AFRICAN JOURNAL OF SCIENCE, TECHNOLOGY AND SOCIAL SCIENCES

Journal website: https://journals.must.ac.ke

A publication of Meru University of Science and Technology

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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ARTICLE INFO

Keywords

Sand Dams

Seasonal rivers

Semi-Arid environments

Water resources

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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https://doi.org/10.58506/ajstss.224

AFRICAN JOURNAL OF SCIENCE, TECHNOLOGY AND SOCIAL SCIENCES. ISSN:2958:0560

ly strains local ecological systems. In these dryland areas, rainfall is received as being extreme and still short lived, causing increased river flow rates and consequently decreased rates of infiltration. These incidences therefore worsen water scarcity mostly during the dry periods *(Liu et al., 2022)*.

Sand rivers are seasonal rivers mostly found in dryland regions and are characterized by a continuous dry sand channel. During the rainy seasons, when the run off rates is high, the sand is able to store large amounts of water in its sub-surface pores. The stored water is mostly utilized during the dry seasons (Lasage et al., 2008). The sand river ecosystems play a very important role in raising the water table levels which support vegetation growth, attracts diverse animal species and act as major water sources for local communities *(Saveca et al., 2022)*.

To support the utilization of Sand rivers, Sand dams have been adopted by diverse development organizations and community members. They are built primarily from concrete, creating barriers built across these rivers to allow for seasonal sand deposition and reduced run-off rates which allows for water storage within the sub-surface pores of the accumulated sand*(Eisma et al., 2021*). The stored water is not subject to contamination and evaporation making sand dams important technological strategies to improve water accessibility and availability in arid and semi-arid regions *(Ritchie et al., 2021)*.

Although sand dams have been widely implemented in dryland regions, there is still limited understanding of the natural and anthropogenic elements that determine their effectiveness. Majority of previous studies focus on their water provision benefits, giving little attention to their spatial distribution, structural variations and their relationship to the surrounding landscape. Additionally, most of the time the physical and socio-ecological factors affect the sand dam's performance, making it important to analyze them according to their adjacent natural and human-made features (*de Trincheria et al.*, 2018). Integrated evaluations focusing on the sand dams' characteristics can particularly support better planning, construction and management practices.

Makueni County in Kenya has a semi-arid climate with relatively low rainfall of approximately 115milimeters annually that adds a lot to its semi-aridity*(Ndunge et al.,2019)*. Sand dams have been widely implemented in this county especially along Kikuu Sand River to address water shortages. Never the less, a comprehensive analysis addressing the natural and human-made features has not been fully explored. Comprehending these features is critical to utilizing their full potential and to ensuring long-term functionality.

This study was aimed at characterizing the natural and human-made features adjacent to sand dams along Kikuu Sand River, Makueni, County, Kenya. By combining Geographical Information System mapping, and field observational surveys, the study reviewed the sand dams' structure, sand accumulation and land use. Through combining the spatial and descriptive data, the study offers a better understanding of sand dam construction in arid and semi-arid regions. The study offers evidence-based insights that can inform future sand dam implementation strategies, and policy frameworks for sustainable water resource management in arid and semi-arid areas.

Methodology

The investigation was carried out within the Kikuu Sand River as shown in *Figure 1*, situated in the Nzaui/Kilili/Kalamba Ward of Makueni County, Kenya. The investigation utilized descriptive and confirmatory approaches to document the structural presence of sand dams as well as their corresponding physical environment. The investigation was organized around three explicit objectives: to map the spatial location of sand dams along the Kikuu Sand River, to identify and describe natural anthropogenic features in proximity to sand dams (vegetation cover, river bank structure, and geophysical features), and to identify and describe anthropogenic features near sand dams (land use, access roads, footpaths, and structures).

To accomplish these objectives, in-field data collection was conducted with a Garmin eTrex 30x GPS unit. During the field data collection phase, geographical coordinates (latitude and longitude) were collected for 21 sand dams running along the river from upstream until the sand dam's confluence with the Muuoni River. Observational data were concurrently collected at each sand dam location to describe the visible natural and anthropogenic features.

Following the collection of data, previously recorded GPS coordinates were introduced to the open-source Geographic Information System Software

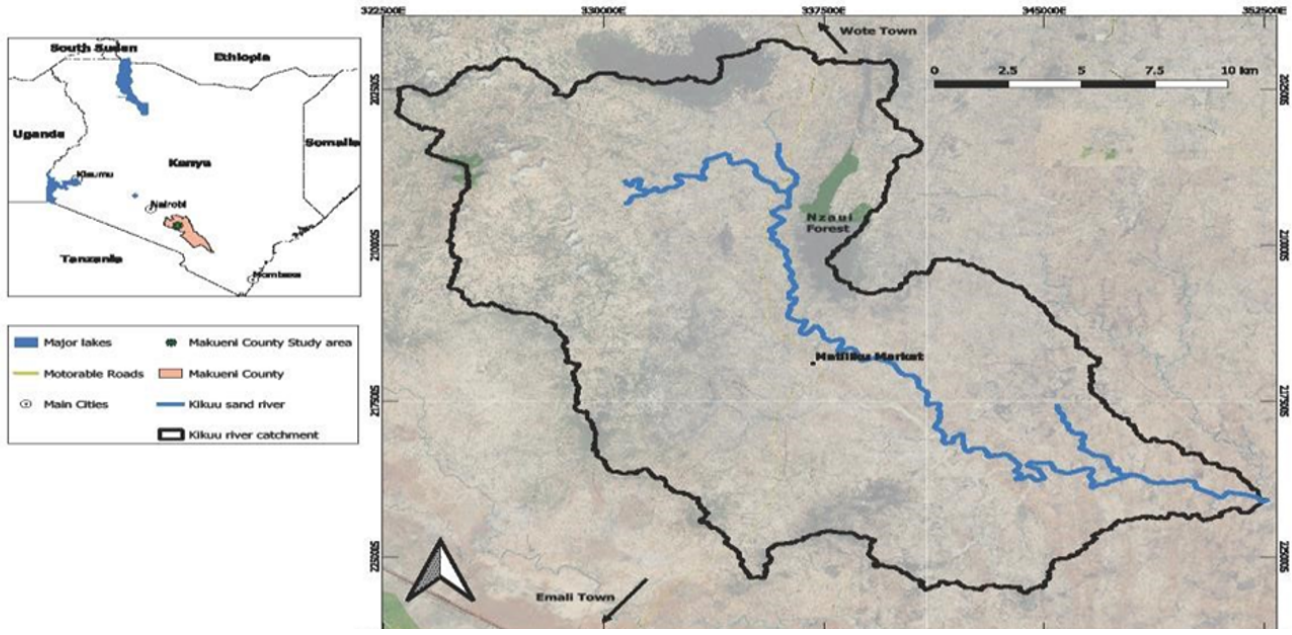

Figure 1 *The Kikuu Sand River, Makueni county, Kenya (Karimba, 2024)*

QGIS. The GPS coordinates were instrumental in providing a spatial representation of the distribution and arrangement of the sand dams along the river channel. This, potentially allowing for a description of the immediate physical features surrounding the sand dams, with respect to the river's flow, course, and stream bank slope and terrain. While remote sensing and satellite images were not utilized in this study, the immediate GPS-based field mapping provided high accuracy for geographically mapping the sand dams and visualizing their relationship to the immediate river system and environment.

The mapping provides spatial and description of how sand dams are situated in the riverine landscape providing insights into the relationship between sand dams and other surrounding natural and human modified features. The mapping framework provides a repeatable and properly designed study for informing future sand dam mapping and associated environmental context in semi-arid regions.

Results

This section presents the outcomes of this study showing the physical and ecological attributes of 21 sand dams situated along the Kikuu Sand River within the Nzaui/Kilili/Kalamba Ward of Makueni County, Kenya. The findings are derived from a map generated using QGIS, detailed field assessments, and on-site documentation. The analysis is structured around mapped sand dams as observed in *Figure 2* revealing the distribution of twenty-one sand dams along the Kikuu sand river, in Makueni County, Kenya, their natural characteristics, man-made constructions, water extraction mechanisms, disruptions (e.g., sand extraction, grazing, agricultural expansion), and observable ecosystem services, aligning with the objective of characterizing the natural and human-made features of the sand dams.

Natural Features of Sand Dams along Kikuu River

The sand dams are dispersed along the Kikuu River, spanning from the upper to lower catchments, where variations in landforms, vegetation cover, and adjacent land use are apparent. In the upper catchment, riparian vegetation including acacia trees, xerophytic grasses, and shrubs adapted to arid conditions is generally denser and more diverse compared to downstream areas, where human activities have resulted in noticeable degradation.

Geological conditions played a crucial role in dam placement. For instance, Kwa Mutula Sand dam (constructed in 2012), Mivati Sand Dam (2014), and Kwa Mutio Sand dam (2012) were erected at locations with shallow, exposed bedrock, providing stable anchorage. Conversely, at Kwa Kimongo Sand Dam (2012) visible rock was scarce, necessitating reliance on narrow streambanks and gentle slopes for support.

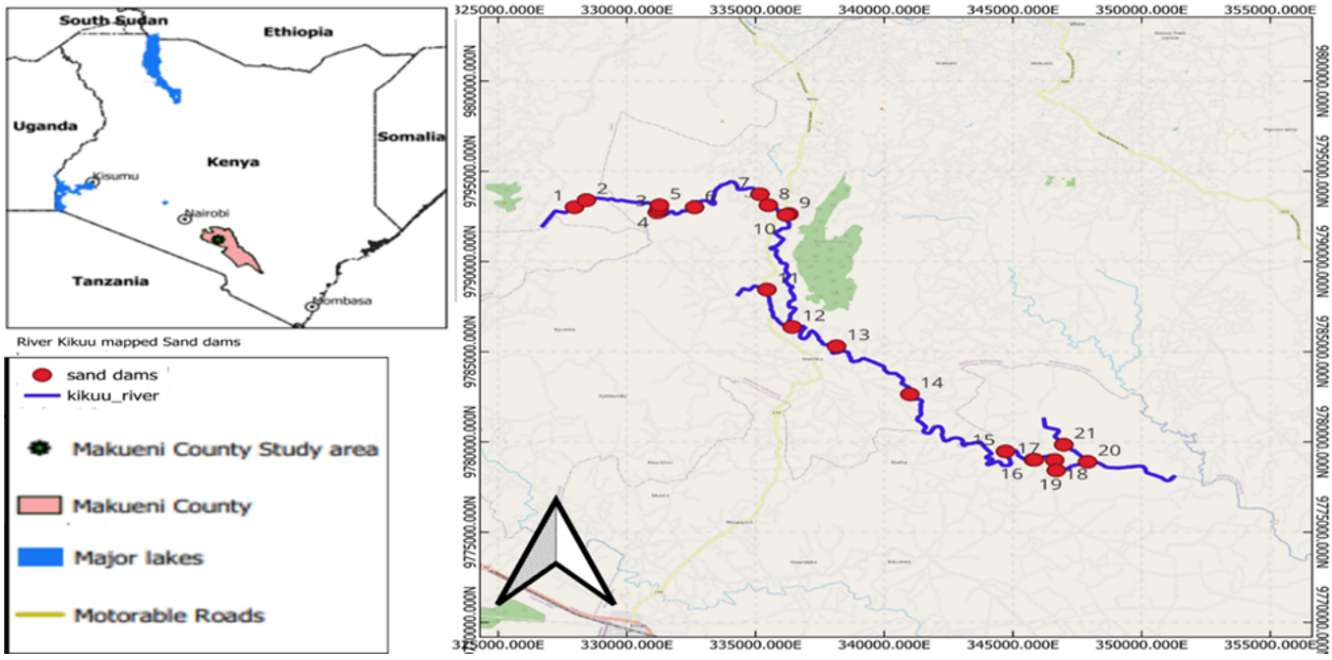

Figure 2: *Mapped Sand dams in Kikuu Sand River, Nzaui/Kilili/Kalamba Ward*

Field observations revealed a clear up-stream-downstream variation in sand texture; At dam sites such as Kwa Mutula, the sand was coarse and well-drained, whereas at dam sites like Nzange and Kwa Mutio downstream, finer sediments were evident suggesting slower stream flow and increased deposition.

Structural and Anthropogenic Features of the Dams

The 21 sand dams exhibited considerable variability in construction and physical condition. Nzange Sand dam (built in 2019) is situated in an area with minimal adjacent farming, yet extensive sand harvesting is visible along the banks. In contrast, Kwa Mutula Sand Dam (2012) features a 7-meter-high masonry wall with an equivalent sand accumulation and benefits from piped water supply and active farming (with crops such as arrowroots, sugarcane, and bananas).

Mivati Sand Dam (2014) is 5 meters high and is integrated with a nearby piped water system that supports both domestic use and agriculture (with nurseries for kales, tomatoes, and cabbages located within 50 meters). Kwa Mutio Sand Dam (2012) is well known locally for its beekeeping activities; its 8-meter wall and 6-meter sand build-up, along with a riparian zone of Greater Woodrush and cat foot grass, enhance its structural stability.

At Kwa Kimongo Sand Dam (2012), a 6-meter sand build-up supports pawpaw and mango cultivation, while the consistent presence of false oat grass and cat foot grass helps maintain ecological balance. Ikindui Sand Dam (constructed in 2021) is 4 meters high, with comparable sand accumulation; its banks are used for mango farming and water is accessed by hand scooping. Mbukoni Sand Dam (constructed in 2021) stands at 7 meters but has only a 3.5-meter sand fill; the surrounding area supports diversified farming mangoes, pawpaw, pumpkins, bananas, and sugarcane and includes an inbuilt 10-meter tank for water storage.

Kwa Moses Sand Dam (constructed in 2012) is 7 meters high, supports farming of mangoes and oranges, and shows signs of localized sand harvesting. Kalamba Sand Dam (constructed in 2020) is one of the largest structures at 9 meters, employing an electric pump system to supply water via underground storage tanks and is surrounded by indigenous trees, napier grass, and cat foot grass. A variant of Kalamba recorded in 2021 is 5 meters high and lacks a sand harvesting site, though its dam wall is damaged yet still provides water through traditional scoop holes. Choewo Sand Dam (constructed in 2009) relies solely on manual water collection via hand scoops, with its banks featuring acacia and moringa trees alongside Greater Woodrush and cat foot grass. Kikuu 2

Sand Dam, originally constructed in 2011 with sand and stone filters and a solar-powered pump system, now has a diesel pump (modified in 2019) after a delivery pipe was destroyed in heavy rains, and it no longer hosts active sand harvesting.

Chamela Sand Dam (constructed in 2019) uses diesel water pumps to support both domestic and farm needs. Kwa Katili Sand Dam (completed in 2022) is served by a water pump and hand scoop system, and Kwa Sammy Sand Dam (built in 2022) employs a diesel pump plus hand scoops, with regulated sand harvesting. Kikuu 1 Sand Dam (built in 2012 as a response to drought) features a 10-meter-high wall, though limited sand accumulation has partly compromised its functionality. Dange Sand Dam (constructed in 2019) was observed to supply water utilizing gas and diesel pumps, hand scooping, and also had an adjacent sand harvesting site.

Water Abstraction Features

Almost all studied sand dam locations had diversified water abstraction methodologies. The vast majority of extraction at Kwa Moses Sand Dam (2012) was done via traditional scoop holes, augmented by diesel and gas-powered pump systems. Kalamba Sand Dam (2020)—an electric pump delivered water via piped supply from underground storage tanks. Kikuu 2 sand dam had a solar pump installed and was reclaimed in 2023, but after infrastructure was being damaged, they used a diesel pump for water source access. Before its commissioning in 2019, Chamela Sand Dam relied on diesel-driven pumps for both domestic and agricultural uses. Water extraction was done using both traditional hand scoops and mechanized pumps at Kwa Katili Sand Dam (2022) and Kwa Sammy Sand Dam (2022). Diesel pump was mainly known to support manual water collection at Kwa Sammy. Kikuu 1 Sand Dam (2012) was hand scoops, while Dange Sand Dam (2019) combined several water abstraction technologies including gas and diesel pumps alongside hand scooping. These observations highlight different strategies adopted by local communities dependent on River Kikuu in accessing the river water during the streams of the dry periods.

Sand Harvesting

Field observations showed that human induced disturbances were heterogeneous between sites. That is to say, there was significant harvesting of sand at Nzange Sand Dam (2019) where the concentration of large quantities of sand extraction was noticeable along the riverbank, an act which can greatly reduce water retention. Similarly, at Choewo Sand Dam (2009), sand removal had its' reservoir morphology altered, leading to channel widening and reduced infiltration. Over grazing near the sand dams was also documented at Kikuu 1 Sand Dam (2012) and Dange Sand Dam (2019), where livestock tracks and compacted sand near water abstraction points was observed indicating additional disturbances on the structure. Moreso, agricultural activities were observed at Kwa Mutula Sand Dam (2012) and Kalamba Sand Dam (2020), with farming extending towards riparian zones, causing vegetation loss and increased sand dam and sand river bank erosion.

Ecosystem Services

Regardless of these disturbances, all twenty-one mapped sand dam provided observable ecosystem services. Provisioning services, for example provisioning of consistent water for domestic consumption, livestock, and irrigation were well realized at Kwa Mutula Sand Dam (2012), Mivati Sand Dam (2014), and Kalamba Sand Dam (2020). Regulating (increased soil moisture content, and erosion control) services were observed at Kwa Mutio Sand Dam (2012), and Kwa Kimongo Sand Dam (2012) as greater vegetation coverage and stabilized the river banks were detected from these areas. Also mentioned were supporting ecosystem services at Ikindui Sand Dam (2021) and Kalamba Sand Dam, where improved vegetation growth led to microhabitats that attracted insects and birds.

These results highlight the different natural and human alterations observed on sand dams on the Kikuu River. The difference of features of the adjacent sand dams such as water abstraction technologies and level of disturbances indicate the necessity of localized planning and effective establishment of management strategies. At the same time, the mapped distribution of sand dams (*See Figure 2 above*) provides significant spatial context for providing an understanding of how the geographic location, infrastructure, and land use interact to bring around dam performance, effectiveness and the provision of ecosystem services.

Discussion

Natural Features of Sand Dams along Kikuu River

The study found that there are significant differences between the Kikuu Sand River sand dams and the surrounding natural surroundings. At Nzange Sand Dam for instance, there was more sediment accumulation as a result of reduced farming activities along its banks, indicating that sand accumulates more with reduced human modifications. Additionally, in the same site, areas where the sand sediments accumulated and remained natural, there was increased growth of natural riparian vegetation as described from the results. This aligns with Eisma et al. (2021), whose research also found that sand collection can reduce farming success and lower water storage effectiveness while still highlighting that managing sand collection is crucial for the long-term efficiency of sand dams in conserving soil and water. Kim et al. (2022) also adds to the findings, reporting that sustainable sand collection is possible with proper management to maximize sand dams' potential.

Structural and Anthropogenic Features of the Dams

Kwa Mutula Sand Dam greatly highlights the adaptability nature of the sand dams, as it was initially constructed to allow for easier water supply through pipes, supplying water that was mostly used for domestic purposes and for orchard irrigation near the local community homes. This sand dam enhances water accessibility and availability, increasing agriculture productivity by frequently irrigating their farms and orchard. Similarly, Castelli et al. (2022), revealed that sand dams particularly in dryland regions enhanced plant or vegetation stabilization over time, agreeing with this, is Mivati Sand Dam as it highlights that sand dams are able to support small-scale farming by providing stable irrigation systems. There are also numerous nurseries around this sand dam, supporting farming of cabbage, kale, and tomatoes highlighting the role of sand dams in enhancing agricultural productivity. Ryan and Elsner (2016) support the findings of this research by noting that sand dams lead to agricultural production variations by offering provision of reliable water sources crucial for irrigation. Other Sand dams like Kwa Mutio, have enhanced beekeeping activities by forming micro-habitats consisting of riparian vegetation where bees and butterflies can perform pollination. Lasage et al. (2008) also collaborates this, suggesting that the sand dams increase pollination by forming riparian habitats which consequently enhance biodiversity, emphasizing on the role of sand dams not only in increasing water availability and accessibility but also plays an important role in maintaining ecological balance.

Water Extraction Techniques

There was an observation of diverse water extraction methods that were used in all twenty-one sand dams that were mapped. They were evaluated in this research as key elements to demonstrate the sand dam's effectiveness in water supply and to agricultural production. Ikindui Sand Dam for instance, revealed horticultural activities that were supported by use of water extracted through manual traditional hand scooping. This highlights the importance of integrating sand dams use with simple, readily available manual methods of water extraction provide enough of water for farming while still ensuring that over-extraction of water resources has been avoided. Castelli et al. (2022) supports this by highlighting that sand dams enhance agricultural production in semi-arid regions, where accessibility to water through proper water extraction methods are necessary for enhancing horticulture activities while still ensuring preservation of the sand dams. Similarly, Kwa Katili Sand Dam, utilized an integrated approach of combining petrol, diesel, and gas-powered water pumps and manual method like the traditional hand scooping method, illustrating the potential for using both mechanized and manual water abstraction practices in improving sand dam performance when it comes to water provision. Chung et al. (2022) collaborates with these results by pointing out that the use of both of mechanized and manual mechanisms, significantly improved water abstraction efficiency to meet the demands of the local population. Yet, mechanical breakdowns, such as those illustrated at the Kikuu 2 Sand Dam, when a solar-powered pump was regarded as not useful because of infrastructural deterioration, posed a major threat to the potential of sand dams of achieving efficient water supply. This is consistent with the work of Quinn et al. (2019), who emphasized that maintenance of water extraction systems is key if sand dams are to succeed in the long term.

Sand Harvesting

Sand harvesting happened often in some of the sand dam sites. Which have both varying advantages and disadvantages. At Kwa Moses Sand Dam, community members harvested sand and still used the sand dams' riparian regions to grow mangoes and oranges by the sand dam banks, showing that sand dams can support both fruit-farming and still provide sand resources. Never the less, if too much sand is harvested, especially without permission or proper monitoring, like observed at the Choewo Sand Dam, could be harmful. Uncontrolled sand harvesting can reduce the amount of water that the sand dam can hold by reducing the accumulated sand sediment. Eisma & Merwade (2020)supports these findings by reporting that taking too much sand from matured sand dams can reduce their functioning efficiency. At Choewo Sand Dam, reduced sand meant there was less space for water storage, impacting farming activities negatively.

Regardless of that, regulated sand harvesting, as observed at Kwa Sammy Sand Dam, led to the preservation of the sand dams, allowing them to achieve their potential. This is similar with the conclusions of Castelli et al. (2022), who highlighted that regulated sand harvesting supports water retention in an efficient manner allowing the sand dams to maximize their potential.

Ecosystem Benefits

All sand dams in this research, contribute substantially to the provision of ecosystem services. For example, the Kalamba Sand Dam, which is one of the largest sand dams, used an electric powered water pump to enhance efficient water supply to the Kalamba fruit-processing factory kilometers away, revealing that sand dams are also able to support industrial applications that lead to processing of fruits revealing food provisioning ecosystem services. Along the Kalamba sand dam bank as illustrated by the results, there was increased riparian vegetation compared to other sand dams being dominated by the locally known 'Mwangi' grass that was known to very nutritive providing proper nourishment to the cattle feeding on them. This also demonstrated the sand dam's potential of providing food provisioning ecosystem services along with the water provisioning ecosystem services revealed. This is consistent with the findings of Yifru et al. (2021), who suggested that sand dams contribute to economic development by providing water for agriculture and industrial activities.

Sanzama Sand Dam supported environmental sustainability through effective sand and water retention which enhanced native vegetation growth and crops. Similarly, Ryan and Elsner (2016) collaborates the findings by reporting that sand dams help in restoring plants and allowing for the growth of crops or year-round while still supporting vegetation that can survive droughts, which are key for the ecosystem enhancement.

Challenges and Prospects

Even though there are many discovered advantages of sand dams, challenges also exist that needs to be addressed if their full potential is to be achieved. To add on that, infrastructural issues at the Kikuu 2 Sand Dam along with increased sand mining at the Choewo Sand Dam, highlights the importance of constant monitoring and maintenance of sand dam infrastructures. Quinn et al. (2019) and Eisma et al. (2021) collaborating with this study's findings, indicated that mechanical failures and sand sediment loss are common challenges in sand dams that are able to reduce their efficiency.

Conclusion

Sand dams along river Kikuu differed in terms of structure, accumulation of sand, water abstraction methods, and associated land use practices. These features influenced their ability to retain water in their sub-surface pores, support vegetation, and support productivity when it comes to land use. These Sand Dams were seen to have played a pivotal role in provision of food and water, a major source of livelihood for the community living along river Kikuu, even during very dry seasons. However, while majority of the studied sand dams supported diverse farming systems and ecosystem functions, others faced challenges such as reduced sand accumulation as a result of unregulated sand harvesting and structural dam wall damages. These variations showed the need to understand the physical conditions and the patterns of how the local community use the sand dams to maximize their potential.

Recomendation

To support the long-term usefulness of sand

dams along the Kikuu Sand River, this research recommends regular monitoring of sand dams, encouraging responsible sand harvesting, and supporting communities in adopting suitable water abstraction methods that match local needs and dam capacity.

Acknowledgement

I acknowledge Meru University of Science and Technology and POLKA project or facilitating my data collection.

References

Castelli, G., Piemontese, L., Quinn, R., Aerts, J., Elsner, P., Ertsen, M., Hussey, S., Filho, W. L., Limones, N., Mpofu, B., Neufeld, D. G., Ngugi, K., Ngwenya, N., Parker, A., Ryan, C., de Trincheria, J., Villani, L., Eisma, J., & Bresci, E. (2022). Sand dams for sustainable water management: Challenges and future opportunities. In Science of the Total Environment (Vol. 838). https://doi.org/10.1016/j.scitotenv.2022.156126

Chung, I. M., Lee, J., Kim, M. G., Kim, I. H., & Yifru, B. A. (2022). Analysis of Water Supply Capacity of a Sand Dam. Water (Switzerland), 14(19). https://doi.org/10.3390/w14193039

de Trincheria, J., Leal, W. F., & Otterpohl, R. (2018). Towards a universal optimization of the performance of sand storage dams in arid and semi-arid areas by systematically minimizing vulnerability to siltation: A case study in Makueni, Kenya. International Journal of Sediment Research, 33(3). https://doi.org/10.1016/j.ijsrc.2018.05.002

Eisma, J. A., & Merwade, V. M. (2020). Investigating the environmental response to water harvesting structures: a field study in Tanzania. Hydrology and Earth System Sciences, 24(4), 1891–1906.

Eisma, J. A., Saksena, S., & Merwade, V. (2021). Assessing the impact of land cover, soil, and climate on the storage potential of dryland sand dams. Frontiers in Water, 3, 671455.

Harhay, M. O. (2011). Water stress and water scarcity: A global problem. In American Journal of Public Health (Vol. 101, Issue 8, pp. 1348–1349). https://doi.org/10.2105/AJPH.2011.300277

Kim, B. R., Lee, S. Il, & Yu, S. M. (2022). Conjunctive Operation of Sand Dam and Groundwater Well for Reliable Water Supply during Drought Conditions. Water (Switzerland), 14(14). https://doi.org/10.3390/w14142249

Lasage, R., Aerts, J., Mutiso, G.-C., & De Vries, A. (2008). Potential for community-based adaptation to droughts: Sand dams in Kitui, Kenya. Physics and Chemistry of the Earth, Parts A/B/C, 33(1–2), 67–73.

Ndunge, D., Mbuge, D. O., & Omuto, C. T. (2019). Protocol for Evaluating Sand Dam Water Quality in Semi-Arid Areas: A Case Study of Makueni County International organization of Scientific Research. IOSR Journal of Engineering (IOSRJEN) Www.Iosrjen. Org ISSN, 09(1).

Quinn, R., Rushton, K., & Parker, A. (2019). An examination of the hydrological system of a sand dam during the dry season leading to water balances. Journal of Hydrology X, 4. https://doi.org/10.1016/j.hydroa.2019.100035

Ritchie, H., Eisma, J. A., & Parker, A. (2021). Sand Dams as a Potential Solution to Rural Water Security in Drylands: Existing Research and Future Opportunities. In Frontiers in Water (Vol. 3). https://doi.org/10.3389/frwa.2021.651954

Ryan, C., & Elsner, P. (2016). The potential for sand dams to increase the adaptive capacity of East African drylands to climate change. Regional Environmental Change, 16(7).https://doi.org/10.1007/s10113-016-0938-y

Saveca, P. S. L., Abi, A., Stigter, T. Y., Lukas, E., & Fourie, F. (2022). Assessing Groundwater Dynamics and Hydrological Processes in the Sand River Deposits of the Limpopo River, Mozambique. Frontiers in Water, 3. https://doi.org/10.3389/frwa.2021.731642

Wambua, B. N. (2019). Analysis of the Current and Potential Future Climate Hazards and their Impacts on Livelihoods and Adaptation Strategies in Arid and Semiarid Lands. Asian Journal of Agriculture and Food Sciences, 7(4). https://doi.org/10.24203/ajafs.v7i4.5835

Yifru, B. A., Kim, M.-G., Lee, J.-W., Kim, I.-H., Chang, S.-W., & Chung, I.-M. (2021). Water storage in dry riverbeds of arid and semi-arid regions: Overview, challenges, and prospects of sand dam technology. Sustainability, 13(11), 5905.