IMPACT OF SELECTED ANTHROPOGENIC DISTURBANCES ON THE TEMPORAL VARIABILITY OF RIPARIAN VEGETATION IN THE RIVER KATHITA BASIN, THARAKA NITHI COUNTY, KENYA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been submitted for examination or for an award of a diploma or conferment of a degree to any other institution.

Signature.. Date....22/10/2024.........

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Recommendation

This thesis has been examined, passed and submitted with our approval as the University supervisors.

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DEDICATION

To my family; My Mother, Brother and Sister

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ABSTRACT

Riparian areas play a significant role in provision of environmental goods and services and are hotspots for biodiversity. These fragile ecosystems however are increasingly threatened by human activities such as sand harvesting, charcoal burning and livestock grazing which alter their structure and composition. This study investigated the impact of the selected anthropogenic disturbances specifically; sand harvesting, charcoal burning and livestock drinking bays on the riparian vegetation variability of River Kathita, Tharaka sub-catchment area, Kenya. The study employed satellite imagery analysis using Normalized Difference Vegetation Index (NDVI) from 2003 to 2023. The results revealed a decline in vegetation health, with NDVI values dropping from a mean of 0.41 to 0.32 over the 20 years. Land use and land cover analysis indicated a decline of 30% forest area and an increase of 466.7% in development area. Sites affected by sand harvesting, charcoal burning and livestock grazing exhibited lower species diversity ($0 \geq H < 1.5$) while undisturbed sites maintained higher diversity ($1.1 > H \leq 2$). Although Kruskall-Wallis test for tree diversity among the sites was not statically significant (p=0.07), results for tree species richness were (p=0.047). Charcoal burning sites were characterized by large tree diameters at breast height (DBH) but lower tree heights. Sand harvesting and charcoal burning sites had high diversity of seedlings and saplings in abandoned sites indicating ability to recover and re-establishment of vegetation in absence of disturbance and with protection. Livestock drinking bays showed a shift in vegetation composition from grasses and shrubs to dominance by forbs and herbaceous plants. There were strong correlations between sand harvesting, charcoal burning, livestock grazing and tree diversity which was significant for livestock grazing (p=0.01) and marginally insignificant for sand harvesting and charcoal burning (p=0.06). The study recommends local and national stakeholders regulate sand harvesting, charcoal production in riparian areas and develop strategies for managing livestock access to drinking bays. Future research should explore the combined effects of climate change, agriculture and land-use policies on riparian habitats ecosystems.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA:	Analysis of Variance
ASAL:	Arid and Semi-Arid Land
DBH:	Diameter at Breast Height
FAO:	Food and Agriculture Organization
GPS:	Global Positioning System
NDVI:	Normalized Difference Vegetation Index
NRC:	National Research Council
NLC:	National Land Commission
NEMA:	National Environment Management Authority
USGS:	United States Geological Survey
UTaNRMP:	Upper Tana Natural Resource Management Project
WRA:	Water Resources Authority

CHAPTER ONE
INTRODUCTION
1.1 Background Information

Riparian ecosystems serve as critical zones for biodiversity and provide essential services such as water filtration, habitat for wildlife, thermal regulations, and erosion control. However, in Kenya, these invaluable areas face significant degradation due to human disturbances like sand mining, charcoal burning and grazing. A study in Cauvery Wildlife Sanctuary, India, showed a 50% reduction in species richness in the disturbed riparian area (Sunil et. al., 2011), emphasizing the need for local research. The River Kathita, a vital water source in Tharaka Nithi County, is under similar threat due to anthropogenic disturbances, yet little research exists on its riparian vegetation.

Additionally, anthropogenic disturbances continue degrade and threaten riparian habitats in many of Kenya's Wetlands and water resources. Lake Ol'bolosat faces near extinction from continued intense pressure from human and natural induced stressors such as unsustainable livestock / agricultural production, encroachments for human settlements and climate change and climate variability among others. Lake Naivasaha has faced similar challenges which resulted in over-exploitation and degradation of riparian resources. The alarming state of Lake Naivaisha and the degradation of its riparian prompted intervention measure like Lake Naivasha Protection Order (2011), specific to Lake Naivasha, for protecting riparian lands around significant water bodies in Kenya, addressing concerns about encroachment and environmental degradation (EAWLS 2017; MLPP 2022). In Tharaka-Nithi County, Tharaka North Sub County, Thanantu River has experienced comparable predicaments as a result of land use practices. Over the past 15 years, land use in Tharaka North Sub County has shifted dramatically. Initially dominated by forests, the area is now primarily agricultural. This transition has led to several adverse effects on the Thanantu River such as the conversion of riparian forests to agricultural land which has resulted in the loss of riparian vegetation (Kirema, 2020). Analogous to the Thanantu River, River Kathita has faced severe degradation due to extensive sand harvesting, charcoal burning and livestock overgrazing in the drinking bays. These activities have led to significant loss of riparian vegetation.

As human population continues to grow, the delicate balance to vital ecosystems like the riparian ecosystem continually get disrupted through activities like dam constructions for irrigation, sand mining, clearing vegetation for farming or grazing among others. These disturbances most often have produced large-scale changes in the plant community structure and composition and are the greatest risk to riparian ecosystem conservation and their biodiversity. These riparian ecosystems are regarded as the most fragile ecosystems and most of these habitats are classified as either threatened or vulnerable (Miserendino et al., 2011). The human-induced disturbances along the fragile riparian ecosystems have significant ecological disruptions like loss of biodiversity and ecological services rendered by the riparian vegetation. Further, the disruptions on the riparian areas have spillover effects to the water channels and water quality as the riparian ecosystem and the streams/rivers are inseparable units. Therefore, riparian areas closely influence their adjacent rivers and in turn influence the livelihood of communities heavily depended on them and hence ought to be the focal point of conservation.

A study by Mendez-Toribio et al., (2014) in Mexico, found out that, human-influenced activities such as logging, livestock foraging and clearing of vegetation modified the riparian vegetation attributes, mostly species diversity and richness which resulted into drastic loss of species diversity. Those finding were similar to a study by Zogaris et al., (2009) that found out those areas where livestock grazing and trampling, clearing of vegetation, cutting of trees and mining were prevalent in Montane riparian areas in Greece, the areas were lacking several tree species that were abundantly distributed in other areas of the riparian forest. Human alterations in riparian ecosystems not only affect the present riparian vegetation structure and composition but also expose the riparian habitats to invasive and non- native species as well as result in fragmentation of riparian habitats. Despite the human perturbations posing threats to the riparian ecosystem, vegetation and habitat, most of the studies such as Miserendino (2011) and Chabari (2020) among have concentrated on water quality and stream habitat and hence seldom information on the riparian ecosystem vegetation composition and structure due to human-caused disturbances.

River Kathita flows from Meru County through Tharaka-Nithi County and drains in the Tana River. It is one of the two permanent rivers in the dry lands of Tharaka South constituency and therefore many communities along the river are highly depended on it thus establishing it as a key area for conservation efforts. Most economic, social and cultural activities of the locals in Tharaka South constituency are closely tied to this riparian zone. There is very little information and research about riparian areas in Kenya and significantly less information in Tharaka-Nithi County. There are limited studies on the state of the riparian vegetation on the study area and hence the study aims to bridge that gap in understanding how various disturbance-causing activities are altering riparian habitats in Marimanti, potentially jeopardizing the provision of ecosystem services. The study findings will be useful in formulating sound decisions and policy brief(s) for efficient management and utilization of riparian resources.

1.2 Statement of the Problem

River Kathita and its riparian zone are vital for livelihoods of residents in Tharaka-Nithi County, providing essential ecosystem services. However, indiscriminate activities such as sand harvesting, charcoal burning, livestock overgrazing and trampling are degrading these areas, leading to biodiversity loss and disruption of ecosystem functions. High sand demand for construction purposes has increased the sand harvesting activities along River Kathita basin where sand harvesting is predominately done. Sand harvested is used in Meru, Tharaka-Nithi and Embu County increasing pressure to clear more areas for the sand mining activities. Marimanti area is also famed for quality charcoal, increasing demand for charcoal production along the riparian zones, as well as livestock rearing which is a primary economic activity in the region causing overgrazing and trampling on the drinking bays along the River and its riparian. Despite the ecological and economic importance of these riparian zones, previous studies have focused primarily on water quality, leaving a gap in understanding of the impact of human disturbances on riparian vegetation. This study aims to fill the gap by investigating the impact of these disturbances on riparian vegetation variability in River Kathita, Tharaka sub-catchment area.

1.3 Research Objectives

1.3.1 General Objective

To investigate the impact of sand harvesting, charcoal burning and livestock drinking bays on the riparian vegetation variability of River Kathita, Tharaka sub-cathment area.

1.3.2 Specific Objectives

i. To assess temporal changes in the riparian vegetation health along the River Kathita between the years 2003 and 2023
ii. To determine the influence of sand harvesting on riparian vegetation diversity of River Kathita.
iii. To evaluate the influence of charcoal burning on composition and structure of riparian vegetation of River Kathita
iv. To determine the influence of livestock drinking bays on riparian vegetation diversity of River Kathita.

1.4 Research Hypothesis

The following hypotheses are to be tested;

H_{01}: There is no statistically significant temporal variation in the riparian vegetation health of River Kathita.

H_{02}: There is no statistically significant influence of sand harvesting on riparian vegetation diversity of River Kathita.

H_{03}: There is no statistically significant influence of charcoal burning on the composition and structure of riparian vegetation River Kathita.

H_{04}: There is no statistically significant influence of livestock drinking bays on riparian vegetation diversity of River Kathita.

1.5 Significance of the Study

Despite the ecological and economic values of the riparian ecosystems, in Kenya and in Tharaka-Nithi County they have received minimal attention regarding their conservation or regular scientific assessments of their status and biodiversity, resulting in limited data that could hinder the conservation of riparian zones. Marimati area which is an arid and semi-arid land (ASAL) is ecologically fragile in nature and the disturbances in the riparian ecosystem may take long time to recover. Charcoal burning, livestock drinking bays and sand mining may result in irreversible impacts in riparian biodiversity, vegetation structure and composition. Insufficient knowledge and data on status of riparian areas in Kenya has resulted into poor management of the riparian areas (NLC 2018).

This study will provide essential data on the impact of anthropogenic disturbances on riparian vegetation along River Kathita, addressing a significant gap in current research. The finding will inform local conservation authorities, such as Water Resources Authority (WRA), National Environment Management Authority (NEMA) as well National authorities such as National Land Commission (NLC) on strategies for managing riparian zones, ultimately contributing to more effective conservation policies and sustainable resource use.

1.6 Scope of the Study

The study was conducted on the lower riparian zone of River Kathita between Marimanti (37°58'32.79"E, 0° 9'29.63"S) and Kibuka area (38° 0'4.40"E, 0°15'55.32"S). This study focuses on the lower riparian zone of River Kathita between Marimanti and Kibuka due to its exposure to diverse anthropogenic disturbances. Data was collected from 15 sites. Disturbed sites were 12, that is, 4 sites for sand harvesting sites, 5 sites for livestock drinking bays, 4 sites for charcoal burning sites while un-disturbed sites were 3, used as control sites.

1.7 Limitations of the Study

The study was confined to riparian zone of River Kathita, Tharaka sub catchment area. It was also confined on one side of the River Kathita riparian zone due to flooding and heavy rains during the study period that rendered most areas in accessible and hence may limit the generalizability of the findings. Additionally, focusing on only the three disturbance variables, that is, sand harvesting, charcoal burning and livestock drinking bays due to resource and time constraints may not capture the full range of environmental factors affecting riparian vegetation variability. To mitigate the limitation of the study time frame and on the variables focused on, the study in addition used temporal assessment to investigate the vegetation health, and land use and land cover changes.

1.8 Operational Definition of Terms

Charcoal Burning	:	To make charcoal through logging of mature desire trees and preparing charcoal through dust, vegetation and grass kilns
Diameter at Breast Height	:	It is diameter of a standing tree trunk at approximately 1.3 m above ground, measured as the tree circumference
Livestock Drinking Bays	:	They are sites along the riparian habitat that the livestock utilize to access watercourse
Non-Disturbed Site	:	They are areas with minimal visible anthropogenic disturbances selected for the study
Selected Anthropogenic Disturbances	:	The selected anthropogenic disturbances for this study are sand harvesting, charcoal burning and livestock drinking bays
Sand Harvesting	:	Extraction of sand on riparian areas using simple tools like shovel by first clearing the top vegetation
Vegetation Variability	:	Differences in plant structure, composition and diversity

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview of Riparian Zones

Riparian zones are defined as intermediary zones between aquatic and terrestrial ecosystems. They are those areas adjacent to rivers, streams, lakes and other water bodies (NRC, 2002). They are among the earth's most precious ecosystems, delivering a wide range of goods and services. The riparian vegetation has great ecological importance and play critical functions of river bank stabilization, preventing erosion, trapping sediments and pollutants from plunging into the river/stream hence keeping the water clean. The riparian vegetation also provides habitats to diverse fauna and the fallen logs and leaves provide breeding grounds and food for fish. The riparian vegetation also functions as thermal cover against stressful extreme temperatures during different seasons of the year as well as to slow and dissipate floodwaters that would damage fish spawning areas as well as act as natural buffer against surges and floods (Brennan & Culverwell, 2004; Kingcounty, 2023; Singh et al., 2021). Apart from numerous benefits that the riparian ecosystems provide to humans, they are areas of high diversity and productivity.

In Kenya, the Environmental Management and Coordination Act of 2009 specifies that a riparian reserve is the area adjacent to a river, lake, or sea, measured from the highest water mark. This highest water mark represents the historically highest point where the water has touched the bank or shore. The land between the highest and lowest water marks is distinct from the riparian reserve (CoK 62(1, l)).The legislation defining this public land referred to as riparian land is not standard and varies among the different legal provisions. The definition of the riparian zone and determination of its width zone lay the drawbacks under which human-induced perturbations have continued to degrade the riparian zones.

2.1.1 Legal Frameworks

Definition and regulations of riparian zones is codified in various laws, regulations and policies in Kenya. The Environmental Management and Coordination Act (EMCA) of 1999 mandate a riparian reserve of 6 to 30 meters from the highest recorded flood level. Similarly, the Water Act of 2002 specifies a riparian buffer of 6 to 30 meters from the river's edge. The Agricultural Act requires a buffer of 6 to 10 meters, while the Physical Planning Act stipulates a minimum height of 2 meters and a maximum horizontal distance of 30 meters from the river's edge. The Survey Act mandates a minimum of 30 meters from the high water mark. The Water Quality Regulations of 2006 under EMCA set a riparian width of 6 to 30 meters on either side of the river, based on the highest recorded flood level. The Water Resource Management Rules of 2007, derived from the Water Act, define riparian land as extending 6 meters or the full width of the watercourse, up to a maximum of 30 meters on either side of the bank, measured from the top edge of the bank. Local by-laws also enforce a maximum distance of 30 meters from the high water mark.These legal provisions provide varying and conflicting definitions of riparian zones in terms of the measurements and user rights allowable. Interpretation of the regulations is often biased depending on the side of the interpreter which impedes enforcements and conservation efforts of the riparian zones.

2.1.2 Land Use

Whereas the right to access of riparian zones is provides in Kenyan laws, there exist strict restrictions on the nature of activities permitted on these fragile ecosystems. The Environmental Management and Coordination Act (EMCA) (1999) and the Water Resource Management Rules provide that "no person without prior written approval can excavate, drill, tunnel or disturb the river, direct or block any river. The Environmental Management and Coordination Regulations (2009) on wetlands, river banks, lake shores and sea shore management, allows for a variety of activities to be undertaken along a riparian area, including brick making, sport fishing, cultivation, commercial exploitation, construction of roads and railways. Under National Land Policy, 2009, Physical and Land Use Planning Act, 2019, Water Act, 2012, Building Code and Guidelines among others, the fragility nature of these zones is protected through prohibiting construction of permanent buildings on riparian land is prohibited, cultivation within a specific buffer zone is restricted and extraction of resources like sand from riparian zones is prohibited unless authorized under stringent conditions. On the contrary, the Water Act (2002) forbids tillage or cultivation; clearing of indigenous trees or vegetation; disposal of any form of waste; excavation of soil or development of quarries and planting of exotic species on riparian lands. These legislations provide conflicting direction on the allowable land uses on riparian land.

2.1.3 Institutional Mandate

In our Constitution 2010, Land Act 2012 and National Land Commission Act 2012, Rivers and their riparian zones have been classified as public lands under the preview of National Land Commission. The Land act gives powers to the commission to identify ecological sensitive areas such as the riparian zones and provide guidelines indicating the management principles and land use. On the other hand, the EMCA Act (1999) mandates NEMA in with environmental management functions as well as to regulate environmental resources utilization including riparian resources, gazetting riparian land as a protected area and issue guidelines and prescribe measures for the management and protection of areas of environmental significance. The Water Act also, mandates Water Resource Authority (WRA) to regulate of the management and use of water resources as well as regulations of activities on riparian land. More so, under the new constitutional dispensation, land use planning and development control are devolved functions under the jurisdiction of the County Government (County Government Act 2012).

It is this lack of clear and unambiguity in authority and management of riparian land and the evident overlaps on government mandate in delineation and management of riparian land that has resulted into detriment of these habitats. The lack to protect riparian zones contravenes our Constitution 2010 commitment and obligation to the environment as the people as well as article 69 (1) (2), which oblige the state and the people to protect the environment and promote the sustainable development and utilization of natural resources. The fragmented laws and overlapping mandates among constitutional bodies, authorities and state department leads to enforcement challenges and the inconsistency complicates compliance which has exposed the riparian zones to degradation from uncontrolled human disturbances.

The anthropogenic activities cause disturbances that produce large scale changes in plant community and structure which poses a risk in biodiversity of the whole ecosystem (Stephan and Issa 2007). In China an investigation into the effects of human activities on riparian herbaceous communities along the Lijiang River found out that human activities including sand mining, grazing and tourism affected and changed species composition, led to decreased species diversity, altered the natural species distributions, drove species to local extinction and fragmented riparian habitats (Yuan *et al.* 2019). A status report on riparian vegetation in the United States of America indicated that over 95% of riparian vegetation has been lost and that information about the quality of the riparian habitats is scanty. Although the information is scanty and studies assessing riparian areas limited, they show that the coverage of the riparian forests drastically shrunk and the functions of the riparian vegetation greatly diminished (NRC 2002), attributing it to anthropogenic activities like construction of dams, agriculture, mining activities, urbanization and recreational activities as the cause of degradation of the riparian areas.

A study on land use dynamics in South-western Nigeria found out that there was an alarming decline in riparian forests as a result of extensive deforestation (Adeoye *et al.* (2012).This was collaborated by Momodu *et al.* (2011) study, that found riparian forest in Nigeria have declined by almost 50% from 1978-2000. Additionally, a study to evaluate the effects of land use on the dynamics of riparian vegetation in Nigeria found out that land use especially agriculture and construction on riparian forest ecosystems were the main factors leading to the reduced distribution of vegetation and biodiversity (Borisade *et al.* 2021).

In Kenya, a study along Rivers Njoro and Kamweti found out that the stress caused by agriculture and built-up area led to variations in plant abundance, composition, and diversity (Koskey *et al.* 2021). The study found out that human induced stresses from activities like vegetation clearing, agriculture and grazing which alter the riparian vegetation structure and composition and contributed to decline of overall condition of the stream and loss of some of the benefit offered by the riparian ecosystem. More so, it revealed that there was far less indigenous species and poor riparian ecological conditions in agricultural and built-up areas. The study linked the decline of riparian vegetation along the two rivers to human activities such as clearing, livestock grazing, agricultural practices, and settlements.

Land use activities such as agriculture, urbanization, and industrial development in Lake Victoria basin have led to a continuous reduction in vegetation cover. Mostly, intensive agricultural activities, especially in the Nzoia River Basin (Kenya), Nakivubo Wetland (Uganda), and Simiyu drainage basin (Tanzania), have been attributed to the significant vegetation loss (Twesigye et al., 2011). Nairobi River riparian zone has faced serious threats from settlement development in Nairobi City County. Rapid urbanization has led to the encroachment of settlements into riparian zones. This encroachment often results in the degradation of these areas. The development of settlements often involves the clearing of riparian vegetation. This loss of vegetation reduces the ecological functions of riparian zones (Poulman, 2022). The study identified challenges in enforcing regulations that protect riparian zones as inadequate enforcement due to legal and institutional overlaps and loopholes. Similarly, River Kathita riparian basin has come under serious threats from sand mining activities, charcoal burning, overgrazing and trampling from livestock drinking bays along the riparian and the river.

2.2 Influence of Sand Harvesting on Riparian Vegetation Diversity

Sand mining affects the riparian flora through destruction of vegetation and clearing of vegetation to expose sand by bar skimming. Clearing of road and parking areas for the heavy trucks to access the sand also contributes to clearing of vegetation exposing river banks leading to increased river banks erosion (Rentier and Cammeraat 2022). The riparian vegetation provides cover, bank stabilization, and nutrients among other functions (Padmalal and Maya 2014) and anthropogenic activities like sand harvesting destroys the fragile riparian vegetation which is catastrophic to the riverine ecosystem.

Sand harvesting is a crucial economic activity in Kenya, largely driven by the thriving construction industry. The demand for construction materials, fueled by rapid urbanization and infrastructure development, has significantly increased the need for sand, an essential component in building and road construction (Buke et al., 2024). Additionally, sand harvesting offers employment opportunities for many local communities, particularly in rural areas where alternative income sources are scarce (Muendo, 2015). However, this activity is often plagued by conflicts and "sand wars" over site control and labor, similar to the challenges faced by India's sand industry. In India, the lack of regulation has led to illegal sand mining and the rise of "sand mafias" (Aliu et al., 2022), resulting in severe socio-economic and environmental issues such as land degradation and habitat destruction (Poonia et al., 2024).

In Kenya, sand harvesting is frequently informal and unregulated, unlike in countries like France, which has stringent regulations and policies for comprehensive planning and enforcement of environmental laws (Cojan, 2019). China, the largest consumer of sand globally, has shifted towards using manufactured sand to mitigate the depletion of natural sand resources, supported by strict government policies and regulations (Wang et al., 2024).

Countries like France and China are leveraging technological innovations, investing in sustainable sand extraction technologies, and alternative sources of sand for construction. They also enforce strict regulations on sand mining and monitor mining activities closely. India has explored strategies such as Community-Based Management, involving local communities in monitoring and managing sand resources, rehabilitating and restoring mined areas, and educating the public about the environmental and social impacts of sand mining (UNEP, 2023; Poonia et al., 2024; Wang et al., 2024). In Kenya, although there are sand harvesting regulations (Environmental Management and Co-ordination (Sand Harvesting) Regulations, 2022) and standards for rehabilitating sand-harvested areas provided by NEMA, these regulations are often not adhered to, indicating lax enforcement by regulatory bodies. Post-harvesting procedures are also frequently neglected, leading to incidents of deaths and other environmental and social hazards at many quarries and mined sites.

A study by Kondolf *et al.* (2007) in France found that the development of access roads and storage areas for sand mining has fragmented riparian forests. The findings coincided with those of Kumar and Kumar (2012), India. Healthy floral communities and biodiversity within the riparian zone have been lost to excessive in stream sand mining (Akankali *et al,* 2017).A study by Kori and Mathada (2012) in South Africa discovered that gravel extraction in riparian areas of Nzehele Valley required clearing vegetation to access sand and gravel therefore, affecting the flora along the riparian land. These results collaborated similar finding from a study by Agbor (2014) that in stream sand mining leads to the destruction of riparian habitat.

In Kisumu County, Kenya, a study by Bingo and Oyoo (2021) indicated that indeed sand harvesting affected the land cover and flora along riparian land through the clearing of vegetation as the topsoil is harvested as sand. Disturbances in vegetation alter the general riparian ecosystem productivity. In Tharaka Nithi, sand harvesting in River Kathita basin cater for the high demand in Tharaka-Nithi, Embu and Meru counties has led to heightened vegetation clearance along the riparian to expose more sand, environmental degradation, and overall ecological compromise. The enforcement of sand regulations is often weak, local government focusing on paying revenue "cess" only and lack of proper post harvesting rehabilitation of the River's riparian.

2.3 Influence of Charcoal Burning on Riparian Vegetation Composition and Structure

Charcoal and firewood serve as primary energy sources in both urban and rural areas across Africa. They are used by over 80% percent of the population (FAO 2010). It is anticipated that a significant portion of the population in developing countries will continue to rely on this type of fuel in a near and medium term in reference to rapid population growth which in turn will have a huge negative impact on already declining forest cover.

Charcoal production and firewood collection contributes to deforestation which is a gradual loss of trees in an area over a period of time. Continued deforestation contributes to loss of diversity, disturbance and change in species structure and vegetation composition. Deforestation and forest degradation are primary drivers of forest cover change, leading to long-term reductions in carbon stocks and the loss of other ecological services provided by trees (Achard *et al.* 2007). In Tanzania, charcoal burning contributed to about 75% of deforestation (Malimbwi and Zahabu 2005). Additionally, charcoal burning significantly affects the resilience of forest sites over time. The process often involves removing specific tree species, such as acacia, which are preferred for their high-quality charcoal. This selective logging reduces tree diversity, making forests less resilient to environmental changes and disturbances like droughts or pests.

A study by Mweru (2002) in Kibwezi ,documented that charcoal making was the greatest contributor of vegetation cover loss through tree felling and vegetation clearance which led to sparse distribution of tree species preferred for charcoal burning, loss of tree cover as the charcoal burners cleared space to set their kiln. The study also found out that tree harvesting in Kibwezi resulted in change in tree species composition. Charcoal producers use a selective logging approach, choosing trees based on species and size which exposes some trees species to high likelihood of being logged and hence, altering their densities. Logging changes the structure of the plant community, the distribution of trees species, the densities and the species available. Some tree species especially Acacia and Balanites species are targeted more because they produce desirable charcoal that burns more with less soot (Mweru 2002) and hence are targeted more by charcoal burners leading to loss in the habitats. This decreases plant diversity, local extinctions and loss of available habitat for wildlife.

Various countries have addressed this challenge through different policies, including bans and regulations on charcoal production. Additionally, involving local communities in forest management and providing alternative income sources, along with education and awareness campaigns about the impacts of charcoal burning and sustainable practices, have been effective strategies. In countries like Indonesia and Mexico, community participation in forest restoration projects has been crucial. These projects involve tree planting and maintaining restored areas, while educational programs raise awareness and provide training on sustainable land management practices, fostering a sense of ownership and responsibility (Ceccon et al., 2020).

In Kenya, the charcoal ban implemented in 2018 faced significant challenges and was not entirely successful. Despite the ban, charcoal production and smuggling continued, with the trade going underground and leading to widespread illegal activities. Weak enforcement due to limited resources and corruption made it difficult to control illegal production and transportation. The ban negatively impacted the livelihoods of many people who depend on charcoal production, leading to resistance and non-compliance (Sola & Cerutti, 2021).

The enforcement of the ban lacked provisions for alternative livelihoods, which is crucial for the effectiveness of such policies. It also lacked community involvement and education on the impacts of charcoal burning and sustainable practices. Similar challenges are faced in Tharaka-Nithi, where economic difficulties in areas like

Marimant, Murio-Mburaga, and Kibuka have led to increased illegal charcoal production in the River Kathita habitat.

2.4 Influence of Livestock Drinking Bays on Riparian Vegetation Diversity

Livestock grazing has a huge negative impact on riparian vegetation diversity. Drinking bays utilized by huge number of livestock to access watercourses results in livestock trampling on vegetation, overgrazing on few select patches of the riparian vegetation, thus, destroying biological soil crusts and compacting of underlying soils which lead to degradations of the riparian vegetation, loss of vigor, biomass and diversity.

More so, the disturbances lead to loss of indigenous vegetation, delicate and fragile species whose long-term cumulative effects includes alterations in the structure, composition, and productivity of riparian flora and fauna, leading to an overall decline in biotic richness and diversity. It is observed that as livestock go down the river for a drink, they graze on specific preferred indigenous riparian vegetation which overtime lead to local extinction of those plant species (NRC 2002).

Livestock coming out of the water drinking points takes cover under the cool trees and graze in their patched areas. There is always a huge possibility that those are the favorite spots that they always rest every drinking trip down the stream hence exposing those patches to overgrazing and trampling. Mbaya and Oruonye (2019) concluded that livestock grazing had a significant impact on vegetation growth and contributed to increased land degradation. The impacts of livestock drinking bays on riparian ecosystem results from trampling where excessive livestock grazing in riparian zones has been observed to reduce vegetation vigor weakened by hoofs and from livestock concentration on specific or preferred patches such as drier portions in growing seasons leads to overgrazing on those areas (Clary & Kruse 2004).

A study by Kyalo (2009) in the River Njoro Watershed, Kenya, revealed that uncontrolled open grazing along riparian zones led to significant land degradation and increased pressure on natural resources. This finding aligns with research conducted in the River Nairobi basin, which indicated that livestock grazing contributes to habitat loss, soil erosion, and pollution, thereby affecting the riparian ecosystem

(Majumdar & Avishek, 2023). Both studies recommend best practices for managing livestock access to riparian zones, such as implementing rotational grazing systems to prevent overgrazing and allow vegetation recovery, using fencing to restrict livestock access to sensitive areas, establishing riparian buffer zones, and providing alternative watering points away from riparian zones to reduce trampling and pollution.

Different East African countries have adopted various strategies to address the challenges of livestock management in riparian zones and mitigate the impact on these vulnerable areas. In Ethiopia, community-based approaches to managing grazing lands involve local communities in decision-making processes, establishing grazing reserves, and promoting the use of indigenous knowledge for sustainable rangeland management. These interventions have successfully improved vegetation cover and reduced conflicts over grazing resources (Baninla et al., 2022). In Tanzania, a USAID-funded deferred rotation grazing project rotates livestock between different grazing areas, allowing pastures to recover. This method has significantly improved pasture health and productivity, reduced soil erosion, and maintained biodiversity (Musau, 2021). In Kenya, the Climate-Smart Livestock Systems program, implemented by GIZ, ILRI, and the World Bank, has promoted sustainable livestock management practices by emphasizing rotational grazing and improved pasture management. These efforts have helped reduce overgrazing and land degradation, enhancing the resilience of pastoral communities to climate change (Crane et al., 2022).

Kenya faces challenges in implementing riparian management strategies due to discrepancies between traditional land use practices and formal land tenure laws. According to the law, riparian land is public land with limited access and use, conflicting with traditional practices where riparian communities freely accessed and used land adjacent to water bodies. This often leads to clashes between national policies and the needs and practices of communities, especially in areas dependent on the river and its riparian zones for their livelihoods, such as the River Kathita riparian communities. Additionally, a lack of coordination among various government institutions responsible for land, water, and environmental management, which have overlapping mandates, has led to fragmented and ineffective management efforts, making it difficult to implement integrated watershed management strategies.

The River Kathita basin riparian habitat faces similar challenges to the River Njoro watershed. However, the River Kathita faces a unique challenge as it is one of the few permanent rivers in an arid and semi-arid land (ASAL) area where the main economic activity is livestock rearing. Other rivers in the area, such as the Thanatu, have faced similar challenges, leading to significant degradation of their riparian zones and subsequent drying up (Kirema, 2020). This raises serious concerns about the River Kathita facing similar trends of incursion and overgrazing on its riparian zones. Currently, there are no known measures or conservation efforts in place to rehabilitate or promote the sustainable use of its riparian habitat.

2.5 Conceptual Framework

The riparian vegetation is diverse as well as fragile. Its functions extend beyond the habitat itself and the goods and services offered by this ecosystem benefit humans and other species. Their ability to offer ecosystem goods and services is affected and influenced by environmental and anthropogenic factors. The anthropogenic disturbance on the riparian ecosystems' causes' the biodiversity loss, destabilization of the structure and composition of vegetation and overall degeneration of the habitat quality.

Various anthropogenic disturbances, such as sand harvesting, charcoal burning, and livestock grazing increasingly threaten riparian zones. This study aims to investigate the impact of these disturbances on riparian vegetation, focusing on how they affect vegetation variability. The conceptual framework outlined here integrates the independent variables (charcoal burning, sand harvesting, overgrazing, and trampling), the dependent variable (vegetation variability), and the moderating factors (land use, land tenure, and government policy) to provide a comprehensive understanding of these interactions.

Charcoal burning leads to deforestation and habitat destruction, reducing plant cover and biodiversity. Charcoal burning affects the vegetation structure by targeting mature trees and affects vegetation composition by selecting specific desired species for charcoal production. Sand harvesting disrupts on riparian zones involve indiscriminate clearance of the vegetation to expose toil soil harvested as sand negatively impacts the structural integrity and species composition of riparian vegetation. Overgrazing and trampling compact soil, reduce plant cover, and promote the growth of invasive species. Overgrazing led to the loss of native vegetation and soil degradation. Moderating factors like land use, influence different land use practices which exacerbate or mitigate the impacts of anthropogenic disturbances on riparian vegetation. Land use such as agricultural expansion may increase pressure on riparian zones; while land uses such conservation efforts can enhance vegetation recovery. Secure land tenure can promote sustainable land management practices, while insecure tenure may lead to overexploitation and degradation of riparian zones. Government policies including regulations, and programs aimed at managing land use and conserving natural resources can mitigate the impacts of anthropogenic disturbances by promoting sustainable practices and protecting riparian zones. Conversely, weak or poorly enforced policies may fail to prevent degradation.

The conceptual model for this study integrates the independent variables, dependent variable, and moderating factors to illustrate the hypothesized relationships and interactions. The model posits that charcoal burning, sand harvesting, overgrazing, and trampling directly impact vegetation variability in riparian zones. These impacts are moderated by land use practices, land tenure security, and government policies, which can either, amplify or mitigate the effects of disturbances.

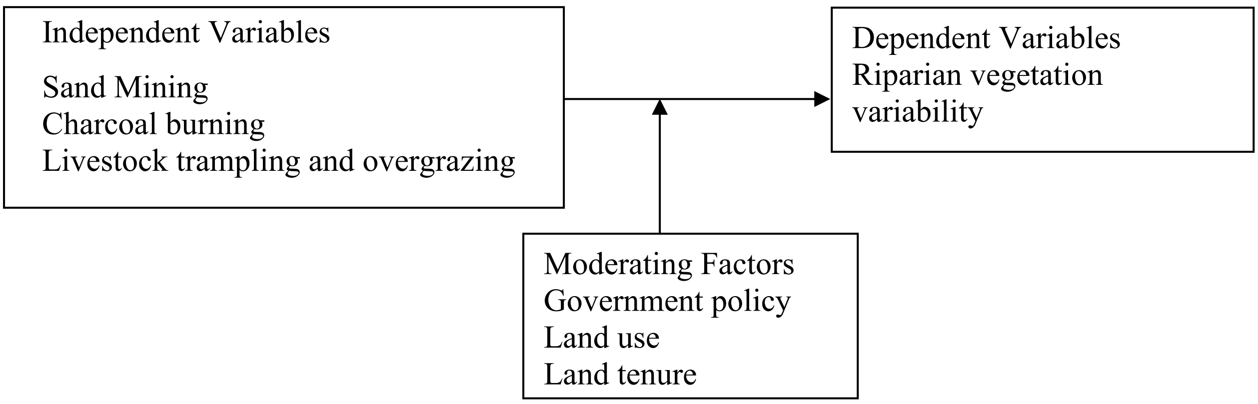

Figure 1: Conceptual Framework (Researcher's)

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study area is situated in Tharaka South Sub County, Tharaka Nithi County, Kenya. Tharaka-Nithi County comprises four sub-counties: Meru South, Maara, Igambang'ombe, and Tharaka. The county spans a total area of 2,662.1 km², including the shared Mt. Kenya forest, which is estimated to cover 360 km² within Tharaka Nithi County. It borders Embu County to the south, Meru County to the north, Kirinyaga and Nyeri to the west, and Kitui to the east. The county is located between latitudes 00°07' and 00°26' South and longitudes 37°19' and 37°46' East (Tharaka-Nithi County First Integrated Development Plan, 2017). The study area was the River Kathita, Tharaka sub-ctachment riparian zone, that is between Marimanti (37°58'32.79"E, 0° 9'29.63"S) and Kibuka (38° 0'4.40"E, 0°15'55.32"S) (figure 2)

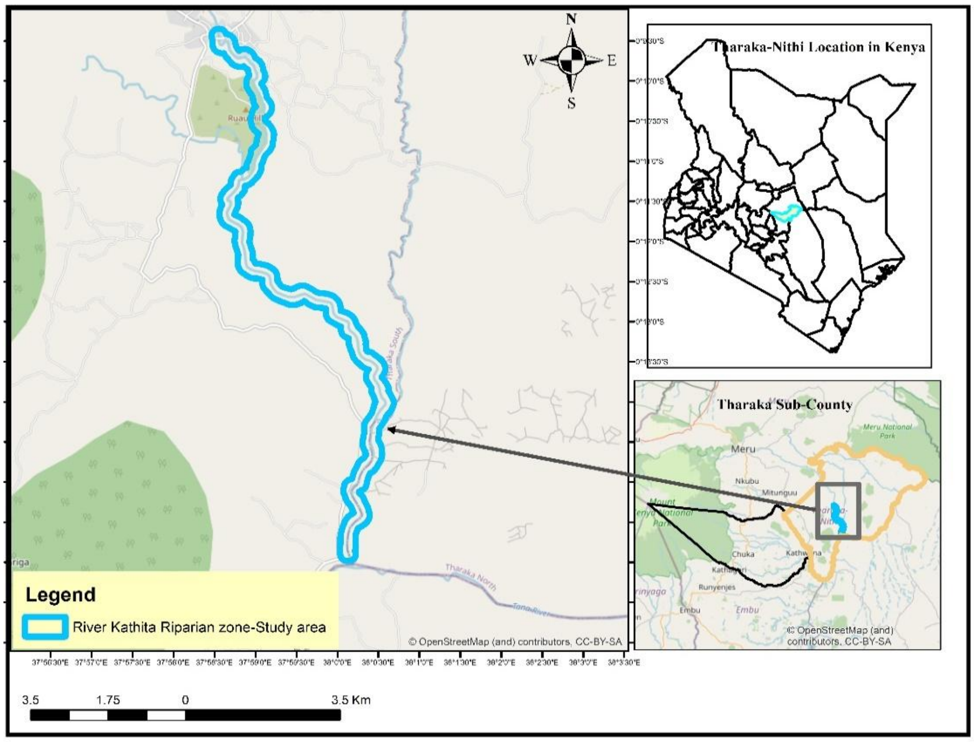

Figure 2: Study Area Map (OpenStreet and Own 2024)

3.1.1 Administration and Demography

Tharaka South Sub County spans 637 km² and includes three administrative wards: Chiakariga, Marimanti, and Nkondi. Situated in the southern part of Tharaka Nithi County, it borders Kitui and Meru Counties. The Sub County has a population of approximately 75,250 people (County Government of Tharaka Nithi, 2017) and is classified as arid and semi-arid lands (ASAL).

3.1.2 Climatic Characteristics

The climatic conditions in the County vary widely but considerably influenced by the relief of Mt. Kenya and the Aberdare Range. This indicates that the local climate is affected by various factors, including the El Niño Southern Oscillation, the Intertropical Convergence Zone, latitude, altitude, and sea surface temperatures (Odingo et al., 2002). According to the Köppen-Geiger climate classification, Tharaka Sub County falls within the dry climatic zone.

Temperatures in the highlands regions of Meru South and Maara ranges between 14^0c to 30^0c while that of the lowland areas that is the Tharaka South and North range between 22^0c and 36^0c. In Tharaka South Sub County where the study location is, temperatures are intermittently high of up to 40^o C (GoK, n.d.). The county experiences a bi-modal rainfall pattern, with long rains occurring from April to June and short rains from October to December. Rainfall averages around 2200mm in higher altitude regions, while in Tharaka, it averages 500mm and is irregularly distributed. Due to the low altitude (2,054 ft-600 ft) and high temperatures, the area receives low and unreliable rainfall, leading to reduced water volumes in the rivers (Tharaka-Nithi County First Integrated Development Plan, 2017).

More so, climate change has severely affected the climatic conditions in the sub county and the changes drastically affect the rainfall patterns in the area while the temperatures soaring high in the sub-county. Climate change also has high economic costs through impacts of climate change such as flooding and droughts (UTaNRMP 2014). High temperatures, low and erratic rainfall which cannot sustain favorable farming activities, drastically reduce the land use potential and productivity affecting the primary productivity. This leads to over reliant on the few permanent rivers like River Kathita as source of water for domestic and livestock and other economic activities by adjacent communities resulting to degradation of the rivers riparian habitat

3.1.3 Physical Characteristics

Tharaka Nithi has unique, diverse and picturesque physical features. The upper areas or southern part lies on the slopes of Mount Kenya while lower sections or the northern part is characterized by rolling hills and valleys. There are several gazetted and un-gazetted forests in Tharaka-Sub County, spring among other spectacular natural resources The County is also blessed with several rivers and streams, including the River Thuci, River Mutonga, and River Kathita. These water bodies not only add to the beauty of the county but also provide a source of water for irrigation and domestic use (Tharaka-NithiCounty First Integrated Development Plan, 2017).

3.1.4 Topography and Drainage

Tharaka South Sub County features major rivers such as Mutonga, Thingithu, Ura, Thanantu, Thangatha, Kithinu, and Kathita, which originate from Mt. Kenya and flow into the River Tana (County Government of Tharaka Nithi, 2017). The drainage of these rivers is influenced by the slopes and shape of the tertiary volcanic formations, the direction of Mt. Kenya's slopes, and the structure of the basement system. The area predominantly exhibits a radial drainage pattern in the upper and middle sections, transitioning to flatter areas in the basement system. The perennial rivers flow through moderate valleys in the south and through deep valleys in the northwest, creating deeply incised V-shaped valleys that flatten towards the basement system (UTaNRMP, 2014).

Most of the permanent rivers in the area are now seasonal which has been attributed to land use changes and degradation of those rivers riparian habitats (Kirema 2020). River Kathita which is one of the two permanent rivers in the territory and a water source for many households is threatened due to destruction of riparian vegetation Snoussi, Maria *et al*. (2004).

3.1.5 Soils and Geology

The Tharaka area features thin sandy soils overlying metamorphic rocks, including granitoid gneisses. These rocks appear as folded and fractured gneisses and schists, often forming steep hills. The region's geology influences the velocity, turbidity, and mineral content of its rivers. The basement system is heavily intruded by large masses of ultra-basic rocks associated with fluorspar. Additionally, the geology includes mafic and ultramafic rocks with limestone minerals (Schoeman, 2007). This rock system is particularly visible in seasonal streams where it is exposed. The Precambrian rock, covered by loose sandy soil mixed with weathered gravel, forms the topsoil from 0-4 meters deep. This permeable layer allows for groundwater recharge during rains and supports vegetation such as shrubs, grass, and acacia trees. The combination of this geology, low and unpredictable rainfall, and high temperatures results in limited vegetation diversity and restricts agricultural diversification. Consequently, livestock rearing is the predominant economic activity in the area.

3.1.6 Crops and Vegetation

In Tharaka-Nithi County, farming in different regions is reliant on the climatic conditions of the respective areas. In higher areas tea and coffee is planted mostly while in low altitude areas sorghum, maize, green grams and millet is practiced.

The most common tree species along River Kathita riparian habitat are *Acacia elatior*, *Acacia ataxacantha, Acacia Senegal*, *Acacia mellifera, Maerua endlichii, Euphobia scheffleri* and *Ficus sycomorus.* Most common shrubs are *Ricinus communis*, *Senna didymobotrya* and *Senna occidentalis*. The most common grass species is *Cyperus rotundifolia* and the most common herbaceous vegetation being *Achyranthes aspera*, *Acanthospermum hispidum* and *Indigofera tinctoria*. *Acacia elatior* and *Acacia tortilis* are the most targeted species for charcoal production because they produce quality charcoal.

3.1.7 Socio-Economic

In Tharaka Sub-County, agro-pastoralism is the primary socio-economic activity. Agriculture is divided into three main categories: mixed farming, small mixed farming zones, and rain-fed farming zones. More than 70% of the local population relies on farming and animal husbandry for their income and livelihood. The sub-county is not served by any formal financial institution, that is the banks, and financial services are offered by micro-finance sector like Sacco's and other informal sectors like local lenders, chama's and others

3.1.8 Land Use

Tharaka region has been undergoing significant land use changes driven by the growing demand for agricultural land and urbanization. Changing of forest areas, riparian areas into farming, settlements and urban centers has led to desertification and has also changed permanent rivers into seasonal rivers or resulting into reduction in water levels in the permanent rivers due to water abstraction (Kirema 2020). These changes in land uses have led to great concern about food insecurity and poverty in the area. Land use changes in Tharaka region has affected and altered the hydrologic cycle of the rivers in the Rivers in the region such as Thanantu and Thingithu and are a call for alarm to the few reaming permanent rivers like River Kathita which may be at risk due to on-going pressure from competing land uses.

3.2 Research Design

The study used both observational research design and ecological survey. Observational research design involved monitoring changes in the riparian vegetation cover using historical satellite imageries to assess trends over temporal scales. Ecological survey involved field observations, survey transect and identification of riparian vegetation.

3.3 Sampling

The study used purposive and simple random sampling techniques along the 15 Km transect. Purposive sampling was used while walking along the transect to target disturbed sites whereas simple random sampling was used for vegetation sampling within the sites that were targeted. Three non-disturbed sites were used as control sites and were randomly sampled. Vegetation sampling was done on 16 sites which included, 4 sites for sand harvesting sites, 4 sites for charcoal burning sites, 5 sites for livestock drinking bays, and 3 as control sites. The choice of 16 sites balanced the need for detailed data with practical constraints such as time, resources, and accessibility. The sites number chosen allowed for manageable fieldwork while still providing enough data points to draw meaningful conclusions. This was supported by guidelines for practical considerations in field research and guide to effective monitoring of aquatic and riparian resources (Kershner, 2004). The three variables, sand harvesting, charcoal burning and grazing bays were chosen due to their observed impact on the River's habitat and they were the most predominant disturbance on the riparian. Control sites were chosen from areas with minimal observed human activities along the riparian. The observational units were 20M by 20M quadrats for trees, 5m by 5m quadrats for shrubs and 1m by 1m quadrants for grasses and herbaceous plants. Smaller quadrats were nested within the 20 by 20 M quadrant.

3.4 Data Collection

3.4.1 Satellite Imageries for Temporal Assessment of Riparian Vegetation Health

Temporal assessment of the study area was done through remote sensing using satellite imageries for a period of 20 years, that is, from the year 2003 to 2023 at an interval of 10 years. That time period was chosen due to easy availability to satellite imageries. Landsat images for the month of February, years 2003, 2013 and 2023 were used for uniformity and due to clear skies in that month which is ideal for remote sensing. The Landsat images used for analysis were downloaded from USGS (United States Geological Survey) Earth explorer which is a free source. For the years 2003 and 2013, Landsat 7 was used for obtaining imageries of the study area because it was available for those years while for the year 2023, Landsat 9 was used.

3.4.2 Mapping Anthropogenic Disturbances Hot Spots

Anthropogenic disturbances along the riparian zone were assessed through observations, recorded and delineated by ground coordinates. The disturbed sites were identified by recording the nature of the observed anthropogenic activities on the site that is, presence of sand trucks or tire truck evidence for sand harvesting sites, presence of livestock or their hove prints for livestock drinking bays and presence of kilns for charcoal burning sites. Data on intensity of the disturbances was however not collected because it was not on the study’s focus.

3.4.3 Vegetation Diversity, Composition and Structure

Species identification for trees, shrubs, grasses and herbaceous plants in all the sampled sites was done by classification of the vegetation from family to the species level through use of leaves, barks, fruits and flowers and using plant identification guide books such as Dharani, N. (2011) and Maundu, P., et al. (2005). To assess the vegetation structure within the laid quadrant, measurements on DBH using the measuring tape, measurements of tree height using calibrated poles and estimated canopy and ground cover was recorded.

3.5 Data Analysis

3.5.1 Satellite Imageries for Temporal Assessment of Riparian Vegetation Health

Landsat imagery data for Landsat 7 and Land sat 8 were accessed through USGS Earth Explorer by first defining my study area by first creating the shape file of river Kathita and it riparian and uploading it. Landsat 7 ETM+ and Landsat 8 OLI/TIRS were used as the data sets. Landsat 7 ETM+ imageries, scan lines were corrected using the Landsat gap fill tool. The date range to confine imageries to the month of February were set and additional criteria to refine by cloud cover percentage and other parameters were added to select images with minimal cover.

The downloaded images were processed by doing atmospheric correction as a preprocessing step to remove the effects of the atmosphere by use of surface reflectance products in USGS which provide pre-corrected surface reflectance products, which save time and effort. Images were geometrically corrected using ground control points and digital elevation models (DEMs). Multiple satellite images were stitched together through mosaicking to create a seamless composite, larger image covering a broader area by doing geometric correction to ensure all images are geometrically aligned and have the same spatial reference, doing radiometric balancing to adjust the brightness and contrast of images to ensure uniformity across the mosaic and by doing seamless blending blend the edges of adjacent images to avoid visible seams. Filtering cloud noises was done by cloud masking by applying cloud masking algorithms available in Google Earth Engine to filter out cloudy pixels.

Calculating NDVI was done by loading the red and near-infrared (NIR) bands from the Landsat imagery and applying the NDVI formula. The NDVI images were saved and exported. Statistical analysis for NDVI means was done using Kruskal-Wallis test. The non-Parametric test was chosen for its ability to compare across multiple groups and its ability its ability to analyze data that does not meet the stringent requirements of parametric tests.

NDVI analysis was performed to each image using the formula;

$$NDVI = \frac{\mathrm{NIR} - \mathrm{R}}{\mathrm{NIR} + \mathrm{R}}$$

NIR represents the Near Infrared Band while the R represents the Red band in the visible spectrum. The bands used in Landsat 7 were band 4 to represent NIR and band 3 to represent R, while bands used in Landsat 9 were band 5 to represent NIR and band 4 to represent R. The index is defined by the equation [Float (Band 5–Band 4/ Band 5+Band 4)] for Landsat 9 and [Float (Band 4–Band 3/ Band 4+Band 3)] for Landsat 7.

NDVI values range from -1 to +1, with different ranges indicating various vegetation conditions:
-1 to 0: Typically represents non-vegetated areas such as water bodies, snow, or clouds.
0 to 0.1: Indicates barren areas of rock, sand, or snow.
0.1 to 0.3: Represents sparse vegetation such as shrubs and grasslands or senescing crops.
0.3 to 0.6: Indicates moderate vegetation, which might be under some stress.
0.6 to 0.9: Represents dense, healthy vegetation.

Depending on the study area and data from the ground trothing the riparian habitat of River Kathita was spare trees with open spaces and sparse ground cover in most of its parts. The mean NDVI for its riparian would fall on the third category of sparse vegetation with an average value of 0.3. NDVI as a tool to monitor vegetation health has been used widely. In Kenya studies such as assessment of the ecological Health of Afrotropical Rivers (Nzoia, Nyando, Sondu–Miriu, and Mara) NDVI was used to monitor riparian vegetation health (Achieng 2021). In developing riparian lands conservation and management policy framework the National Land Commission (NLC) of Kenya used NDVI was one of the tools used to assess vegetation health and identify degraded areas (NLC 2018)

Land Use/Land Cover classification involved categorizing image pixels into various land cover classes based on their spectral signatures. This process, which included classes like forests, water bodies, urban areas, and agricultural fields, was conducted using supervised classification. Training data was collected by gathering samples for each land cover class (e.g., water, vegetation, urban). Post-classification processing for accuracy assessment was done to validate the classification results using ground truth data. Different time period classified images were used to compare and analyze land cover changes. Area calculation was done by measuring the area of each land cover type in each time period, land cover change is determined by subtracting the initial value (old value) from the final value and percentage change by multiplying by 100. Maps to visualize NDVI and Land cover maps using Arcgis were also created. Similar studies in Kenya that have used temporal analysis to assess land cover and land use in riparian ecosystems such as a study by Mango (2011), in conducted River Mara basin, a study by Kipkorir and Cheserk (2018) in the Saiwa Swamp Watershed and Okeyo and Omondi (2020) on the riparian zones of Sironga wetland have aided the researcher to identify the pattern in the spatial and temporal land cover changes.

3.5.2 Vegetation Diversity, Composition and Structure

Vegetation diversity was analyzed through calculating species richness, Shannon-Weiner and Simpson diversity indexes. The ground cover was estimated as the percentage area covered by vegetation within the quadrant and the average was calculated to estimate the ground cover of each sampling site. Tree cover was estimated as the proportion of the ground area that is covered by the tree crowns when viewed from above as was expressed as a percentage. Standard deviation was used to estimate variability in vegetation structure data in the estimated DBH, height and canopy cover for the trees. Statistical testing for the NDVI means, species richness, Shannon-Weiner, Simpson indices and vegetation attributes for significance differences was done through Kruskal-Wallis test. The test was preferred over the other non-parametric tests for its versatility with various datasets and its applicability to small and large samples sizes, providing reliable results even when the sample size is not large enough to meet the assumptions of parametric tests. Spearman correlation was used to test relationship between anthropogenic activities and the vegetation diversity. The test was preferred for its robustness with outliers, non-assumption for normality and its ease for interpretation.

Shannon-Weiner Index;

$$H^{'} = -\sum_{i=1}^{s} pi\,(In\,pi)$$

Where:

ln: Natural log

p_i: The proportion of the entire community made up of species i

Simpson index; 1-D

$$D = N(N-1)\sum ni \quad (ni \quad -1)$$

Where:

ni: Number of individuals in the i-th species; and

N**:** Total number of individuals in the community.

3.6 Ethical Considerations

The study was done and met all ethical standards by ensuring the confidentiality of the collected data. A clearance form was secured from the Chuka University ethics and research committee (Appendix II and Appendix III), and a research permit was obtained from the National Commission for Science, Technology and Innovation (NACOSTI) prior to starting the research (Appendix IV). Oral request or permission to engage local community was done through local administration, that is, "mzee wa mtaa". The local guide and the members of the communities were involved in identification of the vegetation in their local languages. Data collection and analysis procedures were done upholding a high level of integrity. The principals involved in research ethics were followed. Plagiarism was avoided in the entire research process by acknowledging the sources of all information obtained elsewhere through citations.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Temporal Assessment of Riparian Vegetation Health

Normalized Difference Vegetation Index (NDVI) along the riparian transect for the years 2003, 2013 and 2023 was used to compare the health and density of vegetation. The NDVI range for 2003 was a low value of -0.24 to the highest value of 0.67, in 2013, low value was -0.28 and highest was 0.62. In 2023 the lowest value was -0.11 and highest was 0.57. The mean NDVI dropped from 0.41 in 2003 to 0.32 in 2023 (table 1). River Kathita riparian habitat with an NDVI of 0.32 indicate sparse vegetation and moderately below healthy levels which is normally an NDVI index of >0.5.

The mean NDVI for 2003 was 0.41 which was relatively high NDVI value suggesting healthy and dense vegetation cover. This was an indicator of a good overall ecosystem health. In 2013 the significant drop in NDVI value to 0.26 indicates a decline in vegetation health and density this was attributed to up rise in settlements and urban area especially on the side of Marimanti and deforestation as a result for demand of cheap fuel in form of firewood and charcoal. Similar studies show that decline in NDVI values over the years was attributed to livestock grazing agriculture, settlements and other anthropogenic disturbances (Jaelani, 2021; Guan *et al*. 2021). In 2023 there was a slight recovery in NDVI value compared to 2013, but still lower than 2003 with a mean value of 0.32. This suggests some improvement in vegetation health which was attributed to the implementation of a logging ban in 2018 to protect its forests and water catchment areas. However, this ban was lifted in July 2023 to boost economic growth and create jobs which was 5 months from when the study period. Additionally, this is exacerbated by the high demand for sand in counties of Tharaka-Nithi, Meru and Embu which is extracted from River Kathita and its habitat due to demand of the River's high quality sand.

There is a need for further research to compare the vegetation health in 2024 after lifting of the ban with the previous years to ascertain the health of the riparian vegetation. Continued decline of the riparian vegetation health will directly affect local communities that rely on natural resources for their livelihoods, such as agriculture and grazing and it will deny the riparian communities of Marimanti-

Kibuka area the ecosystem services such as water regulations in an area which is classified as an ASAL and which the people are over-dependent on River Kathita as their main source of fresh water for their household and livestock. Statistical test however indicated the differences were not statistically significant which was indicated that the changes were not large to be detected with the given data of the 3 years and therefore future research is needed to compare more years and longer-term monitoring to better understand vegetation dynamics and the effectiveness of conservation efforts

Table 1: NDVI Mean Trends

Year	NDVI
2003	0.41
2013	0.26
2023	0.32

Normalized Differences Vegetation Index variations for the 3 years, were nevertheless not statistically significant (p =0.26) (table 2).

Table 2: Kruskal-Wallis Statistical Results for NDVI Means

Variable	Statistic	p-value
NDVI mean	1.26	0.26

In the year 2003 most of the riparian area had a moderately high NDVI along significant portions of the sampled section. The NDVI value range was 0.48 to 0.67 in 2003. There was noticeable reduction in NDVI values for the year 2013 ranging from 0.35 to 0.62. In 2023 the NDVI ranged from 0.45 to 0.57 The Maximum NDVI values continually dropped from 0.67, 0.62 to 0.57 which indicated reduce in the vegetation health and density in the study area between the periods of the year 2003 to the year 2023. Figure 3 illustrate the NDVI variations in the study area. The red sections represent the water, rocks and bare ground, brown and yellow representing low and sparse vegetation cover and green indication areas with high vegetation health and density.

The red section on upper section of the river that had near zero and negative NDVI values indicated non-vegetated surfaces which the ground trothing and land use and land cover analysis found out to be built-ups and settlements. Land use and Land cover analysis indicated that built ups increased by 466.7% from 200-2023 and the ground trothing data on mapping of anthropogenic disturbances indicated that the built-ups included private, schools and government among other built ups along the riparian habitat. The yellow and browning color that indicated poor vegetation health, observed in the middle and lower sections continued to increase in the years under the study. The poor riparian vegetation health was attributed to the anthropogenic activities mapped in the study area including sand harvesting, charcoal burning and livestock drinking bays.

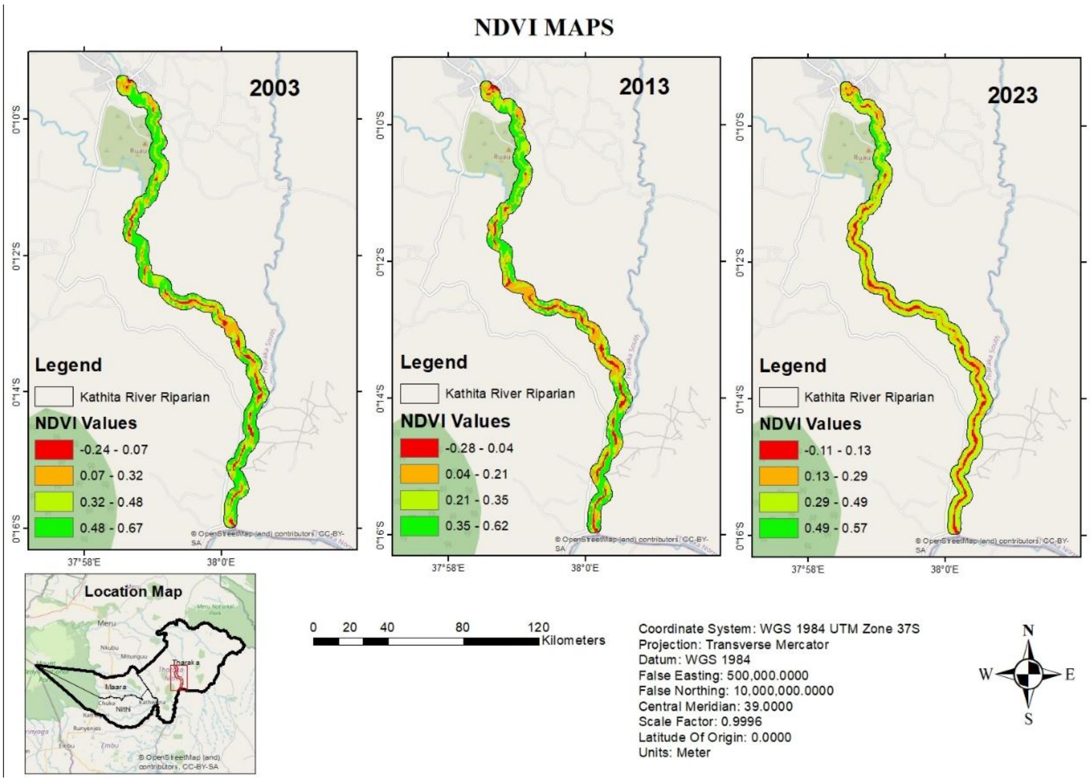

Figure 3: NDVI Variations for 2003, 2013 and 2023

4.1.1 Land Use Land Cover Assessment

Land use and land cover assessment was done for the 5 class categories of forest/trees, bare lands, open spaces (scattered trees), development and river. 30% of the area under forest category was lost, open spaces increases by 1.4%, bare land area increased by to 12.8%, river are increased by 21.92% and area classified as development increased by 466.7% (table 3). The results align with Yangouliba's (2023) research in West Africa, which identified notable LULC changes from 1990 to 2020 where woodland and shrub land areas diminished by 45% and 68%, respectively in contrast to the areas of water bodies, croplands, and bare land/built-up zones which expanded by 233%, 51%, and 75%. Likewise, the study by Mehra and Swain (2024) on the assessment of land use and land cover change in India, using artificial neural network-based cellular automation, reported a 20% reduction in forest cover over the last ten years. In contrast, urban areas and bare land expanded by 15% and 10%, respectively.

Table 3: Land Use and Land Cover Variations

Class	Area(ha) 2003	Area(ha) 2013	Area(ha) 2023
Open Space	208	245	211
Bareland	109	65	123
Developed	3	28	17
Forest/Trees	157	148	110
River	73	64	89
Total	550	550	550

Comprehensive examination of the changes in land use and land cover (LULC) between the years 2003 and 2013, emphasizing the percentage shifts across various land cover classes indicated a 42.89% of the land categorized as River in 2003 was reclassified as another class, whereas 57.11% of the area remained River in 2003. There was a substantial shift in the forest/trees sector, with 57.30% moving to other uses and 42.70% staying the same. Notable shifts occurred in area classified as open space and bare land, which were left in their original categories with just 55.67% and 17.16%, respectively. The group that showed the biggest rise was developed (built-up), which included 68.57% of all areas in 2013. The results show a significant decrease in the percentage of each class over the decade, that is, 17.58% for bare land, 12.86% for river, 4.89% for forest/trees, 17.58% for open space, and 77.14% for developed areas (table 4)

Table 4: Land Use and Land Cover Change from 2003-2013

Final State 2013	Initial State 2003	River	Forest	Open Space	Bareland	Developed	Class Total
River		57.11%	2.53%	1.65%	12.79%	8.57%	99.57%
Forest		8.16%	42.70%	22.81%	22.86%	2.86%	97.52%
Open Space		15.08%	42.82%	55.67%	40.10%	5.71%	97.24%
Bareland		2.72%	9.43%	13.29%	17.16%	2.86%	96.43%
Developed		16.69%	0.75%	3.03%	5.36%	68.57%	100%
Class Total		100%	100%	100%	100%	100%	0.00
Image Difference		-12.86%	-4.89%	17.58%	-39.93%	77.14%	0.00
Class Change		42.89%	57.30%	44.33%	82.84%	31.43%	0.00

Every row denotes the starting point in 2003, and every column displays the end state in 2013. The "Image Difference" row displays the net change in the percentage of each class over the decade, while the "Class Changes" row displays the overall percentage of change for each class.

The land use and land cover changes from 2013 to 2023 revealed notable shifts in land cover categories. There was a decline of 46.93% of the area categorized as river class from 2013-2023, which shifted into other categories, 65.68% of area under forest underwent changes in usage, 57.32% of area under open spaces shifted to other categories, 65.66% of the bare land changed into other land uses and 88.46% of areas under development moving to other categories. The net changes show significant increases of 41.06% and 87.42% in the areas covered by River and bare land, respectively. Conversely, the categories of forest/trees, open space, and developed saw declines of 25.45%, 14.09%, and 40.71%, respectively (table 5).

Table 5: Land Use and Land Cover Changes from 2013-2023

Final State 2023	Initial State 2013	River	Forest/Trees	Open Space	Bareland	Developed	Class Total
River		53.07%	12.91%	8.67%	11.49%	29.17%	99.70%
Forest/Trees		6.56%	34.32%	18.10%	7.66%	10.26%	97.17%
Open Space		19.97%	31.73%	42.68%	37.62%	33.01%	94.07%
Bareland		11.73%	16.65	23.53%	34.34%	14.10%	94.96%
Developed		7.96%	1.27%	1.71%	3.01%	11.54%	98.92%
Class Total		100%	100%	100%	100%	100%	0.00
Image Difference		41.06%	-25.45%	-14.09%	87.42%	-40.71%	0.00
Class Changes		46.93%	65.68%	57.32%	65.66%	88.46%	0.00

The decrease in forest areas was attributed to clearing of the trees for farming, settlements and charcoal production as it was collaborated by ground trothing data, the decline in forest areas also explained and accounted for the increase in open spaces as well as increase in area categorized as developments/built-ups. The increase in size of the river was attributed to erosion of river banks from disturbances like sand mining and livestock drinking bays. Fig 4 below shows the land use and land cover map changes for the year 200,2013 and 2023 with increase in developed class on the upper side towards Marimanti, which were associated with the built ups along Kathita riparian habita in that area and the increase in opean spaces and bare classes in the middle and lower sections of the river which were assocated with the mapped anthropogenic disturbances in that region, that, is sand harvesting, charcoal burning and livestock drinking bay.

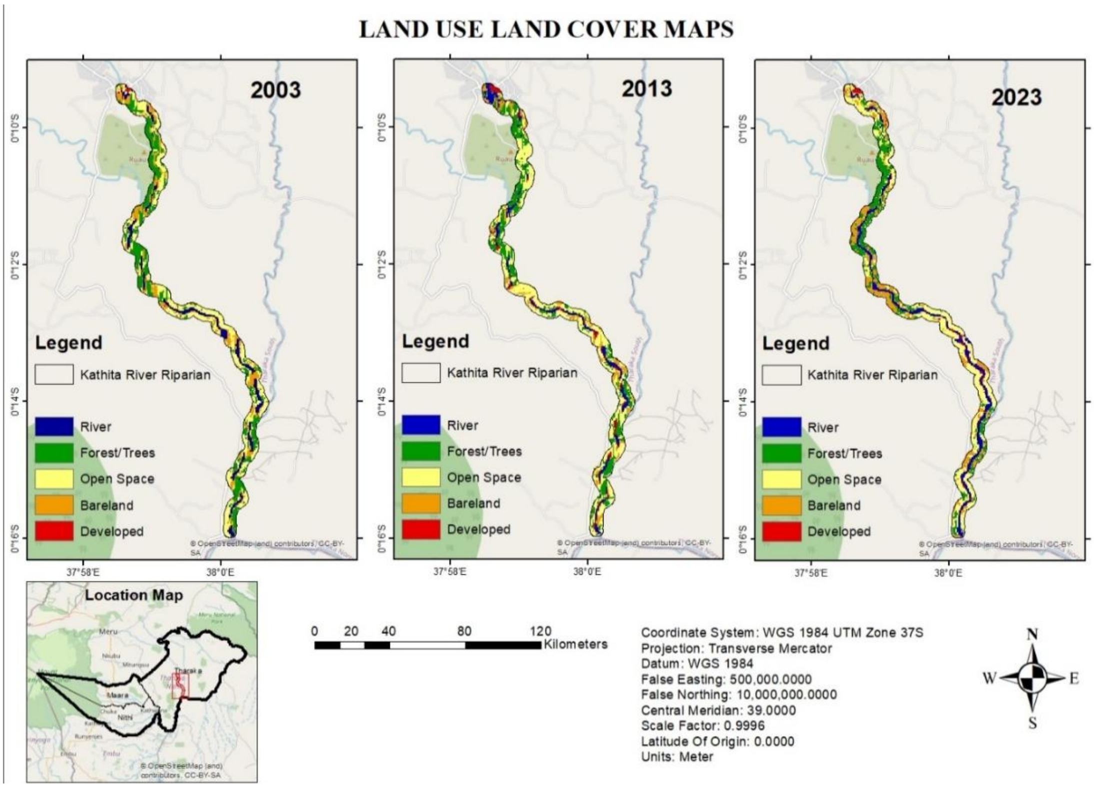

Figure 4: Land use land cover map

4.1.2 Mapping of Anthropogenic Disturbances hotspots

Anthropogenic disturbances along River Kathita riparian were identified, recorded and mapped. There were 7 cattle drinking bays, 4 sand harvesting sites and 5 charcoal burning sites (table 6). Cattle drinking bays were the major anthropogenic disturbances, representing 7 out of the 16 anthropogenic hotspots recorded. This was attributed to livestock keeping being a major economic activity for the nearby community. Additionally, since the study area is arid, River Kathita serves as the only permanent water source in the region. Mukanoheri *et al*. (2023) observed that livestock grazing and agriculture were the main anthropogenic disturbances along Rongai River Nakuru. Majority of the disturbances were on the lower side towards where the River Kathita joins with River Sagana. These findings align with previous studies in South West Mau (Njue *et al*., 2016), which reported an increase in disturbances from upstream to downstream, primarily due to livestock grazing and urban settlement in the downstream areas. Downstream areas are relatively flat making them not only more accessible but also increase their vulnerability to anthropogenic disturbances

Table 6: Anthropogenic Disturbances

Disturbance type	Count	Co-ordinates	
Cattle drinking bay	7	389017	9972187
		388959	9972256
		386537	9977560
		386026	9982395
		388853	9970940
		389527	9974856
		389035	997563
Sand harvesting	5	389070	9972653
		389035	997563
		388433	9975539
		388155	9975583
Charcoal burning sites	5	389527	9974856
		388812	9971137
		388828	9971192
		388811	9971084
		389070	9972653
		388155	9975583
Others			
Built ups		386024	9982508
Farming		388857	9970665

4.2 Influence of Sand Harvesting on Riparian Vegetation diversity Composition

4.2.1 Floristic Composition

Trees had 19% in sand harvesting sites as compared to 38% in undisturbed sites. The highest composition was from herbaceous species with 32% in sand harvesting sites as compared to 16% in undisturbed sites (fig 5a and b). A study by Zhao *et al* (2015) showed that herbaceous species had a higher coverage compared to other vegetation types in mined sites, with herbaceous species covering 60% of the area, while other species covered 40%. Moreover, in reclaimed mines in China, Zhang *et al*. (2020) discovered that herbaceous species made up 60% of the plant diversity after six years of reclamation. This indicated that herbaceous plants in sand harvesting disturbed sites were more resilient to the disturbances as compared to other species.

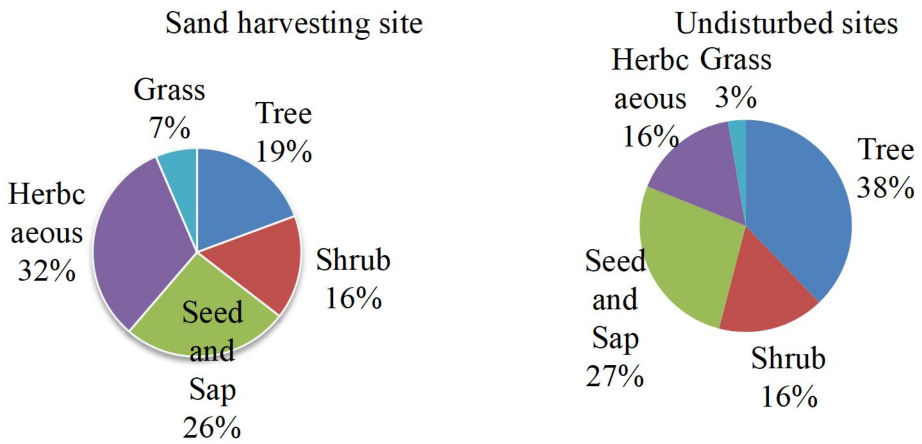

Figure 5: (a) Sand Harvesting Sites (B) Undisturbed Sites

Floristic analysis of vegetation species that were sampled in four different sand harvesting revealed that the trees belonged to 4 families, 5 genera and 6 species (table 7)

Table 7: Tree Composition for the Sand Harvesting Sites

Sites	Trees	No.	DBH	Height	Canopy cover %
Site 1					
Site 2	*Acacia senegal*	1	10	4	1
	Sclerocarya birrea	1	100	8	
Site 3	*Hyphaene compressa*	4		8	10
	Lawsonia inermis	2	15	3	
	Acacia tortilis	1	70	12	
	Bridelia taitensis	1	20	6	
	Bridelia taitensis	2	15	4	
Site 4	*Acacia tortilis*	2	40	7	1

In the three undisturbed sites the sampled tree belonged to 11 families, 11 genera and 14 species (table 8). The undisturbed sites had 133.33% more species than the sand harvesting sites.

Table 8: Tree Composition for the Undisturbed Sites

Control	Trees	No.	DBH (cm)	Height (m)	Canopy cover %
Site 1	*Ficus sycomorous*	1	90	13	90
	Ficus sycomorous	2	160	15	
	Senna didymobotrya	1	25	3	
	Mangifera indica	1	35	2.5	
	Acacia nilotica	1	25	2	
	Balanites aegyptica	1	10	2	
	Erythrina malanacantha	1	5	3	
	Acacia tortolis	1	70	20	
Site 2	*Commiphora madagascariensis*	1	20	5	30
	Commiphora madagascariensis	1	20	6	
	Euphorbia bicomacta	1	8	2	
	Acacia ataxacantha	1	15	5	
	commiphora madagascariensis	2	12	2.5	
	Acacia ataxacantha	1	14	2.5	
	Acacia tortilis	1	12	3	
	Acacia Senegal	2	10	3	
	Acacia ataxacantha	3	10	3	
	Commiphora madagascariensis	2	10	6	
	Acacia Senegal	1	8	3	
	Acacia ataxacantha	1	5	2	
	Ficus sycomorus	1	15	5	
	Combretum micranthum	1	15	5	
	Commiphora madagascariensis	1	30	7	
Site 3	*Acacia tortolis*	1	15	8	60
	Acacia tortolis	2	10	7	
	Acacia tortolis	1	10	7	
	Acacia Senegal	1	7	7	
	Maerua endlichii	1	3	2	
	Acacia tortolis	1	10	5	
	Acacia tortolis	1	15	11	
	Maerua endlichii	1	3	2	
	Acacia Senegal	1	7	10	
	Acacia tortolis	1	5	5	
	Acacia tortolis	2	2	2	
	Acacia Senegal	1	5	4	
	Acacia Senegal	1	8	5	
	Acacia eliator	1	15	16	

In the sand harvesting sites the shrub belonged 4 families, 5 genera and 5 species, seedling and saplings belonged to 6 families, 7 genera and 8 species (table 9).

Table 9: Shrub, Seedling and Saplings Composition for the Sand Harvesting Sites

	Shrubs	No.	Sapling and seedling	No.
Site 1	*Indigofera trinctoria*	6		
	Ricinus communis	1		
Site 2	*Justica odora*	1	*Acacia tortilis*	4
			Lawsonia inermis	2
			Acacia senegal	7
			Commiphora madagascarinsis	1
			Acacia mellifera	1
Site 3	*Flueggea virosa*	1	*Acacia tortilis*	7
	Indigofera tinctoria	1	*Lawsonia iermis*	6
			Balanites aegyptica	4
			Acacia mellifera	1
			Combretum micrabithum	2
			Acacia tortilis	7
			Lawsonia iermis	6
Site 4	*Senna didymobotrya*	9	*Acacia tortilis*	9
			Lawsonia inermis	1
			Hyphaena Compressa	4

In the undisturbed sites the shrubs belonged to 4 families, 6 genera and 6 species, seedling and saplings belonged to 7 families, 9 genera and 10 species (table 10). The number of shrub species had marginal difference with the number of shrub species in sand harvesting species similar to the number of sapling and seedling among the sand harvesting and undisturbed sites.

Table 10: Shrubs, Seedling and Sapling Composition for the Undisturbed Sites

Sites	Shrub	No.	Seedling and Sapling	No.
Site 1	*Flueggea virosa*	4	*Acacia Senegal*	1
	Triumfetta rhomboidea	4		
	Indigofera tinctoria	3		
Site 2	*Grewia bicolor*	1	*Osyris lanceolata*	2
	Ricinus communis	1	*Berchemia discolour*	1
	Entada leptostachys	1	*Combretum micranthum*	1
			Acacia ataxacantha	2
			Acacia tortilis	1
			Ficus sycomorus	1
			Terminalia prunioides	3
			Triumfetta rhomboidea	2
Site 3	*Indigofera tinctoria*	1	*Acacia Senegal*	1
			Maerua endlichii	2

In the sand harvesting sites herbaceous vegetation belonged to 3 families, 3 genera and 3 species and grass species belonged to 2 families, 2 genera and 2 species (table 11)

Table 11: Herbaceous and Grass Species Composition for the Sand Harvesting Sites

Sites	Herbaceous plants	No.	Ground cover %	Grasses	No.	Ground cover %
Site 1	*Commelina vulgaris*	10	32			
Site 2				*Aristida adscensionis*	4	3
Site 3	*Pupalia lappacea*	1	3		N/a	
	Oxygonum sinuatum	2				
Site 4	*Pupalia lappacea*	3		*Cyperus rotundifolia*	100	30
	Oxygonum sinuatum	3				

In the undisturbed sites the herbaceous vegetation belonged to 6 families, 6 genera and 6 species while grass belonged to 1 family, 1 genera and 1 species (table 12). Herbaceous species was more in undisturbed sites as compared to sand harvesting sites by 200% while grass was less by 200%.

Table 12: Herbaceous and Grass Species Composition for the Undisturbed Sites

Control Sites	Herbaceous plants	No.	Ground cover %	Grasses	No.	Ground cover %
Site 1	*Achyranthes aspera*	5	60			
	Commelina vulgaris	3				
Site 2	*Kirundu kia muthitu*	2		*Eragrostis racemosa*	1200	90
	Hibiscus micranthus	3				
Site 3	*Ocimum kilimandscharium*	173	67			
	Achyranthes aspera	200				
	Aspilia mossambicensis	1				

4.2.2 Species Diversity Analysis

Tree species richness for the sites with sand harvesting activities ranged from 0-4 while those of the undisturbed sites that were used as control ranged from 4-7 species, Shannon-Weiner index ranged from 0-1.34 in sand harvesting sites as compared to a range of 1.1-1.83 in undisturbed sites, Simpson index ranged from 0-1 in areas with sand harvesting while the range for undisturbed sites was 0.64-0.92 (table 13).

Whereas Kruskall-Wallis indicated overall differences in tree species richness, pairwise comparison did not which was attributed to the narrow significance difference from the Kruskall-Wallis test or the magnitude of the differences was not strong enough. Low tree species richness in sand harvesting sites was attributed to cutting trees on to create paths for the sand trucks, create space for the stock piles as well as expose sand among other sand harvesting activities. The finding were similar to the observations of Agbor, (2014), that sand and gravel mining in Luku region led to deforestation and loss of species.

Although Shannon-Weiner and Simpson diversity indexes were not statistically significant different among the sites the diversity scores in sand harvesting site 1-4 as compared to undisturbed sites was observable low. Low diversity in sand harvesting sites was caused by clearing of trees to make way for sand trucks and for easy of sand harvesting in the sites. The finding coincides with Nasare *et al*. (2023) that observed Shannon -Weiner index was higher in undisturbed site, compared to the sand mining sites in Dallung-Kukou catchment. The finding were also in agreement with a study by Garbin *et al*. (2018) that reported undisturbed sites had high vegetation diversity as compared to sand harvested areas.

Nevertheless the statistical insignificance of the Shannon-Weiner and Simpson index calls for further research to understand the drivers of biodiversity loss and the best practices for restoration and conservation. The restoration and conservation effort set by the authorities should be community centered since the nature of the disturbances is community driven from economic gains of sand harvesting business. Long term monitoring to assess the effectiveness of conservation strategies and adapt them as needed should also be utilized as well as full enforcement of NEMA sand harvesting regulations.

Table 13: Tree's Diversity for Sand Harvesting Sites

Sites	Species Richness	Shannon-Weiner index	Simpson index
Site 1	0	0	0

Site 2	2	0.69	1
Site 3	4	1.34	0.73
Site 4	1	0	0
Control 1	7	1.83	0.92
Control 2	7	1.74	0.82
Control 3	4	1.1	0.64

Kruskall-Wallis test for tree species richness differences among the sites indicated marginal statistically significant , Shannon-Weiner and Simpson indices were not (p=0.047, p=0.08 and p=0.48 respectively) (table 14).

Table 14: Kruskall-Wallis Statistical Results for Tree's Diversity-Sand Harvesting Sites

Variable	statistic	p-value
Species Richness	3.92	0.047
Shannon Weiner index	3.18	0.08
Simpson Index	0.51	0.48

Species richness for shrubs in the sand harvesting area ranged from 1-2 while for the undisturbed sites 1-3, Shannon-Weiner index for the sand harvesting sites ranged from 0-0.69 as compared to 0-1.09 for undisturbed sites, Simpson index for the sand harvesting sites was between 1-0.76 while for the undisturbed sites it ranged from 0.33-1 (table 15).

Species richness and diversity of the shrubs was low for both sand harvesting sites and the undisturbed sites with marginal observable differences in favor of the undisturbed sites. Low species richness and diversity for shrubs in all the sites could not be attributed to any anthropogenic factors observable suggesting this may have been induced by ecological or environmental factors. The observed similarity in species richness and diversity concurred with Gabrin *et al*. (2018) findings that restinga vegetation in Brazil had similar species composition between the sand mined and undisturbed sites which he attributed to the spatial proximity of the two sites.

Table 15: Shrubs Diversity for Sand Harvesting Sites

	Species Richness	Shannon-Weiner index	Simpson's index
Site 1	2	0.41	0.76

Site 2	1	0	1
Site 3	2	0.69	0.5
Site 4	1	0	1
Control 1	3	1.09	0.34
Control 2	3	1.1	0.33
Control 3	1	0	1

Species richness, Shannon Weiner and Simpson indices for the shrubs were not statistically significant (p=0.14, p=0.17 and p= 0.17 respectively) (table 16)

Table 16: Kruskal - Wallis Statistical Results for Shrub's Diversity -Sand Harvesting Sites

Variable	Statistic	P-Value
Species Richness	2.20	0.14
Shannon Weiner index	1.86	0.17
Simpson Index	1.86	0.17

Similar results as for the shrubs' richness and diversity were also observed for the herbaceous species in both sand harvesting sites and undisturbed sites (table 17). Sand harvesting sites that had herbaceous vegetation had similar species as the undisturbed sites, and marginal difference in terms of richness, Shannon-Weiner and Simpson indices between the sand harvesting sites and undisturbed.

Some sand harvesting sites had similar species diversity as the undisturbed sites indicating the ecological similarity of the study area which collaborate the findings of Gabrin *et al*. (2018) in Brazil that spatial proximity of the sand harvesting sites and undisturbed sites was reason for similarity in species composition the sites. Lack of observable and statistical differences in diversity of shrubs and herbaceous also indicates that the shrubs and herbaceous species are highly adaptable to disturbances and this should inform on rehabilitation species that can be used. Needless to say that also further research on long-term disturbance effect on the herbaceous and shrub diversity would be recommended.

Table 17: Herbaceous Diversity for Sand Harvesting Sites

	Species Richness	Shannon-Weiner index	Simpson index

Site 1	1	0	0
Site 2	0	0	0
Site 3	2	0.6365	0.667
Site 4	2	0.6931	0.6
Control 1	2	0.6616	0.5357
Control 2	2	0.673	0.6
Control 3	3	0.7072	0.5014

Herbaceous species richness, Shannon Weiner and Simpson Indices were not significantly different between the sand harvesting sites and undisturbed sites (table 18).

Table 18: Kruskal - Wallis Statistical Results for Herbaceous Diversity - Sand Harvesting Sites

Variable	statistic	p-value
Species Richness	2.43	0.12
Shannon Weiner index	2.04	0.15
Simpson Index	0.03	0.86

Saplings and seedling diversity ranged from 0-5 for sand harvesting sites as compared to 1-8 in undisturbed sites, Shannon-Weiner 0-1.43 for sand harvesting sites as compared to 0-1.94 for undisturbed sites, Simpson index 0-0.5 for sand harvesting sites and a range of 0.15-1 for undisturbed sites (table 19).

Although the saplings and seedlings richness and diversity were not statistically significant, the richness and diversity was observably high on sand harvesting sites as compared to the undisturbed sites. This was attributed to the fact that the undisturbed sites were composed of mature vegetation and hence very little saplings and that the clearance of trees on the sand harvesting sites opened the habitat and the immediate prolonged wet season (el-nino) before the study allowing regrowth of the seedlings. These finding coincides with Muñoz Mazón (2022) that found out that, open low altitudes area supported more regrowth of seedling and their survival. This indicated resilience of the habitat and ability to recover in absence of disturbance and adaptive management strategies can be implemented based on ongoing observations to support ecosystem recovery and engage communities to implement sustainable practices.

Table 19: Saplings and Seedling Diversity for Sand Harvesting Sites

Sites	Species Richness	Shannon-Weiner index	Simpson’s index

Site 1	0	0	0
Site 2	5	1.34	0.32
Site 3	5	1.43	0.27
Site 4	3	0.83	0.5
Control 1	1	0	1
Control 2	8	1.99	0.15
Control 3	2	0.64	0.56

Sapling and seedlings species richness, Shannon Weiner and Simpson indices among the site were not statistically significant (p=0.48, p=0.71 and p=0.46 respectively) (table 20)

Table 20: Kruskal - Wallis Statistical Results for Sapling and Seedling - Sand Harvesting Sites

Variable	Statistic	P-Value
Species Richness	0.5091	0.4755
Shannon Weiner index	0.1346	0.7137
Simpson Index	0.5385	0.4631

Sand harvesting greatly affected the canopy cover and the ground cover in their sites. The canopy cover was below 10% for all the sites as compared to a minimum of 30% for the undisturbed sites. Ground cover was below 30% for all the sand harvesting sites as compared to a minimum of 30% for the undisturbed sites (table 21).

Canopy cover and ground cover were statistically significant and Dunn test for post hoc analysis indicated that the undisturbed site (1, 2 and 3) were statistically significant different from sand harvesting site 1, 2, 3 and 4. The low canopy cover is explained by the low trees species in the sand harvesting sites as a result of cutting the trees to create truck roads, sand storage sites and other activities leading to habitat degradation. Low ground cover in sand harvesting sites was due to unbridled clearing of the vegetation which exposes the soil to agents of erosion especially in fragile ecosystem like the riparian habitat. This also explains the land use and land cover results that showed that area under the river has been increasing as one of the contributing factor. These finding were collaborated by Oyoo (2021) that noted that land cover are destroyed to expose the top soil which is harvested as sand in riparian land in Kisumu region. Ashraf *et al.*, (2011), observed that Sand harvesting in Malaysia leads to the complete removal of vegetation. He attributed the destruction of vegetation to heavy equipment and sand piles near extraction sites. Same observations were made by Kori & Mathada, (2012) in South Africa and Mohammed *et al*., (2022) in Nigeria.

Table 21: Canopy and Ground Cover for Sand Harvesting Sites

Sites	Canopy cover %	Ground cover %
Site 1	0	32
Site 2	1	3
Site 3	10	3
Site 4	3	30
Control 1	70	60
Control 2	30	90
Control 3	40	67

Canopy cover and the ground cover between sand harvesting sites and undisturbed were statistically significant (p=0.03 and p=0.03 respectively).

Table 22: Kruskal–Wallis Statistical Results for Canopy and Ground Cover - Sand Harvesting Sites

Variable	statistic	p-value
Canopy cover %	4.582	0.03
Ground cover %	4.582	0.03

Sand harvesting has a strong negative impact on tree diversity. 53% of the variability in tree diversity was attributed to the impact of sand harvesting activities. For shrub diversity, sand harvesting activities had week negative impact and 20% of the variability in shrub diversity was attributed to the impact of sand harvesting activities. Sand harvesting activates had a moderate negative impact on herbaceous diversity which accounted for 34% of the variability. However, the sand harvesting activities had had week positive impact on sapling and seedling diversity accounting for 0.49% of the variability (table 23). The correlations were nevertheless not statistically significant and further research would need to be conducted to ascertain that the variability were not by chance.

Table 23: Spearman Correlation Analysis for Sand Harvesting Sites

Type	ρ	ρ2	p-value
Tree diversity	-0.73	0.53	0.06
Shrub diversity	-0.45	0.20	0.31
Herbaceous diversity	-0.58	0.34	0.17
Seedlings and Sapling diversity	0.07	0.05	0.89

The strong negative correlation, although not statistically significant, suggests that tree diversity is likely impacted by disturbances. This could imply that disturbances such as sand harvesting significantly reduce tree diversity, potentially affecting ecosystem stability and services. The moderate negative correlations indicate that disturbances might also negatively affect shrub and herbaceous diversity, though the effects are less pronounced compared to trees. These plants might be more resilient or recover faster from disturbances. The very weak correlation suggests that seedlings and saplings are not significantly affected by disturbances. This could indicate a high potential for recovery and regeneration in disturbed sites, as young plants are still establishing themselves. Conduct long-term studies to observe changes over time. Future research should incorporate long-term monitoring and season variations to help identify trends and long-term effects that might not be apparent in short-term studies.

4.3 Influence of Charcoal Burning on Riparian Vegetation Composition and Structure

4.3.1 Floristic Composition

Trees had 29% in charcoal burning sites as compared to 38% in undisturbed sites. Herbaceous species was also among the highest with 29% in charcoal burning sites as compared to 16% in undisturbed sites (fig 6 a and b). These findings collaborates a study by Stephan *et al*., (2010) that noted post-fire recovery often leads to a higher percentage of herbaceous species compared to other vegetation type and a study by Masunga *et al*., (2013) in the Kalahari Sand System which found that fire and grazing significantly affected herbaceous plant species composition, with herbaceous species showing higher cover and biomass compared to other vegetation types.

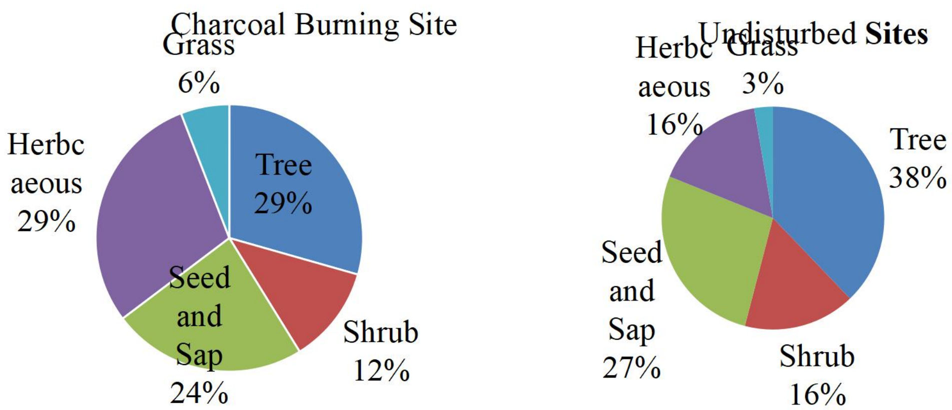

Figure 6: (a) Charcoal Burning Sites (b) Undisturbed Sites

Tree species in all 4 charcoal burning sites belonged to 6 families, 7 genera and 10 species (table 24). Undisturbed sites had 14 species which was 40% more tree species than the charcoal burning sites.

Table 24: Trees Composition for Charcoal Burning Sites

Sites	Trees	No.	DBH	Height	Canopy cover %
Site 1	*Adansonia digitata*	1	105	5	1
Site 2	*Acacia mellifera*	1	80	10	50
	Acacia Senegal	1	220	7	
	Euphorbia scheffleri	1	60	5	
	Ficus sycomorous	1	20	3	
	Acacia mellifera	2	10	5	
	Adenia Venenata	1	5	3	
	Acacia senegal	40	12	5	
Site 3	*Combretum micranthum*	1	45	4	35
	Combretum micranthum	1	30	4	
	Acacia ataxacantha	1	15	5	
	Acacia mellifera	1	48	6	
	Euphorbia scheffleri	1	30	6	
	Euphorbia scheffleri	2	30	4	
	Acacia ataxacantha	3	10	5	
	Maerua endlichii	1	15	2.5	
Site 4	*Acacia elatior*	1	80	20	1

Trees in charcoal burning sites had large basal diameter and short height. Site 2 and site 3 which were abandoned charcoal sites had more tree species as compared to active charcoal burning sites mostly composed of *Acacia* species. Shrubs in charcoal burning sites belonged to 3 families, 4 genera and 4 species while the seedling and saplings belonged to 4 families, 6 genera and 8 species (table 25) which was similar species number as the undisturbed sites.

Table 25: Shrub, Seedling and Saplings Composition for Charcoal Burning Sites

Sites	Shrubs	No.	Seedling and saplings	No.
Site 1	*Indigofera tinctoria*	1		
Site 2	*Capporis spinosa*	1	*Acacia Senegal*	3
	Barleria prionitis	1	*Commiphora rostrata*	1
			Ficus sycomorus	1
			Sida ovate forrsk	1
			Commiphora rostrata	3
Site 3			*Acacia ataxacantha*	1
			Lannea tryphylla	1
			Ficus sycomorus	1
			Sida ovate forrsk	1
			Acacia mellifera	1
Site 4	*Senna occidentalis*	1	*Acacia elatior*	2
	Barlaria prionitis	1		

Similar shrub species in charcoal burning and in undisturbed sites indicated similar ecological conditions and ability of shrubs to adopt in disturbed sites. Sapling and seedling were more in undisturbed sites. Herbaceous vegetation in charcoal burning sites belonged to 8 families, 9 families and 10 species while grass in the charcoal burning sites belonged to 2 families, 2 genera and 2 species (table 26) as compared to undisturbed sites that had 6 herbaceous species and 1 grass species .

Table 26: Herbaceous and Grass Composition for Charcoal Burning Sites

Sites	Herbaceous	No.	Grass	No.	ground cover	Density
Site 1			*Cyperus rotundifolia*	80	31	26.66667
			Eragrostis racemosa	1		
	Acanthospermum hispidum	6				2.666667
	Galinsonga parviflora	2				
Site 2	*Achyranthes aspera*	1			8	
	Cissampelos mucronata	2				1
Site 3	*Ocimum kilimandscharium*	1			25	11
	Achyranthes aspera	2				
	Commelina vulgaris	4				
	Welwitschia mirabilis	3				
	Thunbergia guerkeana	1				
	Achyranthes aspera	3				
	Hibiscus cannabinus	1				
	Acanthospermum hispidum	1				
	walvastrum coromandelianum	17				
Site 4	*Acanthospermum hispidum*	54			30	18

4.3.2 Species Diversity Analysis

Tree Species richness for the charcoal burning sites ranged from 1-6 while for the undisturbed sites ranged from 4-7, Shannon-Weiner index ranged from 0-1.47 and undisturbed sites it ranged from 1.1-1.83, Simpson's index from 0-0.82 as compared to undisturbed sites that ranged from 0.64-0.92 (table 27).

The low observable species richness, Shannon- Weiner and Simpson index in charcoal burning sites was attributed to logging of trees for charcoal production. These observations were in agreement with submissions of Kouami *et al*. (2009) that reported Species richness and Shannon-Weiner index were higher in unexploited sites than in charcoal production sites in the zones of Sudanian and Guinean savanna Forests, Togo and with Kalema & Witkowski (2012) that reported low species richness and diversity in savanna woodlands of Nakasongola District Uganda was attributed to unsustainable harvesting of wood plant species for charcoal as well as study by Arnold and Persson (2003) in Southern Africa that found selective cutting cause depletion of preferred tree species. The overall in significant differences in the Species richness, Shannon-Weiner and Simpson index was in agreement with a study by Kiruki *et al*., (2017) in semi-arid areas in Kenya which reported that low charcoal production does not have clear effects on the woodland diversity, structure and density.

The abandoned showed vegetation recovery in both species richness and moderate Shannon-Weiner and Simpson indices mostly from young trees. Concurrent finding by a study conducted in the Guánica Commonwealth Forest in Puerto Rico found that abandoned charcoal pits had a higher diversity of native tree species compared to active sites. The abandoned sites showed significant recovery with native species dominating the regrowth (Colón and Lugo 2006). Similarly a study by Schmidt *et al*., (2016) in Hesse, Germany, found that abandoned charcoal kiln sites supported a more diverse range of young tree species, compared to active sites.

Low tree diversity in active charcoal burning sites attributed to cutting down trees and burning them to produce charcoal directly reduces tree diversity by removing trees and disrupting the habitat and this indicates that continued intense and frequent charcoal production will have detrimental implications to the riparian tree diversity and cover with possible outcome of desertification of the River Kathita habitat. The abandoned charcoal sites had moderate to high tree diversity indicating a natural process of re-establishment of trees and succession after disturbance that allow for the re-establishment of tree species, indicating that in absence of the disturbances these sites can gradually develop a tree community that is similar to undisturbed sites when there is favorable conditions for growth.

Table 27: Tree Diversity For Charcoal Burning Sites

	Species Richness	Shannon-Weiner index	Simpson index
Site 1	1	0	0
Site 2	6	0.64	0.28
Site 3	5	1.47	0.82
Site 4	1	0	0
Control 1	7	1.83	0.92
Control 2	7	1.74	0.89
Control 3	4	1.1	0.64

Tree species richness was observably high in undisturbed sites and also moderate in abandoned charcoal burning sites (site 2 and site 3) as compared to active charcoal burning sites, similarly Shannon-Weiner and Simpson indices were higher in undisturbed sites, moderate in abandoned charcoal burning sites as compared to the active burning sites. However the observed overall differences were among the sites was not statistically different (p =0.15, p=0.07 and p=0.07 respectively) (table 28).

Table 28: Kruskal - Wallis Results for Charcoal Burning Diversity

Variable	statistic	p-value
Species Richness	2.07	0.15
Shannon Weiner index	3.18	0.07
Simpson Index	3.18	0.07

Basal diameter for the active charcoal burning sites (1 and 3) was bigger than for the abandoned sites (2 and 3) but their height was similar. The basal diameter in charcoal burning sites ranged from a mean of 18-105 as compared to 7-64 in undisturbed sites (table 28). Trees in charcoal burning sites had observable large basal diameter and short height which indicated disturbances that hindered optimal growing conditions. A study by Sapkota *et al*., (2019) in Nepal attributed anthropogenic disturbances to the shift in average DBH of trees to medium and large-sized trees suggesting a reduction in the forest population structure. Similarly, Aabeyir *et al*., 2020) in Ghana observed that in Charcoal disturbed sites, the trees had a large basal area and short height because the larger trees are harvested for charcoal, and the remaining trees, which are often suppressed or younger, do not grow as tall. The differences in the basal area and tree height in Charcoal burning sites was however not statistically significant among the sites (table 29).

The observed large DBH and short height indicated that the change in the tree attributes and structure to charcoal burning disturbance. This was in agreement with a study by Sapkota *et al*., (2019) in Nepal that attributed anthropogenic disturbances to the shift in average DBH of trees to medium and large-sized trees in the disturbed sites indicating declining forest population structure and results to mid-sized and mature trees. Trees that had larger basal diameter were in active charcoal burning sites which indicated that they were preferred for selective logging for the purposes of charcoal production which was in agreement with a study in Ghana that found that trees used for charcoal often had larger DBH but were shorter in height compared to those in undisturbed areas (Aabeyir *et al*., 2020) due to selective harvesting practices that target larger diameter trees.

Table 29: Basal Diameter and Height for Charcoal Burning Sites

	DBH	Height
Site 1	105	5
Site 2	18.3	5.06
Site 3	24.82	4.59
Site 4	80	20
Control 1	64.4	8.39
Control 2	12.8	3.875
Control 3	7.75	6.25

Diameter at breast height and the tree height among the sites was not statistically significant (table 30).

Table 30: Kruskal - Wallis Statistics Results for Basal Diameter and Height - Charcoal Burning Site

Variable	statistic	p-value
DBH	2	0.16
Height	0	1

Shrubs in charcoal burning sites ranged from 0-3, Shannon-Weiner from 0-0.69 and Simpson index from 0-1 while in undisturbed sites species richness ranged from 1-3, Shannon-Weiner from0-1.1 and Simpson index from 0-1 (table 31).

Marginal observable difference in shrub diversity that was statistically insignificant in charcoal burning sites as compared to undisturbed sites was attributed to ability of shrub species to adapt and recover after disturbances. Concurring findings by Jones *et al*., (2023) in USA observed that shrub density and diversity did not differ in fire sites versus undisturbed sites and indicated that native shrub cover can recover in the long term, making the shrub communities in burned sites similar to those in undisturbed site. Similarly, a study by Smith at al., (2013) found that shrub cover in burned sites can recover to levels similar to undisturbed sites over time, depending on factors like precipitation and fire frequency.

Table 31: Shrub Diversity for Charcoal Burning Sites

	Species Richness	Shannon-Weiner index	Simpson index
Site 1	1	0	0
Site 2	2	0.69	1
Site 3	0	0	0
Site 4	2	0.67	0.03
Control 1	3	1.09	0.73
Control 2	3	1.1	1
Control 3	1	0	0

The marginal observable differences in species richness, Shannon-Weiner and Simpson indices for shrubs in all the charcoal burning sites and in undisturbed sites were subsequently not statistically significant (table 32).

Table 32: Kruskal-Wallis Statistical Results for Shrubs' Diversity -Charcoal Burning Sites

Variable	statistic	p-value
Species Richness	1.62	0.20
Shannon Weiner index	1.21	0.27
Simpson Index	0.31	0.58

Sapling and seedling species richness for the charcoal burning sites ranged from 0-5 while for the undisturbed sites it ranged from1-8, Shannon-Weiner ranged from 0-1.61 in charcoal burning sites while undisturbed sites ranged from 0-1.99and Simpson index ranged 0-1 in charcoal burning sits while it ranged from 0-0.92 for the undisturbed sites (table 33).

Table 33: Seedling and Saplings Diversity

	Species Richness	Shannon-Weiner index	Simpson index
Site 1	0	0	0
Site 2	4	1.22	0.75
Site 3	5	1.61	1
Site 4	1	0	0
Control 1	1	0	0
Control 2	8	1.99	0.92
Control 3	2	0.64	0.67

In charcoal burning sites, abandoned charcoal sites had high species richness indicating the ability to recover in absence of the disturbances. The observed ability of abandoned charcoal burning sites to recover concurred with a study by Ndegwa *et al*. (2016) in Mutoma reported that there were comparably high saplings species richness and density in disturbed woodlands in charcoal burning areas displaying the potential of the woodland vegetation to recover. Similar observations were made by Vieira *et al*., (2006) that recently cut and cleared dry forests of Central America, regeneration rapidly restored the number of species on a given site.

And identical observations have been made by Aguilar *et al*., (2012) in Mexico and in Kenya (Okello *et al*., 2001), with variations in recovery period.Additionally, these findings of the vegetation resilience and the ability of abandoned sites to recover suggests that ecosystems can bounce back if given time and protection The seedling and saplings were observed to be mostly from *Acacia* species which were native species. The observable differences in seedling and saplings diversity among the sites was however not statistically significant (table 34) and hence the study recommend further long-term research to track the observed changes in seedling and sapling diversity.

Table 34: Kruskal-Wallis Statistical Results For Sapling And Seedling Diversity-Charcoal Burning Sites

Variable	statistic	p-value
Species Richness	0.29	0.59
Shannon Weiner index	0.13	0.71
Simpson Index	0	1

Herbaceous species richness ranged from 0-8 as compared to 0-2 from the grasses in charcoal burning sites. The undisturbed sites had species richness for herbaceous ranging from 2-3 and for grasses from 0-1 (table 35). Similar to sand harvesting sites, herbaceous species were observed to be similar to the undisturbed sites. Grass species in the charcoal burning sites had similarly the same trend. While herbaceous showed resilience across multiple sites, the study also observed the role of fire is shaping the vegetation community. Density of the herbaceous species in charcoal burning sites was more as compared to the sand harvesting sites and additionally the grass species.

The observed pattern concurred with a study by Spicer *et al*., (2022) explored patterns of herbaceous diversity in forest ecosystems and highlighted the role of disturbances in shaping plant communities. It noted that disturbances, including fire, can create conditions that promote herbaceous diversity. The findings were also in agreement with a study by Vachova *et al*., (2021) in Czech that investigated plant diversity in different forest types and found that disturbances lead to increased herbaceous diversity

Table 35: Herbaceous and Grass Diversity for Charcoal Burning Sites

	Herbaceous				Grasses		
	Species Richness	Shannon -Weiner index	Simpson index		Species Richness	Shannon -Weiner index	Simpson index
Site 1	2	0.56	0.43	Site 1	2	0.07	0.03
Site 2	2	0.64	0.67	Site 2	0	0	0
Site 3	8	1.53	0.71	Site 3	0	0	0
Site 4	0	0	0	Site 4	1	0	0
Control 1	2	0.66	0.53	Control 1	0	0	0
Control 2	2	0.67	0.6	Control 2	1	0	0
Control 3	3	0.71	0.50	Control 3	0	0	0

The charcoal burning sites had similar herbaceous as the undisturbed site say for not site 3 as well grass diversity. Diversity for herbaceous and grass among the sites was also not statistically significant (table 36).

Table 36: Kruskal-Wallis Statistical Results for Herbaceous and Grass Diversity's - Charcoal Burning Sites

Vegetation diversity	Variable	statistic	p-value
Herbaceous diversity	Species Richness	0.15	0.7
	Shannon Weiner index	1.13	0.29
	Simpson Index	0	1
Grasses diversity	Species Richness	0.35	0.55
	Shannon Weiner index	0.75	0.39
	Simpson Index	0.75	0.39

Charcoal burning activities had a strong negative impact on tree diversity, accounting for 53% of the variability; however it was not statistically significant. Charcoal burning activities had week negative impact on shrub diversity. A 20% of the total variability in shrub diversity was attributed to the impact of sand harvesting activities. Charcoal burning activities had a moderate, negative impact on herbaceous diversity which accounted for 18.49% of the total variability of herbaceous diversity in the sites. Charcoal burning activities had weak negative impact on sapling and seedling diversity accounting for 2.25% variability of sapling and seedling diversity in the sites (table 37).

Table 37: Charcoal Burning Correlation for Vegetation Diversity

Vegetation type	ρ	ρ2	p-value
Tree diversity	-0.73	0.53	0.06
Shrub diversity	-0.45	0.2	0.31
Herbaceous diversity	-0.43	0.19	0.31
Seedlings and Sapling diversity	-0.15	0.02	0.75

The strong negative correlation indicates that tree diversity, seedlings and saplings diversity was impacted by livestock overgrazing and trampling in the drinking bays. Charcoal burning disturbances greatly affect the diversity of trees in the riparian habitat. The moderate negative correlations for the shrub and herbaceous diversity indicate that disturbances also negatively affect shrub and herbaceous diversity although not as profound as the tree diversity indicating that they might be more resilient or quick to recover from the disturbances than the trees. This should inform decision makers on the enforcement measures and regulations on charcoal production. The very weak correlation suggests that seedlings and saplings are not significantly affected by disturbances or the sites have high potential for recovery. Further research to investigate these relationships of longer term and comparison with the riparian habitats with similar disturbances in the area is recommended.

4.4 Influence of Livestock Drinking Bays on Riparian Vegetation Diversity

4.4.1 Floristic Composition

Trees had 27% in charcoal burning sites as compared to 38% in undisturbed sites. Herbaceous species was the highest with 41% in charcoal burning sites as compared to 16% in undisturbed sites (fig 7 a and b). Concurring studies by Okach *et al*., (2019) in a humid savanna found out that in grazing areas, herbaceous cover often exceeded 45% during peak growing seasons. Simmilary Abebe *et al*., (2024) in the Simien Mountains Ethiopia found that herbaceous species cover was higher in grazed areas compared to ungrazed areas.

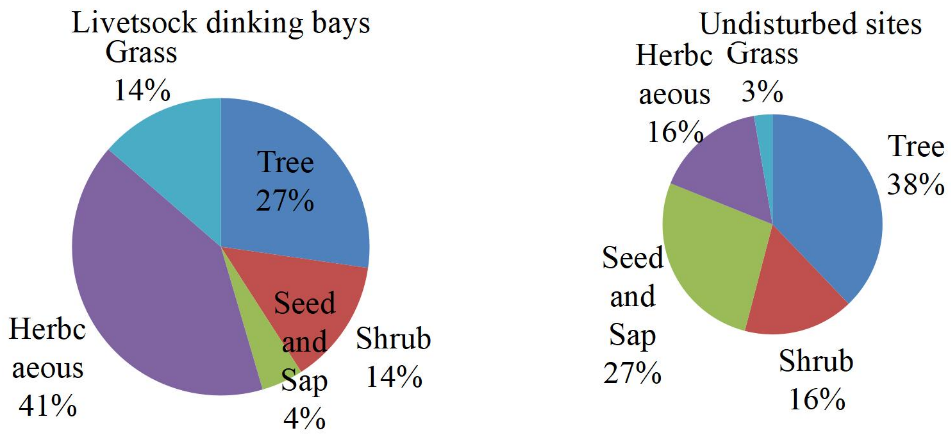

Figure 7: (a) Livestock Drinking Bays (B) Undisturbed Sites

Floristic analysis of vegetation species that were sampled in five different livestock drinking bays revealed that the trees belonged to 4 families, 5 genera and 6 species (table 38) while the undisturbed sites had 11 families, 11 genera, and 14 species. The tree species in livestock drinking bays were very old but scattered as observed from their tree attributes and canopy cover, which were used as shade in the drinking bays. There were no young trees in the drinking bays which indicated the impact of grazing and trampling disturbance on these livestock drinking bays. This altered the vegetation composition in the livestock drinking bays where other competitive vegetation such as herbaceous species and invasive shrubs seemed to thrive. A study by Akbarzadeh *et al.* (2007) in Kuhrang found that after 24 years of excluding livestock, the total canopy cover inside the enclosure was greater than outside, suggesting that grazing had hindered the establishment of new and young trees.

Table 38: Tree Composition for Livestock Drinking Bays

Site	Trees	No.	DBH	Height	Canopy cover %
Site 1		–	–	–	–
Site 2	*Albizia amara*	1	80	7	20
	Tamarindus indica	1	140	8	
	Combretum micranthum	1	38	3	
Site 3	*Acacia ataxacantha*	1	20	20	25
	Maerua endlichii	1	30	15	
	Stercullia africana	1	35	20	
Site 4	*Acacia ataxacantha*	1	63	5	1
Site 5	*Maerua endlichii*	1	130	12	1

In Livestock drinking bays, the floristic analysis for the shrubs, seedling and sapling composition revealed that the shrubs in livestock drinking bays belonged to 1 family, 2 genera and 3 species and seedling and saplings belonged to 1 family, 1 genus and 1 species (table 39) as compared to undisturbed sites which had shrubs vegetation belonging to 4 families, 6 genera and 6 species while the seedling and sapling for the undisturbed sites belonged to 7 families, 9 genera and 10 species.

The main shrub species in the livestock drinking bays were the invasive *Senna* species in almost all the drinking bays. *Senna didymobotrya* and *Senna occidentalis* are highly adaptable and tolerant to disturbances and have ability to thrive in disturbed areas like the livestock drinking bays. Their ability to adapt and out-compete other species was attributed to the reason for their dominance in these drinking bays. Bellows (2003) reported that in riparian zones in USA, grazed sites were predominantly occupied by unpalatable or inedible species, mainly consisting of invasive weeds and plants.

Table 39: Shrub, Seedling and Sapling Composition for Livestock Drinking Bays

Sites	Shrub	No.	Seedling and Saplings	No.
Site1	*Senna occidentalis*	1		
	Senna didymobotrya	1		
Site 2				
Site 3	*Indigofera tinctoria*	3		
Site 4			*Lawsonia inermus*	1
Site 5	*Senna didymotrya*	6		
	Senna occidentalis	1		

Grasses and herbaceous floristic analysis revealed that in livestock drinking bays, grasses belonged to 2 families, 3 genera and 3 species and herbaceous vegetation belonged to 8 families, 9 genera and 9 species (table 40) as compared to the undisturbed sites that had 1 grass species and 6 herbaceous species.

Table 40: Grasses and Herbaceous Composition for Livestock Drinking Bays

Site	Grass species	Herbaceous	No.	Ground cover %	Density
Site 1		*Rugoya*	1	13	0.33
Site 2	*Cyperus rotundifolia*		1100	70	366.67
		Tridax procumbens	1		1.33
		Boerhavia eracta	1		
		Rugoya	1		
		Cucumis anguria	1		
Site 3	*Carex flacea*		12	36	4
		Achyranthes aspera	2		1.33
		Cucumis anguria	1		
		Ocimum kilimandscharium	1		
Site 4	*Cyperus rotundifolia*		500	70	166.67
		Justicia odora forrsk	152		51.33
		Euphorbia hirta	1		
		Satureja hortensis	1		
Site 5	*Cyperus rotundifolia*		1	22	0.67
	Echinochloa colona		1		
		Trianthema portulacastrum	3		1.333333
		Achyranthes aspera	1		

Herbaceous species dominated more in livestock drinking bays as compared to other vegetation species in all the livestock drinking bays. However the grasses had the highest density and contributed the largest percentage of the ground cover.

4.4.2 Species Diversity Analysis

Livestock drinking bay tree species richness per site ranged from 1-3 while for undisturbed site it was 4-7, Shannon-Weiner index <1.1 for the drinking bays while for undisturbed sites was 1.1-1.83 and Simpson index range of 0.33-1 and for the undisturbed sites was 0.64-0.92 (table 41). Observable differences in tree diversity among the livestock drinking bays and undisturbed sites indicate that the tree diversity was considerably high for the undisturbed sites, although not statistically significant. Similarly, a study by Kauffman *et al*., (2022) in USA found out that riparian vegetation species richness and diversity was higher in the un-grazed reaches as compared to the grazed reaches. The findings also concurred with a study by Schulz *et al*., (2019) that found that grazing at high intensities significantly reduced almost all measures of alpha and beta diversity in the tree layers.

A study by Mathewos and Berhanu (2023) in Ethiopia also found out that tree species richness and diversity were significantly reduced by grazing. The study observed that grazing intensity influenced the tree species diversity with livestock drinking bays 2 and 3 that had fewer livestock signs in the bays differing marginal with the ones that had more observed signs of livestock. The more the intensity, the less diverse the site was. This was attributed to the intensity of grazing and trampling that have deleterious effect on young trees. The mixed grazing of the livestock from goats, sheep and cattle was also attributed to the factor that they feed on variety of vegetation species hence exacerbating the effect. Similar observations (Török 2024) found that the impact of grazing on vegetation, including tree diversity was dependent on type of herbivore, grazing intensity, and the specific vegetation.

Table 41: Tree's Diversity for Livestock Drinking Bays

	Species Richness	Shannon-Weiner index	Simpson index
Site 1	1	0	0
Site 2	3	1.1	1
Site 3	3	1.1	1
Site 4	1	0	0
Site 5	1	0	0
Control 1	7	1.83	0.92
Control 2	7	1.74	0.82
Control 3	4	1.1	0.64

The tree species richness, Shannon Weiner and Simpson indices were observably higher in undisturbed sites but nevertheless the observable differences was not huge enough to be statistically significant (p=0.13, p=0.14 and p=0.77 respectively) (table 42).

Table 42: Kruskal-Wallis Statistical Results for Tree's Diversit -Livestock Drinking Bays

Variable	statistic	p-value
Species Richness	2.244	0.1342
Shannon Weiner index	2.215	0.1367
Simpson Index	0.0886	0.7659

There was only 1 sapling recorded in all the 5 livestock drinking bays which indicated that grazing and trampling in livestock drinking bays was detrimental to establishment of seedlings and growth of the saplings. A meta-analysis by Wadud *et al*. (2024) on livestock effects in oak agroforestry systems revealed that livestock, particularly smaller animals like sheep and goats, significantly hindered oak regeneration and establishment. This finding is consistent with the types of livestock observed in the study area. It is therefore crucial to developing effective grazing management and that integrating indigenous and traditional ecological knowledge to enhance sustainable grazing management with understanding of local socio-economic contexts to improve grazing practices. Shrub species richness ranged of 0-2 for livestock drinking bays and for the undisturbed sites from 1-3, Shannon-Weiner index for livestock drinking bays 0-0.69, for the undisturbed sites0-1.09, Simpson index for livestock drinking bays was from 0-1 while for undisturbed site was from 0-0.73 (table 43).

Marginal observable differences in shrub richness, Shannon-Weiner and Simpson indices in undisturbed sites and all the anthropogenic disturbances indicated that the ecological environment was similar and shrubs are more tolerant to disturbances. Concurrent observations (Díaz-Perea *et al*, 2014) on the key attributes to the disturbance response of montane cloud forest trees indicated that shrubs often possess specific regeneration traits that make them more resilient to disturbances, such as fire and land use changes, compared to other plant types. The resilience traits of shrubs to disturbances was observed in all the three disturbances sites for sand harvesting, charcoal burning and livestock drinking bays, similar to the herbaceous vegetation.

Table 43: Shrub's Diversity for Livestock Drinking Bays

Sites	Species Richness	Shannon-Weiner index	Simpson index
Site 1	2	0.69	1
Site 2	0	0	0
Site 3	1	0	0
Site 4	0	0	0
Site 5	2	0.41	0.29
Control 1	3	1.09	0.73
Control 2	3	1.1	1
Control 3	1	0	0

There was marginal difference in observable differences between shrub richness, Shannon-Weiner and Simpson index which was also subsequently not statistically significant (p=0.08, 0.17 and 0.35 respectively) (table 44)

Table 44: Kruskal-Wallis Statistical Results for Shrubs' Diversity -Livestock Drinking Bays

Variable	statistic	p-value
Species Richness	3.15	0.08
Shannon Weiner index	1.92	0.16
Simpson Index	0.86	0.35

However, in livestock drinking bays unlike the other two disturbances, herbaceous species were more dominant than the other vegetation species that is, trees, shrubs, grasses, seedlings and sapling in drinking bays as well as in other disturbance sites (table 45).

This indicated a shift in dominance from grasses, shrubs and trees to other herbaceous in livestock drinking bays suggest that grazing pressure and trampling was detrimental to trees, saplings, seedlings grasses and shrubs and it inhabited their growth. Comparably, Gebremedhn *et al*., (2023) in Sahel discovered that with increasing grazing pressure, the plant species composition shifted from being dominated by grass cover to being dominated by forb cover. Similarly, Chaichi *et al*., (2005) in Iran, found out that grazing over the years there was increase in broad leaf herbs as compared to grass. Additionally, experimental studies of grazing on grasslands found that grazing significantly reduced biodiversity and multi functionality in more arid steppes. This reduction was associated with a shift towards herbaceous vegetation, particularly in areas with higher aridity (Zhang *et al*., 2023). Concurrent findings by Kariuki (2010) in Laikipia, Kenya, indicated that grazing influenced the community species composition to a certain extent. Shift in vegetation type and dominance of invasive shrubs suggest that there is need to initiate effective management practices, such as rotational drinking bays in order to maintain the ecological integrity of the riparian habitats

Table 45: Herbaceous Species Richness for Livestock Drinking Bays

Sites	Herbaceous Richness	Tree Richness	Shrub Richness
Site 1	1	1	2
Site 2	5	3	0
Site 3	3	3	1
Site 4	3	1	0
Site 5	2	1	2
Mean	2.8	1.8	1

Ground cover in livestock drinking bays varied with the grazing intensity. In livestock drinking bays with high estimated number of livestock presence the ground cover ranged from 13%-36% cover while in drinking bays with moderate to low estimated number of livestock presence, the ground cover was 36%-70%. In undisturbed sites ground cover ranged from 60%-90%. The canopy cover in livestock drinking bays ranged from 0%-25% while in undisturbed sites it was 30-70% (table 46)

Grass species had the largest density compare to herbaceous accounting the big part of the ground cover in the livestock drinking bays and livestock drinking bays that had moderate canopy cover was attributed to mature trees used as shade for livestock in the bays. Overall, canopy cover and ground cover in livestock drinking bays was lower than in undisturbed sites. These results were collaborate Smith *et al.* (2012) who reported that visual estimates of ground cover in Midlands region, showed that grazing resulted in reduction of ground cover, increasing the bare grounds and change of plant species composition. This was also collaborated a study by Xu, *et al.*, (2014) in Northen China that found out that increased grazing intensity decreased vegetation height affecting canopy cover and it reduced plant species abundance affecting and above ground biomass. The observed low % ground cover in livestock drinking bays also concurred with finding of Chaichi *et al.*, (2005) that in Iran, ground cover decreased from 38 to 9.5% at the end of the grazing period and with Bellows (2003) that reported that grazing in America's coastal regions led to a decrease in herbage cover.

Table 46: Canopy and Ground Cover for Livestock Drinking Bays

Site	Canopy cover %	Ground cover %
Site 1	0	13
Site 2	20	70
Site 3	25	36
Site 4	1	70
Site 5	1	22
Control 1	70	60
Control 2	30	90
Control 3	40	67

Despite the observable difference in ground cover and canopy cover that show undisturbed sites had higher ground and canopy cover they were not statistically significant (table 45).

Table 47: Kruskall-Wallis Statistical Results for Ground and Canopy Cover - Livestock Drinking Bays

Variable	statistic	p-value
Canopy cover %	2.5823	0.1081
Ground cover %	0.0843	0.7715

Livestock drinking bays had a strong negative impact on tree diversity. 75.69% of the variability in tree diversity was attributed to the impact of cattle drinking bays and the variance was statistically significance. For shrub diversity, livestock drinking bays had a moderate negative correlation. They accounted for 23% of the variability in shrub diversity. The drinking bays had a strong negative impact on sapling and seedling diversity accounting for 54.76% of the variability in seedling and sapling diversity. This variability was statistically significance. There was a weak negative correlation between livestock drinking bays and herbaceous diversity accounting for 2.89% of the variability in herbaceous diversity in the sites (table 48).

Table 48: Spearman Correlation for Livestock Drinking Bays

Type	ρ	ρ2	p-value
Tree diversity	-0.87	0.76	0.005
Shrub diversity	-0.48	0.23	0.23
Herbaceous diversity	-0.74	0.55	0.04
Seedlings and Sapling diversity	-0.17	0.03	0.69

The strong negative correlation indicates that tree diversity was impacted by charcoal burning disturbances. Livestock overgrazing and trampling in drinking vats greatly reduced tree diversity, seedling and sapling diversity and can lead to decreased habitat complexity, affecting species that rely on trees for food and shelter and hinder vegetation reestablishment and regeneration. The moderate negative correlations for the shrub diversity as seen in other disturbance types indicate that they might be more resilient or quick to recover from the disturbances than species. The overall significant negative correlations for tree and herbaceous diversity highlight the critical impact of disturbances on these vegetation types. In addition to effective management strategies such as rotational drinking bays, education of the community on alternative source of livelihood may lift the livestock pressure on the riparian habitat. Further experimental research on the rotational drinking bays would be recommend to study the effectiveness of this suggestion as an ecological control measure

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of the Findings

This study analyzed satellite imageries of riparian vegetation on the study area and gathered data on diversity, structure and composition on the selected anthropogenic disturbed sites and relatively undisturbed sites.

The Normalized Difference Vegetation Index (NDVI) analysis indicated a reduction in mean NDVI from 0.41 to 0.32, however it was not statistically significant (p=0.26).The reduction in the mean NDVI was attributed to land cover and land use change indicating 30% of the area under forest category was lost, open spaces increases by 1.4%, bare land area increased by to 12.8%, river are increased by 21.92% and area classified as development increased by 466.7%. Additionally, the reduction in NDVI mean was attributed to the anthropogenic disturbance hotspots mapped and recorded mostly in the mid and lower section of the river with the disturbances mostly dominated by the livestock drinking bays.

Vegetation data analysis revealed that the selected anthropogenic disturbances had negative impact on vegetation composition, structure, diversity and density. Sand harvesting sites had low tree and shrub species richness and diversity as compared to undisturbed sites. Sand harvesting activities had a strong negative impact on tree diversity accounting for 53% of the variability in trees diversity, a moderate negative effect on shrub and herbaceous diversity accounting for 20% and 34% of the variability respectively. Sand harvesting .activities had a weak positive impact on sapling and seedling diversity account for 0.49% of the variability. Charcoal burning activities had a strong negative impact on tree diversity accounting for 53% of the variability, moderate negative effect on shrub and herbaceous diversity accounting for 20% and 18.49% of the variability. Overgrazing and trampling in livestock drinking bays had a strong negative impact on tree diversity accounting for 75.69% of the variability, moderate negative impact on seedling, sapling and shrub diversity with the overgrazing and trampling on livestock drinking bays accounting for 54.76% and 23% of the variability.

5.2 Conclusions

Anthropogenic disturbances had negative impact on vegetation diversity which alongside with the change land use and land cover changes negatively affected on the vegetation health. The mean NDVI value of 0.32 for 2023 indicates that River Kathita riparian habitat consist of sparse vegetation that is below healthy riparian vegetation health. Although all the disturbances had deleterious effect on vegetation diversity, in all shrubs and herbaceous species showed trends of tolerance than other species. In sand harvesting sites and charcoal burning sites, there was high seedling and saplings for the abandoned sites indicating the resilience of the habitat and ability to recover and reestablish in absence of disturbances and with protection. However, in livestock drinking bays the study did not record presence of saplings and seedling. Indicating that grazing and trampling in livestock drinking bays was detrimental to establishment of seedlings and growth of the saplings. The study instead observed a shift in dominance of herbs and other herbaceous from grasses and shrubs in the livestock drinking bays.

5.3 Recommendations

Policy recommendation:

i. Local and national stakeholders should enforce stricter controls on sand harvesting following NEMA guidelines to prevent further vegetation degradation. Stringent permitting processes and environmental safeguards to mitigate the impacts of sand mining have been used successfully to regulate industrial sand mining in USA (Krumenacher and Orr 2016). Additionally, policies that put taxation on sand mining have been found was found to significantly decrease sand extraction and positive economic effects (Hübler and Pothen (2021)
ii. Encouraging the riparian communities to plant more trees in degraded areas to meet the national 10% forest cover. Community-Based Management approaches have been used successfully to reduce illegal charcoal burning. Such CBM's that have been used successfully before is Kenya's green belt movement. The CBM's are anchored in the Forests Act of 2005
iii. Implementing and enforcing stricter regulations on charcoal production and trade to help control illegal activities to promote sustainable practices. In, Tanzania charcoal regulations of 2006 introduced strict licensing and permit

systems for charcoal production and transportation which helped reduce illegal charcoal production and promote sustainable practices

iv. Implement rotational access points to drinking bays as a strategy to ease pressure on vegetation at livestock drinking bays. Holistic and adaptive approaches to grazing management in riparian areas such as implementing rotational grazing systems to allow riparian areas time to recover between grazing periods and controlling livestock access to riparian areas have been used successful as strategies to achieve sustainable grazing while maintaining or enhancing riparian ecosystem functions (Wyman et al., 2006)

v. Incorporation of traditional and indigenous knowledge in conservation and rehabilitation programs

5.4 Suggestion for Further Research

The study suggests further research on:

i. Log-term research on the identified anthropogenic disturbances to monitor their effect on vegetation variability

ii. Research on how climate change may exacerbate riparian vegetation degradation, using precise climate and hydrological data

iii. Further research on other observed anthropogenic disturbances like agriculture and built up which could provide a more comprehensive understanding of land-use change impacts on riparian health.

iv. Research on the effectiveness of existing land policies and how they shape riparian habitat conservation and management for the long –term planning.

REFERENCES

Aabeyir, R., Adu-Bredu, S., Agyare, W. A., & Weir, M. J. (2020). Allometric models for estimating aboveground biomass in the tropical woodlands of Ghana, West Africa. *Forest Ecosystems, 7*(1), 1-23. https://doi.org/10.1186/s40663-020-00234-9

Abebe, B., Ashagrie, M., & Eshete, G. (2024). Effects of livestock grazing on herbaceous species composition and biomass in the Simien Mountains National Park, Ethiopia. Israel Journal of Ecology and Evolution. https://doi.org/10.1163/22244662-bja10087

Achieng, A. O., Masese, F. O., Coffey, T. J., Raburu, P. O., Agembe, S. W., Febria, C. M., & Kaunda-Arara, B. (2021). Assessment of the ecological health of Afrotropical rivers using fish assemblages: A case study of selected rivers in the Lake Victoria Basin, Kenya. *Frontiers in Water, 2*, 620704. https://doi.org/10.3389/frwa.2020.620704

Aliu, I. R., Akoteyon, I. S., & Soladoye, O. (2022). Sustaining urbanization while undermining sustainability: The socio-environmental characterization of coastal sand mining in Lagos, Nigeria. GeoJournal, 87(6), 5265-5285. https://doi.org/10.1007/s10708-022-10567-8

Baninla, Y., Sharifi, A., Allam, Z., Tume, S. J. P., Gangtar, N. N., & George, N. (2022). An overview of climate change adaptation and mitigation research in Africa. Frontiers in Climate, 4, 976427. https://doi.org/10.3389/fclim.2022.976427

Bentsi-Enchill, F., Damptey, F. G., Pappoe, A. N. M., Ekumah, B., & Akotoye, H. K. (2022). Impact of anthropogenic disturbance on tree species diversity, vegetation structure and carbon storage potential in an upland evergreen forest of Ghana, West Africa. *Trees, Forests and People, 8*, 100238. https://doi.org/10.1016/j.tfp.2022.100238

Borah, N., Athokpam, F. D., Garkoti, S. C., Das, A. K., & Hore, D. K. (2014). Structural and compositional variations in undisturbed and disturbed tropical forests of Bhuban hills in south Assam, India. *International Journal of Biodiversity Science, Ecosystem Services & Management, 10*(1), 9-19. https://doi.org/10.1080/21513732.2014.883386

Brennan, J. S., & Culverwell, H. (2005). Marine Riparian: An assessment of riparian functions in marine ecosystems. *Washington Sea Grant Program*.

Buke, M., Musau, J., & Muiruri, P. (2024). Sand harvesting and its social, economic, and environmental effects on households' livelihoods in Homabay County, Kenya. International Academic Journal of Arts and Humanities, 1(4), 40-60. https://iajournals.org/articles/iajah_v1_i4_40_60.pdf

Ceccon, E., Méndez-Toribio, M., & Martínez-Garza, C. (2020). Social participation in forest restoration projects: Insights from a national assessment in Mexico. Human Ecology, 48(5), 609-617. https://doi.org/10.1007/s10745-020-00178-w

Chabari, K. S., Njagi, E. C., Magana, A., & Ogolla, F. O. (2020). Bacteriological water quality assessment of Nkenye Stream in Meru South in Tharaka Nithi County, Kenya. *Journal of Water and Health, 18*(4), 1-10. https://doi.org/10.2166/wh.2020.004

Clary, W. P., & Kruse, W. H. (2004). Livestock grazing in riparian areas: Environmental impacts, management practices and management implications. In *Riparian areas of the southwestern United States: Hydrology, ecology, and management* (pp. 237-258). CRC Press. https://doi.org/10.1201/9780203497753

Cojan, I., & Abriak, N. (2019). Sand, an increasingly scarce resource that needs to be replaced. I'MTech. https://imtech.fr/sand-scarce-resource-replacement

Colón, S. M., & Lugo, A. E. (2006). Recovery of a subtropical dry forest after abandonment of different land uses. *Biotropica: The Journal of Biology and Conservation, 38*(3), 354-364. https://doi.org/10.1111/j.1744-7429.2006.00158.x

Crane, T. A., Habermann, B., Marty, E., Arndt, C., Leitner, S., Worku, T., & Gichuki, L. (2022). Climate change adaptation and mitigation in extensive livestock systems in East Africa: Findings from the Programme for Climate-Smart Livestock Systems. Frontiers in Climate, 4, 976427. https://doi.org/10.3389/fclim.2022.976427

Dharani, N. (2011). *Field guide to common trees & shrubs of East Africa*. Penguin Random House South Africa.

Dharani, N. (2011). *Field guide to common trees & shrubs of East Africa*. Penguin Random House South Africa.

Díaz-Perea, F. J., Equihua, M., Jaramillo, V. J., Méndez-Ramírez, I., & Fragoso, C. (2014). Key attributes to the disturbance response of montane cloud forest trees: Shade tolerance, dispersal mode and the capacity to form a seed bank. *Annals of Forest Science, 71*, 437-451. https://doi.org/10.1007/s13595-014-0375-3

Díaz-Perea, F. J., Equihua, M., Jaramillo, V. J., Méndez-Ramírez, I., & Fragoso, C. (2014). Key attributes to the disturbance response of montane cloud forest trees: Shade tolerance, dispersal mode and the capacity to form a seed bank. *Annals of Forest Science, 71*, 437-451. https://doi.org/10.1007/s13595-014-0375-3

East African Wild Life Society. (2017). Enhancing environmental regulations in safeguarding Lake Ol Bolossat in Nyandarua County, Kenya. Stakeholders Workshop Report.

East African Wild Life Society. (2017). Enhancing environmental regulations in safeguarding Lake Ol Bolossat in Nyandarua County, Kenya. Stakeholders Workshop Report.

Environmental Management and Coordination (Water Quality) Regulations. (2006). Legal Notice No. 120. National Environment Management Authority (NEMA), Kenya.

Environmental Management and Coordination (Water Quality) Regulations. (2006). Legal Notice No. 120. National Environment Management Authority (NEMA), Kenya.

Garbin, M. L., Misaki, F., Ferreira, P. F., Guidoni-Martins, K. G., Soares, R. B., Mariotte, P., & Silva, A. G. (2018). Long-term regeneration of a tropical plant community after sand mining. *Ecology and Evolution, 8*(11), 5712-5723. https://doi.org/10.1002/ece3.4127

Garbin, M. L., Misaki, F., Ferreira, P. F., Guidoni-Martins, K. G., Soares, R. B., Mariotte, P., & Silva, A. G. (2018). Long-term regeneration of a tropical plant community after sand mining. *Ecology and Evolution, 8*(11), 5712-5723. https://doi.org/10.1002/ece3.4127

Garg, S., Joshi, R. Kr., & Garkoti, S. C. (2021). Effect of tree canopy on herbaceous vegetation and soil characteristics in semi-arid forests of the Aravalli hills. *Arid Land Research and Management, 36*(2), 224–242. https://doi.org/10.1080/15324982.2021.1953634

Garg, S., Joshi, R. Kr., & Garkoti, S. C. (2021). Effect of tree canopy on herbaceous vegetation and soil characteristics in semi-arid forests of the Aravalli hills. *Arid Land Research and Management, 36*(2), 224–242. https://doi.org/10.1080/15324982.2021.1953634

Gebremedhn, H. H., Ndiaye, O., Mensah, S., Fassinou, C., Taugourdeau, S., Tagesson, T., & Salgado, P. (2023). Grazing effects on vegetation dynamics in the savannah ecosystems of the Sahel. *Ecological Processes, 12*(1), 54. https://doi.org/10.1186/s13717-023-00454-9

Gebremedhn, H. H., Ndiaye, O., Mensah, S., Fassinou, C., Taugourdeau, S., Tagesson, T., & Salgado, P. (2023). Grazing effects on vegetation dynamics in the savannah ecosystems of the Sahel. *Ecological Processes, 12*(1), 54. https://doi.org/10.1186/s13717-023-00454-9

Guan, J., Yao, J., Li, M., & Zheng, J. (2021). Assessing the spatiotemporal evolution of anthropogenic impacts on remotely sensed vegetation dynamics in Xinjiang, China. *Remote Sensing, 13*(22), 4651. https://doi.org/10.3390/rs13224651

Guan, J., Yao, J., Li, M., & Zheng, J. (2021). Assessing the spatiotemporal evolution of anthropogenic impacts on remotely sensed vegetation dynamics in Xinjiang, China. *Remote Sensing, 13*(22), 4651. https://doi.org/10.3390/rs13224651

Jaelani, L. M. (2021). A long-term spatial and temporal analysis of NDVI changes in Java Island using Google Earth Engine. In *IOP Conference Series: Earth and*

Environmental Science (Vol. 936, No. 1, p. 012038). IOP Publishing. https://doi.org/10.1088/1755-1315/936/1/012038

Jones, A. M., Kane, J. M., Engber, E. A., Martorano, C. A., & Gibson, J. (2023). Extreme wildfire supersedes long-term fuel treatment influences on fuel and vegetation in chaparral ecosystems of northern California, USA. *Fire Ecology, 19*(1), 28. https://doi.org/10.1186/s42408-023-00128-9

Kaigongi, M., & Musila, F. (2015). Ethnobotanical study of medicinal plants used by Tharaka people of Kenya. *International Journal of Ethnobiology and Ethnomedicine, 1*(1), 1-8.

Kalema, V. N., & Witkowski, E. T. F. (2012). Land-use impacts on woody plant density and diversity in an African savanna charcoal production region. *International Journal of Biodiversity Science, Ecosystem Services & Management, 8*(3), 231–247. https://doi.org/10.1080/21513732.2012.681070

Kathambi, V., Mutie, F. M., Rono, P. C., Wei, N., Munyao, J. N., Kamau, P., & Wang, Q. F. (2020). Traditional knowledge, use and conservation of plants by the communities of Tharaka-Nithi County, Kenya. *Plant Diversity, 42*(6), 479-487. https://doi.org/10.1016/j.pld.2020.09.004

Kershner, J. L., Archer, E. K., Coles-Ritchie, M., Cowley, E. R., Henderson, R. C., Kratz, K., Quimby, C. M., Turner, D. L., Ulmer, L. C., & Vinson, M. R. (2004). Guide to effective monitoring of aquatic and riparian resources (Gen. Tech. Rep. RMRS-GTR-121). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://doi.org/10.2737/RMRS-GTR-121

King County. (2023). The value of riparian vegetation. https://kingcounty.gov/en/legacy/services/environment/watersheds/general-information/riparian-vegetation

Kipkorir, E. C., & Cheserek, G. J. (2018). Land use-land cover changes in Saiwa Swamp Watershed, Western Kenya. *International Journal of Research in Environmental Science, 4*(4), 1-12. https://www.arcjournals.org/pdfs/ijres/v4-i4/1.pdf

Kirema, M. M. (2020). Effects of land use changes on Thanantu River, Tharaka North Sub County, Tharaka-Nithi County.

Kiruki, H. M., van der Zanden, E. H., Gikuma-Njuru, P., & Verburg, P. H. (2017). The effect of charcoal production and other land uses on diversity, structure and regeneration of woodlands in a semi-arid area in Kenya. *Forest Ecology and Management, 391*, 282-295. https://doi.org/10.1016/j.foreco.2017.02.022

Koskey, J. C., M'Erimba, C. M., & Ogendi, G. M. (2021). Effects of land use on the riparian vegetation along the Njoro and Kamweti Rivers, Kenya. *Open Journal of Ecology, 11*(11), 807. https://doi.org/10.4236/oje.2021.1111050

Kouami, K., Yaovi, N., & Honan, A. (2009). Impact of charcoal production on woody plant species in West Africa: A case study in Togo. *Scientific Research and Essay, 4*(9), 881-893.
Krumenacher, T., & Orr, S. (2016). Regulatory control of industrial sand mining in the Midwest USA. *Environmental Management, 58*(3), 456-467. https://doi.org/10.1007/s00267-016-0734-5

Kyalo, W. D. (2009). Impact of policy and socioeconomic factors on spatial distribution of livestock production systems in River Njoro Watershed, Kenya (Doctoral dissertation, Egerton University). Retrieved from Egerton University Repository.

Lelo, F. K., Chiuri, W., & Jenkins, M. W. (2005). Managing the River Njoro Watershed, Kenya: Conflicting laws, policies, and community priorities. Retrieved from ResearchGate.

Lezama, F., Baeza, S., Altesor, A., Cesa, A., Chaneton, E. J., & Paruelo, J. M. (2014). Variation of grazing-induced vegetation changes across a large-scale productivity gradient. *Journal of Vegetation Science, 25*(1), 8-21. https://doi.org/10.1111/jvs.12099

Majumdar, A., & Avishek, K. (2023). Riparian zone assessment and management: An integrated review using geospatial technology. Water, Air, & Soil Pollution, 234(5), 319. https://doi.org/10.1007/s11270-023-06329-1

Mango, L. M., Melesse, A. M., McClain, M. E., Gann, D., & Setegn, S. G. (2011). Land use and climate change impacts on the hydrology of the upper Mara River Basin, Kenya: Results of a modeling study to support better resource management. *Hydrology and Earth System Sciences, 15*(7), 2245-2258. https://doi.org/10.5194/hess-15-2245-2011

Masunga, G. S., Moe, S. R., & Pelekekae, B. (2013). Fire and Grazing Change Herbaceous Species Composition and Reduce Beta Diversity in the Kalahari Sand System. Ecosystems, 16(2), 252-268. https://doi.org/10.1007/s10021-012-9611-6

Mathewos, M., Sisay, A., & Berhanu, Y. (2023). Grazing intensity effects on rangeland condition and tree diversity in Afar, northeastern Ethiopia. *Heliyon, 9*(11). https://doi.org/10.1016/j.heliyon.2023.e12345

Maundu, P., Ngugi, G., & Karanja, N. (2005). *Useful trees and shrubs of Kenya*. World Agroforestry Centre.

Mbaya, L. A., & Oruonye, E. D. (2019). An assessment of the impact of livestock grazing on riparian ecosystem along Gongola River, Dadin Kowa Yamaltu/Deba Local Government Area, Gombe State, Nigeria. *Jalingo Journal of Social and Management Science, 1*(2).

Mehra, N., & Swain, J. B. (2024). Assessment of land use land cover change and its effects using artificial neural network-based cellular automation. Journal of Engineering and Applied Science, 71, Article number: 70. https://doi.org/10.1186/s44147-024-00402-0

Méndez-Toribio, M., Zermeño-Hernández, I., & Ibarra-Manríquez, G. (2014). Effect of land use on the structure and diversity of riparian vegetation in the Duero river watershed in Michoacán, Mexico. *Plant Ecology, 215*, 285-296. https://doi.org/10.1007/s11258-014-0302-3

Mestre, L., Toro-Manríquez, M., Soler, R., Huertas-Herrera, A., Martínez-Pastur, G., & Lencinas, M. V. (2017). The influence of canopy-layer composition on understory plant diversity in southern temperate forests. *Forest Ecosystems, 4*, 1-13. https://doi.org/10.1186/s40663-017-0103-8

Ministry of Land and Physical Planning. (2022). *The Lake Naivasha riparian survey report*.

Miserendino, M. L., Casaux, R., Archangelsky, M., Di Prinzio, C. Y., Brand, C., & Kutschker, A. M. (2011). Assessing land-use effects on water quality, in-stream habitat, riparian ecosystems and biodiversity in Patagonian northwest streams. *Science of the Total Environment, 409*(3), 612-624. https://doi.org/10.1016/j.scitotenv.2010.10.034

Momodu, A. S., Siyanbola, W. O., Pelemo, D. A., Obioh, I. B., & Adesina, F. A. (2011). Carbon flow pattern in the forest zones of Nigeria as influenced by land use change. *African Journal of Environmental Science and Technology, 5*(9), 700-709.

Muendo, M. N. (2015). The socio-economic effects of sand harvesting in River Thwake, Kathiani Division, Machakos County, Kenya (Doctoral dissertation, University of Nairobi). http://erepository.uonbi.ac.ke/handle/11295/92932

Mukanoheri, C., Murei, E. K., Obwoyere, G. O., & Makanji, D. L., Olekaikai, N. (2023). Effects of land-use changes on vegetation structure and composition along the Rongai River in Nakuru County, Kenya. *Environmental and Earth Sciences Research Journal, 10*(3), 85-92. https://doi.org/10.18280/eesrj.100301

Muñoz Mazón, M., Klanderud, K., & Sheil, D. (2022). Canopy openness modifies tree seedling distributions along a tropical forest elevation gradient. *Oikos, 2022*(11), e09205. https://doi.org/10.1111/oik.09205

Murray, M. W., Steinman, A. D., Allan, J. D., Bratton, J. F., Johnson, L. B., Ciborowski, J. J. H., & Stow, C. A. (2019). Conceptual frameworks and Great Lakes restoration and protection: A white paper. *National Wildlife Federation, Great Lakes Regional Center: Ann Arbor, MI, USA*.

Musau, E. M., Mukiri, J., Nzogela, B., Paul, B. K., & Notenbaert, A. M. O. (2021). Assessing the environmental impacts of smallholder dairy intensification through improved feeding strategies in the Southern Highlands of Tanzania. Agricultural Systems, 191, 103137. https://doi.org/10.1016/j.agsy.2021.103137

Mweru, K. P. (2002). An assessment of the impact of charcoal making on distribution of some tree species in Kibwezi division; A thesis submitted in partial fulfillment for the award of the degree of Master of Environmental Studies (Science), Kenyatta University.

Nasare, L. I., Opoku, S. A., Amponsah, A., Tom-Dery, D., Asante, W. J., & Baatuuwie, B. N. (2023). Effect of sand mining on riparian landcover transformation in Dallung-Kukou catchment of the White Volta basin, Ghana. *Heliyon, 9*(8). https://doi.org/10.1016/j.heliyon.2023.e12345

National Land Commission. (2018). *Riparian lands conservation and management policy framework*. Renaissance Planning Ltd.

National Research Council. (2002). *Riparian areas: functions and strategies for management*. National Academies Press.

Ndegwa, G. M., Nehren, U., Grüninger, F., Iiyama, M., & Anhuf, D. (2016). Charcoal production through selective logging leads to degradation of dry woodlands: A case study from Mutomo District, Kenya. *Journal of Arid Land, 8*, 618-631. https://doi.org/10.1007/s40333-016-0045-9.

Njue, N., Koech, E., Hitimana, J., & Sirmah, P. (2016). Influence of land use activities on riparian vegetation, soil and water quality: An indicator of biodiversity loss, South West Mau Forest, Kenya. *Open Journal of Forestry, 6*, 373-385. http://dx.doi.org/10.4236/ojf.2016.65030

Okach, D. O., Ondier, J. O., Rambold, G., Tenhunen, J., Huwe, B., Jung, E. Y., & Otieno, D. O. (2019). Interaction of livestock grazing and rainfall manipulation enhances herbaceous species diversity and aboveground biomass in a humid savanna. Journal of Plant Research, 132(3), 345-358. https://doi.org/10.1007/s10265-019-01105-x

Okeyo, A. I., & Omondi, S. O. (2020). Evaluating spatial and temporal changes in land cover in the riparian zone in Sironga wetland in Nyamira County, Kenya between 2009 and 2019. *International Journal of Research and Scientific Innovation, 7*(5), 45-52. https://www.royalliteglobal.com/ijoras/article/view/763

Orimoogunje, O. (2021). Assessing the impacts of land use on riparian vegetation dynamics in Osun State, Nigeria.

Oyoo, E. (2021). Sustainable moderation of sand harvesting effects and conservation on land cover, flora and fauna along the riparian land.

Parikesit, P., & Withaningsih, S. (2024). Vegetation change analysis using Normalized Difference Vegetation Index (NDVI) in Sumedang Regency. In *E3S Web of Conferences* (Vol. 495, p. 02007). EDP Sciences. https://doi.org/10.1051/e3sconf/20249502007

Poonia, K., Kansara, P., & Choudhary, P. (2024). Environmental impacts of sand mining: A comprehensive review. International Journal of Environmental Research and Public Health. https://doi.org/10.3390/ijerph21010001

Poulman, O. A. (2016). Settlement development and its implications on Nairobi River riparian zone, Nairobi City County, Kenya. Kenyatta University.

Project Watershed. (2018). Riparian ecosystems lesson. https://projectwatershed.ca/2018/03/08/riparian-ecosystems-lesson

Ren, Y., Wang, D., & Li, X. (2019). Impacts of human disturbances on riparian herbaceous communities in a Chinese karst river. *Nature Environment and Pollution Technology, 18*(4), 1107-1118.

Schmidt, M., Mölder, A., Schönfelder, E., Engel, F., & Fortmann-Valtink, W. (2016). Charcoal kiln sites, associated landscape attributes and historic forest conditions: DTM-based investigations in Hesse (Germany). *Forest Ecosystems, 3*, 1-16. https://doi.org/10.1186/s40663-016-0071-1

Schulz, K., Guschal, M., Kowarik, I., Silva de Almeida-Cortez, J., Valadares de Sá Barreto Sampaio, E., & Cierjacks, A. (2019). Grazing reduces plant species diversity of Caatinga dry forests in northeastern Brazil. *Applied Vegetation Science, 22*(2), 348-359. https://doi.org/10.1111/avsc.12434

Singh, R., Tiwari, A. K., & Singh, G. S. (2021). Managing riparian zones for river health improvement: An integrated approach. *Landscape and Ecological Engineering, 17*, 195-223. https://doi.org/10.1007/s11355-020-00421-1

Smith, A. G., Newingham, B. A., Hudak, A. T., & Bright, B. C. (2019). Got shrubs? Precipitation mediates long-term shrub and introduced grass dynamics in chaparral communities after fire. *Fire Ecology, 15*, 1-16. https://doi.org/10.1186/s42408-019-0034-5

Smith, R. W., Statham, M., Norton, T. W., Rawnsley, R. P., Statham, H. L., Gracie, A. J., & Donaghy, D. J. (2012). Effects of wildlife grazing on the production, ground cover and plant species composition of an established perennial pasture in the Midlands region, Tasmania. *Wildlife Research, 39*(2), 123-136. https://doi.org/10.1071/WR11120

Sola, P., & Cerutti, P. O. (2021). Kenya has been trying to regulate the charcoal sector: Why it’s not working. The Conversation. Retrieved from https://theconversation.com/kenya-has-been-trying-to-regulate-the-charcoal-sector-why-its-not-working-154383

Spicer, M. E., Radhamoni, H. V. N., Duguid, M. C., Queenborough, S. A., & Comita, L. S. (2022). Herbaceous plant diversity in forest ecosystems: Patterns, mechanisms, and threats. *Plant Ecology, 223*(2), 117-129. https://doi.org/10.1007/s11258-022-01200-5

Stephan, J., & Issa, D. (2017). Anthropogenic impacts on riparian trees and shrubs in an eastern Mediterranean stream. *Plant Sociology, 54*, 43-50. https://doi.org/10.7338/pls2017541/05.

Stephan, K., Miller, M., & Dickinson, M. B. (2010). First-Order Fire Effects on Herbs and Shrubs: Present Knowledge and Process Modeling Needs. Fire Ecology, 6(1), 95-114. https://doi.org/10.4996/fireecology.0601095

Sunil, C., Somashekar, R. K., & Nagaraja, B. C. (2011). Impact of anthropogenic disturbances on riparian forest ecology and ecosystem services in Southern India. *International Journal of Biodiversity Science, Ecosystem Services & Management, 7*(4), 273-282. https://doi.org/10.1080/21513732.2011.621737

Török, P., Lindborg, R., Eldridge, D., & Pakeman, R. (2024). Grazing effects on vegetation: Biodiversity, management, and restoration. *Applied Vegetation Science, 27*(3), e12794. https://doi.org/10.1111/avsc.12794

Twesigye, C. K., Onywere, S. M., Getenga, Z. M., Mwakalila, S. S., & Nakiranda, J. K. (2011). The impact of land use activities on vegetation cover and water quality in the Lake Victoria watershed. *The Open Environmental Engineering Journal, 4*(1).

Vachova, P., Vach, M., Skalicky, M., Walmsley, A., Berka, M., Kraus, K., … & Mudrak, O. (2021). Reclaimed mine sites: Forests and plant diversity. *Diversity, 14*(1), 13. https://doi.org/10.3390/d14010013

Wadud, A. I., Bugalho, M. N., & Vaz, P. G. (2024). Meta-analysis of livestock effects on tree regeneration in oak agroforestry systems. *Journal of Environmental Management, 364*, 121498. https://doi.org/10.1016/j.jenvman.2023.121498

Wang, H., Zhang, Y., Li, X., & Liu, J. (2024). Substantial increase in China's manufactured sand supply since 2010. Nature Geoscience. https://doi.org/10.1038/s41561-024-01023-4

Wyman, S., Bailey, D., Borman, M., Cote, S., Eisner, J., Elmore, W., & Winward, A. (2006). Riparian area management: Grazing management processes and strategies for riparian-wetland areas (Technical Reference 1737–20. BLM/ST/ST-06/002+ 1737 (pp. 105). Denver, CO: US). Bureau of Land Management, National Science and Technology Center: Department of the Interior. https://www.blm.gov/documents/national-office/blm-library/technical-reference/grazing-management-processes

Xu, M. Y., Xie, F., & Wang, K. (2014). Response of vegetation and soil carbon and nitrogen storage to grazing intensity in semi-arid grasslands in the agro-pastoral zone of northern China. *PLoS One, 9*(5), e96604. https://doi.org/10.1371/journal.pone.0096604

Yangouliba, G. I., Zoungrana, B. J. B., Hackman, K. O., Koch, H., Liersch, S., Sintondji, L. O., & Koffi, B. (2023). Modelling past and future land use and land cover dynamics in the Nakambe River Basin, West Africa. Modeling Earth Systems and Environment, 9(2), 1651-1667.

Zhang, L., Liu, W., & Ma, Y. (2020). Effects of meteorology and soil on the herb species diversity in plantations in a reclamation area of coal mine after 6 years. Journal of Environmental Management, 264, 110455. https://doi.org/10.1016/j.jenvman.2020.110455

Zhang, M., Delgado-Baquerizo, M., Li, G., Isbell, F., Wang, Y., Hautier, Y., & Wang, L. (2023). Experimental impacts of grazing on grassland biodiversity and function are explained by aridity. *Nature Communications, 14*(1), 5040. https://doi.org/10.1038/s41467-023-50640-5

Zhao, Y., Zhang, P., Hu, Y., & Huang, L. (2015). Effects of Re-vegetation on Herbaceous Species Composition and Biological Soil Crusts Development in a Coal Mine Dumping Site. Environmental Management, 57(2), 298-307. https://doi.org/10.1007/s00267-015-0607-91

Zogaris, S., Chatzinikolaou, Y., & Dimopoulos, P. (2009). Assessing environmental degradation of montane riparian zones in Greece. *Journal of Environmental Biology, 30*(5), 719.

APPENDICES

Appendix I: Species Checklist

S/No.	LOCAL NAME	SCIENTIFIC NAME	FAMILY
1	Chonge	*Acanthospermum hispidum*	Asteraceae
2	Ciagaconde	*Boerhavia erecta*	Nyctaginaceae
3	Ciakamomora	*Tridax procumbens*	Asteraceae
4	Gakenakena	*Indigofera tinctoria*	Fabaceae
5	Gakumukumu	*Dobera glabra*	Salvadoraceae
6	Gikuri	*Ocimum kilimandscharium*	Lamiaceae
7	Kariaria	*Euphorbia hirta*	Euphorbiaceae
8	Kaya na Mwana	*Echino colona*	Poaceae
9	Kirella	*Momordica charantia*	Cucurbitaceae
10	Mubobua	*Balanites aegyptiaca*	Zygophyllaceae
11	Mucunku	*Trianthema portulacastrum*	Aizoaceae
12	Mugaa	*Acacia tortilis*	Fabaceae
13	Muganjoganjo	*Senna occidentalis*	Fabaceae
14	Mugenda na Akuru	*Senna didymobotrya*	Fabaceae
15	Mugookora	*Lawsonia inermis*	Lythraceae
16	Mugugu	*Stercullia africana*	Sterculiaceae
17	Mugunga	*Acacia elatior*	Fabaceae
18	Muhute	*Aspilia mossambicensis*	Asteraceae
19	Mukurungu	*Erythrina melanacantha*	Fabaceae
20	Mukururu	*Flueggea virosa*	Phyllanthaceae
21	Mukuyu	*Ficus sycomorus*	Moraceae
22	Mungoora	*Acacia senegal*	Fabaceae
23	Muntunka	*Pyrostria phyllanthoidea*	Rubiaceae
24	Munyaritha	*Entada leptostachys*	Fabaceae
25	Muragwa	*Grewia trichocarpa*	Malvaceae
26	Muramata	*Pupalia lappacea*	Amaranthaceae
27	Muramba	*Adansonia digitata*	Malvaceae
28	Murangare	*Acacia ataxacantha*	Fabaceae
29	Muratha iiga	*Osyris lanceolata*	Santalaceae
30	Murema ngige	*Dodonaea angustifola*	Sapindaceae
31	Murigica	*Combretum micrabthum*	Combretaceae
32	Murundu	*Sida Ovate*	Malvaceae
33	Muthana	*Maerua decumbens*	Capparaceae
34	Muthigiu	*Rhus natalensis*	Anacardiaceae
35	Mutherema	*Lannea triphylla*	Anacardiaceae
36	Muthigira	*Acacia mellifera*	Fabaceae
37	Muthithi	*Tamarindus indica*	Fabaceae
38	Muthurii	*Euphorbia scheffleri*	Euphorbiaceae
39	Muthwana	*Berchemia discolour*	Ulmaceae
40	Mutinda	*Albizia amara*	Fabaceae
41	Mutoro	*Terminalia pruniodes*	Combretaceae

42	Mware	*Maerua endlichii*	Capparaceae
43	Mwariki wa Nkoma	*Ricinus communis*	Euphorbiaceae
44	Mwegere	*Hibiscus micranthus*	Malvaceae
45	Mwemba	*Acacia nilotica*	Fabaceae
46	Mwinya Nthanga	*Adenia Venetata*	Passifloraceae
47	Ndago	*Cyperus rotundifolia*	Cyperaceae
48	Ndundu	*Triumfetta rhomboidea*	Malvaceae
49	Ngwata ngoco	*Tragus berteronianus*	Poaceae
50	Nkengeiya	*Commelina vulgaris*	Commelinaceae
51	Nkuno	*Dracaena dawei*	Asparagaceae
52	Ntaka ya nguuo	*Cucumis anguria*	Cucurbitaceae
53	Nthande	*Justicia odora*	Acanthaceae
54	Nthare	*Achyranthes aspera*	Amaranthaceae
55	Nthunju	*Thunbergia guerkeana*	Acanthaceae
56	Mukuu	*Commiphora madagascariensis*	Burseraceae
57	Ngaatu	*Carex flacea*	Cyperaceae
58	Muthegeyu	*Commiphora baluensis*	Burseraceae
59	Kirundu kia Muthitu	*unkown*	unkown
60	Mparia	*unkown*	unkown
61	Kamutu	*unkown*	unkown
62	Rugoya	*unkown*	unkown
63	unkown	*Satureja hortensis*	Lamiaceae
64	unkown	*Hibiscus cannabinus*	Malvaceae
65	unkown	*Walvastrum coromandelianum*	Asteraceae
66	Kirara	*Hyphaene compressa*	Arecaceae

Appendix II: Bond

Plate 1: Cattle drinking bay **Plate 2: Sand harvesting site**

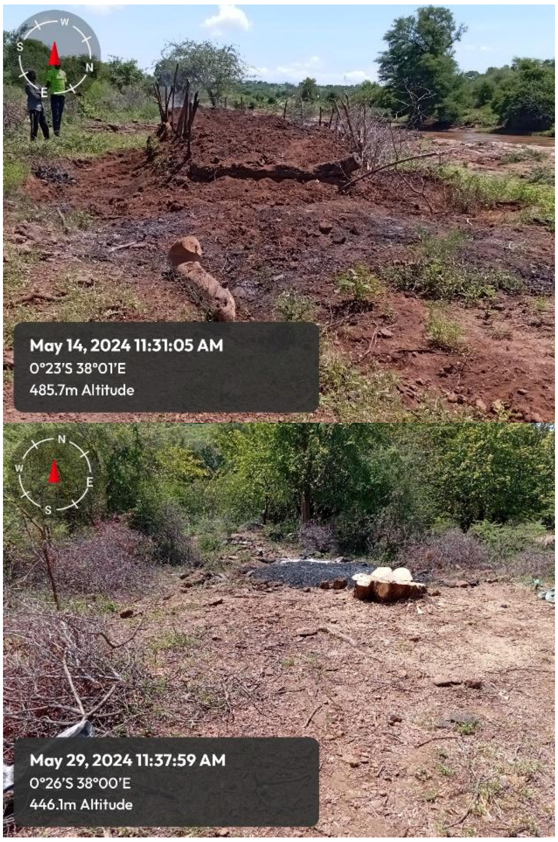

Plate 3: Active charcoal burning sites

Appendix III: Introductory Letter

CHUKA UNIVERSITY

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OFFICE OF THE DIRECTOR

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REF: NM22/58089/22 **28th March, 2024**

Director
National Commission for Science Technology and Innovation
Off Waiyaki Way, Upper Kabete
P O Box 30623, 00100
Nairobi.

Dear Sir / Madam,

DENIS KIBAARA MUGAMBI

The above-named person is a *bona fide* student of Chuka University pursuing MSC in Natural Resource Management proposal titled: **Influence of Selected Anthropogenic Disturbances on the Riparian Vegetation Diversity of River Kathita, Tharaka Nithi County, Kenya.**

Mr. Mugambi has defended at the Faculty level and is now expected to conduct research. Any assistance accorded will be highly appreciated.

Yours sincerely,

CHUKA UNIVERSITY 27 MAR 2024 BOARD OF POSTGRADUATE STUDIES AND RESEARCH

Prof. Moses Muraya, Ph.D.

DIRECTOR
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Appendix IV: Ethics Review

CHUKA UNIVERSITY

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CHUKA UNIVERSITY INSTITUTIONAL ETHICS REVIEW COMMITTEE

Telephones: 020-2310512/18 **P. O. Box 109-60400, Chuka**

Direct Line: 0772894438 **Email: info@chuka.ac.ke,** **Website: www.chuka.ac.ke**

19th March, 2024

REF: CUIERC/ NACOSTI/476

TO: **Dennis Kibaara Mugambi**

RE: Influence of Selected Anthropogenic Disturbances on the Riparian Vegetation Diversity of River Kathita, Tharaka Nithi County, Kenya

This is to inform you that *Chuka University IERC* has reviewed and approved your above research proposal. Your application approval number is *NACOSTI/NBC/AC-0812.* The approval period is 19th March, 2024 – 19th March, 2025.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used

ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by *Chuka University IERC*.

iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to *Chuka University IERC* within 72 hours of notification

iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to *Chuka University IERC* within 72 hours

v. Clearance for export of biological specimens must be obtained from relevant institutions.

vi. 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.

vii. Submission of an executive summary report within 90 days upon completion of the study to *Chuka University IERC*.

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely

Dr. Benjamin Kanga
SECRETARY

Appendix V: Research Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Ref No: **437601**

Date of Issue: **03/May/2024**

RESEARCH LICENSE

This is to Certify that Mr.. Denis Kibaara Mugambi of Chuka University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Tharaka-Nithi on the topic: INFLUENCE OF SELECTED ANTHROPOGENIC DISTURBANCES ON THE RIPARIAN VEGETATION DIVERSITY OF RIVER KATHITA, THARAKA-NITHI COUNTY, KENYA for the period ending : 03/May/2025.

License No: **NACOSTI/P/24/34650**

437601

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

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See overleaf for conditions