Concentration	5822	A2	< -0.006118	94.7008	< -0.001914	< -0.020615	0.008505	< -0.026467	< 0.059343	< -0.026467	< -0.026467	< -0.026467	> 26.439	< -0.026467	< -0.366867	—	> 0.015988
Single	07/05/24 11:13	Multielement 001	Concentration	5823	A3	< 0.001600	86.9582	< 0.001600	< 0.008062	< 0.006400	< 0.000000	0.327388	< 0.000000	< 0.000000	< 0.000000	9.257	< 0.000000	< 0.080000	—	> 0.008551
Single	07/05/24 11:14	Multielement 001	Concentration	5824	A4	< 0.001600	77.36106	< 0.001600	< 0.008062	0.008505	< 0.000000	< 0.000000	< 0.000000	< 0.000000	< 0.000000	> 26.439	< 0.000000	< 0.080000	—	> 0.009768
Single	07/05/24 11:15	Multielement 001	Concentration	5825	A5	< -0.003755	62.4775	< -0.002649	< -0.020787	< 0.003438	< -0.020588	0.91146	< -0.020588	< -0.020588	< -0.020588	7.81	< -0.020588	< -0.014225	—	> 0.013827
Single	07/05/24 11:16	Multielement 001	Concentration	5826	A6	< -0.003755	55.1586	< -0.002649	< -0.020787	< 0.003438	< -0.020588	0.91146	< -0.020588	< -0.020588	< -0.020588	7.81	< -0.020588	< -0.014225	—	> 0.012691
Single	07/05/24 11:17	Multielement 001	Concentration	5827	B1	< -0.006118	86.5585001	< -0.001914	< -0.020615	0.008505	< -0.026467	< 0.059543	< -0.026467	< -0.026467	< -0.026467	> 26.439	< -0.026467	< -0.366867	—	> 0.020712
Single	07/05/24 11:18	Multielement 001	Concentration	5828	B2	< 0.001600	92.6658001	< 0.001600	< 0.008062	< 0.006400	< 0.000000	0.91146	< 0.000000	< 0.000000	< 0.000000	7.81	< 0.000000	< 0.080000	—	> 0.022974
Single	07/05/24 11:19	Multielement 001	Concentration	5829	B3	< -0.003886	85.2871581	< -0.002508	< -0.017638	< 0.001318	< -0.028645	< 0.075667	< -0.028645	< -0.028645	< -0.028645	> 35.850	< -0.028645	< -0.312720	—	> 0.022974
Single	07/05/24 11:20	Multielement 001	Concentration	5830	B4	< -0.003886	78.8304001	< -0.002508	< -0.017638	< 0.001318	< -0.028645	< 0.075667	< -0.028645	< -0.028645	< -0.028645	> 35.850	< -0.028645	< -0.312720	—	> 0.022974
Single	07/05/24 11:21	Multielement 001	Concentration	5831	B5	< 0.001600	71.9868001	< 0.001600	< 0.008062	< 0.006400	< 0.000000	0.327388	< 0.000000	< 0.000000	< 0.000000	9.257	< 0.000000	< 0.080000	—	> 0.022974
Single	07/05/24 11:22	Multielement 001	Concentration	5832	B6	< 0.001600	64.2685001	< 0.001600	< 0.008062	< 0.006400	< 0.000000	< 0.000000	< 0.000000	< 0.000000	< 0.000000	> 35.850	< 0.000000	< 0.080000	—	> 0.022974
Single	07/05/24 11:23	Multielement 001	Concentration	5833	C1	< -0.001644	107.79708	< -0.000851	< -0.023020	0.043023	< -0.015762	3.888	< -0.015762	< -0.015762	< -0.015762	> 13.727	< -0.015762	< -0.015100	—	> 0.022974
Single	07/05/24 11:24	Multielement 001	Concentration	5834	C2	< -0.001644	98.70439	< -0.000851	< -0.023020	0.043023	< -0.015762	3.888	< -0.015762	< -0.015762	< -0.015762	> 13.727	< -0.015762	< -0.015100	—	> 0.022974
Single	07/05/24 11:25	Multielement 001	Concentration	5835	C3	< -0.006118	91.4757	< -0.001914	< -0.020615	0.008505	< -0.026467	< 0.059543	< -0.026467	< -0.026467	< -0.026467	> 26.439	< -0.026467	< -0.366867	—	> 0.022974
Single	07/05/24 11:26	Multielement 001	Co- centration	5836	C4	< 0.001600	84.88898	< 0.001600	< 0.008062	0.043013	< 0.000000	3.888	< 0.000000	< 0.000000	< 0.000000	> 13.727	< 0.000000	< 0.080000	—	> 0.022974
Single	07/05/24 11:28	Multielement 001	Concentration	5837	C5	< -0.003881	78.22538	< -0.003018	< -0.020224	< -0.001283	< -0.023845	0.327389	< -0.023845	< -0.023845	< -0.023845	> 9.257	< -0.023845	< 0.002932	—	< -0.015698
Single	07/05/24 11:29	Multielement 002	Concentration	5838	C6	< -0.003881	70.44809	< -0.003018	< -0.020224	< -0.001283	< -0.023845	0.327389	< -0.023845	< -0.023845	< -0.023845	> 9.258	< -0.023845	< 0.002932	—	< -0.029548
Single	07/05/24 11:30	Multielement 003	Concentration	5839	D1	< -0.003753	107.79038	< -0.002649	< -0.020787	< 0.003438	< -0.020588	0.91146	< -0.020588	< -0.020588	< -0.020588	> 9.259	< -0.020588	< -0.014225	—	> 0.012691
Single	07/05/24 11:31	Multielement 004	Concentration	5840	D2	< -0.006118	103.65788	< -0.001914	< -0.020615	0.008565	< -0.026467	< 0.059543	< -0.026467	< -0.026467	< -0.026467	> 26.439	< -0.026467	< -0.366867	—	> 0.020712
Single	07/05/24 11:32	Multielement 005	Concentration	5841	D3	< 0.001600	96.46800	< 0.001600	< 0.008062	< 0.006400	< 0.000000	0.91146	< 0.000000	< 0.000000	< 0.000000	> 7.81	< 0.000000	< 0.080000	—	> 0.022974
Single	07/05/24 11:33	Multielement 006	Concentration	5842	D4	< -0.003886	88.86726	< -0.002508	< -0.017638	< 0.001318	< -0.028645	< 0.075667	< -0.028645	< -0.028645	< -0.028645	> 35.850	< -0.028645	< -0.312720	—	> 0.022974
Single	07/05/24 11:34	Multielement 007	Concentration	5843	D5	< -0.003886	83.21866	< -0.002508	< -0.017638	< 0.001318	< -0.028645	< 0.075667	< -0.028645	< -0.028645	< -0.028645	> 35.850	< -0.028645	< -0.312720	—	> 0.022974
Single	07/05/24 11:35	Multielement 008	Concentration	5844	D6	< 0.001600	75.49256	< 0.001600	< 0.008062	< 0.006400	< 0.000000	0.327388	< 0.000000	< 0.000000	< 0.000000	9.257	< 0.000000	< 0.080000	—	> 0.022974
Single	07/05/24 11:36	Multielement 009	Concentration	5845	E1	< 0.001600	110.9562	< 0.001600	< 0.008062	< 0.006450	< 0.000000	< 0.000000	< 0.000000	< 0.000000	< 0.000000	> 35.850	< 0.000000	< 0.080000	—	> 0.022974
Single	07/05/24 11:37	Multielement 010	Concentration	5846	E2	< -0.001644	106.8635	< -0.000851	< -0.023020	0.043023	< -0.015762	3.888	< -0.015762	< -0.015762	< -0.015762	> 13.727	< -0.015762	< -0.015103	—	> 0.022974
Single	07/05/24 11:38	Multielement 011	Concentration	5847	E3	< -0.001644	99.63682	< -0.000851	< -0.023020	0.043023	< -0.015762	3.888	< -0.015762	< -0.015762	< -0.015762	> 13.727	< -0.015762	< -0.015103	—	> 0.022974
Single	07/05/24 11:39	Multielement 012	Concentration	5848	E4	< -0.006118	93.2281	< -0.001914	< -0.020615	0.008505	< -0.026467	< 0.059543	< -0.026467	< -0.026467	< -0.026467	> 26.439	< -0.026467	< -0.366867	—	> 0.022974
Single	07/05/24 11:41	Multielement 013	Concentration	5849	E5	< -0.006118	88.3845	< -0.001914	< -0.020615	0.008505	< -0.026467	< 0.059543	< -0.026467	< -0.026467	< -0.026467	> 26.439	< -0.026467	< -0.366867	—	> 0.011502
Single	07/05/24 11:42	Multielement 014	Concentration	5850	E6	< -0.006118	78.6583	< -0.001914	< -0.020615	0.008505	< -0.026467	< 0.059543	< -0.026467	< -0.026467	< -0.026467	> 26.439	< -0.026467	< -0.366867	—	> 0.015988
Single	07/05/24 11:43	Multielement 015	Concentration	5851	UT1	< -0.009901	250.8198	< -0.003018	< -0.020224	< -0.001283	< -0.023845	0.327389	< -0.023845	< -0.023845	< -0.023845	9.257	< -0.023845	< 0.002932	—	[illegible]

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February 11, 2020

Head Department of Biochemistry,
Makerere University,
P.O Box 7062,
Kampala, Uganda.

MAKERERE UNIVERSITY
APR 2024
O. BOX 7062 KAMPALA

Dear Prof / Dr. / Sir / Madam

RE: INTRODUCTION LETTER FOR ECODU MICHAEL AND REQUEST FOR SUBSIDIZING RATES FOR LABORATORY TESTS TO BE CONDUCTED.

Mr. Ecodu Michael is a student of Kyambogo University undertaking Master of Science in Water and Sanitation Engineering from the Department of Civil and Building Engineering. He is conducting a research study on "Investigating spatial variation of Arsenite concentrations into River Awoja, physiographic determinants and treatment options". The research is being supervised by Dr. Charles Onyutha,

In his research, Ecodu Michael will require support on a number of occasions for the various specific objectives of the study (see next page). Both primary and secondary data shall be required for this research. The researcher wishes to test his samples in the laboratory of your department. Because there will be several samples to be tested. I hereby write to your office requesting for subsidizing of the laboratory tests. The necessary support to enable the researcher timely conduct the laboratory tests and complete his research will be dully acknowledged in the dissemination of the results.

I shall be grateful for any assistance rendered to Mr. Ecodu Michael to allow him conduct his research study timely.

Yours sincerely,

THE HEAD OF DEPARTMENT
CIVIL AND BUILDING ENGINEERING
KYAMBOGO UNIVERSITY

Dr. Lawrence Muhwezi
Head of Department of Civil and Building Engineering

CC Dean, School of Graduate Studies, Kyambogo University
Dr. Charles Onyutha – Department of Civil and Building Engineering, Kyambogo University
Eng. Dr. Anne Nakagiri – Department of Civil and Building Engineering Kyambogo University

Echodu Michael

Sample	Cd	ppm Ni	As-(5.16)	Pb	Hg	Fe (ppm)
S1 Fe×100	0	0 → All	20.28	0 → All	0 → All	0.075×100
S1(i) Fe100	0		23.37		0.013	~~0.13×100~~
S1(ii) Fe100	0		25.70			0.156×100
S1(iii) Fe100	0		20.43	ND		0.149×100
S2	0		26.00			2.464
S2(i)	0	ND	21.66		ND	4.136
*S2(ii) Fe×10	0.002		24.62			0.789
S2(iii)	0		24.72			2.885
S3	0		27.56			2.185
S3(i)	0		25.45			1.121
S3(ii)	0		24.57			1.547
S3(iii)	0		24.04			2.256
S4	0		26.78			0.952
S4(i)	0		24.04			0.922
S4(ii)	0		24.68			1.057
S4(iii)	0		22.62			1.196

$ppm = \frac{1}{10^6}(1:10^6) = 1mg/L$

Completed lab analysis
Tukesa Ambrose PhD
05/04/2024