IMPACTS OF SAND DAMS ON BIODIVERSITY AND ECOSYSTEM SERVICES: CASE STUDY OF KIKUU SAND RIVER, MAKUENI COUNTY, KENYA

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DECLARATION

This thesis is my original work and has not been presented for the award of a degree in any other institution.

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I dedicate this work to my family, my husband Pastor Morris Murimi Mugambi and daughter Favour Nyawira who despite the many barriers and challenges supported me throughout the period that I sat and researched and came up with this special document

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LIST OF ACRONYMS

ADPs:	Annual Development Plans
CBD:	Convention on Biological Diversity
CIDPs:	County Integrated Development Plans
GFGP:	Grain for Green Project
GIS:	Geographic Information System
LULC:	Land use and Land cover

DEFINITION OF TERMS

Term	Definition
Delineate	To identify, describe, and map out the boundaries or distinguishing features of a natural or human-made system.
Drought-resistant plants (Xerophytes)	Plants with morphological and physiological adaptations such as deep root systems, reduced leaf surfaces, or water-storing tissues, enabling survival in arid and semi-arid environments with limited water availability.
Ecosystem services	Benefits human beings receive from the Ecosystem.
Functional sand dams	Sand dams that are structurally intact, well-maintained, and capable of storing and supplying water consistently for domestic, agricultural, and ecological purposes.
Non-functional sand dams	Sand dams that have lost their capacity to store or supply water due to structural damage, siltation, poor design, or lack of maintenance, thus providing minimal or no benefits.
River morphology	The physical form and structure of a river channel
Riverine system	The interconnected ecological, hydrological, and geomorphological features associated with rivers.
Sand dams	Small concrete or masonry barriers constructed across seasonal sandy riverbeds.
Sand reservoir	A subsurface formation consisting of sand deposits capable of holding water or other fluids.
Sand rivers	Seasonal rivers characterized by continuous sand channels.

ABSTRACT

This study investigates the environmental impacts of sand dams on biodiversity and ecosystem services along the Kikuu River in Makueni County, Kenya, an arid and semi-arid region where water scarcity and food insecurity remain critical challenges. While sand dams are widely promoted as sustainable water management interventions, their ecological effects on biodiversity and ecosystem services are less documented compared to their hydrological benefits. Addressing this knowledge gap, the study aimed to evaluate how sand dam construction influences plant and animal diversity as well as the provision of ecosystem services in the Kikuu River system. The research was carried out between 2023 and 2024 and covered a 35 km stretch of the Kikuu River, where 21 sand dams were identified. A total of 306 households were sampled. Data collection involved mapping natural (e.g., Acacia species, xerophytic grasses) and human-made features (e.g., water pumps, roads), biodiversity surveys of plants and animals in both sand dam and control sites, and household interviews on ecosystem services. Sampling methods included perpendicular transects, spot checks, and sweep counts. Data were analyzed using Welch's ANOVA with Games-Howell post-hoc tests, Pearson Chi-square tests, and regression analyses. The results indicated that sand dam sites supported higher plant and animal biodiversity compared to control sites without dams ($p < 0.001$). For instance, the Kwa Moses and Mbukoni dams demonstrated rich vegetation cover and increased animal presence, while regression analysis revealed that sand dams had a positive and significant relationship with ecosystem service ratings, particularly in water provision, irrigation, and soil stability. However, variations in performance among dams highlight the influence of design, location, and maintenance. The study concludes that sand dams significantly enhance biodiversity and ecosystem services in semi-arid landscapes but require site-specific management strategies, continuous monitoring, and design improvements to maximize benefits and reduce ecological trade-offs. It recommends the strategic expansion of sand dams, coupled with community participation and post-construction monitoring, to strengthen ecological resilience and sustainable development in water-scarce regions.

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

Sandy rivers, found in arid and semi-arid regions, are intermittent water channels that resemble conventional rivers but flow only during rainy seasons and remain dry during extended dry periods (Vidal-Abarca *et al.*, 2020). They are formed through natural processes of erosion, deposition, and weathering (Kale, 2020). Although often appearing deserted, sandy rivers play vital ecological roles by supporting diverse flora and fauna and providing water resources to adjacent communities. Their sandy beds, composed of variable grain sizes influenced by geology and climate, create habitats for drought-tolerant plants and migratory routes for animals, thereby enhancing local biodiversity (Glasby *et al.*, 2021).

Sand dams, constructed across these ephemeral sandy rivers, have emerged as effective water management solutions. They trap sediments and store water within the sand matrix, gradually increasing groundwater recharge and raising water tables (Maddrell *et al.*, 2018). Once sand accumulation reaches the crest of the spillway, the dam is considered fully mature, ensuring sustainable water retention for agricultural and domestic use (Ritchie *et al.*, 2021). Experiences from India show that sand dams enhance drought resilience by boosting groundwater recharge, while in Kenya and Zimbabwe, they have improved soil moisture retention and agricultural productivity (Gaur *et al.*, 2020; Eisma & Merwade, 2021).

Ecologically, sand dams contribute to biodiversity conservation by creating habitats for plants and animals. Vegetation such as Acacia species, grasses, and shrubs thrive near functional sand dams, while improved soil moisture supports water-dependent species. However, these benefits are not uniform; variations in soil texture, watershed characteristics, and dam design can influence outcomes (Lasage *et al.*, 2008; Yifru *et al.*, 2021). For example, some dams enhance vegetation and wildlife diversity, while others suffer from sedimentation or poor maintenance, leading to reduced functionality.

Kenya has constructed more than 3,000 sand dams since 1979, with the majority located in the counties of Makueni, Kitui, and Machakos (Eisma & Merwade, 2021). These dams are particularly important in enhancing water security in semi-arid areas facing recurrent droughts and erratic rainfall patterns linked to climate change. The ecological benefits of sand dams extend beyond water provision: they promote carbon sequestration, reduce erosion, and enhance ecosystem services such as food production, soil stability, and microclimate regulation (Masson-Delmotte *et al.*, 2021).

Despite these potential benefits, most research on sand dams has emphasized their hydrological impacts, with limited attention to their ecological effects, particularly on biodiversity and ecosystem services (Bergkamp *et al.*, 2000; Eisma & Merwade, 2021). Given the increasing reliance on sand dams as climate-resilience strategies in drylands, there is a pressing need for localized ecological assessments. This study therefore seeks to document the natural and human-made features of sand dams, and to evaluate their impacts on biodiversity and ecosystem services along the Kikuu River in Makueni County, Kenya.

1.2 Problem Statement

Makueni County in Kenya faces persistent challenges of water scarcity and food insecurity**,** driven by its semi-arid climate, recurrent droughts, and the compounded effects of climate change and population growth (de Trincheria *et al.*, 2018). Sand dams have been widely adopted in this region as a climate-resilience strategy to alleviate water shortages and improve agricultural productivity. However, while the hydrological benefits of sand dams have been studied, there remains limited understanding of their ecological impacts, particularly on biodiversity and the provision of ecosystem services such as soil quality improvement, food production, and climate regulation (Quinn *et al.*, 2019).

The potential benefits and trade-offs of sand dam construction for biodiversity conservation and ecosystem restoration in the Kikuu River catchment remain largely unexplored. Given the growing reliance on sand dams as nature-based solutions for water security and environmental management, it is critical to assess how they influence plant and animal diversity, as well as the ecosystem services that sustain livelihoods.

This research therefore addresses the gap by evaluating the ecological effects of sand dams in the Kikuu River, with a focus on their implications for biodiversity and ecosystem services in semi-arid landscapes.

1.3 Significance of the Study

Communities in the arid and semi-arid regions of Makueni County face persistent challenges of water scarcity and food insecurity. Sand dams have been introduced as practical solutions because they collect runoff water, recharge underground reservoirs, and support agricultural productivity. However, despite their widespread use, there is limited understanding of their ecological consequences, particularly their impacts on biodiversity and ecosystem services.

This study is significant because it provides scientific evidence on how sand dams influence the abundance of plant and animal species, and how they contribute to ecosystem services such as soil stability, groundwater recharge, and improved vegetation cover. By addressing this gap, the study enhances understanding of the trade-offs and ecological benefits associated with sand dam construction in semi-arid landscapes.

The findings have direct relevance for policy makers, conservation practitioners, and local communities, as they inform sustainable water and land management strategies in areas facing biodiversity risks. Furthermore, the study contributes to global development priorities by aligning with the Sustainable Development Goals (SDG 6: Clean Water and Sanitation, and SDG 15: Life on Land). By highlighting both the opportunities and challenges posed by sand dams, the research provides a basis for improved design, implementation, and monitoring of sand dam projects in Kenya and other semi-arid regions.

1.4 Research questions

i. What is the distribution of sand dams along the Kikuu River and what natural and human-made features are surrounding them?

ii. What differences exist in target plant and animal species between areas with sand dams and control areas?

iii. What is the relationship between ecosystem services in sand dam areas and those in control areas?

1.5 Objectives

1.5.1 Main Objective

Assessing impacts of sand dams on biodiversity and ecosystem services, a case study of Kikuu Sand-River within Makueni County of Kenya.

1.5.2 Specific Objectives

i To delineate the natural and human-made features of the Kikuu Sand River in Makueni County, Kenya.

ii To compare differences in target plant and animal biodiversity between areas with sand dams and control areas along the Kikuu Sand River in Makueni County, Kenya.

iii To assess the effects of sand dam construction on ecosystem services along the Kikuu Sand River.

1.6 Assumptions and Limitations

This study is based on certain assumptions that provide a foundation for the research design, as well as limitations that define the scope of the findings. Assumptions outline the conditions accepted as true for the purposes of the study, while limitations highlight the constraints that may affect the interpretation and generalization of the results.

1.6.1 Assumptions

The study assumed that the ecological survey methods applied, including distant riverbank sampling at 500 meters, perpendicular transects, spot checks, and sweep sampling, would provide a representative picture of biodiversity and ecosystem services across the Kikuu River system. These methods were expected to capture species abundance in both visible and hidden habitats, including elusive species, and to reflect ecological relationships accurately. This assumption is supported by their successful application in similar ecological surveys (Wei et al., 2020).

1.6.2 Limitations

The study faced several limitations. First, elevation differences and rugged terrain restricted access to certain remote areas, reducing the extent of data collection for species inhabiting those locations. Second, logistical challenges limited repeated sampling across all dam sites within the available study period. To mitigate these challenges, complementary methods such as perpendicular transects, spot checks, and sweep sampling were employed to improve coverage. Although these approaches strengthened the representativeness of the data, the study acknowledges that some areas may still have been under-sampled. Future research is therefore recommended to expand spatial coverage and incorporate multi-seasonal surveys to address these limitations.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter reviews existing literature on sand rivers, their biodiversity functions, and the impacts of sand dams as water management interventions. It synthesizes evidence from global and local perspectives to evaluate the ecological trade-offs of sand dam construction. The review builds a foundation for assessing how sand dams influence biodiversity and ecosystem services in Makueni County, Kenya.

2.2 Delineating the Natural and Humanmade Features of Kikuu Sand River in Makueni County, Kenya

Sand rivers are ephemeral watercourses found in arid and semi-arid regions, including parts of the Sahara, the Kalahari, Australian deserts, and the southwestern United States. They are shaped by erosional and depositional processes that create sandy channels with intermittent water flow (Duker *et al.*, 2022). Unlike perennial rivers, sand rivers carry water only during rainy seasons, often through flash floods, after which they dry out during extended dry periods (Wekesa *et al.*, 2020).

The hydrological dynamics of sand rivers depend on riverbed morphology, topography, rainfall patterns, and soil composition. Their lateral influence may extend up to 500 meters, with wide and gently sloping beds distributing water more efficiently than narrow, steep channels (Maddrell *et al.*, 2018). Floods transport sediments and nutrients that enhance soil fertility, supporting vegetation growth (Benavides *et al.*, 2023).

Biodiversity in sand river ecosystems reflects adaptation to extreme variability in water availability. Plants such as drought-tolerant grasses, shrubs, and trees develop deep roots or specialized seed dispersal systems to survive prolonged dry periods. Aquatic invertebrates, amphibians, fish, reptiles, birds, and mammals synchronize their life cycles with seasonal floods, ensuring access to water and food resources (Dingle *et al.*, 2020;

Sánchez-Montoya *et al.*, 2023). Burrowing amphibians and reptiles survive droughts by sheltering in sandy substrates, while migratory birds depend on sand river habitats as stopovers during long-distance movements (Chlachula, 2021).

Despite their ecological value, sand rivers face increasing threats from human activities, including groundwater extraction, dam construction, agriculture, grazing, mining, and stream channelization. These disturbances disrupt hydrological processes, alter sediment flows, and degrade habitats, resulting in biodiversity loss and reduced ecosystem services such as water provision, nutrient cycling, and aquifer recharge (Paszkowski *et al.*, 2021).

Maintaining intact sand river systems is therefore critical. Restoration strategies emphasize re-establishing natural channel morphology, floodplain connectivity, and native vegetation to support ecosystem resilience (Li *et al.*, 2022). Conservation of sand rivers is further justified by their contribution to global biodiversity: although freshwater ecosystems cover only about 1% of the Earth's surface, they support nearly 40% of all known species (Song *et al.*, 2024). Effective management of sand rivers aligns with international conservation priorities that address biodiversity loss and climate change (Arneth *et al.*, 2020; Schneider-Mayerson, 2022).

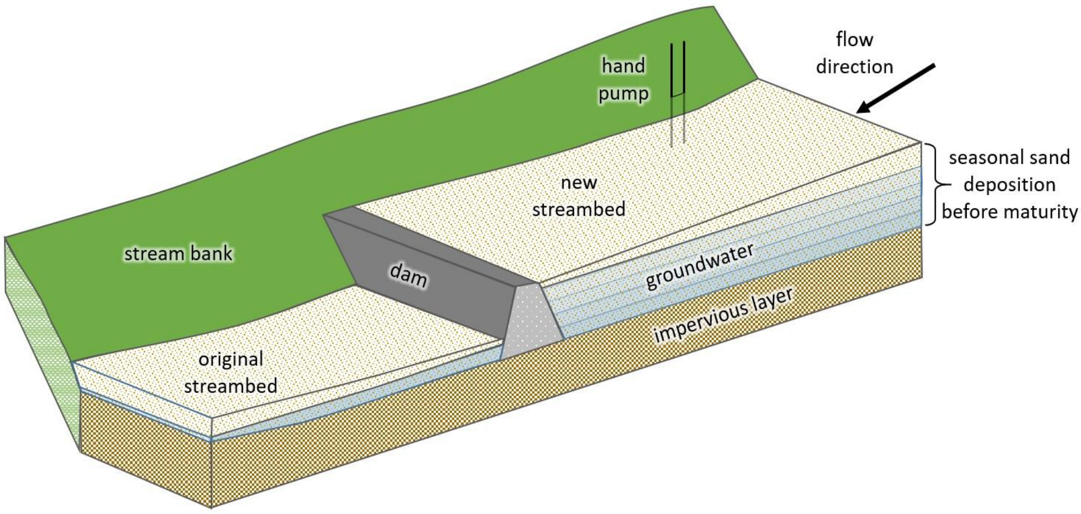
2.3 Sand Dams

Sand dams are small concrete or masonry structures built across ephemeral sandy rivers. They trap sediments carried during floods, allowing water to infiltrate and be stored in the sand matrix behind the dam (Eisma *et al.*, 2021b). Over successive rainy seasons, sand gradually accumulates until it reaches the top of the sand dam, at which point it is considered mature. The stored water can then be accessed through scoop holes, shallow wells, or infiltration galleries, providing communities with reliable water supplies during dry seasons.

Globally, sand dams are recognized as low-cost, sustainable water storage solutions for drylands. Programs such as the Drylands Development Programme in East Africa and community initiatives in Tigray, Ethiopia, highlight their effectiveness in improving water availability, agricultural productivity, and resilience to drought (Adamie, 2021). In addition to hydrological benefits, sand dams influence ecological dynamics by altering vegetation patterns, groundwater recharge, and habitat availability, making them important to study in relation to biodiversity and ecosystem services.

Figure 1

Sand Dam Dynamics



Eisma et al., (2021b)

Globally, sand dams are increasingly recognized as effective solutions for addressing water scarcity in arid and semi-arid regions, while also contributing to long-term environmental and socio-economic resilience. One notable initiative is their role in the Great Green Wall in the Sahel, where sand dams have been used to regenerate degraded landscapes and counter desertification. By improving water supply, they have supported tree planting, agriculture, and ecological recovery, thereby enhancing both food security and environmental sustainability (Turner *et al.*, 2021).

Beyond water provision, sand dams contribute to livestock production, agricultural practices, and community resilience, thereby strengthening environmental stability and supporting economic growth (Yifru *et al.*, 2021). Their impacts extend beyond water storage to include biodiversity conservation and the reduction of migration pressures. Assessing these impacts often involves evaluating improvements in water accessibility, agricultural productivity, and ecological outcomes. For instance, a study in Rajasthan, India demonstrated that sand dams significantly increased water availability for households, livestock, and farming, while also raising soil moisture content, vegetation growth, and biodiversity (Hoque *et al.*, 2022).

Governments in Jordan and Israel have also integrated sand dams into national water strategies, while countries in Latin America, including Brazil and Mexico, are testing their potential in semi-arid regions (Raqeeb *et al.*, 2021). In Southeast Asia, research in Thailand and Cambodia is exploring how sand dams can improve agricultural water availability (Van Der Esch, 2022).

In Africa, sand dams have been adopted as practical tools for breaking the cycle of water scarcity and promoting sustainable development. In Uganda, more than 320 sand dams have been constructed, directly benefiting over 220,000 people, and they are now included in national water management plans (Ryan & Elsner, 2016). In Tanzania**,** community-led initiatives have shown positive results in improving water access and agricultural productivity (Eisma & Merwade, 2021). In Kenya, the Africa Sand Dam Foundation (ASDF) has advanced sustainable water management strategies in line with Kenya's Vision 2030, particularly in Makueni County, where local development projects have enhanced both water security and community livelihoods (Ndunge *et al.*, 2019).

Research in Makueni has also shown that sand dams help control sedimentation during rainy seasons while improving water access for rural communities (Ngugi *et al.*, 2020a).

These dual benefits highlight their importance in simultaneously supporting ecological and socio-economic development. However, long-term research is needed to monitor how sand dam-dependent communities adapt over decades and how their needs change with environmental and social conditions (Yifru *et al.*, 2021).

Despite their many benefits, sand dams can also introduce ecological risks. Poorly managed dams may facilitate the spread of invasive species that compete with native biodiversity and disrupt ecosystem balance (Neufeld *et al.*, 2021). Although these risks are more commonly associated with large reservoirs, smaller structures such as sand dams can also be affected if ecological safeguards are neglected (Mutati *et al.*, 2018). This calls for improved ecological management and regular monitoring.

Equally, the social sustainability of sand dams depends on community engagement, ownership, and maintenance. Castelli *et al.* (2022) stress that local participation and capacity building are essential for long-term success, while cautioning that conflicts over water access and risks of overexploitation must be addressed through governance and monitoring systems.

Currently, sand dams enjoy global recognition as sustainable and climate-resilient water management tools. To maximize their potential, collaboration between governments, NGOs, and research institutions is crucial. Knowledge sharing and context-specific designs are needed to ensure that sand dams continue to provide reliable water while supporting biodiversity and community well-being (Yifru *et al.*, 2021).

2.4 Comparing Biodiversity Differences of Target Plant and Animal Species Between Areas with and Without Sand Dams Along Kikuu Sand River, Makueni County Kenya

This study compares biodiversity differences of selected plant and animal species between areas with sand dams and those without along the Kikuu Sand River in Makueni

County, Kenya. The comparison provides insights into how sand dams influence ecological patterns and species distribution, thereby contributing to an understanding of their role in biodiversity conservation within semi-arid landscapes.

2.4.1 Impacts of sand dams on local communities

Sand dams are widely recognized for their role in improving access to water in arid and semi-arid regions. In Kenya, communities that were previously water-stressed now rely on these structures to reduce walking distances and waiting times at water points. For example, in Kitui County, research showed that sand dams increased groundwater availability in the Mwewe River, which translated into shorter water collection times and higher reliability of household supply (Lasage et al., 2008).

Beyond access, sand dams improve local food security. Stored water supports crop diversification and reduces losses during dry spells, enabling communities to maintain year-round agricultural production. This has positive implications for nutrition, food storage, and trade, while also helping households cope with drought and flood events. Reliable water access also contributes to psychological well-being by reducing anxiety about water scarcity (Ndunge et al., 2019).

Sand dams further influence community social dynamics. Studies report that easier water access reduces domestic conflicts and cases of gender-based violence, since women spend less time fetching water (Castelli et al., 2022a). Community management committees play a critical role in sustaining these projects, fostering local ownership and self-reliance. However, the long-term effectiveness of such committees still requires careful monitoring and evaluation, particularly in counties like Kitui and Makueni where sand dams are central to development strategies (Mutati et al., 2018).

2.4.2 Economic opportunities in sand dam communities

Sand dams also create economic opportunities by freeing up time and resources. With reduced water collection effort, households can invest in income-generating activities such as brick-making, basket weaving, small-scale trade, laundry services, and beekeeping. These activities improve household incomes and provide buffers during drought years. In some Kenyan sand dam communities, households were estimated to gain up to 130 euros annually per person, equivalent to nearly 20% of the country's per capita income (Ritchie et al., 2021).

Improved economic mobility is also evident. For instance, bicycle ownership rose by more than 200% among sand dam communities, reflecting better livelihoods and access to markets (Ertsen & Hut, 2009). However, the benefits are not always evenly shared. Households closer to sand dams, or those owning carts and donkeys, often gain more than those living further away (Cassin & Ochoa-Tocachi, 2021).

Pastoralist groups also benefit as sand dams reduce livestock deaths and increase herd sizes. Although pastoralists often make limited financial contributions to construction, they participate as casual workers in building projects and later profit from improved grazing conditions. Yet, unequal benefit distribution remains a concern, and targeted governance strategies are needed to ensure that all community groups including distant households share equitably in sand dam outcomes (Lasage et al., 2008; Neufeld et al., 2021).

2.4.3 Impacts on biodiversity

Biodiversity underpins ecological resilience and the provision of ecosystem services. Sand rivers such as Kikuu sustain plants, animals, and microorganisms even under extreme climatic conditions. However, human activities, particularly sand mining and water diversion, threaten these ecosystems (Bendixen et al., 2021). In Asia, large-scale sand extraction has altered floodplain morphology, destroyed aquatic habitats, and reduced fish diversity (Marschke & Rousseau, 2022).

Sand dams have mixed effects on biodiversity. On the positive side, they increase water and vegetation availability, creating habitats that support birds, amphibians, invertebrates, and small mammals. Studies have shown that microbial diversity in sand dam sediments promotes nutrient cycling, while increased vegetation offers nesting and feeding habitats for bird species (Šumrada et al., 2021; Eriksen et al., 2021).

Nevertheless, sand dams may alter sediment flow, reducing breeding habitats for aquatic species. Invasive species can also establish more easily in modified ecosystems, particularly where management is weak (Mutati et al., 2018). Masson-Delmotte et al. (2021) note that sediment changes affect fish feeding and reproduction, while Singh et al. (2021) observed that interruptions to natural flooding cycles influence bird migration and reproduction patterns. Overall, sand dams create valuable ecological niches, but their impacts vary by site, requiring long-term monitoring and adaptive management.

2.5 To Assess the Impact of Sand Dam Construction in The Ecosystem Services in the Kikuu Sand River

This section seeks to assess the impact of sand dam construction on ecosystem services along the Kikuu Sand River. Sand dams are recognized not only as water conservation structures but also as interventions that influence ecological processes and community livelihoods. Evaluating their role in supporting ecosystem services such as water availability, soil fertility, vegetation growth, and habitat provision helps to determine their broader contribution to environmental sustainability in semi-arid landscapes.

2.5.1 Land cover changes

Land cover changes are among the most visible outcomes of sand dam construction. By trapping sediments and altering infiltration rates, sand dams raise local groundwater levels and soil moisture, directly influencing vegetation cover and erosion patterns (Nguyen et al., 2023). In arid counties such as Makueni, greener landscapes and improved soil stability have been linked to functional sand dams (Neufeld et al., 2021).

However, the impacts vary spatially. Communities living close to dams often experience more pronounced benefits, while downstream areas may face reduced water and nutrient flow. UNEP and IWMI research found that sand dams enhanced irrigation potential and food security in Kenya and Zimbabwe, but downstream ecosystems experienced challenges linked to reduced water quantity (Barati et al., 2023; Ali et al., 2023).

Land cover modifications also interact with social dynamics. Expanding agriculture due to sand dam irrigation has improved livelihoods but can also accelerate deforestation or land degradation if not well managed (Ali et al., 2023). For Makueni County, where agriculture and biodiversity coexist, balancing these effects is crucial to ensure that ecosystem services are enhanced rather than undermined.

2.5.2 Ecosystem services

Ecosystem services influenced by sand dams can be categorized as provisioning, regulating, supporting, and cultural. Provisioning services are the most visible: sand dams provide water storage, recharge groundwater, and support agriculture. Ertsen and Ngugi (2021) note that sand dams in Kenya have enabled year-round irrigation and improved food security.

Regulating services include sediment retention, erosion control, and improved soil fertility. Castelli et al. (2022a) showed that sand dams capture fertile sediments, protecting agricultural lands, while Hoque et al. (2022) observed that altered sediment flows may reduce downstream water quality and affect aquatic ecosystems.

Supporting services benefit from the creation of micro-ecosystems in and around sand dams. Studies reveal that microbial activity in sediments contributes to nutrient cycling and vegetation growth, which in turn support birds and mammals (IWMI, 2022). Similarly, Dickens et al. (2020) highlight that properly designed sand dams can help restore ecological balance in degraded riparian zones.

Cultural services are also important. Sand dams provide recreational opportunities, scenic landscapes, and community cohesion through collective construction and management efforts. Improved water security reduces psychological stress, contributing to better community well-being (Huynh et al., 2022).

Despite these benefits, sand dams also present trade-offs. Poorly planned structures may promote invasive species (Neufeld et al., 2021), reduce downstream flows (Hoque et al., 2022), or trap excessive sediments (Beswetherick et al., 2018). Thus, long-term sustainability requires continuous monitoring, adaptive governance, and integration of ecosystem service assessments into planning. Case studies across Kenya, Zimbabwe, and other semi-arid countries show that sand dams transform degraded land into productive farmland, reduce soil erosion, and enhance food security (Mashala et al., 2023). Yet, as emphasized by Dickens et al. (2020), success depends on careful site selection, community involvement, and balancing hydrological and ecological trade-offs.

CHAPTER THREE: RESEARCH METHODOLOGY

3.1 Introduction

This chapter explains the methodology used to investigate the ecological and social impacts of sand dams along the Kikuu River in Makueni County. It begins with an overview of the research design, followed by a description of the study location and its environmental setting. The chapter also outlines the sampling strategy, data collection procedures, and analytical methods used to assess biodiversity, ecosystem services, and community perspectives. The methodological choices were guided by the study objectives, previous ecological survey approaches, and the need to address both ecological and social dimensions in a semi-arid environment.

3.2 Research Design

The study employed a mixed-methods design, combining observational ecological surveys with household surveys and semi-structured interviews. This approach was adopted to capture both quantitative biodiversity data and qualitative insights on ecosystem services, ensuring triangulation and enhancing validity.

The ecological component focused on comparing the abundance of target plant and animal species in sand dam sites and control areas. Species data were collected through perpendicular transects, spot checks, and sweep-ups, which are widely used in arid ecosystem studies to detect elusive and widely distributed species (Wei et al., 2020). The ecosystem services component was assessed through household surveys and interviews, which provided insights into provisioning, regulating, cultural, and supporting services perceived by local residents.

Spatial analysis was conducted using QGIS to map sand dam locations and examine land cover changes, allowing for an assessment of how sand dam placement interacts with surrounding landscapes. This geospatial layer enriched both ecological and socio-economic analyses.

The choice of a mixed-methods designs directly responded to examiner concerns on demonstrating methodological justification: ecological surveys provided objective species data, while interviews ensured that community experiences and perceptions of ecosystem services were adequately captured.

3.2.1 Study location

The research was conducted in river Kikuu, Makueni County, Kenya, a region classified as arid and semi-arid, where rainfall is scarce and unreliable. The Kikuu River catchment, the study area, receives an average of about 115 mm of annual rainfall, based on the last 20 years of rainfall records (Gevera et al., 2022). This limited precipitation intensifies water scarcity and has led to the adoption of sand dams as alternative water sources.

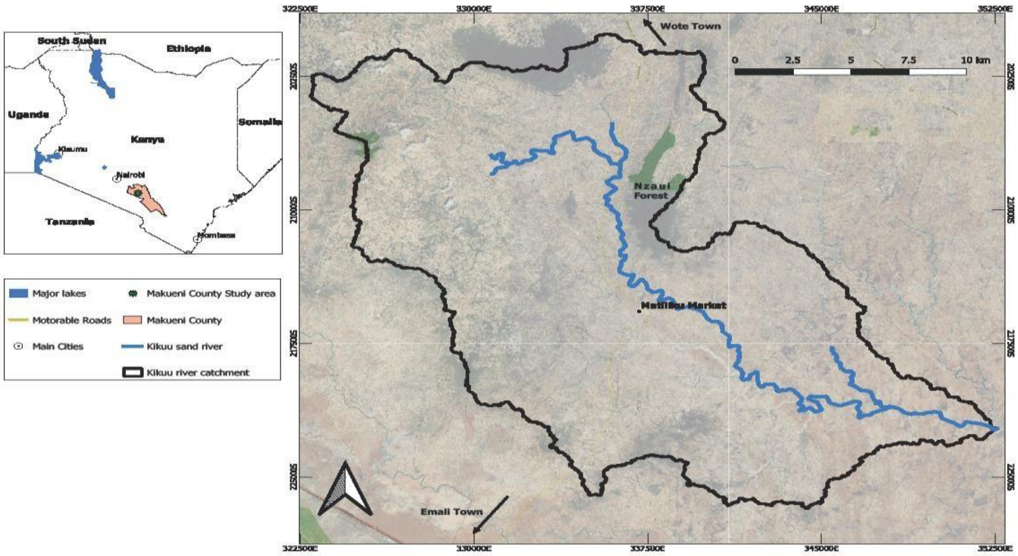
Vegetation in the county is a mixture of natural drought-tolerant species (such as acacia and shrubs adapted to dry conditions) and artificial vegetation established through tree planting and agricultural practices.

Hydrologically, the county is defined by four major watersheds: Kaiti Watershed – 660 km^2, Kikuu Watershed (study site) – 1,249 km^2, Mtito Andei and Kambu Watershed – 1,600 km^2, Thwake Watershed – 1,146 km^2

The Kikuu catchment was chosen because of its relatively high density of sand dams, active community involvement in dam projects, and its ecological importance as a seasonal river system. Its characteristics make it suitable for evaluating both biodiversity and ecosystem service outcomes associated with sand dam construction.

Figure 2

Study area: The River Kikuu Sand River, Makueni County, Kenya



Karimba, (2024)

3.2.2 Sample determination and data collection

For the first objective, which sought to delineate natural and human-made features of the Kikuu River, QGIS software was employed to map sand dam distribution, settlement patterns, and land cover. GPS-assisted field surveys were conducted to record the exact locations of sand dams. Satellite imagery was used to verify dam locations, while photographs provided qualitative evidence of adjacent features. This spatial delineation provided essential context for understanding the riverine system.

For the second objective, which compared biodiversity differences between areas with and without sand dams, ecological surveys were carried out in four sites: two sand dam areas and two adjacent control areas. Of the 21 dams identified along the Kikuu River, two were deliberately selected for extensive sampling. The Kwa Moses sand dam represented the most functional structure, while the Kikuu 2 sand dam represented the most structurally degraded. This decision was guided by Villani (2019) and Lasage et al. (2008), who emphasized that contrasting sites often provide the widest range of ecological outcomes. Resource and time constraints further necessitated focusing on two dams.

Within these sites, biodiversity surveys were conducted within 500 meters of the river channel. Five transects were laid perpendicular to the river at 100-meter intervals, extending between 100 and 500 meters inland. At each transect, systematic sweep-ups and spot checks were conducted at four randomly selected points per 100-meter interval, consistent with ecological protocols for assessing species presence and abundance (Dufrene et al., 2011; UK River Restoration Centre, 2021). Target species included xerophytic grasses, acacia trees, maize, mangoes, citrus, French beans, tomatoes, watermelons, termites, rodents, squirrels, lizards, snakes, and birds. Surveys were timed during early mornings and late afternoons to maximize species detection when both warm-blooded and cold-blooded animals were most active.

For the third objective, which assessed the impact of sand dams on ecosystem services, semi-structured interviews were conducted with household heads. Stratified random sampling was used to ensure representation of all seven villages located within 500 meters of the river. Based on data from the Kikuu Water Users Association (WRUA), approximately 30% of the 5,000 households in the catchment live within 500 meters of the river, giving a relevant population of 1,500 households.

$N=0.30\times5000=1500$ households

To determine the sample size, Cochran's formula for large populations was used to estimate the initial sample size:

$$n_0= [Z^2\cdot p\cdot (1-p)]/e^2 \qquad (1)$$

Where:

n_0: Initial sample size Z: Z-value for a 95% confidence level (Z=1.96)

p: Estimated proportion of the population, assumed to be 0.5 to maximize sample size

e: Margin of error, set at 5% (e=0.05)

Plugging in the values: $n_0 = [1.96^2 \cdot 0.5 \cdot (1-0.5)]/0.05^2$

$= [3.8416 \cdot 0.25]/0.0025$

$=0.9604/0.0025$

=384 households

Since the population is finite (N=1500), the sample size was adjusted using the finite population correction (FPC):

$n= n_0 / [1+ [\{n_0-1\}/N]]$ Substituting the values: $n=384/ [1+ \{383/1500\}] =384/1+0.255$

$=384/1.255$

=306 households

Proportion p and Margin of Error e

When there is no specific information about the population the value p=0.5 provides the maximum variability to ensure a reliable sample size. The researchers selected e=0.05 for determining the margin of error so that the findings could achieve both high confidence levels of 95% and practical field research capability. No pilot survey was conducted to determine p or e; standard values were used in line with similar field studies.

Cochran's formula estimated a sample size of 306 households. However, due to overlapping household heads and data saturation, interviews were conducted with 80 household heads, a sample sufficient to capture the diversity of perspectives while avoiding oversampling (Mugenda & Mugenda, 2009; Onwuegbuzie, 2007).

The interviews (Appendix C) explored provisioning services (water access, irrigation, food production), regulating services (flood and soil erosion control, groundwater recharge), and cultural services (income generation, well-being, and local practices). Simplified explanations and visual aids were used to avoid misinterpretation, following

Mavhura (2023), who emphasized contextualizing ecosystem services for respondents in community-based interviews.

3.2.3 Sampling design

Sampling combined stratified and random approaches to achieve representativeness. Villages within 500 meters of the river formed the strata, ensuring coverage of all seven villages. Within each stratum, random sampling was used to select households. For ecological surveys, two sand dam sites and two adjacent control areas were sampled to allow for direct comparisons under similar geographic conditions.

The integration of transects, sweep-ups, and spot checks was designed to minimize bias and maximize species detection across different habitats (UK River Restoration Centre, 2021). Multiple sampling techniques were used alongside Games-Howell post-hoc tests, an approach supported by Mulatu et al. (2017) for biodiversity studies in semi-arid environments.

3.3 Data Analysis Techniques

Data analysis utilized a mixed method approach where both descriptive and inferential analytical techniques were used to analyze quantitative data. Qualitative data were analyzed through narrative analysis. Geospatial analysis using GIS software was first employed to map the locations of sand dams along the Kikuu Sand River. Human-made and Natural features observed at the sand dams were also captured and documented and visual representation of the sand dams provided. This aimed at providing insights into the distribution and characteristics of sand dams within the study area.

An ANOVA test was utilized to compare the presence of target species between areas with and without sand dams. This statistical analysis was aimed at helping to determine if there are significant differences in biodiversity differences of target plant and animal species between these areas. A multi-comparison Post Hoc test was also used to determine which pairs had the highest mean differences and whether or not the mean differences were significant.

Assessing impacts of sand dam construction on ecosystem services was done by applying descriptive statistics and Regression analysis which was employed to examine the relationship between sand dam presence and the target ecosystem services indicators which are water quality and presence, accessibility to water by local communities for household and irrigation purposes, underground water recharge, Crop productivity, soil stability and structure. Thematic analysis of interview data was also used to help identify common themes related to changes in food and water and soil provisioning ecosystem services reported by the community members interviewed and specifically the themes that were attributed to sand dam construction.

The investigation used a key indicator table as shown in Table 1 to guide in data collection.

Table 1

Key Indicators of Biodiversity Changes and Ecosystem Services Provision as a Result of Sand Dam Construction in the Kikuu River, Makueni County

Research Question	Key Indicators	Data Collection Methods	Data Analysis
To delineate the natural and human-made features of Kikuu Sand River in Makueni County	Number of sand dams; Locations of sand dams	Field observations: GPS mapping of sand dams; Satellite imagery to verify locations	Geospatial analysis using GIS software; Visual interpretation of satellite images
To compare	Species presence and	Field	Analysis of

biodiversity changes between areas with and without sand dams along Kikuu Sand River	abundance (xerophytic grasses, acacia, mangoes, citrus, maize, beans, tomatoes, watermelons, termites, burrowing insects, rodents, squirrels, lizards, snakes, birds)	observations: Perpendicular transects, sweep-ups, spot checks; Community interviews on perceived changes	Variance (Welch and Games Howell post Hoc test
To assess the impact of sand dam construction on ecosystem services	Presence and levels of water retained behind sand dams; Condition and abundance of grasses, shrubs, trees; Community perceptions of provisioning, regulating, and cultural services	Field observations: Vegetation assessment; Interviews with community members on ecosystem service changes	Chi-square test: Thematic analysis of interview data; Descriptive statistics on ecosystem service perceptions

Source: Researcher (2023)

Indicators were selected in line with previous sand dam studies (Villani, 2019; Lasage et al., 2008; Ngugi et al., 2020a).

3.7 Eligibility Criteria

3.7.1 Inclusion criteria

The study included data on the Kikuu River catchment, biodiversity differences, and ecosystem services directly linked to sand dam construction. Data were included only if they met quality standards of accuracy, reliability, and relevance.

3.7.2 Exclusion criteria

Data outside the study area or unrelated to sand dam construction were excluded. Ecosystem service data not directly attributable to sand dams were also excluded.

3.8 Ethical Considerations

All interviews and surveys were conducted with the informed consent of participants. Respect for local customs and traditions was maintained, and visual aids were used to enhance understanding. Ethical clearance was obtained from the National Commission for Science, Technology, and Innovation -NACOSTI (See Appendix B) and the institutional Research Ethics Review Committee (MIRERC).

CHAPTER FOUR:RESEARCH RESULTS

4.1 Introduction

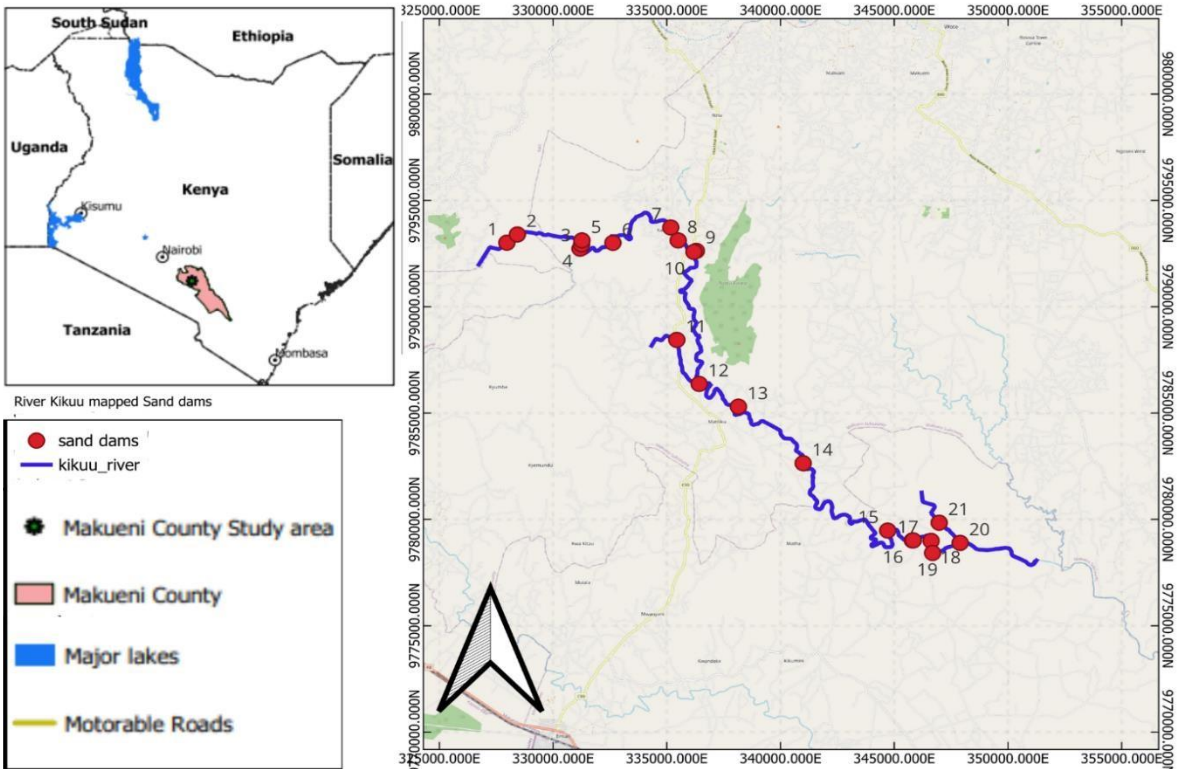
This chapter presents the results for the three objectives in the following order: delineation of natural and human-made features along the Kikuu River, including the mapped distribution of sand dams; comparative findings on target plant and animal species between sand dam sites and adjacent control areas; and community-reported ecosystem services associated with sand dams. The results integrate geospatial outputs (QGIS mapping), field species counts analyzed using Welch's ANOVA, Games–Howell post hoc comparisons and Pearson's χ^2 tests, and thematically analyzed interview responses from household heads living within 500 m of the Kikuu River.

4.1.1 Delineating the natural and human-made features of Kikuu Sand River in Makueni County, Kenya

A total of twenty-one (21) sand dams were identified and mapped along the Kikuu River within Nzaui/Kilili/Kalamba Ward, Makueni County presented in Figure 3 below. The mapped distribution shows sand dams spaced along the main sand-river channel and its immediate reaches, reflecting both topographic suitability and community investment in water-retention infrastructure.

Figure 3

Mapped sand dams along the Kikuu River in Nzaui/Kilili/Kalamba Ward, Makueni County.



Source: Researcher (2023)

In addition to the dam locations, adjacent natural and human-made features were recorded near each structure, including bedrock exposures at dam abutments, riparian vegetation cover, cultivated fields on river terraces, beekeeping sites, water-abstraction technologies, and localized sand-harvesting areas. These observations are summarized in Table 2 below, which provides a concise, side-by-side account of the key features observed near each mapped dam to support interpretation of spatial patterns.

Table 2

Summary of Mapped Sand Dams and Associated Features Along Kikuu River

Sand Dam no.	Sand Dam name	Year Built	Structural Status & Height	Human-Made Features	Natural Features	Additional Notes
	Mivati	2014	Height: 5 m; Sand accumulation: 5 m	Piped water for households; nurseries (kales, tomatoes, cabbages)	Napier grass; Rocks	Farming near riverbank
	Kwa Mutula	2012	Height: 7 m; Sand accumulation: 7 m	Piped water; farming (arrow roots, banana, sugarcane)	Greater woodrush; Rocks	—
	Mbukoni	2021	Height: 7 m; Sand accumulation: 3.5 m	Farming (mangoes, pawpaw, pumpkin, banana, sugarcane)	Xerophytic grasses; Acacia; Rocks	—
	Kwa Moses	2012	Height: 7 m; Sand	Farming (mangoes,	Xerophytic plants;	Active sand

		accumulation: 7 m	oranges); sand harvesting	Acacia; Rocks	harvesting site
Ikindui	2021	Height: 4 m; Sand accumulation: 4 m	Hand scooping for water; mango farming	Rocks; Vegetation on sand bank	—
Rianthokoo	2020	Height: 5 m	Diesel/gas pump; hand scoop holes	Indigenous trees; Xerophytic grass; Rocks	—
Sanzama	2021	Height: 5 m	No sand harvesting; hand scooping for water	Napier grass; Acacia; Greater woodrush; Cats foot grass	Dam wall damaged but water accessible upstream
Kalamba	2020	Height: 9 m; Sand accumulation: 9 m	Electric pump; underground tanks	Indigenous trees; Napier grass; Cats foot grass; Rocks	2 underground tanks present

	Kavingasi	1999	Height: 7 m; Sand accumulation: 6 m	Diesel water pump; no sand harvesting	Greater woodrush; False oat grass; Cats foot grass; Acacia	No rocks
.	Chamela	2009	Height: 6 m; Sand accumulation: 5 m	Diesel pumps; farming (pawpaw, mangoes, napier grass); sand harvesting	Greater woodrush; Xerophytic grass; Acacia; Rocks	—
.	Choewo	2019	Height: 5 m; Sand accumulation: 4 m	Sand harvesting; hand scooping for water	Acacia; Moringa; Cats foot grass; Greater woodrush; Rocks	Insufficient sand accumulation
.	Kwa Katili	2022	Height: 7 m; Sand accumulation: 6 m	Farming (mangoes, oranges, napier grass); water pump; hand scoop	Acacia; Greater woodrush; Rocks	—

.	Kwa Sammy	2022	Height: 6 m; Sand accumulation: 5 m	Farming (sweet potatoes, kales, pigeon peas); diesel pump; sand harvesting; hand scoops	Greater woodrush; Acacia; Rocks	Gabions installed; monitored sand harvesting
.	Kikuu 2	2011	Height: 8 m; Sand accumulation: 7 m	Built-in tank with filters; solar pump; sand harvesting	Acacia; Greater woodrush	Nonfunctional in 2023 (broken pipe; submerged dam)
.	Kikuu 1	2012	Height: 10 m	Farming (napier, orange, peas, maize); no sand harvesting	Acacia; Greater woodrush; Cats foot grass; False oat grass; Rocks	Bridge damage reduced function
.	Dange	2019	Height: 6 m; Sand	Farming (peas,	Indigenous vegetation;	—

			accumulation: 5 m	oranges); gas/diesel pumps; sand harvesting	Rocks; Greater woodrush; Cats foot grass; Acacia	
.	Nzange	2019	Height: 5 m; Sand accumulation: 4 m	Sand harvesting; no farming	Rocks	—
.	Kwa Kimongo	2012	Height: 7 m; Sand accumulation: 6 m	Farming (pawpaw, mangoes); no sand harvesting	Cats foot grass; False oat grass; Rocks	—
.	Kwa Mutio	2012	Height: 8 m; Sand accumulation: 6 m	Beekeeping; no farming	Greater woodrush; Cats foot grass; Rocks	—
.	Kikuo Kwama tungo Bridge	2020	Height: 6 m; Sand accumulation: 5 m	Farming (peas); sand harvesting, gabions; hand scoops	Greater woodrush; Cats foot grass; Acacia; Rocks	—
.	Kwamatungo	2021	Height: 7 m; Sand	Farming (oranges,	Acacia; Greater	Scoop holes

		accumulation: 6 m	peas); sand harvesting; hand scooping	woodrush; Cats foot grass; Rocks	refilled to avoid contamination

Source: Researcher (2023)

4.1.2 Integrated Benefits and Challenges of Sand Dams in Semi-Arid Landscapes

The majority of the dams were built between 2012 and 2022, with heights ranging from 4 to 10 meters and sand accumulation depths of 2 to 9 meters. Mbukoni sand dam as observed in Figure 4 has a height of 7m with sand accumulation almost reaching the top of the spill way. The figure illustrates the benefit of sand dams when used as water storage structures highlighting that the underground tank on the far right is able to store significant amounts of water which the local residents use to engage in large scale farming initiatives.

Figure 4

Mbukoni sand dam with underground built in tank on the right side, with sand accumulation almost reaching the height of the sand dam wall 7m

Source: Researcher (2023)

In addition to saving water, sand dams are frequently used as usable roads in rural regions, especially in the dry season. Sand dams' level or gently sloping surfaces offer a secure base for cattle, people, and cars to cross rivers, bringing vital connectivity to remote communities.

The compacted stones and sand in the dams provide a stable foundation during dry spells, improving community mobility and economic prospects. Produces are transported to markets by farmers with greater ease, and the local economy is boosted by more efficient movement of commodities and services. But when the rainy season arrives and the water levels rise, sand barriers become impassable, limiting accessibility. In these situations, elevated footbridges or other paths might be required to keep the connection intact as observed in Rianthokoo sand dam and illustrated by Figure 5 as shown below.

Figure 5

Rianthokoo sand dam used as a bridge allowing for crossing of animals, people and cars, also elevated to allow for passage during rainy seasons

Source: Researcher (2023)

Sanzama Sand dam for instance was noticed to have been destroyed as illustrated in figure 6 and needed renovation, it was also noted that at least 5 people were swept by floods in the last rains as they tried to cross the damaged Sanzama Bridge.

Figure 6

Damaged Sanzama Bridge posing a risk to community members who cross the bridge during rainy seasons

Source: Researcher (2023)

The majority of the sand dams had rocks and natural flora, including acacia trees, greater woodrush. Several sand dams for instance the Kalamba Sand Dam also reported the presence of false oat grass as shown in Figure 7 Dams like Mbukoni and Kwa Moses had considerable growth of xerophytic plants, indicating that most of the vegetation was acclimated to semi-arid conditions.

Figure 7

Kalamba Sand dam Along River Kikuu, home to a variety of vegetation like the False Oat grass: Famous for maintaining river flow on its path, locally known as 'Mwangi'

Source: Researcher (2023)

Several dams also aided farming along the riverbanks, producing products such as mangoes, bananas, oranges, and Napier grass. Notably, Mbukoni and Kwa Mutula as observed in Figure 8 hosted a variety of farming operations, including sugarcane, pumpkin, and arrowroots. Others like Kwa Moses sand dam in Figure 9 hosted bee keeping at the trees serving as riparian ecosystems of the River Kikuu.

Figure 8

Arrow Root and sugar cane farming 30m from the edge of Kwa Mutula Sand Dam

Source: Researcher (2023)

Figure 9

Bee keeping observed at Kwa Moses Sand dam

Source: Researcher (2023)

4.1.3 Operational Status and Water Abstraction Technologies of Sand Dams

The dams' functionality varied considerably, most were operational, with water being extracted through Petrol powered water pumps as observed in Figure 10. Sand dams like Dange Sand dam revealed unique technologies that were not observed anywhere else by utilizing gas generated water pumps to pump water to their famers as observed in Figure 11. Traditional hand scooping as seen in Figure 12 could only be used to abstract water solely intended for domestic purposes. Solar-powered water pump as observed at Kikuu 2 sand dam with a solar panel illustration presented in Figure 13, Kalamba sand dam utilizing an electric power pump (See Figure 14) and Kikuu 2 were famous for their underground storage tanks and pipe systems; however, Kikuu 2 became inoperable in 2023 owing to deterioration.

Diesel powered water pumps as illustrated in Figure 11 at Kwa Kimongo sand dam reveals the technological advancements in abstracting water from the innovative sand dam structures. Other dams, such as Kavingasi, Sanzama, and Kikuu 1, were damaged and required restoration because of sand over-accumulation and dam wall collapse, but water could still be collected by hand scooping from the accumulated sand left upstream.

Figure 10

Petrol Water Pump, pumping water to household tanks and Irrigating Fruit Orchards at Kikuu 1 Sand Dam

Source: Researcher (2023)

Figure 11

Farmers pumping water to their farms using Gas generated Water Pump at Dange Sand Dam

Source: Researcher (2023)

Figure 12

Traditional Hand Scooping of water from scoop holes at Kwa Katili Sand Dam

Source: Researcher (2023)

Figure 13

Kikuu 2 Sand Dam utilizing solar generated power to pump water from in built underground tank

Source: Researcher (2023)

Figure 14

Electric Pump House, Pumps water to Kalamba Fruit Processing Factory at the Kalamba Sand Dam

Source: Researcher (2023)

Figure 15

Diesel Water Pump at Kwa Kimongo Sand Dam

Source: Researcher (2023)

Many dams had sand harvesting locations, but others like Ikindui and Kwa Kimongo did not. Sand Dams, such as the Kikuu Kwamatungo Bridge and Chamela Sand Dam as observed in Figure 16, allowed for monitored sand gathering and collection which helped to avoid erosion and sand loss.

Figure 16

Truck Harvesting Sand from Chamela Sand Dam

Source: Researcher (2023)

Twenty-one Sand dams in total were mapped all having diverse ranges of water abstracting technologies. Most of the sand dams were fully mature and being utilized, while others were non-functional due to reasons like lack of enough sand accumulation, damage from the intense rains received in the November to December periods and January to May, others were fully submerged and the delivery pipes connecting the sand dams with built in tanks also being destroyed. The researcher also noticed that some of the sand dams were constructed at very close distances approximately from 200m to 300m apart, through field observational survey, these areas showed improved agricultural activities and outputs

4.2 Comparing Biodiversity Differences of Target Plant and Animal Species Between Areas with and Without Sand Dams Along Kikuu Sand River, Makueni County Kenya

This study compares biodiversity differences of selected plant and animal species between areas with sand dams and those without along the Kikuu Sand River in Makueni County, Kenya. The comparison provides insights into how sand dams influence ecological patterns and species distribution, thereby contributing to an understanding of their role in biodiversity conservation within semi-arid landscapes.

4.2.1 Target plant species analyses

Table 3 as shown illustrates the descriptive statistics results performed on the target plant species dataset, highlighting the variables that were put into consideration during the analysis, the species counts revealed dependent variables while distance and sites were considered as independent variables.

Table 3

Descriptive statistics of target plant species counts, distances from sand dams, and site locations along Kikuu River, Makueni County (N = 160). The table shows variability in species counts, sampling distances, and site distribution.

	N	Minimum	Maximum	Mean	Std. Deviation
Species Count	160	0	27	6.76	6.58
Distance (m)	160	100	500	300.00	141.87
Site	160	1.00	4.00	2.50	1.12
Valid N (list wise)	160				

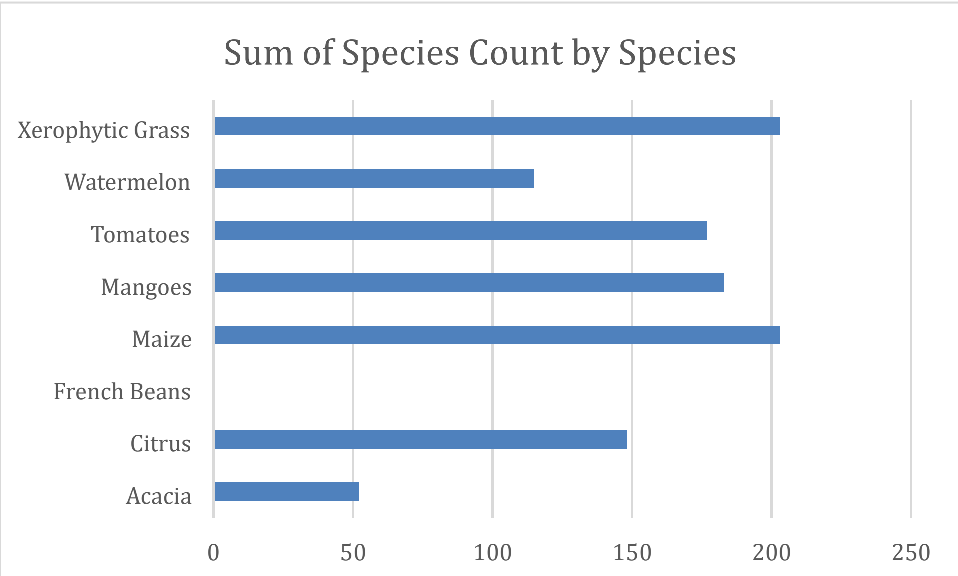
Source: Researcher (2023)

The mean plant species count is 6.76 and a standard deviation of 6.584, demonstrating heterogeneity in the number of plant species counted between sites and distances. The smallest plant species count was zero, while the greatest was 27. This large range illustrates the variations in biodiversity found in different places. Distances measured ranged from 100m to 500m from the sand dam, with a mean of 300m and a standard deviation of 141.865. This indicated a fairly even distribution of sampling sites. Locations were classified from 1 to 4, with a mean of 2.5 and standard deviation of 1.12154, indicating proportional selection across every one of the locations. The four locations (1–4) received a comparable number of observations, with 40 samples (25% each). This proportional selection offered an equitable depiction in the analyses. The data set had eight distinct plant species, each accounting for 12.5% of the total sample. This balance across the observed plant species helped to guarantee that each and every variety of the species was fairly represented in the study's results. Likewise, distances were taken into consideration and sampled equally, with 32 samples collected at each interval (100m, 200m, 300m, 400m, and 500m), accounting for 20% of the overall samples across every distance.

Figure 17 illustrates the sum of the species counts against the species type highlighting that Maize and Xerophytic grass were most abundant in the study sites, followed by Mangoes, tomatoes, Citrus, watermelons, acacia trees and French beans being the least observed recording zero number of species counted in the same area which was attributed to change of season.

Figure 17

Total counts of each target plant species across all study sites with maize and xerophytic grasses being most abundant, while French beans were absent in some sites, likely due to seasonal changes.



Source: Researcher (2023)

Sites and distances were taken into consideration and sampled equally, with 32 samples collected at each interval (100m, 200m, 300m, 400m, and 500m), accounting for 20% of the overall samples across every distance.

4.2.2 Comparisons of plant species count vs site

To assess the impact of sand dams on target plant species, a comparison of plant species counts within the sites was conducted across the study sites. Table 4 presents the results of this comparison, showing variations in the number of plant species recorded at each site, with and without sand dams. Site 1 (Sand Dam 1) had the greatest mean species count of 10.98, whereas Control Area 2 had the lowest at 2.55.

The overall mean of plant species count across all sites was 6.76, with a standard deviation of 6.584, indicating variation between sites.

Species Count

Table 4

Mean plant species counts per site, comparing sand dam and control areas. Sites with sand dams had higher mean species counts than control sites.

	N	Mean	Std. Deviation	Minimum	Maximum
1.00	40	10.98	8.056	0	27
2.00	40	3.75	3.201	0	12
3.00	40	9.75	6.376	0	21
4.00	40	2.55	2.459	0	10
Total	160	6.76	6.584	0	27

Source: Researcher (2023)

An ANOVA test was used to determine whether there were any significant differences in plant species count in all the four sites (Sand Dam 1, Control Area 1, Sand Dam 2, and Control Area. 2) and results presented in Table 5.

Table 5

ANOVA summary comparing plant species counts across four sites. The F-value and significance indicate that sand dam presence significantly affected plant species richness.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2139.619	3	713.206	23.414	.000
Within Groups	4751.875	156	30.461		
Total	6891.494	159			

Source: Researcher (2023)

The Sum of Squares between Groups was 2139.619 which represented the variability in plant Species Count that could be attributed to differences between the four sites; (Sand Dam 1, Control Area 1, Sand Dam 2, and Control Area 2). It captured how much the group means (average plant species counts for each site) differ from the overall mean. The Sum of Squares within Groups was 4751.875 which represented the variability within each site, capturing the spread of data points within each site around their respective means. This value reflected the variation in plant species count within individual sites. The Degrees of Freedom between Groups (DF = 3) showed the number of groups minus 1; there were 4 sites, so DF = 4 - 1 = 3. The DF within Groups (DF = 156) showed the total number of observations (160) minus the number of groups (4), so DF = 160 - 4 = 156. The total used DF = 159 representing the total number of observations minus 1 (160 - 1 = 159).

The Mean Square was the sum of squares divided by the degrees of freedom. Between Groups Mean Square was 2139.619 ÷ 3 = 713.206 reflecting the average variation between the sites. Within Groups Mean Square was 4751.875 ÷ 156 = 30.461 which showed the average variation within each site.

The F-statistic: 23.414, addressed the ratio of the Between Groups Mean Square to the Within Groups Mean Square (F = 713.206 ÷ 30.461 = 23.414). A larger F value suggested greater variance between the groups compared to the variance within the groups.

The F-statistic was used to test the null hypothesis that the means of the species counts were equal across the four sites. The p-value associated with this F-statistic was less than 0.001, indicating that the results were highly statistically significant, meaning that there was a very low probability (less than 0.1%) that the observed differences in species counts across the four sites were due to random chance. The investigation of this objective therefore rejected the null hypothesis and concluded that there were significant differences in plant species counts between the sites, meaning that the presence or absence of sand dams had a statistically significant effect on the number of plant species observed at these locations.

However, ANOVA only showed that at least one of the sites was different from the others, but not specifically which one. To determine which pairs of sites had significant differences, the study performed the Games-Howell post hoc test on the plant species dataset.

The "Robust Tests of Equality of Means" in Table 6 showed the results of the Welch ANOVA test on plant species counts at various places or distances. This test was performed because on the standard ANOVA test, the dataset revealed that there was a violation of equal variances and so this robust test was used to confirm the significance even when the variances were unequal.

Table 6

Welch ANOVA test for plant species counts across sites, accounting for unequal variances. Results confirm significant differences between sites.

	Statistic[a]	df1	df2	Sig.
Welch	25.131	3	80.886	.000

a. Asymptotically F distributed.

Source: Researcher (2023)

The result 25.131 showed a considerable difference in plant species counts between the groups being compared. The numerator has three degrees of freedom, while the denominator had 80.886 degrees. This indicated that the sample sizes for the groups were not equal, which was a common situation when using Welch's ANOVA due to unequal variances. The p-value of.000 (less than the used alpha threshold of 0.05) indicated a statistically significant difference in means between the groups.

The "Multiple Comparisons" illustrated in Table 7 presents the results of the Games Howell post-hoc test for species counts across different sites showing which paired sites had the highest mean differences and which mean differences were particularly statistically significant.

Table 7

Games-Howell post-hoc comparisons of plant species counts between sites. Asterisks (*) indicate statistically significant differences (p < 0.05), showing higher counts in sand dam areas compared to controls.

(I) Site	(J) Site	Mean Difference (I-J)	Std. Error	Sig.
1.00	2.00	7.225*	1.371	.000
	3.00	1.225	1.624	.875
	4.00	8.425*	1.332	.000
2.00	1.00	-7.225*	1.371	.000
	3.00	-6.000*	1.128	.000
	4.00	1.200	.638	.245
3.00	1.00	-1.225	1.624	.875
	2.00	6.000*	1.128	.000
	4.00	7.200*	1.081	.000
4.00	1.00	-8.425*	1.332	.000
	2.00	-1.200	.638	.245
	3.00	-7.200*	1.081	.000

Source: Researcher (2023)

Each site was represented as follows: Site 1 for Sand Dam 1, 2 for Control Area 1, 3 for Sand Dam 2, and 4 for Control Area 2. The table showed the mean differences between pairs of sites, indicating how plant species counts vary. Asterisks (*) next to mean differences indicated that these differences were statistically significant at the 0.05 level. The study focused on comparing Sand Dam 1 (1) vs. Control Area 1 (2) where the mean difference is 7.225 (p = .000), suggesting significantly more plant species in Sand Dam 1. At Sand Dam 2 (3) vs. Control Area 2 (4) where the mean difference is 7.200 (p = .000), it showed significantly that there were more plant species in Sand Dam 2 as compared to its adjacent control area. The Games-Howell post-hoc test results indicated that both Sand Dam 1 and Sand Dam 2 significantly supported higher plant species counts compared to Control Area 1 and Control Area 2. This suggests that sand dams are effective in promoting biodiversity compared to control areas.

4.2.3 Target Animal Species Analyses

Descriptive Statistics

The dataset contained data from 140 cases for animal species count in all sites, with no missing values. The average animal species count was 3.96, with 4 target animal species present at each site. The site variable had a mean of 2.50, indicating an even distribution across the four sites. The standard deviation for animal species count was 4.248, indicating significant variation between sites. The range for animal species count was 20, indicating considerable variability, while the range for site was 3 as shown in Table 8.

Table 8

Descriptive statistics of target animal species counts, sampling distances, and site locations (N = 140). Shows distribution and variability across sites.

	N	Minimum	Maximum	Mean	Std. Deviation
Species Count	140	0	20	3.96	4.248
Distance (m)	140	100	500	300.00	141.865
Site	140	1.00	4.00	2.5000	1.12154
Valid N (list wise)	140				

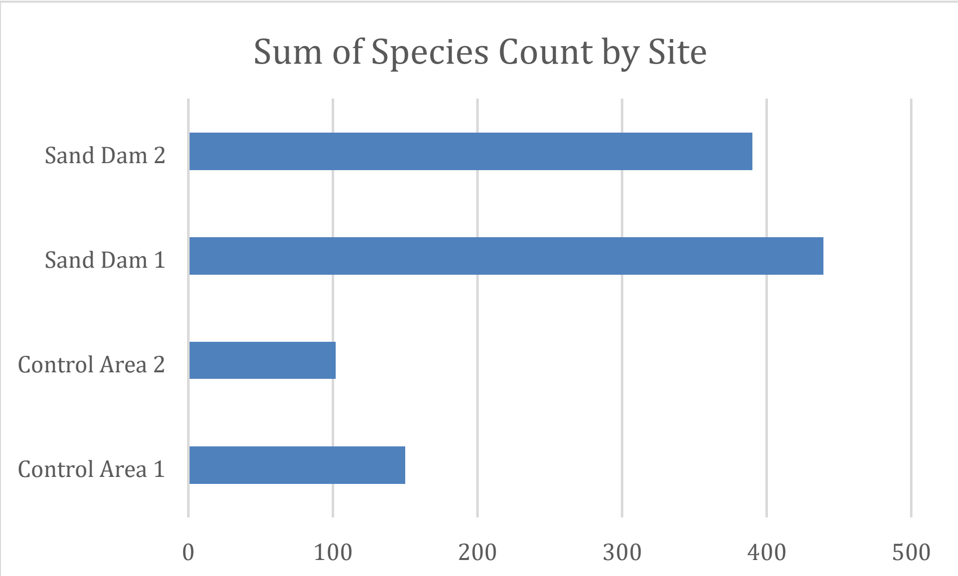
Source: Researcher (2023)

The distances ranged from 100 to 500 meters, with an average distance of 300 meters from the reference point (a central point in a river in the control areas or sand dam). The variation in distances is quite large, indicating that the observations were taken from diverse locations. Observations were collected across four sites, with an even distribution between them.

Figure 18 shown illustrates the sum of species count by site showing that the sand dam areas had more animal species counts as compared to control areas.

Figure 18

Total animal species counts by site. Sand dam sites (Sites 1 and 2) have higher species counts than control areas (Sites 3 and 4).



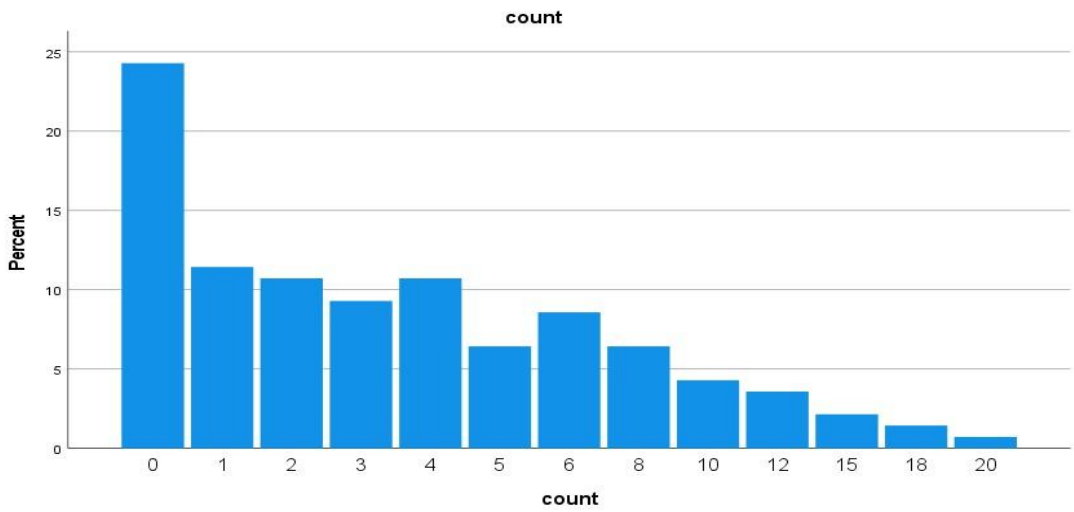
Source: Researcher (2023)

The above figure presents a high degree of variability in species count across the four sites, as indicated by the standard deviation and range. On average, approximately 4 animal species were observed per site, with some sites showing higher species counts than others. The site codes are well-distributed, as seen from the mean of 2.50 and the balanced standard deviation. The data set also included observations within a diverse range of distances from the river that is from 100m showing the minimum distance of observations to 500m showing the maximum distance of observations.

The Bar chart in Figure 19 shows the frequencies of species count in all four sites:

Figure 19

Frequency distribution of animal species counts across all sites. Most locations (46.4%) had 0–2 species, while 18.6% of locations had 8 or more species.



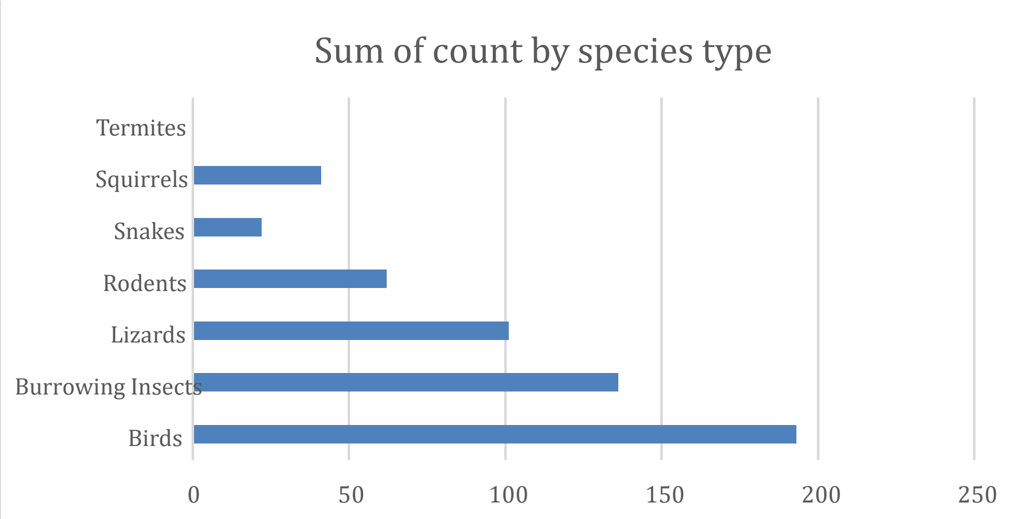
Source: Researcher (2023)

The bar chart shows, High Frequency of Low Species Counts: The majority of surveyed locations (46.4%) had 0 to 2 target animal species, indicating that many regions were appropriate for high biodiversity and Moderate to High Species variety in Some Areas: Around 35% of the sites contained 3 to 6 species, whereas 18.6% of the observations had rather high animal species variety (8 or more species).

Figure 20 illustrates the variability of the animal species counts when plotted against the animal species types.

Figure 20

Frequency distribution of animal species counts across all sites. Most locations (46.4%) had 0–2 species, while 18.6% of locations had 8 or more species.



Source: Researcher (2023)

The figure 20 illustrates that birds were the most observed animal species within the study sites followed by burrowing insects, lizards, rodents, squirrels then snakes. Termites were not observed at all in the study region. All four sites were also equally sampled, with each site contributing 25% to the total dataset as shown in the bar graph above. This suggests a balanced study design, where each site is given equal weight, ensuring that no particular site dominates the dataset. The results from each site were directly comparable due to the uniform distribution of data. The equal representation ensures that any observed differences in biodiversity or animal species count can be attributed to the ecological differences between the sites, rather than sample size bias.

An ANOVA test was used to show whether there were significant differences in animal species counts among the sampled sites. Tabel 9 shows the variance between and within groups and also illustrates the significance level.

Table 9

ANOVA summary for animal species counts across the four sites. Results indicate significant differences in species richness between sand dam and control sites.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	380.193	3	126.731	8.097	.000
Within Groups	2128.629	136	15.652		
Total	2508.821	139			

Source: Researcher (2023)

The sum of squares between groups is 380.193, demonstrating a significant variation in species counts due to differences between the four sites. The total of squares within groups is 2128.629, indicating the variation in species counts within each location. The total shows the entire sum of squares is 2508.821, representing the total variability in the data. There are three degrees of freedom between groups (number of groups - one), and 136 degrees of freedom within groups (total observations minus number of groups).

The mean square between groups is determined as 126.731. The mean square within groups is estimated as 15.652. The F-ratio is 8.097 shows the ratio of variability between groups to variability within them. A higher F value often indicates bigger variances between group means in comparison to the variability within the groups. The p-value (Sig.) is 0.000, lower below the standard alpha level of 0.05. This suggests that there are statistically significant variances in animal species counts between the four sites.

A robust test of equality of mans was conducted due to violation of an assumption in homogeneity of variances. Table 10 presents the Welch statistical value as well as the significance and at which level.

Table 10

Welch robust test for equality of means for animal species counts, accounting for unequal variances. Significant differences exist between sites.

	Statistic[a]	df^1	df^2	Sig.
Welch	8.272	3	71.767	.000

a. Asymptotically F distributed.

Source: Researcher (2023)

The test statistic (Welch) is 8.272. This value represents the degree of divergence between group means in relation to the variability within the groups. Higher levels typically indicate a stronger influence. Degrees of freedom (DF1 and DF2) shows df1 = 3: This shows the degree of freedom across groups (number of groups minus one). Df2 = 71.767being so, indicates the degrees of freedom within groups, which may be non-integer due to the Welch adjustment for uneven variances. Significance (sig): The p-value is.000 (often stated as <.001). This shows that there is a statistically significant difference in means between the groups. As the p-value is smaller than the typical alpha level of 0.05, you can reject the null hypothesis, which claims that there are no differences in means across the groups.

Alternately a Games-Howell Post Hoc Test: the Games-Howell post-hoc test for multiple comparisons following the Welch's ANOVA was performed. This test is used to determine which specific group means differ after establishing that at least one group means is significantly different.

Multiple Comparisons

A multiple comparison post hoc test was also performed and illustrated in Table 11 to show pairwise comparisons, the mean differences and whether or not they were significant.

Table 11

Games-Howell post-hoc comparisons for animal species counts between sites. Asterisks (*) indicate significant differences ($p < 0.05$), confirming sand dam areas have higher species counts than control sites.

(I) site	(J) site	Mean Difference (I-J)	Std. Error	Sig.
1	2	1.457	1.205	.623
	3	3.371*	1.016	.009
	4	4.229*	.977	.000
2	1	-1.457	1.205	.623
	3	1.914	.913	.167
	4	2.771*	.870	.013
3	1	-3.371*	1.016	.009
	2	-1.914	.913	.167
	4	.857	.580	.457
4	1	-4.229*	.977	.000
	2	-2.771*	.870	.013
	3	-.857	.580	.457

Source: Researcher (2023)

The test was performed at a 95% Confidence Interval Levels at 0.05 and as the study focused on significance between 2 groups that is, Site 1(Sand Dam 1) and Site 3 (Control Area 1) showed a mean difference of 3.371, and a significant p value of .009 indicating that Site 1: Sand Dam 1 has a higher mean than Site 3: Control Area 1 and Site 2 (Sand Dam 2) vs. Site 4 (Control Area 2) had a mean difference of 2.771, which was also significant with a p value at .013), indicating that Site 2 has a higher mean than Site 4.

This indicates that there are notable differences in counts among the sites, highlighting that sand dam areas significantly enhanced biodiversity.

4.3 Assessing the impacts of sand dam construction on ecosystem services along the Kikuu Sand River.

The Research also conducted a total of 80 in depth interview majorly to assess the impacts of sand dam's construction on ecosystem services in River Kikuu, Makueni County, Kenya. 80 semi-structured interviews in total were conducted to household's heads living near the sand dams and control areas (500m from the river) until saturation. Semi structured interview questions were aimed at undressing the ecosystem services that community members get as a result of the sand dams.

Thematic analysis was done according to major themes and responses observed which were first coded numerically. Regression, and chi square tests analyses were then done through IBM SPSS 27 to show the relations between target variables; sand dam, and control areas. The major variables and themes coded included soil stability and crop productivity, water quality and accessibility for various purposes, changes in and animal and plant species observations, other benefits included water provision, food provision, flood regulation, income generation and whether or not there are improved livelihoods in areas with sand dams compared to control areas.

Another additional variable was included which was adopted by summing up Ecosystem Services Coded Numerical Values: Ecosystem services score was adopted by summing up the numerical score that was given to each of the ecosystem services targeted by the research investigation during thematic and numerical analysis. After Thematic Analysis where all responses were combined and coded similarly: If for instance a respondent stated that Water Quality had Increased Upstream or that Salt content in water had reduced upstream, the coded answer was "Increased" to which later on, Numerical values were given to each coded response depending on the interview respondents, that is if the there was an increased accessibility to water resources or increased water quality and accessibility in sand dam areas the score given was “3”, no changes was numerically coded as “2” and decreased accessibility was given the value “1”, so ecosystem services with the highest numerical values represented a positive response and summing up all the ecosystem services created a total of ecosystem service score values’ which further underwent analysis.

Descriptive statistics performed to the interview dataset was presented in Table 12 and includes variables such as ecosystem service scores, observed biodiversity differences, and respondent demographics.

Table 12

Descriptive statistics of ecosystem service scores, observed biodiversity, and respondent demographics (N = 80).

	N	Minimum	Maximum	Mean	Std. Deviation
Sand Dam ID	80	1	4	2.51	1.136
Ecosystem Service Scores	80	14.00	27.00	22.2125	2.97540
Other Benefits	80	1	7	6.05	1.882
Soil Stability and Crop Productivity Code	80	2	3	2.70	.461
Water Quality and accessibility for various purposes Code	80	1	3	2.86	.497
Differences in the Number of Plant and Animal Species Observed Code	80	2	4	3.84	.514

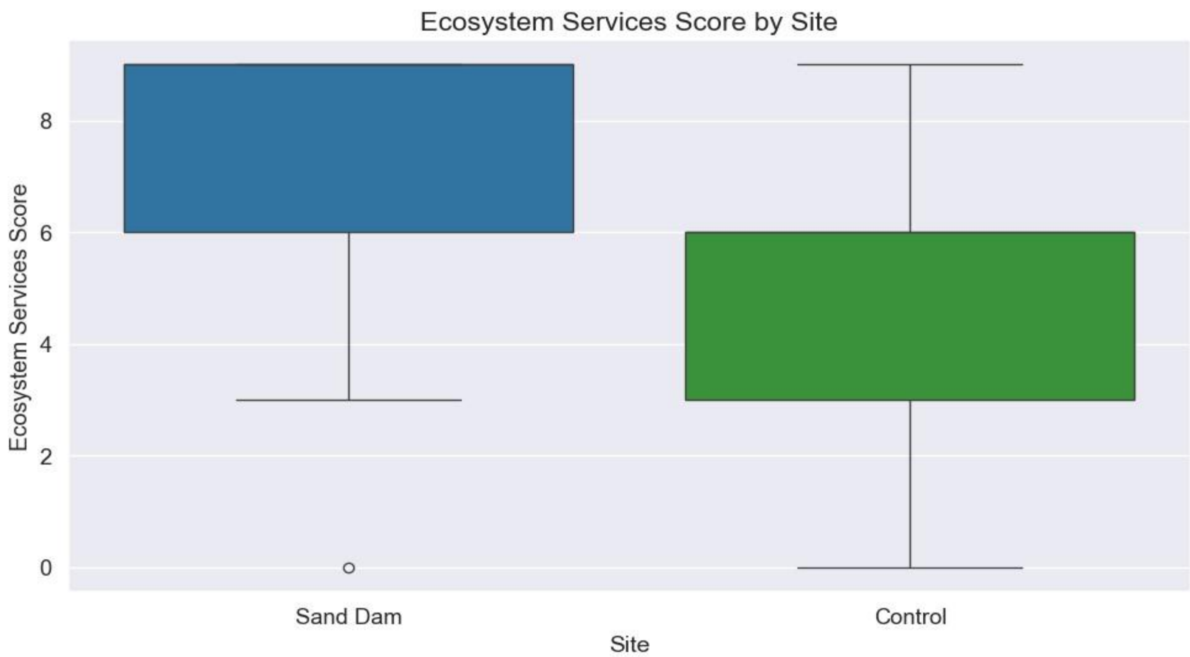
Plant Species Observed Code	80	1	7	4.08	1.999
New Animal Species Observed Code	80	0	3	1.00	1.273
Animal Observed Code	80	1	3	2.69	.493
Occupation Code	80	1	6	2.00	1.691
5_Years_of_Experienc	80	2	50	20.45	8.955
3_Age	80	24	70	47.79	9.490
Valid N (list wise)	80				

Source: Researcher (2023)

Figure 21 presents a boxplot comparison of ecosystem services scores between sites with sand dams and control sites (those without sand dams). The visualization illustrates the distribution, central tendency, and variability in ecosystem service scores across the two site categories.

Figure 21

Boxplot comparing ecosystem service scores between sand dam sites and control sites.



Source: Researcher (2023)

The figure shows the distribution of ecosystem services scores across two sites: Sand Dam (blue) and Control (green). The Sand Dam site has a higher concentration of scores at the upper end (9.0), while the Control site has more scores distributed in the middle range (particularly at 6.0 and 3.0), showing that sand dams provided increased ecosystem services from the in-depth interview insights.

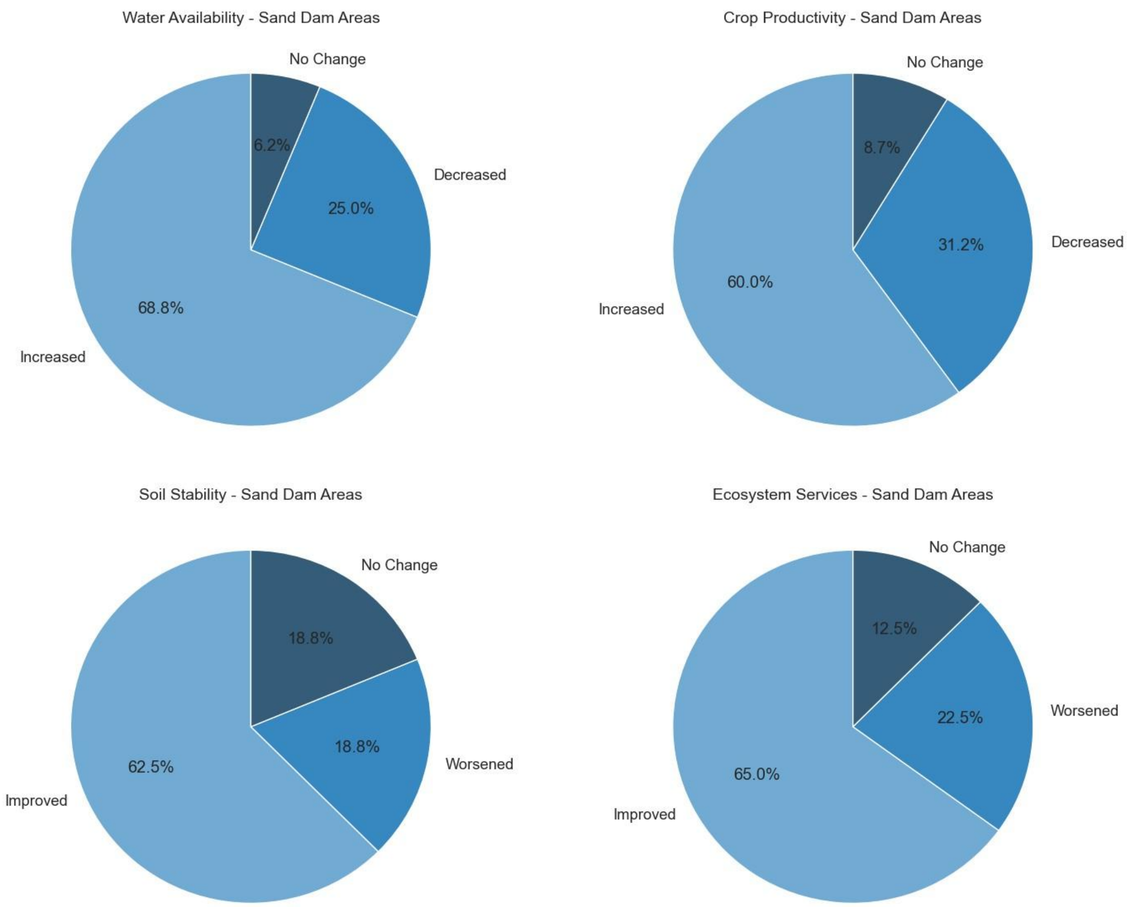
4.3.1 Sand dam and control areas percentage responses

The Figure 22 contains four pie charts summarizing interview responses about the effects of sand dams on water availability, crop productivity, soil stability, and ecosystem services. Across all categories, the majority of respondents perceived positive impacts, with water availability (68.8%) and ecosystem services (65.0%) showing the highest reported improvements. However, some respondents reported negative effects, such as 31.2% stating decreased crop productivity and 22.5% noting worsened ecosystem services. A smaller percentage of participants observed no change across all aspects, ranging from 6.2% (water availability) to 18.8% (soil stability).

These sand dams' responses revealed improved ecosystem services.

Figure 22

Pie charts showing the proportion of positive, negative, and no-change responses on water availability, crop productivity, soil stability, and ecosystem services in sand dam areas.



Source: Researcher (2023)

The Figure 23 also contains four pie charts summarizing interview responses about the effects of control areas (without sand dams) on water availability, crop productivity, soil stability, and ecosystem services. Majority of respondents reported negative impacts, with 62.5% noting decreased water availability, 68.8% reporting decreased crop productivity, and 60.0% perceiving worsened ecosystem services.

This being attributed to the increased water usage upstream and reduced water storage and availability in the areas without sand dams. Soil stability was also negatively affected, with 56.2% saying it worsened, while only 22.5% saw improvements. Compared to sand dam areas, control areas had lower reported improvements and higher negative perceptions, suggesting that sand dams if incorporated to water resource management may contribute positively to Ecosystem condition

Figure 23

Pie charts showing the proportion of positive, negative, and no-change responses on water availability, crop productivity, soil stability, and ecosystem services in control areas.

Source: Researcher (2023)

4.3.2 One-way ANOVA results on coded interview data

The ANOVA test results as presented in Table 24 indicated significant differences in several ecosystem service indicators within different sand dam IDs. The table provided the Sum of Squares, degrees of freedom (df), Mean Square, F-statistic, and significance level (Sig.) for each factor, highlighting whether the observed differences were statistically significant.

Figure 24

One-way ANOVA results for coded interview data on ecosystem service indicators across sand dam sites.

	Sum of Squares		Mean Square	F	Sig.
Other Benefits					
Between Groups	20.483	3	6.828	2.001	.121
Within Groups	259.317	76	3.412		
Total	279.800	79			
Soil Stability and Crop Productivity					
Between Groups	9.141	3	3.047	30.234	.000
Within Groups	7.659	76	.101		
Total	16.800	79			
Changes in Number of Plant and Animal Species Observed					
Within Groups	3.601	3	1.200	5.277	.002
Between Groups	17.287	76	.227		
Total	20.888	79			

Water Quality and accessibility for various purposes					
Between Groups					
Within Groups	2.306	3	.769	3.400	.022
	17.182	76	.226		
Total Groups	19.487	79			
Between Groups	144.207	3	48.069	21.321	.000
Plant Species Code					
Within Groups	171.343	76	2.255		
Total	315.550	79			
New Animal Species					
Between Groups	35.775	3	11.925	9.827	.000
Within Groups	92.225	76	1.213		
Total	128.000	79			
Animal Observed					
Between Groups	3.761	3	1.254	6.176	.001
Within Groups	15.427	76	.203		
Total	19.188	79			

Source: Researcher (2023)

For Other Benefits, the analysis revealed a sum of squares of 20.483 between groups, resulting in an F-value of 2.001 with a significance level of 0.121. The other benefits code represented benefits such as improved livelihoods, increased income and income generating activities. This suggested that there were no statistically significant differences in the perceived other benefits provided by the sand dams across the different groups.

In contrast, Soil Stability and Crop Productivity showed substantial variability, with a sum of squares of 9.141 and an F-value of 30.234, resulting in a significance level of 0.000. This indicates significant differences among the groups, suggesting that the construction of sand dams positively impacts soil stability and productivity. The results for Changes in the Number of Plant and Animal Species Observed were also significant, with an F-value of 5.277 and a significance level of 0.002. This finding suggests that the presence of sand dams was associated with significant variations in biodiversity observed across different sites. Similarly, Water Quality and Accessibility showed significant differences among groups, with an F-value of 3.400 and a p-value of 0.022, indicating that the construction of sand dams influences water quality positively.

In terms of plant biodiversity, the ANOVA test for Plant Species Observed Changes yielded an F-value of 21.321 and a significance level of 0.000, showing that sand dams significantly enhance and support plant species diversity. The analysis of New Animal Species Observed indicated significant differences as well, with an F-value of 9.827 and a p-value of 0.000, suggesting that sand dam construction may foster the introduction of new animal species.

Finally, the ANOVA results for Animals Observed indicated significant differences among groups with an F-value of 6.176 and a significance level of 0.001, reinforcing the positive impact of sand dams on local animal species populations.

4.3.3 Regression Analyses

The model summary indicated that the regression analysis included Sand Dam ID as the predictor variable for the dependent variable, Ecosystem Service Scores. The R^2 value of 0.258 indicated that approximately 25.8% of the variance in ecosystem service scores was explained by the model, while the adjusted R^2 value of 0.249 accounted for the number of predictors in the model. It is important to note that the two lower Sand Dam IDs (1 and 2) represented actual sand dam areas, while IDs 3 and 4 were coded as Control Areas 1 and 2, respectively. These control areas did not have sand dams, making them an important baseline for comparison with the sand dam areas. The standard error of the estimate is 2.57900, indicated the average distance that the observed values fall from the regression line, this is as shown in the table 13 below:

Table 13

Regression model summary showing Sand Dam ID as predictor for ecosystem service scores.

Model Summary

Model	R	R^2	Adjusted Square	Std. Error of the Estimate
1	.508[a]	.258	.249	2.57900

a. Predictors: (Constant), Sand Dam ID

Source: Researcher (2023)

Figure 25 shows a linear regression comparing ecosystem services scores between Control (0) and Sand Dam (1) sites, with each blue dot representing individual data points. The upward sloping red line with a pink confidence interval indicated that Sand Dam sites have higher ecosystem services scores on average compared to Control sites.

Figure 25

Scatterplot and regression line showing the relationship between Sand Dam ID and ecosystem service scores.

Source: Researcher (2023)

4.3.4 ANOVA Test Analyses

The ANOVA results presented in Table 14 provides insight into the overall significance of the regression model. The regression sum of squares was 180.590, while the residual sum of squares was 518.798, resulting in a total sum of squares of 699.387. The degree of freedom for the regression was 1, and for residuals was 78. The F-value is 27.151 with a significance level of 0.000 indicated that the model was statistically significant, meaning that Sand Dam ID significantly predicts the ecosystem service scores.

Table 14

ANOVA results for regression analysis examining the overall significance of Sand Dam ID on ecosystem service scores.

Model	**Sum of Squares**	**Df**	**Mean Square**	**Sig.**
Regression	180.590	1	27.151	.000[b]
Residual	518.798	78	**6.651**	
Total	699.387	79		

a. **Dependent Variable: Ecosystem Service Scores**

b. **Predictors: (Constant), Sand Dam ID**

Source: Researcher (2023)

The regression equation generated by the coefficients Table 15 indicated that for each one-unit increase in Sand Dam ID, ecosystem service scores decrease by 1.331 units, as shown by the unstandardized coefficient B=−1.331B = -1.331B=−1.331. The negative relationship is further supported by the standardized coefficient (Beta) of 0.508. The t-value of -5.211 and p-value of 0.000 confirm that this negative trend is statistically significant.

The lower Sand Dam IDs (1 and 2), representing the actual sand dam areas, had higher ecosystem service scores, while the higher Sand Dam IDs (3 and 4), representing control areas for sand dam 1 and 2 respectively, had lower ecosystem service scores. This revealed that sand dam construction was linked with or associated with improved ecosystem services.

Table 15

Regression coefficients for the relationship between Sand Dam ID and ecosystem service scores.

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.
1	(Constant)	25.556	.703		36.330	.000
	Sand Dam ID	-1.331	.255	-.508	-5.211	.000

a. Dependent Variable: Ecosystem Service Scores

Source: Researcher (2023)

4.3.5 Chi-Square Test

The cross tabulation of Ecosystem Service Scores by Sand Dam ID provided a count of the number of observations for each combination of service scores and sand dam/control site identifiers. The lower Sand Dam IDs (1 and 2) represent actual sand dam sites, while IDs 3 and 4 represent control areas without sand dams.

Higher Ecosystem Service Scores (scores ranging from 22 to 27) were more frequently associated with lower Sand Dam IDs (1 and 2). For example, Sand Dam ID 1 has 10 counts for a score of 26, and Sand Dam ID 2 has 5 counts for a score of 22. The Pearson Chi-Square test presented in Table 16 examines whether there is a significant association between the Sand Dam IDs and the Ecosystem Service Scores.

Table 16

Chi-square test results examining the association between Sand Dam IDs and ecosystem service scores.

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)	Point Probabil
Pearson Chi-Square	33.029[a]	9	.000	.000		
Likelihood Ratio	35.006	9	.000	.000		
Fisher-Freeman-Halton Exact Test	24.537			.000		
Linear-by-Linear Association	.332[b]	1	.565	.603	.302	.035
N of Valid Cases	80					

a. 12 cells (75.0%) have expected count less than 5. The minimum expected count is 1.42.

b. The standardized statistic is .576.

Source: Researcher (2023)

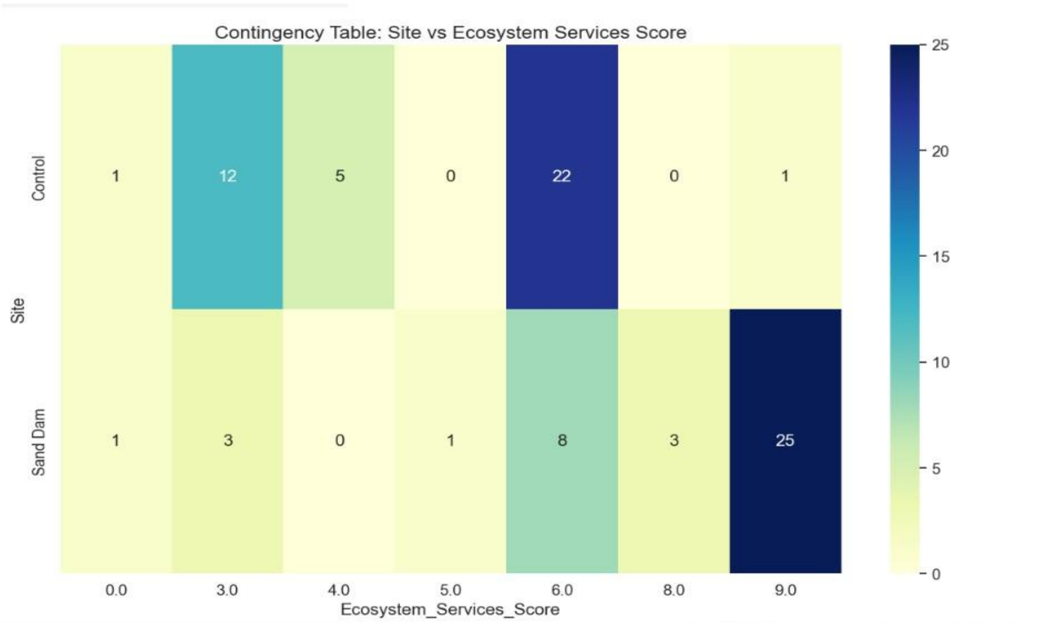
The test result showed a chi-square value of 33.029 with a p-value of 0.000, which was less than the significance level of 0.05. This indicates that there was a statistically significant relationship between the two variables. Therefore, the sand dam areas and control areas significantly differ in terms of the ecosystem services provided. The likelihood ratio chi-square test confirms the result from the Pearson Chi-Square test; With a value of 35.006 and a p-value of 0.000, a significant association is indicated between Sand Dam IDs and ecosystem service scores. It further reinforces the finding that the differences in scores between the sand dam areas and control areas were significant.

The Fisher-Freeman-Halton Exact Test is used when the expected cell counts are low and this was adopted in this study (where 12 cells had an expected count less than 5). The exact p-value of 0.000 confirms the significant relationship between Sand Dam IDs and Ecosystem Service Scores, validating the results of the previous chi-square tests. Interestingly, the Linear-by-Linear Association tests measured whether there was a linear trend between Sand Dam ID and Ecosystem Service Scores and the p-value of 0.565 indicated that no significant linear association existed between the two variables. This suggested that the relationship between Sand Dam ID and ecosystem service scores did not follow a strict linear trend.

The contingency heatmap shown in Figure 26 illustrates the frequency distribution of ecosystem services scores across Control and Sand Dam sites, with darker blue indicating higher counts. Control sites had their highest concentration at score 6.0 (22 counts), while Sand Dam sites had their highest concentration at score 9.0 (25 counts), showing sand Dam sites tend to provide higher ecosystem services.

Figure 26

Heatmap of ecosystem service score frequencies across sand dam and control sites; darker blue indicates higher counts.



Source: Researcher (2023)

CHAPTER FIVE: DISCUSSION

5.1 Introduction

This chapter presents the discussion of results. Findings on geographical distributions of sand dams as well as water collection methods are explored. The target species frequency and behavioral patterns as well as their effects on biodiversity and ecosystem services have also been examined discussed.

5.2 Delineating Natural Features and Human Made Features in Kikuu Sand River Which Is Located in Makueni County in Kenya

Observations of sand accumulation behind majority of the sand dams show maturity. The accumulation creates specialized ecological areas that support ecological growth while revitalizing water table levels matching previous studies indicating that sand dams operate as natural sediment collecting structures (Lasage et al., 2008).

The study also revealed that sand harvesting at high levels and poor sediment control resulted in downstream erosion. The unexpected sediment disruption led to erosion along the stream channel and this was mostly observed downstream. According to Yifru et al. (2021) sustainable management practices like controlled sand harvesting in some regions as evidenced by the study serve as essential methods to prevent these kinds of impacts.

Sand dams like Kalamba and Kwa Katili demonstrate that attached piped water systems boost water accessibility throughout the community. Better water infrastructure development brings about social justice and educational benefits to families attributed to reduced workloads for women and children. This research establishes the essential role that sand dams play in supporting welfare advancements and economic growth within communities. The implementation of sand dams establishes animal water supply points which reduces their travel requirements and also minimizes water availability disputes between communities. Animals in Kwa Katili and Kwa Mutula needed fewer kilometers to reach water sites because of the sand dams resulting in improved pasture conditions and reduced stress on the pastrol environment. The research outcomes by Ertsen & Ngugi. (2021b) align with those of this study showing that cattle near sand dam communities remain healthier and local residents achieve better socio-economic results.

The riparian areas of Mbukoni and Kwa Sammy contained abundant vegetation consisting of Acacia trees together with larger woodrush and xerophytic grasses. The ongoing accumulation of sand and organic materials which accumulate behind the dams creates ecological habitats for plants that boost biodiversity and strengthen ecological resistance particularly by creating resistance to erosion instances. A study published established that these plants both secure riverbanks and lower soil erosion risks and replenish underground water resources aligning with the findings of the current study (Muia et al., 2021).

The Kwa Mutio sand dam serves as water reservoir while still functioning as dry-season crossing points for people and animals. The infrastructure enables better market and health-care facility and school accessibility for increased social integration, economic exchange and trade. Research by Nel et al. (2022) supports the dual-purpose capability of sand dams in rural development illustrating that the constructive advantages of sand dams like observed in Kikuu 2 and Sanzama as well as sand overextraction undermines their operational effectiveness and that their effectiveness are countered by structural deterioration of infrastructure.

5.3 Comparing Biodiversity Differences of Target Plant and Animal Species Between Areas With and Without Sand Dams Along Kikuu Sand River, Makueni County Kenya

5.3.1 Target plant species

The observed species abundance data shows a variation of 6.76 with 6.584 as the standard deviation across different locations and distance zones. Results from our study matched previous findings of Mungai et al. (2024) which demonstrated diverse species types and counts representing the increased biodiversity discovered around sand dam areas.

The results found a significant difference in species count between the sites, yielding a total sum of squares of 6891.494. The mean square between the groups was 713.206, revealing the average variability of species abundance across the four sites. Meanwhile, the mean square within the groups was 30.461, indicating that the average variation in Count the species at each place was high. The F-value was substantial, indicating that the differences found between the sites were unlikely to arise by chance. As a result, the study concluded that the species counts vary statistically significantly between sites.

Welch's ANOVA showed a significant variation in species counts across the four sites, with $F(3, 156) = 23.414$, $p < 0.001$. This suggests that biodiversity differs greatly across controlled and uncontrolled ecosystems. Sand Dam 1 had the highest average species count (10.98), while Control Area 2 had the lowest (2.55). This shows that sand dams offer favorable ecological conditions that promote increased biodiversity.

The Welch ANOVA and Games-Howell post-hoc analyses revealed significant differences in species counts, particularly between Sand Dam 1 and Control Area 1, and Sand Dam 2 and Control Area 2. The statistical significance of these findings supports the idea that sand dams considerably improve local biodiversity These findings are consistent with previous research by Muia et al. (2021), which found that sand dams have a positive influence on species diversity.

Sand Dam 1 and Sand Dam 2 had greater species counts than the control regions, highlighting the function of sand dams in promoting biodiversity. Sand Dam 1 had the greatest average species count (M = 10.98, SD = 8.06), followed by Sand Dam 2 (M = 9.75, SD = 6.38). These higher species count in sand dam locations were attributable to enhanced water availability and soil moisture levels caused by sand dams, which produce favorable conditions for both plant and animal species (Ngigi et al., 2007).

In contrast, Control Areas 1 and 2 exhibited much lower species counts, with mean values of 3.75 (SD = 3.20) and 2.55 (SD = 2.46, respectively). This research suggests that places without sand dams as a result of limited water resources are likely to host a less biodiversity. These findings are consistent with prior research, which has shown that sand dams improve ecosystem services by enhancing water retention and minimizing soil erosion, promoting vegetation development and improving habitats for diverse species (Pichler & Ingalls, 2021).

5.3.2 Target animal species

The test figure (Welch) being 8.272 demonstrated how much group means deviate from each other relative to the group internal variations. Strong influencing power therefore appeared at higher statistic levels. Research on target animal species around sand dam sites established that their population numbers differed significantly across the four investigation areas. The findings showed that study sites hosted an average of 3.96 species while the high variability pointed to a standard deviation of 4.248, validating previous research by Fahrig et al. (2011) who revealed that as a result of enhanced habitat diversity, greater biodiversity is observed and that ecological conditions near sand dams potentially create suitable habitats for particular species.

Statistical analysis through ANOVA demonstrated substantial variation in site-species counts since F reached 8.097 and p remained below 0.001. The realized statistical significance demonstrated that sand dams significantly affect biodiversity. The construction of sand dams led to improved local ecosystems through enhanced water storage and improved habitat structure which resulted in increased flora and fauna diversity. The Welch test provided evidence of statistical verification since it proved that variations in species counts did not stem from random sample adjustments but from presence of real differences.

The Games-Howell post-hoc tests showed precise information regarding each pair of group comparison results. The Species count at Site 1 (Sand Dam 1) exceeded Site 3 (Control Area 1) by 3.371 species on average ($p = 0.009$). The findings demonstrate that constructed sand dams enable better ecological conditions for supporting biodiversity compared to control areas. The number of species observed at Site 2 (Sand Dam 2) surpassed Site 4 (Control Area 2) by 2.771 species according to the analysis with a p value of 0.013). Findings from the first objective revealing human-made structures also confirm that sand dams increase habitat diversity which leads to enhanced species diversity.

The ecological consequences of sand dams become more understandable through the findings on biodiversity variations. Enhanced biodiversity tends to strengthen ecosystems and enable them resist environmental dangers resulting from climate change and habitat loss. Similarly, Harris, (2007) highlights the importance of understanding ecological consequences stemming from biological variations and that good habitat management strategies should serve as the basis for conservation efforts in areas where species counts remain low.

5.4 Assessing the Impact of Sand Dam Construction on Ecosystem Services along the Kikuu Sand River.

The ANOVA results revealed that sand dam construction significantly impacted several ecosystem services specifically on soil stability, crop productivity, and biodiversity. These findings align with previous research that indicated that sand dams contributed to enhanced water retention, improved soil quality, and increased biodiversity in arid and semi-arid regions (Castelli et al., 2022).

The significant differences observed in the ANOVA test, particularly for soil stability and plant species changes suggest that specific sand dam sites (notably ID 1: KWA MOSES Sand dam Upstream) was more effective at providing these ecosystem services. This was attributed to better construction practices, location advantages, effective management strategies as well as the total number of sand dams constructed in that area. The constructed sand dams at close proximities with sand dam id 1: KWA MOSES, were Mbukoni and Rianthokoo sand dams which were less than 200 meters apart. Sand dam ID 3: KIKUU 2 Sand Dam Downstream also had indicated significant differences compared to ID 4; Control Sand dam 2.

The Games-Howell post-hoc test results further clarified which specific sand dam IDs differed significantly from one another. The high performance of Sand Dam ID 1 in terms of soil stability and plant biodiversity suggests that certain practices or environmental conditions at this site facilitated these reported positive outcomes. On the contrary, Sand Dam ID 4 which was coded as control area 2 exhibited less favorable results across multiple indicators, signaling potential areas for improvement or management intervention.

Moreover, the significant positive relationships found in the changes in plant and animal species observed provides basis for accepting the alternative hypothesis stating that sand dams can enhance and are able to impact local biodiversity. The variations in water quality and accessibility in the different sites also highlighted the importance of continuous monitoring and assessment of the ecosystem services provided by sand dams.

The regression model that included only ecosystem scores data indicated a moderate link between Sand Dam ID and ecosystem service scores based on the R squared value of 0.258. Although Sand Dam IDs explained substantial variations in ecosystem services, Findings suggested that there were additional elements which also shaped these values. Higher sand dam ids revealed decreased ecosystem service scores indicating that control areas perform worse than sand-dam when it comes to provision of ecosystem services and investigating the benefits resulting from the sand dam's construction.

The ANOVA analysis and overall study findings shows strong proof against the null hypothesis through its 0.000 p-value which confirmed that Sand Dam ID's have significant impacts on ecosystem services. Rueangsan et al. (2021) explored site specific characteristics explaining the effectiveness of sand dams for enhancing ecosystem services.

Research data from cross-tabulation and chi-square tests also demonstrated that sand dams created better ecosystem services than the areas without dams. The ecosystem service scores of Sand Dam IDs 1 and 2 were higher than the scores of control areas with IDs 3 and 4. The chi-square test also indicated through its Pearson Chi-Square ($p < 0.001$) and Likelihood Ratio ($p < 0.001$) that the sand dam areas demonstrate noticeable differences compared to control areas regarding ecosystem services provision. Sand dam construction was therefore attributed to creating positive ecological results through increased water accessibility and availability while still stabilizing soils and preserving biodiversity.

The insubstantial linear-by-linear association of 0.565 further revealed that there was no direct link that existed between Sand Dam ID numbers and ecosystem service scores. General trends showed distinct distinctions between the examined groups indicating that site-specific construction quality and environmental elements along with dam maintenance practices likely caused these observed non-linear relationships between the area variables. Ertsen & Ngugi, (2021c) collaborates the findings of this study indicating that sand dams enhance both water storage and improve agricultural productivity while strengthening soil structure. Sand dams are also said to enhance natural habitat resistance against climate change and support biodiversity development within these challenged areas. The investigation findings showing enhanced ecosystem service delivery by sand dam areas validate previous research conclusions (Castelli et al., 2022b).

CHAPTER SIX: CONCLUSION, RECOMMENDATIONS, AND PUBLICATIONS

6.1 Introduction

This chapter presents the main conclusions drawn from the study on the impacts of sand dams on biodiversity and ecosystem services along the Kikuu Sand River, Makueni County, Kenya. It summarizes key findings regarding natural and human-made features, biodiversity patterns, and ecosystem service provision. Recommendations are provided based on the research findings and observed gaps to guide sustainable sand dam management and policy interventions.

6.2 Conclusion

The study established that sand dams along the Kikuu Sand River have a profound impact on both ecological and socio-economic systems. A total of twenty-one sand dams were mapped, featuring varied structural characteristics such as heights ranging from four to ten meters and sand accumulation of two to nine meters. Natural features observed included xerophytic vegetation, Acacia trees, woodrush, and grasses, particularly along the Kwa Moses and Mbukoni sand dam areas. Human-made features included dam walls, solar and diesel water pumps, and small-scale irrigation systems. These structures play a critical role in enhancing water availability during dry periods while simultaneously supporting ecological functions such as soil stabilization, groundwater recharge, and riparian vegetation growth.

Biodiversity was notably higher in sand dam areas compared to control sites. Both plant and animal species counts were significantly greater around sand dams, with Sand Dam 1 demonstrating the highest levels of species diversity. Statistical analyses, including Welch ANOVA and Games-Howell post-hoc tests, confirmed that these differences were significant. Sand dams provide favorable ecological conditions by increasing soil moisture, creating microhabitats, and improving water table levels, all of which contribute to enhanced ecosystem resilience.

The study also demonstrated that sand dams substantially improve ecosystem services, including soil stability, crop productivity, and water quality. Areas with sand dams consistently recorded higher ecosystem service scores than control sites, as confirmed by ANOVA, regression, and chi-square analyses. Site-specific differences revealed that proper placement, construction quality, and maintenance practices are critical for maximizing these benefits. Although some sites experienced structural deterioration and limited community engagement, the overall positive impact of sand dams on local ecosystems and livelihoods was clear.

Overall, sand dams are effective nature-based solutions that enhance biodiversity, stabilize soils, improve water availability, and support community welfare. Their ecological and socio-economic benefits are most pronounced when combined with proper maintenance and active community participation. Additionally, sand dams contribute to rural development by reducing labor for water collection, improving agricultural productivity, and increasing access to education, markets, and health services.

6.3 Recommendations

To maximize the ecological and socio-economic benefits of sand dams, several measures are recommended. Regular monitoring and maintenance programs should be established to prevent structural deterioration and ensure sustainable functioning. Local communities should be actively involved in sand dam upkeep, which will improve long-term management and reduce overharvesting of sand.

Expanding sand dam coverage in areas with low species counts is recommended to enhance habitat restoration and biodiversity conservation. Sand dam planning should be integrated with broader conservation strategies to protect riparian vegetation and native fauna. Strategic placement of sand dams in degraded areas will further enhance soil stability, water retention, and agricultural productivity. Complementary interventions, such as vegetation planting and soil erosion control, can strengthen ecosystem resilience and improve overall effectiveness.

Policy frameworks should support sand dam construction as a climate-adaptive measure in arid and semi-arid regions. Community training and awareness programs are essential for promoting participation in sand dam management and monitoring of ecosystem services. Finally, further research is recommended to investigate the long-term impacts of sand dams on water quality, sedimentation, and climate adaptation, as well as to explore the economic valuation of ecosystem services provided by these structures to inform policy and investment decisions.

6.4 Publications

Gaceri F., Mworia K., Muriungi R., Mutuma B., Matheka R., (2025) Characterizing natural and human-made features of sand dams in seasonal rivers of semi-arid regions in Kenya; a case of Kikuu sand river in Makueni County. African journal of science, technology and social sciences. 4(2)2025, pas17-24; https://doi.org/10.58506/ajstss.v4i2.304

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APPENDICES

Appendix A: Target Plant and Animal Species Raw Data Averages

Group	Common Name	Scientific Name	Sand Dam Average	Control Average
Plant	Xerophytic Grass	*Various species*	13.6	6.0
Plant	Acacia	*Acacia spp.*	2.8	1.0
Plant	Mangoes	*Mangifera indica*	15.4	2.4
Plant	Citrus	*Citrus spp.*	11.7	1.2
Plant	Maize	*Zea mays*	11.4	4.1
Plant	French Beans	*Phaseolus vulgaris*	0.0	0.0
Plant	Tomatoes	*Solanum lycopersicum*	12.4	3.3
Plant	Watermelon	*Citrullus lanatus*	8.6	2.2
Plant Group Average	—	—	**9.49**	**2.53**
Animal	Termites	*Isoptera spp.*	0.0	0.0
Animal	Burrowing Insects	*Various species*	9.0	4.6
Animal	Rodents	*Muridae spp.*	4.5	1.7
Animal	Squirrels	*Sciuridae spp.*	3.0	1.1
Animal	Lizards	*Lacertilia spp.*	7.0	3.1
Animal	Snakes	*Serpentes spp.*	1.6	0.6
Animal	Birds	*Aves spp.*	13.4	5.9
Animal Group Average	—	—	**5.50**	**2.41**

Appendix B: Interview Guide

Section I: SAND DAM AREA
Kigorwe Faith Gaceri
Masters of Science Degree in Environmental Science and Resource Management
Impacts of Sand Dams on Biodiversity and Ecosystem Services: Case Study of Kikuu Sand River, Makueni County, Kenya

Introduction and Purpose

My name is Faith Gaceri Kigorwe and as part of my Master of Science program in Environmental Science and Natural Resources Management, I am conducting research on the impacts of sand dams on biodiversity and ecosystem services: case study of Kikuu sand river, Makueni County, Kenya. The primary objective of this study is to investigate how the construction of sand dams influences biodiversity indicators and key ecosystem services in the region by getting insights on both times before and after construction of these structures. Through this interview paper, I aim to gather valuable insights from individuals with direct experience in the study area. I assure everyone of confidentiality in any responses they give and also assure you that your details are no going to be used anywhere else without your consent. With Your permission I will proceed to the questions.

Section		Question	Responses	Extra Information
Background Information	1.	What is your name?		
	2.	How old are you?		
	3.	What is your occupation?		
	4.	How many years of experience do you have?		
Species Observations		**General Species Presence**		
	5.	Which animals Have you been seeing around the sand dam?		
	6.	Have any new animal species appeared since its construction? Which ones?		
Species Observations		**Plant Species**		
	7.	What types of plants are growing around the sand dam?		
	8.	Have you observed any new plant species since the sand dam was built? Which ones?		
Species Behavior		**Animal Behavior**		
	9.	How do animals use the sand dam area (e.g., drinking, nesting, foraging)?		

	10.	Have you noticed any changes in animal behavior since the sand dam was built? What are these changes?		
Species Behavior		**Plant Behavior**		
	11.	How has plant growth around the sand dam changed?		
Changes Over Time		**Observation of Changes**		
	12.	How the numbers of animal species changed since the sand dam have been built?		
	13.	What changes in vegetation types have you observed over the years?		
	Ecosystem Services			
Water Provisioning Ecosystem Services		**Water Provisioning**		
	14.	How has household water availability changed since the sand dam was built?		
	15.	How has water availability for livestock changed?		
	16.	How has the sand dam affected water availability for irrigation?		
Water Provisioning Ecosystem Services		**Food Provisioning**		
	17.	How has crop productivity changed since the sand dam was constructed?		
Regulatory Ecosystem Services		**Soil Regulation**		
	18.	Have you noticed improvements in soil stability and structure?		

	19.	How has the sand dam affected soil moisture levels in your fields and gardens?		
Regulatory Ecosystem Services		**Water Quality Regulation**		
	20.	How has the sand dam impacted the quality of drinking water?		
General Questions on Ecosystem Services		**Overall Benefits**		
	21.	What are the main benefits of the sand dam to your community?		
	22.	How has the sand dam improved your quality of life and that of others?		

Section II: Control Area
Kigorwe Faith Gaceri
Degree of Masters of Science in Environmental Science and Resource Management
Impacts of Sand Dams on Biodiversity and Ecosystem Services: Case Study of Kikuu Sand River, Makueni County, Kenya

Introduction and Purpose

My name is Faith Gaceri Kigorwe and as part of my Master of Science program in Environmental Science and Natural Resources Management, I am conducting research on the impacts of sand dams on biodiversity and ecosystem services: case study of Kikuu sand river, Makueni County, Kenya. The primary objective of this study is to investigate how the construction of sand dams influences biodiversity indicators and key ecosystem services in the region by getting insights on both times before and after construction of these structures. Through this interview paper, I aim to gather valuable insights from individuals with direct experience in the study area. I assure everyone of confidentiality in any responses they give and also assure you that your details are no going to be used anywhere else without your consent. With Your permission I will proceed to the questions.

Section	Question	Response	Extra Information
Background Information	What is your name?		
	How old are you?		
	What is your occupation?		
	How many years of experience do you have?		
Species Observations	**General Species Presence**		
	What specific animals		

	have you seen in this area?		
	Have any new animal species appeared here recently? Which ones?		
	Have any animal species that were common before now become rare or disappeared? Which ones?		
Species Observations	**Plant Species**		
	What types of plants are growing in this area?		
	Have you observed any new plant species recently? Which ones?		
	Are there plant species that have become more or less common over time? Which ones?		
Changes Over Time	**Observation of Changes**		

Section	**Question**	**Response**	**Extra Information**
	How have the numbers of animal species changed over time?		
	What changes in vegetation types have you observed over the years?		
Provisioning Ecosystem Services	**Water Provisioning**		
	How is the availability of water for household use in this area?		
	How is water availability for livestock?		
	How is water availability for irrigation?		
Regulatory Ecosystem Services	**Water Regulation**		

	How is water flow control during the rainy season?		
	How is groundwater recharge in your area?		
Regulatory Ecosystem Services	**Soil Regulation**		
	How is soil erosion in the area?		
	Have you noticed improvements in soil stability and structure?		
Section	**Question**	**Response**	**Extra Information**
General Questions **Ecosystem Services**	**Overall Benefits**		
	What are the current environmental conditions to your community? And how does it benefit you?		
Conclusion	**Summary**		
	Summarize the key points discussed during the interview.		
	Ask if the interviewee has any additional comments or observations.		
Conclusion	**Thank them, and Follow-Up**		
	Thank the interviewee for their time and insights.		
	Provide contact information for further observations or questions.		

Conclusion: Your valuable insights and expertise will significantly contribute to the success of this research project, aiding in the understanding of the environmental impacts of sand dams along the Kikuu Sand River. Your participation in this interview will help shape recommendations for sustainable development and conservation efforts in the region. Thank you for your time and contribution to this study.

Appendix C: LNACOSTI Research Permit

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Date of Issue: 05/November/2024

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Appendix D: Plagiarism report

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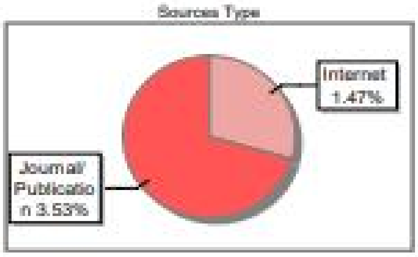

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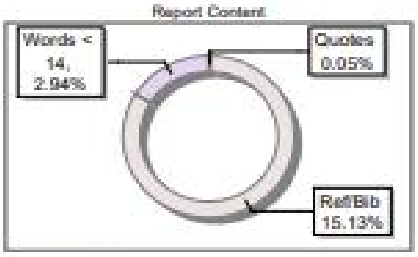

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Appendix A:Publication

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Characterizing natural and human-made features of sand dams in seasonal river of semi-arid regions in Kenya; a case of Kikuu sand river in Makueni County.

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ABSTRACT

Sand dams have been broadly used as water harvesting technologies in semi-arid regions and are constructed to enhance water accessibility and availability during the dry seasons. Sand dams' effectiveness relies on proper interactions between natural and human-made features. However, there are few studies that have documented these characteristics and elements comprehensively. This study was aimed at identifying and describing natural and human-made features with a specific focus on sand dams along River Kikuu, Makueni county, Kenya. Field observational surveys were conducted on twenty-one (21) sand dam sites. Mapping was conducted using GIS with geospatial analysis done using QGIS software. The recorded elements were sand dam wall height, sand accumulation depths, and surrounding land cover characteristics. This study reports that studied sand dams varied in terms of dam heights, length, usage and adjacent natural as well as human modifications. Interestingly, sand dams along the Kikuu Sand River in Makueni county supported diverse farming systems and ecosystem functions, acting as a big source of livelihood for the community, enhancing food security. However, it was observed that some of the sand dams faced challenges such as reduced sand accumulation as a result of unregulated sand harvesting and structural dam wall damages. Because of this, there is need for regular monitoring of the sand dams, encouraging responsible sand harvesting, and supporting communities in adopting suitable water abstraction methods that match local needs and dam capacity. The study provides basis for informing future initiatives when it comes to planning, construction, placement, and comparisons of sand dams in other arid and semi-arid regions.

Introduction

Water scarcity is a critical issue facing arid and semi-arid environments disrupting more than 1.2 billion people worldwide, with extreme impacts in Sub-Saharan Africa (Harhay, 2011). Arid and semi-arid regions cover about eighty-nine percent of the land and they also occupy mor than 36 percent of the total population. Despite of that, they are known to receive less than 30 percent of total rainfall in the country according to Wambua, (2019). The variation of rainfall all year round leads to water scarcity issues, reduces agricultural production and most important-

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