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Original Research Article

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

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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 19^{th} 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.

In Brazil decortication of sisal fiber generated large amounts of waste water which are stored in lagoons, ponds or discarded in rivers. This has caused environmental problems due to 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 analysis from influent and effluent sisal wastewater resulted in environmental and human impact (Yhedgo, 2015). The study showed that waste water from sisal industries increased acidity (P^H) of water bodies. The study also showed that effluent waste water had non-conformity 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 revealed lack of pollution from heavy metals in the sisal wastewater (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) which is evident through the 2021 sisal exports that were at 14,822 metric tons, and had an income generation of 2.45 billion Kenya shillings (Agriculture and Food Authority-2022). 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 aimed at identifying whether the disposal of sisal waste in ponds situated near river channels negatively affects the quality of water in the rivers around the environs of the industries. Consequently, it aimed at identifying the quality of domestic water sources for community members who live near sisal industries and how the industries mitigate pollution from sisal waste disposal. The data collected in this study was used to clarify the impact of sisal processing industries on water quality and availability in Rongai Sub County.

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. The specific objective of this research was to evaluate the impacts of sisal industries' waste disposal on water quality in Molo River, Rongai River, Majani-Mingi River, and surrounding boreholes in Rongai Sub County.

LITERATURE REVIEW

Water Quality

Water quality encompasses its physical, chemical, and microbiological properties**,** which determine its suitability for domestic, agricultural, and industrial use (Banjeer and 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 as 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 bacteria that may pose health risks to consumers (Kumple et al., 2017).

In Most African urban towns and cities, there is low access to piped water with the average coverage reported as 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 which include rivers, springs, wells and boreholes spread across the county. In Rongai Sub County, main sources of domestic water supply are the river Molo (Permanent River), River Rongai (Seasonal River) and boreholes. Other sources include piped water from Chemasus 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/cars next to river channels have had serious effects on 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 at risk of contamination due to 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 such as rivers, springs, wells, and boreholes playing a critical role in water supply (NEMA, 2020). However, these sources are vulnerable to contamination from human activities, industrial effluents, and agricultural runoff (Mwangi and Gabriel, 2008).

Sisal waste has been identified as a significant source of water 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 (2022), 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 et al., 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, 2022).

Another concern is the presence of heavy metals such as lead and chromium, which are sometimes found in sisal waste due to 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 (Yang 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, 2022).

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). This excessive algal growth can block sunlight penetration, disrupt aquatic food chains, and result in mass 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 (Sa'id, 2013).

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 (Sa'id, 2013).

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, 2022).

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^H greater 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 low P^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 suppliers maintain 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 (Manjar, 2010; Atlas Scientific, 2022).

Sisal waste contains organic acids and compounds that significantly influence water P^H levels. During the decortication process**,** large quantities of organic matter and residual pulp are produced, which undergo microbial decomposition and release acidic compounds into water bodies (FAO, 2022). 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 et al., 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 (Sa'id, 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 (Yang et al., 2013). 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, 2022). This poses a serious threat to food safety and public health, as these contaminants can enter the human food chain through fish consumption (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 (Sa'id, 2013). 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 (Yang et al., 2012). This can help minimize sisal industry's environmental footprint and protect water resources from acidification-related degradation (FAO, 2022).

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 a light is shined on the water sample (Lenntech, 2023).Small particles like clay, silt, algae 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 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, runoff or debris, wastewater, decay of 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, 2022). 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 (Yang 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 et al., 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 (Sa'id, 2013). 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 sisal industry effluent can lead to long-term siltation, which alters river flow patterns and contributes to flood risks in affected areas (FAO, 2022).

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).

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). The aesthetic objective for water temperature for Drinking Water Quality is 15°C (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 like heavy metals that include cadmium, zinc and lead (White C, 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 C̊ for maximum flavor, or chilled cold 6C̊ for maximum refreshment but for achieving proper hydration, Sa'id 2013, showed that a water temperature of 16℃ 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 (Yang et al., 2012). The release of warm effluents into natural water bodies alters thermal regimes, potentially affecting aquatic ecosystems (FAO, 2022).

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 result in hypoxic conditions, which negatively impact fish and other aquatic organisms, 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 bio-available 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, 2022).

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 (Sa'id, 2013). Proper wastewater management can help maintain ecological balance, minimize oxygen depletion, and reduce the risks associated with thermal pollution in sisal-producing regions.

Electrical conductivity

Water conductivity is the measurement of the ability of water to pass electrical flow 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 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 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, 2022). 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 (Sa'id, 2013)

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 an important parameter in determining water quality, as high concentrations can indicate pollution and 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 (Yang 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, 2022). 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 result in soil salinization, reducing agricultural productivity and impacting 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 (Sa'id, 2013). 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).

Dissolved Oxygen(DO).

Amount of oxygen present in water (DO) is considered an important measure of water quality as it is adirect 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, and wastewater treatment plants, feedlots, failing septic systems, urban storm water 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 will be (Tchobanoglous G, 2003). The higher the concentration of dissolved oxygen the better is 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 chemically oxidize organic matter present in water, 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 consist of organic matter that reduces dissolved oxygen in water resulting in poor quality of water.

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 (Yang 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, 2022). Additionally, the accumulation of sisal waste at the bottom of water bodies can lead to the production of hydrogen sulfide (H_2S), a toxic gas that further reduces oxygen availability and creates an unpleasant odor (Sa'id, 2013).

RESEARCH METHODOLOGY

Research design

Experimental research designs were adopted for this research project. An experimental research design is a research method that allows researchers to establish a cause-and-effect relationship between two or more variables in a controlled environment in order to draw specific conclusions about a hypothesis or to answer a research question. This study adopted an experimental research design to assist in determining 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 standards on drinking water quality.

Location of the study area

The study area was located in Soin Ward, Rongai Sub County in Nakuru County, between Nakuru City to the south and Mogotio Town to the north. It covered an area of 292.5 sq. km, with geographic coordinates of Latitude: -0°1'59.99" and Longitude: 35°58'0.02". It lay at an altitude of 1590 meters above sea level.

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 1 km, 0.8 km, 0.6 km, 0.4 km, 0.2 km, and 0 km from both upstream and downstream the sisal industry effluent discharge entry to the river 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.

Water Quality Analysis

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

Temperature

The temperature of each water sample was measured using a thermometer with scale of 0 – 110 ^oC. The thermometer was cleaned and inserted into 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.

P^H for acidity and alkalinity Measurement

A P^H meter was used to measure the P^H of water sample. The samples were collected in a clean container and the electrode of the P^H meter were 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 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.

Turbidity

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

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 re-inserted into the sample and continuously stirred to allow the water to stabilize and to wait for the dissolved oxygen readings to stabilize for accurate results.

Total Dissolved Solids

Total dissolved solids was 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 re-inserted into the sample and continuously stirred to allow the water to stabilize and to wait for the total dissolved solids readings to stabilize for accurate results.

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 re-inserted into the sample and continuously stirred to allow the water to stabilize and to wait for the conductivity readings to stabilize for accurate results.

Data Analysis Procedure

Water samples were collected and analyzed in the laboratory using specific reagents and testing tools. The results of the water analysis were presented using tables and graphs. This analyzed data was utilized to illustrate the relationships between industrial waste disposal and water quality in rivers and boreholes. Water samples were analyzed 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.

RESULTS AND DISCUSSION

The analysis of the effect of sisal waste on water quality on 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.

P^H Levels of water

Table 1 below 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.

One-Sample T-Test results (comparing with 0.2 km upstream value) shows 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 is 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 downstream. Majani-Minig River had a t-statistic of -4.87 and a p-value of 0.0046. This is 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 downstream 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 before the sisal industry and after the sisal industry showed that there was a decline in P^H levels. The P^H levels gradually declined (Table 1) 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 discharge of effluents from the sisal processing industries into the river.

Molo River exhibited the steepest decline of 0.8 (Table1), 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 12), which also showed significant acidification, reinforcing concerns over increased water acidity. Rongai River experienced the least decline of 0.3 (Table 1), possibly due to differences in local buffering capacities or exposure to pollution sources.

River water P^H from the three rivers were not conforming to WHO standards required for water 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 reflects a need for interventions to address acidification effects, which could harm aquatic ecosystems and downstream water users.

Temperatures

Table 2 below shows temperatures stability and fluctuations that will provide insights into river dynamics and potential anthropogenic impacts.

A one sample T-test showed that Rongai River had a t-statistic of 1.58 and a p-value of 0.175, indicating 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 lack of statistically significant change ($p > 0.05$). For Majani-Minig 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-Minig 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, while Rongai River displayed the most variation of 17-19°C at specific points during its flow downstream, however the temperatures of all the rivers reverted back to their initial temperatures at 0.8km downstream.

This suggest potential external influence on river water temperature on River Rongai and river molo as it flowed down stream in close proximity to the industry, however, there were no observable effluent entry points into the river. The consistent temperatures at Majani-Mingi river is attributed to the closure of Majnai-Mingi sisal processing industry. NEMA standards of river water temperature is at 20°C though this is influenced by location and seasonal weather changes. The overall river water temperatures were close to the NEMA standard indicating minimal external influence.

Temperatures remained within ranges suitable for aquatic life, the variations highlight areas requiring closer monitoring, especially in Rongai and Molo rivers as shown in figure 1 below.

Total Dissolved Solids (TDS)

Table 3 below shows TDS levels in the three rivers which reflect organic matter (sisal waste) content and potential mineral content in river water.

Based on the statistical analysis (One sample T-test), which compared each measurement point to the upstream reference, changes in Rongai river data is barely significant with a mean difference of +2.6 mg/L and a p-value of 0.049 (just barely significant at $\alpha=0.05$). Molo River data change in TDS is highly statistically significant with a mean difference of -13.2 mg/L and a p-

Table 1. Data on river water P^H along the river channel

Point of collection	Rongai River	Molo River	Majani-MinigRiver	WHO standards
0.2 km upstream (from the company)	6.4	6.4	6.2	6.5-8.5 *(World Health Organization, 2011)*
O km (next to company)	6.1	6.1	5.5	
0.2 km down stream	6.2	5.9	5.5	
0.4 km down stream	6.2	5.7	5.4	
0.6km down stream	6.1	5.8	5.3	
0.8 Km down stream	6.1	5.6	5.4	

Table 2. Fluctuations in river water temperature along the river channel before during its flow close 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 company)	19°*C*	18°*C*	19°*C*	
0.2 km down stream	20°*C*	18°*C*	19°*C*	
0.4 km down stream	20°*C*	17°*C*	19°*C*	
0.6km down stream	19°*C*	19°*C*	19°*C*	
0.8 Km down stream	19°*C*	17°*C*	19°*C*	

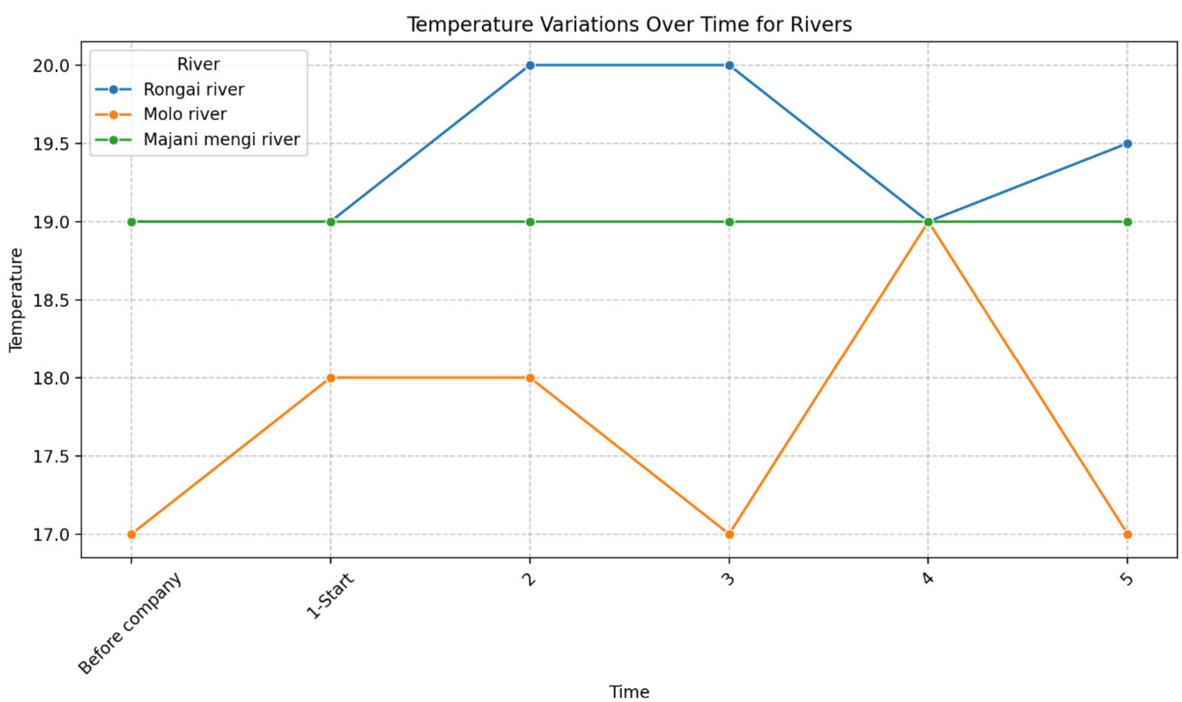

Figure 1. Temperature variations in Rivers at different points along the river channel

Table 3. Total Dissolved Solids (TDS) in River Water

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

Table 4. Conductivity of river water

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

Table 5. 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 – 8mg/L
O km (next to company)	4.5	4.4	3.5	
0.2 km down stream	4.5	4.5	3.7	
0.4 km down stream	4.5	4.2	3.6	
0.6km down stream	4.7	4.1	3.5	
0.8 Km down stream	4.7	4.0	3.5	

value of 0.00008. Majani-Mingi River changes in TDS levels is 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 + company locations to the upstream reference point, with 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 (Table 3), suggesting elevated dissolved matter content, from industrial discharge. Molo River showed a significant decline of 95mg/L to 83 mg/L. MajaniMingi River consistently had the lowest TDS which reduced from 40 mg/Lto34mg/L with a slight decreasing trend, reflecting relatively pristine conditions. The total amount of TDS in all the three rivers conforms with World Health Organization standards from TDS in drinking water which is at less than 600mg/L (World Health Organization, 2011).

Conductivity of water

Table 4 above shows the changes in water conductivity in the three rivers before it comes in close contact with the sisal processing industry and during its flow in close proximity to the sisal processing industries.

A One-Sample T-Test compared water conductivity data with reference to the 0.2KM upstream data. The test showed that Rongai River had a t-statistic of 3.87 and a p-value of 0.0117, which is a statistically significant

Table 6. 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 Bore hole	5.7	40	4.97	63

increase ($p < 0.05$), indicating 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 significant 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, Rongai River had a conductivity increases downstream while Molo River and Majani-Minig River had a conductivity decreases downstream. These changes suggest different impacts, possibly due to different chemicals used in industrial discharge.

The results on conductivity as shown on table 15 shows that conductivity trends correlate with dissolved solids and potential pollutants when compared to table 14 above. Rongai River displayed an initial increase in conductivity from 173µS/cm to 183µS/cm after the river channel came in close proximity to the sisal industry as shown in Table 5 above. This was followed by stabilization with minor fluctuations, suggesting an initial increase in pollutants with subsequent improvements.

Molo River displayed an initial decrease in conductivity, followed by subsequent increased conductivity downstream. This suggests ineffective mitigation measures as shown in Table 4 above. MajaniMingi River showed consistent decreases in conductivity from 60 µS/cm to 53 µS/cm and the lowest level of conductivity (Table 4), further supporting its characterization as the least impacted river. However, all the three rivers are within the WHO standards of drinking water conductivity which is less than 400µS/cm (Meride and Ayenew, 2016).

Dissolved Oxygen (DO)

Dissolved oxygen is a critical parameter for aquatic ecosystems which is affected by organic matter like sisal waste. Table 5 shows the parameters of DO on various points along the river channels.

Based on the statistical analysis (One sample T-test), which compared each measurement point to the upstream reference**,** Rongai River had a t-statistic of -2.24 and ap-value of 0.0756. This showed lack of statistical 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 lack of statistical significance ($p > 0.05$), showing no significant variation in dissolved oxygen downstream. Majani-Minig 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 significant drop in dissolved oxygen levels downstream. Overall, Rongai and Molo Rivers had n**o** significant change in dissolved oxygen levels while Majani-Minig River had a **s**ignificant decrease in dissolved oxygen downstream.

All three rivers showed a slightly decreased amount of dissolved oxygen after it came into close proximity with the sisal processing industries. Though Rongai River initially reduced from 4.7 mg/L to 4.5 mg/L, it gradually increased to 4.7 as shown in Table 5above.

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 a factor in the reduced oxygen levels because of ecological and biological processes such as oxygen consumption during decomposition of fallen organic matter such as leaves and dead plant matter, which significantly influence water quality.

Water from the three rivers have 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 this rivers for an improved ecological balance.

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 Lomoloas shown in table 6below.

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 recorded the highest P^H at 6.4, which is slightly below the acceptable range but closer to the guideline as shown in Table 6 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 World Health Organization (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 Organization, 2011)*, as it 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 is 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/L according 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 6shows that the ionic content in water is higher as compared to 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 which, influences the concentration of ions resulting in high conductivity. The increased acidity may be caused by poor sisal waste disposals that undergo biodegradation in soil releasing soluble acidic gases that dissolve on raining water making it acidic, which later on infiltrates the soil into underground water aquifers causing changes in ionic concentrations in the borehole water, however further research is recommended to prove this.

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 the impacts of sisal industry waste disposal on the water turbidity in River Molo and River Rongai .Figure 2 below shows the varying turbidity of river water samples collected from the three rivers.

River water samples from Rongai River exhibited the highest turbidity, followed closely by samples from Molo River, while those from MajaniMingi River were the least turbid. The lower turbidity in MajaniMingi 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. It is likely that 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 is made up of fibrous and particulate matter and contains 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.

DISCUSSION

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 such as P^H, temperature, total dissolved solids (TDS), conductivity, dissolved oxygen (DO), and turbidity were evaluated 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 revealed 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. Temperature fluctuations were minimal, with all rivers remaining within acceptable standards. TDS and conductivity levels were within WHO guidelines, though Rongai River exhibited the highest values, suggesting low level contamination. Dissolved oxygen levels were below WHO standards in all rivers, particularly in MajaniMingi River, highlighting potential stress on aquatic ecosystems. 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. River water turbidity was highest in Rongai River but showed no significant correlation with sisal waste, as heavy rains and natural factors appeared to have a greater influence. Overall, the study underscores the need for improved waste management practices to mitigate acidification, low oxygen levels, and potential contamination, ensuring the protection of aquatic ecosystems and water resources. Further research is recommended to explore long-term impacts and effective mitigation strategies.

CONCLUSIONS

Sisal waste disposal has led to water acidification, reduced dissolved oxygen levels, and increased conductivity in nearby rivers, posing risks to aquatic ecosystems and water usability. The analysis of river water revealed significant environmental concerns. P^H levels consistently declined downstream of sisal processing areas, with Molo River experiencing the steepest drop. Dissolved oxygen levels also decreased, particularly in MajaniMingi 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. 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 affects soil erosion, were identified as the primary contributors to turbidity. The closure of the Majani-Mingi sisal industry and its relocation to Lomolo influenced 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.

RECOMMENDATIONS FROM THE STUDY

The sisal industry in Rongai Sub-County significantly impacts the environment and local communities, necessitating strategic interventions to mitigate harm and promote sustainable development. Amore integrated and sustainable approach is recommended, combining improved waste treatment technologies, community education, and innovative repurposing of sisal waste. This would not only mitigate the negative effects of sisal waste on water quality and public health but also promote environmental sustainability and economic resilience in the region.

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