RIVER SAND HARVESTING AND CHALLENGES TO RIPARIAN CONSERVATION STRATEGIES IN TWO RIVERS IN KAKAMEGA COUNTY, KENYA

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A thesis submitted to the School of Natural Sciences in partial fulfillment of the requirements for the degree of Master of Science in Environmental Science to Masinde Muliro University of Science and Technology

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DECLARATION

This research thesis is my original work prepared with no other than the indicated sources and support and has not been presented elsewhere for a degree or any other award.

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DEDICATION

I dedicate this to my late father, Charles Lwanga, Augustine, and my son Charles Muuo.

Lessons from them have made me who I am today.

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ABSTRACT

Sand harvesting has potential consequences on the river ecosystem. This study sought if sand harvesting impacts the riverine ecosystem and consequently, riparian conservation on two rivers in Kakamega County. Specifically, the study sought to map the distribution of sand harvesting on two rivers in the County; determine the effects of sand harvesting on river water quality and soil physico-chemical properties of the riparian areas; quantify the impacts of sand harvesting on floral and soil macro-fauna diversity within the riverine ecosystem; and assess the mitigative strategies and challenges of Water Resources Users Associations (WRUAs) and river system conservation. The study combined quasi experimental and qualitative research design. There were five quasi experimental sites and five control sites that were used, in three replicates in the months of June, September and December 2020, to undertake the study. Distribution of sand harvesting activities was assessed by a reconnaissance survey on the rivers. Areas identified were mapped using a GPS. Turbidity was determined in-situ by a turbidimeter. Riverbank erosion was assessed by satellite imageries. 500ml water samples were collected and taken for analysis of total suspended sediments (TSS) in the Water Resources Authority (WRA) Regional laboratory in Kakamega. Soil moisture content, nitrogen (N), phosphorus (P), pH, organic carbon (OC) and textural class were determined by collecting a 500g composite soil sample and taken to Kenya Agricultural and Livestock Research Organization (KALRO) Kakamega Laboratory for analysis. A total of thirty 10mx10m quadrats were established randomly on either side of the riverbank in which trees, saplings, herbs and soil macro-fauna were sampled. 105 questionnaires, interviews and Focused Group Discussions (FGDs) were used to assess mitigative strategies and challenges of conservation by WRUAs. Questionnaires were tested for validity and reliability by pre-testing which gave a Cronbach alpha index of 0.717. Turbidity, TSS, soil moisture, N, P, OC and pH were analysed using IBM SPSS Statistics Version 22. Shannon-Wiener diversity index was used to determine floral and soil macro-fauna diversity. Data from the questionnaire was entered into SPSS Statistics and analysed. A spatial map of 18 sand harvesting hotspots identified was developed using ArcGIS. Sand harvesting significantly affected changes in river width ($p = 0.008$), TSS in rivers ($p = 0.001$), turbidity in rivers ($p = 0.006$), total nitrogen content in the riparian area ($p = 0.036$), soil organic carbon content ($p = 0.003$) and soil pH ($p = 0.001$), as there was significant difference between the control and the sand harvesting sites for these parameters. However, it did not significantly affect riparian soil phosphorus content ($p = 0.810$), soil percent moisture content ($p = 0.309$) and soil textural classes ($p = 1.000$). Also, sand harvesting significantly affected tree abundance in the riparian area ($p = 0.048$), but there was no correlation between the tree species diversity index and sand harvesting activities ($r=.125$); significantly affected sapling abundance ($p = 0.036$) leading to invasive species like *Psidium* being most abundant, but had no correlation with the sapling species diversity index ($r=-.284$); significantly affected herbaceous species abundance ($p = 0.042$) as well as had negative correlation with herbaceous species diversity index ($r= -.608$); and significantly affected soil macrofauna species abundance ($p = 0.049$) and had no correlation with soil macrofauna species diversity index ($r= -.317$). Most applied river system conservation strategy by WRUAs was planting of trees (83%, n=87). About 54% (n=57) WRUAs understood their role and training was proposed as one of the measures to improve their confidence in riverine ecosystem conservation concepts, as there lacked a recognized institution for consulting on sand harvesting issues. Hence, it is evident river Shiatsala and Lusumu are facing significant pressure from sand harvesting.

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OPERATIONAL DEFINITION OF TERMS AND CONCEPTS

Mitigation	Actions taken to reverse or stop the degradation of the river ecosystem in the long term.
Mitigative Strategies	Framework for identifying, prioritizing, and implementing measures that lower the risk of riverine ecosystem degradation.
River Ecosystem	Waters flowing from the land and all the living (micro-organisms, plants, and animals) and non-living (physical and chemical) interactions of the flowing waters.
Satellite Imagery	Images of the Earth and features in it, obtained from satellites managed either by governments or businesses.
Soil Auger	Drilling device used for collecting soil samples.
Soil Macro-fauna	Visible soil organisms, of sizes larger than 2mm, including earthworms, ants, termites, millipedes, and beetles, among others.
Turbidimeter	Device used to measure and compare the turbidity of river waters.

ABBREVIATIONS AND ACRONYMS

CBO	Community-Based Organization
DBH	Diameter at Breast Height
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
KALRO	Kenya Agricultural and Livestock Research Organization
KEBS	Kenya Bureau of Standards
MMUST	Masinde Muliro University of Science and Technology
NTU	Nephelometric Turbidity Unit
SOM	Soil Organic Matter
SPSS	Statistical Package for the Social Sciences
UNEP	United Nations Environmental Programme
WRA	Water Resources Authority
WRUAs	Water Resources Users Associations

CHAPTER ONE

INTRODUCTION

1.1 Background Information

Sand is one of the extractives mined as a raw material for the construction sector. Sources of sand include land and water and sand-harvesting is both on small and large-scale, depending on the tools used. Simple types of equipment like spades, wheelbarrows, and hoes are used in small-scale sand harvesting, while harvesting on a large scale involves the use of machinery (Musa, 2009). Sand harvested from rivers is referred to as river sand and is the focus of this study.

Globally, mineral aggregates are the most extracted substances. Mineral aggregates include river sand and gravel. Given that Africa has the world's significant mineral reserves (Attiogbe & Nkansah, 2017), Kenya seeks to enhance the contribution of the mining sector to the country's gross domestic product (GDP) (Barreto et al., 2018). In 2015, this share was 0.8% in 2015, and the government aims at 10% by 2030 through the Mining and Minerals Policy, 2016, National Sand Harvesting Guidelines, 2007 and a new Mining Act (Kareithi, 2014). These legislations are to guide the sustainable mining of minerals, including extractives such as river sand.

It is projected that between 32 and 50 billion tonnes of river sand and gravel are harvested worldwide annually (UNEP, 2014). These are the resources that the infrastructural developments in all urban centres have depended on since Roman times. River sand and gravel are also used for reclaiming land. Given the current extensive availability of river sand deposits and the low-cost techniques for harvesting, transport is usually the limiting expense, necessitating most sources of river sand to be situated near marketplaces and urban areas (Koehnken & Rintoul, 2018).

Adgolign & Rao (2014) in their study on sustainable water resources development, assert that the analysis of remotely sensed data in GIS software is significant in obtaining and analyzing environmental data. Hence, GIS software will be used in this study, to assess and map the distribution of sand harvesting activities as proof of sand harvesting activities. Besides the rampant distribution of river sand harvesting activities, there are also concerns about the possibility of the river sand harvesting activities degrading the river water quality and riverine soils. Attiogbe & Nkansah (2017) noted that several surface water bodies that provide water for the mining communities had been damaged, contaminated, or dried up. Contamination is one way of degrading the quality of the river water as well as reducing the productivity of land (Menta, 2012). The productivity, and fertility of soils are linked to the amount of vegetation cover that the riparian area has (Lawal, 2011). As a remedy for rehabilitation of degraded land and protection of the integrity of riverine ecosystems, vegetation is usually planted to remove these contaminants and improve the productivity of the soils (Said, 2009).

Trees can grow in severe climatic conditions, conserve the soil, and provide organic material by their crown and roots. Organic matter from trees and other vegetation provides soil nutrients such as phosphorus, nitrogen, and sulphur and maintain the soil's biological, chemical and physical properties (Asiamah et al., 2001). Trees are therefore the preferred choice for rehabilitating degraded lands (Said, 2009). Soil conditions on the other hand can be degraded by human activities such as sand harvesting, leading to a simplified and lowered abundance of organisms and plant communities (Menta, 2012). Most WRUAs have been, as a result, been, planting vegetation such as trees to rehabilitate degraded riverine ecosystems within their areas of jurisdiction.

Water Resource Users Associations (WRUAs) are viewed as the locally responsible associations that ensure water resources are sustainably used at the grassroots levels. Diverse river basin conservation activities are some of their key roles. Assessing the activities done by WRUAs within the rivers selected for this study will help determine whether WRUAs understand their role in conserving river catchments from unsustainable river sand harvesting practices.

River sand harvesting activities, whether done skillfully or casually, affects water (Attiogbe & Nkansah, 2017). River sand harvesting is likely to have long-term impact on the quality of the adjacent surface water when the sand harvesting activities have long ceased (Gardner et al., 2015). The search for river sand, whether in large or small-scale, pose a potential a threat to the water resources and the Lusumu and Shiatsala rivers, especially in Kakamega County where there is limited and scant information, despite the rampant river sand harvesting activities. It is against this background that this study assessed the effects of river sand harvesting on riverine ecosystem along two rivers with extensive sand mining activities in Kakamega County.

1.2 Statement of the Problem

Efforts towards sustainable exploitation of riverine ecosystems face several challenges, including water pollution from sedimentation, loss of biodiversity, and water catchment destruction. Unsustainable sand harvesting practices caused by high demand from the construction and housing sector pose serious environmental problems to these ecosystems. The widespread distribution of river sand-harvesting activities continues to degrade river water quality through resuspension of solids and increased sedimentation in the river channel. Attiogbe & Nkansah (2017) and Menta (2012) reported damaged, contamination or drying-up of waterbodies that provide water to communities near mining activities. Sand-harvesting also modifies the physico-chemical composition of river water by influencing chemical parameters including turbidity, TSS, magnesium and iron (Attiogbe & Nkansah, 2017), posing risks to aquatic and human life (Nilsson & Svedmark, 2002).

The primary impacts of river sand harvesting on soil physico chemical properties and riparian land biodiversity are the direct removal of vegetation, which alters the rates of nitrogen cycling in the soil hence the productivity of the ecosystem (Koehnken & Rintoul, 2018). At the same time, sand harvesters degrade the riparian areas and river system, yet do not rehabilitate them, thus dwindling the mitigative efforts being applied by the respective Water Resources Users Association. In Kenya, there is scant information on sand harvesting activities and a lack of or inadequate policy frameworks and enforcement. Due to insufficient enforcement of the policy framework, there is widespread unregulated illegal sand harvesting activities that seek to meet the high demands for sand in the construction industry. And now there are 'Sand Wars' – a widely reported phenomenon in many countries, including Kenya. Sand wars involve highly organized groups or 'mafias' operating with the involvement of regulators and protection from prosecution (Koehnken & Rintoul, 2018). The immediate impacts are on the provision of clean drinking water, river bank erosion, degradation and destruction of catchment areas and the deterioration of water quality. This calls for an urgent need to rethink how to manage such threatened riverine ecosystems. While researchers can determine how constructions such as buildings and roads affect their surroundings, the impacts of sand and gravel harvesting to build these structures have received minimal attention. There is clearly, inadequate research that quantifies the physical alterations that accompany sand harvesting and how they are linked to ecological impacts (Koehnken & Rintoul, 2018). In Kakamega County, mining is widespread. Data on its effects on water and the surrounding environment is scant. The Kakamega County Integrated Development Plan (KCIDP) (2018), documents various mining activities. For instance, every year, some 278,000 tons of sand, 592,941 tons of murram, 148,920 tons of hardcore, and 51,968 tons of ballast are mined. These activities are livelihoods that support some 80,271 people. The health of rivers such as Shiatsala, Yala and Isiukhu have been degraded by the extensive sand harvesting activities. This study seeks to assess and quantify the impacts of river sand harvesting activities on River Shiastala and River Lusumu in Kakamega County.

1.3 Justification of the Study

Riparian zones hold key and diverse biodiversity worldwide. However, floodplains and rivers are already facing significant pressure from river sand harvesting. The pressure is due to the development of urban centres. Moreover, as the development of modern facilities continue in urban centres, the demand for river sand is expected to grow. The resultant impacts from river sand harvesting are a cause for concern even by the UN (UNEP, 2014; Koehnken et l., 2020; Gavriletea, 2017; Aliu et al., 2022). World Wide nature Fund (WWF) acknowledges that there is a lack of information on rivers in developing countries and calls for the need to carry out further scientific research into river sand harvesting in waterways, including long-term studies to understand how river ecosystems respond to both climate and human-related changes over the long-term. In Kenya, for instance, the building and construction industry has intensified demand for river sand to meet its ever-rising needs, due to the rapidly increasing populations in urban areas (Mutisya, 2006). Besides, rivers in which vulnerable or endangered species with known habitat needs exist would provide a suitable primary focus for research (Koehnken

& Rintoul, 2018). It is worth noting that natural river systems can play a role in adapting to water shortage and flooding that result from climate change, through the water regulation services they provide (Palmer et al., 2008). In Kakamega, there were concerns about losing indigenous flora, including medicinal plants. Some of this biodiversity are restricted to riverine ecosystems (Zhang et al., 2022; Lwanga et al., 2022) making them a conservation priority under climate change (Zhang et al., 2022). Analyzing plant biodiversity along river banks will inform the economic trade-offs of species that are endangered and are perhaps growing along these river banks. Hence, the study will help conserve and increase biodiversity as outlined in the Convention of Biological Diversity (CBD). Despite the economic potential of river sand harvesting and its capacity as a source of income and employment for the youths and women in rural areas, its effect on the river ecosystem is not well documented. Previous studies on river sand harvesting over the years tended to concentrate on management and regulation, stream habitat and fish communities, and water supply and quality (Koehnken & Rintoul, 2018; Nzula et al., 2018) and socio-economic aspects (Nthambi & Orodho, 2015). Attempts by Jose & Venkatesh (2014) to study rivers with sand harvesting activities focused on physico-chemical characteristics and not as an entire ecosystem despite river ecosystems being a significant component of watersheds. Kori & Mathada (2012) and Bingo et al. (2016) attempted to study the effect of river sand harvesting on river ecosystems and riparian land. However, the researchers based their studies on the qualitative approach and survey, respectively, as the only methodology of the study. In this research, quasi experimental designs are included. There have been no studies or policies in Kakamega County on river sand harvesting and riverine ecosystem. It is clear, that the sustainability of the widespread river sand harvesting activities within Kakamega that convert existing river ecosystems to active river sand harvesting sites has to be questioned in the long term. The information from this study will be useful to artisanal river sand harvesters who depend on the river as a provider for ecosystem services, as well as to the authorities responsible for promoting sustainable river sand harvesting activities as it provides a mechanism to guide sustainable sand harvesting and conservation of the riparian zones. The findings will also be key in helping develop or improve riparian management plan(s) and to the County government of Kakamega as it added inputs to the Kakamega County Natural Resources Management, Act 2022. The study will as well create knowledge that other researchers will subsequently benefit from in addressing river sand harvesting and the river ecosystem gap as well as open door for further studies.

1.4 Objectives

1.4.1 General Objective

The main objective of this study was to investigate how river sand harvesting impacts riverine ecosystems and challenges facing riparian conservation in Kakamega County, Kenya.

1.4.2 Specific Objectives

The specific objectives of this study were to:

1. Assess and map the distribution of sand harvesting activities on River Lusumu and River Shiatsala which have intensive sand harvesting activities.
2. Determine the effects of river sand harvesting on river water quality and soil physicochemical properties of the adjacent areas.
3. Quantify the impacts of river sand harvesting on floral and soil macro-fauna biodiversity within the riverine ecosystem.

4. Assess the mitigative strategies and challenges faced by the Water Resources Users Association to river sand harvesting and riverine ecosystem conservation.

1.5 Research Questions

1. What is the spatial distribution and abundance of river sand harvesting activities along rivers?
2. How does river sand harvesting affect river water quality and soil physico-chemical properties?
3. Does river sand harvesting affect local floral biodiversity and soil macro-fauna?
4. What mitigative strategies and challenges are faced by WRUAs to conserve river systems?

1.6 Hypotheses

1. River sand harvesting does affect river water quality and soil physicochemical properties of the adjacent areas.
2. River sand harvesting has an impact on floral and soil macro-fauna biodiversity within the riverine ecosystem.

1.7 Limitations of the Study

Limited cost and time affected tests on riverbank erosion, which would have provided current data on erosion rates. Limited time affected analyses of suspended sediments, soil physico-chemical properties and biodiversity. Finally, the analysis of soil macro-fauna was affected by variability in time and space. The reason was that though macro-fauna interacts with the soil, this depends on the organism’s life phase spent in the ground and varies in different taxa.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides an overview of previous research on river sand harvesting and river ecosystems. It reviews previous work on mapping the distribution of river sand harvesting activities. Earlier studies on the effects of river sand harvesting on river quality, soil physicochemical properties, floral biodiversity, and soil macro-fauna are reviewed. Studies on the challenges and mitigative strategies of the Water Resources Users Association to river sand harvesting and river system conservation are discussed. Knowledge of past research will expose knowledge gaps that warrant investigation.

2.2 Assessment and Spatial Distribution of Sand Harvesting Activities

Tiny silica grains form sand particles. On the other hand, weather effects do decompose sandstones leading to the formation of silica grains that end up forming the sand (Pettijohn et al., 2012). Natural sources of sand include pit sand obtained from pits in the soil; river sand obtained from river bank and beds; and sea sand obtained from seashores (Susmita, 2020). However, of the three sources, river sand is the preferred choice.

Many reasons make rivers a preferred source of sand. The reasons include (i) low cost of transport due to towns tending to be closer to rivers; (ii) eliminated expensive steps of harvesting, pounding and sorting as rocks are ground into gravels and river sand by the energy in the river; plus (iii) the resilient and definite shape of river sand which is desired for building (Koehnken & Rintoul, 2018). As noted, therefore, river sand deposits provide the benefit of being naturally produced and inexpensively sourced as a ready construction raw material.

As a result, activities of river sand harvesting have mushroomed, especially in developing countries. Mushrooming of these activities is characterized by over-harvesting to meet the demand for river sand. Riverine ecosystem health is jeopardized by over-harvesting of river sand (Azamathulla et al., 2010; Jayanthu, 2013; Ghani & Azamathulla, 2014). In Malaysia, for instance, the Department of Irrigation and Drainage of Malaysia (DID, 2009) realized that river sand demand had increased due to rapid development. Therefore in response, Malaysia developed River Sand Harvesting Management Guidelines in 2009 (DID, 2009). In Kenya as well, the rate of river sand harvesting has become so alarming. National Enviromental Management Authority (NEMA) had to develop National Sand Harvesting Guidelines in 2007 (Mwangi, 2007). While many countries have laws that regulate river sand harvesting (Sonak et al., 2006; Mwangi, 2007; Peckenham et al., 2009), increasing demand from the industry and construction sector has turned river sand harvesting into a severe ecological problem (Lawal, 2011).

For a long time, there have been desires in Kenya to devolve developmental activities to the grassroots level. Therefore, following the enaction of the 2010 Constitution, County Governments were created (GoK, 2010). With devolution, there has been an increase in infrastructural development, with a considerable rise in river sand demand. Given the lack of adequate monitoring programs in Kenya, rapid river sand harvesting activities may destroy the riverine ecosystem (Bingo et al., 2016). Also, the fact that the construction industry in developing countries focuses mainly on river sand as raw material which makes river sand depletion possible.

River sand, as a resource, is naturally and continually being made. However, its rate of usage is higher than the rate at which it is replaced (Bingo et al., 2016). Various media articles have stressed that developing countries are faced with diminishing river sand availability despite the intensified demand for the river sand. However, Koehnken & Rintoul (2018) postulated that the same could not be said of scientific studies because there are relatively few researchers that have studied river sand harvesting and its effects. The Kakamega County Integrated Development Plan (KCIDP) (2018), documents that approximately 278,000 tons of sand, both from land and river, is harvested every year. This is done in small scale using simple tools.

2.3 Effect of River sand Harvesting on River Water Quality and Soil Physico-Chemical Properties

2.3.1 Effect of River Sand Harvesting on River Water Quality

2.3.1.1 Effect of River Sand Harvesting on Riverbank Erosion

River sand harvesting activities degrade the quality of the water in rivers, both in the short and long term. The river's physical characteristics like river flow and state of the riverbank are also changed. For instance, the river flow may either decrease or change, and the riverbank may be eroded or collapse (Lusiagustin & Kusratmoko, 2017). A case example is the deepening of the Metsimotlhabe and Ditlhakane riverbanks (Madyise & Moja, 2013). Also, the proximity of river sand harvesting sites can lead to subsidence and collapse of riverbanks that may cause accidents and the death of manual loaders. The reason for these changes is attributed to continual and intensified riverbed sand harvesting (Padmalal & Maya, 2014).

Vegetation plays a crucial role in river ecosystem health. It was discovered by countries such as Malaysia that excessive energy is left in the rivers if the riverbed sand is harvested in large quantities. As a result, there are two consequences. (i) if the riverbank has protection from engineering works and vegetation, the riverbank will not be affected.

However, only the riverbed may be eroded and deepened, and, (ii) if the riverbanks are not protected by vegetation, the riverbank will be eroded, making it collapse and possibly cause riparian land loss (SECDM, 2000).

2.3.1.2 Effect of River Sand Harvesting on Turbidity and Total Suspended Sediments

River sand harvesting can be done either at the riverbank or in the riverbed. Studies by Lawal (2011) revealed that riverbed sand harvesting re-suspends sediments in the river leading to temporary increased turbidity in the river which significantly affects the living organisms found in the river (Madyise & Moja, 2013). The bed load and suspended sediments transported along with other organic material in the river channel therefore determine the characteristics of the river ecosystem (Balasubramanian, 2016).

Presence of suspended sediments reduce penetration of sunlight that is used by aquatic plants for photosynthesis. River sand harvesting has an impact on total suspended sediments in the river. Madyise & Moja (2013) postulate that riverbed harvesting of sand continuously increases sediments suspension. Teo et al. (2017) similarly noted that continuous river sand harvesting might lead to downstream sedimentation.

2.3.2 Effect of River Sand Harvesting on Soil Physico-Chemical Properties

Soil physical and chemical properties can be modified through various forms of disturbances. Human activities such as river sand harvesting are one form of soil disturbance. Activities of river sand harvesting, including transport and preparation of the site affect content of soil moisture. Moisture content in the soil is as a result of soil being able to retain and transmit water. Ayuke (2010) found that the number of soil particles that are water-stable correlates negatively with sand content in the soil. Therefore, high sand content will directly affect the environment and plant productivity.

The nutrient content of soil includes nitrogen and phosphorus. Nitrogen is one of the soil resource quality parameters. The amount of soil nitrogen in the soil enables natural ecosystems to decompose and release nutrients. Nitrogen use efficiency of crops has also been known to be enhanced by soil fauna, and when high-grade vegetation remains is added to the soil (Ayuke, 2010). The primary impacts of river sand harvesting are the direct removal of vegetation, which alters the rates of nitrogen cycling hence the productivity of the ecosystem (Koehnken & Rintoul, 2018). Also, river sand residues left on the soil alters soil profiles and the soil nutrient concentrations. Sand harvesting activities have also been noted to reduce the ability of riparian soil to remove nitrogen (Qin et al., 2020) due to absence of sufficient mineralizable organic nitrogen and reduced mineralization rate (Saviour & Stalin, 2012).

Sand harvesting also impacts soil organic carbon. Qin et al. (2020) in their study found out that the soil organic carbon density of the sand mining areas was lower than that of the riparian forestlands. Also, compared with those of the riparian forestland, the sand mining area exhibited a dramatic reduction in the CO_2^-fixed gene abundances (cbbL) and a significant change in the composition of cbbL-containing bacteria. As a result, riparian land productivity long-term is impacted (Menta, 2012). Hence the overall river ecosystem health is affected.

River sand has high silica content (Koehnken & Rintoul, 2018), a substance with a neutral pH of 7. Soil pH has an enormous influence on the distribution of soil macro-fauna. For instance, Menta (2012) found that the epigeic earthworms' activities were not affected by low pH while the activity of endogeic worms was restricted when they were exposed to soil with pH less than 5.

Menta (2012) reported in his study that sand and sandy soils are profoundly affected by toxic substances such as pesticides compared to loam, clay and organic soils. The reason is that organic soils are rich in bacteria and fungi that are responsible for chemical degradation. Therefore, soils rich in silica content, and thus, low organic matter content tends to have a low buffering capacity making them more vulnerable to acidification (McCauley & Jones, 2009).

Sanogo & Yang (2001) also noted that the occurrence and intensity of soybean Sudden Death Syndrome (SDS) increased approximately twice or four times, as the content of sand in soil rose from 53 to 100%, respectively. Hence, this shows the need to assess how river sand harvesting activities impacts soil pH, and thereby, the integrity of the riparian ecosystem.

2.4 Impact of River Sand Harvesting on Floral and Soil Macro-Fauna Biodiversity

2.4.1 Impacts of River Sand Harvesting on Floral Biodiversity

High plant biodiversity exists in the river ecosystems, including those most threatened and of greatest value to people (Dudgeon et al., 2006). Supposedly, human activities pressure river ecosystems more than any other ecosystem (Von et al., 2017). For instance, the Amazon River basins experienced increased river sediments, soil erosion and biodiversity decrease (Sunil et al., 2010). In-stream sand harvesting creates a nick site that may be eroded by flowing waters (Koehnken & Rintoul, 2018). Ultimately, this causes channel widening and loss of many hectares of fertile riparian areas that are habitats to various vegetation (Lawal, 2011).

Harvesting of river sand near riverbeds destroys vegetation as river sand harvesters prepare sand harvesting sites, and loaders make way for vehicles that transport harvested river sand. These are direct ways of plant species disturbance (Madyise & Moja, 2013). Plant biodiversity along riparian areas is significant in connecting the terrestrial and aquatic ecosystems, as they provide dispersal corridors and hiding places for aquatic insects (Koehnken & Rintoul, 2018). Continuous removal of vegetation leads to loss of some vegetation cover, exposing the riverine land to erosion (Madyise & Moja, 2013). It also changes the riparian vegetation structure (Koehnken & Rintoul, 2018). As a result, the aesthetic values of the riverside land and the abundance of these plant communities reduces.

Koehnken & Rintoul (2018) also reported impacts on plant population and diversity, including the loss of some native riparian zone species and an increase of invasive species. The effects are due to degraded soil environmental conditions, which the native plants no longer find habitable. A reduction in the number of plant species coupled with loss of valuable tree resources at river sand harvesting areas create tree product scarcity, a decrease in riparian land productivity, and reduced faunal populations (Lawal, 2011).

2.4.2 Impacts of River Sand Harvesting on Soil Macro-Fauna

Soil is a living unit, made up of inseparably combined liquid, solid and gaseous parts, and the below-ground biodiversity (flora and fauna). The below-ground fauna includes soil macro-fauna, which consists of easily seen animals whose size is between 2mm and 20mm (Menta, 2012). The primary soil macro-fauna groups are termites, earthworms, and ants. Ruiz et al. (2008) referred to them as “soil engineers.”

The soil macro-fauna are critical elements of the soil ecosystem as they control processes like organic matter decomposition, and stimulate structuring and maintenance of the soil. For instance, earthworm droppings and castings have plenty of phosphorus, nitrogen, and potassium. Soil macro-fauna also biologically control diseases and pests that are soil-borne (Ayuke, 2010).

River sand harvesting activities are associated with soil profile destruction and clearing of plant cover. As a result, soil macro-fauna habitats are destroyed, and consequently, a reduction in their populations (Lawal, 2011). Soil macro-fauna diversity and abundance modification can cause severe soil compaction (Ruiz, Lavelle, & Jiménez, 2008).

2.5 Assessment of the mitigative strategies and challenges faced by Water Resources Users Association to river sand harvesting and riverine ecosystem conservation

At the grassroots level, Water Resource Users Associations (WRUAs) have common interests and are the locally responsible association for ensuring sustainable use of water resources. The Kenya Water Act (2002) enactment which was revised in 2016, introduced the involvement of WRUAs in the management of water. WRUAs are vehicles established for solving water use-related conflicts and ensuring collective management of water resources. The WRUAs key role is to: (i) carry out diverse river basin conservational activities; (ii) ensure equitable and sustainable use of existing water resources; and (iii) improve water resources management stakeholders and local community involvement in the management of water resources (Baldwin et al., 2018).

The Water Act 2016, under section 11(1), established the Water Resource Authority (WRA). Water Resource Authority (WRA) is a national government agency that regulates water resources management and utilization. WRUAs are to prescribe to regulations developed by WRA in the jurisdiction of their mandate (Muigua, 2017). Reports from WRA show that although WRUAs existed for a long time, there was a declining trend in river basins water flow (Mworia, Sande, & Kiboro, 2019). Also, Olajuyigbe & Fasakin (2010) established that 60% of the WRUA members in Nigeria had low literacy and knowledge on water resource protection, environmental matters, laws, and legislations of riparian protection. It is, therefore, crucial to assess whether the WRUAs within Kakamega County understand their mandates of riparian area conservation.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Introduction

This chapter describes the study area and the locations of study sites, the sampling design, methods of data collection, and data analysis.

3.2 Study Area

This research was done in two selected rivers within Kakamega County, Kenya (Figure 1). The study rivers were Shiatsala and Lusumu, that had actual or potential river sand harvesting activities. River Shiastala had two WRUAs (Lower Lubao Sasala and Upper Lubao Sasala) while River Lusumu had one WRUA (Lusumu).

The county lies between latitudes 0˚07’0’’ N and 0˚16’30’’ N, and longitudes 34˚37’30’’ E and 34˚49’0’’ E. Kakamega County lies to the North West of Nairobi and is approximately 390km away (Agevi, 2020). It covers an area of 3,034km^2 with Kakamega Town as its administrative headquarters. A number of counties border Kakamega County. To the East is Nandi, to North and the North West lies Bungoma, to the West is Busia, Siaya is to the South West, to the South is Vihiga and to the North East is Uasin Gishu (County Government of Kakamega, 2013; Figure 1).

Figure 1: Map showing the location of Kakamega County. (Source: County Government of Kakamega, 2013)

The County's altitude varies from 1,240 to 2,000 metres. There are several notable physical features in the County that include, the Nandi Escarpment to the East and several hills such as Butieri, Eregi, Imanga, Lirhanda, Kambiri, Kiming'ini, Mawe Tatu, Misango, and Sikhokhochole among others. A number of large rivers traverse the County, including Yala, Shiastala, Isiukhu, Lusumu, and Nzoia (Figure 2).

The mean annual precipitation is 1280.1mm and rainfall is bi-modally distributed, with the short rains from August to October and long rains starting from March to May (Tsingalia, 1988; County Government of Kakamega, 2015; Ongoma, Chen & Omony, 2018). The annual temperature ranges between a maximum of 21.4^{o}C and a minimum of 19.3^{o}C with December to February being the hottest and May to July being the coldest (Kitungulu et al., 2021).

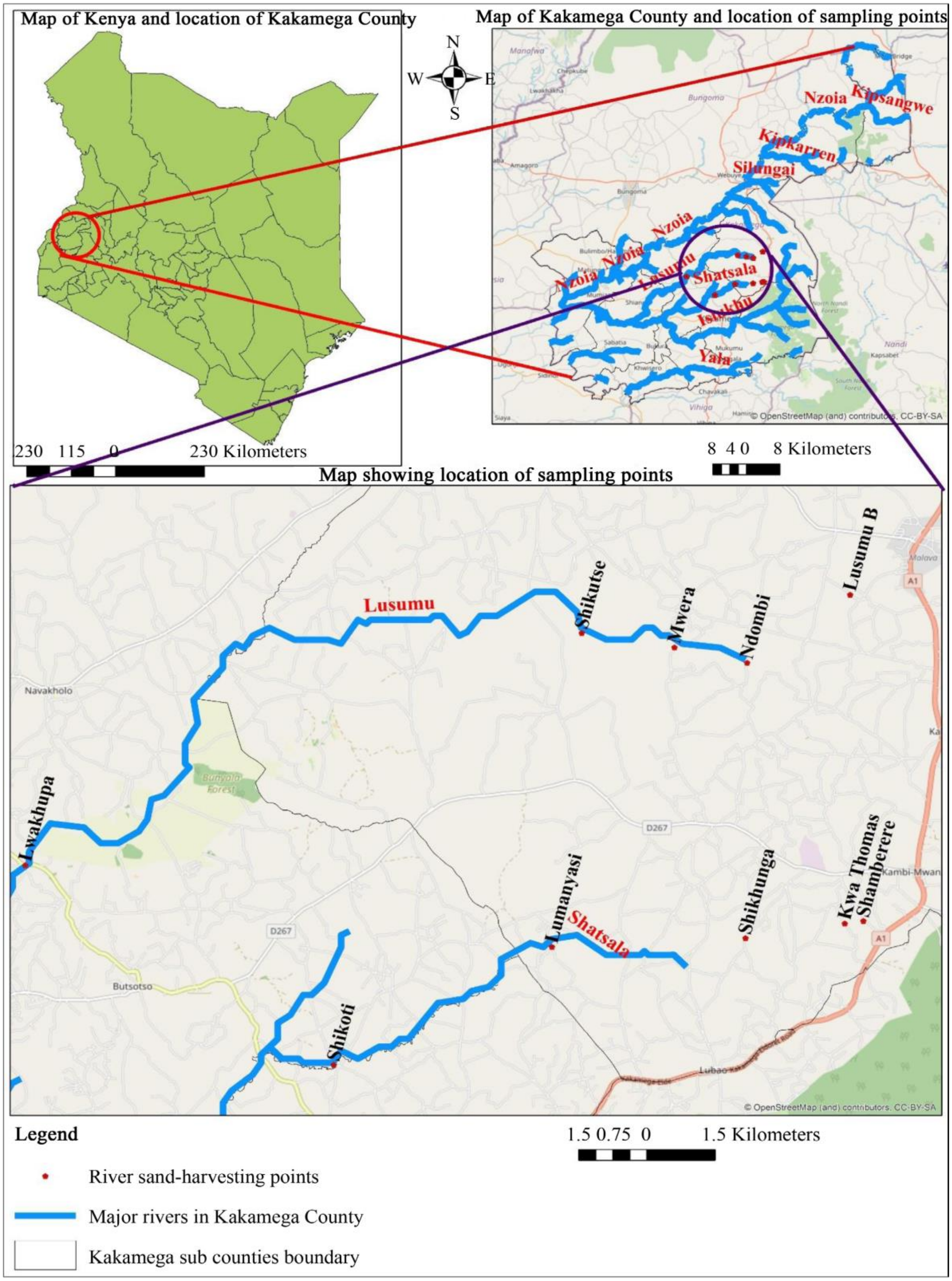

Figure 2:The location map of Kakamega County showing the rivers traversing the County and the sampling points. Major rivers are labelled in red. Sampling points are labelled in black. (Source: Author)

3.3 Research Design

The study combined quasi experimental and qualitative research design. Quasi experimental research design was used to determine the effects of river sand harvesting on river water quality, soil physico-chemical properties, floral and soil macro-fauna biodiversity. There were five quasi experimental sites and five control sites that were used. The qualitative research design was used to assess the mitigative strategies and challenges of the Water Resources Users Association to riverine ecosystem conservation. In this design, direct observations, questionnaires, focused group discussions (FGDs) and structured interviews were used.

3.4 Sampling Site Selection

Study done by Madyise & Moja (2013) on sand harvesting did collect samples from two rivers, where each had two sampling sites. For Kumar (2015) study, the sand harvesting experimental study was done in 8 lease mines along the Yamuna River to determine the ecological impacts. Teo et al. (2017) did their study at Muda, Langat, and Kurau rivers. Each river had six sites for thorough sediment transport capacity analysis. Nzula et al. (2018) did their sand harvesting study at River Thwake and obtained eight water samples from two sampling sites for physicochemical analysis.

Based on this sampling site selection review, this study sampled a total of ten sites from River Shiastala and River Lusumu. For thorough quasi experimental analyses in order to establish the effect of sand harvesting on water quality, soil physicochemical properties of the adjacent areas, floral and soil macro-fauna biodiversity within the riverine ecosystem, sampling from the identified points was done at two months intervals for a period of seven months in the months of June, September and December 2020. While for riverbank erosion, sampling from the identified points was done at seven years intervals for a period of fourteen years in the years 2005, 2012 and 2019. The same routine was repeated for control sites upstream and the results compared to those of study sites. The replication resulted in a total of thirty (30) measurements made both at the five study sites and the five control sites.

3.5 Selection of Sampling Study Sites Along the Rivers

The study sought to establish the effect of sand harvesting on water quality, soil physicochemical properties of the adjacent areas, floral and soil macro-fauna biodiversity within the riverine ecosystem. This was achieved through sampling five (5) different sites from each of the two rivers. The sampling sites were obtained through a reconnaissance survey that identified sites with and those without sand harvesting activities. The approximate distance from one sampling site to the other varied between 2km to 15km. The sampling sites were as indicated in Figure 2 and Table 1.

Table 1: Details of the sampling sites

STUDY SITES				CONTROL SITES			
No	**NAME**	**COORDINATES**	**RIVER**	**No**	**NAME**	**COORDINATES**	**RIVER**
1.	Shikhunga	0˚21’44.6’’N, 34˚49’36.2’’E	Shiastala	1.	Lusumu B	0˚25’13.2’’N, 34˚49’44.6’’E	Lusumu
2.	Shikutse	0˚25’35.5’’N, 34˚47’13.4’’E	Lusumu	2.	Shamberere	0˚21’50.88’’N, 34˚50’41.52’’E	Shiastala
3.	Lumanyasi	0˚21’39.7’’N, 34˚46’52.2’’E	Shiastala	3.	Ndombi	0˚25’13.1’’N, 34˚49’11.2’’E	Lusumu
4.	Lwakhupa	0˚22’41.0’’N, 34˚40’37.3’’E	Lusumu	4.	Kwa Thomas	0˚21’57.1’’N, 34˚50’20.7’’E	Shiastala
5.	Shikoti	0˚20’10.9’’N, 34˚44’16.9’’E	Shiastala	5.	Mwera	0˚24’6.1’’N, 34˚49’9.5’’E	Lusumu

3.6 Methods of Data Collection

3.6.1 Assessment and Mapping of the Distribution of River Sand Harvesting Activities

The adjacent areas affected by the river sand harvesting activities were assessed through observations. The distribution of river sand harvesting activities was determined by carrying out a reconnaissance survey along Lusumu and Shiatsala rivers within the sub counties of Malava, Navakholo, and Lurambi. Reconnaissance data revealed that, these were the rivers with the highest river sand harvesting activities. The survey was done on a river by a river basis using scouts who located areas with intensive river sand harvesting. Scouting was done between 11th and 28th December 2019 (Plate 1). For every sand harvesting site identified, the GPS coordinates were obtained using a Garmin GPS receiver 64x series.

3.6.2 Determination of the Effects of River Sand Harvesting on River Water Quality and Riparian Soil Physico-Chemical Properties

3.6.2.1 Assessment of the Effect of River Sand Harvesting on River Water Quality

The following river water quality parameters were sampled: riverbank erosion, river turbidity and total suspended sediments in the water.

3.6.2.1.1 Determination of the effect of River Sand Harvesting on Riverbank Erosion

Riverbank erosion was determined by the use of aerial and satellite imagery of 2005, 2012 and 2019 obtained from the Google Earth Pro application. This application provided a detailed view of the channel and river bank lines. The identified sampling sites of sand harvesting along the selected rivers were exported from ArcGIS as a layer, into the Google Earth Pro application. Transfer of the layer enabled ease and accuracy in locating the sand harvesting sites on the Google Earth Pro application. At each of the study points in each of the rivers, three sites were randomly identified along the river. At each of these sites, the width of the channel was marked (white for satellite imageries obtained in 2005, sky blue for satellite imageries obtained in 2012 and red for satellite imageries obtained in 2019) and recorded. The readings recorded were averaged to get the mean width of the river channel at each selected sampling site during that particular year.

3.6.2.1.2 Determination of Turbidity and Total Suspended Sediments (TSS)

For water sampling, 500ml plastic bottles were dipped inside the middle part of the river to a depth of 30cm, to collect samples on either side of the identified sampling points. The 500ml plastic bottles had been washed using detergent then thoroughly rinsed with distilled water. The bottles were later rinsed again with the sample water before the actual sampling. The samples were then mixed in a bucket to form a 500ml composite sample. The collected samples were then transferred into 500ml pre-sterilized bottles and then labeled accordingly. Turbidity was determined onsite using an MRC turbidity meter model TU-2016. For TSS analysis, the labeled samples were kept in a cool box, and transported for analysis of sediments in the Water Resources Authority (WRA) Regional laboratory in Kakamega.

Total Suspended Solids (TSS) were determined using APHA 2540D analytical method at WRA Kakamega Regional Laboratory. The TSS was calculated as follows:

$$\text{Total dissolved solids/L)} = \frac{(A - B) \times 1000}{\text{Sample volume(mL)}}$$

Where: A = weight of dried residue + dish, mg

B = weight of dish, mg

3.6.2.2 Effect of River Sand Harvesting on Soil Physico-Chemical Properties

Soil physico-chemical properties were determined by collecting soil samples from each sampling site and analyzing the soil moisture content, nitrogen, phosphorus, pH, organic carbon and soil textural class.

5mx5m quadrats were established in both the study and control sites 5m away from the river bank and on one side of the river within the riparian land with and without sand harvesting activities. In each sampling site, soil samples were collected using a soil auger at 0-15cm and 15-30cm depths. 500g of soil was collected from 5 points within the quadrat in a zig zag fashion (Figure 3) a design best recommended for soil sampling (Hardy et al., 2008). These were then mixed and a composite of soil sample taken, labelled, kept in a cool box, and transported to Kenya Agricultural and Livestock Research Organization (KALRO) laboratory in Kakamega for analysis of the physico-chemical properties.

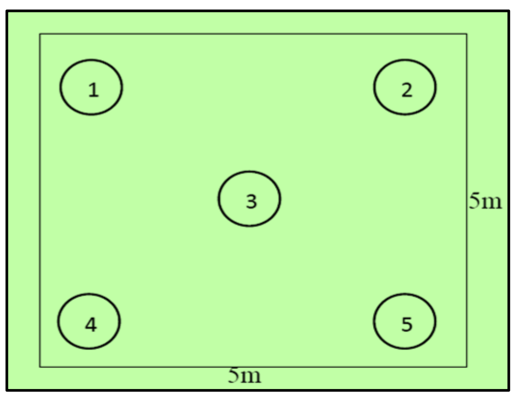

Figure 3: Diagrammatic representation of 5mx5m quadrat for sampling soil physico-chemical properties. (Source: Author)

Moisture content was determined by measuring the weight of the fresh soil sample then oven-drying drying it and measuring the weigh again. It was obtained using the formula:

$$MC\ (\%) = \left\{\frac{W_1 - W_2}{W_1}\right\} \times 100$$

Where:

MC is moisture content,

W_1 is the weight of the fresh sample, and

W_2 is the weight of the dried sample

The electrochemical method was used to determine the soil pH (Sikora & Moore, 2014). This was done by oven drying the soil sample then crushing it using pestle and mortar and sieving it through 2mm sieve. Deionized water was added to the soil sample then shaked on a shaker for 10minutes. The soil suspension was allowed to rest for 30 minutes and then stirred again for 2 minutes. Using pH 4 and pH 7 buffers the pH meter was calibrated to finally measure the soil suspension pH.

Phosphorous was determined by the Mehlich Double Acid Extraction method (Mehlich, 1953) which was initially referred to as the Double Acid method. The extracting reagent for Mehlich-1 comprised of 0.025N H_2SO_4 and 0.1N HCl. Phosphorus (P) was quantified in the extract via spectrophotometry by reacting P with a molybdate molecule to form a blue-colored complex as well as utilizing inductively coupled plasma-atomic emission spectrometry (ICP-AES). The amount of phosphorus content in the soil sample was determined by reading the optical density of the spectrophotometer after one hour at a wavelength of 430nm.

Colorimetric method was used to determine total Nitrogen in the soil (Willis, Montgomery & Allen, 1996). The soil sample was digested at 360^0C for two hours using digestion mixture that contained 14g lithium sulphate, 0.42g selenium powder, 350ml hydrogen peroxide together with 420ml sulphuric acid and topped up to 1000ml with distilled water. A clear solution was obtained from the soil sample and digestion mixture suspension. There were two reagents that were used. The first one contained dissolved sodium salicylate, sodium citrate, sodium tartate, sodium nitroprusside and distilled water. While the second one contained dissolved sodium hydroxide, sodium hypochlorite and distilled water. These reagents were made 24hours before use and stored in the dark. The standard used was made of dissolved 11.793g ammonium sulphate dissolved in a volumetric flask and made up to the mark with distilled water. Absorbency was measured at 650nm in the UV-spectrophotometer where the blue color was stable for at most ten hours. This determined amount of total nitrogen in the soil.

Organic carbon was determined by the Walkley Black method (Walkley & Black, 1934). 0.3g of dry ground soil was put into a digestion tube then 5ml of potassium dichromate and 7.5ml of concentrated sulfuric acid was added. The tube was then placed in a pre-heated block at 145-155^{o}c for 20 minutes. The contents were cooled then washed into 200ml conical flasks. 0.3ml of the indicator was then added. The indicator comprised of 1.485g of ortho-phenanthroline monohydrate and 0.025M ferrous sulphate mixed in 100ml distilled water. After adding the indicator, the solution was titrated while stirring, against 0.2M ferrous ammonium sulphate. The end point was reached with a colour change from greenish to brown. Percent OC was calculated using the formula;

$$\%C = \frac{T \times W \times 0.2}{V}$$

Where T= titrating volume of blank titrating volume of sample

W= volume of the indicator and

0.2 is a constant.

The textural class was determined by Bouyoucos/Hydrometer method by Bouyoucos (1962) using Calgon solution (sodium hexametaphosphate). The density of the soil suspension is determined with a Bouyoucos hydrometer at specific times while making temperature corrections, depending on the particle size being measured. Specifically, soil of less than 2mm obtained by sieving the soil sample with a 2mm sieve) was air-dried then 100g of it was put into a 400ml beaker. The soil was then saturated with distilled water and 10ml of 10% Calgon solution, then allowed to stand for 10 minutes. The suspension was then transferred to shaking bottle where 300ml of tap water was added, and the suspension shaken overnight on mechanical shaker for 13 to 16 hours. The suspension was transferred into a graduated cylinder and the remaining soil rinsed into the cylinder with distilled water. The hydrometer was then inserted into the suspension and water added to 1130ml mark, then the hydrometer was removed. The cylinder was covered with a tight-fitting bung and the suspension mixed by inverting the cylinder carefully ten times. The time after the 10th inverting was then noted, and quickly, 3 drops of amyl alcohol was added to the soil suspension to remove the froth. After 20 seconds, the hydrometer was gently placed into the cylinder column. Reading of the hydrometer was recorded at 40 seconds and the temperature of the suspension also measured. The cylinder was allowed to stand undisturbed for 2hours then both the hydrometer and thermometer readings taken again. Temperature corrections were made and the percentage of each textural component (sand, silt and clay) calculated. Soil texture triangle chart was then used to classify the soil into a recognized textural class based on the obtained relative amounts of sand, silt and clay as a percentage.

3.6.3 Analysis of the Impact of Sand Harvesting on Floral and Soil Macro-Fauna Biodiversity

3.6.3.1 Impact of River Sand Harvesting on Floral Biodiversity

Sampling of plant biodiversity was done using duplicate nested quadrats within a 10mx10m quadrat on either side of the river bank. All tree species with a diameter at Breast Height (DBH) ≥10cm were measured, identified and recorded within the quadrat in a data sheet in the 10mx10m quadrat. DBH was measured using a tape measure to measure the circumference from which the diameter was deduced. Within the 10mx10m quadrat, a 5mx5m quadrat was established (Figure 4), and all saplings were quantified and recorded in a data sheet to the species level. Similarly, herbs were identified and quantified using a 2mx2m quadrat in which all herbaceous plants were identified, counted and recorded in a data sheet. The species were identified based on the data from the *Flora of Tropical East Africa* (FTEA; Zhou et al., 2017) and other published sources (Beentje et al., 1994; Maundu & Tengnäs, 2005; Fischer et al., 2010; Seswa et al., 2018). In addition, the National Museums of Kenya EA herbarium through BioNET-EAFRINET, the East African partnership for Taxonomy, IAS fact sheet of the Priority 100 IAS in the region was used (http://keys.lucidcentral.org/keys/v3/eafrinet/weeds/key/weeds/Media/Html) in further identifying the various flora.

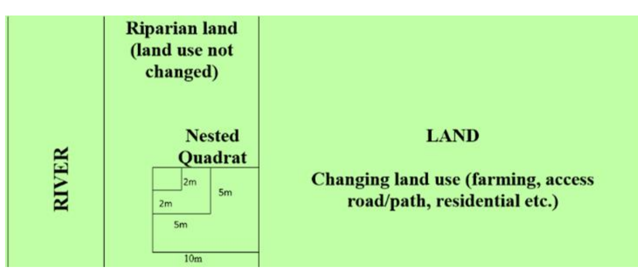

Figure 4: Diagrammatic representation of nested quadrat for sampling floral biodiversity (Source: Author)

3.6.3.2 Impact of Sand Harvesting on Soil Macro-Fauna

Within the 5mx5m quadrat in Figure 4, 5x1kg of soil samples up to 30cm depth were taken using a soil auger. A composite sample of 1kg was spread on a gunny bag where visual examination for macro-fauna such as earthworms and other arthropods was done. All macro-fauna observed were counted and put in labelled sealed plastic containers and preserved in 70% alcohol. The containers with macrofauna samples were transported to MMUST Zoology laboratory where they were identified using morpho-anatomical keys and other published sources (Ruiz & Jiménez, 2008; Moreira et al., 2012; Kamau et al.,2020) to the species level. Further analysis was done using a dissecting microscope.

3.6.4 Assessment of the mitigative strategies and challenges faced by Water Resources Users Association to river sand harvesting and riverine ecosystem conservation

Mitigative strategies of WRUAs were assessed using questionnaires and direct observations between 14th July, and 20th August, 2020. The questions were both structured and open-ended and divided into four sections (Appendix 1). Each of the three WRUAs within the two rivers is made up of approximately hundred members, hence totaling to a population of 300 members. Hence based on formula developed by Israel (1992), for a population of 300, the sample size for ±9.9% precision levels where confidence level is 95% and P=.5 is 105 as computed below.

$$n_o = \frac{z^2pq}{e^2}$$

Where: $\mathbf{n_o}$ = sample size

$\mathbf{z^2}$= abscissa of the normal curve that cuts off an area a at the tails (1 - a equals the desired confidence level, i.e., 95%). The value for Z is found in statistical tables which contain the area under the normal curve.

p = estimated proportion of an attribute that is present in the population.

q = 1-p

e = desired level of precision

Therefore, $n_o = \frac{(1.96)^2(0.5)(0.5)}{(0.099)^2}$ = 105 WRUA members

The first section of the questionnaire focused on the socio-demographic background of respondents. The questions dealt with the family, age, and gender of sample WRUA members. The second section identified the respondents' understanding of the causes of the river system degradation and rate of sand harvesting in their areas. The third section examined the current capacity of the WRUA members to address sand harvesting and river system conservation issues. The last section contained questions to elicit expectations about the WRUAs' role in preventing the river system hazards and the current mitigative strategies applied. The answers provided were confirmed by direct observation to verify the activities undertaken.

A focused group discussions (FGDs) and structured interviews for the WRUA committee members, church leaders, local administration, CBOs, county water officers, ward representatives, and Water Resources Association officers were carried out between 20th and 30th August 2020. A moderator was used to guide the group discussion while observing the Covid 19 protocols. The checklist used was as presented in appendix 2.

3.7 Validity and Reliability

The validity of the questionnaire was ensured using the supervisors. The test for the reliability of the questionnaire was done by pre-testing it on a similar pre-sample of the Bukhungu Water Resources Users Association, whose river (River Isiukhu) was not part of the study. The internal consistency of the survey questions, was measured by doing the Cronbach α test, which was .717; hence the questionnaire used was internally consistent.

3.8 Data Analysis

Spatial distribution and abundance of sand harvesting activities analysis was done using ArcGIS 10.8 software to generate spatial map. Data obtained from the spatial distribution of the sand harvesting activities were mapped to give an overall overview of their spatial distribution. The provided sand harvesting sites were marked on topographic maps and defined using the collected GPS coordinates to obtain a river sand harvesting hotspots map layer. The spatial map layer of river sand harvesting hotspots was overlaid with the spatial map layers of major rivers and sub counties in Kakamega County and a sand harvesting hotspots map developed. Then using ArcGIS tools, the spatial distribution of the sand harvesting activities was determined. There were actual counts of sand harvesting hotspots of Shiatsala and Lusumu rivers within Malava, Navakholo and Lurambi sub-counties. The amount of sand harvested in wheelbarrows was extrapolated into tonnes per year for each season.

Riverbank erosion was analyzed using the Google Earth Pro to determine changes in the width of the rivers, as shown in the satellite imageries obtained from different times (2005, 2010 and 2019). The difference in width of the channel was obtained by subtracting the channel width in 2010 from the channel width in 2005, and channel width in 2019 from the channel width in 2005, respectively. Comparisons of the data for sand harvesting sites and control sites were made.

Data obtained on the water quality, soil physico-chemical parameters and floral and soil macrofauna biodiversity were subjected to descriptive statistics and Pearson's correlation analyses on IBM SPSS Statistics Version 22. Significant effect of sand harvesting on the water quality, soil physico-chemical parameters and floral and soil macrofauna biodiversity was tested using One Way ANOVA. Independent Sample T test at a 5% level was used to test the hypothesis that sand harvesting significantly affects water quality, soil physico-chemical parameters and floral and soil macrofauna biodiversity.

Floral and soil macro-fauna diversity was further analyzed using the Shannon-Wiener index (Shannon & Weaver, 1963):

Shannon Wiener Index = $-\Sigma p_i \ln p_i$

Where:

s is the total sample

$\sum$ is the sum of the calculations,

p_i is the fraction of entities of one single species found (n) divided by the total number found (N),

ln is the natural log.

Data on mitigative strategies and challenges was entered in an IBM SPSS Statistics version 22 and analyzed. Univariate analysis of variance was used to assess the mitigative strategies applied by WRUAs in addressing sand harvesting and river system conservation issues. General descriptive and comparative analyses were applied to elucidate the relationship between independent variables and outcome variables. The independent variables used in this study were socio-demographic background of the WRUA members, like age, gender, marital status, size of family, level of education and other daily activities engaged in. While the outcome variables were: Self-assessment towards sand harvesting and river system conservation capacity — Assessment of the capacity of the WRUA members to address sand harvesting and river system conservation issues through evaluating respondents' technical capacity and their understanding of the causes of the river system degradation; Mitigative strategies applied by Water Resources Users Association members in addressing sand harvesting and river conservation issues; and Challenges faced by Water Resources Users Association members in addressing sand harvesting and river conservation issues — This was based on the capacity gaps in terms of training, level of understanding of some selected concepts, presence of an advisory unit, level of confidence and how to address the level of confidence.

3.9 Data Presentation

Results were presented through charts and tables, as well as descriptive statistics and of the variables.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter presents findings of the study from the data collected with interpretation of each research findings on sand harvesting and challenges of riparian conservation in Kakamega County, Kenya.

4.2 Assessment and Spatial Distribution of Sand Harvesting Activities

4.2.1 Assessment of river sand harvesting activities

Sand harvesting hotspots had observable features like riverbank erosion, destruction of vegetation covers due to footpaths and vehicle tracts, cutting down of trees and the presence of oil droplets from the sand carrying lorries and tractors (Plates 1-3).

The amount of sand harvested was demand-driven and varied with the rainy season having higher demands compared to the dry season (Figure 5). At Lumanyasi Bridge, Shikoti, Shikutse and Lwakhupa sites active sand harvesting was evident in both seasons, with dry season recording lower amounts. Shikoti recorded the highest amount both in the rainy and dry season of 3,387.2 tonnes and 2,646.25 tonnes respectively.

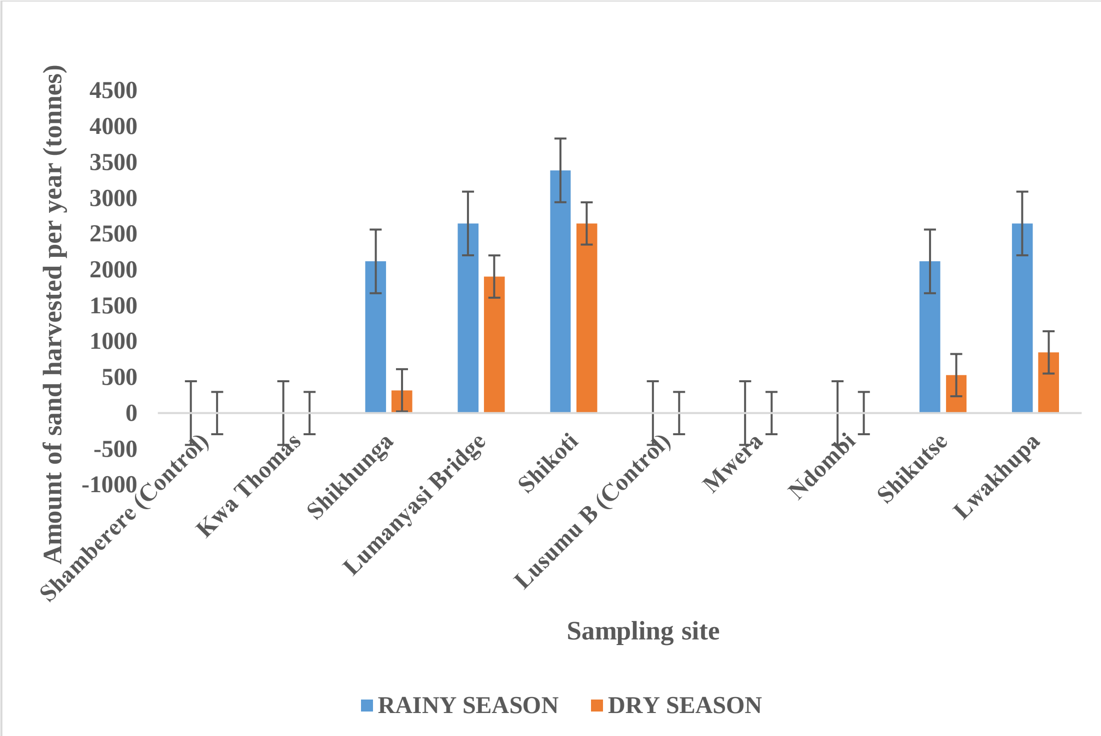

Figure 5: Graph of the amount of sand harvested.

4.2.2 Spatial Distribution of Sand Harvesting Activities

Ground truthing of sand harvesting activities established rampant sand harvesting, activities, especially in Malava Sub County (Plates 2,3,5 and 6). At Esenyi (Plate 8), a new access road had been created. Women, men and children took part in sand harvesting (Plates 5,6 and 7).

Despite Shiatsala being a smaller river compared to river Lusumu, it had more sand harvesting hotspots, concentrated within a short distance. River Shiatsala had 10 sand harvesting hotspots while River Lusumu had 8 hotspots (Figure 6). These hotspots were distributed along a 15km length of river Shiatsala and approximately 30km of River Lusumu, within rural areas of Malava, Navakholo and Lurambi Sub Counties and close or along access roads and bridges.

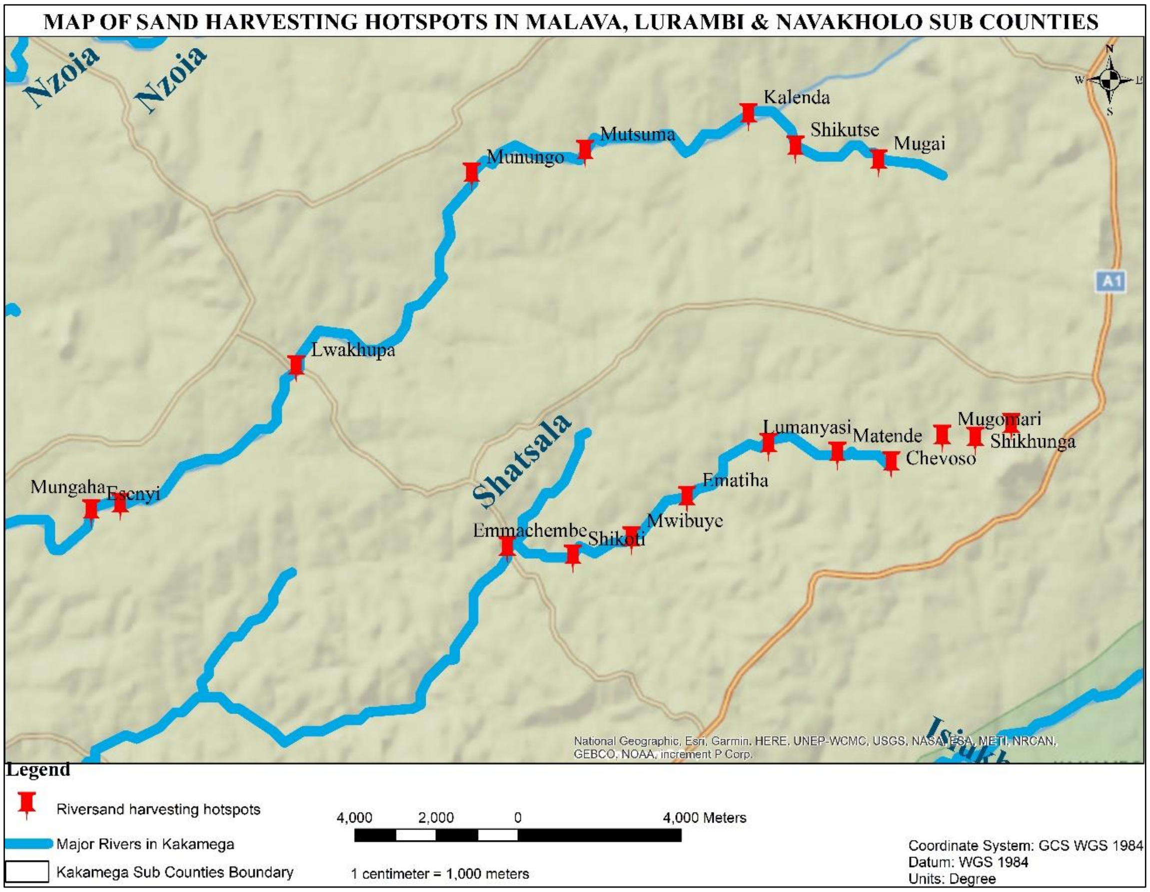

Figure 6: Sand harvesting hotspots along River Lusumu and Shiatsala within Malava, Navakholo and Lurambi sub-counties of Kakamega County. (Source: Author)

4.3 Effect of River sand Harvesting on River Water Quality and Soil Physico-Chemical Properties

4.3.1 Effect on Riverbank Erosion

Results of the mean river channel widths as per the satellite imageries show that, there were evidences of farming activities around the riverbank in all the sand harvesting sites both in 2012 and 2019. However, little or no sand harvesting activities happened around 2005, as all the sampling sites had little or no evidence of sand harvesting such as access paths created and/or bare-unvegetated sites near the riverbank. However, in 2019, evidence of sand harvesting such as existence of bare-unvegetated sites and access paths were visible at Shikhunga, Lumanyasi Bridge, Shikoti, Mwera, Shikutse Bridge and Lwakhupa sand harvesting sites while at Shamberere and Lusumu B control sites these evidences were not present.

At Shamberere, the riverbanks were not visible and site visits in June and December 2020 revealed that the river width was less than a meter wide. Besides, most study areas had little agricultural and infrastructural developments as of 2005, for instance, the Ndombi Bridge sampling site had no access road in 2005 but in 2012 satellite imagery and 2020 site visits (Plate 14), there was a bridge with an access road. In addition, an increasing trend in channel width, degradation of riparian vegetation and erosion of riverbanks was noted at the sand harvesting sites as presented in Table 2.

Table 2: Changes in river channel width

Local Name	**Name of River**	**2005 (metres)**	**2012 (metres)**		**2019 (metres)**	
		Average	**Average**	**Change in width**	**Average**	**Change in width**
			Control sites			
Shamberere	Shiastala	1.00	1	0	1	0
Lusumu B	Lusumu	4.27	4.81	0.54	5.48	1.22
Mwera	Lusumu	5.83	6.27	0.45	7.19	1.37
Ndombi Bridge	Lusumu	4.87	5.57	0.7	6.22	1.35
Kwa Thomas	Shiastala	1.84	1.95	0.12	2.31	0.47
			Quasi-experimental sites			
Shikhunga	Shiastala	2.12	2.66	0.54	6.51	4.39
Lumanyasi Bridge	Shiastala	3.85	6.76	2.92	15.57	11.72
Shikoti	Shiastala	4.17	7.33	3.16	11.59	7.43
Shikutse	Lusumu	7.00	8.28	1.28	12.35	5.35
Lwakhupa	Lusumu	11.22	13.61	2.39	21.52	10.3

Pearson’s correlation revealed that change in riverbank erosion positively correlated with increase in sand harvesting activities ($r= 0.476$, $p= 0.05$). One Way ANOVA analysis revealed that the differences between changes in width for the control and sand harvesting groups were statistically significant ($F_{(1,28)}$ =8.196, p=0.008). Similarly, independent sample t-test revealed that sand harvesting statistically significantly affected changes in river width ($t_{(28)}$ = -2.863, p = 0.008).

4.3.2 Effect of River Sand Harvesting on Total Suspended Sediments

Figure 7 shows analysis of suspended sediments (TSS) in river water at each of the sand-harvesting sites in comparison to the control sites. TSS for the control group is almost similar throughout the seven-month period while for the quasi-experimental sites the TSS values increase during the seventh month of analysis.

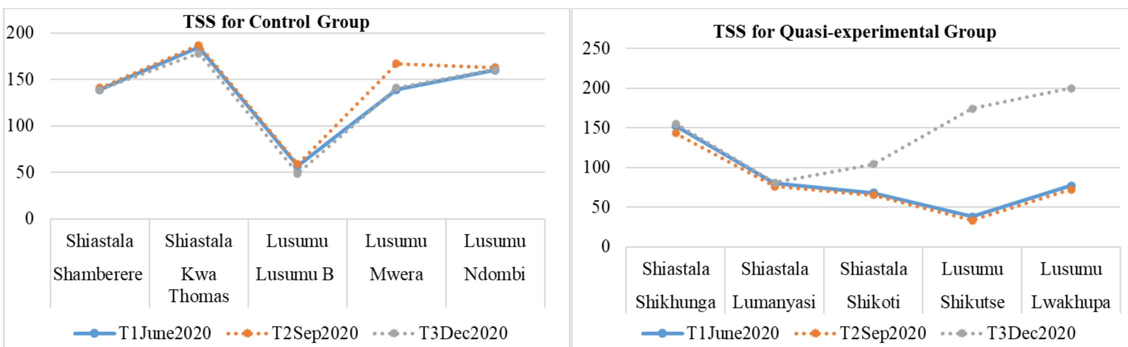

Figure 7: Total suspended sediments values for the control and quasi-experimental group

Pearson's correlation revealed that change in TSS value positively correlated with increase in sand harvesting activities (r= .575, p= 0.01). One Way ANOVA analysis revealed that the differences between changes in width for the control and sand harvesting groups were statistically significant ($F_{(1,28)}$ =13.795, p=0.001). Similarly, independent sample t-test revealed that sand harvesting statistically significantly affected level of TSS in rivers ($t_{(28)}$ = -3.714, p = 0.001).

4.3.3 Effect of River Sand Harvesting on Turbidity

Results from turbidity readings during the seven-month analysis period are shown in Figure 8. Turbidity was higher at the quasi-experimental sites compared to the control sites. Sites with higher amounts of sand harvested (Lumanyasi, Shikoti and Lwakhupa) had extremely higher turbidity levels.

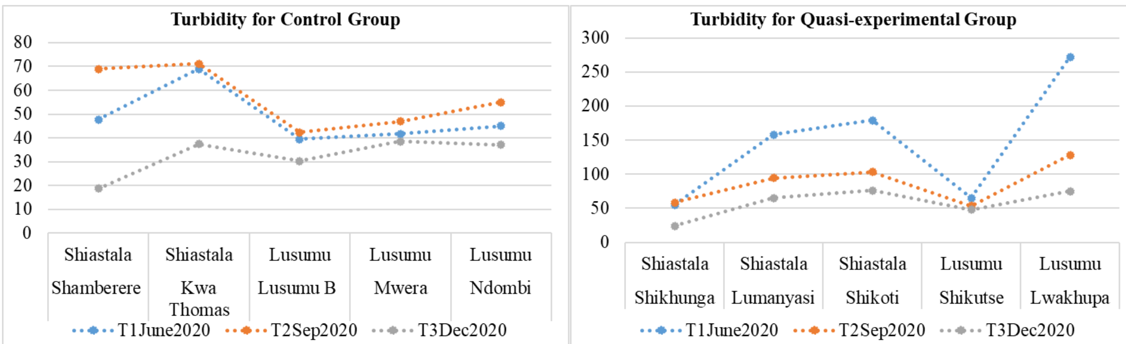

Figure 8: Turbidity values for the control and quasi-experimental group

Pearson's correlation revealed that change in turbidity value positively correlated with increase in sand harvesting activities (r= .493, p= 0.01). One Way ANOVA analysis revealed that the differences between changes in width for the control and sand harvesting groups were statistically significant ($F_{(1,28)}$ =8.974, p=0.006). Similarly, independent sample t-test revealed that sand harvesting statistically significantly affected level of turbidity in rivers ($t_{(28)}$ = -2.996, p = 0.006).

4.3.3 Effect on Soil Total Nitrogen Content

Analysis of soil total nitrogen content showed a variation in nitrogen content of 0.2ppm and 0.5ppm (Figure 9). The soil total nitrogen content generally decreased during the seven-month analysis period for all the control sites. At the sand harvesting sites (n=5), the soil total nitrogen content decreased then increased at the end of the seven-month analysis period, with Lwakhupa having the least amount of total nitrogen content.

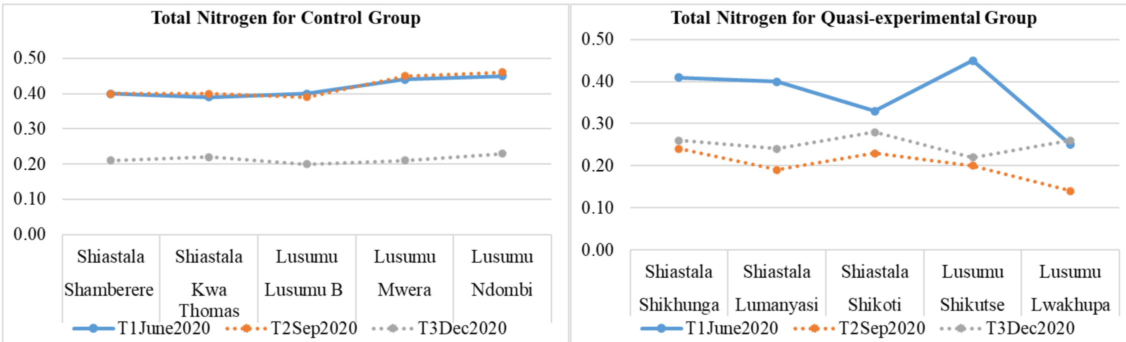

Figure 9: Total nitrogen content for the control and quasi-experimental group

Pearson's correlation revealed that change in Total Nitrogen content negatively correlated with increase in sand harvesting activities (r= -.385, p= 0.05). One Way ANOVA analysis revealed that the differences between Total Nitrogen content for the control and sand harvesting groups were statistically significant ($F_{(1,28)} = 4.869$, p=0.036). Similarly, independent sample t-test revealed that sand harvesting statistically significantly affected total nitrogen content in the riparian area ($t_{(28)} = 2.206$, p = 0.036).

4.3.4 Effect on Soil Organic Carbon Content

Analysis of soil organic carbon content showed that the organic carbon content ranged between 0.8per cent and 2.0 percent during the seven-month analysis period (Figure 10). At the sand harvesting sites (n=5), the soil organic carbon content decreased then increased at the end of the seven-month analysis period, with Lwakhupa having the least amount of soil organic carbon content.

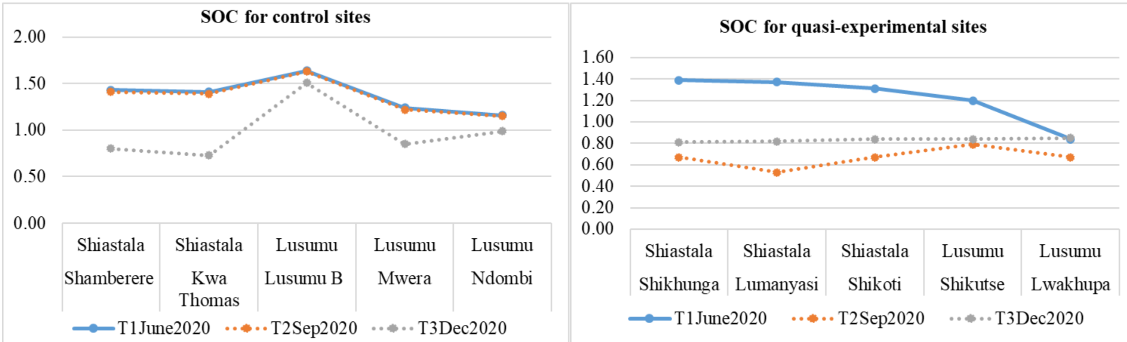

Figure 10: Soil organic carbon content for the control and quasi-experimental group

Pearson's correlation revealed that change in soil organic carbon content negatively correlated with increase in sand harvesting activities (r= -.518, p=0.01). One Way ANOVA analysis revealed that the differences between Soil organic carbon content for the control and sand harvesting groups were statistically significant ($F_{(1,28)}$ =10.258, p=0.003). Similarly, independent sample t-test revealed that sand harvesting statistically significantly affected soil organic carbon content in the riparian area ($t_{(28)}$ = 3.203, p = 0.003).

4.3.5 Effect on Soil Phosphorus Content

The soil phosphorus content varied between 22ppm and 600ppm in the seven-month analysis period. The trend for amount of phosphorus content in both control and quasi-experimental group is almost similar as indicated in Figure 11.

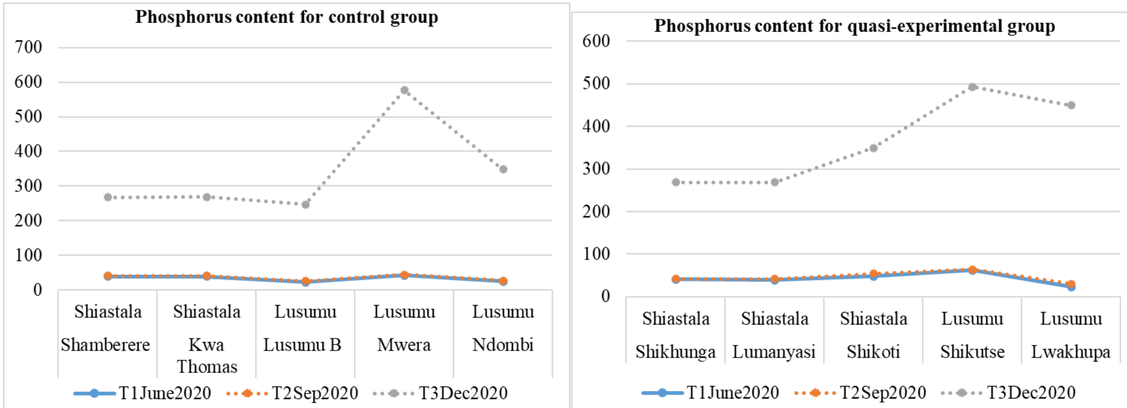

Figure 11: Soil phosphorus content for the control and quasi-experimental group

Pearson's correlation revealed no correlation between phosphorus content and sand harvesting activities (r= .046, p= 0.05). One Way ANOVA analysis revealed no significant differences between soil phosphorus content for the control and sand harvesting groups ($F_{(1,28)}$ =0.059, p=0.810). Similarly, independent sample t-test revealed no statistically significant effect of sand harvesting on riparian soil phosphorus content ($t_{(28)}$ = -0.243, p = 0.810).

4.3.6 Effect of River Sand Harvesting on soil moisture content

The percent moisture content for all the sites did not differ significantly (Figure 12). All the sites, had a decrease in percent moisture content during the end of the seven-month analysis period. However, at Shikoti, the moisture content increased from 25.25% during the rainy season to 32.5% during the dry season.

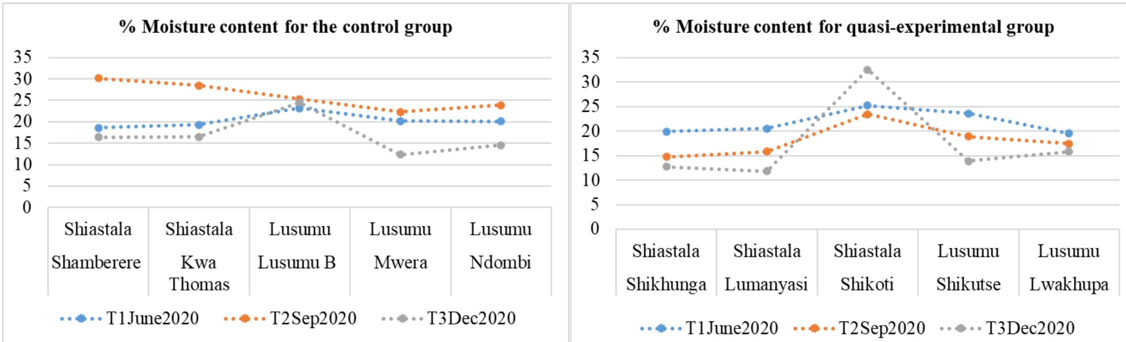

Figure 12: Percent moisture content for control and sand harvesting groups

Pearson's correlation revealed no correlation between the percent moisture content and sand harvesting activities (r= -.192, p= 0.05). One Way ANOVA analysis revealed no significant differences between percent moisture content for the control and sand harvesting groups ($F_{(1,28)}$ =1.074, p=0.309). Similarly, independent sample t-test revealed no statistically significant effect of sand harvesting on riparian soil percent moisture content ($t_{(28)}$ = 1.036, p = 0.309).

4.3.7 Effect on soil pH

Analysis of soil pH revealed an acidic to neutral pH that ranged between 5.0 and 7.0 during the seven-month analysis period (Figure 13). The soil pH for the control group increased while that for the sand harvesting sites decreased during the end of the seven-month analysis period.

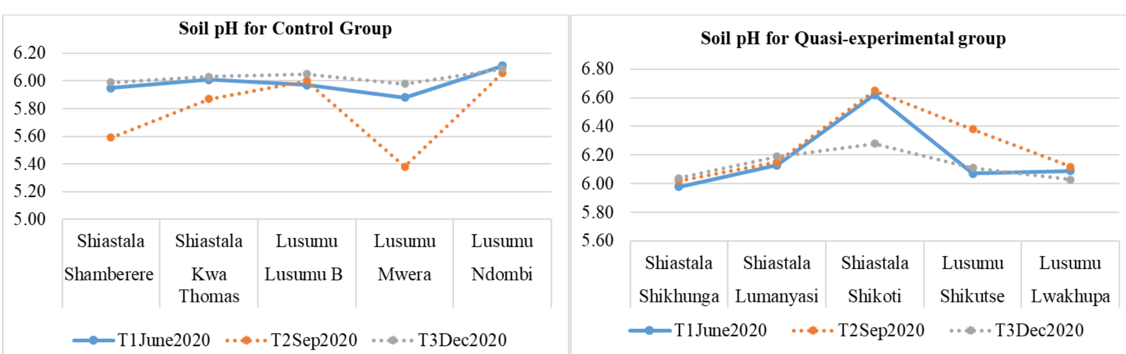

Figure 13: Soil pH for the control and quasi-experimental group

Pearson's correlation revealed that change in soil pH positively correlated with increase in sand harvesting activities (r= .554, p= 0.01). One Way ANOVA analysis revealed that the differences between soil pH for the control and sand harvesting groups were statistically significant ($F_{(1,28)}$ =12.392, p=0.001). Similarly, independent sample t-test revealed that sand harvesting statistically significantly affected soil pH in the riparian area ($t_{(28)}$ = -3.520, p = 0.001).

4.3.8 Effect on Soil Textural Class

Analysis of soil textural classes showed that the textural classes were either sandy loam or sandy clay loams during the seven-month analysis period.

Table 3: Soil textural class

Site	June 2020	Sep 2020	Dec 2020
	Control Group		
Shamberere	Sandy loam	Sandy loam	Sandy loam
Kwa Thomas	Sandy loam	Sandy loam	Sandy loam
Lusumu B	Sandy loam	Sandy loam	Sandy loam
Mwera	Sandy clay loam	Sandy clay loam	Sandy clay loam
Ndombi Bridge	Sandy loam	Sandy loam	Sandy loam
	Quasi experimental Group		
Shikhunga	Sandy loam	Sandy loam	Sandy loam
Lumanyasi Bridge	Sandy loam	Sandy loam	Sandy loam
Shikoti Tumaini	Sandy clay loam	Sandy clay loam	Sandy clay loam
Shikutse	Sandy clay loam	Sandy clay loam	Sandy clay loam
Lwakhupa	Sandy loam	Sandy loam	Sandy clay loam

Pearson's correlation revealed no correlation between the soil textural classes and sand harvesting activities (r= .000, p= 0.05). One Way ANOVA analysis revealed no significant differences between soil textural classes for the control and sand harvesting groups ($F_{(1,28)}$ =.000, p=1.000). Similarly, independent sample t-test revealed no statistically significant effect of sand harvesting on riparian soil textural classes ($t_{(28)}$ = .000, p = 1.000).

4.4 Impact of River Sand Harvesting on Floral and Soil Macro-Fauna Biodiversity

Tree species abundance are given in Table 4. A total of 27 tree individuals belonging to 8 different tree species were sampled in the study area along the two selected rivers. Species richness was (N=8) which were both indigenous and exotic and belonged to 7 different families (Table 7). *Psidium guajava* was observed in all sites either as a sapling or a tree except at Kwa Thomas site. *Eucalyptus saligna* was the most abundant species (n=10) followed by *Pinus patula* (n=4). The least abundant species was *Bischofia javanica* (n=1). *Eucalyptus* had been rampantly grown even in sensitive ecosystems like the riverbanks.

Pearson's correlation revealed that change in tree species abundance negatively correlated with increase in sand harvesting activities (r= -.364, p= 0.05). One Way ANOVA analysis revealed that the differences between tree abundance for the control and sand harvesting groups were statistically significant ($F_{(1,28)}$ =4.266, p=0.048). Similarly, independent sample t-test revealed that sand harvesting statistically significantly affected tree abundance in the riparian area ($t_{(28)}$ = 2.066, p = 0.048).

Table 4: Tree species observed in the quadrats studied

Species	**Family**	**Type**	**Abundance (in %)**		
			June 2020	**Sep 2020**	**Dec 2020**
Croton megalocarpus	Euphorbiaceae	Indigenous	11	11	10
Prunus africana	Rosaceae	Indigenous	7	7	5
Eucalyptus saligna	Myrtaceae	Exotic	37	37	39
Psidium guajava	Myrtaceae	Exotic	7	7	11
Cordia africana	Boraginaceae	Indigenous	7	7	6
Markhamia lutea	Bignoniaceae	Indigenous	11	11	7
Pinus patula	Pinaceae	Exotic	15	15	16
Bischofia javanica	Phyllanthaceae	Exotic	4	4	4
Total			**100**	**100**	**100**

Species diversity of different flora are given in Table 5. At Lusumu B, there was a eucalyptus plantation, with only 5 indigenous trees (*Markhamia lutea* and *Cordia africana*) near the riverbank hence the low tree species diversity index. However, Shamberere had a higher tree diversity index compared to Lusumu B. Shamberere had natural vegetation (*Croton megalocarpus, Prunus Africana* and *Markhamia lutea*) which allowed for natural regeneration, while Lusumu B had a *Eucalyptus* plantation by the riverbank which restrained natural regeneration of the two indigenous species (*Croton megalocarpus* and *Markhamia lutea*) available at the riverbank. At Kwa Thomas, there was only 1 tree species (*Eucalyptus saligna*) resulting in a tree diversity index of zero in June and September 2020 (Table 5). A comparison of data on tree species diversity index using Pearson correlation analysis revealed that, there was no correlation between the tree species diversity index and sand harvesting activities (r=.125, p= 0.05).

For saplings, a total of (N=36) tree individuals belonging to 8 different sapling species were sampled in the study area along the two selected rivers (Table 6). Species richness was (N=8) which were both indigenous and exotic and belonged to 7 different families (Table 9). *Bambusa vulgaris* and *Calliandra calothyrsus* were the most abundant sapling species (n=7) in June 2020, due to the river system restoration efforts being made by WRUA members. In December 2020, *Datura stramonium* and *Psidium guajava* were the most abundant species (n=6). *Datura* is a common agricultural weed while *Psidium* is an invasive species. The sapling diversity index was highest at Mwera (1.5866) followed by Lusumu B (1.3648) and Shamberere (1.3337) control sites. The species diversity index during the rainy season at Mwera and Ndombi bridge was slightly higher probably because the two sites had been abandoned and were under rehabilitation through the planting of trees.

Table 5: Species diversity of different floral types along riverbanks in Kakamega County

Site	Floral diversity index								
	Trees			**Saplings**			**Herb**		
	June 2020	**Sep 2020**	**Dec 2020**	**June 2020**	**Sep 2020**	**Dec 2020**	**June 2020**	**Sep 2020**	**Dec 2020**
Control Group									
Shamberere	1.08	1.09	1.38	1.27	1.33	1.30	1.60	1.63	1.60
Kwa Thomas	0.00	0.00	1.10	0.00	0.44	0.68	1.22	1.29	1.28
Lusumu B	0.44	0.45	0.47	1.35	1.36	1.36	1.39	1.13	1.17
Mwera	1.15	1.15	1.20	1.58	1.59	1.59	1.12	1.37	1.15
Ndombi Bridge	1.04	1.02	1.33	1.05	1.11	1.21	1.20	1.29	1.24
Quasi-experimental Group									
Shikhunga	0.89	0.77	1.21	0.56	0.45	0.97	0.94	0.87	0.97
Lumanyasi Bridge	1.31	1.12	1.44	1.24	1.21	1.28	0.97	1.05	1.07
Shikoti	0.66	0.96	1.04	1.01	1.04	1.09	0.95	0.89	0.99
Shikutse	0.69	0.68	0.64	0.68	0.67	0.69	1.25	1.21	1.31
Lwakhupa	1.10	0.90	0.87	1.06	1.06	1.08	1.25	1.20	1.31

Pearson's correlation revealed that change in sapling abundance negatively correlated with increase in sand harvesting activities (r= -.384, p= 0.05). One Way ANOVA analysis revealed that the differences between sapling abundance for the control and sand harvesting groups were statistically significant ($F_{(1,28)}$ =4.838, p=0.036). Similarly, independent sample t-test revealed that sand harvesting statistically significantly affected sapling abundance in the riparian area ($t_{(28)}$ = 2.200, p = 0.036).

Table 6: Sapling species observed in the quadrats studied

Species	Family	Type	Abundance (in %)		
			June 2020	**Sep 2020**	**Dec 2020**
Croton megalocarpus	Euphorbiaceae	Indigenous	9	9	11
Calliandra calothyrsus	Fabaceae	Exotic	20	20	14
Eucalyptus saligna	Myrtaceae	Exotic	9	9	3
Psidium guajava	Myrtaceae	Exotic	11	11	17
Cordia africana	Boraginaceae	Indigenous	14	14	14
Markhamia lutea	Bignoniaceae	Indigenous	9	9	14
Bambusa vulgaris	Poaceae	Exotic	20	20	11
Datura stramonium	Solanaceae	Exotic	9	9	17
Total			**100**	**100**	**100**

A comparison of data on sapling species diversity index using Pearson correlation analysis revealed that there was no correlation between the sapling species diversity index and sand harvesting activities ($r=-.284$, $p= 0.05$).

The herbaceous species observed and identified belonged to 10 different families and 14 different herbaceous species depicting a species richness of (N=14). *Gallinsoga parviflora* was the densest species (16 in June 2020 and increased to 21 in December 2020) followed by *Pennisetum clandestinum (*17 in June 2020 and decreased to 12 in December 2020). The abundance of herbaceous individuals sampled in the study area along the two selected rivers was expressed in percent cover (Table 7).

Pearson's correlation revealed that change in herbaceous species abundance negatively correlated with increase in sand harvesting activities ($r= -.373$, $p= 0.05$). One Way ANOVA analysis revealed that the differences between herbaceous species abundance for the control and sand harvesting groups were statistically significant ($F_{(1,28)} =4.530$, $p=0.042$). Similarly, independent sample t-test revealed that sand harvesting statistically significantly affected herbaceous species abundance in the riparian area ($t_{(28)} = 2.128$, $p = 0.042$). Pearson's correlation revealed that change in herbaceous species diversity index negatively correlated with increase in sand harvesting activities ($r= -.608$, $p= 0.01$).

Table 7: Herbaceous species observed in the quadrats studied

Species	Family	June 2020		Sep 2020		Dec 2020	
		% cover	Density (per m²)	% cover	Density (per m²)	% cover	Density (per m²)
Pennisetum clandestinum	Poaceae	16.6	17	16.6	17	13.7	12
Phragmites mauritianus	Poaceae	12.0	1.2	12.0	1.2	22.0	2.2
Axonopus compressus	Poaceae	25.0	2.5	25.0	2.5	28.0	2.8
Gallinsoga parviflora	Asteraceae	15.6	16	15.6	16	20.6	21
Bidens pilosa	Asteraceae	30.0	3	30.0	3	23.0	2
Striga hermonthica	Orobanchaceae	25.0	3	25.0	3	21.0	2
Commelina bengalensis	Commelinaceae	3.5	1	3.5	1	7.0	1
Argyreia nervosa	Convolvulaceae	3.0	0	3.0	0	4.0	0
Ipomoea leucantha	Convolvulaceae	17.5	4	17.5	4	35.0	4
Oxalis latifolia	Oxalidaceae	9.0	4	9.0	4	10.5	4
Cyperus rotunda	Cyperaceae	9.5	2	9.5	2	11.5	2
Galium aparine	Rubiaceae	5.5	1	5.5	1	4.0	1
Justica flava	Acanthaceae	12.0	1	12.0	1	22.0	2
Stephania abyssinica	Menispermaceae	10.8	4	10.8	4	13.7	12

4.4.1 Evaluation of the Impacts of Sand Harvesting on Soil Macro-fauna

A total of 214 soil macrofauna individuals were found during the rainy season and 259 individuals during the dry season. These macrofauna belonged to 12 species in nine families (Table 8). *Solenopsis invicta* was the most abundant species both in June 2020 (24%, n=51) and in December 2020 (33%, n=85) and was found in selected sand harvesting sites and one control site (Lusumu B). The least abundant soil macrofauna species were *Cafius algophilus* and *Copris fallaciosus.*

Table 8: Soil macrofauna species observed in the quadrats studied

Species	Family	Abundance (in %)		
		June 2020	**Sep 2020**	**Dec 2020**
Pheidole megacephala	Formicidae	23 (n=50)	23 (n=50)	27 (n=69)
Solenopsis invicta	Formicidae	24 (n=51)	24 (n=51)	33 (n=85)
Lasius niger	Formicidae	23 (n=49)	23 (n=49)	10 (n=26)
Hodotermes mossambicus	Rhinotermididae	10 (n=22)	10 (n=22)	9 (n=24)
Odontotermes horni	Rhinotermididae	10 (n=21)	10 (n=21)	13 (n=33)
Lumbricus terrestris	Lumbricidae	1 (n=3)	1 (n=3)	2 (n=5)
Gryllotalpa africana	Gryllotalpidae	5 (n=11)	5 (n=11)	4 (n=11)
Eriophora spp	Arachnidae	1 (n=2)	1 (n=2)	1 (n=2)
Hyllus multiaculeatus	Salticidae	1 (n=2)	1 (n=2)	1 (n=2)
Blatta orientalis	Blattidae	0 (n=1)	0 (n=1)	N/A
Copris fallaciosus	Scarabaeidae	0 (n=1)	0 (n=1)	N/A
Cafius algophilus	Staphylinidae	0 (n=1)	0 (n=1)	1 (n=2)
Total		**100 (N=214)**	**100 (N=214)**	**100 (N=259)**

Pearson's correlation revealed that change in soil macrofauna species abundance negatively correlated with increase in sand harvesting activities (r= -.363, p= 0.05). One Way ANOVA analysis revealed that the differences between soil macrofauna species abundance for the control and sand harvesting groups were statistically significant ($F_{(1,28)}$ =4.250, p=0.049). Similarly, independent sample t-test revealed that sand harvesting statistically significantly affected soil macrofauna species abundance in the riparian area ($t_{(28)}$ = 2.062, p = 0.049).

Soil macro fauna diversity indices at Kwa Thomas, Shikhunga, Mwera, Ndombi Bridge and Lumanyasi Bridge were higher in June 2020 than in December 2020 while at Shikoti, Shikutse, and Lwakhupa diversity index was higher in December 2020 than in June 2020

(Table 9). The presence of earthworms at Lumanyasi Bridge in June 2020 increased its diversity index (Table 9). The control sites showed no differences in the seven-month study period. During the rainy season, *Blatta orientalis* was observed at Shikhunga sand harvesting site. The highest mean diversity index was at Kwa Thomas sand harvesting site (H'=1.26) while the lowest mean diversity index was at Shikoti sand harvesting site (H'=0.68).

Table 9: Species diversity of different soil macro fauna

Site	**Soil macro fauna diversity index**		
	June 2020	**Sep 2020**	**Dec 2020**
Control Group			
Shamberere	0.9042	0.9135	0.9042
Kwa Thomas	1.2801	1.2867	1.2424
Lusumu B	1.0953	1.1400	1.04
Mwera	0.8503	0.9132	0.7412
Ndombi Bridge	0.849	0.8510	0.6952
Quasi-experimental Group			
Shikhunga	1.4112	1.3960	0.8619
Lumanyasi Bridge	0.8899	0.8520	0.774
Shikoti	0.5848	0.5673	0.772
Shikutse	0.6695	0.6430	0.7425
Lwakhupa	0.6382	0.6210	1.04

A comparison of data on sapling species diversity index using Pearson correlation analysis revealed that, there was no correlation between the soil macrofauna species diversity index and sand harvesting activities (r= -.317, p= 0.05).

4.5 Assessment of the mitigative strategies and challenges faced by Water Resources Users Association to river sand harvesting and riverine ecosystem conservation

4.5.1 Socio-economic characteristics of the survey respondents

105 respondents from Lusumu, Lower Lubao Sasala and Upper Lubao Sasala WRUAs successfully participated in the survey. Out of the 105 respondents 56% (n=59) were men and 44% (n=46) were women (Table 10). The age of the respondents ranged from 18 to above 53 years old where 20% (n=21) were youths while majority of the participants (33%, n=33) were between the age of 36 to 41. Based on the responses on the questionnaires, 60% (n=63) of the respondents were active in WRUA activities. 5% (n=5) were somewhat active while 33% (n=35) did not answer and 1% (n=1) was not active.

Table 10: Gender, family size and level of schooling of the WRUAs

Name of WRUA	Lusumu	Upper Sasala	Lower Lubao Sasala	Total percent
Gender				
Male	49% (n=17)	57% (n=20)	63% (n=22)	56% (n=59)
Female	51% (n=18)	43% (n=15)	37% (n=13)	44% (n=46)
Family size				
2-5	40% (n=14)	46% (n=16)	29% (n=10)	38% (n=40)
6-9	37% (n=13)	37% (n=13)	49% (n=17)	41% (n=43)
Above 10	3% (n=1)	14% (n=5)	17% (n=6)	11% (n=12)
N/A (single)	20% (n=7)	3% (n=1)	6% (n=2)	10% (n=10)
Level of schooling				
Primary level and below	29% (n=10)	43% (n=15)	11% (n=4)	28% (n=29)
Secondary level	49% (n=17)	31% (n=11)	57% (n=20)	46% (n=48)
Diploma level	14% (n=5)	11% (n=4)	31% (n=11)	19% (n=20)
Bachelor’s degree level	9% (n=3)	11% (n=4)	0% (n=0)	7% (n=7)
Post-graduate level and above	0% (n=0)	3% (n=1)	0% (n=0)	1% (n=1)

A total of 61% (n=64) of the survey respondents considered the level of sand harvesting to be rampant (33% as high, 28% as very high) in their area of jurisdiction (Figure 14).

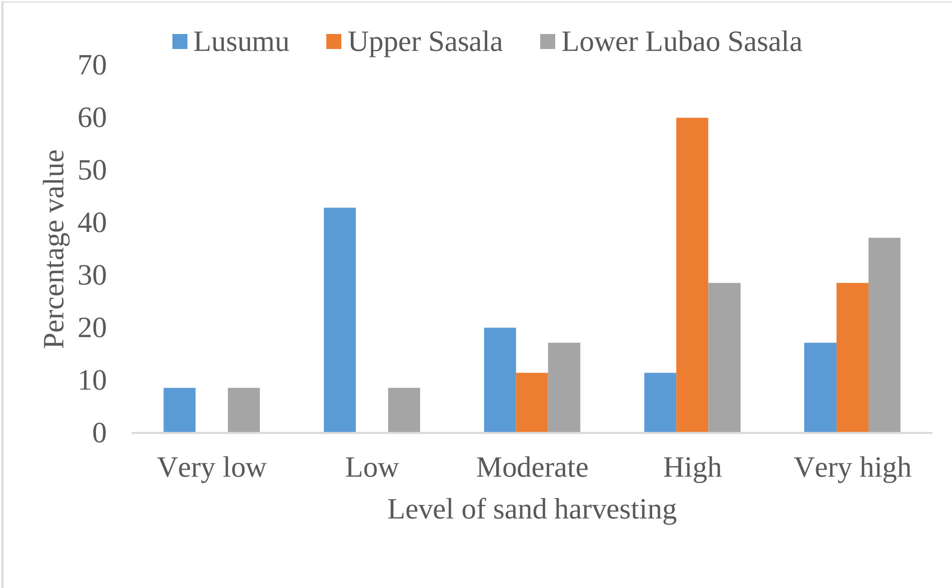

Figure 14: Level of river sand harvesting

Of the 64 respondents (61%) who considered level of sand harvesting to be rampant, 16% (n=10) were from Lusumu WRUA, 48% (n=31) from Upper Sasala WRUA which was a newly formed WRUA as per the responses given and 36% (n=23) from Lower Lubao Sasala.

4.5.2 Mitigative strategies by Water Resource Users Association on riverine system conservation

Besides being WRUA members, the 105 respondents also engaged in other daily activities. Some of them engaged in farming 63% (n=66), others in enterprising activities such as owning shops 22% (n=23), others were involved in transport sector business as motorbike riders 13% (n=14) and others were retired employees 2% (n=2). Of the 105, 10% (n=10) were employed as either teachers or casual labourers in construction sites and salons.

Fifty seven percent (57%; n=60) had environmental concerns including damage of riverbanks as a reason that influenced them to be WRUA members, 20% (n=21) joined because they wanted to develop their communities either through creating awareness and promoting nature-based enterprises, 17% (n=18) joined because they wanted personal growth through creating networks and receiving trainings and 2% (n=2) joined because activities taken part in as a WRUA members played a role in their source of income activities.

The WRUA members identified eight mitigative strategies that they used in addressing river ecosystem issues (Figure 15). The most significant mitigative strategy applied was planting of water friendly trees which was applied by 83% of the WRUA members. These trees included indigenous and native trees that can withstand the wet conditions of the riverbank area. The tree species planted included *Pinus spp*, *Croton spp* and *Cordia spp* which were part of the tree species sampled for floral diversity. This was the most applied strategy. The strategy was evident during the site visits. For instance, there were also evident restoration efforts at Ndombi Bridge using trees (Plates 4 and 12). At Lwakhupa sand harvesting site, indigenous trees and bamboo had been planted on one side of the river while the other side of the river was neglected.

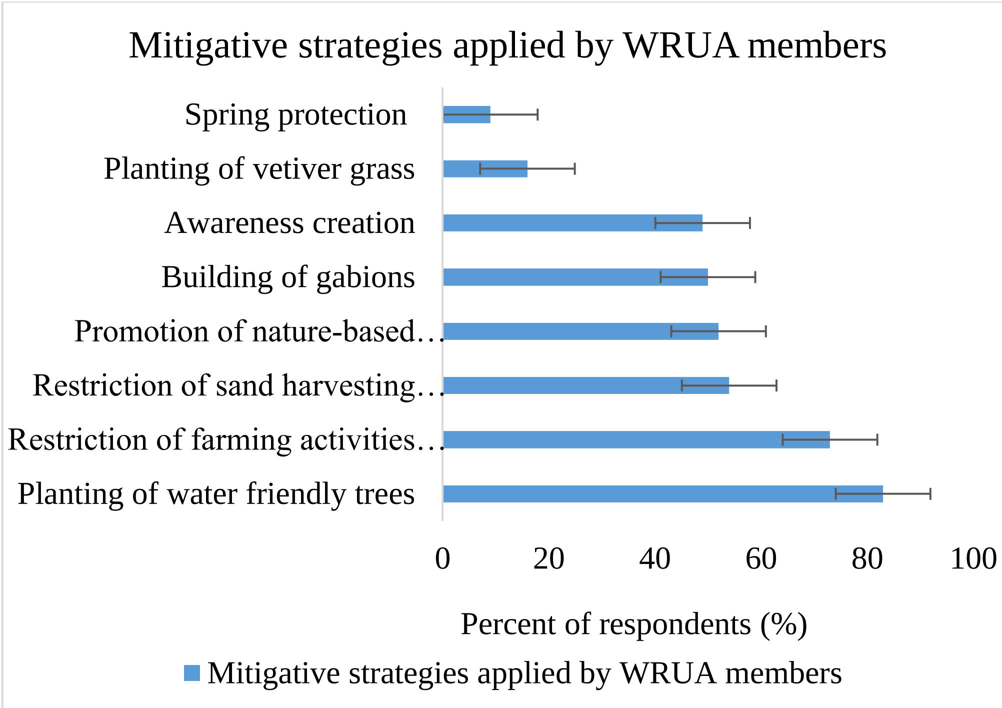

Figure 15: Mitigative strategies applied by WRUA members

Other strategies applied included restriction of farming activities on riparian zones (73%) of the WRUA members, restriction of sand harvesting in rivers (54%), promotion of nature-based enterprises (52%), building of gabions (50%), awareness creation (49%) and spring protection (9%) (Figure 15).

4.5.3 Capacity of the WRUA members to mitigate sand harvesting and riverine system conservation challenges

Figure 16 shows responses by WRUA members on their ability to understand concepts related to river system conservation. An average of 64% (n=68) expressed understanding and ability to relate concepts related to WRUAs role and river system conservation and to their work as WRUA members. The least understood concept was alternative sustainable use of the riparian zone which only 40% (n=42) understood while the most understood concept was causes of river system degradation which was understood by 73% (n=77) of the respondents.

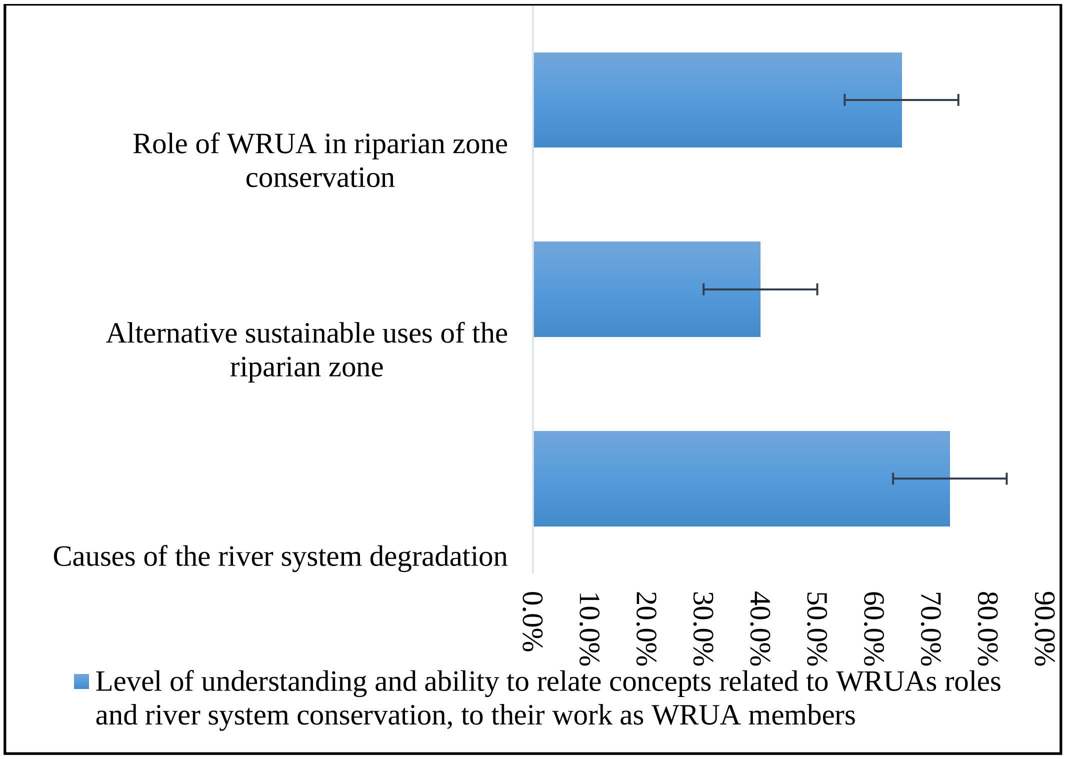

Figure 16: WRUA members' ability to understand and relate concepts related to WRUAs role and riverine ecosystem conservation.

Twenty-nine (29%) percent (n=30) of the respondents reported that they had not received any form of training. Of the 29% (n=30), 90% (n=27) were from Lower Lubao Sasala WRUA, 7% (n=2) from Lusumu WRUA and 3% (n=1) from Upper Sasala WRUA (Figure 17). The Lower Lubao Sasala WRUA was newly formed and that may explain the absence of training.

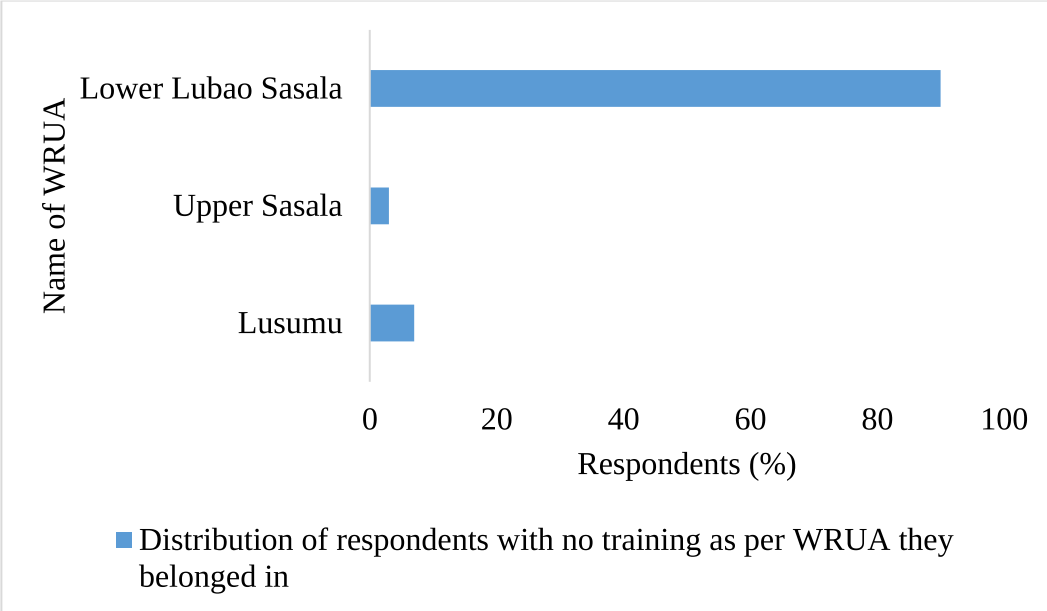

Figure 17: Distribution of WRUA members with no training as per WRUA they belonged in.

Majority of the respondents (71%, n=74) reported that they had received some form of training, with 93% (n=69) having received agricultural related training. All of them had received environmental, leadership and governance, resource mobilization and financial management, and networking and collaboration related trainings (Figure 18).

From the responses, 42% (n=44) were not contented with the training received. The 42% indicated that there was still a skills gap despite having received environmental training.

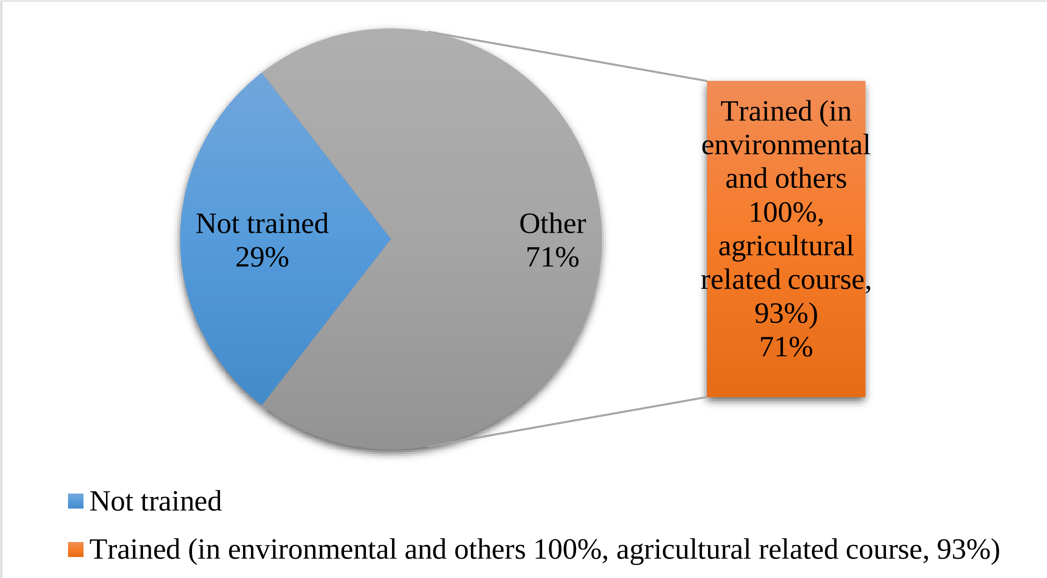

Figure 18: Kind of training received by WRUA members.

4.5.4 Challenges of River System Conservation

There were a few challenges being faced while addressing river ecosystem issues. A major challenge identified by respondents was lack of an advisory unit (69%, n=72). There appear to be no recognized organization to advise and consult on issues and regulation of sand harvesting. There were 31% (n=33) respondents who mentioned county government officers such as administrators and water officers and national government officers such as chiefs, Water Resources Authority (WRA) and National Environmental Management Authority (NEMA) officers as the people they consulted.

Another challenge was level of confidence in addressing river system conservation issues at the grassroot level. Majority of the respondents (69%, n=72) were very confident that they could address sand harvesting issues, while 31% (n=33) still had confident issues that needed addressing. Level of confidence is always attributed to inadequacy in capacity or related skills because to address the level of confidence issue, the majority of them (92%, n=97) mentioned training as a confidence booster and financial support (5%, n=5) as the least of concerns.

Table 11 shows the remedies proposed for boosting confidence among WRUA members. The WRUA members noted that to boost their confidence, more training sessions on sand harvesting should be conducted 92% (n=97). In addition, they added guidelines, tools and methods on possible river system mitigative strategies should be provided to them 68% (n=71), awareness creation activities on sustainable sand harvesting should be carried out 62% (n=65) and case studies or best practices dissemination 46% (n=48) as other confidence boosters.

Table 11: Remedies on raising the level of confidence among WRUAs

Proposed remedies	**Per cent**
Training sessions on sand harvesting.	92
Guidelines, tools and methods on possible mitigative strategies	68
Case studies/ best practices dissemination	46
Awareness creation activities on sustainable sand harvesting.	62
Other (s) Please mention: e.g. How to stop soil erosion on sloppy land, financial support etc.	5

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter discusses the findings of the study on the river sand harvesting and challenges of riparian ecosystem conservation in Kakamega County, Kenya.

5.2 Assessment and Spatial Distribution of Sand Harvesting Activities

Sand harvesting activities were rampant especially in river Shiatsala probably because the river was easily accessible and shallower than River Lusumu. Access roads are vital for sand harvesting activities. Arwa (2013) in his study done in Machakos County Kenya, extensively discussed the issues, including stating some community members surrendering their land to be used as access roads. In addition, Department of Irrigation and Drainage (DID) (2009) study showed that in-stream sand harvesting was rampant in Malaysia because sand harvesting sites were usually near urban centres or along a transportation route, which could reduce transportation costs. Hence, this affirms the reason why most of the sand harvesting sites in this study were located close or along access roads. However, according to National Environmental Management Authority (NEMA, 2007) river sand harvesting should not take place within 100 meters of either side of physical infrastructure including bridges and roads, which most of the hotspots contravened.

The sand harvesting hotspots were distributed along river Shiatsala and Lusumu, within rural areas of Malava, Navakholo and Lurambi Sub Counties. Similarly, Muendo (2015) noted in his study that the increasing demand for sand had resulted in sand harvesting at increasing rates at the seasonal rivers flowing through the rural areas of Machakos County.

Sand harvesting hotspots had observable features like riverbank erosion, destruction of vegetation covers due to footpaths and vehicle tracts, cutting down of trees and the presence of oil droplets from the sand carrying lorries and tractors (Plates 8-11). These are localized effects by sand harvesting activities that degraded the aesthetic value of these riparian areas, making them more prone to bank and soil erosion. This increased siltation into the rivers. Kariuki (2002), agreed to the fact that sand mining has direct impact on the physical environment through degradation of their aesthetic value and to the biodiversity. Similar findings were observed in a study by Arwa (2013) where soil erosion and reduced vegetation were similarly mentioned as some of the environmental impacts. The amount of sand harvested was demand-driven and varied with the rainy season having higher demands compared to the dry season. Similarly, respondents in Madyise & Moja (2013) study mentioned that they harvested sand or bought sand only when they needed it, thus affirming the demand-driven aspect of sand harvesting. Shikoti, which is a sand harvesting site on the middle part of river Shiastala recorded the highest amount of sand harvested. Similarly, John, Maya & Padmalal (2014) study in India on River Periyar, concluded that relatively larger amounts of sand were harvested in the middle parts.

5.3 Effect of River sand Harvesting on River Water Quality and Soil Physico-Chemical Properties

The changes in river width analyses using satellite imageries show that, little or no sand harvesting activities happened around 2005, as all the sampling sites had little or no evidence of harvesting such as access paths created and/or bare-unvegetated sites near the riverbank. However, in 2019, evidence of sand harvesting such as existence of bare-unvegetated sites and access paths sand were visible at the sand harvesting sites. This is because the Google Earth Pro application provided a detailed view of the channel and river bank lines as the imageries are at spatial resolutions from Landsat (15–30 m) to QuickBird (60 cm) (Liang, Gong & Li, 2018). Also, all sampling sites had agricultural activities but little infrastructural developments as of 2005, for instance, the Ndombi Bridge sampling site had no access road in 2005 but in 2019 satellite imagery and 2020 site visits, there was a bridge with an access road. In addition, an increasing trend in channel width, degradation of riparian vegetation and erosion of riverbanks was noted at the sand harvesting sites. This is because Google Earth is a virtual world software that gives free, easy and stable access to a global inventory of satellite imagery collections (Liang & Li, 2018). The significant increase in channel width observed in sand harvesting sites in 2019 could probably be attributed to sand harvesting activities that resulted to increase of river flow rates, water depth and velocities. These are the factors that increase riverbank erosion rates (Duan et al., 2018). Oyoo (2021) also noted soil erosion and river bank collapsing as the leading effects of sand harvesting in his study. The negligible increase at the control sites could be attributed to natural occurrences such as flooding, a phenomena of climate change, that naturally contributes to riverbank erosion as suggested by El-Dien et al. (2015).

Lumanyasi Bridge, Shikoti and Lwakhupa, sites had extremely higher TSS values. Yen & Rohasliney (2013), Aazami et al. (2015) and Lwanga et al. (2022) concluded in their studies that extremely high levels of TSS were as a result of sand harvesting activities. However, Yen & Rohasliney (2013) also noted logging activities in the upstream areas as a contributing factor. All the control sites, had almost similar TSS value in June and December 2020, despite December being a dry season. This could be attributed to reduced water levels in the river channel during the dry season and as a result the suspended sediments from the riverbank erosion were concentrated within the reduced water column making the TSS value to be higher than in the dry season (Kilonzo et al., 2019). For Mwera control site, the TSS value slightly increased in September 2020 which was a rainy season. The reason is because naturally, runoff from rainfall allows for increased silt and clay to flow into the river from the catchment (Prasanna & Ranjan 2010).

Higher turbidity levels recorded during September 2020 which was a rainy season resonates with study by Yen & Rohasliney, (2013) which asserted that was expected because rivers usually tend to have higher turbidity during the rainy season. There was statistically significant difference in turbidity levels between the control sites and the sand harvesting sites. Sites with higher amounts of sand harvested (Lumanyasi Bridge, Shikoti and Lwakhupa) had extremely higher turbidity levels during the rainy season. These are the mid parts of the rivers (Figure 5). Study by John, Maya & Padmalal (2014) concluded that, larger amounts of sand were harvested from the midland part of the Periyar river compared to highlands and lowlands physiographic zones of the river. This clearly shows that sand harvesting caused rise in river turbidity levels. In addition, sand harvesting was observed to be the main cause of high turbidity in the Kelantan River for years (Yen & Rohasliney, 2013).

There was negative correlation between total nitrogen content and sand harvesting activities as well as significant differences between total nitrogen content for the control and sand harvesting groups. Similarly, there was statistically significant effect of sand harvesting on riparian soil total nitrogen content. This could be because of the probability that sand harvesting reduces rate of nitrogen mineralization (Saviour & Stalin, 2012), hence could be the probable reason why nitrogen content was affected by the sand harvesting activities. This study added that the deficiency of nitrogen in sand mined soil is often due to the lack of adequate mineralizable organic nitrogen. A Similarly, Ayuke's (2010) study noted soil disturbance can affect soil nitrogen content. River sand harvesting and loss of riparian vegetation are some of the causes of riverbank soil disturbance.

There was negative correlation between soil organic carbon content and sand harvesting activities as well as significant differences between soil organic carbon content for the control and sand harvesting groups. Similarly, there was statistically significant effect of sand harvesting on riparian soil organic carbon content. Saviour & Stalin (2012) also noted in their study that organic carbon level in soil dumps from sand mining of different ages was found to be very poor. The primary impacts of river sand harvesting are the direct removal of vegetation (Lwanga et al., 2022), a phenomenon which could affect soil organic carbon stabilization (Guo et al., 2016). and This could be because vegetation changes following short disturbance events and succession may strongly alter soil organic carbon chemical composition in forested ecosystems, such as riparian areas, as suggested by study done by Guo et al. (2016). River sand harvesting activities studied in this research is one of the short-term disturbances of riparian areas.

Although Ayuke's (2010) study also noted soil disturbance can affect soil phosphorus content, there was no correlation between the phosphorus content and sand harvesting activities and neither was their significant differences between phosphorus content for the control and sand harvesting groups. Similarly, there was no statistically significant effect of sand harvesting on riparian soil phosphorus content. This could be because the short-term period of this study could not manifest the indirect impact of sand harvesting on soil phosphorus content, as the primary impacts of river sand harvesting are the direct removal of vegetation (Lwanga et al., 2022), a phenomenon which could affect soil phosphorus content. Similarly, Zhao et al. (2011) insinuated in their study that it is also possible that the effects of removal of understory vegetation (a direct impact of sand harvesting activities) on soil physical and chemical properties may be manifested in the long term but not in the short period of their study. Hence, there is a high probability with prolonged and longer-term sand harvesting activities at these sand harvesting sites, the scenario would change and soil phosphorus content may be affected.

Although Ayuke's (2010) study also noted soil disturbance can affect soil moisture content, there was no correlation between the percent moisture content and sand harvesting activities and neither was their significant differences between percent moisture content for the control and sand harvesting groups. Similarly, there was no statistically significant effect of sand harvesting on riparian soil percent moisture content. This because the topsoil of most riparian areas in the sand harvesting sites were not excessively eroded or mixed up with sand, a situation, which Saviour & Stalin (2012) insinuated in their study and when coupled with use of heavy machinery, led to change in moisture content level in sand harvesting sites in India. Hence, there is a high probability with prolonged and longer-term sand harvesting activities at these sand harvesting sites, the scenario would almost be similar hence moisture content would be affected.

There was positive correlation between soil pH and sand harvesting activities as well as significant differences between soil pH for the control and sand harvesting groups. Similarly, there was statistically significant effect of sand harvesting on riparian soil pH, as the soil pH decreased in the sand harvesting sites during the end of the seven-month study period. This finding is similar to the study done by Zhao et al. (2011) which noted that removal of plants, a direct impact of sand harvesting activities, significantly decreased soil pH.

There was no correlation between the soil textural classes and sand harvesting activities and neither was their significant differences between soil textural classes for the control and sand harvesting groups. Similarly, there was no statistically significant effect of sand harvesting on riparian soil textural classes content. This because the topsoil of most riparian areas in the sand harvesting sites were not excessively eroded or mixed up with sand, a situation, which Saviour & Stalin (2012) insinuated in their study and when coupled with use of heavy machinery, led to change in soil textural classes in sand harvesting sites in India. Hence, there is a high probability with prolonged and longer-term sand harvesting activities at these sand harvesting sites, the scenario would almost be similar hence riparian soil textural classes would be affected.

5.4 Impact of River Sand Harvesting on Floral and Soil Macro-Fauna Biodiversity

There was negative correlation between tree abundance and sand harvesting activities as well as significant differences between tree abundance for the control and sand harvesting groups. Similarly, there was statistically significant effect of sand harvesting on tree abundance. This is because the primary impacts of river sand harvesting are the direct removal of vegetation (Lwanga et al., 2022). *Psidium guajava* was one of the species observed in all the sand harvesting sites either as a sapling or a tree. It is considered an invasive species in most parts of Kenya (Kawawa et al., 2016). *Eucalyptus saligna* was the most abundant species, planted even in some of the control sites, followed by *Pinus patula*. The least abundant species was *Bischofia javanica* which is known to treat skin diseases (Panda et al., 2020). Also, *Prunus africana* has been used for generations in African traditional medicine to treat prostate cancer (Nambooze et al., 2022). Hence empasising that riparian areas contain valuable biodiversity. *Eucalyptus* had been rampantly grown even in sensitive ecosystems like the riverbanks. A similar case where eucalyptus was being planted in sensitive ecosystems was in Nyanturago water catchment in Kisii Kenya (Menge, 2013). Studies by Agevi et al (2019) and Agevi (2020) found out that this tree is more abundant in this region.

At Lusumu B, which is a control site, there was a eucalyptus plantation, with only 5 indigenous trees (*Markhamia lutea* and *Cordia africana*) near the riverbank hence the low tree species diversity index. However, Shamberere had a higher tree diversity index compared to Lusumu B. Shamberere had natural vegetation (*Croton megalocarpus*, *Prunus Africana* and *Markhamia lutea*) which allowed for natural regeneration, while Lusumu B had a *Eucalyptus* plantation by the riverbank which restrained natural regeneration of the two indigenous species (*Croton megalocarpus* and *Markhamia lutea*) available at the riverbank. Native tree species seedling emergence was noted to be inhibited by the roots of eucalyptus trees (Zhang et al., 2016).

At Shikhunga, Lumanyasi Bridge, Shikoti, Shikutse and Lwakhupa sand harvesting sites, there was lower tree diversity indices. This may be explained perhaps by the fact that there was evidence of cutting down trees during the rainy season, probably to create access paths for the sand harvesters. Madyise & Moja (2013) also noted destruction of vegetation along river banks to make access roads into sand harvesting areas as one of the negative effects of sand harvesting activities. Hence, the reduced sand harvesting activities during the dry season allowed for the growth of the saplings to trees thus increasing the diversity index.

Bambusa vulgaris and *Calliandra calothyrsus* were the most abundant sapling species in June 2020, due to the river system restoration efforts being made by WRUA members. In December 2020, *Datura stramonium* and *Psidium guajava* were the most abundant species at the sand harvesting sites compared to the control sites. The two sapling species (*Datura stramonium* and *Psidium guajava*) may have taken advantage of the gap created through the felling of trees. *Datura* is a common agricultural weed while *Psidium* is an invasive species. The abundance of *Datura* could be because it is a colonizing annual weed characterized by high rates of growth (Valverde, 2003). The fact that *Psidium* which is an invasive species was also the most abundant species observed agrees with Koehnken & Rintoul (2018). The two reported that sand harvesting impacts on plant population and diversity included the loss of some native riparian zone species and an increase of invasive species. There was negative correlation between sapling species abundance and sand harvesting activities as well as significant differences between sapling species abundance for the control and sand harvesting groups. Similarly, there was statistically significant effect of sand harvesting on sapling species abundance. This is because the primary impacts of river sand harvesting are the direct removal of vegetation (Lwanga et al., 2022). *Gallinsoga parviflora* was the densest herbaceous followed by *Pennisetum clandestinum* in June 2020, which decreased in December 2020 in all control sites due to onset of dry season. At Shikhunga, Lumanyasi Bridge, Shikutse, Mwera and Lwakhupa sand harvesting sites, the herbaceous plants were able to thrive due to the breathing space offered as a result of reduced sand harvesting activities in December 2020 that allowed for their growth. The *Eucalyptus* plantation at Lusumu B, a control site, probably did not allow for undergrowth making it hard for some herbs to thrive, hence the reduced herbaceous species diversity index. *Pennisetum clandestinum* is a common grazing grass, hence explains the decrease in density during the dry season. While, *Gallinsoga parviflora* is a common herb often found in disturbed habitats besides agricultural areas. *Gallinsoga* lacks seed dormancy, grows and develops rapidly, flowers early, has many generations per growing season, and produces a great number of seed in a wide range of environmental circumstances, making it to be a troublesome weed (Damalas, 2008). Hence explains the high density of *Gallinsoga* and its increase in density during the dry season. In general, there was negative correlation between herbaceous species abundance and sand harvesting activities as well as significant differences between herbaceous species abundance for the control and sand harvesting groups. Similarly, there was statistically significant effect of sand harvesting on herbaceous species abundance. This is because the primary impacts of river sand harvesting are the direct removal of vegetation (Lwanga et al., 2022).

Solenopsis invicta was the most abundant species and was found in selected sand harvesting sites and one control site (Lusumu B). The least abundant soil macrofauna species were *Cafius algophilus* and *Copris fallaciosus. Solenopsis spp* diet consists of dead animals, including insects, earthworms and vertebrates (Collins & Scheffrahn, 2002). Probably the reason they were more abundant. During the rainy season, *Blatta orientalis* was observed at Shikhunga sand harvesting site. The reason could be because the soil was so moist and damp. The least abundant soil macrofauna species were *Cafius algophilus.* The reason is because *Cafius algophilus* prefer open habitats where cattle dung exist (Jay-Robert et al., 2008). The species was found at Lwakhupa sand harvesting because the site was near a cattle watering site. Shikoti, Shikutse and Lwakhupa dry season diversity index were higher because the sand harvesting activities were reduced in December 2020, allowing for soil macrofauna such as brown ants and spiders to thrive. Termites also were present which could be attributed to the fact that the sites had sandy clay loam soil in December 2020, an environment where termites do survive. Similarly, at Lusumu B, a control site, predatory red ants and black ants thrived in December 2020.

The presence of earthworms at Lumanyasi Bridge could be attributed to conservational efforts being done at the sampling site, despite the rampant sand harvesting activities, as trees such as *Pinus patula, Croton spp* and *Cordia africana* were present at the site. Termites were noted to be more abundant in December 2020. This could be attributed to the fact that all the sites had a loam (some degree of silt)-sand (silica) soil texture. Termites are humivores insects that deliberately feed on mineral soil, with some degree of selection of silt and clay fractions and higher proportions of Soil Organic Matter (SOM) and silica, and lower proportions of recognizable plant tissue than in other groups.

Earthworms feed on dead organic material and convert nutrients to a form plant can use. Probably explains the reason why their abundance was low in all the sand harvesting sites. *Lasius spp*- black ants follow well–defined trails around food sources. They prefer sweet foods though they may also take foods with high protein. Hence, the reason why they were largely observed at all the sampling sites except Shamberere, as sugarcane farming was done close to the riverbanks. *Gryllotalpa africana*, *Cafius algophilus*, *Hodotermes mossambicus* and *Odontotermes horni* are considered sources of food and medicine in the soil. They were abundant in the control sites in Septemebr 2020, when predatory insects were less abundant. Spiders and predatory beetles are predators that hunt for pests in leaf litter and the soil, and were abundant in the sand harvesting sites. In general, there was negative correlation between soil macrofauna species abundance and sand harvesting activities as well as significant differences between soil macrofauna species abundance for the control and sand harvesting groups. Similarly, there was statistically significant effect of sand harvesting on soil macrofauna species abundance. This is because the primary impacts of river sand harvesting are the direct removal of vegetation (Lwanga et al., 2022), an impact that indirectly affects existence of soil moacrofauna (Ayuke, 2010).

5.5 Assessment of the mitigative strategies and challenges faced by Water Resources Users Association to river sand harvesting and riverine ecosystem conservation

The WRUA members identified eight mitigative strategies that they used in addressing river ecosystem issues. The most applied river system conservation strategy was planting of water friendly trees (83%) while the least applied was spring protection (9%). A study on sand harvesting in Machakos County by Arwa (2013) revealed that building of gabions, creation of alternative job opportunities for the community, restricting sand harvesting, tree planting and provision of alternative water sources were among the recommended environmental improvements mentioned by his survey respondents. In Kakamega County, similar mitigative strategies were observed to be implemented by WRUAs.

Farming is the main socio-economic activity in the rural areas of the study area. Due to population growth, people adjacent to rivers and streams have the tendency to farm to the riverbanks. Hence, restriction of farming activities on riparian zones involved enforcement as per the Environmental Management and Coordination, (Water Quality) Regulations 2006. Sites where there was diverse biodiversity such as indigenous trees with cultural or medicinal importance formed part of the restricted sites for sand harvesting. Similarly, Oyoo (2021) recognized that enacting necessary legislative laws related to flora and fauna conservation as a sustainable measure.

Having positive awareness programmes on conservation measures of biodiversity is a sustainable measure (Oyoo, 2021). As a result, the community may take part in river system conservational activities and the sand harvesters may practice sustainable sand harvesting activities. Vetiver grass (*Vetiveria zizanioides*) is important in protecting the watershed as it slows down and spread runoff on farms, recharges the ground water, reduces siltation of river channels and water bodies, reduces agro-chemicals loading into water bodies and rehabilitates degraded soils (Jiru & Wari 2019). Promotion of nature-based enterprises was another strategy applied. The strategy involved carrying out environment friendly activities as alternative sources of income. These activities included tree nursery establishment, bee keeping and rearing of fish in ponds. Spring protection was the least applied strategy by 9% of the WRUA members. It involved conserving the natural springs in the catchment area where the community obtains water for domestic use and for drinking. This is an adaptative strategy as its intention is to provide alternative sources of safe and clean water for drinking and domestic use.

Capacity of WRUA members to mitigate sand harvesting and riverine system conservation challenges was assessed based on the trainings received and level of understanding of river system conservation concepts. The 90% from Lower Lubao Sasala WRUA cited that the WRUA was newly formed as the reason for having not received any form of training yet. Probably, there was a river system conservation need that necessitated its formation. There were indications that there was still a skills gap despite some WRUA members having received environmental training. There was still need to increase their capacity and knowledge on river system conservation.

However, there were challenges being faced by WRUAs in their line of duty. One of the challenges faced was lack of an advisory unit, that is recognized to advise and consult on sand harvesting issues. This is because the Sand Harvesting Guidelines of 2007 became obsolete when devolution was introduced as it refers to districts (Arwa, 2013). And in Kakamega there is yet a law that gives effect to a sand advisory unit or management committee. This is because the County Government Act, 2012 urges counties to conserve the environment which includes riparian areas, from sand harvesting cess fees.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter contains the conclusions made and recommendations on the river sand harvesting and challenges to riparian conservation in Kakamega County, Kenya.

6.2 Conclusion

Sand harvesting is key for any development to occur, however harvesting it and the activities that accompany it are rampant within Shiatsala and Lusumu rivers. This clearly show that these rivers are facing significant pressure from river sand harvesting driven by construction demands from the urban centres and the development of modern facilities.

River sand harvesting activities impact water quality through re-suspension of sediments in the river resulting in temporary increased turbidity. This makes the river waters unfit for domestic use. River sand harvesting also degrades the aesthetic value of the riparian areas. As a result, rivers become prone to bank and soil erosion, thereby increasing siltation into the rivers. It is evident from the results of this study that soil disturbance by sand harvesting activities affected the soil physico-chemical properties such as moisture content, total nitrogen, phosphorous and organic carbon to some extent, thus putting productivity of riparian land at risk.

From the results, it is evident that invasive species such as *Psidium guajava* are becoming dominant in sensitive and ecologically important ecosystems including riparian areas. *Eucalyptus* is been rampantly grown even in these sensitive ecosystems. In addition, river sand harvesting activities has a significant impact on the herbaceous diversity and allows for growth of troublesome weed such as *Gallinsoga* and *Datura.* The soil macrofauna diversity was also affected with *Solenopsis* being the most abundant species observed. *Solenopsis invicta* was the most abundant species both during the rainy season and the dry season and was found in selected sand harvesting sites and one control site (Lusumu B) which had a *Eucalyptus* plantation at the riparian area. Despite that, it is also evident that there are river system restoration efforts being made by WRUA members.

Mitigative strategies are being applied by WRUA members. However, there is no evidence for nature-based enterprises being promoted at the riverbanks. There were a lot of challenges on restricting farming activities and the ongoing rampant sand harvesting activities. Notably, there was no unit or entity to advise and consult on sand harvesting issues.

6.3 Recommendations

There is a need for the County Government and other relevant authorities to regulate sand harvesting activities to avoid haphazard sand harvesting activities, by licensing the sand harvesters. Through this, the county can also get revenue to rehabilitate the degraded sand harvesting sites.

Given that sand harvesting degrades the aesthetic value of riparian areas and lowers the physico-chemical qualities of the soil, the government should come up with policies that can compel sand harvesters to rehabilitate sand harvesting sites instead of abandoning them in degraded states. These policies can ensure that bank erosion is well controlled and managed to enhance the water quality.

Since sand harvesting activities degrade biodiversity around riverbanks, there is a need to create awareness to sand harvesters on the river system conservation through sustainable sand harvesting practices.

The government and WRUAs need also to encourage the local community members to also engage in other economic activities such as farming and nature-based enterprises, to reduce the over-reliance on sand harvesting activities as a source of income. This is because WRUAs are key stakeholders in river system conservation.

6.3.1 Suggestions for further studies

There is a need for more studies on alternative raw materials for construction that can be used in place of river sand so as to reduce the pressure exerted on rivers for sand; How to monitor in the long-term effect of sand harvesting and its related activities on riverbank erosion, soil physico-chemical properties and riparian biodiversity; The factors that affect the effective and sustainable management of sand harvesting activities in Kakamega County so that riverine biodiversity can be conserved; and Alternative nature-based enterprises that can be promoted by WRUA members as a possible mitigative strategies for river system conservation.

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APPENDICES

APPENDIX 1: QUESTIONNAIRE FOR ASSESSMENT OF WRUAS MITIGATIVE STRATEGIES

Survey on Mitigative Strategies of WRUAs to Sand Harvesting and River System Conservation

2020

-Questionnaire-

My name is Aquila Lwanga and I am a research student. This survey is being conducted in fulfilment of my Master's Degree from Masinde Muliro University of Science and Technology. All of the answers you give will be kept private. Your identity will not be revealed to the County Government or the Water Resources Association as the survey data will be reported in a summarized form. Also, we shall code the information thus researchers will not be able to identify individual participants. The research finding will be published in a journal. Please answer the questions as honest as possible.

INTRODUCTION

In Kenya, Water Resource User Associations (WRUAs) have been formed whose members are entirely voluntary water users, including small-scale farmers and other businesses. WRUA achievements so far have included: protecting riparian land and water sources; transforming degraded land through agroforestry; reducing the illegal disposal of waste in rivers; reducing conflicts over water resources; and increasing crop yields and incomes of small-scale farmers while reducing soil erosion, among others.

Therefore, this survey aims to generate information regarding sand harvesting, river system conservation as well as the capacity of WRUAs to protect our riparian zones from sand harvesting hazards. The survey is being carried out using a questionnaire and is part of an undertaking to assess the mitigative strategies of WRUAs to sand harvesting and river system conservation, in response to a research study on riparian zone conservation.

[SCREENING QUESTION]

S1 How active would you consider yourself as a Water Resources Users Association (WRUA) Member of Kakamega County? Tick appropriately

Answer	Very active	Active	Somewhat active	Not active	I do not know
Tick					

[END SCREENING]

We are grateful for your response. Thank you for accepting to take part in this survey.

It will take about **20 minutes** to complete this survey.

A: SOCIODEMOGRAPHIC BACKGROUND (Tick appropriately)

i. In which WRUA do you belong? ________________________________

ii. Which age group do you belong to?

Answer	18-35	36-41	42-47	48-53	Above 53
Tick					

iii. What is your gender:

Male	
Female	

iv. What is your marital status?

Answer	Single	Married	Separated	Widowed
Tick				

v. If married, what is the size of your family?

Answer	2-5	6-9	Above 10
Tick			

vi. What is the highest level of schooling you have finished?

Answer	**Tick**
Primary level and below	
Secondary level	
Diploma level	
Bachelor's degree level	
Post-graduate and above	

vii. Besides being a WRUA member, what other daily activity do you engage in?

Ans.	Farming	Enterprising (e.g. shop)	Transport sector (e.g. Boda)	Employed (e.g. teacher)	Other (please mention)
Tick					

B: PERCEIVED RELEVANCE OF ISSUES ON RIPARIAN ZONE CONSERVATION

i. What influenced your choice to be a WRUA member in your community? Please explain.

____

____

____

ii. How would you describe the level of sand harvesting along riverbanks in your WRUA?

Answer	Very high	High	Moderate	Low	Very low
Tick					

iii. Based on what you understand about the riparian zone, do you think sand harvesting should be done along riverbanks?

Answer	Absolutely yes	Maybe yes	Maybe no	Absolutely no
Tick				

iv. Based on your experience concerning sand harvesting, are you in agreement or disagreement with the statements below? (Tick appropriately)

Statement	Firmly agree	Agree	Disagree	Firmly disagree
Sand harvesting activities should be done in designated sites.				
Lorries for sand transportation should use access roads that are designated.				

Sand harvesting sites that are no longer in use should be rehabilitated appropriately by the WRUA, County and approved sand dealers with close supervision by NEMA.	
The requirements of an environmental impact assessment/ audit, according to the Environmental Management and Co-ordination Act No. 8 of 1999 should be fulfilled.	
Approved sand dealers should support local community projects and environmental conservation activities in consultation with the WRUA.	

v. Assume you were asked to participate in the sand harvesting rehabilitation and mitigation program. Before participating, would you agree or disagree with the statements below? (Tick appropriately)

Statement	Firmly agree	Agree	Disagree	Firmly disagree
Participating in the program would be easy.				
Participating will make me feel like I am assisting the sand dealers.				

I will be curious to know the effect of sand harvesting on river systems.	
I will be concerned that the information I provide may be used against me.	
I will be concerned about the County and WRA having information about me.	

vi. How important would the following be to you, in deciding to participate or not participate in the sand harvesting rehabilitation and mitigation program?

Statement	Extremely important	Somewhat important	Not very important	Completely not important
Monetary compensation for my time				
Being provided with information about my catchment area				
Knowing the kind of research being done using the obtained database				
Having my privacy protected				
Knowing the focal person to go to with a question or complaint				
if need be, being allowed to change my mind and withdraw my membership in the program				

C: SELF-ASSESSMENT TOWARDS SAND HARVESTING AND RIVER SYSTEM CONSERVATION CAPACITY

i. How would you evaluate the contribution of your work towards sand harvesting and river system conservation?

Answer	Positive	Neutral	Negative	I do not know
Tick				

ii. a) Have you received any kind of training?

Yes	
No	

b) If yes, which kind of training was it?

Answer	**Tick**
Environmental related course	
Leadership and governance- accountability, transparency, participation, gender representation, inclusive decision-making.	
Agriculture-related course	
Communication and knowledge management - access, data capture, processing, storage and dissemination, documentation of lessons, application of best practices and lessons learnt.	
Public health-related course	
Resource mobilization and financial management – proposal development, bookkeeping, expenditure returns and submission of financial accountability statement.	
Networking and collaboration – link and cooperation with county governments, government agencies, other WRUAs, community, donors as well as the development of partnerships.	
Other (s)	

c) Do you agree or disagree with the statement below?

I am contented with the training/awareness creations have received so far.

- Firmly agree ☐
- Agree ☐

- Disagree ☐
- Firmly Disagree ☐

iii. Please select the option that best describes your current level of understanding of the following concepts, and relate it to your work as a WRUA member.

Statement	I understand the concept and can relate it to my work	I understand the concept but I have difficulty applying it to my work	I have only a poor understanding of the concept and I often experience confusion with other related concepts	I have no understanding
Causes of the river system degradation				
Riparian zone conservation				
Alternative sustainable uses of the riparian zone				
Role of WRUA in riparian zone conservation				
Guidelines and other legislations on sand harvesting				

D: MITIGATIVE STRATEGIES AND RECOMMENDATIONS ON ADDRESSING SAND HARVESTING

i. Are there occasions that you volunteered in a project or activity that is beneficial to the community?

- Yes ☐
- No ☐
- Not sure ☐

ii. a) Have you participated in a project that conserves the riparian zone in the recent two years?

- Yes ☐
- No ☐
- I cannot remember ☐

b) What type of activities did you take part in?

Answer	**Tick**
Planting of water-friendly trees	
Building of riverbank protection	
Promoting nature-based enterprises along riverbanks	
Restriction of farming activities up to the riverbank	
Restriction of sand harvesting at vulnerable river ecosystem sites	
Promotion of beneficial alternative projects to community members	

Other (s) Please mention:	

iii. a) Is there an advisor/unit to consult on sand harvesting in your community?

Yes	
No	

b) If yes, please mention which one:

____

____

iv. How confident are you in addressing sand harvesting issues in your duties as a WRUA member?

- Very confident ☐
- Somewhat confident ☐
- I do not feel confident ☐
- I do not know ☐

v. What kind of support would you need to improve your confidence in addressing sand harvesting issues in your work?

Answer	**Tick**
Training sessions on sand harvesting	
Guidelines, tools and methods on possible mitigative strategies	
Case studies/ best practices dissemination	

Awareness creation activities on sustainable sand harvesting	
Other (s) Please mention:	

We are very grateful for having taken your time to finish our survey.

In regards to this study, do you have any suggestions or comments you would like to share?

____

____

____

Please notify us on 0716953995 if you have any concerns to make the survey questions simple to understand.

APPENDIX 2: STRUCTURED INTERVIEW CHECKLIST FOR ASSESSMENT OF WRUAS MITIGATIVE STRATEGIES

Survey on Mitigative Strategies of WRUAs to Sand Harvesting and River System Conservation

2020

-FGDs and Structured Interview Checklist-

My name is Aquila Lwanga and I am a research student. This survey is being conducted in fulfilment of my Master's Degree from Masinde Muliro University of Science and Technology. All of the answers you give will be kept private. Your identity will not be revealed to the County Government or the Water Resources Association as the survey data will be reported in a summarized form. Also, we shall code the information thus researchers will not be able to identify individual participants. The research finding will be published in a journal. Please answer the questions as honest as possible.

INTRODUCTION

In Kenya, Water Resource User Associations (WRUAs) have been formed whose members are entirely voluntary water users, including small-scale farmers and other businesses. WRUA achievements so far have included: protecting riparian land and water sources; transforming degraded land through agroforestry; reducing the illegal disposal of waste in rivers; reducing conflicts over water resources; and increasing crop yields and incomes of small-scale farmers while reducing soil erosion, among others.

Therefore, this survey aims to generate information regarding sand harvesting, river system conservation as well as the capacity of WRUAs to protect our riparian zones from sand harvesting hazards. The survey is being carried out using a structured interview and is part of an undertaking to assess the mitigative strategies of WRUAs to sand harvesting and river system conservation, in response to a research study on riparian zone conservation.

[SCREENING QUESTION]

S1 How active would you consider yourself in the involvement of Water Resources Users Association (WRUA) activities? Tick appropriately

Answer	Very active	Active	Somewhat active	Not active	I do not know
Tick					

[END SCREENING]

We are grateful for your response. Thank you for accepting to take part in this survey.

It will take about **20 minutes** to complete this survey.

A: SOCIODEMOGRAPHIC BACKGROUND (Tick appropriately)

Name of institution and area of jurisdiction

Which age group do you belong to?

Answer	18-35	36-41	42-47	48-53	Above 53
Tick					

What is your gender?

Male	
Female	

How long have you been working in this area?

Answer	0-3yrs	4-10yrs	11-15yrs	Above 15yrs
Tick				

What is the highest level of schooling you have finished?

Answer	**Tick**
Primary level and below	
Secondary level	
Diploma level	
Bachelor's degree level	
Post-graduate and above	

What is your relationship with WRUA members?

Answer	Very good	Good	Fair	Bad	Very bad
Tick					

B: PERCEIVED RELEVANCE OF ISSUES ON RIPARIAN ZONE CONSERVATION

What impact have WRUA members made in your area of jurisdiction? Please explain.

____

____

How would you describe the level of sand harvesting along riverbanks in your area of jurisdiction?

Answer	Very high	High	Moderate	Low	Very low
Tick					

Based on what you understand about the riparian zone, do you think sand harvesting should be done along riverbanks?

Answer	Absolutely yes	Maybe yes	Maybe no	Absolutely no
Tick				

Based on your experience concerning sand harvesting, are you in agreement or disagreement with the statements below? (Tick appropriately)

Statement	Firmly agree	Agree	Disagree	Firmly disagree
Sand harvesting activities should be done in designated sites.				
Lorries for sand transportation should use access roads that are designated.				
Sand harvesting sites that are no longer in use should be rehabilitated appropriately by the WRUA, County and approved sand dealers with close supervision by NEMA.				

The requirements of an environmental impact assessment/ audit, according to the Environmental Management and Co-ordination Act No. 8 of 1999 should be fulfilled.				
Approved sand dealers should support local community projects and environmental conservation activities in consultation with the WRUA.				

Assume you were asked to participate in the sand harvesting rehabilitation and mitigation program by WRUA members. Before participating, would you agree or disagree with the statements below? (Tick appropriately)

Statement	Firmly agree	Agree	Disagree	Firmly disagree
Participating in the program would be easy.				
Participating will make me feel like I am assisting the sand dealers.				
I will be curious to know the effect of sand harvesting on river systems.				
I will be concerned that the information I provide may be used against me.				

I will be concerned about the WRUA members having information about me.				

How important would the following be to you, in deciding to participate or not to participate in the sand harvesting rehabilitation and mitigation program being done by WRUA members?

Statement	Extremely important	Somewhat important	Not very important	Completely not important
Monetary compensation for my time				
Being provided with information about my area of jurisdiction				
Knowing the kind of research being done using the obtained database				
Having my privacy protected				
Knowing the focal person to go to with a question or complaint				
if need be, being allowed to change my mind and withdraw my membership in the program in case of any red flags				

C: SELF-ASSESSMENT TOWARDS SAND HARVESTING AND RIVER SYSTEM CONSERVATION CAPACITY

How would you evaluate the contribution of your work towards WRUA sand harvesting and river system conservation?

Answer	Positive	Neutral	Negative	I do not know
Tick				

a) Have you received any kind of training?

Yes
No

b) If yes, which kind of training was it?

Answer	**Tick**
Environmental related course	
Leadership and governance- accountability, transparency, participation, gender representation, inclusive decision-making.	
Agriculture-related course	
Communication and knowledge management - access, data capture, processing, storage and dissemination, documentation of lessons, application of best practices and lessons learnt.	
Public health-related course	
Resource mobilization and financial management – proposal development, bookkeeping, expenditure returns and submission of financial accountability statement.	

Networking and collaboration – link and cooperation with county governments, government agencies, other WRUAs, community, donors as well as the development of partnerships.	
Other (s)	

Do you agree or disagree with the statement below?

I am contented with the training/awareness creations have received so far.

Firmly agree ☐ Disagree ☐

Agree ☐ Firmly Disagree ☐

Please select the option that best describes your current level of understanding of the following concepts, and relate it to your work with WRUA members.

Statement	I understand the concept and can relate it to my work	I understand the concept but I have difficulty applying it to my work	I have only a poor understanding of the concept and I often experience confusion with other related concepts	I have no understanding
Causes of the river system degradation				
Riparian zone conservation				
Alternative sustainable uses of the riparian zone				

Role of WRUA in riparian zone conservation				
Guidelines and other legislations on sand harvesting				

D: MITIGATIVE STRATEGIES AND RECOMMENDATIONS ON ADDRESSING SAND HARVESTING

1. a) Are there occasions that you volunteered or participated in a project or activity that is being done by WRUA in the recent two years?

Yes ☐

No ☐

I cannot remember ☐

b) If yes, what type of activities did you take part in?

Answer	**Tick**
Planting of water-friendly trees	
Building of riverbank protection	
Promoting nature-based enterprises along riverbanks	
Restriction of farming activities up to the riverbank	
Restriction of sand harvesting at vulnerable river ecosystem sites	
Promotion of beneficial alternative projects to community members	
Other (s) Please mention:	

2. a) Have the WRUA members ever consulted you on sand harvesting in your area of jurisdiction?

Yes	
No	

b) If yes, please mention which one (s):

____

____

____

3. How confident are you in addressing sand harvesting and river conservation issues in your duties?

Very confident ☐

Somewhat confident ☐

I do not feel confident ☐

I do not know ☐

4. What kind of support would you need to improve your confidence in addressing sand harvesting issues around your area?

Answer	**Tick**
Training sessions on sand harvesting	
Guidelines, tools and methods on possible mitigative strategies	
Case studies/ best practices dissemination	
Awareness creation activities on sustainable sand harvesting	
Other (s) Please mention:	

We are very grateful for having taken your time to finish our survey.

In regards to this study, do you have any suggestions or comments you would like to share?

____

____

____

Please notify us on 0716953995 if you have any concerns to make the survey questions simple to understand.

APPENDIX 3: PLATES

Plate 1: Sites where vegetation cover had been destroyed

Plate 2: Evidence of tree cutting at Lwakhupa sand harvesting site

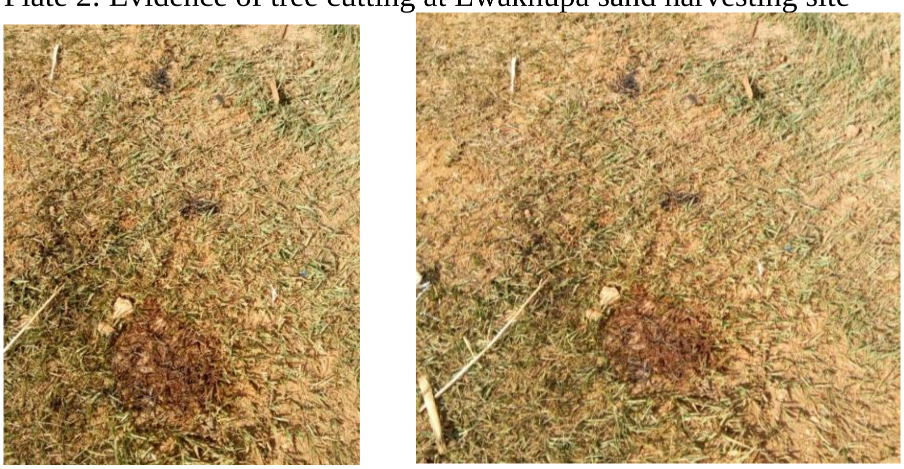


Plate 3: Evidence for oil droplets

Plate 4: Restoration efforts at Ndombi Bridge

Plate 5:Women taking part in sand harvesting at Shikhunga

Plate 6: One of the scouts interviewing men taking part in sand harvesting

Plate 7: Children taking part in sand harvesting

Plate 8: A newly cleared access road to the Esenyi sand harvesting site

Plate 9: Evidence of eroded riverbanks

Plate 10: A strip of bamboo planted along the riverbank at Lwakhupa

Plate 11: Undisturbed ground cover at Lwakhupa riverbank point where instream sand harvesting takes place

Plate 12: Ndombi Bridge with an access path passing by during the 2020 field visits

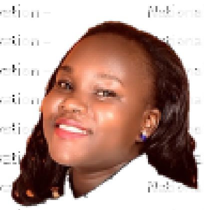
APPENDIX 4: RESEARCH PERMIT FROM NACOSTI

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 910086 **Date of Issue: 25/November/2020**

RESEARCH LICENSE



This is to Certify that Ms.. AQUILA ISERE LWANGA of Masinde Muliro University of Science and Technology, has been licensed to conduct research in Kakamega on the topic: River Sand Harvesting and Challenges of Riparian Conservation in Kakamega County for the period ending : 25/November/2021.

License No: **NACOSTI/P/20/7226**

910086

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE,TECHNOLOGY & INNOVATION

Verification QR Code

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Website: www.nacosti.go.ke

APPENDIX 5: LETTER PERMITTING TO CARRY OUT THE STUDY FROM MMUST

MASINDE MULIRO UNIVERSITY OF SCIENCE AND TECHNOLOGY
(MMUST)

Tel: 0702597360/61
: 0733120020/22
E-mail: directordps@mmust.ac.ke
Website: www.mmust.ac.ke

P.O Box 190
50100 Kakamega
KENYA

Directorate of Postgraduate Studies

Ref: MMU/COR: 509099

16th September, 2020

Aquila Isere Lwanga
SEV/G/01-52969/2018
P.O. Box 190-50100
KAKAMEGA

Dear Ms. Lwanga,

RE: APPROVAL OF PROPOSAL

I am pleased to inform you that the Directorate of Postgraduate Studies has considered and approved your Masters proposal entitled: ***"River Sand Harvesting and Challenges of Riparian Conservation in Kakamega County"*** and appointed the following as supervisors:

1. Dr Humphrey Agevi - MMUST
2. Prof. Harrison Mugatsia Tsingalia - JOUST

You are required to submit through your supervisor(s) progress reports every three months to the Director of Postgraduate Studies. Such reports should be copied to the following: Chairman, School of Natural Sciences and Technology Graduate Studies Committee and Chairman, Department of Biological Sciences. Kindly adhere to research ethics consideration in conducting research.

It is the policy and regulations of the University that you observe a deadline of two years from the date of registration to complete your Master's thesis. Do not hesitate to consult this office in case of any problem encountered in the course of your work.

We wish you the best in your research and hope the study will make original contribution to knowledge.

Yours Sincerely,

Sign:
Prof. John Obiri
DIRECTOR, DIRECTORATE OF POSTGRADUATE STUDIES

APPENDIX 6: DATA COLLECTION SHEETS

1. **Spatial Distribution and Abundance of the Sand Harvesting Activities**

Site code	Area local name	Name of river	Sub County	X coordinate	Y coordinate	State of SH			Frequency of SH		Amount of sand harvested			Frequency of transporting sand in a week/month
						OG	PS	AB	Daily	No. in a week	In WB	In TS	In LS	

SH: sand harvesting **PS:** paused **OG:** ongoing **AB:** abandoned
WB: Wheelbarrows **TS:** trailers/tractors **LS:** lorries

2. Effects of Sand Harvesting on Water Quality

Sample No.	S:	Area local name	Name of river	Sub County	X coordinate	Y coordinate	Riverbank erosion (length in metres)			Parameter of analysis		Other observations/ Notes
	Date						2001	2020	Diff.	Turbidity	TSS	

S=Season **Diff.**=Difference **TSS=** Total Suspended Sediments

3. **Effects of Sand Harvesting on Soil Physico-Chemical Properties**

Sample No.	**S:**	**Area local name**	**Name of river**	**Sub County**	**X coordinate**	**Y coordinate**	**Parameter of analysis**				**Other observations/Notes**
	Date						**MS**	**N**	**P**	**pH**	

S=Season **MS=**Moisture Content **N=**Nitrogen **P=**Phosphorus

4. **Impacts of Sand Harvesting on Plant Biodiversity** **Season:** **Date:**

Sample No.	Area local name	Name of river	Sub County	X coordinate	Y coordinate	Distance from river (in metres)	No. of type of plant			Other observations/Notes
							Trees D≥10cm	**Saplings**	**Herbaceous**	
						0				
						25				
						50				
						0				
						25				
						50				
						0				
						25				
						50				
						0				
						25				
						50				
						0				
						25				
						50				
						0				
						25				
						50				

D=DBH

5. Impacts of Sand Harvesting on Soil Macro-fauna **Season:** **Date:**

Sample No.	**Area local name**	**Name of river**	**Sub County**	**X coordinate**	**Y coordinate**	**Type & No. of Macrofauna observed**							**Other observations/ Notes**
						Termites	E.W	Ants	Molluscs	Arachnids			

EW=Earthworms