ASSESSMENT OF THE EFFECTS OF LAND USE/COVER CHANGES ON SURFACE WATER QUALITY AND TREATMENT COSTS IN RIVER MALABA CATCHMENT, EASTERN UGANDA

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DECLARATION

I, **Mbabazi Sarah**, certify that the contents of this research thesis are original, except where noted, and have never been submitted to any university or institution for an award.

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APPROVAL

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LIST OF ACRONYMS

Acronym	Description
ANOVA	Analysis of Variance
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
EC	Electrical Conductivity
GIS	Geographical Information Systems
GPS	Global Positioning System
HTH	High Test Hypochlorite
ISODATA	Iterative Self-Organizing Data Analysis Technique Algorithm
LULC	Land Use and Land Cover Change
NEMA	National Environment Management Authority
NWSC	National Water and Sewerage Cooperation
Ph	Potential of Hydrogen
SD	Standard Deviation
SOC	Soil Organic Carbon
SWAT	Soil and Water Assessment Tool
TSS	Total Suspended Solids
USGS	United States Geological Survey

ABSTRACT

Changing land use and cover (LULC) is a major contributor to water quality degradation in various regions of the world. Unfortunately, there are not enough data on how LULC change affects water quality and prices in different catchments. Therefore, the research has covered gaps left by previous research by looking at three different aspects of the River Malaba catchment: first, the extent to which land use and cover have changed, second, the impact that land use has had on water quality, and finally, the impact that water quality has had on treatment costs. Sentinal-2 images of 2015 and 2021 were downloaded and analyzed using GIS. Water samples were picked at different land use/ cover types along the river and analyzed for physical-chemical as well as bacteriological parameters, statistical tools such as ANOVA at 95% confidence interval were done to understand land use/cover influence on water quality. Costs of water treatment influenced by water quality were analyzed retrospectively using data from the National Water and Sewerage Corporation and ANOVA at a 95% confidence interval. Results indicated LULC patterns shifted radically between 2015 and 2021, with most conversions to farming. The farmlands (15.3%) and built-up (1.0%) increased over time as woodlands (-2.8), grasslands (-13.2), and wetlands (-0.2) shrunk during the study period. Land use/cover significantly affected COD (P=0.023), Electrical Conductivity (P=0.004), and Nitrate levels (P=0.004), COD was observed highest in farmland and least in woodlands, and EC and Nitrates were highest in wetlands and also least in woodlands. Seasons also showed significance across all water quality parameters except for Feacal Coliforms (P=0.233) Total Phosphates (P=0.943) and Total Iron (P=0.147). Water quality parameters significantly affected the costs of Aluminium Sulphate, high-test hypochlorite, and polymer. Costs of water treatment were high downstream than the upstream, also in the rainy season than in the dry season.

These findings suggest that River Malaba basin has been subjected to LULC changes as a result of human activities, which has repercussions on the quality of water, hence increasing the cost of water treatment. This has repercussions for the livelihoods and well-being of humans, for instance by increasing the likelihood of disease and limiting the use of water to provide material items such as food. Therefore, interventions should be implemented to conserve these catchment regions. In addition, because this study was conducted over a short period of time and with limited monitoring of water quality and trends in water treatment costs, future studies should be clear in examining LULC developments over time and how they relate to water quality and treatment costs.

CHAPTER ONE: INTRODUCTION

1.1 Background

Changes in land use and cover (LULC) have affected the riparian ecosystem services as a result of natural and human activities (Chu et al., 2013; Wagner et al., 2013). Human activities like; Deforestation, agriculture, and urbanization are the primary drivers of land use/cover change that influences water quality in water bodies, as emphasized by numerous researchers (Miko et al., 2007; Bekele et al., 2019; Berihun et al., 2019). An individual or combination effect of these activities have an impact on the quality of water resources(Nepomuscene et al., 2018). Surface water quality is critical for a wide range of purposes, such as drinking and bathing as well as farming and disease prevention (Nabeela et al., 2014; Yadav & Kumar, 2021). Around 28% of the 924,7 million people in Sub-Saharan Africa (SSA) have been estimated to reside in degraded areas since the 1980s (Le et al., 2015). More than 40% of the land area covered by grasslands, is most affected by land degradation (Le et al., 2015). According to Prăvălie, (2021) and Hao Li et al., (2021) roughly 26% of forest land and 12% of agriculture have been degraded in China. The quality of surface water resources like rivers and streams in the region could be negatively impacted by the depletion of these land resources. In East African countries like Tanzania, for example, the quality of water has decreased due to changes in land use/cover (Chen et al., 2022). Because of the rising demand for freshwater, it is necessary to assess the quality of the surface water and provide recommendations for ensuring a safe and healthy environment for humans and ecosystems.

Land use is the anthropological land usage of earthly space for trade and industry, housing, leisure, conservation, and management purposes (Camara et al., 2019). The Land use/cover modifications are key drivers in the worsening of the quality of water in watercourses (Nepomuscene et al., 2018), different land uses to speed up or block transmission of runoff into surface water in different ways, increasing toxic waste from land to surface water bodies (Luo et al., 2020). According to Camara et al (2019), the quality of water is an analysis carried out on the water for physical, chemical, and biological parameters.

As a result, changes in land use/cover have significant implications for both the quality and quantity of water within a given watershed (Bonansea et al., 2016; Nkosi et al., 2021). Information on the relationships between land use/cover and river water quality aids in the identification of threats to water quality and the reduction of associated treatment costs. Understanding such relationships is a critical step toward achieving effective and long-term surface water quality management (Seeboonruang, 2012).

Surface water bodies play important roles in the water supply for home and industrial use. On the other hand, altering land use patterns continue to have an effect on river catchments, which has a negative impact on river health (Ayivor & Gordon, 2012). Water contamination is still a major concern worldwide, impacting human well-being and livelihoods and (Schwarzenbach et al., 2010; Chaudhry, 2017; Landrigan et al., 2020). Worldwide, rivers and other surface water resources are increasingly under threat from pollution due to natural and anthropogenic activities, which may reduce their value for human consumption (Wang et al., 2012; Mul et al., 2015). These activities may reduce the value of surface water resources for human consumption (Danquah et al., 2011; Covarrubias Lopez et al., 2021). According to (Mugagga & Nabaasa, 2016)), surface water bodies in Sub-Sahara Africa suffer enormous dangers from anthropogenic activities such as agricultural expansions (Fayiga et al., 2018; Bruce & Limin, 2021). This is because the majority of the rural poor in these vulnerable areas rely primarily on agriculture for a living, and land as a resource is critical to guaranteeing agricultural production (Nkonya et al., 2015).

Several research studies (Nepomuscene et al., 2018; Gong et al., 2019; Kumar et al., 2019; Soltani-Gerdefaramarzi et al., 2021) examining the correlations between LULC and surface water quality have shown that there is a significant association between land use and the quality water indices at the watershed level. Furthermore, Huang et al (2013); Chotpantarat & Boonkaewwan, (2018), have demonstrated that rising population, development, and forests encroachment and grassland for agriculture that degrade river water quality through land use/cover transition.

Eastern Uganda relies heavily on the River Malaba basin, which is the primary source of water for agriculture and domestic use, is under growing threat due to land use/cover changes (Bernard et al., 2019; Mubialiwo et al., 2021). Agricultural activities, as well as rubbish dumping, have been linked to the river's poor water quality (Bernard et al., 2019; Dalahmeh et al., 2020). Unsustainable land agriculture methods near these water resources cause soil erosion and, as a result, deterioration of river water quality owing to sedimentation (Mugagga et al., 2012; Mubialiwo et al., 2022). Nutrient discharge from improper pesticide usage, as well as bush burning, can cause eutrophication and a high nutrient load in river bodies, impacting water quality (Bernard et al., 2019; Mubialiwo et al., 2021).

Despite the unavailability of data, it is clear that water pollution in the Malaba basin has lately grown (Bernard et al., n.d.). Understanding the magnitude of land use/cover change in such regions, as well as its effects, aids in the design and execution of interventions. This study evaluated the extent of changes in land cover and use, as well as the effects of those changes on water quality and the expenses involved with water treatment.

1.2 Problem Statement

As a result of changes in land use and cover in the River Malaba Catchment over time, river water quality has become significantly contaminated (Barasa et al., 2018; Majaliwa et al., 2018; Huang et al., 2013). The cost of treating polluted water may rise as a result of an increase in pollution. Some early evidence suggests that water treatment expenses at the Lirima and Malaba treatment plants (placed upstream and downstream from the Malaba River) have risen by 52 percent and 78 percent, respectively, over the five-year period 2015-2020(NWSC). This can have severe repercussions on the final consumer due to the increasing unit cost of water, as well as on other activities done for a living that require water. For example, deteriorating water quality might make irrigation ineffective, undermining food security and production (Zaman et al., 2018).

According to Profi, (2016) and Barasa et al., (2018), little is known about the effect of the land use/cover on the water quality in River Malaba catchment. The few current studies (Profi, 2016); (Barasa et al., 2018) have not yet covered the recent land use/cover changes within the catchment, and yet this knowledge is crucial for mobilizing resources to ensure the sustainability of the River Malaba catchment. Specifically, it provides a chance to argue the need of designing and implementing policies to ensure enhanced water quality and restricted deterioration surrounding the catchment. For the purpose of bridging this information gap, this study examines changes in land use/cover, water quality, and treatment costs in River Malaba's catchment area, as well as the effects of water quality status on treatment costs.

1.3 General Objective

The purpose of the study is to know the effect of land use/cover change on water quality and treatment costs in the Eastern part of Uganda

1.3.1 Specific Objectives

i. To examine the spatial extent of land use/cover changes in the River Malaba catchment between 2015 and 2021

ii. To assess the effect of land use/cover change on surface water quality seasonality in the River Malaba catchment

iii. To determine the effect of water quality seasonality on treatment costs in the River Malaba catchment

1.3.2 Research Question

Qn1: What is the extent of land use/cover changes in the River Malaba Catchment between 2015 and 2021?

Qn2: What is the effect of land use/cover change on surface water quality seasonality in the River Malaba Catchment?

Qn3: What is the effect of water quality seasonality on treatment costs in the River Malaba catchment?

1.3.3 Hypothesis

H_O1: There are no Land use/cover changes in the River Malaba Catchment between 2015 and 2021

H_O2: Land use/cover change does not significantly affect surface water quality seasonality in the River Malaba catchment

H_O3: Water Quality seasonality does not influence water treatment costs in the River Malaba catchment

1.4 Justification of the Study

The study is pictured to guide science scholars regarding land use/cover change monitoring and modeling, understanding of how water quality is influenced by the different land use/cover types, analysis of different water parameters, and the relation of treatment costs to water quality. It will also inform policy-makers on the need for increased efforts to enhance the sustainability of River Malaba Catchment to limit its change or shrinkage in size as well as the declining water quality relating to increasing treatment cost for effective environmental management and ecological surface water treatment. The study will help water analysts to understand seasons where there is maximum and minimum declinable water quality due to run-off from the different land use/cover and which land-use type leads to an increase in which water parameter hence determining when treatment costs are expected to change. This study will contribute to the realization of Sustainable Development Goals (SDG) 3 and 6 about Good health and well-being, clean water, and sanitation respectively through establishing land use/cover changes and their influence on water quality and costs of obtaining clean water.

1.5 Conceptual Framework

The study hypothesizes that the human population and numerous human activities (Chu et al., 2013) have led to comparable land use/cover changes in the River Malaba watershed as are occurring in other parts of Uganda at unprecedented rates (Mugagga et al., 2012; Zziwa et al., 2012; Egeru et al., 2014; Gabiri et al., 2019). Agribusiness, deforestation, and industrialization have been highlighted as the primary land use/cover change drivers. that is change of woodlands to farmlands, grasslands to farmlands, woodlands to built-up, wetlands to farmlands among others which affects the quality of water in water bodies (Miko et al., 2007; Bekele et al., 2019; Berihun et al., 2019). These activities have an individual or combined effect on the quality of water resources. However, surface water quality is essential for a variety of functions, including domestic, industrial, agricultural, and disease control usage (Nabeela et al., 2014; Yadav & Kumar, 2021). Changes in land use/cover affect a variety of water quality indices, including pH, Turbidity, Color, Total Iron, TSS (Total Suspended Solids), EC (Electrical Conductivity), Total Phosphates, Nitrates, BOD (Biochemical Oxygen Demand), COD (Chemical Oxygen Demand), and Fecal coliforms, among others. Consequently, when water quality varies, so do water treatment costs, as shown by the fluctuating amounts of chemicals required in water treatment (Aluminium Sulphate, Aluminium Chlorohydrate, and high-test hypochlorite).

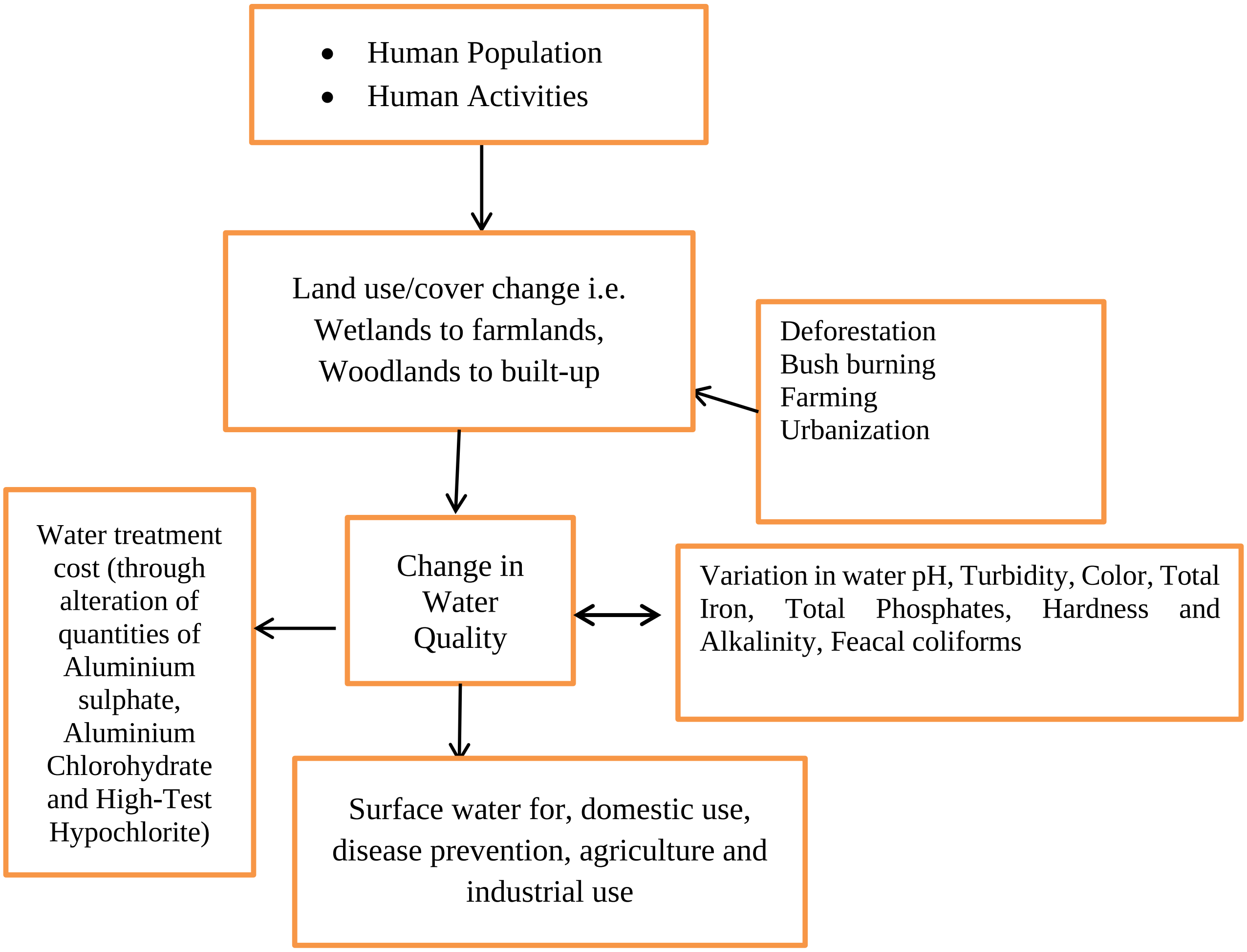

Figure 1. 1: Conceptual framework of the study

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The literature review from many authors is presented in this chapter. It is organized into four primary sections: literature on relevant research, land use/cover changes and their assessment, land use/cover effects on water quality, and land use/cover effects on water treatment cost.

2.2 Land use/cover changes and their assessment

Land use/cover changes are complex processes arising from the spatial and temporal interaction of biophysical and human dimensions (Comber, 2008). Despite this complexity, there is substantial knowledge about how human and environmental factors operate and interact to influence land use/cover patterns and hydrological processes.

Land use/cover (LULC) change has remained a major environmental concern at global and local scales, primarily due to its substantial impact on ecological system sustainability (Vitousek et al., 2008; Yirsaw et al., 2017). An intricate interplay between various underpinning socioeconomic factors, such as technological capability, urbanization, and the growing demand for food production and fiber and shelter for the exponentially growing human population is responsible for most of the changes in LULC (Verburg et al., 2004; Vitousek et al., 2008). LULC conversion has been speeded up in various landscapes due to the aforementioned factors, putting the ecological capacity of the ecosystems concerned to provide their eco-system services at risk (DeFries et al., 2004). According to, Temesgen et al., (2013), conversion of LULC into construction and agricultural land has had catastrophic impacts on soil fertility, water availability, and climate regulation.

Furthermore, habitat destruction by humans is putting the lives of approximately one million aquatic and terrestrial species in danger, and this number is expected to rise in the near future. Therefore, evaluating past LULC changes and predicting plausible future dynamics are essential for sustainable land use planning, management, and monitoring (You et al., 2017).

According to research, human and natural factors play a significant role in LULC changes (Defries et al., 2010; Mohamed et al., 2020). For instance, it has been reported that between the years 1990 and 2000, a portion of the forest that once covered the Congo Basin was cut down to make way for settlements, agricultural land, and hunting grounds (Hansen et al., 2008). Despite the fact that this made up a negligible portion of less than one percent of the total area, the effects it had on the forest ecosystem as a whole were significant. In a similar vein, the effective area of Mozambique's Quirimbas National Park has shrunk over the course of the 39 years between 1979 and 2017 (Mucova et al., 2018). This LULC in Mozambique was primarily linked to the intensive agricultural production as well as the expansion of human settlements. (Mucova et al., 2018).

In Uganda, similar events have been observed in different parts affecting ecosystem goods and services including water (Nakakaawa et al., 2011; Egeru et al., 2014; Kiggundu et al., 2018). In the Mpologoma catchment of Eastern Uganda, it has been observed that LULC change occurred since 1986 dominated by subsistence farming (Bunyangha et al., 2021a). Despite the existence of this data across different scales, information on the LULC changes at local scales is limited. This undermines efforts to design strategic interventions to halt such land use/cover changes and sustain ecosystem values and services. This is important as socioeconomic activities are highly variable across space and time and can have differentiated effects on the LULC (Santos, 2018).

Land use is what humans use the land for while land cover denotes the physical and biological cover on the surface of the land (Rimal, 2011, Demissie et al., 2017). An up-to-date nation must have sufficient information on many multivariate and complex interrelated aspects of its activities to make decisions. Land use is one of these aspects, and having knowledge about how land cover and use is changing has become increasingly important as the nation plans to overcome the problems of haphazard, uncontrolled development, deteriorating environmental quality, loss of forests and prime agricultural lands, destruction of important wetland areas, and loss of aquatic life and wildlife habitat (Rehna, 2016; Doelman et al., 2018). Data on land use are necessary for the analysis of environmental problems such as climate change, which must be comprehended in order for living conditions and standards to either be improved upon or kept at the same current levels. (Searchinger et al., 2018).

During the classification process, it is essential to have a comprehensive understanding of the procedures that are utilized in the process of allocating land cover classes to an image. Both pixel-based classifications and Object-Based Image Analyses have been utilized extensively in the process of land cover classification (Toure et al., 2018; Chen et al., 2018). Earlier land cover classifications relied on pixel-based classification; for instance, the 1900 map of the United Kingdom was created using this technique (Aplin et al., 1999).

Nevertheless, despite the demonstrated utility of pixel-based classification, it has limitations in that it assigns a class to a pixel based on its location in the spectral feature space without considering its spatial relationship to its neighbors. There is a possibility that the spatial level of a pixel does not correspond to the extent of the land cover feature that is of interest. One example of this is the problem of mixed pixels, which occurs when a pixel represents more than one type of land cover. (Wu et al., 2017), often leads to misclassification and this results in inaccurate thematic maps. Another problem may perhaps be that the object of interest is larger than the pixel size (Carleer et al., 2005) and this too can lead to misclassification. To avoid this, pixels are grouped into image objects. One of the objectives of grouping pixels into image objects in Object-Based Image Analysis is to eliminate the so-called salt-and-pepper effect (Blaschke, 2010). Numerous scholars have asserted that Object-Based Image Analysis techniques are ideal for resolving this issue and are superior in categorizing land cover types (Duro et al., 2012). Therefore, it is recommended to merge classes when utilizing Object-Based Image Analysis to improve classification accuracy (Mfitumukiza et al., 2014).

Enderle & Weihjr (2005), underlined that a comparison of the accuracy assessment findings between the integrated classification and the supervised classification provides some justifications for employing the integrated classification, which has an accuracy rate above 75%. First, even though it was small, there was an increase in the overall accuracy of the integrated classification (using both supervised and unsupervised classification) making use of the benefits found in both supervised and unsupervised classification methods (Nepomuscene et al., 2018).

Land use/cover change analysis and other studies relating to land use/cover change have been carried out in the River Malaba by various scholars (Bernard et al., n.d,Mubialiwo et al., 2022) but this left a gap in the recent land use/cover changes and their effect on surface water quality which in turn influence the water treatment costs hence the study

2.3 Land use/cover changes on the water quality

Water contamination is one of the world's most pressing problems, affecting both wealthy and developing nations (Chotpantarat & Boonkaewwan, 2018). Consequently, surface water resources worldwide are increasingly threatened by pollution, particularly rivers (Mul et al., 2015). However, surface water quality is essential for a variety of uses, including home, industrial, and agricultural usage (Nagaraju et al., 2014) and disease prevention (Daud et al., 2017). The quality of water resources is affected by natural and anthropogenic activities (Nepomuscene et al., 2018), which may make them less useful for human consumption. Environmental pollution and pollutants resulting from human activities such as agriculture, deforestation, and urbanization have been identified as the primary drivers of land use/cover, which impacts water quality (Khatri & Tyagi, 2015). These activities have an individual or combined effect on the quality of water resources. Therefore, land use in a region has a significant effect on the water quality and quantity of rivers (Nian et al., 2014).

In the Sub-Saharan regions of Africa, it is projected that 28 percent of the 924,7 million people reside in degraded areas since the 1980s (United Nations, 2014). Grasslands, which comprise 40 percent of the land surface, saw the most severe land degradation, with 26 percent of forestland and 12 percent of farmland also degrading (Von Braun et al., 2012). The degradation of these land resources would have a negative impact on the quality of the region's rivers and streams. In East Africa a study carried out in River Rwizi, Mbarara municipality, results revealed that water pollution in river Rwizi resulted primarily from Built up areas(Mugonola et al., 2015). Therefore, understanding the relationship between land use and river water quality aids in recognizing water quality issues. Identifying this link is important for successful and sustainable surface water quality management, particularly for lowering pollution loads in the water body (Ding et al., 2016).

2.4 Land use/cover changes on water treatment cost

Over 75 percent of the world's population draws their drinking water from reservoirs, tanks, or rivers (Romulo et al., 2018; Tadadjeu et al., 2020). Land cover and land use in river catchment areas, along with geology and point-source pollution, determine water quality and quantity. In settings where people gather their own water, water quality has a direct impact on human health, as does the cost of treating water to the required standard set by water supply agencies (Postel & Thompson, 2005). Land cover/use and freshwater systems interact in a variety of ways, according to hydrological and ecological research (Vose et al., 2011). It is generally accepted that forest areas are better for water quality than other land uses such as farming, industry and urbanization (Dudley & Stolton, 2003). Natural woods that have been well-managed in water catchment areas decrease silt and pollution (Carlson et al., 2014). With their enormous root network, forests create permeable and filtering soils that improve water quality (Abildtrup et al., 2013). Furthermore, forest land covers minimize the concentration of nitrates and other contaminants, which normally make water treatment expensive, compared to other land uses such as agricultural land (Jussy et al., 2002).

The loss of natural forests from watershed areas in developing countries poses dangers to human health and well-being due to declining drinking water quality or increased water service costs, which disproportionately affect poorer populations (Postel & Thompson, 2005). As a result of the conversion of forests to farmland and urbanization, cities in developing nations face a complex dilemma of diminished water quality (Postel & Thompson, 2005). Short-term and long-term economic and health consequences of contaminated water supplies, including infant mortality, loss of work time and productivity, and strain on health facilities that are already overburdened in urban communities (Dudley & Stolton, 2003).

In response to water quality issues caused by land-use changes, developed nations have increasingly resorted to complex treatment procedures to remove algae, pathogens, and other contaminants from raw water sources (Postel & Thompson, 2005). Furthermore, certain nations, water utility companies annually spend significantly more on water treatment chemicals than it would cost to preserve lakes and rivers from pollution in the first place, utilizing strategies such as forest land protection (Postel & Thompson, 2005).

Investing in watershed conservation may be a less expensive option. This correlates with rising worries regarding high rates of deforestation and forest degradation, as well as the dangers to forest ecosystem services in developing nations (Vincent et al., 2016). For water utility companies to invest in watershed management initiatives, it will be necessary to establish conclusively the effect of land cover on the cost of drinking water treatment.

Despite the fact that a large number of hydrological studies have been conducted to investigate the connection between land use and cover and water quality, very few of these studies (Masese et al., 2017, Hongmei Li et al., 2016) have concentrated on determining the role that forests play in the process of water purification for human consumption. Within the latter category, a body of early empirical studies confirmed that cleaner source water is associated with the operating cost of water treatment plants (Forster et al., 1987; Holmes, 1988), and allows utilities to avoid large capital costs (Barten & Ernst, 2004; Spiller et al., 2013). According to (Sthiannopkao et al., 2007) & other researchers, cleaner source water was connected with lower operational costs of water treatment plants. In comparison to other land uses' runoff, forested land has a lower concentration of suspended particles (Bruijnzeel, 2004; Carlson et al., 2014), which suggests an unobserved but substantial economic benefit to society (Brauman et al., 2007).

Understanding the impact of land use/cover changes on water treatment costs is crucial for designing and implementing intervention programs. It allows for the justification of the necessity to protect natural ecosystems and the selection of land use/cover types that maximize benefits. Unfortunately, developing nations such as Uganda have yet to investigate these processes. The current study contributes to bridging this knowledge gap by examining the water quality status across various land-use types and the costs of water treatment upstream and downstream of the river basin specifically in the River Malaba Catchment.

2.5 Effect of Seasonality on Surface Water Quality

Obtaining a better understanding of the current season status and climate-induced risks concerning surface water quality is vital, when seasons change (rainy and dry); water quality is affected due to runoff from surrounding land use/cover types. More concentrations of suspended solids is runoff from forests during the rainy seasons, compared to their concentration in runoff during dry seasons (Bruijnzeel, 2004; Carlson et al., 2014). Another study in East Asia showed that concentrations of dissolved ions tended to be higher during dry periods, concentrations of suspended sediments and dissolved organic matter were significantly higher during wet periods at most sampling locations (Park et al., 2011).

CHAPTER THREE: METHODOLOGY

3.1 Introduction

This chapter covers the data gathering and analysis methodologies that were employed. It is important to note that Treatment Costs or Costs of Water treatment refer to the costs of Chemicals used in the water treatment process keeping other factors like electricity, maintenances of machines, human resources, and many others constant. -The scientific name for the polymer is Aluminium Chlorohydrate.

3.2 Description of the study area

3.2.1 Location

The watershed region of the River Malaba is shared by Kenya and Uganda and is transboundary in nature. The river originates on the slopes of Mount Elgon and drains into central and mid-northern Lake Kyoga in Uganda. Seventy percent of the downstream and midstream sections are located in eastern Uganda between 0° 19′ N and 1° 07′ N and 33° 37′ E and 34° 37′ E (Figure 3.1), while the remaining portion (the upstream section) is located in western Kenya (666168.4N, 79848E), zone 36N. Kenya and Uganda share the watershed drainage basin (approximately 69 percent or 2395 km^2) (around 31 percent or 1100 km^2). The sub-catchment of the River Malaba comprises of the River Malaba and its two tributaries, Lwakhakha and Makalisi, which are later joined by the Lumbaka/Kibimba tributary (Bernard et al., 2018).

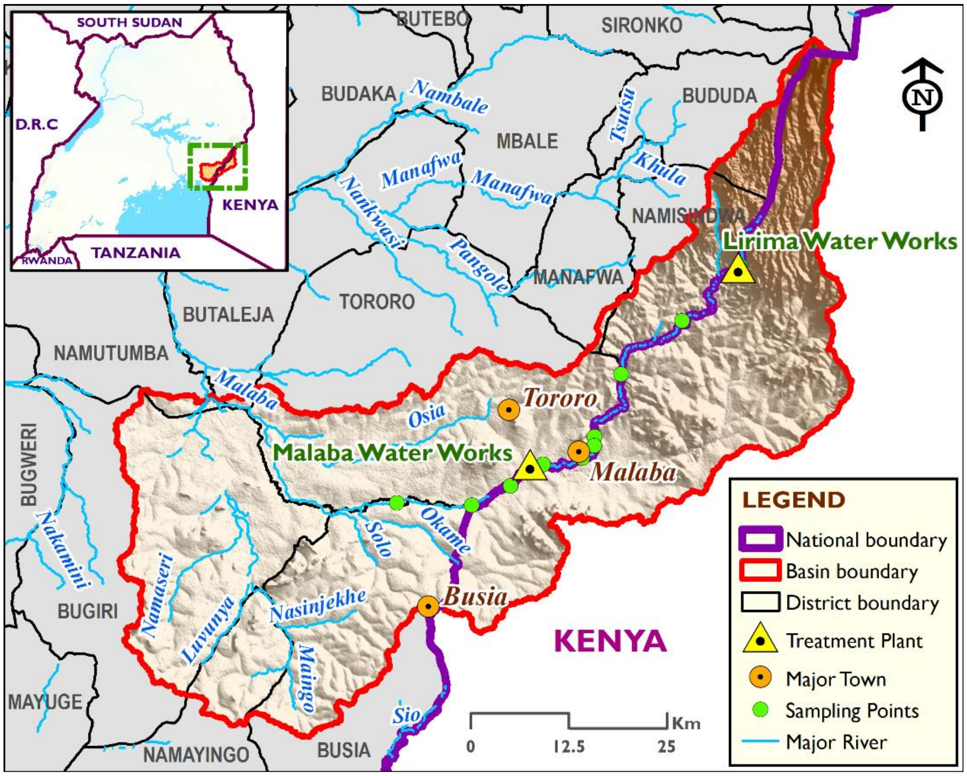

Figure 3.1: River Malaba Catchment and its major tributaries

3.2.2 Climate

The catchment experiences short hot summers, the winters are long, comfortable and wet, mostly cloudy. The average annual temperature in the catchment is approximately 27.9 degrees Celsius, and the highest annual precipitation is 280 millimeters. January and March have the highest possible evapotranspiration rates (148.8 mm/month and 148 mm/month, respectively). The lowest rainfall occurs in May, June, July, and August with 114 mm/month (Barasa et al., 2016).

3.2.3 Vegetation

Significant changes have occurred in the vegetation of the River Malaba basin due mostly to the rise in the amount of land used for agriculture, an increase in the number of people working in gold mines, and the establishment of unauthorized settlements (Barasa et al., 2016). Regarding land cover, the catchment is endowed with a variety of natural and plantation flora, ranging from high altitudinal coniferous vegetation to tropical high forests and wetlands to savannahs, while dense forests are found in the highlands of Mount Elgon, the remaining areas consist of of agricultural and grassland, unplanted land, and remote woodlots(Mubialiwo et al., 2022).

3.2.4 Geology and Soils

The Precambrian and Tertiary Pre-Elgon volcanic type of rocks lie beneath the entire catchment. which comprises of a variety of granites, gneisses, quartzite and small areas of strong folded metamorphic rocks(Barasa, 2014).

Sand loams and clays are the two most common forms of soil. The clays are found in the valleys, whereas the sandy loams are found on the mountains. The soil horizons in each of these kinds vary slightly. Two important soil catena groupings are Petric plinthosols and Gleysols, which cover the majority of soil types. Lixic ferrasols, Acric ferrasols, and Nitisols make up the rest of the soil types. Due to their early stages in weathering, the soil catena groupings can be easily identified (NEMA, 2008).

3.2.5 Socio-demographic characteristics in Uganda

About 4 million people live in the catchment area (UBOS, 2017). 60-96% of the basin's population is employed in agriculture, making it the region's most important economic activity. A majority of the farming is done by hand and on tiny plots of land. Activities such as fishing, poultry keeping, mining sand, brick making, charcoal burning, petty trade, and bicycle taxis (boda-boda) among others (Azza et al., 2017) are also carried out in the catchment as sources of income.

3.3 Data collection and analysis

3.3.1 The extent of land use/cover changes in River Malaba Catchment

3.3.1.1 Data collection procedure

The USGS earth explorer website (https://earthexplorer.usgs.gov/) provided high-resolution Sentinel-2 imagery for the research region. Sentinel data is available beginning in 2015, therefore that year will serve as a starting point for research. Using the Arc SWAT tool, the River Malaba Catchment was defined in ArcGIS.

3.3.1.2 Pre-Processing

Before the detection of change, Satellite image pre-processing was immensely done to establish a more direct affiliation between the acquired data and biophysical phenomena. Image preprocessing should be done before doing other processing such as enhancement, manipulation, interpretation, and classification of satellite images, therefore Data was pre-processed in ArcMap by geo-referencing, mosaicking, and sub setting of the image based on Area of Interest (AOI).

3.3.1.3 Processing

The images were classified using two image classification techniques, which included unsupervised and supervised to improve the overall accuracy of the classified images where the software analyzed the different land uses of interest. Supervised classification for all other image pixels was based on the idea that selected sample pixels in an image were representative of specific classes and direct image from training site reference for processing and unsupervised classification, based on an image clustering algorithm where user-selected clusters of pixels using natural groupings of the spectral properties. During the image classification, twenty-five clusters were used and came up with the various Land use/Land cover changes. (Godwin et al; 2011). As shown in Table 3.1, the identified imagery was divided into six (6) types of land use/covers: built-ups, grasslands, open water, farmlands, wetlands, and woodlands.

Table 3.1: River Malaba Catchment land use and cover types

Land use/cover Types	Description
Built-up areas	Regions that are characterized by the presence of settlements and highways
Open water	Locations that are dominated by water
Farmlands	Agricultural regions that produce crops for both personal consumption and sale.
Grasslands	Regions that are predominately made up of grasses, such as rangelands, grazing lands, developed pastures, and natural vegetation found in savannahs
Wetlands	Marshes that are flooded seasonally or consistently throughout the year.
Woodlands	Wooded areas that have a predominance of trees and bushes and where the trees are taller than 4 meters.

3.3.1.4 Post-processing

The processing and classification of these images were done in ArcGIS 10.8. The unprocessed image bands 4, 3, and 2 obtained from the Sentinel-2 satellite were imported and combined to form a single multispectral image using a composite band tool in ArcGIS. The area of interest was masked out from the composite image and was used to classify land use/cover changes.

3.3.1.5 Accuracy Assessment

In order to evaluate the accuracy of the identified land use/cover types, using a handheld portable Garmin Global Positioning System (GPS) device, 350 ground-truth data points were collected throughout the study region. Uganda's National Forest Authority Land use/cover map for 2015 was used to enhance the verification process (Majaliwa et al., 2018) . To analyze the link between the categorized land use/cover types and the ground land use/cover types, an error matrix was calculated.

The accuracy of the classes produced from the imagery classification method was further assessed using other accuracy statistics, such as the producer's accuracy and the user's accuracy (Campbell, 2007).). Equation (1) was used to calculate kappa statistics (K) for each classification to determine the statistical significance of each classification's alignment (Ramsey, 2008).

Kappa statistic, $K = \frac{\text{Observed}-\text{Expected}}{1-\text{Expected}}$……………………………….Equation(1)

Where:

Observed = Overall value for percent correct

Expected = Estimate of the contribution of the chance agreement to the observed percent correct

Producer's accuracy (%) = 100% − error of omission (%)………………….... Equation (2)

AND

User's accuracy (%) = 100% − error of commission (%)…………………………Equation (3)

Where:

The percentage of observed features on the ground that are not classified in the map is known as an error of omission, and the percentage of classes that should belong to another class but are instead classified as belonging to the class of interest is known as an error of commission (Alrababah & Alhamad, 2006).

3.3.2 The effect of land use/cover types on water quality in River Malaba catchment

3.3.2.1 Water Sampling Approach

Because of the inadequate resources to conduct a large-scale survey, simple random sampling technique was used(Meng, 2013). A total of twelve sampling points at different identified land use/cover types, separated from each other by approximately 1km were selected along the River Malaba (both upstream and downstream), which was already pre-determined by the Ministry of Water and Environment. Each of which represented a distinct land use or cover type. Soono 1, Soono 2, Lwakhakha, Mella, Akaboyi, and Akolondo were the six sites that were chosen to represent the upstream region. In the same manner, six locations were selected in the downstream region. These locations included Abwanget, Nariri bridge, Ndaiga Bridge, Railway, Malaba plant, and Amoni. In order to cover both the wet and dry seasons, water was sampled every other week for a total of six months.

3.3.2.2 Water Sampling

Twelve sites upstream and downstream of the River Malaba basin were used to collect water samples from the river. The sampling was conducted twice per month for six months, providing a total of 288 samples from various land-use areas. Water samples were collected were collected during the wet and dry seasons of 2021

During the sample collection process, the following steps were carried out:

a) Water samples from each location were collected in duplicate using a dip sampler at a depth of one meter, and then they were poured into labeled 40-mL sterile bottles for physiochemical analysis and into 20ml sterile bottles for bacteriological analysis.

b) The bottles containing the water samples were.

c) The hermetically sealed bottles of water were placed in a cooler box and chilled to four degrees Celsius

d) The samples were then transported to the Mbale regional laboratory under the auspices of the National Water and Sewerage Cooperation (NWSC) in order to undergo laboratory analysis.

Plate 3.1: Water sampling from upstream sampling points in River Malaba Catchment

Plate 3.2: Water sampling from downstream sampling points in River Malaba Catchment

3.3.2.3 Laboratory Analysis

The bacteriological and physicochemical parameters of the water were analyzed in the laboratory in accordance with the NWSC Standard Operating Procedures, which included the following:

Color: spectrophotometer (DR 3900) using 120nm wavelength and 10mls of distilled water to zero was used to take a reading after shaking the water sample violently and following the manufacturer's instructions.

Total Suspended Solids (TSS); The water sample was vigorously shaken while adhering to the instrument procedure and 630 nm wavelength on the spectrophotometer DR 3900. This was done by pouring 10 ml of distilled water into the sample cell to zero it out, and then recording the reading after 10 ml of the sample.

Electrical Conductivity (EC); Set the pH/EC meter to EC, poured sample into beaker, rinsed EC electrode with distilled water, waited for it to stabilize, recorded reading.

Total Iron; Poured 10ml of sample and 10ml of distilled water, added 3drops of ferrozine reagent, and followed the instrument procedure to measure iron at wavelength 260 on spectrophotometer DR3900

Turbidity; Shaken sample, poured 10ml into sample cell, measured turbidity in calibrated turbidimeter, recorded reading

pH; Place the pH/EC meter on and set it to the pH mode. Poured the sample into the Beaker, rinsed the pH electrode with distilled water before inserting it into the sample, waited for it to stabilize, and then recorded the reading.

Biochemical Oxygen Demand (BOD); Cleaned digestion bottles, poured 25mls of sample in each, read initial dissolved oxygen (DO) incubated at 20°C in a BOD incubator for five days, read final dissolved oxygen (DO) BOD= final dissolved oxygen- initial dissolved oxygen

Chemical Oxygen Demand (COD); The digestion tubes were cleaned with sulphuric acid at a concentration of 4M, adding 2 ml of sample, 2 ml of digestion solution, and 2 ml of concentrated sulphuric acid to each tube. Then the blank was prepared using the same procedures. Thereafter, heated the digestion tubes for two hours at 150 degrees Celsius in the heat block, allowed them to cool down before taking a reading on the spectrophotometer DR3900 at 620 nanometers.

Total Phosphates; Poured 25ml of sample into a digestion bottle, added 1ml 0.04M Sulphuric acid, and prepared the 25ml blank with distilled water. Heated for 30 minutes at 120°C, cooled to room temperature, added 3ml of combined reagent and 1ml of ascorbic acid, and read at 880nm on spectrophotometer DR3900.

Feacal Coliforms, Plaiting the samples, incubating them at 44 degrees Celsius for 17-24 hours, counting the yellow colonies that developed while using a magnifying glass, and recording the results required sterile equipment and strict adherence to the procedure.

Nitrates; Poured 25ml of sample into one beaker and 25ml of distilled water into another, added one pillow of nitraver 6 followed by one pillow of nitraver 3 reagent to each beaker, shook, and followed the instrument's instructions to read at wavelength 507nm on spectrophotometer DR3900.

Plate 3.3: Laboratory analysis of water samples at Mbale regional laboratory under NWSC

3.3.2.4 Data Analysis

Microsoft Excel 2016 was used to calculate the water quality parameter values. Descriptive statistics were used to present the findings (mean, maximum, minimum, and standard deviation among others). The variability of water quality parameter values was assessed using an analysis of variance (ANOVA) with a 95% confidence level (Tahiru et al., 2020, Nepomuscene et al., 2018) in order to determine the impact of land use/cover on water quality.

3.3.3 Determining the effect of water quality on treatment costs in River Malaba catchment

3.3.3.1 Data Collection

Malaba and Lirima treatment plants under the National Water and Sewerage Corporation (NWSC) data on water quality and treatment costs in the Malaba catchment area between 2016 and 2021 was used. The raw water abstracted, the amount of water delivered, and the chemicals utilized were all included in this data.

3.3.3.2 Data Analysis

The two-way ANOVA was used to organize and analyze the data in order to determine the impact of water quality on water treatment costs (effect of water quality on Aluminium sulphate cost, Aluminium Chlorohydrate, and High-test hypochlorite cost).

CHAPTER FOUR: RESULTS

4.1 Introduction

The findings for each objective are presented in this chapter. It's broken down into three sections: the number of changes in land use/cover in the River Malaba Catchment, The impact of land use/cover on water quality, and the effect of water quality on water treatment cost in River Malaba catchment.

4.2 The spatial extent of land use/cover changes in River Malaba Catchment

According to the findings, grasslands were the most prevalent land cover type in 2015, followed by farmland, with open water being the least prevalent. Farmland was the most common land use type in 2021, while open water was the least common land cover type. Between 2015 and 2021, the area covered by open water remained constant (Table 4.1). In 2015, the dominating land use/cover class was grassland, which later transitioned to farmland 2021.

In the River Malaba Catchment, built-up areas and farmland increased between 2015 and 2021, whereas grasslands, wetlands, and woodlands decreased. Between 2015 and 2021, there was no change in the amount of open water. Farmland had the most significant shifts in land use and cover (Table 4.1 and Figure 4.1).

Table 4.1: Statistics of River Malaba catchment land use/cover changes between 2015 and 2021

Land use/cover Type	**2015**		**2021**		**Net Change (2021-2015)**	
	Area (Sq.km)	**%**	**Area (Sq.km)**	**%**	**Area (Sq.km)**	**%**
Built-up	90.9	2.7	124.9	3.7	34.0	1.0
Farmlands	1,174.1	34.7	1,691.0	50.0	516.9	15.3
Grasslands	1,426.6	42.2	979.4	29.0	-447.2	-13.2
Open Water	14.8	0.4	14.8	0.4	0	0.0
Wetlands	353.3	10.4	345.2	10.2	-8.1	-0.2
Woodlands	323.3	9.6	227.7	6.7	-95.5	-2.8
Total	**3,383.0**	**100**	**3,383.0**	**100**		

The figure 4.1 shows that in 2015, more grassland, built up, and woodland were present, as compared to 2021 where farmland was most dominant, as woodland and grassland decreased. The decrease in grassland, woodland, and open water was noted while the increase in farmland and built up was observed between 2015 and 2021. Open water remained the same between 2015 and 2021

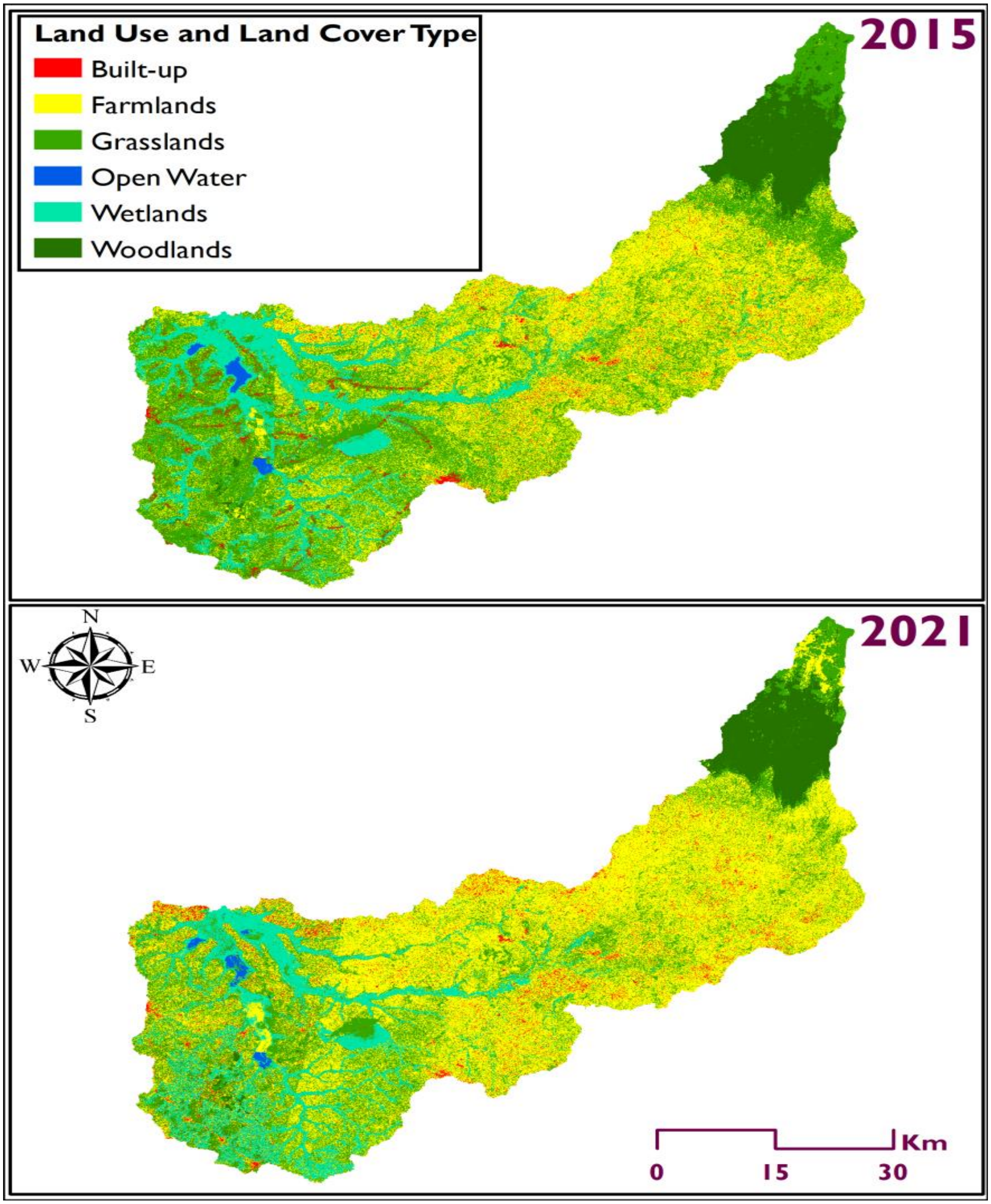

Figure 4. 1: Land use/cover types within River Malaba Catchment in 2015 and 2021

The annual net changes in land use and land cover categories showed that urbanized areas and agricultural lands expanded while natural areas such as forests, wetlands, and grasslands contracted over the course of several years (Table 4.1). No net change was detected in open water between 2015 and 2021. Farmland has the highest net changes, followed by grassland, and then wetlands. Wetlands have the lowest net changes (figure 4.2).

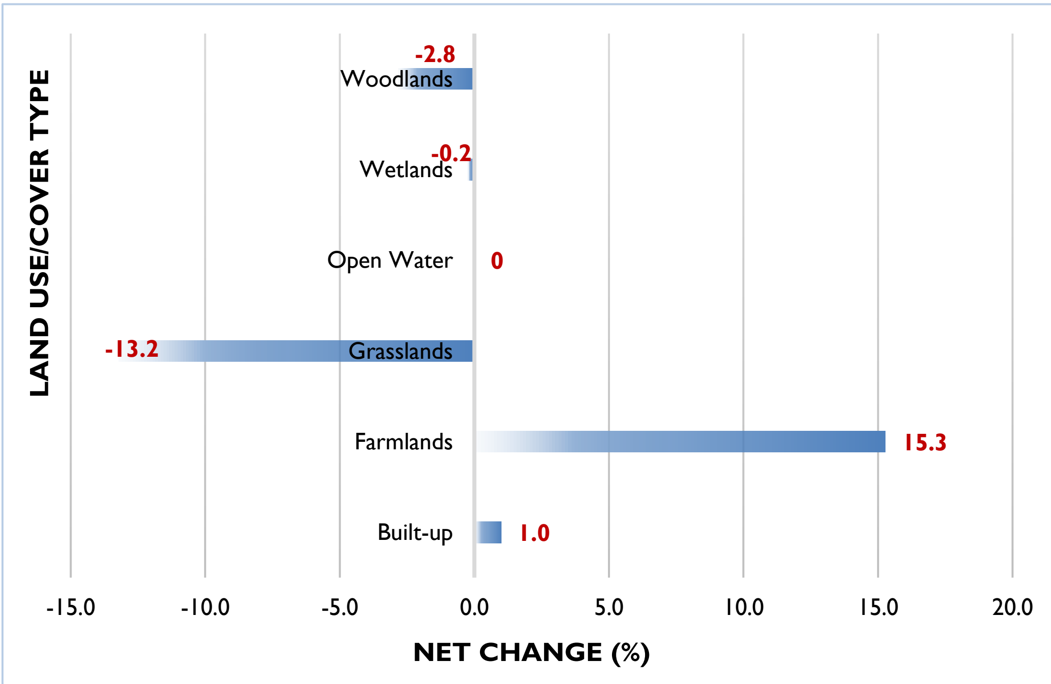

Figure 4.2: Net Changes in Land use/cover in River Malaba Catchment between 2015 and 2021

Land use/cover transitions in River Malaba Catchment between 2015 and 2021

The largest land use/cover transitions between 2015 and 2021 were "grasslands to farmlands," "farmlands to grasslands," and "wetlands to grasslands." The least land use/cover changes between 2015 and 2021 occurred in "built-up to open water", "grassland to woodland", and "wetland to woodland" respectively. (Table 4.3).

Between 2015 and 2021, the predominant land use/cover transitions in the River Malaba basin were from "grasslands to subsistence farmlands" (Figure 4.3), while the least shift was from "open water to built-up". Nonetheless, there was a significant area that did not change during the period of analysis (for example farmlands unchanged means that the area remained farmlands from 2015 to 2021).

Table 4. 2: Land use/cover transitions between 2015 and 2021 in River Malaba Catchment

		2021					
	Land use/cover Type	Built-up	Farmlands	Grasslands	Open Water	Wetlands	Woodlands
2015	Built-up	**30.5**	78.4	16.6	0.06	1.0	0.1
	Farmlands	70.4	**971.2**	259.5	0.1	39.8	4.8
	Grasslands	33.5	520.6	**443.2**	0.5	82.8	0.1
	Open Water	0.05	0.2	1.7	**10.8**	2.0	0
	Wetlands	5.1	67.1	100.4	0.8	**188.2**	0.8
	Woodlands	0.1	7.1	14.5	0.01	0.5	**210.8**

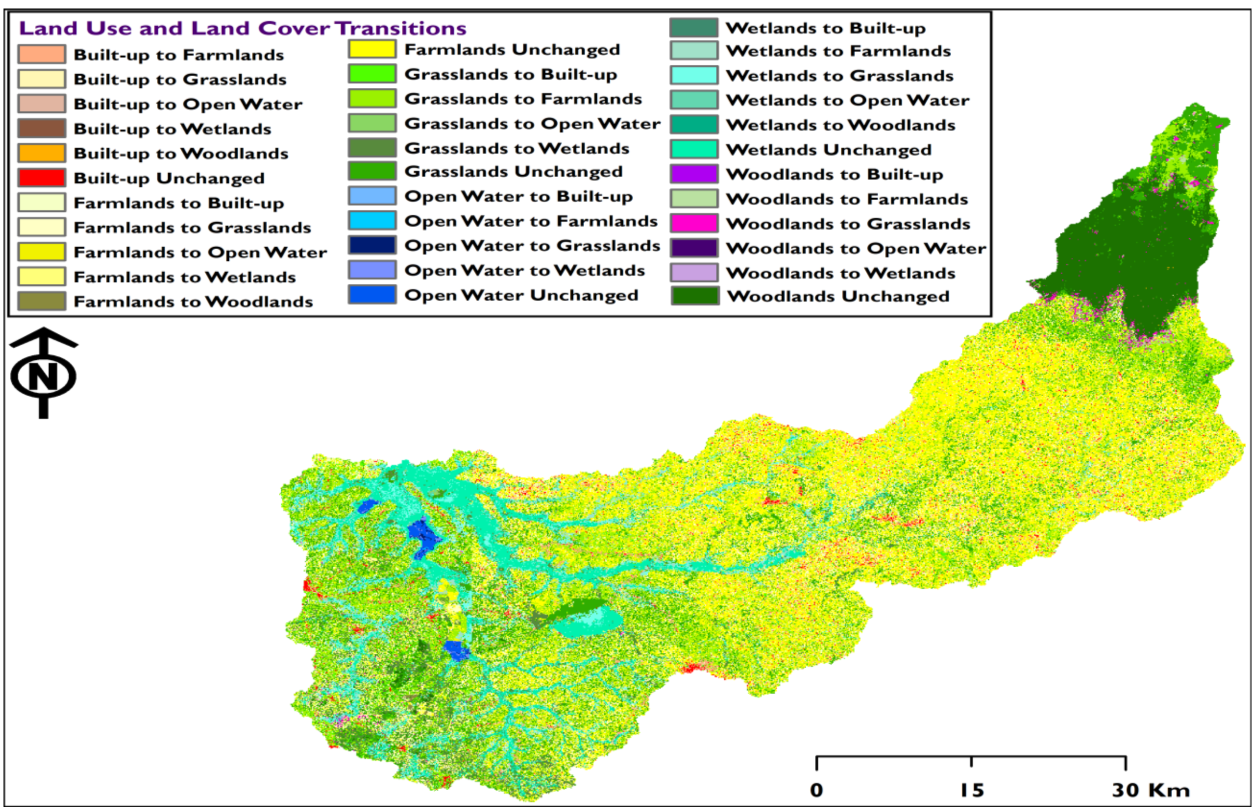

Figure 4. 3: Land use/cover transitions in River Malaba Catchment between 2015 and 2021

Accuracy assessment of Classified images for 2015 and 2021

Above 90% percent was determined to be the overall accuracy rating for all of the classifications. The image for the year 2021 had a Kappa coefficient of 0.9228, making it the one that was classified most accurately. The confusion matrices for each of the years are presented in the appendixes which access the accuracy of the classification.

Table 4.3: Accuracy assessment for the classified images

Year	Overall Accuracy	Kappa Coefficient
2021	0.9228	0.9073
2015	0.9171	0.9005

4.3 The effect of land use/cover on water quality in River Malaba catchment

During wet and dry seasons, as well as between upstream and downstream, the water contamination changed significantly (Table 4.4; Fig. 4.4; Fig. 4.5). During the dry season, compared to the wet season, pollution levels were elevated (Table 4.4; Fig. 4.4). Comparing the levels in the upstream and downstream, the downstream had higher pollution levels than the upstream (Table 4.4; Fig. 4.5). Color, total suspended solids, total iron, turbidity, fecal coliforms, total phosphates, and nitrates were some of the parameters that had concentrations that were higher than the NWSC permissible limits across all seasons and streams. During the dry season, BOD levels remained under tolerable standards. Throughout the streams and throughout the dry season, the COD was within permissible standards, however it was over acceptable limits during the wet season.

Table 4. 4: Mean and SD of water quality parameters in River Malaba Catchment

Water Quality Parameters	Dry Season		Rainy Season		Downstream		Upstream		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Color (PtCo)	**2,541.8**	**3,449.1**	**1,111.3**	**998.2**	**2,335.9**	**2,626.8**	**1,031.0**	**1,968.0**	**1,683.5**	**2,393.3**
TSS (mg/L)	**435.5**	**581.4**	**202.9**	**193.4**	**434.6**	**468.6**	**157.4**	**284.1**	**296.0**	**408.9**
EC (µs/cm)	115.6	35.9	91.5	22.2	114.4	22.3	88.0	32.3	101.2	30.6
Total Iron (mg/L)	**1.5**	**2.5**	**1.1**	**0.7**	**1.7**	**2.0**	**0.8**	**1.0**	**1.3**	**1.7**
Turbidity (NTU)	**629.5**	**710.0**	**232.2**	**260.2**	**588.6**	**599.2**	**193.6**	**346.8**	**391.1**	**524.6**
pH	7.6	0.3	7.5	0.1	7.5	0.2	7.6	0.2	7.5	0.2
BOD (mg/L)	50.0	50.7	**91.8**	**45.7**	**76.4**	**52.7**	**73.7**	**51.4**	**75.1**	**51.6**
COD (mg/L)	57.6	59.1	**107.9**	**54.2**	91.5	63.1	84.1	59.6	87.8	61.0
Total Phosphates (mg/L)	**1,064.4**	**1,504.7**	**1,072.1**	**920.0**	**1,313.3**	**983.9**	**824.7**	**1,313.6**	**1,069.0**	**1,176.7**
Feacal Coliforms (CFU/100mL)	**66.8**	**33.4**	**79.5**	**78.4**	**74.3**	**80.6**	**74.5**	**43.4**	**74.4**	**64.2**
Nitrates (mg/L)	**0.23**	**0.25**	**0.19**	**0.17**	**0.35**	**0.20**	**0.06**	**0.05**	**0.204**	**0.204**

Note: SD stands for standard deviation and the highlighted figures are beyond acceptable limits

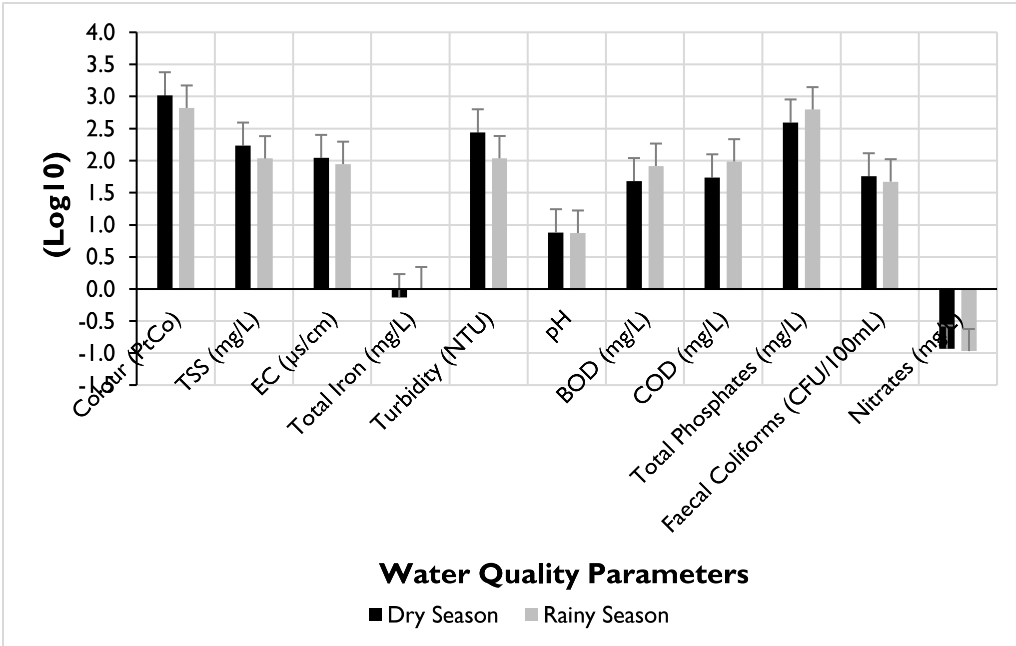

Figure 4. 4: Log mean concentrations of water quality parameters in the dry and rainy season

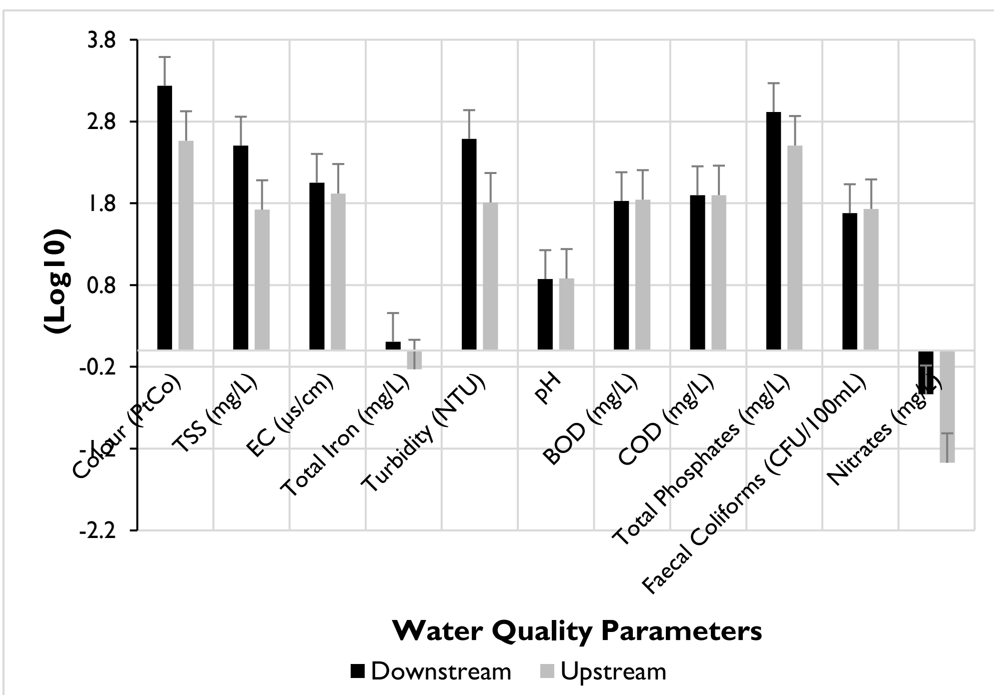

Figure 4.5: Log mean concentrations of water quality parameters upstream and downstream

Land use/cover significantly affected COD ($P=0.023$), EC ($P=0.004$), and Nitrates ($P=0.004$) at a 95% confidence interval. COD was observed highest in farmlands, Grassland, and least in woodland while EC and Nitrates were highest in wetlands and also least in woodland. On the other hand, land use/cover did not affect significantly BOD, Fecal coliforms, TSS, Total Phosphates, Total Iron, Turbidity, and pH at ($p<0.05$). Generally, COD and EC were highest in the downstream and least in the Upstream while Nitrates were highest in the Upstream and least the downstream of the River Catchment

Seasons (Wet and Dry) showed great significance ($P=<.001$) across all water parameters at ($p<0.05$) except for Fecal coliforms, Total Phosphates, and Total Iron. There was the least variation in Total Phosphates as a result of seasons and the highest variation in BOD, COD, EC, TSS, and Turbidity all showing values (< 0.001) at a 95% confidence interval. The study also showed that variation of all water parameters was not influenced by seasons and land use/ cover at ($p<0.05$) (Table 4.5).

Table 4.5: Effect of land use/cover on water quality in River Malaba Catchment

Season	Land use/cover	BOD		COD		EC		Fecal Coliforms		Nitrates		TSS		Total Phosphates		Total Iron		Turbidity		pH	
Dry		**D**	**U**	**D**	**U**	**D**	**U**	**D**	**U**	**U**	**D**	**U**	**D**	**D**	**U**	**D**	**U**	**D**	**U**	**D**	**U**
	Built-up	106	33	125	36.9	116.7	122.9	96.2	79.8	0.145	0.06	176	258	691	1105	0.39	0.95	308	306	7.6	7.6
	Farmland	111	29.5	131	32.8	103	94.1	90	90.2	0.32	0.05	297	310	704	1329	0.46	1.54	572	414	7.5	7.6
	Grassland	52.8	30.7	60.7	35.2	124.9	103.2	44.5	58.7	0.59	0.048	840	308	923	1337	2.82	1.06	1253	411	7.6	7.7
	Wetland	24.2	56.8	28.3	64.1	145	126.2	21	74.2	0.6	0.073	608	588	1090	2452	1.44	2.37	1054	778	7.6	7.6
	Woodland	39	10.5	44.7	12	131.6	70	44.5	69	0.458	0.017*	1098	11	1386	62	4.46	0.2	1411	18	7.7	7.7
Wet/ Rainy	Built-up	49	126	54.5	146.5	97.6	82.7	38	102.3	0.238	0.058	256	68	1322	585	1.46	0.57	271	70	7.4	7.6
	Farmland	106.5	91.2	132	104.3	103.6	72.1	150.8	51.2	0.31	0.08	343	81	1783	687	1.78	0.73	440	104	7.5	7.5
	Grassland	106.4	76.2	129	86.2	112.5	76.7	122.3	78.2	0.304	0.072	348	73	1668	532	1.67	0.62	423	67	7.4	7.6
	Wetland	88	79	110	89.5	112.4	89.9	52.3	67.7	0.322	0.137	349	138	1512	980	1.67	1.14	376	150	7.4	7.6
	Woodland	72.8	96.5	90.3	109	111.1	54.4	62	54	0.382	0.013	419	9	1712	146	1.71	0.18	487	13	7.4	7.4
Land use (P< 0.05)		0.223		0.023		0.004		0.183		0.004		0.353		0.528		0.575		0.193		0.973	
Season (P< 0.05)		<.001		<.001		<.001		0.233		0.029		<.001		0.943		0.147		<.001		0.003	
Season * Land use (P< 0.05)		0.485		0.442		0.464		0.448		0.084		0.463		0.864		0.388		0.238		0.45	

D means downstream and U means upstream

4.4 The effect of water quality on water treatment cost in River Malaba catchment

The study indicated that water quality characteristics have a considerable impact on water treatment costs. Aluminum Sulphate, High Test Hypochlorite, and Polymer costs were significantly affected by the streams of water treatment and time (year of chemical application) (P 0.05) at a 95% confidence range, with HTH having the greatest significance and Polymer the least. The months of water treatment had no discernible effect on the cost variability of Aluminum Sulphate, High Test Hypochlorite, and the polymer (p>0.05) (Table 4.6).

Table 4.6: Effect of water quality on water treatment costs

Chemical	Parameter	Sum of Squares	Mean Square	F Ratio	P-Value
Alum	Month	6.32×10^{13}	5.75×10^{12}	0.79	0.6477
	Year	1.28×10^{14}	4.27×10^{13}	5.87	0.003^*
	Stream	2.21×10^{14}	2.21×10^{14}	30.42	0.000^*
Polymer	Month	6.72×10^{15}	6.10×10^{14}	1.91	0.0528
	Year	7.67×10^{15}	1.92×10^{15}	6.01	0.0003^*
	Stream	1.49×10^{16}	1.49×10^{16}	46.81	0.000^*
HTH	Month	1.69×10^{12}	1.54×10^{11}	0.66	0.7672
	Year	2.90×10^{12}	7.25×10^{11}	3.13	0.0218^*
	Stream	8.21×10^{13}	8.21×10^{13}	353.91	0.000^*

*Significant at 0.05

According to the data presented in Figure 4.6, there was an upward trend in the total costs of water treatment between the years 2016 and 2017, followed by a decline in 2018, followed by an upward trend from 2020 to 2021.

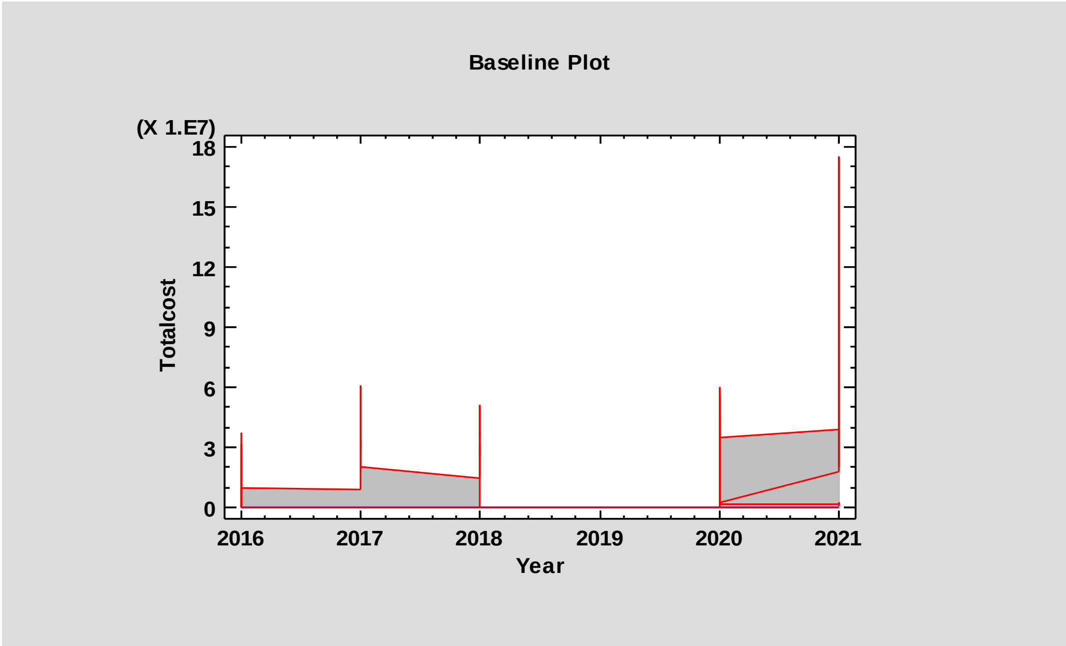

Figure 4.6: shows that the total costs of water treatment had a growing trend between 2016, and 2017, which later declined in 2018 and then increased from 2020 to 2021

At a confidence level of 95 percent, the research indicated that the parameters pH, Color, Turbidity, Alkalinity, Hardness, and Iron had a very significant influence on the variability of the cost of Aluminum Sulphate. This was found in relation to the impacts of water quality on the cost of Aluminum Sulphate. At a confidence level of 95 percent, the effect of EC on the cost of aluminum sulphate was not significant, and feacal coliform did not show any effect on the cost of aluminum sulphate (Table 4.7). The variance in treatment cost values was also significantly affected by the stream (upstream and downstream) and the year in which chemicals were applied. The month of water treatment had no discernible effect on the costs of aluminum sulphate treatment in the study area.

Table 4.7: Effect of water quality on treatment costs using Aluminum Sulphate

Source	***Sum of Squares***	***Df***	***Mean Square***	***F-Ratio***	***P-Value***
pH	3.74×10^{14}	20	1.87×10^{13}	3.9	0.0022*
Color	4.56×10^{14}	17	2.68×10^{13}	168.45	0.0000*
Turbidity	7.97×10^{14}	34	2.35×10^{13}	154.34	0.0000*
Alkalinity	5.07×10^{14}	20	2.35×10^{13}	13.71	0.0000*
Hardness	4.31×10^{14}	18	2.40×10^{13}	4.82	0.0003*
Iron	1.29×10^{14}	7	1.85×10^{13}	51.76	0.0040*
F. Coli	3.24×10^{14}	15	2.16×10^{13}		
EC	6.58×10^{11}	5	1.32×10^{11}	0.64	0.675

***Significant at 0.05, F. Coli means Feacal coliform**

Figure 4.7 demonstrates that between the years 2016 and 2017, there was a downward trend in the cost of treating water with aluminum sulfate, which was followed by a decline in 2018, and then an increase between the years 2020 and 2021.

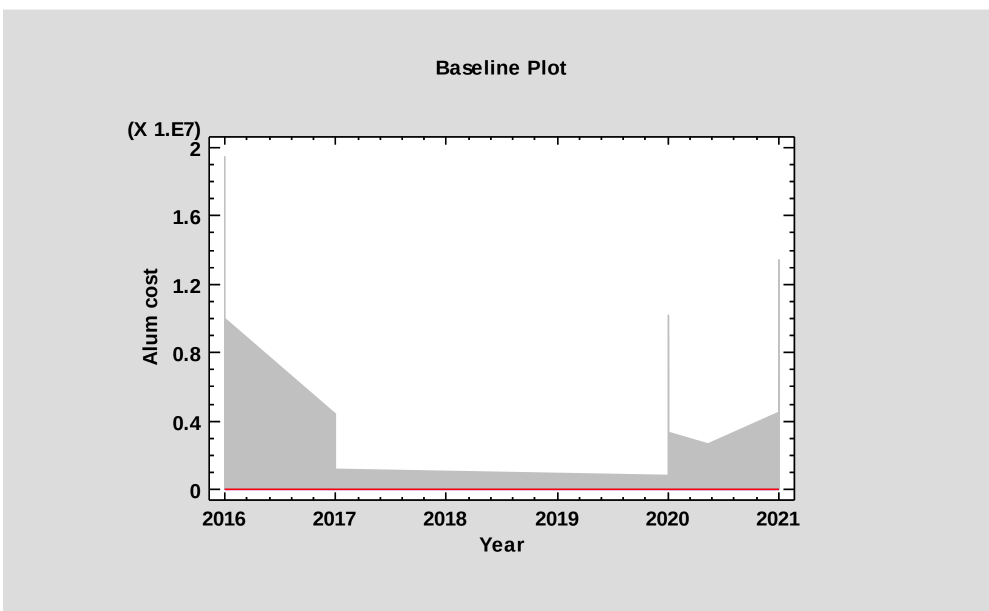

Figure 4.7: Effect of water quality on treatment cost using Aluminium Sulphate in River Malaba catchment

At a confidence level of 95 percent, the research showed that the parameters pH, Color, Turbidity, Alkalinity, Hardness, and Iron had a very significant influence on the variability of the cost of high-test hypochlorite. This is in relation to the fact that water quality has an effect on the costs of high-test hypochlorite. At a confidence level of 95 percent, the effect of *F.Coli* and EC on the cost of high-test hypochlorite was not significant (Table 4.8). The amount of variation in the treatment cost values was significantly impacted by the stream, both upstream and downstream, as well as the year in which the treatment was performed. It was discovered that the treatment month had no significant influence on the costs of water treatment in the study area.

Table 4.8: Effect of water quality on treatment costs using high test hypochlorite treatment

Source	***Sum of Squares***	***Df***	***Mean Square***	***F-Ratio***	***P-Value***
PH	8.10×10^{13}	21	3.86×10^{12}	4.16	0.0001*
Color	1.01×10^{14}	35	2.89×10^{12}	664.52	0.0000*
Turbidity	1.22×10^{14}	51	2.40×10^{12}	4	0.0019*
Alkalinity	1.20×10^{14}	30	3.99×10^{12}	14.57	0.0000*
Hardness	1.17×10^{14}	30	3.91×10^{12}	11.15	0.0000*
Iron	3.61×10^{13}	21	1.72×10^{12}	220.14	0.0004*
F. Coli	1.34×10^{13}	32	4.18×10^{11}	15.31	0.0631
EC	1.95×10^{10}	5	3.91×10^{9}	0.49	0.7771

***Significant at 0.05, F.Coli means Feacal coliforms**

Figure 4.8 shows that the costs of water treatment with high test hypochlorite had a generally increasing trend between 2016 and 2021

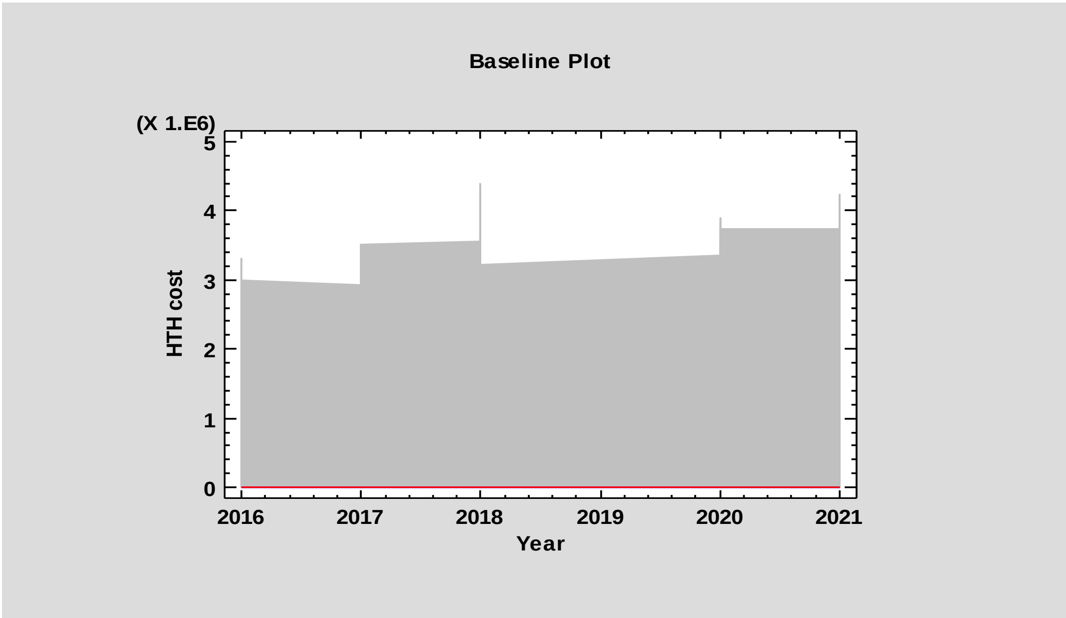

Figure 4. 8: Effect of water quality on water treatment cost using high-test hypochlorite cost in River Malaba catchment

Concerning the effect of water quality on the cost of Aluminium Chlorohydrate (Polymer), the study revealed, with a confidence level of 95%, that Color and Hardness have a significant effect on the cost variability of Aluminium Chlorohydrate. pH, Turbidity, Alkalinity, Iron, *F. Coli*, and EC had no effect on the cost variability of Aluminum Chlorohydrate, and the effect is not statistically significant with a 95% level of confidence. The variability in the treatment cost values was significantly influenced by the stream (upstream and downstream), and the year of treatment. In the study area, the treatment month had no noticeable effect on water treatment costs.

Table 4.9: Effect of water quality on water treatment costs using Aluminium Chlorohydrate treatment costs

Source	**Sum of squares**	**Df**	***Mean Square***	***F-Ratio***	***P-Value***
pH	2.26×10^{16}	24	9.41×10^{14}	1.73	0.0671
Color	1.60×10^{16}	41	3.91×10^{14}	6.5	0.0002*
Turbidity	3.34×10^{16}	59	5.65×10^{14}	0.76	0.7875
Alkalinity	2.59×10^{16}	34	7.62×10^{14}	1.53	0.1061
Hardness	2.84×10^{16}	32	8.86×10^{14}	2.18	0.0113*
Iron	8.10×10^{15}	25	3.24E+14	1.44	0.3985
F. Coli	1.99×10^{16}	41	4.86×10^{14}	0.15	0.9997
EC	7.26×10^{11}	5	1.45×10^{11}	0.56	0.7256

*Significant at 0.05, F.Coli means Feacal Coliforms

Figure 4.9 demonstrates that there was an upward trend in the cost of treating water with Aluminum Chlorohydrate between the years 2016 and 2017, followed by a downward trend in 2018, and then an upward trend between the years 2020 and 2021.

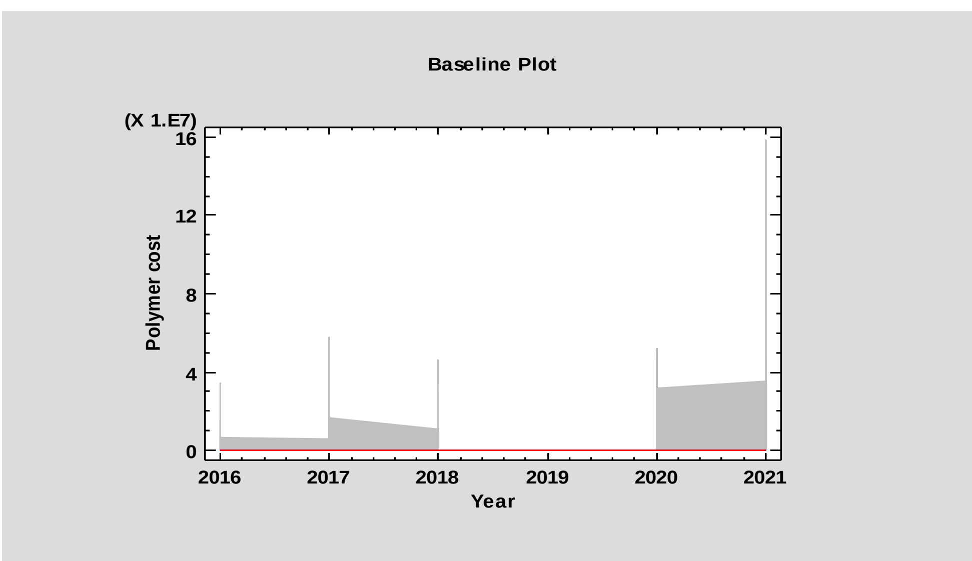

Figure 4.9: Water quality effects on water treatment costs using Aluminium Chlorohydrate cost in River Malaba catchment

The upstream treatment costs and the downstream treatment costs were found to vary seasonally, according to the analysis. When compared to the costs of treating the water downstream, the costs of treating the water upstream were significantly lower during both the dry seasons (DJF and JJA) and the wet seasons (MAM and SON) (Figure 4.10). Figure 4.10 illustrates that during the years 2020 and 2021, the cost of treating water at the treatment plants both upstream and downstream is more expensive during the rainy season (MAM, SON) than it is during the dry season (DJF, JJA).

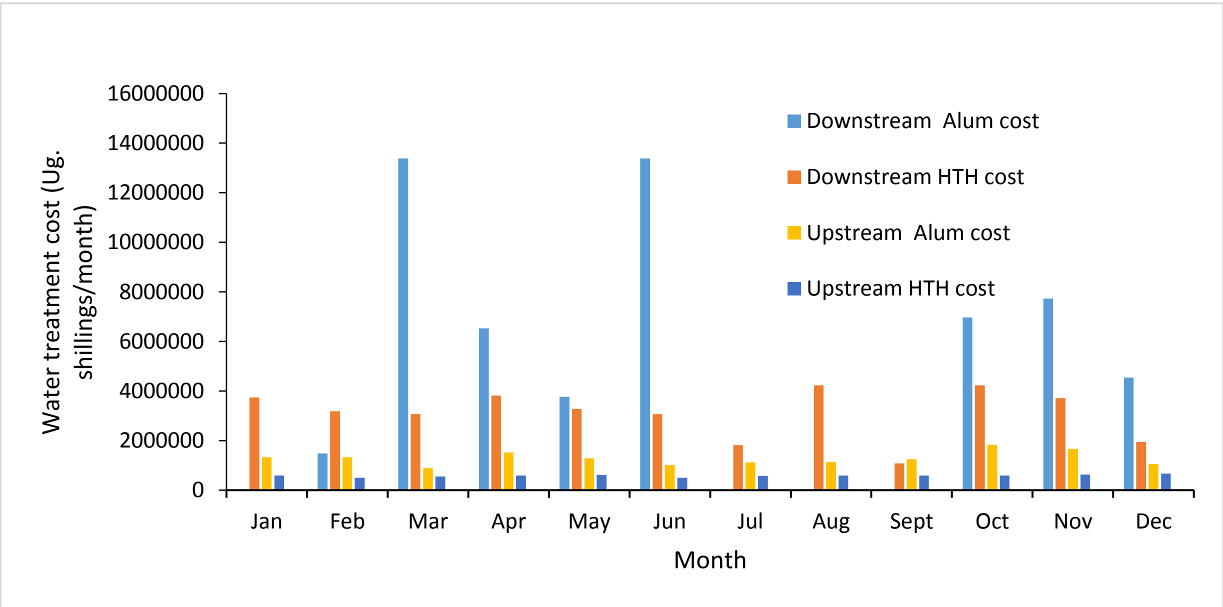

Figure 4.10: Mean treatment costs (Alum and HTH) across the treatment plants for the period of 2020-2021

CHAPTER FIVE: DISCUSSION

5.1 Introduction

This chapter discusses the findings from the preceding chapter by objectives and compares them to findings from other writers in relevant domains.

5.2 Land use/cover changes in River Malaba catchment

The area occupied by Farmlands in the watershed of the River Malaba expanded by 15% (Table4:1). From 2015 to 2021, the most notable change in land use was the conversion to agricultural land. These alterations are attributable to the growing human population for example between 2014 and 2022 the population for Tororo district has increase by 18.6% (UBOS, 2021), which has led to a rise in agricultural activity. Agricultural sector is the primary source of income in the majority of Uganda, which can be attributed to changes in land-use (UBOS, 2014). People frequently alter the land to make it suitable for crop and animal farming which has an effect on the land coverage. Agriculture is the primary driver of land-use changes in the River Malaba watershed, according to previous studies (Bernard et al., n.d.).

Agricultural land use classifications or farmlands lead to land-use changes over the study period. This result was expected and it is consistent with numerous studies that have been conducted for Uganda(Gilbert et al.,2018, and Bunyangha et al., 2021) this is also a constant observation that has been registered across several parts of the world (Demissie et al., 2017). In addition to population growth, and its associated demands for land resources, insufficient enforcement of environmental laws, the economic value of major crops, culture, the majority of the population's low level of education, land tenure, the small size of household land holdings, and political interventions all contribute to farmland being the most significant land use/cover transition(Gilbert et al., 2018).

Consequently, the population increase as revealed in the most recent national census (UBOS, 2017) could have led to an increase in the built-up area within the River Malaba catchment by 1% (Table 4:1). With population increase, built-up areas also increase due to the need for opening more land for settlement, critical and social facilities such as schools, and health facilities among others in the study area. Generally, agriculture and built-up areas are increasing at the expense of wetland and woodland in Uganda as stated by (Kilama Luwa et al., 2021) which is similar to the findings of this study and although the major drivers of land use/cover changes relate with one another, population pressure stands out of all the fundamental drivers of land use/cover changes at both national and local scales.

Additionally, the slopes of Mount Elgon determine the places appropriate for urban development and agriculture (Lee & Pradhan, 2007). Population growth in these regions imposes pressure on biomass resources, such as woodlands, which is followed by deforestation, charcoal burning, and removal of these resources for settlement and agriculture (Temgoua et al., 2018). Some people in the River Malaba watershed burn grasslands to stimulate the growth of grazing and farmed vegetation. In traditional grazing systems, notably among pastoral and agro-pastoral societies in East Africa, certain grazing resource management strategies are prevalent (Maitima et al., 2009).

The results also showed a decrease in Grassland, woodland, and wetland land use/ cover in River Malaba Catchment between 2015 and 2021 by 13.2%, 2.8%, and 0.2% respectively (Table 4:1) agreeing with a study in the catchment which recently reported the decline of grassland, woodland and wetland at rates of 5.52%, 2.47% and 0.63% respectively (Bunyangha et al., 2021a). At the expense of other land use/cover types, it has been suggested that these changes are most likely attributable to the return of a more politically stable climate in Uganda (Bunyangha et al., 2021a). Instability in the political sphere lowers the productive and transactional capacities of the economy, which in turn raises the level of social unrest; as a result, the sociopolitical environment becomes more unstable (Aisen & Veiga, 2011; Dalyop, 2019).Therefore, the normalcy produced by Instability in the political sphere allowed the impacted populations to resume their activities as they had prior to the insurgency that devastated the region and country as a whole.

It was noted in the results that woodland and wetland areas were being cleared rapidly, mostly to make way for farming and settlement area development. Surprisingly, it has been shown that wetland areas are the most impacted by anthropogenic demand, mostly because they provide the most fertile and ideal farming areas and, thus, greater water security to farmers who rely significantly on rain-fed agriculture. This is consistent with wetland degradation patterns identified in Tanzania (Munishi & Jewitt, 2019) that were a result of climate variability driving farmers to shift to wetland areas as a coping technique..

5.3 Effect of land use/cover on water quality in River Malaba catchment

Land use and Land cover shows an evident effect on water quality, for example, the fertilizers used in the cultivated land get into the runoff and flow into the river and ultimately pollute the river water with Nitrates and Phosphates. On the other hand, the vegetation in the surface soil of the cultivated land can absorb, and retain the pollutants(Mirzaei et al., 2020). As a result, the cultivated land plays a complicated role in influencing the water quality in the river catchment. Other pollutants from built-up areas i.e. some of the wastewater ends up in the river impacting the water quality and altering different water quality parameters such as Feacal coliforms. This is very similar to many other studies that have been done to investigate the impact of land use and cover on the quality of water in various parts of the world (Huang et al., 2013, Ding et al., 2016).

In this study land use/cover significantly altered the chemical oxygen demand (COD), electrical conductivity, and nitrate concentrations (Table 4:5). COD was observed highest in farmlands/agricultural farms which can be attributed to flushing off of solvable organic compounds from the organic layer. Studies conducted in other nations, such as Ecuador, also identified similar results (Goller et al., 2006). The highest levels of nitrate and electrical conductivity were found in wetland areas, these act as collection points for polluted river water similar findings from other regions, such as wetland areas surrounding tea plantations in Kenya (Monteith et al., 2015; Jacobs et al., 2017). The relationship between nitrate concentrations and carbon stores is strong. The soil organic carbon (SOC) content of undisturbed fields is often greater than that of cultivated fields (Were et al., 2016).

The lowest levels of electrical conductivity, nitrates, and chemical oxygen demand (COD) were found in woodlands. This finding is consistent with observations made in the Mara river in Kenya, where natural forests were found to release less nitrogen than agricultural fields (Masese et al., 2017). Compared to natural fields, rubber plantations in China were found to release greater nitrogen concentrations (Hongmei Li et al., 2016). Deforestation in the Brazilian Amazon has been linked to up to four times higher total dissolved nitrogen concentrations, with the effect persisting in catchments with more than 66% to 75% deforestation (Biggs et al., 2004).

The results of the study showed more water pollutants were downstream than upstream of the River Malaba Catchment (Figure 4:4). Land use/cover changes are more seen downstream where most grassland and woodland have been changed to farmlands and built-up areas and reflecting on the water quality downstream the catchment. The water quality is severely affected by unsustainable land use and inadequate/missing water purification techniques (Arce-nazario, 2015). The reduced absolution and the return flow of agricultural drainage water lead to critical pollution of the river in the lower parts of the catchment (Groll et al., 2015) which agrees with the finding in this study.

The findings of this study indicate that the changes in land cover and use have a significant impact on water quality; however, the study did not directly investigate how the different land use scenarios play out over a longer period of time and how that has an impact on water quality. This limits comprehension of the effects of various types of land-use on the quality of water. Other land-use types, such as the conversion of natural forest to pasture, have been demonstrated to reduce the concentration of nitrogen in stream water (Neill et al., 2001; Martínez et al., 2009). Therefore, explicit examination over a longer time period would have unraveled the effects of the various changes in land use/cover scenarios of the study. Therefore, in the course of future research, it would be beneficial to take explicit approaches.

5.4 Water treatment costs and water quality in River Malaba catchment

Water quality had a significant influence on the treatment costs within the river catchment, different water parameters such as color, pH, Turbidity, and Total Iron had a considerable impact e on the variability of the costs of high-test hypochlorite, polymer, and Aluminium Sulphate (Table 4:7,4:8 and 4:9) , this agrees with similar studies that raw water quality influences the costs of water treatment (McDonald et al., 2016).

The water treatment costs were also associated with the land use/cover change within the catchment as observed that downstream costs of water treatment are higher than upstream treatment costs (Figure 4:10). The upstream of River Malaba Catchment the land use/cover change is observed to still be negligible. Land use/cover changes alter the soil influencing the release of different substances into the water thus treatment costs for such water thus increases.

A model research in the United States of America reveals that land use and cover changes are severely degrading water quality (Warziniack et al., 2017). Agricultural activities such as grazing nearby watersheds have a significant effect on turbidity, hence raising the cost of water treatment for this parameter (Warziniack et al., 2017). In this respect, these results support those of (Abildtrup et al., 2013, and Brauman et al., 2007), in which the primary benefit associated with forests may be to exclude other land uses and activities in the watershed that cause water pollution although literature also inclines to focus on the role of disturbances, including roads and grazing, rather than landscape-scale characteristics like land use (Stuart & Edwards, 2006; Edwards et al., 2015).

The costs for water treatment were high in the rainy seasons as compared to the dry seasons for both upstream and downstream water treatment plants (Figure 4:10) due to the increased run-off from the surrounding land use/cover into River Malaba experienced during the rainy season influencing the water quality and treatment costs. More concentrations of suspended solids in runoff from forests during the rainy seasons, compared to their concentration in runoff during dry seasons (Bruijnzeel, 2004; Carlson et al., 2014).

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

The conclusions and recommendations drawn from the thesis findings are presented in this chapter.

6.2 Conclusion

Human population increase has led to land use/cover changes in River Malaba Catchment, utmost changes were perceived in farmlands, grasslands, and woodlands and built-up areas. Transitions showed that grasslands have turned to farmlands and this was the ultimate transition between 2015 and 2021.

Land use/cover change significantly influenced water quality parameters like COD (Chemical Oxygen Demand), EC (Electrical Conductivity), and Nitrates. The water pollutant levels were higher downstream than the upstream and seasons also showed significance for water quality parameters across the catchment. COD was observed highest in farmlands, Grasslands, and least in woodland while EC and Nitrates were highest in wetlands and also least in woodland.

Water quality consequently affects treatment costs in the catchment where different water quality parameters significantly affected the costs of Aluminium Sulphate, high-test hypochlorite, and polymer which are chemicals used in the water treatment process. The costs of water treatment were high downstream than the upstream, also in the rainy season than in the dry season due to the increased run-off from the surrounding land use/cover during the rainy season.

This has implications for human health and well-being, as water is fundamental to human survival and its degradation can greatly impair human health and well-being.

6.3 Recommendations

Consequently, greater conservation efforts are required in the catchment areas of the River Malaba to improve its sustainability and human livelihoods. Notably, more efforts are required to halt the shrinking of the catchment area and the deterioration of the quality of water. This can reduce the costs related to water treatment. This can be accomplished by supporting livelihood strategies that have a negligible effect on the catchment, such as grazing, which would increase grassland regeneration and restrict the release of pollutants into the catchment while simultaneously boosting human livelihoods.

In addition, because the research was conducted over a short period of time and with little monitoring of the dynamics and consequences of the various land-use patterns, future research should be conducted over a longer period of time while explicitly examining the consequences of the various land use/cover types. This should be linked to the various costs associated with the treatment of water and other ecological values. A catchment model would be very suitable to stimulate the effects of land use/cover change to water quality if well calibrated and validated.

Planting of trees is recommended in the catchment since woodland land cover type had the least concentrations of the significant water parameter and trees can be inter-planted in farmlands which was the dominant land use/cover type.

In order to improve water treatment and make it suitable for human consumption, it should be scaled up and out upstream and downstream, as well as during the wet and dry seasons. This ought to focus on all aspects of water quality parameters.

The numerous land-use types have to be planned in such a way as to cut down on the quantity of pollutants that flow into the river in order to reduce on the cost of treatment. This might also be accomplished by establishing buffer zones between the various land-use types and the river.

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APPENDICES

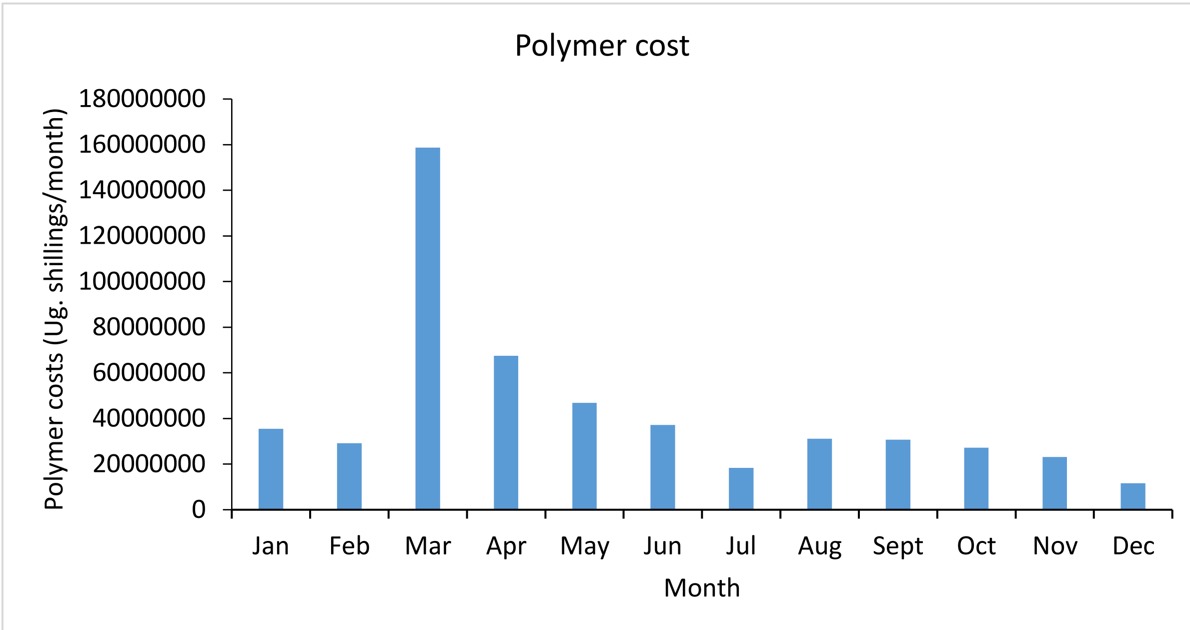
Appendix I: Error matrix for the 2015 land use/cover classification

	Built-up	**Farmlands**	**Grasslands**	**Open Water**	**Wetlands**	**Woodlands**	**Total**	**Error of Commission**	**User's Accuracy**
Built-up	53	0	1	0	2	1	57	7.017	92.982
Farmlands	3	52	2	1	0	0	58	5.172	94.827
Grasslands	2	0	58	1	0	2	63	3.174	96.825
Open Water	1	0	1	55	0	0	57	3.508	96.491
Wetlands	0	0	2	3	49	0	54	9.259	90.740
Woodlands	2	1	4	0	0	54	61	8.196	91.803
Total	61	53	68	60	51	57	350		
Error of Omission	4.918	1.886	10.294	5	3.921	5.263			
Producer's Accuracy	95.081	98.113	89.705	95	96.078	94.736			
Overall Accuracy	0.917								
Kappa Coefficient	0.900								
p(r)	0.167								

Appendix II: Error matrix for the 2021 land use/cover classification

	Built-up	Farmlands	Grasslands	Open Water	Wetlands	Woodlands	Total	Error of Commission	User's Accuracy
Built-up	55	1	2	0	1	3	62	11.290	88.709
Farmlands	2	49	0	0	1	1	53	7.547	92.452
Grasslands	0	1	55	0	2	1	59	6.779	93.220
Open Water	0	0	0	59	1	0	60	1.666	98.333
Wetlands	2	0	1	1	47	1	52	9.615	90.384
Woodlands	0	1	3	0	2	58	64	9.375	90.625
Total	59	52	61	60	54	64	350		
Error of Omission	6.779	5.769	9.836	1.666	12.962	9.375			
Producer's Accuracy	93.22	94.230	90.163	98.333	87.037	90.625			
Overall Accuracy	0.922								
Kappa Coefficient	0.907								
p(r)	0.167								

Appendix III: Mean monthly Polymer costs at the downstream treatment plant for the period 2020-2021



Appendix IV: Average water quality values downstream and upstream in seasons of the year 2020-2021

Downstream												
	Month											
Water Parameters	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
pH	8	6.8	7.9	7.885	7.4	8	7.9	7.4	7.9	7.5	7.71	7.6
Color(PtCo)				5930	4210					2109		
Turbidity(NTU)	98	53	162	368	319	103	85	79	162	168	222	58
EC(µS/cm)												
TSS(mg/L)					2			2				
Total Iron(mg/L)										7.75		
Upstream												
	Months											
Water Parameters	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
pH	7.595	7.62	7.77	7.525	7.305	7.795	7.35	7.45	7.595	7.715	7.595	7.5
Color(PtCo)	30	29	22	10	40	58	20	36	30.5	38	38	44
Turbidity(NTU)	5.84	8.59	10.54	14.165	11.36	11.75	15.91	17.9	14.5	10.49	13.09	11.54
EC(µS/cm)	138	56.6	49.9	113.35	61.3	49.9	88.7	77.3	49.9	49.9	138	56.6
TSS(mg/L)					2							
Total Iron(mg/L)			0.119			0.119		0.013	0.119	0.119		

Appendix V: Water sampling at the different land use/cover type in River Malaba catchment

Appendix VI: Laboratory Analysis at Mbale Regional laboratory for water quality parameters results

Appendix VII: Lirima treatment plant, (upstream)

Appendix VIII: Malaba waterworks treatment plant, (downstream)