Int.J.Curr.Microbiol.App.Sci (2026) *Special Issue-12: 1-13*

EXCELLENT PUBLISHERS

International Journal of Current Microbiology and Applied Sciences

ISSN: 2319-7706 **Special Issue-12–Droughts and Floods in the Arid and Semi-Arid Lands**

Journal homepage: http://www.ijcmas.com

https://doi.org/10.20546/ijcmas.2026.sp12.001

Adversities to Sand Dams Resilience in Management of Droughts and Floods in Arid and Semi-Arid Lands of Kenya

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Article Info

Received:
14 April 2026

Accepted:
26 May 2026

Available Online:
10 June 2026

A B S T R A C T

Since sand dams are often constructed to rely on the natural dynamics of seasonal rivers, improper approaches to their provision frequently lead to failure. When correctly planned, designed and constructed, they serve their purposes of providing water for people, livelihoods and the ecosystem. Importantly, sand dams mitigate drought and flood effects in the Arid and Semi-Arid Lands (ASALs). When poorly done, the structures become ineffective and even cause further environmental degradation. This paper presents findings from a study carried out on 24 sand dams in the semi-arid area of Kyatune-Ikanga Ward of Kitui County, Kenya, to establish the infrastructures contribution to droughts and floods management. A structured questionnaire was used to solicit information from 66 users of the sand dams and 12 water extension services personnel. Descriptive statistics were applied to the accrued data. The study found that sand dams are not explicitly planned, constructed, and utilized as a primary solution to manage droughts and floods but for people and their livelihood water supply. However, when built they contribute to bringing about controls on the two weather whims threats albeit derisorily due to inadequacies arising out of shortages in their planning, designing, construction, and operation and maintenance. As such the study recommends an integrated and collaborative approach to sand dams development cycle that is beneficiary community driven, and conforms to sustainability ideals.

Keywords: Vulnerability, collaborative, planning, construction, maintenance.

1.0 Introduction

Water conservation is a high priority in the drier areas of sub-Saharan Africa, the major parts of which are arid or semi-arid. Consequently, storage of water from the rainy season to the dry season, or even from wet years to dry years is highly important for the region's occupiers' lives, livelihoods and ecosystem. People living in the areas face highly variable rainfall, experience droughts and floods and often have insecure livings. As such, they are in dire need of infrastructures that meet the location specific water provision characteristics. Sand dams offer one of the most cost-effective, nature-based methods for conserving rainwater and recharging groundwater in the milieu dryland environments. The structures operate by trapping sand and water during the rainy season. The underground storage protects water from evaporation and contamination, providing reliable, naturally filtered water during droughts. On the other hand, they provide suitable means of flood controls by regulating the water volume flows for environmental conservation advantages. As such, sand dams play a vital role in climate change adaptation, ensuring year-round water access for communities, livestock, crop farming, and fostering income generation (UNFCCC, 2023).

Global and regional studies reveal that climate change adversely affect the availability of surface water resources in the sub-Saharan region. The impacts include severe droughts and overall drying of rivers and streams in most parts. This not only negatively affects the livelihoods of communities, but also harms aquatic life dependent on the ecosystems. One of the ways of ensuring sustainable water supplies in the dry areas is the harvesting and conserving of water in sand dams. In Kenya, the infrastructures provide a sustainable solution for the water-scarce arid and semi-arid lands (ASALs). The construction of sand dams is easy to achieve and maintain, and lasts for decades, providing water for people of all income levels. The water resources also benefit the local ecology. The structures, which are built across seasonal rivers and streams offer solutions as the flows during the rainy season, particularly during the dry season. The contained sand can hold a relatively high proportion of water for an extended period of time, which is accessed by using traditional scoop holes, and through installation of infiltration galleries that drain into shallow wells, where water is then extracted with a pump.

The sand dams help communities adapt to climate change by ensuring water availability throughout the year for both people, their ecosystem livelihoods. Furthermore, sand dams reduce time needed for community members to collect water, making them particularly beneficial to low income communities in helping to ensure food security and earnings. By storing water within sand, communities gain access to an underground reservoir that retains water for months, consequently contributing to drought resilience. This reduces walking distances for water, improves hygiene by filtering out pathogens, and allows communities to grow food year-round.

Because sand dams are often constructed to rely on the natural dynamics of seasonal rivers and streams, poor planning, improper designs and construction frequently lead to failure. When designed correctly, they mitigate drought and flood effects. The opposite makes the sand dams become ineffective or cause environmental degradation. Sand dams deliver dual-action water management on droughts and floods. Wall structures across seasonal sandy rivers and streams slows down the rapid, destructive flow of flash floods. The walls permit deposition of sediments by allowing heavier materials like sand to settle behind the dam wall, while letting excess water and silt safely flow over the top. By controlling the river's gradient and flow velocity, sand dams contribute to erosion control, consequently stabilizing gullies and preventing topsoil from being permanently washed downstream. During floods, sand dams slow the rapid surge of water that help control surface runoff, mitigate downstream soil erosion, and safely allow excess water to flow over the top while safely replenishing local aquifers.

The accumulated sand reservoir can hold between 25% and 40% of its volume in water. The subsurface storage facilitates in overcoming the effects of drought. Because the water is stored beneath a thick blanket of sand, it is protected from extreme heat and evaporation, even in semi-arid environments. Water trickling through the sand is naturally purified, delivering clean, safe drinking and agricultural water. Importantly, by keeping water trapped locally, the dams raise the local water table, restoring riverbank vegetation and providing long-term drought resilience.

The economic success of sand dam programs has raised interest in the technology as a means to upgrade rain-fed agriculture in sub-Saharan Africa (Aerts *et al.,* 2007; Lasage *et al.,* 2008). This gives credence to the conclusion that rain-fed food production such as through use of harvested water has enormous relevance for global food security, given that the most rapid population growth and the lowest income countries are to a large degree located in the dry tropical and subtropical climate zones (Falkenmark *et al.,* 2001). However, the sand dam technique is realized not to be adapted on a larger scale.

Several challenges are mentioned that relate to development of storage systems in smallholder farming communities in sub-Saharan Africa. First, such storage systems operate at a larger scale than within-field systems, often on a watershed scale, and thereby necessitate addressing issues like ownership, local institutions, and land tenure. Although in absolute terms structures may be of low cost, they still necessitate relatively high capital and labor investments, usually too high for individual households. Simple as the structures may be, the systems demand relatively high design considerations compared to the capacity found on the ground. Siting and design of the structures, necessitates apt technical know-how, especially to avoid siltation or leakage. In the semi-arid parts of Kenya, about 80% of the dams are not performing as they should due to poor designs and construction, with the source of the problem being in supporting institutions having very little capacity nor interest to disseminate best practices and assist in appropriate planning, design and construction Falkenmark *et al.,* (2001).

Sand dams are the least common of all water harvesting systems in sub-Saharan Africa (Falkenmark *et al.,* 2001). The most common are in situ water conservation and runoff farming. Kitui County shows growing land use related economic activities that largely revolve around agropastoralism, backed by supplementary activities such as brick making and bee-keeping. The interventions are related to water access and use. As such, the much available water from sand-storage dams provide an appropriate opportunity to sustain the endeavors (La sage *et al.,* 2008). A secondary benefit is in droughts and floods management. The two weather conditions are reckoned to have negative impacts to the residents social, economic and environmental wellbeing. Existence of the sand dams are expected to facilitate in management of the dry and wet weather conditions. As such, the structures must be sound and sustainable. Therefore, a research was set up to establish the prevailing status of the sand dams in a semi-arid zone with a view to identifying the success and failures of the infrastructure system in meeting the concern of droughts and floods.

2.0 Research Methodology

2.1 Description of the Study Area

The Ikanga-Kyatune Ward area which lies to the South of Kitui County, Kenya is characterized by rainy periods that are highly erratic and unreliable (Borst and Haas de, 2006; Mogaka *et al.,* 2005; Nissen-Petersen, 1982; Opere *et al.,* 2002). There are two rainy seasons, one from April to June (long rains) and one from October to December (short rains). Average precipitation is about 800 mm/year that is considered to be an intermediate amount of rainfall for the larger County. The northwest of Kitui is considered to have the lowest amount of annual rainfall, while the northeast has the highest amount. The importance of spatial distribution becomes even clearer when looking at individual rainfall, for which spatial variation can be quite dramatic.

2.2 Data collection and analysis method

A structured questionnaire was used to solicit information from 66 users of the sand dams and 12 water extension services personnel. The questionnaire focused on the contribution of sands dams to droughts and floods, water accessibility and storage, dam functionality and maintenance, socio-economic impacts, and community perception and adoption. Six focus group discussions (FDGs) were held that brought together opinion shapers and policy implementers in the community. Descriptive statistics were applied to the accrued data to facilitate establishing the frequency distribution. The approach allowed presenting the findings in percentages, bar graphs, and tables.

3.0 Results and Discussions

3.1 Blemishes in Planning

Planning for a sand dam water project is critical for its sustainability. Where the sand dam is to also play part in droughts and floods management, the two have to be well factored in at the planning stage. Cognizance is water structures meet multifaceted needs. As such, a planning a sand dam project requires a holistic approach. Because sand dams trap sediment and recharge aquifers to buffer against drought, construction on seasonal rivers must factor in extreme weather, structural stability against flash floods, and upstream catchment land management. Water extension experts prescribe onboarding community ownership and maintenance as part of the planning process. Therefore, participatory planning is a mandatory cog to engage local communities from site selection to construction, monitoring, evaluation and reporting. The overall impact of this is indicated to be fostered project ownership that has capacity to guarantee apt maintenance for sustainability. As such, the following common pitfalls in sand dams' developments needs to addressed from the onset.

3.1.1 Deficient consultation

92% of the water resources development and management extension services personnel had consensus that the sand dams had failed to meet the required sustainable infrastructural strategies, the genesis being a loud absence of consultative planning. FGDs and community respondents were in agreement that the planning for the 24 sand dams stemmed from an overreliance on community intuition. As a consequence, the projects were implemented without adequate social, economic, and hydrogeological data. Lack of catchment area analysis, including failure to appreciate local rainfall data and peak river runoff, often resulted in spillways that are too small, leading to the dam being overtopped or destroyed during flash floods. This was observed to have led to critical failures like poor site selection, leaking foundations, structural damage from peak runoff, and rapid siltation. The field interviews and discussions showed that a structured approach to sand dam implementation requires avoiding key planning pitfalls that must involve all stakeholders, and be integrated to include weather concerns such as droughts and floods. The community gatekeeper element was indicated by about 68% of the interviewees to herald in elite capture that was dominated by powerful local individuals and groups, resulting in dams being positioned to benefit a few rather than the whole community.

The community gatekeepers served as information bottlenecks as they controlled the flow of information about the project and its timelines, goals, and budgets, meaning that the general public remained uninformed and unable to contribute valid input. 89% of the people living near the sand dams indicated that gatekeepers misrepresented the true needs of the community, prioritizing political or personal agendas over public welfare. Their actions were construed to be of tokenistic participation, where every day local people were excluded from meaningful decision-making, and only utilized for labor.

FDGs presented the view that community gate keepers find the offer of a sand dam by a support organization to provide employment, and a water supply solution. In addition, they stated that while the acceptance often leads to a water source, it denies the intervention community scrutiny and participation. On the other hand, the sand-storage dams were found to have been constructed within a donor pre-defined implementation time frame framework. The absence of participatory planning found in the study appeared to rhyme with findings from elsewhere which indicate results of thwarting the collective choice of technology and service level (Van Wijk-Sijbesma, 2001).

3.1.2 Donor driven planning

FDGs were in agreement that the sand-storage dams' development support organizations did not have clear interests and capacity to empower the local communities in the necessary development and management approaches. Decisions were of top-down orientation, and did not include appropriate collaboration in the provision of the water resources. Communities were only involved through gate keepers, and infrastructure construction by workers who received payments. 45% of the respondent expected the sponsors to take lead in community mobilization and formation of sand dam committees, and effect capacity building through training the of the hatched outfits on the envisaged water supply scheme development and management. The acquired capacity was envisaged to help the committees to mobilize target beneficiaries in having them participate in agreeing on the location of their dam, and defining the role of the community in the sand dam project development cycle. About 90% of the community respondents find this to form the hallmark of sand dam projects, with the potential to make the beneficiary community members to for example contribute labor and materials in the project. Added, the involvement offers the possibility of community capacity strengthening for the after construction phase, leading to improvement in community leadership and organization. Engaging local populations in the sand dam projects was vouched for by about 65% of respondents to ensure that infrastructure is tailored to the unique realities of their environment, protecting ecosystems and lowering failure rates.

FDGs were categorical that integrating locally led adaptation principles framework into sand dam project management guarantees that the host communities take ownership, leading to long-term watershed restoration and climate resilience. On their part, 90% of the water extension services specialists added that by familiarizing and relying on the lived experiences of residents, organizations and authorities can gain highly localized, actionable insights. Local people were reputed to hold deep, generational knowledge of localized rainfall intensity, flash flood frequency, and the historical behaviors of ephemeral rivers. To the professionals, this has the capacity to inform the precise sizing, placement, and spillway design of sand dams. Indigenous knowledge regarding ecological indicators that revolve around specific soil types, bedrock location, and vegetation cover are respected to helps prevent ecological degradation and identify natural sediment availability. Participatory planning ensures the socio-economic needs are on boarded, and the sand dams consequently situated where it is most accessible for domestic and other uses, directly reducing the time burden.

Figure 1 shows the organizations that have initiated and funded construction of sand dams in the Kyatune-Ikanga Ward. The Kitui County government picked from the local and international NGOs' efforts and consequently invested in 38% of the dams in the study area. Before the county government took cue, the central government had invested in 4 sand dams. Noteworthy, the local people have not invested in sand dams. FGDs relate the prevailing laxity to a lack of understanding on the technology, and the community social and economic challenges. Land ownership has been individualized, leading to reduces access to the seasonal rivers. The community is also realized to be growing more individualistic, and wanting to have own individual water sources at the household levels. Those with access to the water sources use them or scoop water from the seasonal rivers. An individual from outside the area bought land to grow fruits and built a sand dam for the venture. He however abandoned the farming and migrated elsewhere, which also led to desertion of the sand dam.

3.2 Faults in Design

The 12 water professionals in the study had a consensus that proper design of a sand dam is critical for its long-term sustainability. The itemized key elements of an appropriate design include anchoring the wall into impermeable bedrock, using a staged construction process to trap coarse sand while washing away silt, ensuring the spillway spans the entire riverbed, and designing a secure extraction system to keep water clean.

A well-designed sand dam was prescribed to also incorporate a way to access the stored water. Extracting water by digging directly into the sand was pointed out to provide risks of contamination from people and livestock. As such, designing an appropriate draw-off system such as perforated collector pipes embedded in the sand during construction was given by about 60% of the water experts as viable. These are specified to feed into protected sumps, allowing people to safely pump the naturally filtered water without disturbing the riverbed ecosystem. The water experts added that by ensuring that the designed sand dams store ample water underground, sand dams prevent evaporation losses compared to open reservoirs, thus aiding in fighting droughts. At the same time, sand dams that are well designed were reckoned to slow down peak river flows, reduce the mechanical force of water, and prevent destructive river down cutting. Once the dam fills with sand, subsequent floodwaters flow harmlessly over the crest. The following aspects of design were prescribed to require mandatory addressing in the design of sand dams.

3.2.1 Absence of Investigations

None of the 24 sand dams was subjected to adequate geological investigations, leading to usage of poor bedrock location. A prime requirement for a sand dam is a shallow, impermeable layer beneath the riverbed. If dams are built where the bedrock is too deep or highly fractured, water will seep underneath rather than being stored in the sand. The genesis of inadequate designs was indicated by 80% of the water extension personnel to be organizational failures, most commonly caused by improper site selection, poorly sized spillways, and inadequate foundation keys. The absence of geological site assessment led to missing out on sediment composition in the sand dams, with the reservoir accumulating too much fine silt, which severely reduces water storage volume and extraction rates. The structural integrity of the river and water yield depends on coarse sand.

Absence of appropriate surveys leading to relevant design flaws were indicated to have compromised the effectiveness of the sand dams, leading to failure to appropriately provide water for people and their livelihoods, support the local ecology, and mitigate droughts and floods in the setting.

Consequently, the extension personnel opined for adherence to correct sand dams provision approaches that allow proper water storage and conservation, whose achievement is enshrined in collaborative and integrated line of planning. Table 1 shows that the majority (38%) of the sand dams are not in use because of siltation while 21% are silted but users can access some water from the sources. The absence of geological investigations led to construction of dams on unfortunate foundations, with impacts being manifested in water getting lost at the wall bottom in 13% and wing walls in 8% of the water retaining structures. 21% of the dams have been washed away as a result of inadequate anchoring.

The cycle of poor design, lack of consultation, and project failure unfolded as presented in Table 2. The common design and construction faults were identified by the water extension personnel to have severely impacted the sand dams' functionality. The inadequacies in sand dam designs were indicated to shoot directly from poor stakeholder consultation.

Table.1 Resultant effects of faulty design

Status		[N=24]
1.	Silted but in use	5
2.	Silted and not in use	9
3.	Wall washed away	5
4.	Leaking at the wall bottom	3
5.	Leaking at the wall sides	2

Table.2 Common design and construction flaws

Fault		[N=12
1.	Inadequate planning	12
2.	Inappropriate wall	9
3.	Insufficient spillway height and staging	11
4.	Poor siting	10
5.	Lack of catchment analysis	8
6.	Indecorous foundation	10
7.	Derisory wing walls	9
8.	Scant sand blankets	10

Local communities, regulatory authorities, and hydrogeological experts were bypassed, with donors ending up funding flawed structures that bypassed underground aquifers, silted up, or failed. The cycle of poor consultation spanning over decades was cited in all FDGs and community members, largely emanating from top-down funding from the international and local NGOs and donors who dictated project parameters from afar, prioritizing quotas over proper hydrological site investigations. The donor-driven flaws were experienced when donors dictated the budget and design without consulting locals, the resulting structures ignored local hydrological realities, such as riverbed geology and seasonal flow. The approach heralded in bypassing of local knowledge. The local community has for eons relied on generational knowledge regarding riverbed basement depths, flood patterns, and water usage. This was ignored in the sand dams' development, leading to building the structures in the wrong locations or with the wrong dimensions. Design optimization would have been achieved by integrating traditional knowledge with proper sand dam design, and ensure the structure matches community water usage and livestock needs.

The top-down approach by donors failed to link the projects beneficiaries, leading to low sense of ownership. The participation gap resulted in communities being used as casual laborers rather than co-designers, denying them the opportunity to develop a sense of project ownership that would allow them be active decision-makers. Consequently, when minor defects appeared, communities failed to perform remedial measures, leading to the water supply resource failure. This resulted in the view of the dams being donor projects rather than the beneficiaries own asset. Without community participation to manage catchment degradation and riverbank soil erosion, the sand dams became choked with fine silt, rendering them useless for clean water storage. The extension services personnel advocate that prior to sand dams design and financing, priority need be given to baseline studies that comprise of detailed site surveys and hydrologic assessments involving both engineers and local people. Part of the planning is indicated to require ensuring that the donor's budget allocates funds for community capacity building through training in operation and maintenance, and environmental catchment protection. The water extension services personnel reiterate that effective engagement and consensus building results in long-term ownership, drastically improving post-construction operation and maintenance.

3.2.2 Siting of sand dams

Technical expertise is required to determine the sand dam location, which is informed by analysis of catchment size, runoff production, soil properties establishment, water balance accounting, and interpreting rainfall and climatic data. However, in all the sand dams, this was found not to have been done, which made some of the structures to be over dimensioned.

3.2.3 Retaining Wall

The study established a common practice in all the 24 sand dams of endeavoring to realize heights at once. This has made the dams act as silt traps, allowing fine sediments (silt and clay) to settle instead of coarse sand, consequently reducing the pore space needed to store water and making extraction nearly impossible. Nilsson (1988) and Stengel (1968) recommends that for the sand dam retaining walls to be fully effective, they need to be built in several stages to allow the reservoir to gradually fill up with coarse sediment, as higher flow velocities flush fine particles across the dam. The coarse sediments increase potential storage of the dam as they have higher porosities. Furthermore, abstracting water from the reservoir is easier for coarse material. Policy implementers related the problem to the project sponsors being heavily focused on low-cost, immediate water access, frequently neglecting the long-term structural integrity and maintenance required to sustain the infrastructure against extreme flooding. A check on 5 sand dam design reports revealed an absence of consideration of the structures robustness on the longer term in light of climate change and social and economic developments in the vicinity.

By slowing the velocity of seasonal flash floods, the dams were recognized to dissipate erosive energy, and catch coarse sand and sediments while safely passing excess floodwaters over the spillway, ultimately reducing downstream inundation and stabilizing the riverbed. Silted sand dams were observed to fail to mitigate drought and floods because they either failed to accumulate coarse sand, wash away during heavy flows, or promote rapid water evaporation and drainage. Protecting the upstream catchment from deforestation and overgrazing was indicated by over 80% of the respondents to be essential to ensure that only coarse, water-bearing sand is deposited into the reservoir over time.

3.2.4 Wing Walls

Of the 24 sand dams, 80% have missing or undersized wing walls. Without the concrete extending far enough into the riverbanks or lacking proper lateral support, the technical people indicated that high-velocity flash floods make water flank the sides of the structure and erode the riverbanks, eventually destroying the dam entirely. As such the water professionals recommended that the wing walls stretch well beyond the active flood width of the river to safely direct excess peak flow over the spillway without damaging the banks.

Other than sand dams being anchored securely into the bedrock, 80% of the water experts indicate that they need to be placed deep into the riverbanks. Shallow keys are blamed to allow rushing water to scour beneath the concrete or bypass the dam entirely because of insufficient wing walls. In all the sand dams, the lateral wing walls are too short, making the river channels cut new routes around the dam structure during heavy floods.

Collected fine particles clog the pore spaces in the sediments, reducing the water storage capacity of the sand and making it difficult for people to extract water. This has resulted in floodwater overtopping the wing walls, eroding the riverbanks, causing downstream flooding, and even forcing the river to change its course in 3 of the sand dams.

3.2.5 Flawed Spillways

Unsound spillway design existed in all the studied sand dams, manifested in high initial structures constructed in a single phase that trap fine silt and clay instead of coarse sand. This was noted to drastically limit the void spaces required for water storage. The water extension personnel indicated that spillways should ideally be built in increments, raising them after each rainy season to allow coarse sand to build up layer by layer. Failing to do so also causes the river to unpredictably change its course. Building a spillway too-high-too quickly forces the dam to trap fine silt and clay instead of coarse sand. Continuous water flow over the spillway and along the riverbed threatens the immediate downstream foundation, often requiring retrofitting.

3.2.6 Foundation

Lack of bedrock foundation was found in 19 sand dams. Having the dam foundation not anchored directly onto solid bedrock had led to heavy floodwaters causing water to leak underneath the wall, rendering the dam's storage function useless. 92% of the extension personnel stated that the foundation must be built on impermeable, nonfractured rock to prevent underground water leakage. 83% of the extension personnel indicated siting of sand dams without reaching impermeable bedrocks has been a major cause of failure of the sand dams that has seen 18 of the sand dams constructed on porous, fractured rocks or deep sediment rather than digging down to solid bedrock or an impermeable clay layer for appropriate foundation. The impact of the flaw has been water seeping underneath the dam rather than being blocked in the riverbed. This makes the dam entirely ineffective for both drought storage and flood mitigation.

3.2.7 Scant sand blankets

Capturing sediment that is too coarse or too shallow in depth was indicated by 80% of the extension services staff to allow trapped water to evaporate rapidly under the hot sun. As a result, dams experienced failure in their drought-mitigation purposes because the water buffer dried up prematurely in the dry season. According to the water experts, the ideal design harvests a proper layer of medium-to-coarse sand at least 1.5 to 2 meters deep, which naturally protects the subsurface water from heat evaporation. 80% of the extension were in agreement that unlike open water reservoirs where over 90% of stored water can evaporate in hot, dry climates, sand dams store water in the pore spaces between sand grains underground. This acts as a natural filter, and provides clean water throughout the dry season.

3.3. Flaws in Construction

3.3.1 Inexpert constructions process

Assessments by the water extension staff revealed the flaws in the construction of sand dams to primarily stem from poor site selection, structural engineering mistakes, and inadequate maintenance. The errors have led to water loss, bank erosion, or even the collapse of 2 dams.

Incorrect river profile has led to constructing 18 dams where the river channel is too wide, and 6 on sharp river bends, causing the rivers to eventually bypass the dam altogether, washing away the stored sand. The foundation of most dams leak for lack of core sealing as the walls are not properly keyed into the riverbanks and floor, ultimately having water find the path of least resistance and creating escapes around the sides or base.

90% of the water experts indicate that sand dams are designed to accumulate sand over several rainy seasons. Attempting to build the wall too high at once as has happened in the study area causes muddy silt and clay to settle behind the dam instead of coarse sand, drastically reducing water storage capacity. In addition, poorly designed dam walls aggressively deflect water currents into the riverbanks during peak floods, causing severe bank erosion and altering the river's course.

FGDs narrated that there was inadequate construction supervision at the sand dam sites. They associated the gap to resultant structural failures and performance issues around the sand dams. In the absence of strict oversight, the policy makers and the water extension experts agreed that this was the birth of mistakes like improper foundation depth, poor concrete mix ratios, and inadequate anchoring to bedrock causing structural cracking or water leakages.

The technical concluded the works carried out to be substandard, associating the state to wrong cement mixes. They argued that artisans often eyeball cement-to-sand ratios to save costs. Without supervisor enforcement of proper ratios and slump tests, the resulting concrete becomes highly porous, cracks easily, or fails during seasonal floods. Inadequate oversight is believed to have led to improper alignment of the spillway or incomplete compaction, resulting in water leaking beneath the structure and failing to build up a proper sand reservoir.

3.4 Operation and maintenance of sand dams

Water extension services providers, and policy implementers in the study undertaking echoed that operation and maintenance in sand dam water supply systems ensures safe, adequate, and continuous water delivery. They added that it safeguards public health by preventing contamination, minimizes physical leaks to preserve precious resources, and extends the lifespan of infrastructure.

Therefore, ensuring the system reliability consistent with avoiding unexpected service interruptions and supporting droughts and floods control is paramount, as it is essential to prevent structural damage from floods, ensure water remains clean and safe for consumption, and sustain community water access. Routine checks of the dam wall and nearby riverbanks prevent flash floods from eroding the riverbanks and bypassing or destroying the walls. However, the study found that operation and maintenance aspects were never factored in the sand dam systems as discussed in the following factors.

3.4.1 Disavowal of operation and looking-after facets

The water extension personnel indicated that the long-term success of the sand dams was not factored in the planning and design of the structures. Planning for sand dams was found to focus entirely on the construction phase and not the operation and maintenance. About 80% of the experts associated the challenge with lack of creation of community ownership and, the donor syndrome approach in the development of the water sources. The local people viewed the sand dams as belonging to the organization that paid for their construction rather than their own assets. Minor defects such as cracks or erosions, and accumulation of silt go ignored. Deforestation and poor land use in the catchment area were realized to increase soil erosion, causing too much silt rather than coarse sand to settle behind the dam wall, which severely limited water storage capacity. When the upstream watershed suffered from deforestation or poor land management, excess silt filled the dam, ruining water quality and storage. The ignorance in rightful operation and maintenance was characterized by unmanaged extraction and water contamination. Water in sand beds was frequently extracted by digging open, unprotected scoop holes, which left the water supply vulnerable to contamination from livestock and human activities. Ineffective draw-off systems or deep water extraction wells placed undue stress on the dam structure as they were not properly sealed and protected by vegetation or fencing. Neglecting catchment management left sand dams to rely on seasonal floods to deposit coarse sand while washing silt downstream.

3.4.2 Nonexistence of community accountability

75% of the water extension services benefactors detected that lack of continuous community maintenance leaves the structures under-performing or completely breached over time. They observed the problem to have genesis in the prevailing poor community involvement in sand dams' development, and the insistence of donors to spend their funds without proper community partition. None of the sand dams in the study area was found to have an operation and maintenance aspect included in its design. The genesis of the problem was that the sponsor's interest was the hardware provision. FGD sessions were in agreement that the long-term sustainability of sand dam projects should have community funds established to maintain the infrastructure and water abstraction system, with the fund also helping to upscale sand dams in the area.

FDGs shared that without strict community rules, illegal and unregulated sand harvesting sand extraction takes place, which ultimately destroys riverbanks and causes severe ecological changes. The practice leads to pollution of the seasonal river environment.

Without a clear community-led maintenance framework to clear debris and monitor structural integrity, the economic value of the dam quickly depreciates. Keeping the immediate area and water collection points clear of livestock waste and contaminants is critical for water quality.

The areas along the seasonal rivers and streams where sand dams are constructed are by law public land. However, people with land touching the seasonal water resources try to claim that the sandy areas belong to them.

This has led to claims of sand dams on the river systems belonging to them, while the vast majority of the water users in the region perceive water sources as community property. On the other hand, a considerable minority considers the support agencies as owners of the sand dams. 79% of the respondents feel that a participatory approach to sand dam developments can result in clear ownership description.

Water use decreases the water volume and thus the water level upstream of the dam, whose extent typically depends on the amounts used compared to the size of the dam (Hut *et al.,* 2008). The study results indicate that expected longer-term effects on groundwater levels depends strongly on the way the water is used. Household water use, river banks infiltration and seasonal storage can go hand in hand. However, when water in sand dams is used for higher water demanding activities, the infiltration effect into banks may be minimal.

3.5 Sand Dams Sustainability and Upscaling

FDGs, water extension personnel and about 80% of the communities living around the sand dams were of the opinion that the long term aspects of the structures and their replication were never factored in the projects developments. Priority was in construction of the sand dam. As a result, the water resources became prone to vulnerabilities associated with absence of care and failure to deliver on desired social, economic and environmental needs as discussed below.

3.5.1 Sustainability of Sand Dams

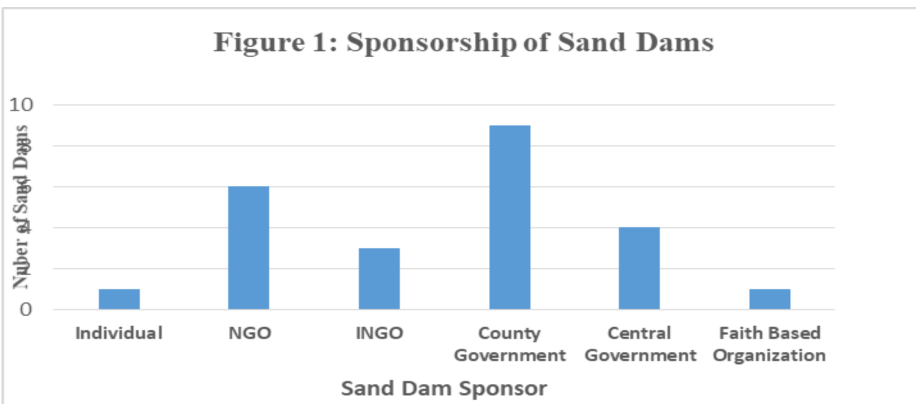
Analysis of the FGDs led to the conclusion that the long-term sustainability of sand dams heavily relies on active community ownership, precise environmental siting, and proper structural engineering. 90% of the water extension services providers recommend that achievement of this requires interaction with all stakeholders in the project cycle. The ensued participation is believed to permit soliciting stakeholders' ideas and data to be factored into a collectively built and subscribed to plan. Cognizance is that decisions taken at an earlier stage of a sand dam project are more important than those taken at a later stage.

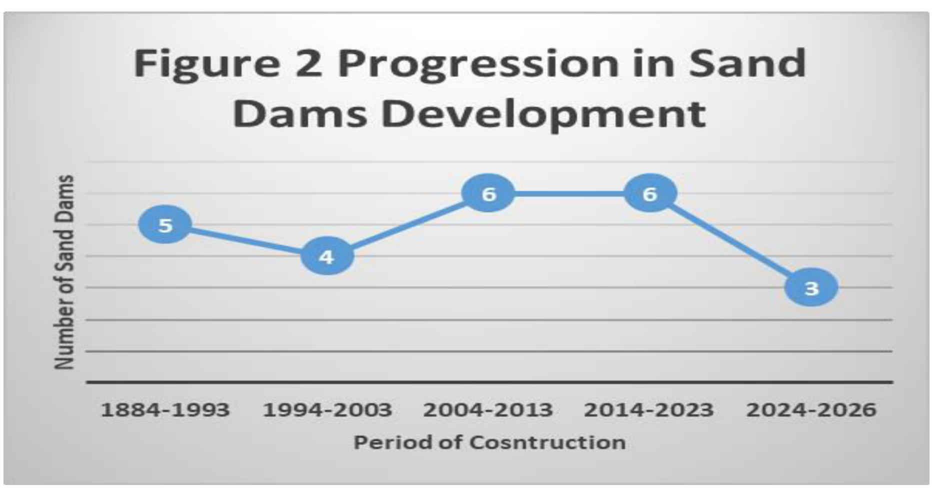
However, conditions and criteria can be reviewed during the design process, whereby the design may restart at an earlier stage. Decisions are not necessarily definitive, but open for review when more, perhaps contradictory information becomes available. The planning, design and construction is vouched for as it encompasses feedback from the context within which it has to be applied. Part of this feedback does come from users as they adapt the structures or manipulate them, even if they were not involved in the process itself.

3.5.2 Upscaling of sand dams

Figure 2 shows that upscaling of sand dams has been low. The earliest sand dam was built in 1984 by an international organization. The following decade realized five more sand dams, and the period between 2004 and 2023 erecting a total of 12 new dams in the Ward.

The rise in sand dams' development attention is associated with the county government's promotion of the infrastructure types in the area. Notably, of the 24 dams developed, only one has been built by an individual comer to the study area who used the dam water for fruit farming. He later did away with the land use, which led to abandonment of the sand dam infrastructure.





FDGs associate the low adoption of the sand dams to social and economic challenges. 85% of the people living around the sand dams associate the low adoption to lack of understanding of the requirements of the technology. The land tenure shifts from communal to individualization were indicated by 69% of the people to discourage having the infrastructures as access to the water points is thwarted by land parcel fencing which lead to blocking of access to the water sources. The sponsors of the sand dams have not been keen to appreciate this development and consequently mobilizing people for common water resources development and water access.

FGDs opined that upscaling of the sand dam technology requires having good pro-active knowledge on consequences of upscaling at the catchment and river basin scale. Falkenmark *et al.,* (2001) agrees with this school of thought, adding that applying water harvesting may not necessarily affect downstream water availability, noting that in some instances, it may even increase availability by enlarging groundwater base flow. Furthermore, when runoff generated upstream flows for only a couple of hours during and after intensive rainstorms, beneficial use of the water may be minimal. It may be the case that upstream water flow inundates flat seasonal wetland zones along its journey downstream and contributes to a large extent to open water evaporation. To understand water fluxes over seasons, including infiltration into the riverbanks and human water use, the temporal and spatial groundwater flow pattern needs to be known. Data from measurements over longer periods are however not available (Borst and Haas de, 2006).

Another relevant issue when one wants to evaluate the potential effect of sand dams is the impact of groundwater storage over decades is the prerequisite to determine whether the technology could be applied elsewhere. Hut *et al.,* (2008) presents results on this issue for a single dam while Quilis (2007) adds from various researches that the influence area of one dam is 350 m in downstream and upstream direction from the dam. The results indicate that the water levels in the vicinity of the three dams were the same as in the one dam case. Modeling results suggested that when several dams are built in a row in the same riverbed with such distances between them than their influencing areas overlap, a rise in the water levels occurs in the area (Ertsen & Hut, 2009). This means that when the purpose of the project is to raise the water levels in a certain area, multiple dams can be constructed close to each other in the target area. From the point of view of stored water volume, however, the closer the dams are to each other, the lower the water volume stored will become compared to those volumes stored by the same number of single dams. The distance between dams in relation to the effects in water level caused by the dams is therefore an important criterion to consider when planning new sand-storage dams in a certain region. If the distance between dams is such that no overlaps of influence areas occur, dams behave as individual structures and effects on groundwater levels of single dams within a network can be added up.

The rise of groundwater table responds to precipitation, which explains the functionality of sand-storage dams in the ASAL areas. Groundwater levels decrease within a few days after rainfall and rise again after the consequent rain. A dry year can lead to less favorable storage in a dam, which may influence the communities' ability and preparedness to remain involved another year. Being able to determine such shorter term risks and options, which can be used in designing an intervention strategy before actually starting interventions is considered an asset.

Hut *et al.,* (2008) indicates that longer-term effects of water use on ground water levels is expected to strongly depend on the way the water is used. Household water use, including small scale agriculture and river banks infiltration can go hand in hand. However, when water in the dams is used for higher water demanding activities, the recharge effect of dams is minimal. Furthermore, this issue links with the distribution of socio-economic benefits.

Users close to the dam are in a position to take most water, whereas users further from the dam would benefit from more extended recharge. FGDs indicate that households on land adjacent to the seasonal rivers with sand dams earn more than before the dam, as they are able to irrigate crops in the dry months, making the income angle attractive to scaling, and indirectly contributing to droughts and floods management.

Stakeholders are in agreement that since the ASALs are prone to droughts and floods, they can benefit from the sand dam infrastructures in reducing peoples and their livelihoods vulnerabilities to the negative consequences of the two weather events. As a result, sand dams can be explicitly planned, constructed, utilized, and promoted as a primary nature-based solution to manage both droughts and floods in the ASALs. By trapping heavy rainfall and coarse sand surging down seasonal rivers, they effectively mitigate climate extremes. While traditional surface reservoirs are built primarily for dedicated flood control, sand dams can be intentionally engineered and constructed exactly for dryland drought resilience and sustainable water security. By obstructing and slowing down torrential flows in seasonal rivers, they reduce soil erosion and help control the destructive energy of floodwaters.

Thus, they provide a holistic ecosystem resilience as the stored water raises the surrounding water table, which prevents desertification and enables communities to have climate-smart practices on their land.

4.0 Conclusion and Recommendations

The study concludes that when appropriately located and built, well-designed sand dams act as nature-based ways out to water supply challenges, and overcoming droughts and floods threats in the ASALs. For the structures to sustainably contribute to management of the two weathers' negative consequences, the study proposes adherence to strict, participatory and meticulous site investigations and step-by-step and construction criteria as a blueprint for success. The sand dams must be built on impermeable bedrocks to prevent water from leaking underneath, and the wing walls adequately secured into the riverbanks. The infrastructure system development must heavily rely on community-led collaboration, which has the advantage of providing the necessary local knowledge on the ecosystem, sourcing of local materials, participation in terracing surrounding farmlands, and maintaining the sand dam river systems, and the linked water access points.

4.1 Conflict of Interest

The authors declare no competing interests.

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How to cite this article:

Mwangi, M. (2026). Adversities to Sand Dams Resilience in Management of Droughts and Floods in Arid and Semi-Arid Lands of Kenya. *Int.J.Curr.Microbiol.App.Sci.* Special Issue-12: 1-13.
doi: https://doi.org/10.20546/ijcmas.2026.sp12.001