ASSESSMENT OF THE IMPACTS OF SISAL PROCESSING INDUSTRIES ON WATER RESOURCES IN RONGAI SUB-COUNTY, KENYA

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A Thesis Submitted to the Institute of Postgraduate Studies of Kabarak University in Partial Fulfilment of the Requirement for the Award of Master of Science in Environmental Science Degree

KABARAK UNIVERISTY

NOVEMBER, 2025

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DEDICATION

This research thesis is dedicated to my parents, who have always encouraged and supported my studies.

ABSTRACT

Sisal farming is a vital large-scale cash crop activity in Rongai Sub-County, Kenya, with over 1,000 hectares of land dedicated to its cultivation. As a primary economic activity, it provides income and employment opportunities for the local population. However, sisal processing industries are significant water consumers, which has led to their establishment near natural water sources, including streams and rivers. This study was conducted to assess the impact of sisal processing industries on water resources in Rongai Sub-County. The research focused on determining the mitigation measures implemented to manage pollution from sisal waste disposal and evaluating the effects of this waste on the water quality in the Molo River, Rongai River, Majani Mingi River, and surrounding boreholes.The study concentrated on three main sisal processing industries, which are:Athinai Sisal Processing Industry, Lomolo Sisal Processing Industry, and the closed Majani Mingi Sisal Processing Industry—as well as the communities located near these industries. To achieve the objectives, the study employed a mixed-methods approach, integrating both descriptive and experimental research designs. Data collection involved administering interviews to household heads, conducting interviews with key informants (including industry representatives and local environmental officers), andcollecting water samples from the three rivers and adjacent boreholes. Laboratory analyses were performed to establish water quality parameters such as pH, dissolved oxygen (DO), temperature, conductivity, and total dissolved solids (TDS). Quantitative data from the interviews and surveys were analyzed using the Statistical Package for the Social Sciences (SPSS), while laboratory results were compared with World Health Organization (WHO) and Kenyan water quality standards.The findings showed that sisal processing activities have a significant impact on local water resources. Water quality tests indicated notable alterations in pH, reduced DO levels, and elevated TDS and conductivity in water bodies adjacent to processing facilities. There were no notable effects on water turbidity. These changes suggest an increase in pollution, potentially affecting both aquatic life and human health. Although some industries and households have adopted mitigation measures, such as chemical treatment of waste, use of mosquito nets to prevent breeding around waste ponds, and planting trees for natural filtration, these interventions were found to be inadequate and inconsistently applied, highlighting the need for more integrated and effective mitigation approaches to safeguard water quality and protect the environment. This study recommends a sustainable approach that involves integrating advanced waste treatment, community education, and innovative waste repurposing strategies to reduce water pollution and health risks, while enhancing environmental sustainability and regional economic resilience.

Keywords: *Boreholes, P^H, Rivers, Rongai SubCounty, Sisal Industries, Sisal Waste, Water Quality*

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CONCEPTUAL OPERATIONAL DEFINITION OF TERMS

Boreholes: Man-made hydraulically drilled narrow shafts into the ground are constructedto access underground water sources from underground aquifers for domestic, agricultural, or industrial use. They aretypically cased to allow a safe and sustainable water supply (BGS, 2021).

Community Perception: The collective opinions, attitudes, or understanding held by a group of people living in the same locality regarding an issue, activity, or development project based on their shared experiences and social interactions (Sood, S. 2013).

Household Heads: An individual in a household who is recognised by other members of the household as the head*, often because of age, economic provision, or decision-making authority."* (United Nations, 2017. They can be either male or female.

Impacts: The positive and negative, primary and secondary long-term effects or consequences of a development intervention on the environment, water quality or community well-being, intended or unintended (OECD, 2002).

Pollution: The introduction of harmful substances or contaminants into the environment, which, because of their chemical composition or quantity, prevent the environment from functioning normally and cause adverse effects on health and ecological systems." *(*WHO, 2018*).*

Rongai Sub-County: Rongai is an administrative unit and one of the eleven sub-counties of Nakuru County, comprising five wards, and is predominantly an agricultural area that supports crops, livestock, and agro-industrial activities *(*County Government of Nakuru, 2018; Nakuru County Integrated Development Plan, 2018–2022*).*

Sewage Ponds/Dams: Man-made basins or lagoons, which are designed to collect and treat wastewater or effluent from sisal factories (Yhedgo 2017).

Sisal: (*Agave sisalana*) is a monocotyledonous, perennial plant primarily cultivated for the extraction of organic fibre for commercial purposes (Mwaniki 2018). It grows in Arid and Semi-Arid areas

Sisal Industry: The economic sector involved in the cultivation, harvesting, processing, and manufacturing of the sisal plant for its fibre and related products and the subsequent sale of these products (FAO, 2013).

Sisal Waste: The by-products generated during sisal fibre extraction and processing are from parts of the sisal plant. It is comprised of organic pulp, short fibres, and water (Yhdego, 2015).

Water Quality: A measure of water's condition and its suitability for a specific use, evaluated by its physical, chemical, and biological characteristics (Banjeer& Morella, 2011). The water quality parameters include turbidity**,** pH levels, dissolved oxygen content, and the presence of heavy metals and organic compounds (Debaba, 2007). Microbiological quality, on the other hand, refers to the presence of pathogens and bacteriathat may pose health risks to consumers (Kumple et al., 2017).

LIST OF ABBREVIATIONS AND ACRONYMS

GDP : Gross Domestic Product

SPSS : Statistical packages for social science

NEMA : National Environmental Authority

SDG : Sustainable Development Goals

GHG : Greenhouse Gases

TDS :Total Dissolved Solids

P^H :Potential of Hydrogen

% :Percentage

BOD : Biological Oxygen Demand

COD : Chemical Oxygen Demand

DO :Dissolved Oxygen

TDS :Total Dissolved Solids

PI :Principal Investigator

WHO :World Health Organization

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Sisal (Agave sisalana) is a monocotyledonous perennial plant that is mainly planted for the extraction of fiber for commercial purposes. Sisal has a lifespan of 7-10 years, producing 200-250 leaves during its lifetime (Mwaniki 2018). It is native to South America and was historically used by ancient Aztecs and Mayans for fabric and paper. In the 19th century, its production and commercialization boomed with Brazil being the major producer (Shamte, 2001). Sisal was introduced to Tanzania in 1893 by the German East African company, which imported bulbils from Florida, USA. The aim of the introduction of sisal to East Africa was to provide the colonial government with the required natural sisal fiber (Shamte, 2001). The transportation of sisal to the mother colonies became a challenge, prompting the development of railroads in East Africa. During the 1930s, sisal spread to Kenya and other parts of East, Central, and Southern Africa. Initially, sisal farming caused environmental degradation as it replaced native forests; however, sisal farming is considered less harmful than other farming methods because of its minimal use of pesticides, herbicides, and tillage (Center for Invasive Species and Ecosystem Health and the National Park Service, 2016).

In Brazil, the decortication of sisal fiber generates large amounts of wastewater, which are stored in lagoons, ponds, or discarded in rivers. This has caused environmental problems due to the generation of greenhouse gases (such as methane) brought about by anaerobic decomposition of organic waste (Terrapon-Pfaff, 2012). Wastewater from sisal production has caused pollution of water bodies and negatively affected aquatic fauna (Terrapon-Pfaff, 2012). A study in Tanzania showed that physical, chemical, biological, and heavy metal analyses of influent and effluent sisal wastewater resulted in environmental and human impacts (Yhedgo, 2015). The study showed that waste water from sisal industries increased the acidity (p^H) of water bodies. The study also showed that the effluent waste water had a non-conformity rate of 75% on both biological demand oxygen (BOD) and chemical demand oxygen (COD), which have adverse effects on dissolved oxygen in water bodies. The study further showeda lack of pollution from heavy metals in the sisal waste water. (Yhedgo, 2015). Sisal fiber is used in the manufacture of ropes, baskets, rugs, sisal jute bags, and brushes.

In Kenya, the sisal industry is a major contributor to the Gross Domestic Product (GDP), as evident in the 2021 sisal exports, which totaled 14,822 metric tons, generating an income of 2.45 billion Kenya shillings (Agriculture and Food Authority, 2022). Sisal in Kenya is grown in Makueni, Kilifi, TaitaTaveta, and Nakuru counties. This research focused on the sisal industry in Nakuru County due to the existing community need, research gap, and close proximity of sisal industries to river streams. In Rongai Sub-County, Nakuru County, sisal is planted over an approximate area of 3,000 hectares of land with four (4) sisal industries. Each sisal company has constructed its waste dump site and a sewage system for waste disposal and water recycling. Their sewage ponds are usually located in close proximity to water resources like river channels from which they procure water for sisal fiber processing.

Therefore, the study aimedat identifying whether the disposal of sisal waste in ponds situated near river channels negatively affected the quality of water in the rivers around the environs of the industries. Consequently, it aimed to identify the quality of domestic water sources for community members living near sisal industries and how the industries mitigate pollution from sisal waste disposal. The data collected in this study were used to clarify the impact of sisal processing industries on water quality and availability in Rongai Sub-County.

1.2 Statement of the Problem

Disposal of industrial waste is usually associated with air, land, and water pollution. In Rongai sub-county, organic sisal waste from the operating sisal industries is processed using large amounts of water from the surrounding river channels. The resultant wastewater is channeled to waste ponds located next to the river channels. The waste ponds are less than one km from the river channels and are usually characterized by foul smell, especially during the rainy season. The surrounding community perceives that the disposal of waste water near a river channel may have negative impacts on water quality. The indicators of poor water quality resulting from waste disposal may include acidic or alkaline pH levels, bad odour, increased turbidity, and a foamy appearance. The surrounding communities depend on the river water for their day-to-day needs, such as washing, cooking, drinking, and feeding their livestock; therefore, the quality of the river water is of great importance to the community. This research investigated the impacts of sisal processing industries on the water resources of Rongai Sub-County, aiming to demystify or confirm the perceived adverse effects of these industries on water quality.

1.3 Objectives of the Study

1.3.1 Broad Objective of the Study

The broad objective of the study was to assess the impacts of sisal processing industries on water resources in Rongai sub-county, Kenya.

1.3.2 Specific Objectives of the Study

The specific objectives of the study were:

i. To establish measures adopted by sisal industries to mitigate pollution from sisal waste disposal in Rongai Sub-County, Nakuru, Kenya.

ii. To establish the impacts of sisal industry waste disposal on water quality in Molo River, Rongai River, Majani Mingi River, and surrounding boreholes in Rongai Sub-County.

1.4 Research Questions

This study sought to answer the following research questions;

i. Which measures have sisal industries adopted in mitigation of pollution from sisal waste disposal in Rongai Sub-County?

ii. How is the water quality of the Molo River, Rongai River, Majani Mingi River,and surrounding boreholes affected by the sisal waste disposal from the industries?

1.5 Significance of the Study

The findings from this research will be significant for future planning of water source allocation in the area. It will also assist in identifying the negative effects of the sisal industries on water quality, and this will help sisal industries and the county government plan corrective actions needed to mitigate these negative effects on water quality. This will, in general, improve the availability and quality of water in Rongai Sub-County. Furthermore, the study will contribute to Sustainable Development Goal 6 (SDG 6), which aims to ensurethe availability and sustainable management of water and sanitation for all.

1.6 Scope of the Study

The study was conducted in Rongai Sub-County, Nakuru County, where data were collected from two active sisal industries, Athinai and Lomolo industries, as well as one inactive sisal industry, Majani-Mingi . Majani Mingi Sisal Industry and its surrounding water sources were used as a control to showcase the differences in the impact of an active and a closed-down industry. Data was also collected from household heads and traders in order to determine the impacts of sisal industries on the quality of water resources in the area. The key informants for this study were: the Sub-County Environmental Officer, area chiefs from three (3) locations, and key technical workers from two (2) of the sisal industries.

The study also captured water quality data from the three rivers: Molo River, Rongai River, and River Majani Mingi, which are in close proximity to the sisal industries. Water analysis was conducted on water samples collected from the river to determine the influence of sisal waste disposal on water quality.

1.7 Limitations of the Study

The study was limited to three sisal industries in Rongai Sub-County. The climatic conditions, population structures, and economic indices, as well as the Sisal Company's strategies in this sub-county, may not have captured the entirety of the social, economic, and environmental impacts of sisal experienced in other parts of Kenya or the globe. Changes in weather patterns, such as increased rainfall, may have led to higher river water levels, which could result in improved river water quality for a short period. Flower Farms and other agricultural initiatives upstream may have dumped their waste into the river prior to data collection. This may have also affected the quality of water sources.

This limitation was addressed by collecting samples of river water before and after it came in close proximity to the sisal industries. Though there are other boreholes in Soin Ward, this study was limited to boreholes that are in close proximity to the sisal processing industries. Although the study was confined to Rongai Sub-County, it is believed that the recommendations from this study are generally applicable and relevant to the rest of the country and the globe.

1.8 Assumption of the Study

This research study had the following assumptions;

1. The domestic water sources used by the residents of Rongai sub-county are from surrounding rivers and borehole water.
2. Disposal of waste from sisal industries has an impact on the water quality of underground water sources, the Molo River, and River Rongai within the environs of the industries in Rongai Sub-County.
3. Sisal industries have adopted suitable measures for the mitigation of pollution from sisal waste disposal in Rongai Sub-County.

1.9 Risk of the Study

- **Physical Risk:** During data collection, there were potential physical risks involved. One risk was the possibility of accidents, such as falling into the river while collecting water samples. Another risk was encountering hostility from the local community, which would have resulted in physical harm. To address these risks, the following measures were implemented:

- **Safety Measures for Water Collection**: A community guide was engaged to identify and show the safest locations for collecting river water samples. This guide had local knowledge of hazardous areas and helped to ensure that the data collection process was conducted safely.

- **Managing Community Relations**: The community guide also played a crucial role in facilitating positive interactions with the local community. By involving the guide, the research team was able to build trust and secure community support for the research, thereby minimizing the potential for hostility.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter examines the history of sisal, offering a concise overview of the plant, its economic importance, and strategies for managing sisal waste. It also examines both the positive and negative environmental impacts of the sisal industry and outlines global strategies adopted to address its environmental challenges. Additionally, the chapter discusses various water quality parameters and the potential effects of sisal waste on them. Finally, it presents a conceptual framework for the study.

2.2 Sisal Waste Mitigation

2.2.1 Sisal Plant

Sisal in Kenya is grown in Makueni, Kilifi, TaitaTaveta, and Nakuru counties. This research focused on the sisal industry in Nakuru County due to the existing community need, research gap, and proximity of sisal industries to river streams.

Figure 1

Counties Growing Sisal Crop on a Large Scale in Kenya

Sisal (*Agave sisalana*) is a hardy, perennial monocotyledonous plant primarily cultivated for its strong, durable fiber, which is widely used in commercial applications. Native to Mexico (FAO, 2021), sisal thrives in hot climates, particularly in arid and semi-arid regions, due to its low tolerance for excessively moist and saline conditions. The plant is highly resilient, requires minimal inputs for production compared to other crops, and is naturally resistant to most pests and diseases, making it a sustainable choice for fiber production (Barman, 2006). Sisal has a productive lifespan of approximately 12 years, with each plant producing between 180 and 240 leaves annually, depending on factors such as location, altitude, and rainfall. The leaves become harvestable six years after planting (FAO, 2008).

Propagation is typically done using bulbils, which are preferred over suckers due to their higher efficiency in establishing healthy plants (Haque et al., 2011). Sisal nurseries require continuous care, including regular weeding and irrigation for about eight months (Mwaniki, 2018). The leaves are considered mature when they reach a length of approximately 0.6 meters or when the terminal spine's color changes to ashy brown (Mwaniki, 2018).

Sisal is adaptable to a variety of soil types but grows best in well-drained soils rich in moisture and nutrients such as lime, magnesia, potash, and phosphoric acid (Ikitoo & Khayrallah, 2001; Mwaniki, 2018). It does not thrive in clay soils, which can impede root development and reduce overall fiber yield. For optimal productivity, harvesting begins from the lowermost whorls and progresses upwards (Shamte, 2001 & 2012; Mwaniki, 2018). The harvesting process is performed manually using a sickle or a curved knife, with workers cutting leaves at the base and trimming the outer spine. On average, 15 leaves are harvested per plant at a time, bundled into stacks of 50, and transported to the decortication site via trolleys (Naik, Dask, R.C., & Goel, 2016; Mwaniki, 2018).

Sisal leaves contain a strong, coarse fiber that must be extracted immediately after harvesting to prevent degradation. The extraction process involves removing the pulp through mechanical decortication or hand-stripping. On average, one hectare of sisal yields approximately one ton of dried fiber; however, with favorable climate and soil conditions, yields can reach up to four tons per hectare (FAO, 2021). The solid waste generated from fiber extraction can be repurposed as organic manure to improve soil fertility and support nursery growth (Oyen, 2003).

In post-extraction, the fibers are washed, dried, and brushed to remove impurities. The drying process is crucial, as improperly dried fiber may deteriorate in quality, affecting its market value. Once processed, the fiber is classified based on length, color, and texture before being packaged for distribution. The highest-grade fibers are used in premium products such as fine textiles, whereas lower grades are utilized in rougher applications like ropes and mats (Mwaniki, 2018).

Sisal fiber is highly versatile, with applications in numerous industries. It is commonly used to manufacture twines, ropes, strings, carpets, mats, and various handicrafts (Mwaniki, 2018). Due to its high fold endurance and absorbent properties, sisal pulp serves as a sustainable alternative to wood fiber in paper and cardboard production (FAO, 2021). Its porous nature makes it ideal for manufacturing tea bags and cigarette filters.

In the textile industry, sisal is used as a buffing material - strong enough to polish steel yet soft enough to prevent scratching (FAO, 2021). Additionally, sisal fiber is used in the reinforcement of composite materials, including fiberglass, rubber, plastics, insulation, and pipes. In the construction sector, sisal-reinforced cement is used in low-cost housing as a sustainable alternative to asbestos, enhancing structural durability while maintaining eco-friendly benefits. Sisal fibers are also utilized in the automotive industry for making biodegradable car interiors and door panels. Beyond fiber production, sisal waste has significant potential in bioenergy production. Some processing plants convert sisal waste into biogas, which can serve as an alternative energy source, thereby reducing reliance on fossil fuels (FAO, 2021; Naik, Dask, & Goel, 2016). The remaining solid waste can be processed into animal feed, offering an additional economic benefit for farmers (Oyen, 2003; Mwaniki, 2018).

Sisal is also used in manufacturing dartboards, furniture padding, and geotextiles for soil erosion control (FAO, 2021). The biodegradability of sisal-based products makes them an eco-friendly alternative to synthetic materials, reducing plastic pollution and supporting sustainable development initiatives worldwide (Haque, Sharma, & Rao, 2011; Shamte, 2012). Sisal farming presents several environmental benefits. As a drought-resistant crop, it thrives in areas where other agricultural activities may be unviable, helping to combat desertification and soil erosion (FAO, 2021; Ikitoo & Khayrallah, 2001). Additionally, its ability to sequester carbon contributes to climate change mitigation (Shamte, 2012). The economic benefits of sisal farming are also significant, providing employment opportunities in rural areas where alternative sources of income may be limited (Mwaniki, 2018).

Countries such as Brazil, Tanzania, Kenya, and China are among the leading producers of sisal, with the global demand for natural fibers driving increased investment in sustainable sisal farming (FAO, 2021; Naik et al., 2016). With the growing concern over synthetic fiber pollution, the shift toward biodegradable, plant-based alternatives, such as sisal, is expected to increase (Barman, 2006).

Sisal is a versatile, eco-friendly crop with significant economic and industrial applications. Its resilience, low maintenance requirements, and sustainability make it a valuable resource across multiple sectors, including agriculture, construction, textiles, and bioenergy (FAO, 2021; Mwaniki, 2018). The efficient utilization of both sisal fiber and its by-products enhances its role in promoting environmental conservation and sustainable development (Naik et al., 2016). As global industries increasingly prioritize sustainability, the demand for sisal and its derivatives is likely to expand, reinforcing its status as a key natural fiber in the modern economy (FAO, 2021; Shamte, 2012).

2.2.2 Sisal Waste

Only 4% of the sisal leaf consists of fiber. In comparison, the remaining 96% becomes organic waste during the extraction process, which must be either discarded or incinerated, resulting in both financial and environmental costs (NIRAS-LTS et al., 2021). This issue of sisal waste disposal is especially prevalent in estate-based production systems, where sisal leaves are transported to a centralized factory for decortication, generating significant biomass waste that requires proper disposal (Shamte, 2001). Many sisal industries rely on water to transport the waste material from the decorticator to a sewage pond system or directly into rivers. However, the direct discharge of liquid sisal waste into water bodies can deplete oxygen levels, reduce water quality, and destroy aquatic habitats (Broeren, Kuling, Worrell, & Shen, 2017). Additionally, sisal wastewater typically has a high pH level (above 8.5), which can impart an unpleasant taste to water and cause tissue damage upon human contact (Shamte, 2001).

Proper recycling of sisal waste is crucial for minimizing environmental pollution while generating valuable commercial by-products (Barman, 2006). Methane emissions from decomposing sisal waste significantly contribute to greenhouse gas (GHG) emissions, highlighting the need for sustainable waste management practices (Broeren et al., 2017). In Tanzania, for instance, four sisal estates generate approximately 90,000 liters of wastewater daily, totaling 32,850,000 liters annually (Yhdego, 2015). This can lead to increased acidity levels in water and a decline in dissolved oxygen, rendering the water unsuitable for domestic use and threatening aquatic life (Yhdego, 2015).

Despite these challenges, sisal waste has significant potential for reuse in various industries. Organic waste residues from the fibre extraction process can be transformed into animal feed, bioenergy, pesticides, organic fertilizers, and pharmaceuticals such as hecogenin, a compound used in steroid drug production (Mwaniki, 2018). Some sisal processing plants have adopted innovative waste management techniques, converting waste into biogas for energy production and utilizing solid residues as soil conditioners to improve agricultural productivity (FAO, 2021). Additionally, researchers have explored the potential of sisal waste in the production of biodegradable packaging materials and composite boards, offering sustainable alternatives to conventional synthetic products (Naik, Dask, & Goel, 2016).

Efforts to mitigate the environmental impact of sisal waste should focus on enhancing industrial efficiency, implementing circular economy strategies, and promoting policies that encourage sustainable management of sisal waste (FAO, 2021). With improved waste utilization, the sisal industry can make a significant contribution to environmental conservation while generating economic benefits for local communities (FAO, 2021).

2.2.3 Sisal Waste Mitigation

Kenya produces approximately 27,000 tons of sisal fibre per annum (Fiber Crops Directorate, 2019). Each ton of fibre generates around 24 tons of residual pulp waste and 100 m^3 of wastewater (Terrapon-Pfaff et al., 2012). While a small portion of the residues may be repurposed as organic fertilizer and animal feed, the majority is discarded in lagoons, ponds, open land, or into watercourses (FAO, 2020; Terrapon-Pfaff et al., 2012). Without appropriate mitigation measures, this waste can cause severe environmental pollution due to its high organic load, presence of heavy metals such as lead and chromium, phenolic compounds, organic solids, and sulphates (Antony, 2024).

After decortication, only 4% of the sisal leaf is used for fibre, while the remaining 96% becomes residual waste, primarily in the form of moisture-rich pulp (NIRAS-LTS et al., 2021). Some sisal processing companies, such as Kilifi Plantations Limited (KPL), have successfully harnessed sisal waste to generate electricity, biogas, and cattle feed (Fischer et al., 2010; KPL, 2020). By converting residual waste into bioenergy, biogas, and feedstock, these efforts mitigate large-scale disposal challenges and provide sustainable economic benefits (Schwaninger, 2012).

One of the major challenges of utilizing sisal decorticated waste (SDW) is its high acidity, which limits its application in various industries. However, innovative recycling approaches have emerged to address this issue. For instance, SDW has been used as a substrate for rearing Black Soldier Fly larvae, which serve as a sustainable protein source in animal feeds (Aziza, 2022). Additionally, research is ongoing to explore alternative uses for SDW, including the development of biodegradable packaging materials and composite boards (FAO, 2021).

According to the Kenya Agricultural Research Institute, several promising methods for treating sisal wastewater have been identified (East African Agricultural and Forestry Journal, XV (No. 1), pp. 3_11). These includes:

- Treatment by sedimentation;

This is where the sisal wastewaters are screened through a wire gauze, and sediments are allowed to settle. This method results in only a slight reduction of the polluting organic particles in the wastewater.

- Treatment with coagulants;

Treatment of sisal waste with chemical coagulants such as calcium hydroxide, ferric chloride, ferric sulphate, and aluminumsulphate will result in a little reduction in the value of B.O.D., which led to the conclusion that the addition of coagulants isnot a suitable method in the treatment of sisal waste.

- Treatment by fermentation;

Natural fermentation of wastewater will lead to increased pH levels to a value of around 8, which is less acidic; however, the value of dissolved oxygen will be reduced. This method is still a suitable option for sisal wastewater treatment due to the reduced p^H levels.

- Treatment by aeration;

This has little impact on the amount of dissolved Oxygen. It is best done alongside activated sludge processing.

- Treatments by biological treatment through the re-use of effluents;

This will result in the release of treated effluent with minimal negative impact on the environment, while allowing for the reuse of wastewater.

These mitigation strategies not only reduce environmental harm but also promote the circular economy within the sisal industry. Encouraging investment in sustainable waste management can enhance productivity while minimizing ecological impacts. Moreover, government policies and private-sector collaboration are essential to scaling up these sustainable waste utilization initiatives.

2.3 Water Quality

Water quality encompasses itsphysical, chemical, and microbiological properties, which determine suitability for domestic, agricultural, and industrial use (Banjeer & Morella, 2011). The physical quality of water includes turbidity, which affects its clarity and potential contamination with suspended particles. The chemical quality of water is determined by factors such aspH levels, dissolved oxygen content, and the presence of heavy metals and organic compounds (Debaba, 2007). Microbiological quality, on the other hand, refers to the presence of pathogens and bacteria that may pose health risks to consumers (Kumple et al., 2017).

In Most African urban towns and cities, there is limited access to piped water, with the average coverage reported at 63% across the continent (Kumple et al., 2017). According to NEMA, water supply coverage in Nakuru County is roughly at 66%. Nakuru County is endowed with natural water resources, including rivers, springs, wells, and boreholes, spread across the county. In Rongai Sub-County, the main sources of domestic water supply are the River Molo, a permanent river; the River Rongai, a seasonal river; and numerous boreholes. Other sources include piped water from the Chemasusu dam and rain-harvested water. According to Mwangi and Gabriel (2008), pollution of surrounding streams due to human activities, effluents from industries, chemical runoffs from horticultural farms, and washing clothes and vehicles next to river channels have had serious effects on the Molo River. All of these pollutants in the river have had harmful results downstream.

Water quality is particularly crucial in urban and peri-urban environments, where water supplies are often vulnerable to contamination from industrial and domestic pollution (Debaba, 2007). In many African towns and cities, access to piped water remains low, with an estimated 63% coverage across the continent (Kumple et al., 2017). In Nakuru County, for example, water supply coverage is approximately 66%**,** with natural water sources, including rivers, springs, wells, and boreholes, playing a critical role in the water supply (NEMA, 2020). However, these sources are vulnerable to contamination from human activities, industrial effluents, and agricultural runoff (Mwangi & Gabriel, 2008).

Sisal waste has been identified as a significant source ofwater pollution, particularly in regions where sisal processing is widespread. During fiber extraction, large volumes of organic waste and wastewater are generated, which, if not properly managed, contribute to the degradation of water quality (Yhdego, 2015). According to FAO (2020), sisal processing plants discharge wastewater with high levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and suspended solids**,** leading to oxygen depletion in receiving water bodies. The high organic load promotes microbial activity, resulting in oxygen depletion that negatively impacts aquatic life (Broeren, Kuling, Worrell, & Shen, 2017).

One of the major chemical effects of sisal waste on water quality is the increase in pH levels due to alkaline compounds present in the waste. Research has shown that sisal effluent often exceeds a pH of 8.5, which can cause harmful effects on aquatic ecosystems (Shamte, 2001). High pH levels reduce the solubility of essential minerals in water, affecting aquatic biodiversity and making the water unsuitable for consumption and irrigation (FAO, 2021).

Another concern is the presence of heavy metals, such as lead and chromium, which can sometimes be found in sisal waste due to the use of processing chemicals (Antony, 2024). When these metals accumulate in water bodies, they pose health risks to both aquatic organisms and human populations, as they can be bioaccumulated and biomagnified through the food chain (Terrapon-Pfaff et al., 2012). Long-term exposure to heavy metals in drinking water has been linked to neurological disorders, organ damage, and reproductive health issues (Mwaniki, 2018).

The microbiological effects of sisal waste on water quality are also significant. Since sisal waste is rich in organic matter, it serves as a breeding ground for pathogenic bacteria and parasites, increasing the risk of waterborne diseases such as cholera, dysentery, and typhoid (Yhdego, 2015). The untreated discharge of sisal wastewater into rivers has been reported to contribute to increased cases of waterborne illnesses in communities that rely on these water sources for drinking and domestic use (FAO, 2020).

Furthermore, sisal waste contributes to eutrophication, a process where excess nutrients, particularly nitrogen and phosphorus, enter water bodies and promote the overgrowth of algae (Fischer et al., 2010). Excessive algal growth can block sunlight penetration, disrupt aquatic food chains, and lead tomass fish die-offs due to oxygen depletion (NIRAS-LTS et al., 2021). In severe cases, eutrophication leads to the formation of harmful algal blooms (HABs), which produce toxic substances that further degrade water quality and pose health risks to both humans and animals (Schwaninger, 2012).

To address the negative impacts of sisal waste on water quality**,** several mitigation strategies have been proposed and implemented globally. Constructed wetlands have been identified as an effective natural wastewater treatment solution, as wetland plants help absorb pollutants and filter contaminants before the water is released into the environment (East African Agricultural and Forestry Journal, 2015). Additionally, anaerobic digestion has proven to be a valuable method for treating sisal wastewater while producing biogas as a renewable energy source (Schwaninger, 2012).

Other treatment technologies, such as coagulation and flocculation, have been employed to remove heavy metals and organic pollutants from sisal wastewater before discharge (Aziza, 2022). The implementation of zero-waste circular economy models, where all components of sisal waste are repurposed for bioenergy, animal feed, or organic fertilizers, has also been recommended as a sustainable approach to sisal waste management (FAO, 2021).

2.3.1 Water Quality Parameters

2.3.1.1 P^H

P^H is a measure of how acidic or alkaline (basic) water is, with a scale ranging from 0 to 14. A P^H of less than **7** indicates acidity**,** a P^Hgreater than 7 indicates alkalinity**,** and a P^H of 7 is neutral (Water Science School, 2019). In its purest form, water has a P^H of 7**.** A lower P^H means there are more hydrogen ions (H^+), while a higher pH indicates fewer hydrogen ions; thus, P^H is a measurement of the concentration of hydrogen ions in water-based solutions (Shah, 2019).

Drinking water and other water-based liquids with varying P^H levels may impact human health in different ways. Water with a very lowP^H can indicate the presence of chemical or heavy metal contamination, which can have negative effects on both human health and the environment. The U.S. Environmental Protection Agency (EPA) recommends that municipal drinking water suppliersmaintain a pH level between 6.5 and 8.5 to ensure safety (EPA, 2023).

Acidity refers to the quantitative capacity of water to react with hydroxyl ions (OH^-) and neutralize an alkali solution (Shah, 2017). Carbon dioxide (CO_2) is one of the primary contributors to acidity in water, as it lowers the pH during precipitation, photosynthesis, respiration, and decomposition (Manjra, 2010; Atlas Scientific, 2022).

Sisal waste contains organic acids and compounds that significantly influence water P^H levels. During the decortications process, large quantities of organic matter and residual pulp are produced, which undergo microbial decomposition and release acidic compounds into water bodies (FAO, 2020). This decomposition process results in a drop in P^H levels, making the water more acidic and unfit for aquatic life and human consumption (Broeren, Kuling, Worrell, & Shen, 2017).

Studies show that sisal processing wastewater has a P^H level below 5.5, which is highly acidic and negatively affects water quality (Yhdego, 2015). Water with such acidity can cause corrosion of pipes and infrastructure, leading to increased levels of toxic metals such as lead, copper, and zinc in drinking water (Schwaninger, 2012). Additionally, low P^H levels can result in toxicity to fish and aquatic organisms by disrupting ion balance and damaging gill tissues (Antony, 2024).

Research conducted in Tanzania found that sisal estate wastewater significantly lowered the P^H of surrounding water sources, causing habitat destruction for aquatic life and making the water unsuitable for irrigation and domestic use (Yhdego, 2015). The presence of sulfuric and tannic acids in sisal waste further contributes to acidification, affecting the biochemical composition of water bodies (Terrapon-Pfaff et al., 2012). Acidic water also reduces the availability of essential minerals such as calcium and magnesium, which are necessary for plant growth and soil fertility (Mwaniki, 2018). Another major impact of sisal waste acidity is its role in enhancing the solubility of toxic heavy metals such as chromium, cadmium, and lead. When sisal waste is discharged into rivers and ponds, the resulting acidity increases the mobility of heavy metals, leading to bioaccumulation in fish and other aquatic organisms (FAO, 2021). This poses a serious threat to food safety and public health, as these contaminants can enter the human food chain through the consumption of fish (Aziza, 2022).

To reduce the negative effects of sisal waste acidity**,** several mitigation strategies have been recommended. Lime treatment ($CaCO_3$) and alkaline neutralization have been widely used to adjust P^H levels and reduce acidity in wastewater before disposal (Schwaninger, 2012). Additionally, constructed wetlands and biological treatment methods have been proposed as sustainable solutions for filtering and neutralizing acidic sisal effluents (East African Agricultural and Forestry Journal, 2015). Adopting anaerobic digestion technologies has also proven effective in P^H, thereby reducing the acidic load in water bodies while providing an alternative renewable energy source (Terrapon-Pfaff et al., 2012). This can help minimize the sisal industry's environmental footprint and protect water resources from acidification-related degradation (FAO, 2021).

2.3.1.2 Turbidity

Turbidity is the measure of relative clarity of a liquid or a measure of the amount of light that is scattered by material in the water when light is shone on the water sample

(Lenntech, 2023). Small particles like clay, silt, and microorganisms can be suspended in water and cause light scattering, giving water a murky or cloudy appearance (Chebet, 2020). High turbidity means that water is not very clear, while low turbidity means that water is clearer. Excess turbidity can mean that heavy metals have been added to the water supply, like mercury, lead, and cadmium, which are toxic to humans (EPA, 2023). Causes of turbidity in water are erosion, runoffdebris, wastewater, and decayed plant and animal material.

Sisal waste contributes significantly to increased turbidity levels in water bodies, particularly in regions where sisal processing plants discharge waste into rivers, streams, and ponds (FAO, 2020). The fibrous residues, organic solids, and wastewater released during the decortication process contain high concentrations of suspended solids, which reduce water clarity and impact aquatic ecosystems (Terrapon-Pfaff et al., 2012).

Studies have shown that sisal wastewater contains high levels of suspended organic matter, which accumulates in rivers and lakes, leading to chronic turbidity (Mwaniki, 2018). Research in Tanzania’s sisal-growing regions found that wastewater from sisal estates led to persistent turbidity problems, affecting water quality and aquatic life (Yhdego, 2015). The accumulation of organic residues in water bodies blocks sunlight penetration, which reduces photosynthesis for aquatic plants and lowers dissolved oxygen levels, ultimately threatening fish populations (Broeren, Kuling, Worrell, &Shen, 2017).

In addition to reducing light penetration, sisal waste turbidity increases the sedimentation rate in rivers and lakes, leading to the degradation of aquatic habitats (Schwaninger, 2012). Suspended sisal particles can clog the gills of fish, leading to respiratory stress and higher mortality rates among aquatic species (Antony, 2024). Furthermore, studies indicate that effluent from the sisal industry can lead to long-term siltation, which alters river flow patterns and contributes to increased flood risks in affected areas (FAO, 2021).

The presence of sisal-derived organic matter in water bodies has also been linked to increased microbial activity, which further depletes oxygen levels and promotes the growth of harmful bacteria (Aziza, 2022). High turbidity in sisal-processing regions has been associated with an increased risk of waterborne diseases, including cholera and dysentery, as pathogens attach to suspended particles and become more difficult to remove through conventional water treatment methods (East African Agricultural and Forestry Journal, 2015).

2.3.1.3 Temperature

Temperature is a measure of the average kinetic energy of water molecules and is measured on a linear scale of degrees Celsius (℃) or degrees Fahrenheit *(*Clean Water Treatment, 2004). Theaesthetic objective for water temperature for Drinking Water Quality is 15 ^{o}C̊ (WHO, 2011). Temperature influences several other parameters and can alter the physical and chemical properties of water (Si, P, 2015). Water temperature can increase the solubility of toxic compounds, such as heavy metals like cadmium, zinc, and lead (White, 1997).

In general, increased water temperature can result in decreased dissolved oxygen available to aquatic life, increased solubility of metals and other toxins in water (Abbas SH, 2014), possible increased toxicity of some substances to aquatic organisms and algae blooms, which typically occur during the summer season or periods of unusually warm temperatures (EPA, 2021),and the EPA’s 2023 Quality criteria for water recommends temperature to be below for aquatic organisms. The best temperature for drinking water is room temperature, 20°C, for maximum flavor, or chilled to 6°C for maximum refreshment. However, for achieving proper hydration, NCBI (2013) showed that a water temperature of 16°C is the optimum point for hydrated athletes or other subjects.

Sisal waste can significantly impact water temperature, particularly in regions where sisal processing plants discharge wastewater into rivers, lakes, or other aquatic systems. The decortication process generates large volumes of wastewater with a higher temperature than natural water bodies, which can lead to localized thermal pollution (Terrapon-Pfaff et al., 2012). The release of warm effluents into natural water bodies alters thermal regimes, potentially affecting aquatic ecosystems (FAO, 2020).

The rise in water temperature due to sisal waste effluents can lead to a decrease in dissolved oxygen (DO) levels, as warm water holds less oxygen compared to cooler water (Si, 2015). Lower DO levels can lead to hypoxic conditions, which negatively impact fish and other aquatic organisms, thereby reducing biodiversity and ecosystem stability (Abbas, 2014). Additionally, an increase in water temperature can accelerate the metabolic rates of aquatic species, increasing their oxygen demand while simultaneously reducing oxygen availability (EPA, 2021).

Another concern related to temperature changes caused by sisal waste discharge is the increased solubility of toxic compounds. Higher temperatures can enhance the dissolution of heavy metals such as cadmium, lead, and zinc, making them more bioavailable and toxic to aquatic life (White, 1997). This exacerbates water contamination issues in sisal-growing regions, posing risks to both wildlife and human populations dependent on these water sources (FAO, 2021).

Furthermore, elevated temperatures in water bodies receiving sisal waste effluents can promote the rapid growth of algae, leading to algal blooms (EPA, 2023). These blooms can reduce light penetration, disrupt aquatic food chains, and further deplete oxygen levels through decomposition processes (Manjar, 2010). Algal blooms have also been associated with the production of harmful toxins that can affect fish, livestock, and even human populations relying on these water sources (Atlas Scientific, 2022).

To mitigate the thermal impacts of sisal waste, strategies such as cooling ponds, constructed wetlands, and improved wastewater treatment systems should be implemented to regulate effluent temperatures before discharge into natural water bodies (Schwaninger, 2012). Proper wastewater management can help maintain ecological balance, minimize oxygen depletion, and reduce the risks associated with thermal pollution in sisal-producing regions.

2.3.1.4. Electrical Conductivity

Water conductivity is the measurement of the ability of water to pass an electrical current through it, and electrical water conductivity is the ability of water to conduct an electric current. Electrical conductivity occurs due to the concentration of ions that come from chemicals or salts breaking down and dissolving in water as negative and positive ions (O`Donnell, 2021). Conductivity increases as the concentration of ions increases (APHA, 2005). Conductivity ranges tell us a lot about the quality of water because it is a direct measurement of how many pollutants and contaminants are in water, and this is an indirect measurement of salinity (Atlas Scientific, 2023). Salty water has a great conductivity, and its electrical conductivity is higher than that of normal water (FONDIREST, 2023). Pure water has a low electrical conductivity (Burton FL, 2003).

Studies have shown that sisal processing wastewater contains elevated concentrations of sodium, potassium, chloride, and sulfate ions, which contribute to increased EC in affected water bodies (FAO, 2020). High electrical conductivity in water affects aquatic ecosystems by altering osmotic balance in aquatic organisms, potentially leading to dehydration or physiological stress in fish and invertebrates (EPA, 2023). Additionally, increased conductivity can negatively impact agricultural practices by causing soil salinization when such contaminated water is used for irrigation (FONDIREST, 2023). To mitigate the impact of sisal waste on water conductivity, effective wastewater treatment strategies such as constructed wetlands, electrocoagulation, and bioremediation should be employed to remove excess ions before discharge into natural water bodies (Schwaninger, 2012).

2.3.1.5 Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) refer to the concentration of dissolved organic and inorganic substances present in water, including minerals, salts, metals, and other solutes. TDS levels are a crucial parameter in determining water quality, as high concentrations can indicate pollution and pose potential health risks (EPA, 2023). Water with excessive TDS can negatively impact aquatic ecosystems, agriculture, and drinking water supplies (Atlas Scientific, 2023).

Sisal processing contributes significantly to TDS levels in water due to the release of organic compounds, alkaloids, and heavy metals during decortication and waste disposal. Studies indicate that sisal wastewater contains high concentrations of organic matter, potassium, calcium, magnesium, and chloride ions, which increase TDS levels in receiving water bodies (Terrapon-Pfaff et al., 2012). High TDS levels can alter the taste of drinking water, making it unpalatable and unsuitable for human consumption, particularly when levels exceed 500 mg/L, as recommended by the World Health Organization (WHO, 2011).

In aquatic environments, elevated TDS levels from sisal waste can lead to reduced dissolved oxygen, making it difficult for fish and other aquatic organisms to survive (FAO, 2020). High concentrations of dissolved solids can also cause water hardness, affecting domestic use and industrial processes (Burton, 2003). Additionally, excessive TDS in irrigation water can lead to soil salinization, which reduces agricultural productivity and negatively impacts crop yields (FONDIREST, 2023).

To mitigate the effects of sisal waste on TDS levels, proper wastewater management techniques such as sedimentation, filtration, and reverse osmosis should be employed before discharge into natural water bodies (Schwaninger, 2012). Additionally, adopting sustainable sisal processing methods, such as biogas production from waste residues, can reduce the volume of dissolved solids released into the environment while providing alternative uses for waste materials (Mwaniki, 2018).

2.3.1.6 Dissolved Oxygen (DO)

Amount of oxygen present in water (DO) is considered an important measure of water quality as it is a direct indicator of an aquatic resource's ability to support aquatic life (US EPA, 2023). The amount of dissolved oxygen used by aerobic organisms to break down organic material present in a water sample is called biochemical oxygen demand (BOD) (Lenntech, 2023*)*. The common sources utilizing BOD are leaves, woody debris, topsoil, animal manure, food-processing plants, wastewater treatment plants, feedlots, failing septic systems, urban stormwater runoff, and effluents from pulp and paper mills and sisal industries.

The greater the BOD in a particular water body, the less oxygen available for the aquatic life forms in that particular water body (APHA, 2005). Aquatic life forms would be more stressed, suffocate, and ultimately die due to high BOD (David A., 2008). If oxygen is not continuously replaced by natural or artificial means in the water, the oxygen concentration will reduce as the microbes decompose the organic materials. This need for oxygen is called the biochemical oxygen demand (BOD).

The more organic material there is in the water, the higher the BOD used by the microbes (Tchobanoglous G, 2003). The higher the concentration of dissolved oxygen, the better the water quality and the lower the BOD. Oxygen is slightly soluble in water and very sensitive to temperature. For example, the saturation concentration at 20°C is about 9 mg/L and at 0°C is 14.6 mg/L (Fondirest, 2023).Chemical oxygen demand is the amount of oxygen required to oxidize organic matter present in water chemically, and is typically measured in wastewater to determine how much oxidizing chemicals were used in water treatment (Tamar M, 1999;Hammer MJ, 2011).Sisal industrial water waste consists of organic matter that reduces dissolved oxygen in water, resulting in poor water quality.

Sisal processing has a significant impact on dissolved oxygen levels in water bodies due to the discharge of organic-rich wastewater generated during the decortication process. This wastewater contains high levels of biodegradable organic matter, which promotes microbial activity when released into aquatic systems. As microorganisms break down the organic matter, they consume oxygen, leading to oxygen depletion in the water (Terrapon-Pfaff et al., 2012). This process, known as biochemical oxygen demand (BOD), can drastically reduce oxygen availability for aquatic life (Yhdego, 2015).

Research conducted in Tanzania's sisal-producing regions indicates that sisal wastewater significantly lowers dissolved oxygen levels in nearby rivers and lakes, resulting in hypoxic conditions that threaten fish populations and aquatic biodiversity (Mwaniki, 2018). Low dissolved oxygen levels can cause fish kills, disrupt breeding cycles, and alter aquatic ecosystems (FAO, 2020). Additionally, the accumulation of sisal waste at the bottom of water bodies can lead to the production of hydrogen sulfide (H_2S). This toxic gas further reduces oxygen availability and creates an unpleasant odor (Schwaninger, 2012).

2.4 Legal Frameworks on Waste Disposal

The legal framework for Kenya's sisal sector involves both government bodies and the private sector. The private sector primarily focuses on production, processing, and sales, while government institutions focus on policy, licensing, and regulation (NIRAS LTS

International, 2001). Some of the policy and regulatory areas provided by the government on the use and management of wastes from sisal processing include:

a. National Environmental Management Authority (NEMA)

This environmental regulatory body is responsible for licensing and enforcing regulations related to environmental pollution from industrial and domestic waste (NEMA ACT of 2010). NEMA requires an Effluent Discharge License (EDL) for any facility generating effluents that could harm groundwater, surface water, or coastal waters.Effluent tests to ensure compliance are carried out at facilities generating effluents annually by NEMA.

b. The Environmental Management and Co-ordination Act (EMCA, 2012)

This act establishes legal and institutional mechanisms for environmental management. This is carried out through a three-pronged approach that involves regulations on impact assessments and audits, as well as water and air quality. The main aim of EMCA is the protection of air, water, and soil quality from poor handling of solid and liquid wastes from industries.

c. The Ministry of Agriculture, Livestock and Fisheries (MoALF)

This is the main body responsible for policy making, technical, legal, and financial support, as well as promotion and advocacy for the sisal sector in Kenya. The Fiber Crops Directorate (FCD), a part of the Agriculture and Food Authority (AFA), serves as the primary support and regulatory body for the sector. (NIRAS LTS International, 2001).

2.5 Theoretical Framework

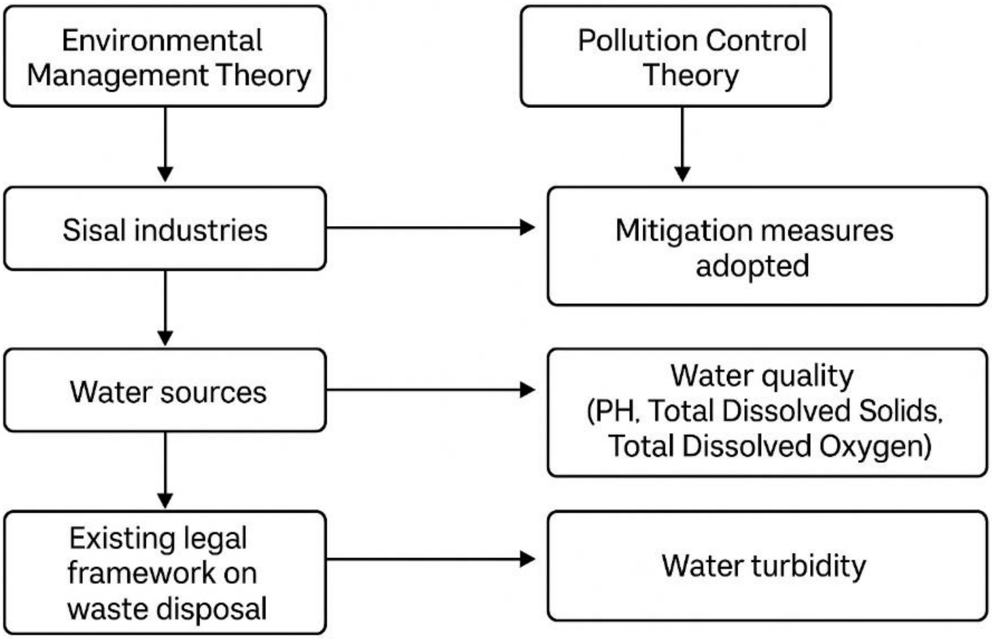
The theoretical framework for this study is grounded in Environmental Management Theoryand Pollution Control Theory, which show the relationship between industrial activities, legal regulatory frameworks, and environmental outcomes.Environmental Management Theoryproposes that industrial operations, such as sisal industries, exert significant impacts on natural resources, including water bodies. The theory posits that sustainable industrial management practices are essential to strike a balance between economic development and ecological integrity.Pollution Control Theory explains how legal frameworks, policies, and mitigation strategies can minimize the negative environmental impacts of industrial and anthropogenic activities. This theory emphasizes the role of existing legal frameworks in influencing the adoption of mitigation measures and the resulting outcomes, such as water quality.

The framework assumes that:

a) The operational presence of sisal industriescontributes to the generation of industrial effluents, which affect water quality indicators such as pH**,** Total Dissolved Solids (TDS)**,** Dissolved Oxygen (DO)**,** and turbidity.
b) The proximity of water sources to sisal industriesinfluences the extent of water usage and contamination risks, thereby affecting local water quality.Existing legal frameworks determine the degree to which industries implement mitigation measures to minimise environmental pollution.

Figure 2

Theoretical Framework

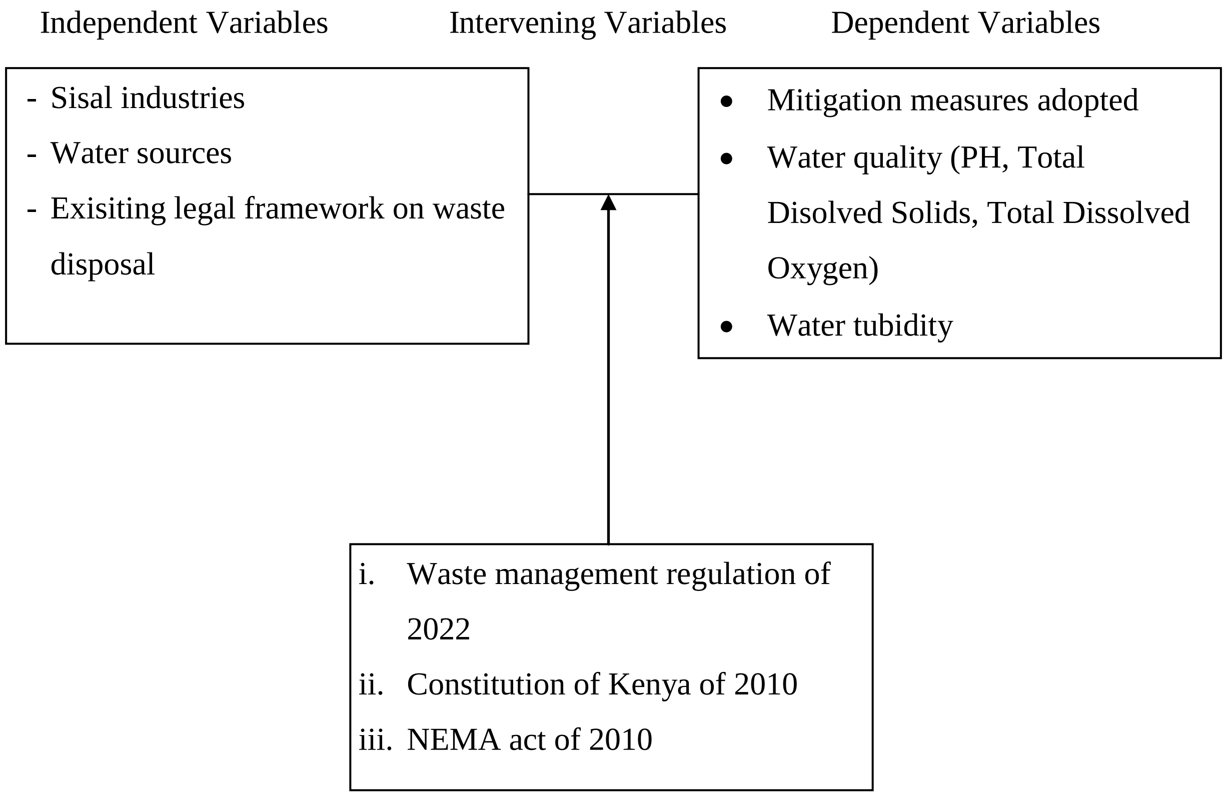


2.6 Conceptual Framework

From the Literature review, a conceptual framework was developed. It illustrates the relationships between the independent, dependent, and intervening variables of the research study.

Figure 3

Conceptual Framework



Source: Authour (2025)

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter outlines the methodology employed in this study, detailing the research design adopted, the study area, target population, sampling procedures, and sample size. It describes the data collection methods and the instruments used for gathering data, discusses the reliability and validity of the study instruments, and outlines the data analysis process. Additionally, it addresses the ethical issues that were observed during the research.

3.2 Research Design

Both descriptive and experimental research designs were adopted for this research. Descriptive research is a form of research method used to obtain information that describes a phenomenon, situation, or population. This design helped answer the 'what, when, where, and how' questions regarding the research problem (Sharma &Sohil, 2019). Descriptive research designs primarily utilizequantitative data. It provided for the identification, measurement, and observation of variables but did not allow for the control or manipulation of those variables. This design facilitated the collection and analysis of data for the research, allowing for the manipulation of variables and thereby enabling a comprehensive understanding of the research questions, which facilitated the acquisition of appropriate answers.

This allowed the researcher to gather information on various variables at individual levels at a specific point in time. This design was adopted to assist in determining Objective One, which focused on measures to mitigate pollution of sisal waste in water resources. Through this research method, surveys were conducted among household heads and key informants, and the results were used to ascertain findings and answer the research questions.

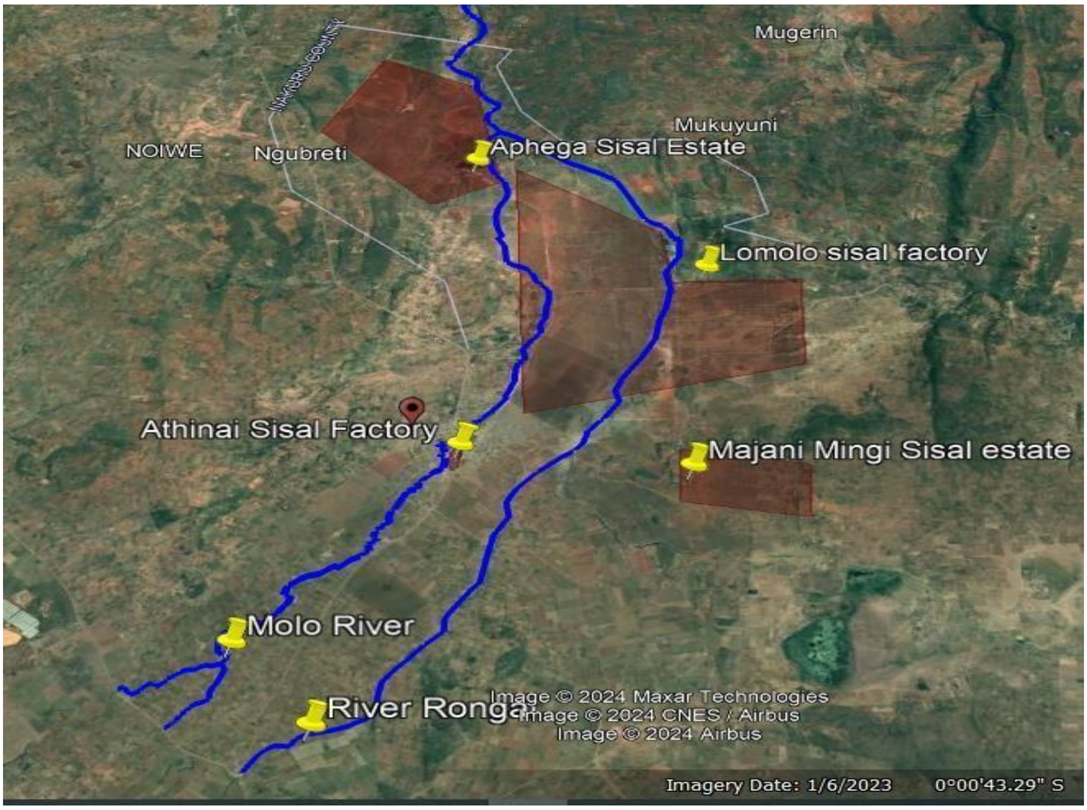
An experimental research design is a research method that enables researchers to establish a cause-and-effect relationship between two or more variables in a controlled environment, allowing them to draw specific conclusions about a hypothesis or answer a research question. This study employed an experimental research design to investigate objective two, which is to determine the effects of sisal waste on water quality. Water samples from the river were analyzed and compared against the WHO and NEMA standards on drinking water quality. The results were used to answer the research questions and contribute to the findings of this study.

3.3 Location of the Study Area

The study area was Soin Ward, Rongai Sub-County in Nakuru County, between Nakuru City to the south and Mogotio Town to the north. It covers an area of 292.5 sq. km, with geographic coordinates of Latitude: -0°1'59.99" and Longitude: 35°58'0.02". It liesatan altitude of 1590 meters above sea level. The region is classified under ecological zone IV, which is a semi-arid area. Figure 4 below shows a map of the two main rivers and four sisal industries in Soin ward.

Figure 4

Map of the Sisal Industries and Rivers in Soin Ward



3.4 Population of the Study

The study area was located in Nakuru County, specifically in Rongai Sub-County, within Soin Ward. Soin ward has a total of 3 rivers (Molo River, Rongai River, and Majani Mingi River). Molo River is a permanent river, while Majani Mingi and Rongai rivers are seasonal rivers. According to the 2019 Kenya Population and Housing Census, Rongai Sub-County had a population of approximately 199,006 people and around 52,348 households. The study targeted three locations with sisal industries: Athinai, Lomolo, and Majani-Mingi . The target population included heads of households, sisal plantation managers, shop attendants, and key informants such as environmental officers, agricultural officers, and the area chief. Table1 below shows the target population size.

Table 1

Target Population

Location	Male	Female	Households
Athinai	4953	5017	2630
Lomolo	1446	1358	732
Majani-Mingi	1667	1624	767

3.5 Sampling Procedure

Several samples were utilized during data collection. Samples collected include samples of household heads and keyinformants, river water samples, and borehole samples.

3.5.1 Sampling for Key Informants

Purposive sampling was used to select participants who were key informants. This included the manager and key technical staff. This method enabled the researcher to gather data from information-rich informants who were highly knowledgeable about the environmental effects associated with sisal industries. By focusing on these specific individuals, the researcher ensured that the collected data was both relevant and insightful for understanding the local environmental impact of sisal production.

3.5.2 Sampling of Household Heads and Sisal Workers

Random sampling was used to select participants for interviews from the sisal industries and the surrounding community. The participants included the household heads and sisal workers. This method allowed for random selection, ensuring that each member of the population had an equal and independent chance of being selected and minimizing bias. This method ensured that the views of the target population were captured and an insightful understanding of the local environmental impact of sisal production was gained.

3.5.3 River Water Sampling Procedure

Purposive sampling was used to select water samples from key points along the river channel that were in close proximity to the sisal industry. Specific locations were selected along the river channels, and three boreholes that are within a 1 km radius of the sisal industries were selected. This allowed the researcher to collect accurate data on the impact of sisal waste from the industry on the quality of water resources in Soin ward.

3.6 Sample Size

Yamane's statistical formula was used to determine the sample size of the population for household heads and key informants. The formula is as follows:

$$n = \frac{N}{1 + Ne^2}$$

Where:

n = is the sample size

N = is the population size

e = is the margin of error/confidence interval, which is at (0.05)

1 = is a constant

This formula helped to calculate an appropriate sample size based on the total population and the desired accuracy of the results.

The sample size for the entire sample area used was calculated as shown below.

$$n = 4129/\ (1+ 4129\ (0.05^2))$$

$$n=365$$

Stratified random sampling was used to determine the sample size for the two locations where the sisal industries were located. This approach ensured that each location was proportionally represented in the study. To achieve this, the formula by Salkind (2010) was applied to calculate the proportion of households required in each of the two locations. The formula is as follows:

$$n_h = n\left(\frac{N_h}{N}\right)$$

Where:

$\mathbf{n^h}$ is the sample size of a location

n is the total sample size of all locations

$\mathbf{N^h}$ is the target population size of a location

N is the total target population size of all locations

The sample size to be used for each location is calculated using the Salkind formula,as shown in Table 2 below.

n (Athinai)= 365 (2630 ÷ 4129) = 232 (Sample size)

Lomolo = 365 (732 ÷ 4129) = 65 (Sample size)

Majani Mingi = 365 (767 ÷4129) = 68 (Sample size)

Table 2

Sample Size of Household Heads and Key Informants

Location	No of households and key informants (N) (2019 census report)	Sample size
Athinai	2630	232
Lomolo	732	65
Majani Mingi	767	68

3.7 Water Samples from Rivers and Boreholes

Water samples were collected from all three rivers in Soin ward (Molo River, Rongai River, and Majani Mingi River). This is because there is existing infrastructure related to sisal industries at a point along these rivers. Water samples were collected from three boreholes that are within a 1 KM radius from the sisal industry (Lomolo borehole, Muya borehole, and Majani Mingi borehole). These boreholes were selected because of their proximity to the sisal industry, which increases the probability of an impact on water quality from sisal waste through underground infiltration.

3.8. Data Collection

Primary and secondary resources were used in the study. Secondary resources were gathered from literature reviews, while primary data were collected by conducting a survey, using questionnaires, key informant interviews, and photography. The survey was conducted in the local language and then translated into English by the researcher to ensure accuracy and consistency. The instruments used for collecting data included questionnaires, interviews with key informants, and photographic documentation of relevant field observations. The instruments used are as follows:

3.8.1 River Water Samples Collection

Water samples were collected in water bottles from all three rivers in Soin ward (Molo River, Rongai River, and Majani-Mingi River). This is because there are existing infrastructures related to sisal industries at a point along these rivers. Eleven (11) river water samples per river were collected at interval distances of 0.2 km upstream and 0.8 km, 0.6 km, 0.4 km, 0.2 km, and 0 km down stream along the river channel next to the sisal industry to ascertain the impact on water quality. Zero Kilometers is the point of the river opposite the sisal factory.

Additionally, water samples were collected from three (3) boreholes, one from each location, to measure the impact of the sisal industries on underground water resources. The water samples were transported to Kabarak University Chemistry laboratory for analysis, where key parameters such as temperature, turbidity, P^H, and dissolved oxygen were measured on the same day when sample collection was done. The analysis was conducted at the Kabarak University chemistry laboratory, ensuring timely and accurate assessments of water quality.

3.8.2 Interviews

The key informants were interviewed, including the area chief, environmental officer, and managerial staff from the sisal plantations. The interview guide is attached in Appendix III. These interviews enabled the researcher to guide the nature of the data collected and ensure that the discussions aligned with the study's objectives. By engaging directly with knowledgeable individuals, the researcher gained deeper insights and a more nuanced understanding of the issues related to the sisal industry and its environmental impacts.

3.8.3 Secondary Resources

Documented resources were sourced from journals, books, past research findings, and secondary data from KNBS on population and the World Health Organization guidelines on water quality. These secondary resources are highlighted in Chapter 2 above and include books by Yehdgo (2015), Mwaniki (2018), Schwaninger (2012), FAO (2021), and Kumpe et al. (2017). These secondary resources provided a solid foundation for the study, offering valuable context and background information on the sisal industries and their environmental impacts in other parts of the world, Africa, and Kenya. By utilizing these sources, the researcher ensured the reliability and validity of the information, which complemented the primary data collected during the fieldwork. This comprehensive approach allowed for a thorough analysis of the research questions and objectives.

3.9 Pilot Study

The pilot study was conducted in the Athinai location, involving 15 household heads who were randomly identified systematically. This pilot study location was selected because of the existence of an active sisal industry in the area, as well as a vibrant community that included sisal workers, a river channel, and sisal waste mitigation ponds, all of which were important factors in this study. The close proximity of this location to the main road allowed for an easy pilot study.

The researcher collected data by selecting every other household head, skipping one house, and choosing the next. According to Sekaran and Bougie (2009), the sample size of the pilot study was statistically acceptable, ensuring that the methodology was robust enough to inform the main study. This preliminary research aimed to test the data collection instruments and refine them based on the findings before the full-scale study.

3.10 Validity of the Instruments

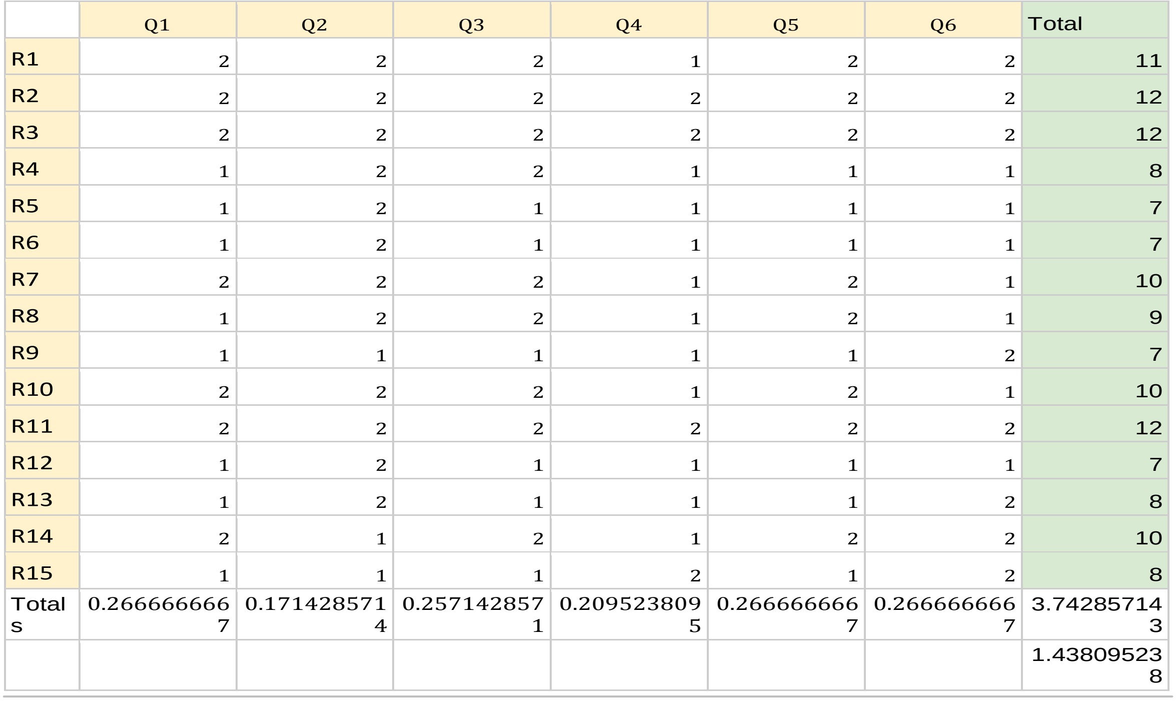
Validity refers to how accurately a concept or instrument measures what it is intended to measure. It encompasses the ability to accurately represent the results among study participants and ensure that these findings reflect the true characteristics of similar individuals outside the study (Mugenda & Mugenda, 2003). The validity of the instruments used in this study was ensured by adopting tools directly relevant to the study's objectives, with guidance and advice from supervisors. This collaborative approach aimed to minimize and eliminate errors, thereby enhancing the reliability of the research findings.

3.11 Reliability of the Instruments

Reliability pertains to the extent to which a measurement of a phenomenon yields stable and consistent results, assessing the degree to which an instrument produces similar outcomes when tested repeatedly (Mugenda & Mugenda, 2003). In this study, Cronbach's Alpha coefficient was utilized to evaluate the reliability of the research instruments. A minimum Cronbach's coefficient of 0.7 is widely regarded as acceptable for demonstrating the reliability of research instruments. In this case, the overall result was 0.74, indicating that the level of reliability for the research instruments used was acceptable and suitable for the study's objectives. Instruments, such as the multi-parameter pH meter, were calibrated before use to ensure accurate results.

Table 3

Pilot Study Sample Survey Data



	Q1	Q2	Q3	Q4	Q5	Q6	Total
R1	2	2	2	1	2	2	11
R2	2	2	2	2	2	2	12
R3	2	2	2	2	2	2	12
R4	1	2	2	1	1	1	8
R5	1	2	1	1	1	1	7
R6	1	2	1	1	1	1	7
R7	2	2	2	1	2	1	10
R8	1	2	2	1	2	1	9
R9	1	1	1	1	1	2	7
R10	2	2	2	1	2	1	10
R11	2	2	2	2	2	2	12
R12	1	2	1	1	1	1	7
R13	1	2	1	1	1	2	8
R14	2	1	2	1	2	2	10
R15	1	1	1	2	1	2	8
Totals	0.2666666667	0.1714285714	0.2571428571	0.2095238095	0.2666666667	0.2666666667	3.742857143
							1.438095238

Formula for Conchobar’s Alpha:

Where N=6 (6 yes and no questions in the interview schedule)

S_2=1.438095238

Summation of total variance= 3.742857143

Cronbach's = (6/5) * (1-(1.43809/3.74285) =0.738

3.12 Water Quality Analysis

Water quality parameters tested in this study included the P^H, temperature, turbidity, dissolved oxygen, and dissolved organic matter. A multi parameter P^H meter was used to analyze the water quality of the collected samples.

3.12.1 Temperature

The temperature of each water sample was measured using a thermometer with a scale of 0 – 110 ^{o}C. The thermometer was cleaned and inserted into a container filled halfway with the water sample at room temperature. After 10 minutes, the thermometer was removed from the water sample, and the temperature readings were recorded for each sample.

3.12.2 PH for Acidity and Alkalinity Measurement

A P^H meter was used to measure the P^H of the water sample. The samples were collected in a clean container, and the electrode of the P^H meter was dipped enough to cover the tip of the electrode. The container was allowed to settle to stabilize the temperature. The probe of the P^H meter was inserted into the sample and left until the meter reached equilibrium. The P^H measurement was then read from the P^H meter. Acidity was determined following the P^H measurement; if the P^H values were below 6.5, the water sample was regarded as acidic. The alkalinity of each water sample was assessed based on the P^H value obtained; if the P^H values were above 7.5, the samples were considered alkaline.

3.12.3 Turbidity

Turbidity was measured through direct observation. The researcher compared water samples against distilled water to observe the turbidity of each river water sample.

3.12.4 Dissolved Oxygen

Dissolved oxygen was measured using a dissolved oxygen sensor. The probe was inserted into the sample water and then removed to release any air bubbles, ensuring a fresh sample for the sensor cap. The sensor was then reinserted into the sample and continuously stirred to allow the water to stabilize. It was then left to stabilize for accurate readings on the levels of dissolved oxygen.

3.12.5. Total Dissolved Solids

When sisal leaves are decorticated to extract fibre, the liquid waste carries significant amounts of dissolved cellulose, microfibers, soluble sugars, organic acids, and inorganic dissolved solids such as calcium and magnesium, potassium, and chlorides (Bisanda et al, 2003). Total dissolved solids were measured using a TDS sensor. The probe was inserted into the sample water and then removed to release any air bubbles, ensuring a fresh sample for the sensor cap. The sensor was then reinserted into the sample and continuously stirred to allow the water to stabilize. It was then left to stabilize for accurate readings on the levels of total dissolved solids.

3.12.6. Conductivity

Conductivity was measured using a conductivity sensor. The probe was inserted into the sample water and then removed to release any air bubbles, ensuring a fresh sample for the sensor cap. The sensor was then reinserted into the sample and continuously stirred to allow the water to stabilize. It was then left to stabilize for accurate readings on the level of conductivity.

3.13 Data Analysis Procedure

3.13.1 Data Analysis of Objective 1

Data collected from surveys and interviews were cleaned and analyzed using the Statistical Package for Social Sciences (SPSS) software application. Descriptive statistics, including frequencies, percentages, and means, were employed in the analysis. The analyzed data were used to determine the measures adopted to mitigate sisal waste pollution.

3.13.2 Data Analysis of Objective 2

For objective 2, water samples were collected and analysed in the laboratory using specific reagents and testing tools. The results of the water analysis were presented using tables and graphs. This analysed data was used to illustrate the relationships between industrial waste disposal and water quality in rivers and boreholes.Water samples were analysed to measure the temperature, P^H, dissolved oxygen, dissolved solids, and conductivity. Turbidity of the water samples was compared against distilled water through direct observation.

3.14 Data Monitoring Plan

The researcher was responsible for overseeing the data collection process, ensuring compliance with the study protocol, and safeguarding the safety and welfare of participants. The researcher had the authority to modify, suspend, or terminate the study if necessary to address concerns or risks. The collected data was reviewed for accuracy and completeness. Data was collected according to the approved confidentiality and data safeguarding measures of Kabarak University.

3.15 Ethical Review

To ensure compliance with ethical requirements, the researcher included key declaratory and explanatory details in the consent letter to participants, covering the study's purpose, objectives, methodology, potential benefits and risks, confidentiality, anonymity, and data handling protocols, including storage and destruction procedures. As evidenced in the consent letters provided in Appendices I and II of this research document, participants were informed of the study's purpose and their rights, including the freedom to decline participation or withdraw at any stage. Personal information was safeguarded, stored securely on a password-protected laptop, and anonymized by assigning numbers to participants during analysis.

CHAPTER FOUR

DATA ANALYSIS, RESULTS AND DISCUSSION

4.1 Introduction

This study assessed the impact of sisal processing industries on water resources in Rongai Sub-County, Kenya. The chapter presents the findings, interpretations, and discussions of the results of this study.

4.2 General and Demographic Information

General and demographic information captured in this study included the response rate of the respondents, their gender, age, and thepercentage of households utilizing sisal products.

4.2.1 Response Rate of Respondents

The sample size for this study consisted of 365 respondents, including household heads and key informants, from Soin ward, Rongai Sub-County, Kenya. This comprised 221 household heads and 144 key informants, including sisal traders, sisal industry workers, an environmental officer, an area chief, and an agricultural officer. Two types of questionnaires were administered to the respondents, namely, "Household heads interview schedule" and "key informant interview schedule." Table 4 shows the response rate for the study.

Table 4

Response Rate of Respondents

Respondent	Sample	Response	Percentage response
Household heads	221	216	98%
Key informants	144	142	98%

The response rate indicated that 216 of the households sampled participated in the study, and 142 of the sisal workers and sisal traders sampled participated in the study. This resulted in a response rate of 98% for household heads and 98% for sisal traders and workers in the sisal industry. The cumulative response rate for this study was 98%.

According to Mugenda, a response rate above 50% is considered adequate, while 60% good and above 70% is considered very good (Mugenda & Mugenda, 2003). This, therefore, implied that the resulting response rate of 98% is considered very good and acceptable. A 98% response rate was achieved with the help of a research assistant who was a resident of Soin ward and therefore familiar with the community dynamics of the area.

4.2.2 Gender of respondents

The table below shows the gender of respondents who participated in the study.

Table 5

Gender of Respondents

Gender	Frequency	Percentage
Female	163	46
Male	195	54

Of the respondents, 46% were female and 54% were male, resulting in an almost equal gender distribution. This balance indicates that the data collection process ensured representation from both genders, allowing for a diverse range of perceptions and opinions regarding the assessment of the impacts of the sisal industry. Such gender inclusivity enhances the reliability and comprehensiveness of the findings by reflecting viewpoints from both male and female respondents.

4.2.3 Age of Respondents

The table below shows the distribution of ages of the household headrespondents who participated in the study.

Table 6

Age of Household Heads Respondents

Age (years)	20-29	30-39	Above 40
Count	72	108	36

All respondents from household heads were above 18 years of age, indicating that they were adults eligible to work in the sisal industry or head their own households. This ensures that the perspectives gathered reflect the experiences and opinions of individuals with the legal capacity and responsibility to engage in and manage household affairs.

4.2.4. Households Utilizing Sisal Products

The table below shows the number of households that directly utilized sisal products, such as ropes, baskets, or beds, while others sold these products as traders.

Table 7

Number of Households Utilizing Sisal Products

Label	Number of respondents	Percentage
Yes	20	9%
No	196	91%

The findings reveal that sisal products are not widely utilised or sold at the household level, with 91% of respondents indicating no involvement in sisal-related utility activities. Only 9% of households reported using or selling sisal products. This indicates a limited direct economic relationship between households and sisal products, which could be attributed to a lack of demand, limited market access, or minimal awareness of sisal’s potential uses.

4.3 Measures Adopted by Sisal Processing Industries to Mitigate Against Water Pollution from Sisal Waste Disposal in Rongai Sub-County

4.3.1 Summary

Objective one of this study was to establish measures adopted by sisal industries in mitigating the pollution effects from sisal waste disposal in Rongai Sub-County. The results showed that the majority of households utilize river water for basic needs (67.7%), while all sisal processing industries in the area rely solely on river water resources. About this, the majority of the households (65%) treat their drinking water before consumption. Additionally, the results showed that sisal industries collect water for sisal processing from rivers with an average daily draw of approximately 95,000 litres.

The majority of respondents (78.7%) admitted to experiencing an effect from sisal waste, with the most common effects being an increased number of mosquitoes and a bad odour. The most common sisal waste disposal method in sisal industries was dumping sisal effluent in sewage ponds. The treatment of this wastewater was achieved through the use of chemicals for effluent treatment, as well as the planting of trees around the ponds. Additionally, households utilized mosquito nets and repellents for protection.

4.3.2 Water Utility

Table 8 below shows the responses from household heads and sisal processing industries regarding the water utility in Soin Ward.

Table 8

Water Utility in Households and Sisal Processing Industries

	Label	Count	Percentage
Primary water source for domestic use in Soin Ward	Borehole water	70	32%
	River water	147	68%
Source of water for sisal processing	Borehole	0	0%
	River water	146	100%
Volume of water used in sisal processing daily (Liters)	Mean	95,465	

The data shows that most respondents (67.7%) rely on river water as their primary source for domestic use, while 32.3% use boreholes. The river water is either from the River Molo, the River Rongai,orthe Majani Mingi River. Borehole water is either from the Muya borehole in Mogotio, the Majani Mingi borehole, or the Lomolo borehole.

Data collected shows that all sisal processing industries and sisal traders draw water for sisal processing only from the rivers.The average amount of water drawn from the river is 95,465 liters per day, as shown in Table 8 above. This shows that the sisal processing industry is heavily reliant on river water.

4.3.3 Effects of Sisal Waste

Table 9 below shows the effects of sisal waste in households and sisal industries.

Table 9

Sisal Waste Effects

	Label	Count	Percentage
Households directly affected by disposed sisal waste	Yes	170	79%
	No	46	21%
Sisal Workers are directly affected.	Yes	118	81%
	No	28	19%
Effects of Sisal Waste on Households	Affects soil fertility	2	1%
	Increase mosquito breeding	120	71%
	Bad smell	37	22%
	Both bad smell and mosquito breeding	9	5%

The majority of the household respondents from the community (household heads) stated that they had been directly affected by sisal waste, with 78.7% experiencing an effect from sisal waste disposal, while 21.3% remained unaffected by sisal waste disposal (Table 9 above). The predominant effect of sisal waste disposal was that it encouraged mosquito breeding. This issue was highlighted by 71% of respondents, making it the most significant effect of sisal waste disposal. The release of bad odour was the second most reported issue, affecting 22% of respondents, while reduced soil fertility was the least reported impact at just 1%. A small proportion of respondents (5%) experienced a combination of effects, primarily mosquitoes and bad odour, as shown in Table 8 above. These findings suggest that immediate and visible nuisances, such as health risks (caused by mosquitoes) and unpleasant smells, are a more noticeable concern to the community compared to long-term environmental issues like soil degradation.

Among sisal workers and traders, 80.8% reported being directly affected by sisal waste, while 19.2% were unaffected, as shown in Table 9 above. Those affected reportedthat the main negative effects of sisal waste were due to bad smell and increased breeding of mosquitoes. This is because they live near the sisal processing industry and its related sewage dams.Lack of proper working gear, such as gloves or boots, caused skin rashes and inflamed hands and legs among sisal workers who came into direct contact with waste sisal effluent.

4.3.4 Sisal Waste Mitigation

Table 10 Below Shows Sisal Waste Mitigation Measures Adopted by Households and the Sisal Industries.

Table 10

Sisal Waste Mitigation Measures

	Label	Count	%
Household respondents adopting sisal waste mitigation in households	No	85	39%
	Yes	131	61%
Water treatment before drinking	Yes	76	35%
	No	139	65%
Household mitigation measures against sisal waste	Mosquito Nets	66	48%
	Mosquito repellant	57	41%
	mosquito nets and repellents	9	7%
	Disposing of waste away from rivers	5	4%
Method of sisal waste disposal	Sewage swamps/dams	138	95%
	Dump sites	8	5%
Sisal waste treatmentusing chemicals in sisal processing industries	Yes	99	67%
	No	47	32%

The most common methods of sisal wastewater disposal were dumping in sewage swamps and sewage dams (95%), reflecting a preference for large-scale natural containment methods, as shown in Table10 above. Disposal in dumpsites was the least utilized option. These practices show the reliance on natural systems and limited adoption of advanced wastewater management techniques, posing potential risks to water quality.

The majority of respondents from households (61%) reported adopting mitigation measures, indicating a proactive response to the negative impacts of sisal waste, as shown in Table10 above. The most common mitigation measures included the use of mosquito nets (48%) and repellents (41%), as shown in Table10 above. A smaller percentage combined these two measures (7%), while others practiced proper disposal of sisal waste away from rivers (4%). However, 39% of household respondents had not adopted any mitigation measures. These results suggest that efforts are heavily focused on controlling mosquito breeding, which is the primary issue identified. However, there is a gap in addressing other long-term environmental impacts, such as soil fertility and water contamination.

Among those using natural water sources (rivers and boreholes), 65% of the respondents treat water before consumption, reflecting an awareness of water safety issues. However, as shown in Table 9 above, 35% of the population does not treat their water, leaving a significant portion at risk of waterborne diseases. The collected data show that a significant majority (99) of respondents from the sisal processing industry reported treating their wastewater using chemicals. In contrast, 47 respondents do not treat their wastewater at all, as shown in Table10 above. This indicates a strong preference for chemical treatment methods over no treatment, with approximately 68% of cases implementing proper chemical treatment. Table 10 below shows mitigation measures adopted by sisal processing industries to mitigate against the negative effects of sisal waste.

Table 11

Sisal Waste Mitigation Strategies in Sisal Industries

Label	Count	Percentage
Demarcation of boundaries to prevent entry by animals or people	10	7%
A combination of planting trees along the borders and using chemical treatments	83	57%
swamp leakage prevention	3	2%
None	49	34%

Respondents from sisal industries, including workers and traders, reported that the merger of using chemical treatments and tree planting emerged as the most common mitigation strategy, with 57% of respondents reporting this approach, as shown in Table 11 above. Other strategies included restricting sisal waste disposal areas to humans and animals (7%) and preventing swamp leakage (2%), which were less commonly implemented. The results demonstrated the adoption of integrated approaches. However, 34% of the respondents reported no mitigation measures, indicating a substantial gap in addressing the environmental impacts of sisal waste. These findings suggest that while efforts are being made to mitigate sisal waste, they remain insufficient and unevenly distributed.

Figure 5

Sisal Waste Pond/Dam

Source: Authour (2025)

Figure 6

Sisal Effluent Moving from One Effluent Dam/Pond to the next. Chemical Treatment is Administered to The Effluents in these Dams/Ponds to Mitigate Against Air and Water Pollution.

Source: Authour (2025)

Figure 7

Solid Sisal Waste Disposed after Decortication

Source: Authour (2025)

4.3.5 Utility of Sisal Waste

Table 12 below presents the utility of sisal waste in households.

Table 12

Utility of Sisal Waste

	Label	Count	Percentage
Benefited from sisal waste	No	153	71%
	Yes	63	29%
Benefits/uses of sisal waste	Animal feed and firewood	36	56.7%
	Manure (Compost)	18	28.3%
	Making a bed mattress	3	4.7
	Firewood	6	9.5

From the 216 household respondents, 71% stated that they did not get any benefit from sisal waste, while 29% respondents benefited from sisal waste. The analysis of this data shows a strong negative perceptionof sisal waste, as shown in Table 12 above. Among the 29% who did benefit, the most common use of sisal waste was as a combination of animal feed and firewood (56.7%), followed by manure (28.3%). Less common uses included use as pure firewood and mattress making. These findings suggest that while some households recognize the potential value of sisal waste, the majority view it as a nuisance rather than a resource, indicating an underutilization of its potential benefits. The utility of sisal waste may be used as a mitigation method to reduce the amount of sisal waste disposed of in the environment.

4.4 Effects of Sisal Waste Disposal on Water Quality

4.4.1 Summary

Objective two of this study was to establish the impact of sisal processing industry waste disposal on water quality in Molo River, Rongai River, and surrounding boreholes in Rongai Sub-County. The results showed minimal impact on water quality in relation to P^H levels, conductivity, dissolved solids, temperature, and dissolved oxygen. No impacts were observed in relation to organic matter and turbidity.

4.4.2 River-Water Analysis

The analysis of the effect of sisal waste on water quality in the three rivers - Lomolo, Molo, and Majani-Mingi - reveals critical insights into water quality parameters. These findings provide a basis for understanding the impacts of sisal processing activities on river water quality.

4.4.1.1 P^H Levels of Water

Table 13 shows data on river water P^H levels along the river channel before and after its flowin close proximity to the sisal waste ponds/sewage, and factory.

Table 13

Data on river water pH along the River Channel.

Point of collection	Rongai River	Molo River	Majani-Minig River	WHO/NEMA standards
0.2 km upstream (from the company)	6.4	6.4	6.2	6.5-8.5 *(World Health Organization, 2011, and NEMA 6th Schedule 2006)*
O km (next to the company)	6.1	6.1	5.5	
0.2 km downstream	6.2	5.9	5.5	
0.4 km downstream	6.2	5.7	5.4	
0.6km downstream	6.1	5.8	5.3	
0.8 Km downstream	6.1	5.6	5.4	

One-Sample T-Test results (comparing with 0.2 km upstream value) show that Rongai River had a t-statistic of 4.54 and p-value of 0.006, which is a statistically significant change ($p < 0.05$), meaning P^H values downstream are significantly different from the upstream value. Molo River had a t-statistic of -4.04 and a p-value of 0.0099, which is a statistically significant change ($p < 0.05$), indicating a significant drop in P^H down stream. Majani-Mingi River had a t-statistic of -4.87 and a p-value of 0.0046. This isa statistically significant change ($p < 0.05$), showing a considerable decrease in P^H downstream. Overall, the one-sample T-test showed that for all three rivers, there is a statistically significant decline in p^H down stream compared to the upstream point. This suggests a notable impact on water quality as it moves downstream.

In general, P^H data collected from the rivers in regions in close proximity tothe sisal industry and after the sisal industry showed that there was a decline in P^H levels. The P^H levels gradually declined (Table 13) as the river channel passed in close proximity to the sisal processing industries. This is potentially linked to factors such as industrial effluents through infiltration, as there were no observable direct discharges of effluents from the sisal processing industries into the river.Molo River exhibited the steepest decline of 0.8 (Table13), indicating higher susceptibility to acidification, which might affect aquatic life and water usability. Majani Mingi River also exhibited a steep decline of 0.8 (Table 13), which also showed significant acidification, reinforcing concerns over increased water acidity. Rongai River experienced the least decline of 0.3 (Table 13), possibly due to differences in local buffering capacities or exposure to pollution sources.

River water P^{H} from the three rivers was not conforming tothe WHO standards required for water with a suitable P^{H} between 6.5 and 8.5 (World Health Organization, 2011). This is because of their slightly acidic nature, which increased slightly after it came into close contact with the sisal processing industries. The overall trend indicates a need for interventions to mitigate the effects of acidification, which could harm aquatic ecosystems and impact downstream water users.

4.4.1.2 Temperatures

Table 14 below shows temperature stability and fluctuations, which will provide insights into river dynamics and potential anthropogenic impacts.

Table 14

Fluctuations in River Water Temperature along the River Channel before and during its Flow Proximity to the River Channel

Point of collection	Rongai River	Molo River	Majani-Minig river	NEMA standards
0.2 km upstream (from the company)	19°*C*	17°*C*	19°*C*	*20°C (Government of Kenya, 2023)*
O km (next to the company)	19°*C*	18°*C*	19°*C*	
0.2 km downstream	20°*C*	18°*C*	19°*C*	
0.4 km downstream	20°*C*	17°*C*	19°*C*	
0.6km downstream	19°*C*	19°*C*	19°*C*	
0.8 Km downstream	19°*C*	17°*C*	19°*C*	

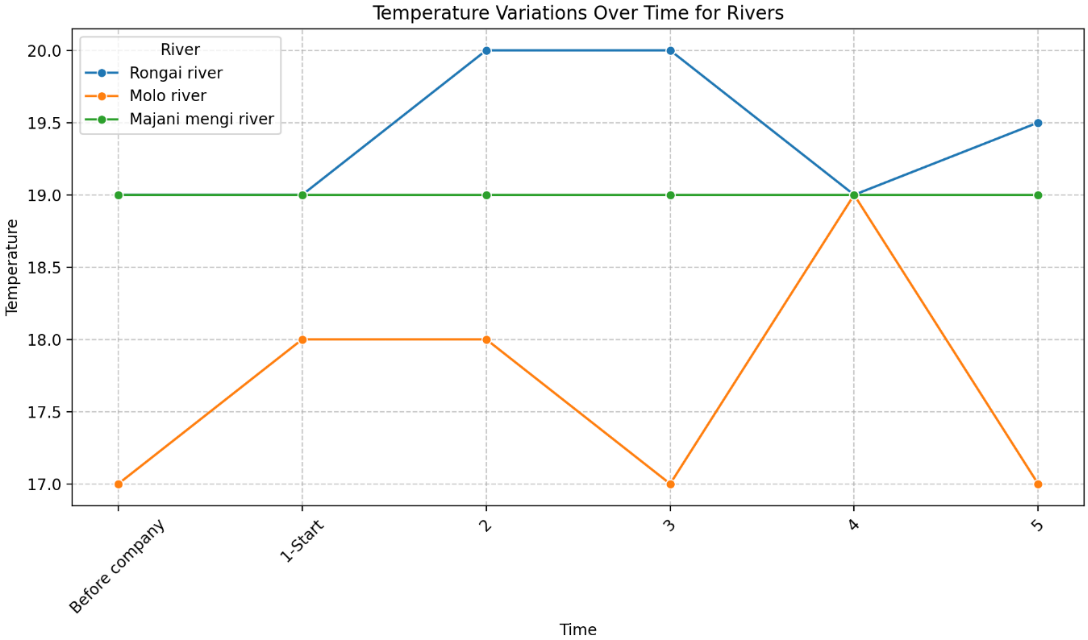
A one-sample t-test showed that the Rongai River had a t-statistic of 1.58 and a p-value of 0.175, indicating a lack of statistically significant change ($p > 0.05$). Molo River had a t-statistic of 2.00 and a p-value of 0.102, indicating a lack of statistically significant change ($p > 0.05$). For the Majani-Mingi River,all values in the dataset are identical, making it impossible to calculate variability. Overall, the T-test shows that there is no statistically significant change in water temperature downstream for any of the rivers. The Majani-Mingi River's temperature remains constant, making statistical analysis impossible.

Majani Mingi River showed remarkable stability of temperature at 19°C, indicating minimal external temperature influences, potentially due to consistent environmental conditions. Molo River exhibited slight fluctuations of 19-20°C, whileRongai River displayed the most variation of 17-19°C at specific points during its flow downstream; however, the temperatures of all the rivers reverted to their initial temperatures at 0.8km downstream.

This suggests potential minimal external influence on river water temperature in River Rongai and River Molo as it flowed downstream in proximity to the industry; however, there were no observable effluent entry points into the river. Majani Mingi Riveris attributed to the closure of the Majani-Mingi sisal processing industry. NEMA standards for river water temperature are 20°C, although this is influenced by location and seasonal weather changes. The overall river water temperatures were close to the NEMA standard, indicating minimal external influence.

Figure 8

Temperature Variations in Rivers at Different Points Along the River Channel



Temperatures remained within ranges suitable for aquatic life; the variations highlight areas requiring closer monitoring, especially in the Rongai and Molo rivers, as shown in Figure 8 above.

4.4.1.3 Total Dissolved Solids (TDS)

Table 15 below shows TDS levels in the three rivers, which reflect organic matter (sisal waste) content and potential mineral content in river water.

Table 15

Total Dissolved Solids (TDS) in River Water

Point of collection	Rongai River (*mg/L)*	Molo River (*mg/L)*	Majani-Minig river (mg/L*)*	WHO/NEMA Standards (World Health Organization, 2011)
0.2 km upstream (from the company)	114	95	40	Less than 600 ppm (mg/L)-WHO
O km (next to the company)	120	79	38	
0.2 km downstream	117	81	38	
0.4 km downstream	116	83	37	*Less than 1200mg/L -NEMA*
0.6km downstream	115	83	36	
0.8 Km downstream	115	83	34	

Based on the statistical analysis (One-sample T-test), which compared each measurement point to the upstream reference, changes in Rongai river data are barely significant with a mean difference of +2.6 mg/L and a p-value of 0.049 (just barely significant at α=0.05). Molo River data change in TDS is highly statistically significant with a mean difference of -13.2 mg/L and a p-value of 0.00008. Majani-Mingi River changes in TDS levels are statistically significant with a mean difference of -3.4 mg/L and a p-value of 0.010. All three rivers show statistically significant differences in TDS when comparing downstream and company locations to the upstream reference point, with the Molo River showing the most dramatic decrease.

Rongai River consistently displayed changes in TDS as it increased from 114 mg/L upstream to a high of 120 mg/L next to the company, but then consistently decreased to 115 mg/L (Table15), suggesting elevated dissolved matter content from industrial discharge. Molo River showed a significant decline from95 mg/L to 83 mg/L. The Majani-Mingi River consistently had the lowest TDS, which decreased from 40 mg/L to 34 mg/L, reflecting a slight decreasing trend, indicating relatively pristine conditions.The total amount of TDS in all three rivers conforms to World Health Organization standards for TDS in drinking water, which is less than 600mg/L (World Health Organization, 2011).

4.4.1.4 Conductivity of Water

Table 16 below shows the changes in water conductivity in the three rivers before they come in close contact with the sisal processing industry and during their flow in proximity to the sisal processing industry.

Table 16

Conductivity of River Water

Point of collection	Rongai River (μS/cm*)*	Molo River (μS/cm*)*	Majani-Minig river (μS/cm*)*	WHO Standards *(Meride & Ayenew, 2016)*
0.2 km upstream (from the company)	173	145	60	50–1500 μS/cm
O km (next to the company)	183	122	58	
0.2 km downstream	178	125	58	
0.4 km downstream	178	127	57	
0.6km downstream.	178	127	56	

A One-Sample T-Test compared water conductivity data concerning the 0.2KM upstream data. The test showed that the Rongai River had a t-statistic of 3.87 and a p-value of 0.0117, which is a statistically significant increase ($p < 0.05$), indicating that the conductivity downstream is significantly higher than upstream. Molo River had a t-statistic of -4.85 and a p-value of 0.0047, indicating a statistically significant decrease ($p < 0.05$), which shows a substantial drop in conductivity downstream. Majani-Minig River had a t-statistic of -3.11 and a p-value of 0.0267. This is a statistically significant decrease ($p < 0.05$), indicating a drop in conductivity downstream. Overall, the Rongai River had a conductivity increase downstream, while the Molo River & Majani-Mingi

River had a conductivity decrease downstream. These changes suggest different impacts, possibly due to the use of different chemicals in industrial discharge.

The results on conductivity, as shown in Table 16, show that conductivity trends correlate with dissolved solids and potential pollutants when compared to Table 15 above on Total Dissolved Solids. Rongai River displayed an initial increase in conductivity from 173 µS/cm to 183 µS/cm after the river channel came in proximity to the sisal industry, as shown in Table 16 above. This was followed by stabilization, with minor fluctuations, suggesting an initial increase in pollutants that was subsequently improved.

Molo River displayed an initial decrease in conductivity, followed by a subsequent increase in conductivity downstream. This suggests ineffective mitigation measures,as shown in Table 16 above. Majani Mingi River showed consistent decreases in conductivity from 60 µS/cm to 53 µS/cm and the lowest level of conductivity (Table 15), further supporting its characterization as the least impacted river. However, all three rivers are within the WHO standards of drinking water conductivity, which is less than 400 µS/cm (Meride &Ayenew, 2016).

4.4.1.5 Dissolved Oxygen (DO)

Dissolved oxygen is a critical parameter for aquatic ecosystems, which is affected by organic matter like sisal waste. Table 17 shows the parameters of DO at various points along the river channels.

Table 17

Dissolved Oxygen in Various Points Along the River Channel

Point of collection	Rongai River (*mg/L)*	Molo River *(mg/L)*	Majani-Minig river (*mg/L)*	WHO Standards *(Government of Northwest Territories, n.d.)*
0.2 km upstream (from the company)	4.7	4.4	4.2	6.5 mg/L – 8 mg/L
O km (next to the company)	4.5	4.4	3.5	
0.2 km downstream	4.5	4.5	3.7	
0.4 km downstream	4.5	4.2	3.6	
0.6km downstream	4.7	4.1	3.5	
0.8 Km downstream	4.7	4.0	3.5	

Based on the statistical analysis (one-sample T-test), which compared each measurement point to the upstream reference, the Rongai River had a t-statisticof -2.24 and ap-value of 0.0756. This showed a lack ofstatistical significance (p > 0.05), indicating no significant change in dissolved oxygen downstream. Molo River had a t-statistic of -1.66 and a p-value of 0.1576. This showed a lack of statistical significance (p > 0.05), showing no significant variation in dissolved oxygen downstream. Majani-Mingi River had a t-statistic of -4.78 and a p-value of 0.0050. This showed a **s**tatistically significant decrease (p < 0.05), indicating a substantial drop in dissolved oxygen levels downstream. Overall, Rongai & Molo Rivers had no significant change in dissolved oxygen levels, while Majani-Mingi River had a significant decrease in dissolved oxygen downstream.

All three rivers showed a slightly decreased amount of dissolved oxygen after they came into proximity with the sisal processing industries. Though the Rongai Riverinitially reduced from 4.7 mg/L to 4.5 mg/L, it gradually increased to 4.7 mg/L as shown in Table 16 above.

Molo River exhibited minor fluctuations, with a general decline indicating a gradual deterioration in oxygen availability from 4.4 mg/L to 4.0 mg/L, potentially affecting aquatic life.Majani Mingi River showed a consistent decrease in DO levels, highlighting a decline in water quality and potential stress on aquatic ecosystems. This river was observed to be shallow and host a large number of swamp vegetation such as reeds and grasses. These plants may have contributed to reduced oxygen levels due to ecological and biological processes, such as oxygen consumption during the decomposition of fallen organic matter, including leaves and dead plant matter, which significantly influence water quality.

Water from the three rivers has lower Dissolved Oxygen levels (average of 4 mg/L) than the general acceptable levels needed to sustain a healthy aquatic life, which is between 6.5mg/L and 8.0 mg/L (Government of Northwest Territories, n.d.). This warrants attention to restore the quality of these rivers for an improved ecological balance.

4.4.2 Borehole Water Quality Analysis

The borehole water quality analysis provides a comprehensive evaluation of P^H, total dissolved solids (TDS), dissolved oxygen (DO), and conductivity across three boreholes: Majani, Muya (Mogotio), and Lomolo,as shown in Table 18 below.

Table 18

Borehole Water Quality Parameters

Point of collection	P^H	Total dissolved solids (*mg/L)*	Dissolved oxygen (*mg/L)*	Conductivity (µS/cm)
Majani Borehole	6.4	71	5.4	10.9
Muya Borehole-Mogotio	5.5	35	5.0	53.6
Lomolo Borehole	5.7	40	4.97	63

The P^H levels across all boreholes fall below the WHO-recommended range of 6.5–8.5, indicating that the water is acidic. Among the boreholes, Majani-Mingi recorded the highest P^H at 6.4, which is slightly below the acceptable range but closer to the guideline as shown in Table 18 above. Muya Borehole exhibited the lowest P^H at 5.5, indicating higher acidity, which could affect water usability and infrastructure over time. Lomolo Borehole, with a P^H of 5.7, was slightly better than Muya but still acidic. According to the World Health Organisation (2011), acidic water can lead to corrosion in pipes, negatively impact the taste of water, and pose potential risks to health and ecosystems if used over a prolonged period.

The Total Dissolved Solids levels in all boreholes were well within the WHO guideline of less than 600 mg/L *(World Health Organisation, 2011),* as they averaged between 71mg/L and 40mg/L, indicating excellent water quality. Majani Borehole recorded the highest TDS at 71mg/L, reflecting slightly higher dissolved organic matter and minerals than the other locations, but still very low. Muya and Lomolo boreholes reported TDS levels of 35 mg/L and 40 mg/L, respectively, confirming minimal dissolved solids across all boreholes. These results indicate minimal contamination from dissolved organic matter from sisal industries.

Dissolved oxygen levels are crucial for aquatic health and water palatability. The recommended values for sustaining aquatic life are between 6.5mg/L and 8.0mg/L (Government of Northwest Territories, n.d.),while the typical good water level of dissolved oxygen in drinking water is greater than 5 mg/Laccording to the World Health Organization. Muya Borehole recorded 5.0 mg/L, acceptable with WHO, which is at the threshold of the recommended level, while Lomolo Borehole had slightly lower DO at 4.97 mg/L, indicating potential issues related to aeration or organic pollution from sisal waste. Although the differences were minor, the lower DO levels in Muya and Lomolo boreholes suggest areas for monitoring and potential intervention to maintain water quality.

Conductivity levels indicated in Table 18show that the ionic content of water in 2 boreholes is within the allowed WHO values of 50–1500 µS/cm. Conductivity varied significantly across the boreholes. Majani Borehole exhibited the lowest conductivity at 10.9 µS/cm, reflecting very low ionic content and a potentially pristine water source. Conversely, Lomolo Borehole (63.0 µS/cm) and Muya Borehole (53.6 µS/cm) had moderate conductivity, both within the typical range of 50–1500 µS/cm. These variations suggest that the differences were caused by differences in water acidity amongst the three boreholes, whichinfluences the concentration of ions, resulting in high conductivity. The increased acidity may be caused by poor disposal of sisal waste, which undergoes biodegradation in soil, releasing soluble acidic gases that dissolve in rainwater, making it acidic. This acidic rainwater later infiltrates the soil into underground water aquifers,causingchanges in ionic concentrations in the borehole water.However, further research is recommended to prove this.

4.4.3 Water Turbidity

Turbidity measures the clarity of a liquid, specifically water, by assessing how much light scatters when passing through it (U.S. Geological Survey, n.d.). Cloudiness or opacity in water is caused by particles such as clay, silt, organic and inorganic matter, algae, plankton, and dissolved colored compounds. This study sought to determine theimpacts of sisal industries' waste disposal on the water turbidity in River Molo and River Rongai. Figure 3 below shows the varying turbidity of river water samples collected from the three rivers.

Figure 9

A Photograph Showing Turbidity of Water Samples. Far right- water samples from Majani Mingi river, middle- water samples from Molo river and on the far left are water samples from Rongai River

Source: Authour (2025)

River water samples from Rongai River exhibited the highest turbidity, followed closely by samples from Molo River, while those from Majani Mingi River were the least turbid. The lower turbidity in the Majani Mingi River is attributed to the presence of swamp vegetation, such as reeds and grasses, which stabilized soil sediments, reduced erosion, and consequently lowered water turbidity. However, no significant difference in turbidity was observed in water samples taken before and after proximity to the sisal industry. Heavy upstream rains influenced water turbidity, suggesting that the sisal industry had no discernible impact on the turbidity levels of the sampled river water.

Previous studies show that sisal waste contains released suspended solids that are made up of fibrous and particulate matter and contain a high organic load of cellulose and hemicellulose (Muya, 2024). However,the lack of direct observable effluent discharge into the river limited the effects of sisal waste on river water turbidity. In this study, there was no observable impact of sisal processing industries on water turbidity.

4.5. Discussion

Objective 1. Mitigation Measures Against Sisal Waste Disposal

The study aimed to identify measures adopted by sisal processing industries in Rongai Sub-County to mitigate water pollution from sisal waste disposal. Findings showed that 67.7% of households rely on river water for domestic use, while all sisal industries depend entirely on river water, drawing an average of 95,465 litres daily. This correlates with findings by Kumpe et al (2017), which showed that less than 65% of the population has access to piped water. The findings of this study also correlate with a study conducted in Tanzania, which showed that four sisal estates generate approximately 90,000 litres of wastewater daily, totaling 32,850,000 litres annually (Yhdego, 2015).

Most households (65%) treat their drinking water, reflecting an awareness of water safety. 78.7% of respondents reported negative effects from sisal waste, primarily increased mosquito breeding (71%) and a bad odor (22%). A smaller percentage (1%) noted reduced soil fertility, while 5% experienced a combination of these effects. Sisal workers, who often live near processing sites, also reported similar issues, including skin rashes from direct contact with sisal waste. Additionally, another study reported similar findings, showing that methane emissions from sisal waste significantly contribute to greenhouse gas (GHG) emissions (Broeren et al., 2017). This is attributed to the unpleasant odour experienced near sisal waste disposal sites.

To address these challenges, sisal industries primarily dispose of liquid waste in sewage ponds (95%), with 67% treating the wastewater using chemicals (for disinfection, PH adjustment, organic and heavy metal contaminant removers, and activated carbon or coagulants). Additionally, 57% of industries adopt integrated mitigation strategies, such as planting trees along borders and using chemical treatments. However, 34% of respondents reported no mitigation measures, highlighting significant gaps in waste management. Households, on the other hand, focus on mitigating immediate nuisances, with 48% using mosquito nets and 41% using repellents. Only 4% reported disposing of waste away from rivers, indicating limited attention to long-term environmental impacts.

Though the majority of the households perceived no benefits from sisal waste, 29% utilized it for animal feed, manure, firewood, or mattress making. This underutilization suggests a need to explore innovative ways to repurpose sisal waste, reducing its environmental impact while creating economic opportunities. This also correlates with findings by Fischer et al (2010), which showed that sisal waste can be used as animal feed, manure, and fuel.

Objective 2. Impact of Sisal Waste on Water Quality

The study analyzed the impact of sisal waste on water quality in three rivers (Lomolo, Molo, and Majani-Mingi) and borehole water in the surrounding areas. Key parameters, including pH, temperature, total dissolved solids (TDS), conductivity, dissolved oxygen (DO), and turbidity, were established to assess the effects of sisal processing activities on water quality. The study reveals a complex interplay between sisal production activities and the local environment.

Results showed that P^H levels in all rivers declined downstream of sisal processing industries, with Molo and Majani Mingi Rivers showing the steepest drops, indicating acidification likely caused by industrial effluents. This correlates with studiesconducted by Schwaninger (2012), Shamte (2001), Mwaniki (2018), and Yhedgo (2015), which showed a relationship between sisal waste and increased pH levels.

Temperature fluctuations were minimal, with all rivers remaining within acceptable standards. TDS and conductivity levels were within WHO guidelines, though the Rongai

River exhibited the highest values, suggesting low-level contamination. Dissolved oxygen levels were below WHO standards in all rivers, particularly in the Majani-Mingi River, highlighting potential stress on aquatic ecosystems. River water turbidity was highest in the Rongai River but showed no significant correlation with sisal waste, as heavy rains and natural factors appeared to have a greater influence. The findings of this study are similar to a study in Tanzania that showed that influent and effluent sisal wastewater resulted in increased acidity (pH) and affected dissolved oxygen (Yhedgo, 2015). Borehole water analysis showed acidic P^H levels and low DO, likely influenced by sisal waste infiltration, though TDS and conductivity remained within safe limits.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

This chapter presents a summary of the study findings, conclusions, and recommendations on the assessment of the impacts of sisal processing industries on the water resource quality in Rongai Sub-County. The research objectives guided the findings, conclusions, and recommendations.

5.2 Conclusion

The study highlights the significant impact of sisal processing activities on water quality in Rongai Sub-County. The reliance on river water for both domestic and industrial purposes was a key finding. Most households (67.7%) depend on rivers such as Molo, Rongai, and Majani-Mingi for domestic use, and all sisal industries and traders exclusively draw water from rivers for sisal processing, averaging 95,465 litres per day.

Sisal waste disposal has led to water acidification, reduced dissolved oxygen levels, and increased conductivity in nearby rivers, posing risks to aquatic ecosystems and the usability of water. The analysis of river water showed significant environmental concerns. P^H levels consistently declined downstream of sisal processing areas, with the Molo River experiencing the steepest drop. Dissolved oxygen levels also decreased, particularly in the Majani-Mingi River, potentially affecting aquatic life. Conversely, borehole water quality, though slightly acidic, met WHO guidelines on dissolved oxygen, with low total dissolved solids (TDS) and stable conductivity across sampled locations.

Additionally, the release of untreated and poorly managed sisal waste caused immediate nuisance, such as increased mosquito breeding and bad odour, affecting both households and sisal workers. While some mitigation measures, such as chemical treatment of wastewater and tree planting, have been adopted by sisal industries, these efforts remain insufficient and unevenly implemented. A significant portion of industries (34%) reported no mitigation measures, and households primarily focused on short-term solutions, such as mosquito nets and repellents, rather than addressing long-term environmental impacts.

The reliance on river water by both households and industries shows the importance of improving waste management practices to protect this vital resource. Furthermore, the underutilization of sisal waste as a potential resource (e.g., for animal feed, compost, or firewood) represents a missed opportunity to reduce waste and create economic benefits. The study found no significant impact of the sisal industry on river water turbidity, as no notable differences were observed in turbidity levels before and after proximity to the industry. Instead, natural factors like upstream heavy rains and vegetation, which affect soil erosion, were identified as the primary contributors to turbidity.

The closure of the Majani Mingi Sisal Industry and its subsequent relocation to Lomolo had a significant impact on water quality in these regions. The improvement in ionic content at Majani Borehole reflected the cessation of industrial activities, while the moderate conductivity and slightly lower dissolved oxygen in Lomolo Borehole might suggest early signs of industrial impact. These observations show the importance of closely monitoring boreholes near industrial activities to prevent potential degradation of water quality.

5.3 Recommendations from the Study

The sisal industry in Rongai Sub-County has an impact on the environment and local communities, necessitating strategic interventions to mitigate harm and promote sustainable development. This research recommends:

a) The use of improved waste treatment technologies as opposed to reliance on natural containment methods.
b) Community Sensitization on Innovative Sisal Waste Repurposing.

Overall, the study highlights the importance of implementing improved waste management practices to mitigate acidification, low oxygen levels, and potential contamination, thereby ensuring the protection of aquatic ecosystems and water resources.

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APPENDICES

Appendix I: Confidentiality Tool Introduction

I am Jackline Kiptui, a Master of Environmental Science student at Kabarak University researching on the "*Assessment of the impacts of sisal processing industries on water resources in Rongai sub-county, Kenya*." I am kindly requesting your time in honestly answering this questionnaire to the best of your knowledge. This research is meant for academic purposes that may be used to inform future development, policy, and educational materials. Your response will be confidential and used for academic purposes only. Participation is voluntary.

Potential Risks

There are no anticipated risks associated with participation in this study during the data collection process. The study has been designed to ensure that respondents' safety and well-being are protected at all times.

Confidentiality and Data Safeguarding

The data collected during this research is intended solely for academic purposes, including informing future development, policy, and educational materials. Here's how we will protect your privacy and ensure the confidentiality of your data:

- **Data Usage**: Collected data will be used exclusively for the research objectives outlined. It will not be utilized for any other purposes.
- **Data Storage**: All data will be stored on a password-protected computer to ensure its security. Access to this data will be restricted to authorized personnel only.
- **Data Retention and Disposal**: Data will be retained for a period of 7 years and will be securely discarded thereafter to ensure it is no longer accessible.
- **Anonymity and Privacy**: During data collection, you have the option to use either your real name or a pseudonym (fake name). This choice will help safeguard your identity and maintain your privacy.
- **Access to Data**: The data will be held by the principal investigator. It will only be released to third parties upon receiving a formal written request, ensuring that any such request is carefully reviewed and authorized.These measures are in place to

uphold your confidentiality and ensure the responsible handling of your data throughout the research process.

Consent

Do you consent to participate in this research voluntarily?

Yes ☐

No☐

Appendix II: Research Instruments

Section 1: Interview schedule Households heads and Sisal workers

Iam Jackline Kiptui, a Master of Environmental Science student at Kabarak University conducting research on the "Assessment of the impacts of sisal processing industries on water resources in Rongai sub-county, Kenya." I am kindly requesting your time in honestly answering this questionnaire to the best of your knowledge. This research is meant for academic purposes that may be used to inform future development, policy, and educational materials. Your response will be confidential and used for academic purposes only. Participation is voluntary.

Section A: General Information

1. Name...
2. Gender Male [] Female [] ....
3. Age…………………………………………………………….
4. Ward...................................
5. Mobile Number………………………….

Section B: Research questions

1. Do you or anyone in your household use or sell sisal products?

Yes ( ) No ( )

2. Have you been directly affected by disposed sisal waste?

Yes () No ()

If yes, how?

1. What measures have you adopted to mitigate the negative impacts of sisal waste?

Yes () No ()

How do they work?

Are there any benefits of sisal waste?

Yes () No ()

If yes, which ones?

1. What is your primary water source for domestic use?
2. Do you treat your water before drinking or using it?

Section 2: Key Informants Interview Schedule

I am Jackline Kiptui, a Master of Environmental Science student at Kabarak University researching on the "*Assessment of the impacts of sisal processing industries on water resources in Rongai sub-county, Kenya*." I am kindly requesting your time in honestly answering this questionnaire to the best of your knowledge. This research is meant for academic purposes that may be used to inform future development, policy, and educational materials. Your response will be confidential and used for academic purposes only. Participation is voluntary.

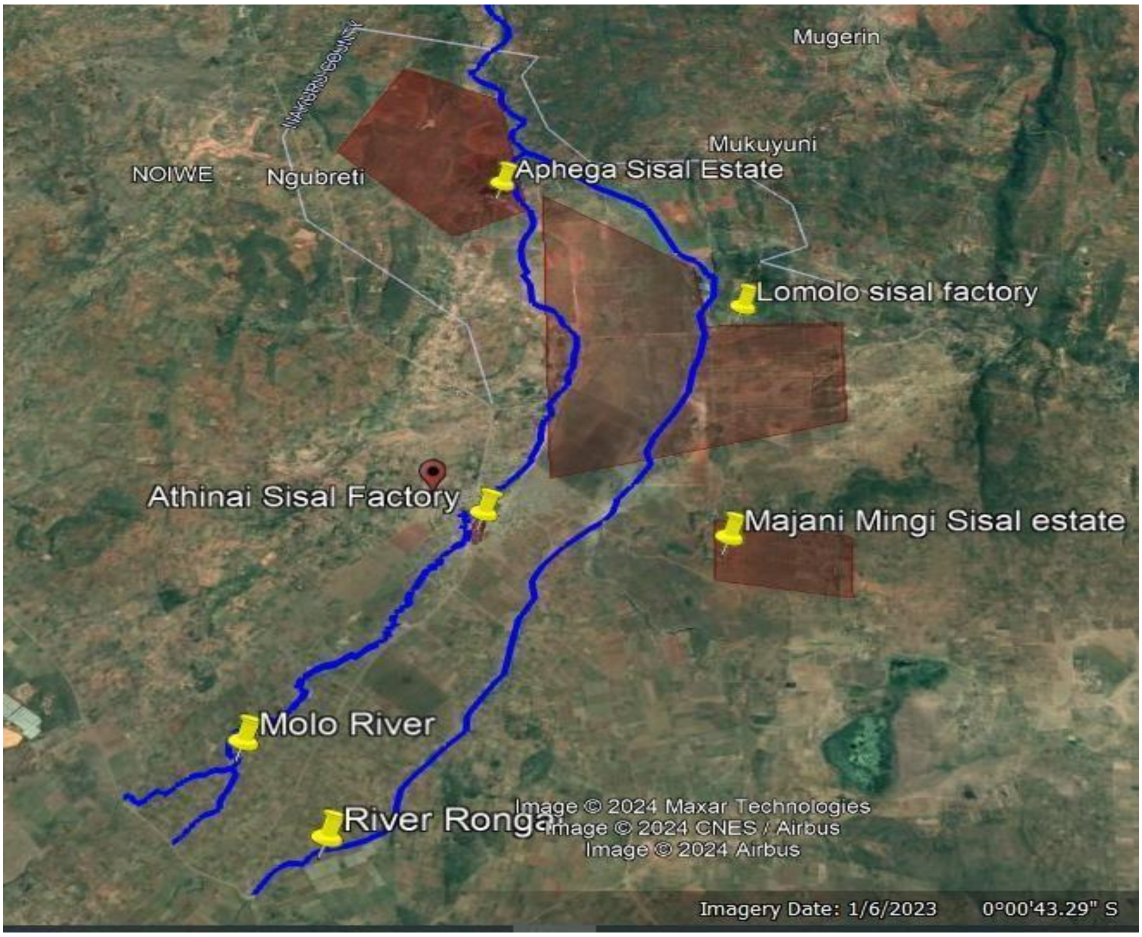
Section A: General Information

1. Name..
2. Gender Male [] Female [] ....
3. Age…………………………………………………………………
4. Ward....................................
5. Mobile Number………………………….

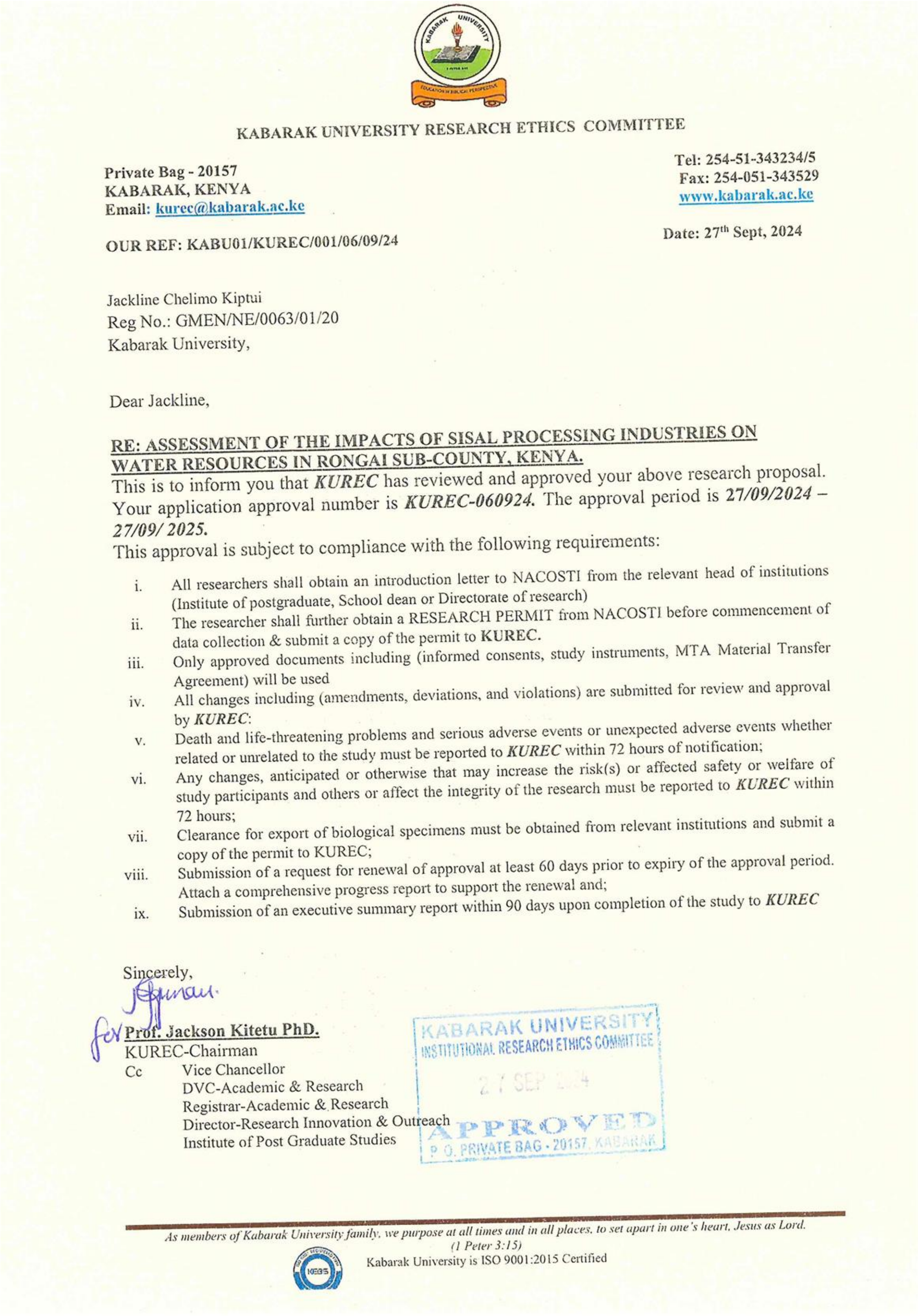
Section B: Research Questions

1. What is your primary water source for industrial use?
2. Where do you draw your water for sisal processing?
3. How much water do you use per day for sisal processing?
4. How do you dispose of your wastewater?
5. Do you treat your wastewater before disposal?
6. Are there any measures you adopted to mitigate the negative impacts of sisal waste?
7. What has been achieved through these mitigation measures?
8. Have you been directly affected by disposed sisal waste?

Appendix III: Map of the Study Area



Appendix IV: KUREC Clearance Letter



KABARAK UNIVERSITY RESEARCH ETHICS COMMITTEE

Private Bag - 20157
KABARAK, KENYA
Email: kurec@kabarak.ac.ke

Tel: 254-51-343234/5
Fax: 254-051-343529
www.kabarak.ac.ke

OUR REF: KABU01/KUREC/001/06/09/24

Date: 27th Sept, 2024

Jackline Chelimo Kiptui
Reg No.: GMEN/NE/0063/01/20
Kabarak University,

Dear Jackline,

RE: ASSESSMENT OF THE IMPACTS OF SISAL PROCESSING INDUSTRIES ON WATER RESOURCES IN RONGAI SUB-COUNTY, KENYA.

This is to inform you that ***KUREC*** has reviewed and approved your above research proposal. Your application approval number is ***KUREC-060924.*** The approval period is ***27/09/2024 – 27/09/ 2025.***

This approval is subject to compliance with the following requirements:

i. All researchers shall obtain an introduction letter to NACOSTI from the relevant head of institutions (Institute of postgraduate, School dean or Directorate of research)
ii. The researcher shall further obtain a RESEARCH PERMIT from NACOSTI before commencement of data collection & submit a copy of the permit to **KUREC.**
iii. Only approved documents including (informed consents, study instruments, MTA Material Transfer Agreement) will be used
iv. All changes including (amendments, deviations, and violations) are submitted for review and approval by ***KUREC***:
v. Death and life-threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to ***KUREC*** within 72 hours of notification;
vi. Any changes, anticipated or otherwise that may increase the risk(s) or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to ***KUREC*** within 72 hours;
vii. Clearance for export of biological specimens must be obtained from relevant institutions and submit a copy of the permit to KUREC;
viii. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal and;
ix. Submission of an executive summary report within 90 days upon completion of the study to ***KUREC***

Sincerely,

for **Prof. Jackson Kitetu PhD.**
KUREC-Chairman
Cc Vice Chancellor
DVC-Academic & Research
Registrar-Academic & Research
Director-Research Innovation & Outreach
Institute of Post Graduate Studies

KABARAK UNIVERSITY
INSTITUTIONAL RESEARCH ETHICS COMMITTEE
27 SEP 2024
APPROVED
P.O. PRIVATE BAG - 20157, KABARAK

As members of Kabarak University family, we purpose at all times and in all places, to set apart in one's heart, Jesus as Lord.
(1 Peter 3:15)
Kabarak University is ISO 9001:2015 Certified

Appendix V: NACOSTI Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **802218**

Date of Issue: **11/October/2024**

RESEARCH LICENSE

This is to Certify that Ms.. Jackline Chelimo of Kabarak University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Nakuru on the topic: Assessment of the impacts of sisal processing industries on water resources in Rongai subcounty, Kenya for the period ending : 11/October/2025.

License No: **NACOSTI/P/24/41007**

802218
Applicant Identification Number

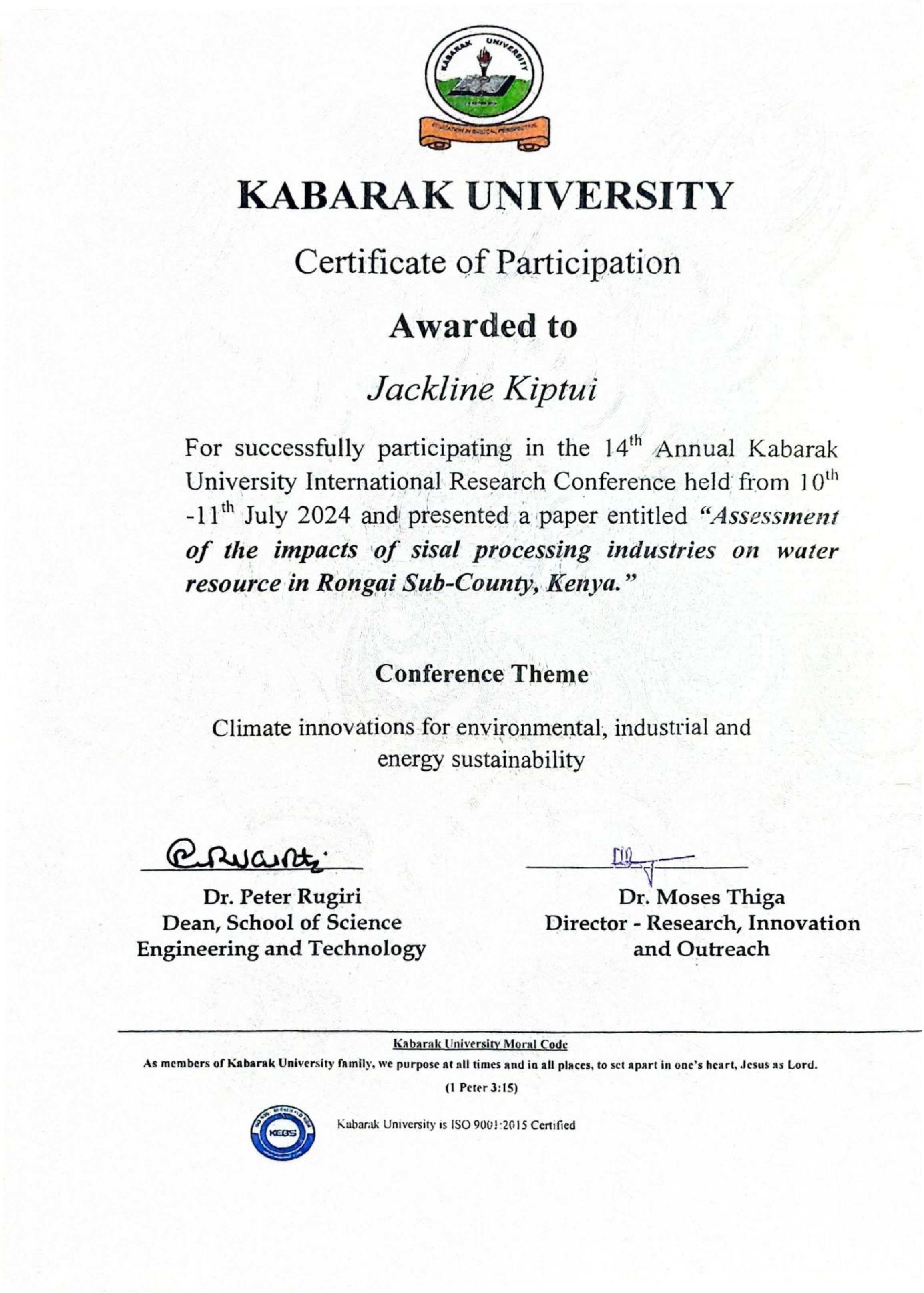
Director General
NATIONAL COMMISSION FOR
SCIENCE,TECHNOLOGY &
INNOVATION

Verification QR Code

NOTE: This is a computer generated License. To verify the authenticity of this document,
Scan the QR Code using QR scanner application.

See overleaf for conditions

Appendix VI: Evidence of Conference Participation



KABARAK UNIVERSITY

Certificate of Participation

Awarded to

Jackline Kiptui

For successfully participating in the 14th Annual Kabarak University International Research Conference held from 10th -11th July 2024 and presented a paper entitled ***"Assessment of the impacts of sisal processing industries on water resource in Rongai Sub-County, Kenya."***

Conference Theme

Climate innovations for environmental, industrial and energy sustainability

Dr. Peter Rugiri
Dean, School of Science
Engineering and Technology

Dr. Moses Thiga
Director - Research, Innovation
and Outreach

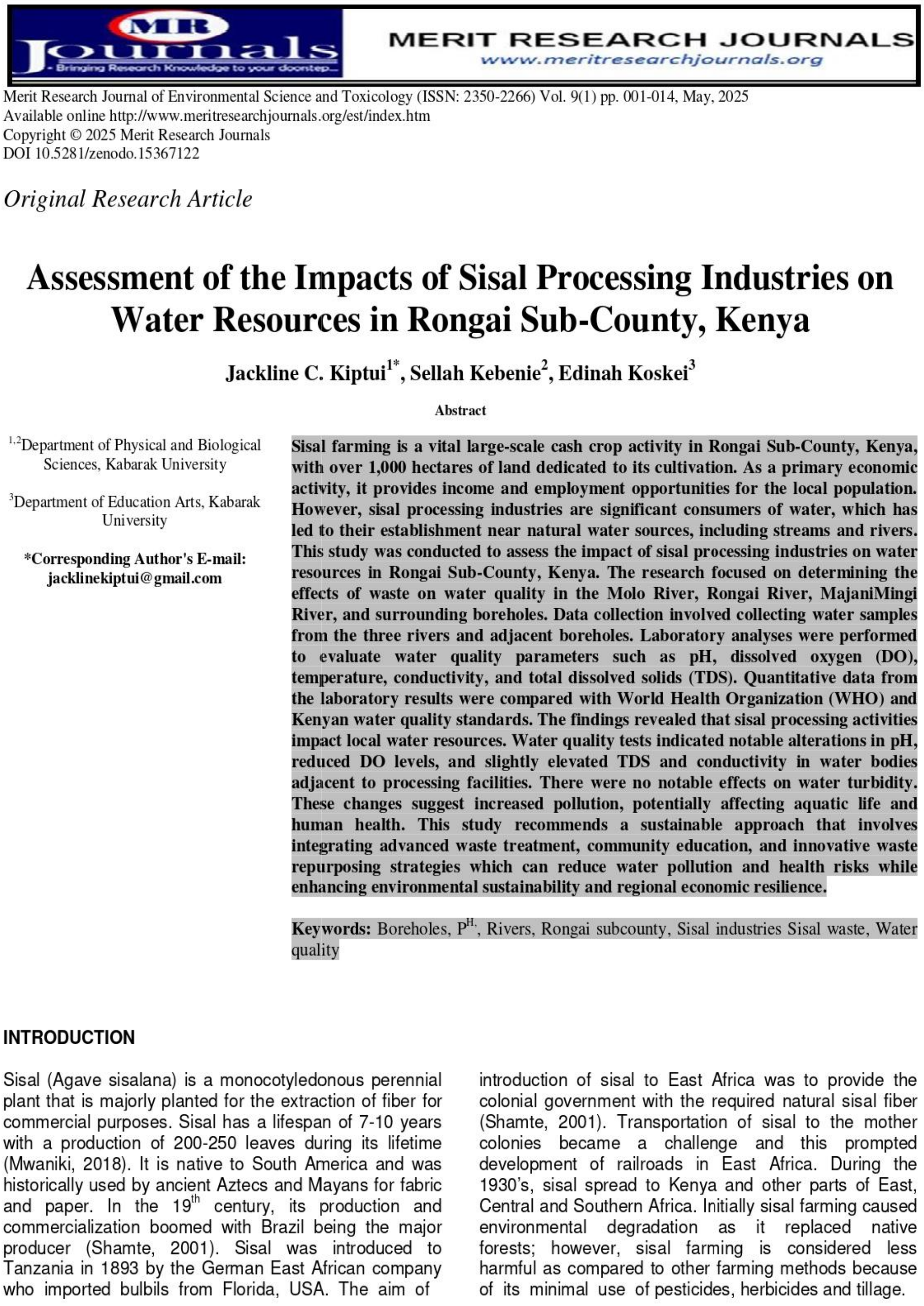
Kabarak University Moral Code

As members of Kabarak University family, we purpose at all times and in all places, to set apart in one's heart, Jesus as Lord.

(1 Peter 3:15)

Kabarak University is ISO 9001:2015 Certified

Appendix VII: List of Publication



MERIT RESEARCH JOURNALS
www.meritresearchjournals.org

Merit Research Journal of Environmental Science and Toxicology (ISSN: 2350-2266) Vol. 9(1) pp. 001-014, May, 2025
Available online http://www.meritresearchjournals.org/est/index.htm

DOI 10.5281/zenodo.15367122

Original Research Article

Assessment of the Impacts of Sisal Processing Industries on Water Resources in Rongai Sub-County, Kenya

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[3]Department of Education Arts, Kabarak University

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Abstract

Sisal farming is a vital large-scale cash crop activity in Rongai Sub-County, Kenya, with over 1,000 hectares of land dedicated to its cultivation. As a primary economic activity, it provides income and employment opportunities for the local population. However, sisal processing industries are significant consumers of water, which has led to their establishment near natural water sources, including streams and rivers. This study was conducted to assess the impact of sisal processing industries on water resources in Rongai Sub-County, Kenya. The research focused on determining the effects of waste on water quality in the Molo River, Rongai River, MajaniMingi River, and surrounding boreholes. Data collection involved collecting water samples from the three rivers and adjacent boreholes. Laboratory analyses were performed to evaluate water quality parameters such as pH, dissolved oxygen (DO), temperature, conductivity, and total dissolved solids (TDS). Quantitative data from the laboratory results were compared with World Health Organization (WHO) and Kenyan water quality standards. The findings revealed that sisal processing activities impact local water resources. Water quality tests indicated notable alterations in pH, reduced DO levels, and slightly elevated TDS and conductivity in water bodies adjacent to processing facilities. There were no notable effects on water turbidity. These changes suggest increased pollution, potentially affecting aquatic life and human health. This study recommends a sustainable approach that involves integrating advanced waste treatment, community education, and innovative waste repurposing strategies which can reduce water pollution and health risks while enhancing environmental sustainability and regional economic resilience.

Keywords: Boreholes, $P^{H,}$, Rivers, Rongai subcounty, Sisal industries Sisal waste, Water quality

INTRODUCTION

Sisal (Agave sisalana) is a monocotyledonous perennial plant that is majorly planted for the extraction of fiber for commercial purposes. Sisal has a lifespan of 7-10 years with a production of 200-250 leaves during its lifetime (Mwaniki, 2018). It is native to South America and was historically used by ancient Aztecs and Mayans for fabric and paper. In the 19th century, its production and commercialization boomed with Brazil being the major producer (Shamte, 2001). Sisal was introduced to Tanzania in 1893 by the German East African company who imported bulbils from Florida, USA. The aim of introduction of sisal to East Africa was to provide the colonial government with the required natural sisal fiber (Shamte, 2001). Transportation of sisal to the mother colonies became a challenge and this prompted development of railroads in East Africa. During the 1930's, sisal spread to Kenya and other parts of East, Central and Southern Africa. Initially sisal farming caused environmental degradation as it replaced native forests; however, sisal farming is considered less harmful as compared to other farming methods because of its minimal use of pesticides, herbicides and tillage.