Sand Dam Assessment

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Acronyms and Definitions

CFGB	Canadian Foodgrains Bank
GIS	Geographic Information Systems
MCC	Mennonite Central Committee
NDVI	Normalized difference vegetation index; a standard way of measuring vegetative greening with satellite imagery
SASOL	Sahelian Solutions Foundation
UDO	Utooni Development Organization
WHO	World Health Organization

Summary and Key Findings

Sand dams are widely used in the Ukambani region of Kenya for water harvesting. Although generally considered successful local solutions to water needs, there is an incomplete understanding of how they are functioning in the communities which use them, and what factors most determine their success. The present study was undertaken to clarify some aspects of sand dam function not addressed by other studies. Results of this study are considered generalizable to the population of sand dams in the region of Ukambani. Eighty-seven dams surveyed were randomly selected from existing records of UDO and SASOL – two organizations that are responsible for a large proportion of the sand dams built in the last 20 years in Machakos, Makueni and Kitui. As there is no centralized list of earlier dams (such as colonial era dams), eight additional colonial era dams surveyed in Kitui as part of a separate study were included in the pool of dams analyzed.

Results are presented in the following general sequence:
1. Evidence on potential and actual storage of water in individual sand dams
2. Evidence for the actual usage of water by communities, recorded both as observational and self-reported data
3. Estimating the general success of sand dams, and an analysis of factors that are associated with sand dam functionality

Key Findings

Storage of water in dams

- The calculated water volume of dams varied by three orders of magnitude, with larger (in water volume) dams correlated with a greater number of beneficiaries. At standard water consumption rates, calculated median water volume (not including groundwater) support 57% of the reported number beneficiaries for a 4 month period. **Water volumes at sand dams are potentially limiting during longer dry stretches.**
- Based on watershed areas and rainfall patterns, individual dams capture on median less than 0.1% of watershed runoff, thus having negligible impacts on downstream volumes of water.
- **Siltation of dams was not the major constraint in the success of surveyed sand dams in Ukambani.** While there was substantial siltation in some cases, we estimate an average decrease in water storage of 10-25% (depending on assumptions of how much water is stored by particle sizes) due to siltation. Thus, while minimizing siltation is an important goal in implementing sand dams, it is neither an inherent limitation of sand dams, nor the major reason some sand dams are not fully utilized.
- Evidence of erosion and possible leakage were widespread, observed in 72% and 33% of dams, respectively. Although they may have some impact on water storage, they did not correlate with sand dam functionality. **Less than 5% of dams were broken**, and thus entirely nonfunctional.
- 86% of dams are fully filled with sediments. Filling of dams with sediments is not a problem in the region.
- 78% of dams had water present in some cores taken from the dam surface. More than half of dams had water present in half or more of the sand cores taken. **Water appears to be present in most of the dams, even during the dry season**.
- Analysis of satellite images for vegetative greening did not find that the area within 100m of sand dams was any more greened than control sites (along the same waterway but without sand dams). Claims of general raising of water tables that greens a wide vicinity of dams may be overstated.

Usage of dam water by communities

- Most dams (61%) had no evidence of agricultural activities that are associated with boosted water levels (such as vegetable fields). Based on transects, **a small percentage (6.3%) of land next to sand dams had agricultural activities that take advantage of water from sand dams**. For those sand dams where agricultural activities were supported by water harvested, multiple activities were usually visible.
- Current water harvesting was observed in 43% of dams and evidence of past water harvesting was observed in an additional 18% of dams. Of the remaining dams where there was no evidence of water harvesting, 81% of those had evidence of water in the sand cores. **This suggests that lack of water was not the main reason for a lack of water harvesting.**
- Of 14 pump wells observed in dry season sampling, only 3 were functional with water.
- Self-reported data indicates that the use of water for drinking and household purposes is most often seen as the primary benefit, and households strongly value the reduced time required to collect water.
- Interviewees reported a wide range of other benefits from sand dams. Important specific benefits included both direct activities (e.g. livestock watering, irrigation, brick-making (harvesting of sand and water) and indirect benefits (e.g. improved school performance, unity/togetherness).
- Benefits to women and girls varied notably from those to men and boys. **Time savings, improved school attendance and performance and improved health were most important to women and girls. Brickmaking, livestock watering and general income generation were most important to men and boys.**
- The frequency of self-reported usage is higher than what is expected based on observational data. Collection of accurate usage (or more generally benefit) data is problematic and should be viewed with caution in this and other studies.

Overall dam functionality

- A range of measured parameters indicating water presence and usage were used to rate dams on their functionality (essentially their success). Most dams would not be considered either "optimal" (ample water throughout the year and robust usage by the community) or "failures" (little capacity for water storage and/or largely unused). **Most dams fall in the center of the rating, showing some clear evidence of use, but also showing some lack of water and/or lack of use by the community**. Dams with high functionality were not strongly clustered in any particular area of the region.
- Dams rated as more functional (presence and/or usage of water) did not show a strong overall correlation with physical factors (siltation, watershed slope, etc). **Physical attributes of sand dams did not explain most of the variation in dam functionality.**
- Of the physical factors, **the degree of siltation and the size of the adjacent population were weakly correlated with dam success**. Silt levels were weakly impacted by watershed slope (higher average slopes are associated with greater siltation).
- For the region, dams were located in areas that had above average population densities, and near average poverty rates. This suggests that, as a population, **dams are sited well to serve a high number of people that have limited income or resource availability**.
- Most dams (72%) did not have any formal management committee. 90% of dams reported there was no "conflict" (likely interpreted as serious conflicts). **Community usually did not manage the sand dam resource through highly formalized structures**.

Although some physical improvements can be made to improve the storage of usable water in sand dams, the most immediate constraint to a successful sand dams appears to be rooted in psychosocial barriers to fully utilize the resource.

Introduction

Sand dams are commonly viewed as a successful and appropriate strategy for providing water to communities in semi-arid regions such as Ukambani. For instance, (Lasage 2015) notes that sand dams are promoted as "…low-cost systems with easy maintenance that can be developed, constructed and operated with a high degree of community involvement, which improves their durability." Other studies have noted their limitations ((DE TRINCHERIA, NISSEN-PETERSEN et al. , Woodring 2014)) or have been outright critical of how they currently used.[1] Indeed, a seminal study of land use changes in Ukambani does not mention sand dams as a defining activity that helped change the agricultural productivity of the region (Tiffen, Mortimore et al. 1994). Thus, there is some lack of clarity on the degree to which sand dams are living up to their expectations.

This study was undertaken to address a number of aspects of sand dam which have not been fully addressed in other evaluations, but which are critical to the general question of the effectiveness of sand dams as a tool for improving livelihoods of communities in water-scarce regions. By some estimations, Ukambani has up to 5000 sand dams, likely making it the site of the largest concentration of sand dams in the world. This makes it a good site for making generalizable conclusions about sand dams. In addition, this study essentially serves as an ex-post evaluation, retrospectively assessing the success of the specific MCC and CFGB funding for sand dams (up to its cessation in 2014).

The design of this study emphasized several aspects:

Randomized selection of dams. A major limitation of many studies has been bias in the sampling of the dams analyzed, making it difficult to generalize conclusions to the concept of sand dams as a whole. In the present study, dams were chosen randomly (to the degree possible) to avoid selection bias. Although a purely random selection of all dams was not possible because of lack of records on dams present, we believe the 97 dams surveyed in this study are representative of the larger sand dam population in Ukambani.[2]

Focus on evaluating fewer parameters at more dams. The effort in this study was to get a larger sample size for a select number of parameters, thus having more confidence of the accuracy of those parameters as representative of sand dams in general (at least in Ukambani). This narrower focus was at expense of getting a comprehensive picture of any single sand dam – we did not, for instance, do extensive focus group interviews at dams that would have collected a wider picture of sand dam function at a single dam. Statistically, the 97 dams represent a 10% confidence interval for the estimated number of dams in Ukambani.[3]

Emphasis on physical factors. The success of sand dams is clearly dependent on both physical and socioeconomic factors. In part by design, and in part due emerging limitations of interpreting the data collected, the most firm conclusions from this study center around the evaluation of physical factors.

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[1] http://www.samsamwater.com/library/Sand_dams_or_silt_traps.pdf
[2] See limitations section for more discussion.
[3] Sample size calculation: https://www.surveymonkey.com/mp/sample-size-calculator/

Emphasis on observational data compared with self-reported data. For data on dam usage, number of users, etc. (socioeconomic, or "nonphysical" data), we collected self-reported data, but place an emphasis on how observational data corroborated (or not) the self-reported data. In short, the reliability of self-reported data alone as a method was treated with skepticism.

Complementing existing evaluations. This study did not attempt to replicate existing evaluations (although general conclusions may point in the same direction). The emphasis in this study was on gathering new data (or more complete data) which complement existing studies. Outstanding questions about sand dams addressed in this study, roughly in order of how successfully they were addressed:

1. Is the water from sand dams clean, either relative to other sources, or in a more absolute sense (compared to WHO standards, for instance)?[4]
2. Is there a consistent issue with siltation in the population of dams in Ukambani? In short, have these dams by and large silted up to the degree that it greatly hinders their successful usage?
3. To what degree are dams actually being used? In particular, how does observational data help answer this question?
4. What are the social dynamics of management and conflict at dams?

General background on sand dams is available in various published studies and unpublished evaluations, and is not elaborated here.

Results

Locations of the sand dams randomly selected for this survey tended to be clustered in certain regions (Fig. 1), reflecting what is known about sand dam distribution – most communities have multiple dams. Once a dam is constructed in an area, it is more likely than one or more additional dams will be built there. To some degree, these areas are closer to the organizational offices (nearer to Kola and Kitui). Although there were fewer dams in the southern region, especially in Makueni, this in part is because a third organization (African Sand Dams Foundation) was not included in this evaluation and is based in Kibwezi, which is located in this southern region and has built around 250 dams[5].

[4] Data for this item is in a separate report.
[5] http://www.asdfafrica.org/our-impact/water-security

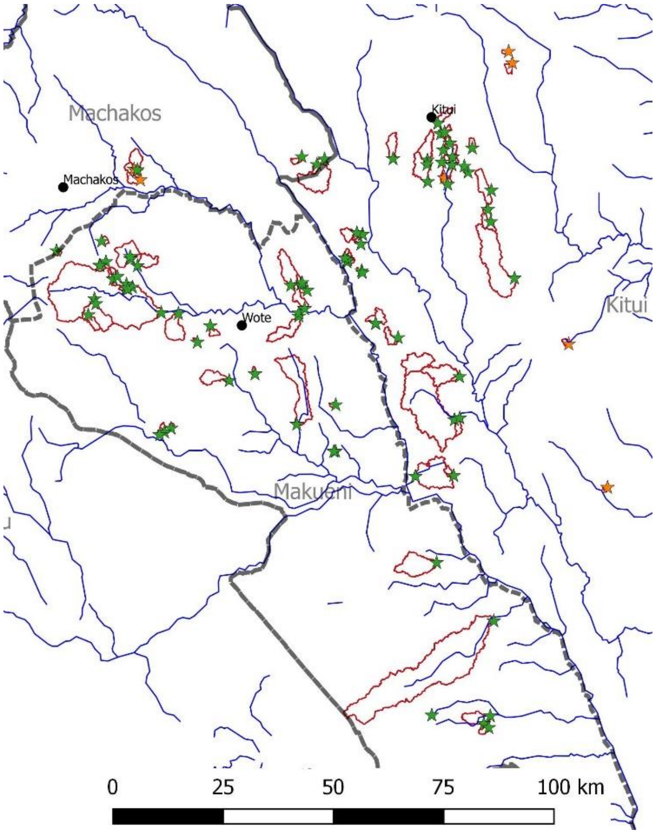


Figure 1 Location of sand dams that were surveyed. Sites in green are UDO and SASOL dams. Sites in orange are colonial-era dams. Watershed areas draining into the sand dams are shown in red outlines.

Case studies of individual sand dams are compiled at https://sites.google.com/site/mcckenyasanddams/case-studies. That website has short descriptions of individual dams visited which illustrate some of the general learnings which come out of the study.

Further results from the evaluation are listed in a hierarchal manner, addressing 1) the potential of sand dams to hold water, and their actual observed water storage, 2) the actual usage of water by communities, and 3) factors that are associated with sand dam functionality (i.e. how might this information be used to improve sand dam performance?).

1. Are the dams holding water?

1.1. Potential storage

1.1.1. Dam volume & potential for filling based on watershed

Calculated water volumes of surveyed dams vary by 3 orders of magnitude (Fig 2; Table 1), illustrating the great difference in how much sediment is accumulated behind the dam structure, depending on the topography of the site. The majority of dams are skewed to the smaller end of this scale, with a few dams having notably larger volumes. Part of these differences, of course, are accounted for by the different sizes of dams. Sand dam volume was significantly correlated with number of users (r^2=0.2).[6] Larger dams obviously provide the potential for more usage, but not surprisingly other important factors are important for whether or not this actually happens, and there is considerable variation. Larger dams could also provide more water per user – a parameter we did not assess in this study.

At water consumption of 15L per day per person (for household consumption, not counting livestock, irrigation or other uses)[7], a median sized dam would support between 37 and 84 people for a 4 month period. Based on individual dam volume, 57% of dams would have enough water to provide 4 months of water to the reported number of beneficiaries (if that were their sole source of water). Dams may have inadequate volumes of water during longer dry periods, which may be of particular concern under future climate change scenarios (e.g. (Aerts, Lasage et al. 2007)). As outlined in the methods and limitations section, these are rough estimates as actual available water volume depends on factors we could not assess, such as the effects of the adjacent water table or the stratification of silt layers.

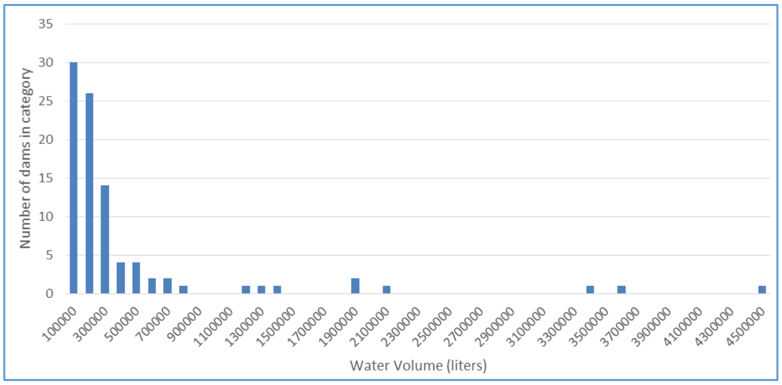


Figure 2. Calculated minimum available water volume of surveyed dams.

Table 1 Minimum and Maximum Water Volume Estimates

	Dam volume (L)	Water volume low estimate (L)	Water volume high estimate (L)
minimum	34,000	5,470	10,852
1st quartile	479,250	77,151	153,514
median	**949,500**	**144,190**	**302,818**
3rd quartile	1,747,500	297,958	554,406
maximum	30,659,000	4,433,016	9,596,272

The amount of water captured by the dams is negligible compared to the total volume of rain falling on the watersheds that serve those dams (Table 2). Median values for percent of the total watershed rain volume that were collected by dams were less than 0.1%. This suggests 1) watershed areas were always large enough to serve the dams, and 2) as is consistent with other studies ((Aerts, Lasage et al. 2007) (Lasage, Aerts et al. 2015)), the quantity captured is not currently enough to decrease water flow downstream. Downstream communities are therefore not at risk of negative impacts resulting for decreased water flows.

[6] see addendum for data.

[7] As per Sphere standards minimum recommendation; http://www.spherehandbook.org/en/water-supply-standard-1-access-and-water-quantity/

Table 2 Estimated percent of watershed water collected by dams. April and November are the height of the rainy seasons; July is in the dry season.

	April watershed rain volume (L)	% captured by dam (high estimate)	July watershed rain volume (L)	% captured by dam (high estimate)	Nov watershed rain volume (L)	% captured by dam (high estimate)
minimum	1,116,075	0.00%	9,705	0.00%	1,911,885	0.00%
1st quartile	173,382,531	0.02%	2,224,023	1.53%	230,262,974	0.01%
median	**544,092,254**	**0.05%**	**6,324,747**	**3.91%**	**760,206,792**	**0.03%**
3rd quartile	2,285,833,527	0.16%	24,890,506	11.24%	3,757,320,320	0.12%
maximum	47,998,230,250	3.51%	1,178,024,450	444.12%	52,058,654,950	2.98%

There are several caveats regarding impacts at the watershed level. First, April and November are the wet seasons; in the dry season month of July, dams would capture a larger percentage of any rain. Second, watersheds almost invariably have multiple dams. There are no records for sites of all dams, and thus it's not possible to calculate watershed effects from all dams. However, we note that hundreds of dams would be needed on watersheds to have (for instance) even a 10% effect on the total water quantity in the watershed. Third, this estimate does not include water captured by the water table. Thus, this represents a lower end estimate (although we used the high estimate for dam volume in order to partially offset this uncertainty). Finally, of course, not all water falling on the watershed would flow to the dam point – much of it will be absorbed in the soil.

Conclusion: Dam size may often be a limitation in how many people can be provided with water, or how long the dam will provide water. A focus on larger dams (or multiple dams) may be justified to provide sufficient water to communities who are fully utilizing the resource. Sand dams do not significantly reduce runoff at the watershed level, and therefore are not having substantial unintended negative impacts downstream.

1.1.2. Degree of Siltation

The usable water content of sediments varies according to the size of the particles (expressed as particle radius in microns), with smaller particles having lower usable water content. Actual water content (void space) varies less, but the large surface area of small particles means most of the water is bound to surfaces, and not easily extracted. Thus, sands have a higher usable water content than silt or clay. The actual amount of usable water in a complex mixture of particles is not exactly define in the literature, and even samples with uniform particle sizes have differing estimates.

In order to estimate how much water is held by sand dams, we used two boundary estimates for common particle size classes (Table 3). Here we've classed particles based on the soil sieve set that we used.[8]

[8] Trincheria and Nissen-Peterson have used the following definitions for their analysis: silt <500um, fine sand 500-1000 um, medium sand 1000-1500 um, coarse sand 1500-5000 um. (http://www.academia.edu/14458042/HOW_TO_GET_MORE_WATER_FROM_SAND_DAMS_FOR_HALF_THE_COST). Selection grain size definitions has a large impact on volume calculations, and their use of large grain sizes in their classes would considerably decrease their volume estimates.

Table 3 Estimates of specific yield (amount of "usable" or "extractable" water) in standard particle size classes. (Johnson 1967)

particle size (microns)[9]		Estimated usable water as percent of total volume	
		Low estimate	High estimate
Fine Gravel	**2000+**	21%	35%
Coarse Sand	**500-2000**	20%	35%
Medium Sand	**250-500**	15%	32%
Fine Sand	**63-250**	10%	28%
Silt & Clay	**0-63**	0%	19%

The size class of greatest concern was silt/clay. This size class was a small percentage in almost all samples (Table 4). Most particles were of fine sand or larger, which hold a larger amount of water. These particles fall in the range large enough to allow drainage of water through most of a sand dam's depth, based on Viducich's depth-based calculations (see Fig. 2.7 in Viducich). (Viducich 2015)

Table 4 Particle size distribution in sampled sand dams.

	Average	Standard Deviation	Minimum	Maximum
Fine gravel	9.8%	5.6%	1.3%	25.4%
Coarse sand	34.1%	11.2%	11.9%	68.9%
Medium sand	28.9%	8.0%	10.6%	51.8%
Fine sand	25.4%	9.9%	7.9%	59.8%
Silt/clay	1.9%	2.4%	0.1%	12.5%
Median particle size D_{50}[10]	0.44 mm	0.11 mm	0.16 mm	0.66 mm

We calculated the total water volume based on the low and high estimates for usable water, and then compared this to total water volume of dams if the dam were entirely filled with coarse sand (*i.e.* an "ideal" dam with respect to particle size). We then expressed the degree of siltation as the percent reduction in usable water due to the presence of the smaller particles (Fig. 3). The average reduction in stored water due to this siltation was between 10-25% (depending on whether low or high estimates of specific yield were used).

This is clearly a simplified analysis of a complex hydrologic situation. For instance it does not take into account stratification. We saw clear evidence of stratification, such as multiple silt layers which result from storm events (Johnson 1967). Others have noted that narrow silt or clay layers could disproportionately restrict the function of the dam ((Viducich 2015); see online case studies from this study for examples). On the other hand, the total volume of water available is probably overestimated, as the adjacent water table is not included in our analysis. Some have suggested that the adjacent water table is in fact the major pool of stored water in dams.[11] In

[9] Definitions approximating size classes from USDA

[10] Calculated according to: https://water.ohiodnr.gov/portals/soilwater/data/doc/Calculating_D50.doc

[11] Borst, L. and S. De Haas (2006). Hydrology of sand storage dams: A case study in the Kiindu catchment, Kitui District, Kenya. The Netherlands, Amsterdam, MSc. Thesis, Free University.

and Jansen, J. (2007). "The influence of sand dams on rainfall-runoff response and water availability in the semi-arid Kiindu catchment." Kitui District, Kenya.

estimate 40% and 75%, respectively, of water in dams is contained in the aquifer. On the other hand, DE TRINCHERIA, J., et al. "FACTORS AFFECTING THE PERFORMANCE AND COST-EFFICIENCY OF SAND STORAGE DAMS IN SOUTH-EASTERN KENYA."

addition, sampling was biased to the top section of the dam (average depth 0.7 m), as deep sampling wasn't possible with the equipment used. Lower layers could have a different particle distribution. However, the depth sampled does represent 60% of the sediment volume at dams, and we believe the samples give a general representation of the level of siltation in dams. Further discussion on this critical point is given in the limitations section.

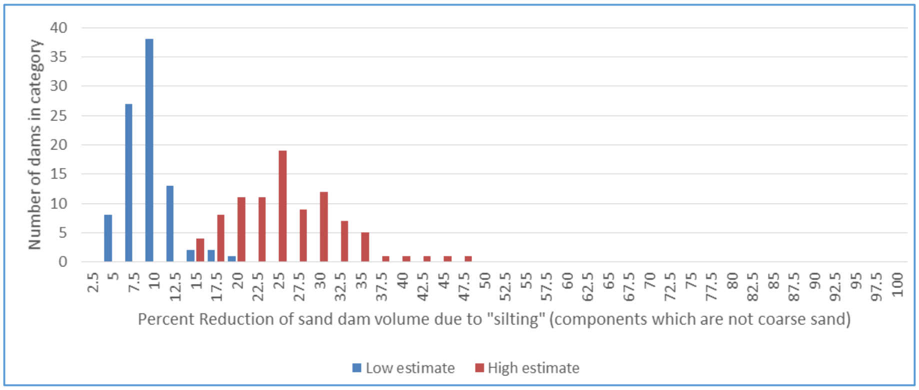


Figure 3 Siltation effects on calculated sand dam water volumes, based on low and high specific yield estimates.

Indirect evidence for the accumulation of some finer particles (especially silt and clay) is indicated by the presence of vegetation growing on the surface of the dam in 63% of the dams.[12] While some of the vegetation is planted intentionally (e.g. vegetables, napier grass), most of the observed vegetation was short grasses and shrubs that have taken root in the "soil" of the dam (see addendum for this and other additional data related to siltation).

Conclusion: While having some effect on reducing water volume, siltation did not severely limit the potential storage capacity in most dams. In broad terms, silt buildup is not the primary constraint to sand dam function. The correlation of the observed degree of siltation at dams on an integrated rating of functionality ("is the dam used successfully?") is considered in section 4.

1.1.3. Erosion & leakage at dams

Evidence of erosion was present in the majority of dams, to varying degrees of severity, and roughly equally between the base and ends of the dam (Figs. 4, 5). Only 4% of the dams were broken, and thus entirely nonfunctional in terms of holding sediments. Data on more subtle damage to dams (*e.g.* cracks) was not consistently collected. Anecdotally, some dams did have cracks, but major cracks were not evident in most dams.

A major issue with damaged or eroded dams could be leakage of water from the dam. Evidence of possible leakage was present in about 1/3 of dams visited, as a single pool or multiple pools below the dam (see addendum).[13] As some dams showed no evidence of water in the sand bed, other dams may also be "leaky" when more water is present.

disputes whether aquifer is a significant factor in available water.

[12] see addendum for correlation of vegetation with smaller particle size.

[13] The reason for pools below dams is, however, difficult to assess. Leakage through cracks, or on the edges, of dams certainly occurs in some cases. Water probably also moves around the dam in cases where a water table is continuous between the upstream and downstream dam areas. For simplicity, we define both "leakage" – movement of water from the dam itself.

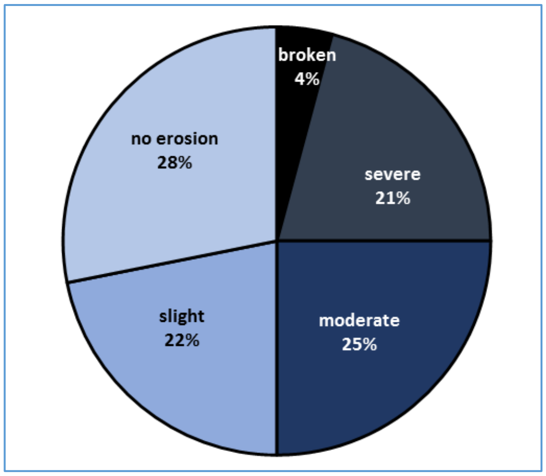


Figure 4 Degree of erosion at dam base or sides.

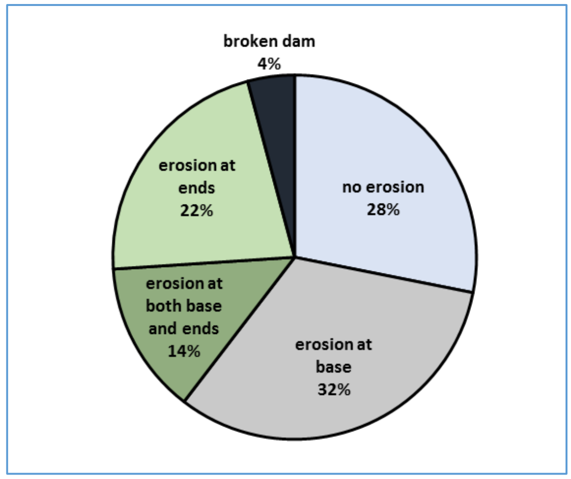


Figure 5 Type of erosion at dams.

Both SASOL and UDO have revised their building techniques over the years, in an effort to address issues such as erosion. This is clearly a positive trend, and has surely avoided worse problems with leakage. The data suggest that continued attention to this issue is warranted, and could make sand dams more robust in the future.

Conclusion: Structural issues do exist in many sand dams, erosion and evidence of leakage is common. In theory, this could impair the ability of dams to provide optimal amounts of water. In practice, however, evidence does not point to a strong impact on overall dam function (see section 4).

1.2 Actual storage of water in dam

1.2.1. Filling of dam.

Of the dams that had not broken, 85.7% of dams were fully filled with sand (or other sediments). Another 11% of dams were half or three-quarters full, with only 2.2% empty or one-quarter filled. Although a few of the dams that were not fully filled were 2 or 3 years old, most were more than 3 years old. Therefore, the lack of filling was not entirely due to the initial filling process of the dam. In the majority of cases, though, there did not seem to be an issue with the dam collecting sand (or other sediments).

Conclusion: Lack of filling is not a constraint in sand dam function – the large majority of dams fill with sediments.

1.2.2. Presence of water in sand.

Multiple core samples were taken at dams from the dam structure to the drawback, and the presence or absence of moisture was recorded. Most (78%) of dams had moisture in the sand from at least some samples, with most dams having moisture in more than half of their samples (Fig. 6). The presence of moisture suggests most sand dams are holding water. Deep coring (on average, our cores were 0.7 m deep) would presumably increase the percentage showing water even more.

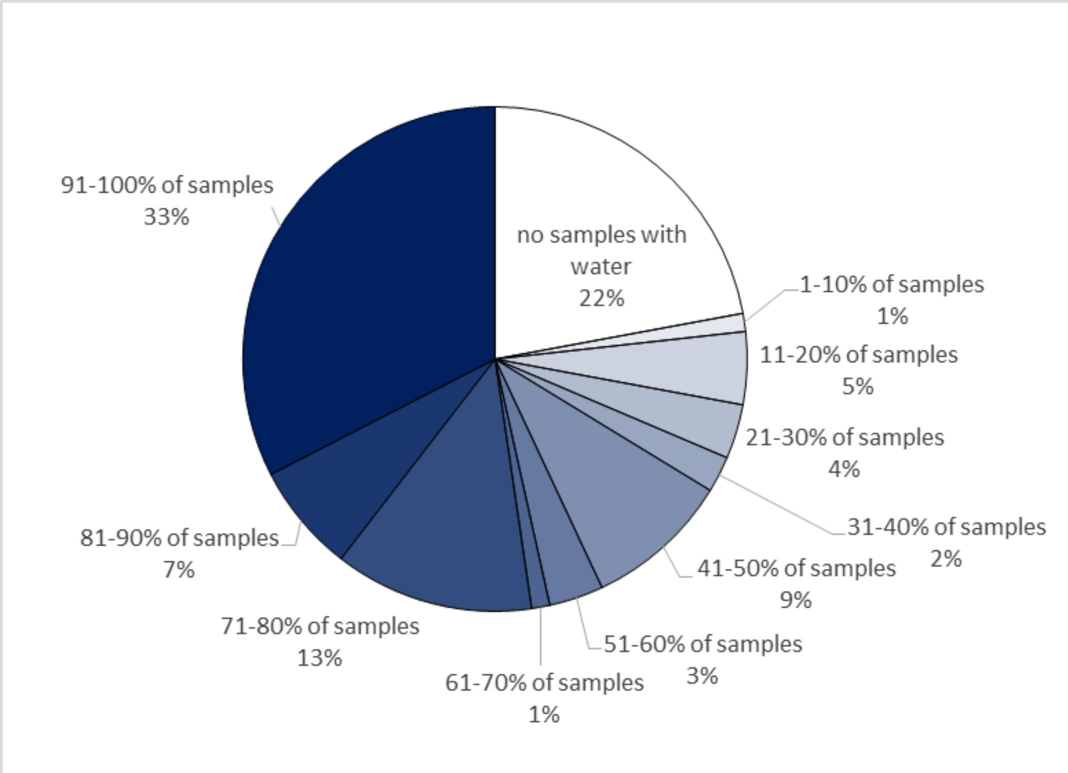


Figure 6. Percent of dams that have moisture in different proportions of samples taken at that dam. The darkest blue wedge, for instance, is the percent of all dams surveyed that had moisture in 91 to 100% of the sand samples taken from that dam.

Conclusion: There was moisture in the sand of most dams visited in the dry season. Extractable water is likely present in most dams, although a smaller fraction of dams are actually being used for water harvesting (see section 3).

2. Evidence of benefits

2.1. Vegetative Index

Satellite images were used to measure the "greening" by vegetation within a 100m range of sand dams, compared with a similar measurement in a comparable control stretch of the waterway (at least 200m upstream or downstream from the sand dam). The NDVI (normalized difference vegetation index) is a standard method of estimating green vegetation health and density[14], and was calculated from Landsat 8 images, bands 4 and 5. Calculated values were between 0 and 0.5, with higher values indicating more greening. A higher NDVI for the sand dam area would indicate greener vegetation, possibly due to an increased water supply. Images were analyzed for both dry seasons (Jan-Mar, and Aug-Oct, with specific dates depending on dates of available images that were free of cloud cover).

[14] e.g. the Kenyan National Drought Management Authority uses NDVI in northern Kenya to trigger release of disaster contingency funds in northern Kenya during droughts; Klisch, A. and C. Atzberger (2016). "Operational drought monitoring in Kenya using MODIS NDVI time series." Remote Sensing **8**(4): 267.

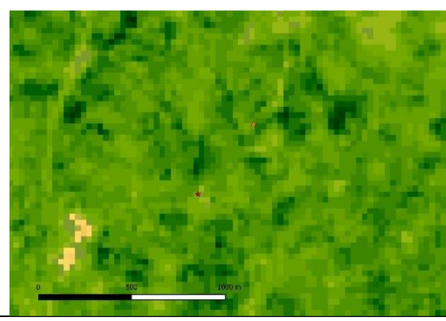
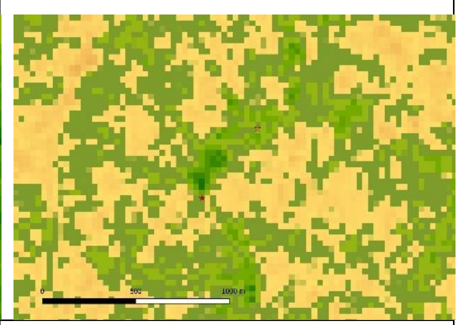
There was no statistical difference ($p>0.05$; paired t-test) between the NDVI at sand dam and control sites for either dry season (Tables 5, 6). At the scale analyzed, there is no evidence of consistent increase in vegetative greening at the dam sites. Results could depend critically on the buffer range chosen (see limitations for more discussion of this), and further analysis with a smaller or larger buffer could reveal differences on a different scale.

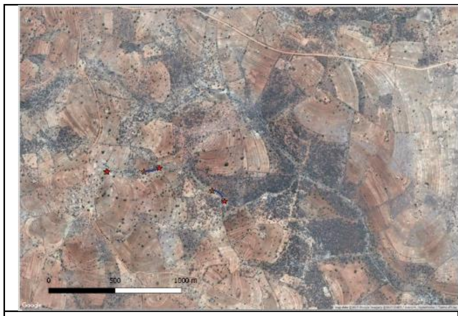
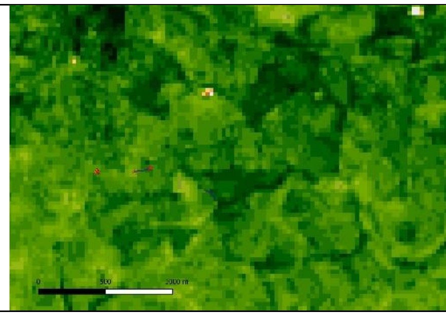
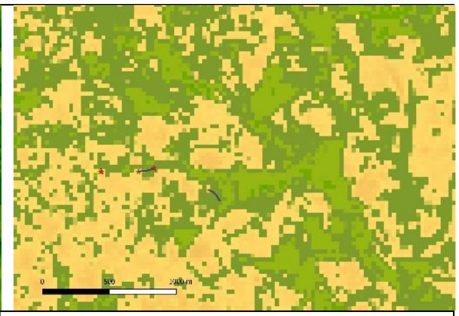
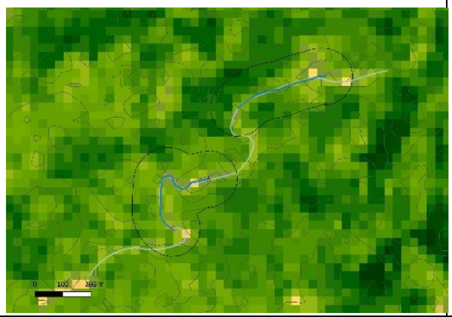
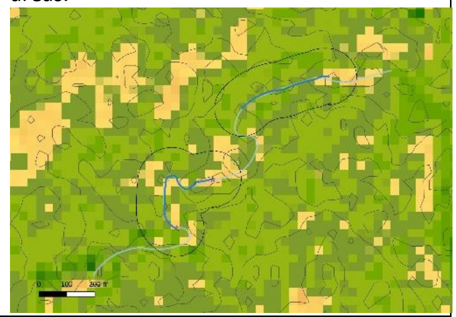
Table 5. Vegetation index at sand dam compared with control (at least 200m away from dam, usually downstream, in absence of sand dam)

	NDVI at sand dam	NDVI at control site	Paired NDVI difference (NDVI at sand dam minus NDVI at corresponding control site)
Jan-Mar dry season	0.266 ± 0.051	0.269 ± 0.053	-0.003 ± 0.022
Aug-Oct dry season	0.176 ± 0.025	0.176 ± 0.028	0.000 ± 0.014

Several examples of satellite and NDVI images for dams are shown below. Several other examples are shown in the addendum.

Table 6 Examples of vegetation index at sand dams

Satellite Image	**NDVI, Jan-Mar dry season**	**NDVI, Aug-Oct dry season**
Makongwe, one of the more successful dams that was visited (red star is dam, orange star is drawback point). On the ground, there was obviously a great deal of vegetation around the dam.	In both wet seasons, a notable green spot is obvious just upstream from the dam (red star) which corresponds with the vegetation seen on the ground.	The increased greenery is especially obvious in the October image. Of all dams visited, this was the most obvious NDVI evidence of greenery associated with sand dams.
		
Munanthi, Makueni. This is an example of a series of dams along a watershed that were obviously not providing water at the time of visits, and for which there was overall less evidence of water storage.	Patches of greenery, and lack of greenery, seems most correlated with agricultural activity – cleared fields lack vegetation in the dry season.	There are obvious areas of greater greenery, especially downstream from the dams visited. These seem correlated with less agricultural clearing, and the general presence of greenery in the watershed, as opposed to sand dams per se.

		
Kyangiti, Kitui. Dam on a larger stream (which contains a good deal of sand throughout its channel).	The 100m buffer zone is shown here, for which NDVI was quantitatively analyzed.	A grove of trees upstream from the drawback shows higher greenery levels, but the sand dam area itself (bottom left buffer) is not obviously greener than other areas.
		

Conclusion: On average, greening of areas around sand dams does not occur at a scale that can be detected using standard vegetative index methods. This was surprising, as some dams have strikingly green areas around the dam. Those greened areas that are observed when visiting dam sites are possibly overestimated, precisely because of their striking nature – a relatively small area of green garners disproportionate attention relative to its size. This does not mean that some vegetative greening near dams is unimportant, greening of modest areas of fruit trees or vegetable can provide substantial benefits. At the scale analyzed (within 100m of dams), however, these benefits are not generalizable as a consistent effect greening all vegetation near the dam due to raised water tables.

2.2. Evidence of usage

2.2.1. Adjacent land usage

Land use was assessed in transects to an estimated 30 m laterally from the dams, at 15-50m intervals (depending on the size of the dam), as a means of quantifying agricultural uses of the land near dams. Most land adjacent to dams was bushland (including scrub trees, pastureland) and unused cropland (*e.g.* crops had obviously been grown in the past, but the land was currently unused) (Fig. 7). Land use as vegetable fields and cultivated grass (*e.g.* napier grass) suggests benefits from the sand dams (as these are less prevalent away from water sources) – these were present in 6.3% of the linear distance of transects. The presence of fruit trees and used cropland were likely also evidence of sand dam usage, although these activities also occur away from sand dams. No active agricultural activities adjacent to dams were observed in 61% of dams surveyed, during the dry season when surveys occurred. In the 39% of dams with agricultural activities, most of these had multiple activities.

Conclusion: Most of the land adjacent to sand dams is not being actively utilized in a way that is linked to an increased water supply. There was a somewhat bimodal pattern of use at dams – they tend to be used either in multiple ways, or not at all, for agriculture.

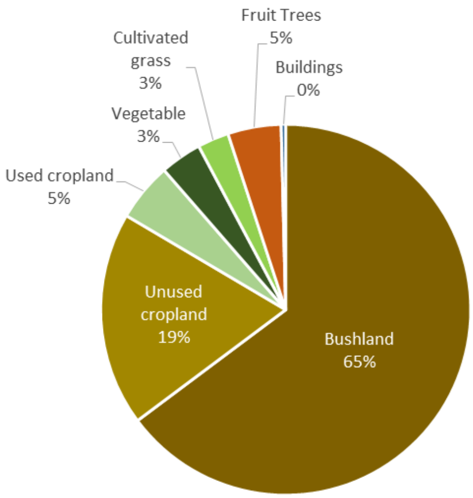


Figure 7 Average percentage of various activities on adjacent land

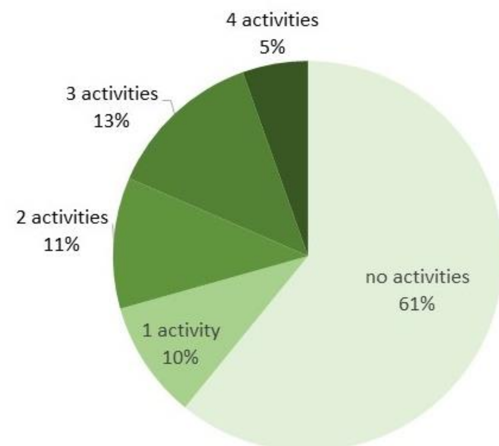


Figure 8 Number of agricultural activities on adjacent land at sand dams

2.2.2. Presence of water harvesting

In 39% of all dams, there was no evidence of attempts to extract water (Fig. 9). Of the remaining dams (where there was evidence of water harvesting), two-thirds were currently extracting water, and the remaining had stopped water usage as sources had dried. Of dams where there was no evidence of water harvesting, 81% had evidence of water in the sand cores.

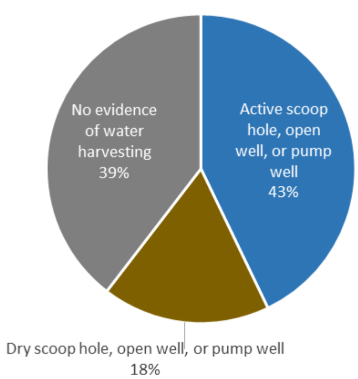


Figure 9 Percent of dams utilized for water harvesting.

Scoop holes were the most common water harvesting technique (Fig. 10). Open wells (permanent excavations with reinforced walls) were more common than pump wells, likely because of the expense associated with pump wells. Only 3 out of the 14 pump wells observed had water – the others were either dry or broken.

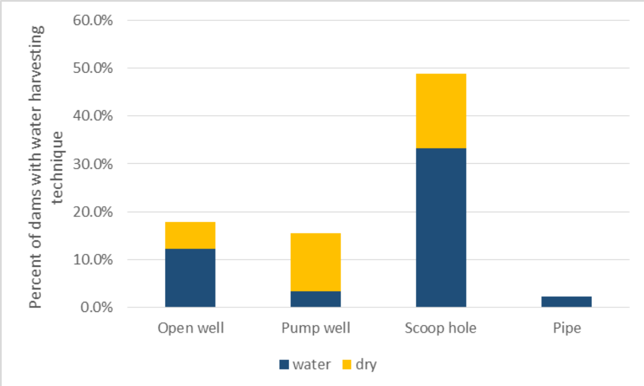


Figure 10 Frequency of water harvesting techniques at dam, indicating whether water was present or source was dry

Conclusion: There is evidence of water in the majority of sand dams, but many of those dams are not currently be used for water harvesting. Many of the dams are underutilized with respect to water harvesting.

2.2.3. Self-reported impacts of sand dams

Users readily report the range of expected uses of sand dams (interviewees were given the answer options for this question), with household usage most commonly reported as the primary usage (Fig. 11). The high percentage of dams reporting various primary activities does not match the lower percentage where water harvesting was observed. Possibly respondents are reporting water use which has occurred at some period, but not at the time dams were visited.

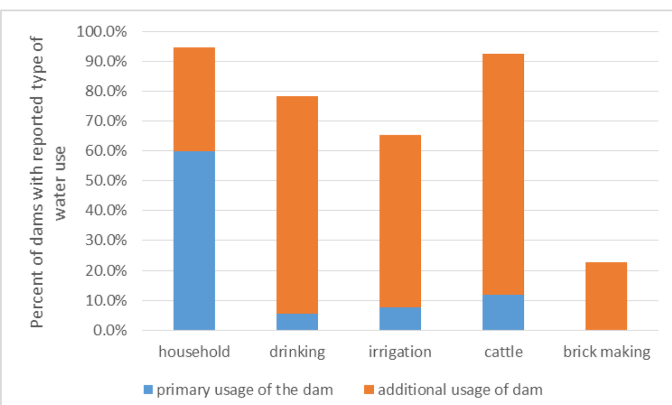


Figure 11. Percent of dams reporting types of usage for water harvested from dam. Interviewed groups reported for all users of dam, listed all uses, and indicated the primary usage of water in the dam.

A separate open-ended question was asked of potential impacts, which could be positive or negative. Respondents gave mostly positive impacts, as expected (Fig. 12). In retrospect, it was not clear whether respondents interpreted this question more in the sense of potential (or aspirational) benefits rather than actual activities happening at that dam, which limited the utility of this item. We include it here, however, as a helpful snapshot of relative importance of what users see as impacts of dams, whether those have actually occurred or not. Several items of note are:

- Benefits are not restricted to traditional water harvesting solely for household or drinking. Other uses, such as water for livestock, brick-making and irrigation are all seen as important benefits by communities.

- Sand harvesting is seen as a major benefit by communities. Benefits are not solely contingent on the presence of water (see section 2.2.4 below).
- Communities understand that there are indirect or more abstract benefits, such as a raised water table, or the facilitation of group activities and togetherness.

Groups were asked about how the benefits differed between men, women, girls and boys. These were open-ended questions, and respondents were not prompted for the categories. For women, the largest benefit was clearly in saving time as they walk shorter distances to get water (Table 7). School attendance was cited most often for girls, but also to a lesser degree for boys. Possibly girls are more involved with gathering water, and thereby benefit more from the dams. Benefits related to education included not only staying in school or increased attendance, but also improved performance as children could do their homework and were not tired during the day. In the absence of nearby water sources, children are reported to walk long distances at night, making children tired during the day. Improved health (*e.g.* through increased washing) was reported more often for women and girls, than for men and boys. "Bringing togetherness and unity" was often cited for girls, and to a lesser extent for women, but rarely for men or boys.

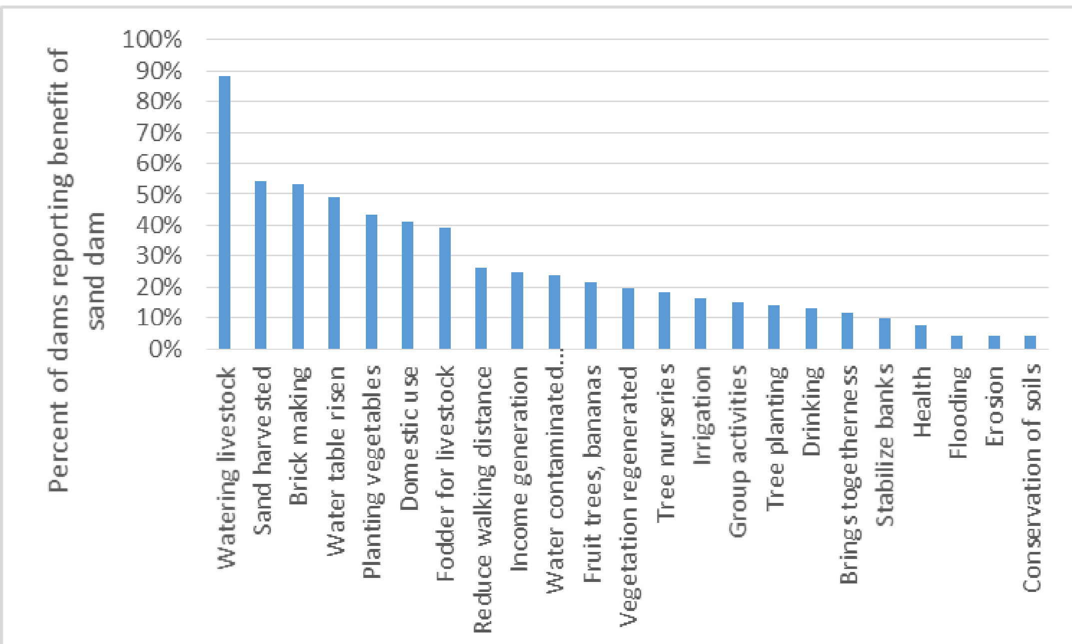


Figure 12. Reported benefits in open-ended question

For men, activities around brick-making, livestock, and other income generation projects were reported most often. Brick-making requires both the collection of sand and water, and appeared to be a common and valued activity for men. The frequency of this activity was higher on this questionnaire item than the earlier item asking whether certain activities were occurring (Fig 11), perhaps because gender-specific usages here were reported as general benefits (across time), whereas the previous item was interpreted as current usage .

Table 7 Reported benefits of sand dams, based on gender and age. The top five items are shown for each category.

Women		**Girls**		**Men**		**Boys**	
Saves time/shorter distance	96.7%	Improved school attendance and performance	75.0%	Brick making/construction	62.0%	Brick making/construction	46.7%

Improved health	42.4%	Improved health	51.1%	Livestock	51.1%	Income generation	37.0%
Income generation	13.0%	Brings unity/brings together	35.9%	Income generation	35.9%	Improved school attendance and performance	29.3%
Brings unity/brings together	5.4%	Saves time/shorter distance	32.6%	Irrigation	10.9%	Saves time/shorter distance	21.7%
Livestock	4.3%	Allows to sleep more	4.3%	Improved health	9.8%	Livestock	16.3%

2.2.4. Sand harvesting

Most locations (88%) report that dams are used as sources of sand harvesting. Most dams where sand is harvested report that the entire community is allowed to harvest sand (90.4%), with the remainder restricting harvesting to group members (8.4%) or in one case to an individual. Sand harvesting was overwhelmingly for community use only; selling sand was only reported to be allowed at one dam site.[15] These results imply that sand dams provide a consistent benefit outside of water provision, and that there is some degree of group control of this resource as they have mutually agreed not to sell the sand.

Conclusions: As expected, the use of water for drinking and household purposes is most often seen as the primary benefit, and strongly value the reduced time required to collect water. However, interviewees reported a wide range of other benefits from sand dams. Important specific benefits included both direct activities (e.g. livestock watering, irrigation, brick-making (harvesting of sand and water) and indirect benefits (e.g. improved school performance, unity/togetherness). Benefits to women and girls varied notably from those to men and boys. The frequency of self-reported usage is higher than what is expected based on observational data (section 2.1). Data in this and other studies on usage is difficult to accurately assess and should be viewed with caution. In general, communities seem aware of the many possible uses and benefits of the sand dams, but actual implementation of many of the uses is inconsistent.

2.3. Compiled dam assessment - Integrated rating of dam functionality and usage

In an effort to rate dams on their functionality – essentially how successful they have been - we took a set of metrics from the study which indicated 1) how much water storage occurs in the dam, and 2) to what degree water is being used by the community.[16] We weighted metrics to account for differences in relative importance

[15] Since the selling of sand has both legal and community agreement implications, it is possible that respondents may not have been fully disclosing activities at the site.

[16] There are non-water related benefits, specifically the accumulation of sand which is used for construction or for sale. However, the focus here is on water related benefits, since this is the explicit focus of sand dam projects.

as indicators of functionality. Although this method relies on subjective judgments, it does give an overall picture of how successful the dams seem to have been.

Not surprisingly, this dam functionality index varies considerably between dams (Fig. 13). A depiction of the dam sites is shown in figure 14 (also viewable online at higher resolution). Visual inspection of the dams compared to their ratings does not indicate any obvious pattern in the appearance of the dam compared with their functionality. This is consistent with the conclusion that the success of dams is more related to pyschosocial factors than biophysical factors (see sections 4.1, 4.2, and further discussion in this report).

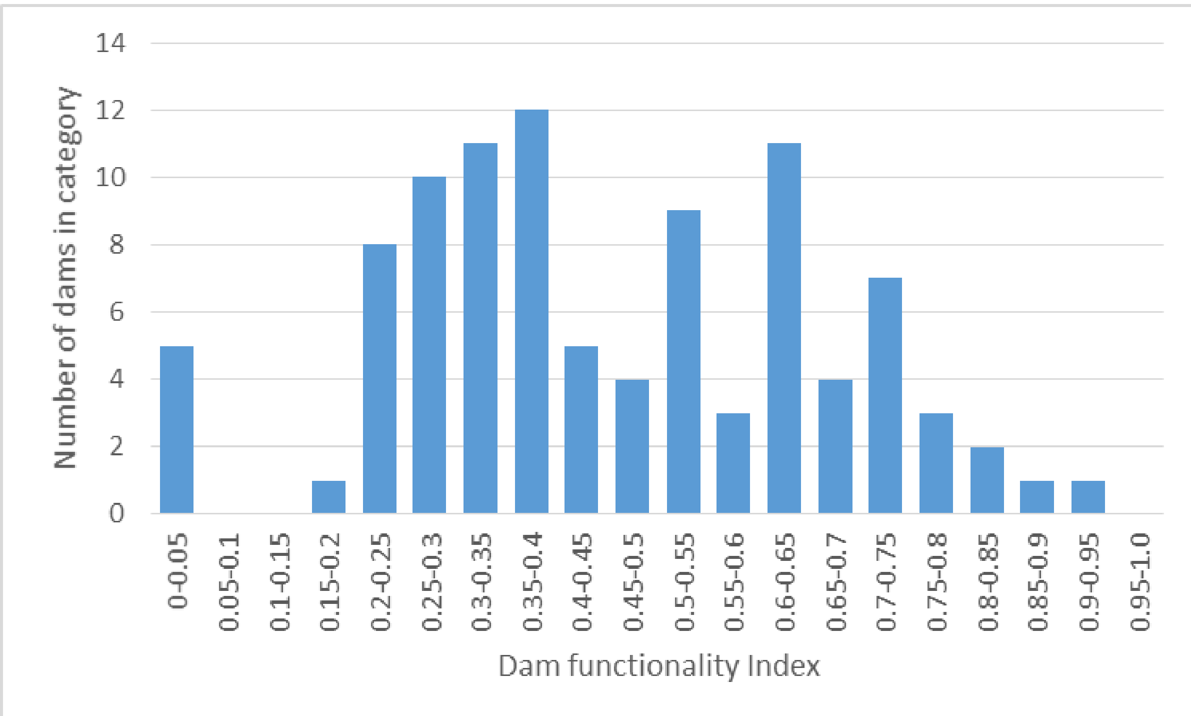


Figure 12 Ratings of dam functionality by category. The five dams rated "0" are those that were broken.

Conclusions: Most dams would not be considered either “optimal” (ample water throughout the year and robust usage by the community) or “failures” (little capacity for water storage and/or largely unused). Most dams fall in the center of the rating, showing some clear evidence of use, but also showing some lack of water and/or lack of use by the community.

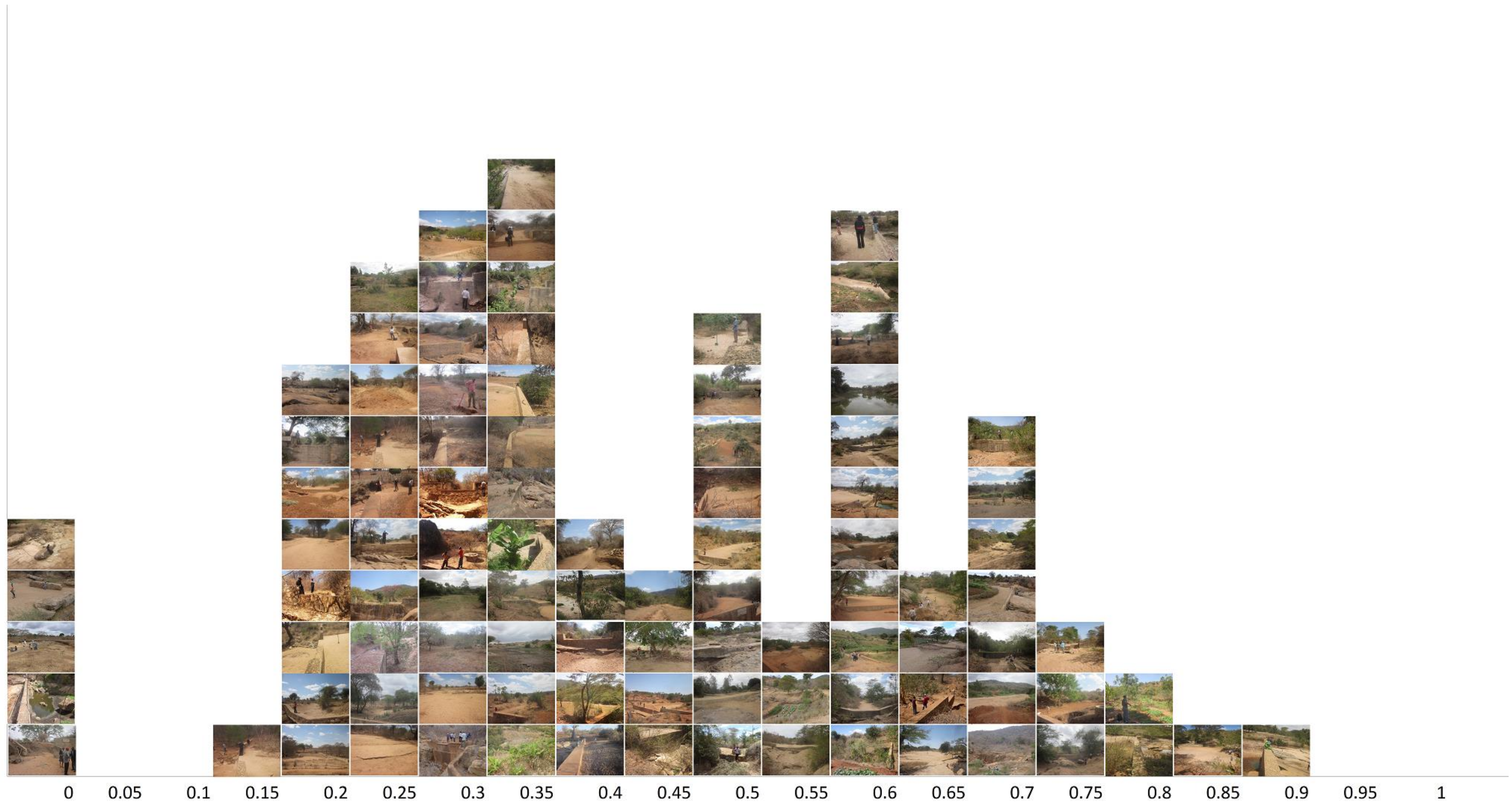


Figure 13. Number of dams in each rating category. (Zoom in on document to see dam pictures in more detail)

There is a slight clustering of the higher functional dams in certain areas of Ukambani (specifically in central Kitui and near the Machakos/Makueni border). Specific causative factors of functionality (including some which area associated with location) are considered in the next section.

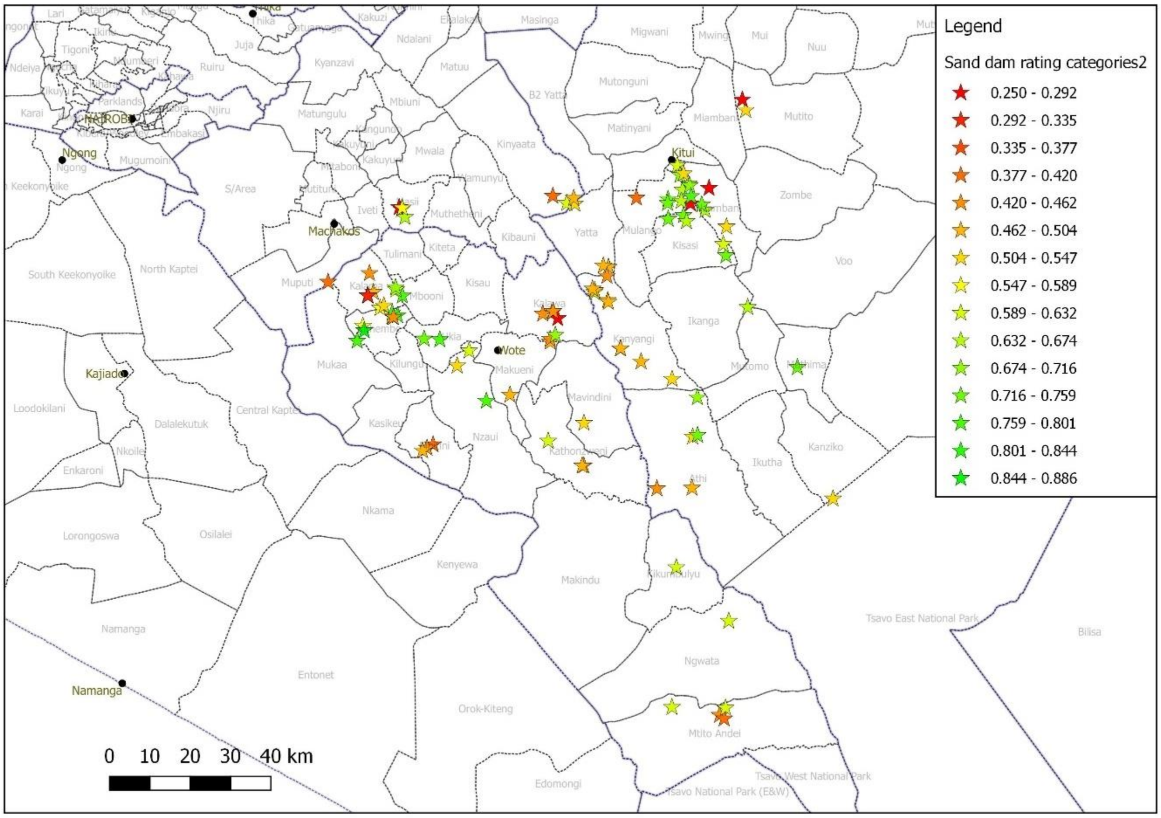


Figure 14. Dam functionality compared with location of the dam.

3. Other metrics

3.1. Population served by dams.

Population estimates from 2015[17] were used to calculate an average of 2709 individuals within 2 km of sand dam locations. Population estimates ranged from 69 to 9531, and did not correlate with the size of the dam (as the estimated volume of sand; see addendum). Average population density at dams was 179/km^2, compared with 74/km^2 in the region as a whole; dams are therefore located in areas of the counties that have a higher than average population density (Fig. 16).

[17] see methods for details of data sources.

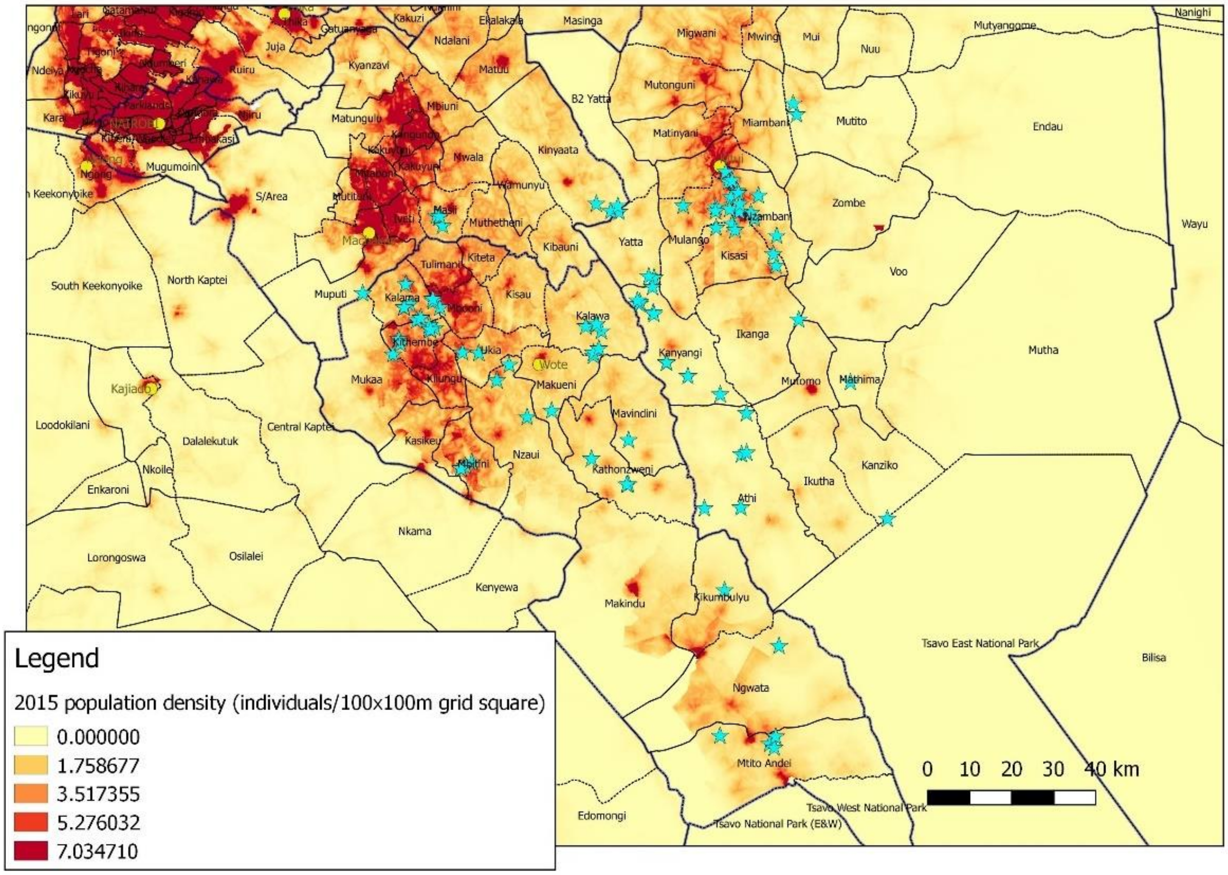


Figure 15 Location of sand dam compared with population density.

The average poverty rate within 2km of sand dams was 43% (Fig. 17), near the average poverty rate in Ukambani (41%).

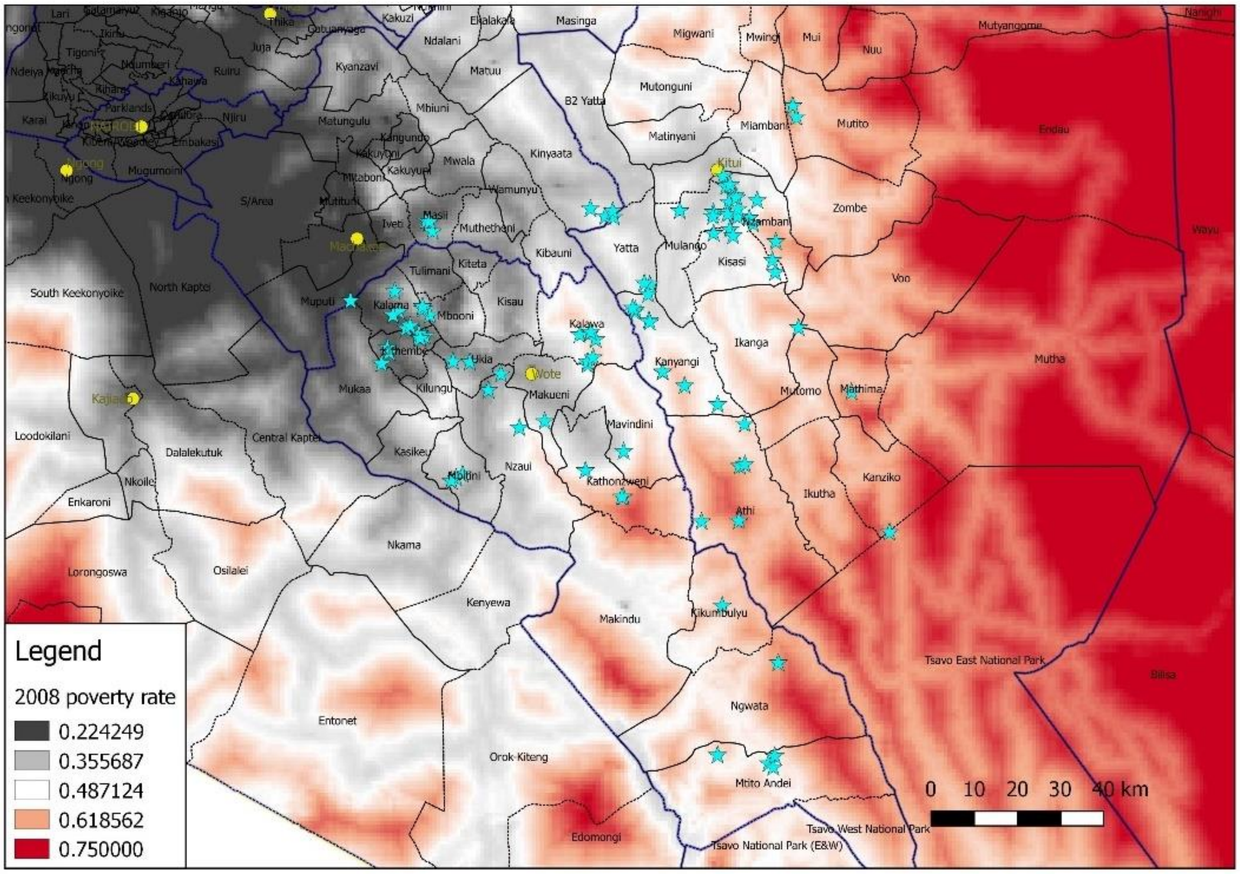


Figure 16. Location of sand dams compared with poverty rates.

Lower population density areas tend to have higher poverty rates. For instance, fewer people live in the southeastern part of the region where rainfall is lowest, farming is marginal, and access to markets and services is low. However, sand dams are located in areas both with higher population density, and with average or higher poverty rates.

Conclusions: Dam locations are well placed with respect to reaching larger numbers of people that are in need - poverty rates at the dams are average for the region despite being in higher population regions.

3.2. Density of dams.

Nearly all interviewees (98%) report that there are other dams near the dam selected for analysis in this study; an average of 3.3 dams is reported "in the vicinity" (distance undefined). For those indicating a distance to the nearest neighboring dam, the average distance was 1.1km.

Ukambani encompasses an area of 38,352 km^2, with 3 million people. The total number of dams is unknown, but probably somewhere over 3000 (Viducich 2015)[18]. Taking an estimate of 4000 dams, the average density of dams would be 9.6 km^2 per dam (an average ~3 km linear distance between dams), and 750 people per dam. Of course, dams are clustered, so there can still be large areas without nearby sand dams. However, in principle this represents a fairly high density of dams located in the county.

[18] http://www.utoonidevelopment.org/resources/research/teel-wayne-s-2011-aug-31/

3.3. Dam Management and Conflict

There was a difference by organizations in how groups reported the dams were initiated. Those in Kitui by SASOL were mostly reported as initiated by SASOL, whereas those in Machakos and Makueni by UDO were reported initiated by the groups themselves. However, data were less consistently recorded for this, and possibly differences were due to how the different interviewers recorded results.

Most often, dams are closely regulated and managed, at least in the formal sense. The large majority of dams (90%) report that everybody in the community is allowed to access the water, and interviewees often reported that users can take as much water as they like (open-ended response). A smaller number of dams (8%) report water harvesting is limited to group members. Most dams (72%) did not have any formal management committee, with 25% having an established management committee. A small number (3%) relied on certain individuals to help manage the dam (e.g. kept a key to water pump). Compiled ratings of dam functionality were not any different between those that reported management (committee or individuals) and those that did not have management (rating averages of 0.51 and 0.48, respectively). However, these data were unlikely to capture the full range of ways that communities interact with respect to sand dams. For instance, sand dams often originated with self-help groups that are still in existence but have moved on to other activities. The groups likely still serve as informal venues for coordinating some activities related to the dams. Responses indicating that most dams have community agreements not to sell sand (section 2.2.4) also suggests that an informal level of management exists.

Responses that illustrate examples of ways that dam usage was reported manage include:

- Water collection for irrigation is only for group members, but everyone can collect for domestic uses and drinking.
- No water collection for commercial uses.
- Water is for group members, but other community members can ask to collect the water.
- Users monitor whether the dam is kept clean
- When water is plentiful anybody can take water; only group members can take when there is less water. A family with old person, or less fortunate can take water.
- No washing is allowed near the dam.
- Lorries are not allowed to take sand.
- Water is harvested and held in a tank, then sold at 5 shillings/jerrycan.
- Those that dig holes can take water, others can buy at 5 shillings/jerrycan.
- Committee focused on tree nursery, now focused more on agriculture.
- Committee runs a farm with tree nurseries which brings in income.
- Committee ensures that everyone pays 100 shillings to security person.
- While the pump well was functional, the chairman charged for collecting water. Pump well is broken, and now anybody can collect water.
- Persons who do not maintain scoop wells pay 200-500 shillings.
- If you do not make a scoop hole, you are not allowed to take water, or you are charged for the water.
- 1000 shilling charge to join use of off-take well.
- After construction, members later agreed to increase the height of the dam.

When asked if there was any conflict associated with the dam, most (90%) reported there was none. The remainder reported some disagreements or resistance. Likely this item was misinterpreted, with “conflict” being associated with more violent types of disagreements, rather than less serious disagreements. While the data don't allow a good assessment of the extent of disagreements which occur, it does suggest a general "live and let live" attitude by communities. Perhaps once dams are established they fall into a normal rhythm of use that avoids conflict and requires minimal active management.

Types of disagreements which occurred include:

- Nonmembers are taking most of the sand.
- Prior to 2012 everybody was allowed, now the owner of the forest where the dam is located rejects villagers from fetching water.
- There is a disagreement with local land owner who wanted reimbursement for adjacent land, and still wants this. However, he actively uses water and sand from the dam for brickmaking.
- Nonmembers steal water and sand.
- During construction there were conflicts between men and women because the women would stay there a long time; there were disagreements on the site as landowners would deny access.
- During construction some members thought they were to be paid for work; they left once they discovered otherwise.
- During construction some homes broke-up because some men would not accept their women to go spend a whole day at the site; many members withdrew from the dam construction.

In an open-ended question on challenges to building sand dams, most (68%) groups identified the labour-intensive nature of the work as a challenge, with people often leaving the group due to the hard work. Other challenges included lack of food (15%), need to fetch water from long distances for cement (10%), impacts on ability to maintain household activities (10%), and a general lack of cooperation (9%).

Conclusions: Data on dam management and conflict associated with the communities was not collected in sufficient detail to give in-depth conclusions. Responses that were collected generally suggested that usage of most dam occurs in the absence of complex formal management structures, and that serious conflicts are minimal. Further information is needed to clarify the social aspects of sand dam function.

4. Predicting Dam Function

We analyzed correlations between dam functionality and various parameters to determine whether there are factors which would be helpful in predicting whether locations or situations are good predictors of dam functionality.

4.1. General comparison of sand dam ratings with potential drivers of functionality.

Table 8 gives a visual representation of the data associated with dam functionality, with individual items color coded (green=higher rating for that metric; red=lower rating for that metric). This table is included not for the specific item details, but for the overall pattern as indicated by the color trends. Dams are sorted from highest to lowest for the overall functionality metric. Data used to create the functionality index (those which indicate water presence and usage) are on the left in light and dark grey headings. Thus, dams at the top of the list show more green, and those at the bottom show more red under these headings.

Data identified as to be potential drivers of the variable functionality are on the right, in the blue and purple headings. Data for potential biophysical drivers was most robust in this study (for example, is the dam silted?), and are primarily those included here. Data for most potential social drivers (for example, does the community work together well?) was not collected or less robust, and we did not include these items.

A visual inspection of this table suggests that the potential drivers of dam functionality do not obviously correlate with the functionality index that was created. In other words, the right side of the table shows no obvious pattern of green and red as one moves from top to bottom (from higher to lower functionality). A more rigorous statistical consideration is explored below, however the results suggest that the variation in the (mostly) biophysical parameters are not the primary explanation for why some dams are more successful than others.

Table 8. Rating categories for individual dams. Individual items are color-coded green (better) to red (worse).

				Is there evidence of water in the dam?				Is the water being used?							Is there potential for holding water in the dam?						Is the water usable?		What potential does the dam location have?				
				Observed presence of water directly in sand	Direct or indirect evidence of water	Impacts on vegetative index	Reported water presence in dam during dry season	Reported number of beneficiary households	Evidence of scoop hole or well usage	Observed evidence of current water usage activities	# of observed agricultural activities on adjacent land	Fraction adjacent area currently as agriculture activities	Reported dam usage during dry season for domestic/drinking	Self-reported usage of dam from list of primary benefits	Degree of sedimentation, calculated reduction water volume using low estimate	Degree of sedimentation, observed	Observed degree of sand/sediment filling	Erosion	Watershed supply of water during April (% collected, low estimate)	Leakage evidence	Measured Salinity	Reported problems with water	Population nearby	Poverty levels	Slope suitability	Soil suitability	Nearby dams or other water sources
8/24/2016	UDO	Kitandi	0.934		1	-0	1	100	1	1	2	0.56	1	4	24.9	0.8	0.75	0.9	0.000103172	0	488	1	5616.366	0.26624	15.00	0.37	2
8/17/2016	UDO	Makanda	0.884		1	-0	1	500	1	0.5	0	0.00	1	4	25.2	0.4	1	0.9	0.00019615	0	684	0	3993.394	0.288818	17.40	0.37	3
8/23/2016	UDO	Kyeni	0.811	100.0%	1	0.01	1	500	1	1	3	0.69	1	5	25.1	1	1	0.7	0.017203918	0	294	1	3381.766	0.284067	14.20	0.40	3
8/23/2016	UDO	Ikankanu	0.808	100.0%	1	0.01	1	280	1	1	4	0.68	1	4	18.9		1	0.9	2.9883E-05	0	365		5004.014	0.324961	12.50	0.38	4
10/4/2016	UDO	Kilili	0.79	75.0%	1	0	1	200	1	1	3	0.55	1	5	27.8	0.75	1	1	9.06305E-05	1	330	1	2703.16	0.462252	10.10	0.40	7
10/25/2016	SASOL	Matinga	0.761	8.3%	1	0.01	1	300	1	0.5	0	0.00	1	4	21.6	0.6	1	0.5	2.55393E-05	1	###	1	435	0.574	5.66	0.66	4
9/22/2016	SASOL	Mitauni	0.755	100.0%	1		0.5	400	1	1	4	0.38	0.5	6	12.7	1	1	0.7	0.000127393	1	345	1	4618	0.423	5.90	0.64	15
10/26/2016	SASOL	Nzamba	0.741	0.0%	1	0.01	1	200	1	0.5	0	0.00	1	5	32	0.4	1	1	0.001471753	0.5	###	0.5	474	0.61	10.90	0.70	3
8/30/2016	UDO	Ngatho	0.739	100.0%	1	0	1	300	1	0.75	2	0.34	1	5	31.1	1	1	1	9.23579E-05	0	280	1	5139.196	0.325585	11.00	0.46	1
9/1/2016	UDO	Kloni	0.737	100.0%	1	0	1	120	1	1	3	0.76	1	5	17.1	1	1	0.7	9.38577E-05	0.5	120	1	3196.391	0.317051	12.20	0.43	2
9/7/2016	SASOL	Makongwe	0.73	83.3%	1	0	0	300		1	4	0.74	1	6	29	1	1	0.9	0.000741083	0	673	0	3489	0.493	6.00	0.64	2
9/13/2016	SASOL	Ikindu	0.724	58.3%	1	-0	0.5	100	1	1	3	0.55	1	6	22.4	0.9	0.5	0.9	0.000115263	1	###	1	2952	0.49	4.83	0.64	2
9/8/2016	SASOL	Ndunda	0.705	91.7%	1	-0	0	300	1	1	3	0.27	1	6	15.9	1	1	0.5	0.000362481	0	418	0.5	1374	0.45	6.22	0.64	4
8/24/2016	UDO	Kithito	0.703		1	-0	0.5	50	1	0.25	1	0.50	1	3	31.8	0.8	1	0.9	0.00080089	1	269	0.5	3827.97	0.279058	13.10	0.40	3
9/8/2016	SASOL	Kamumbuni	0.683	100.0%	1	0	0	250	1	1	3	0.56	1	5	15.5	0.8	1	0.9	0.000259174	0	774	0	4270	0.43	6.51	0.35	4
10/24/2016	SASOL	Kasina	0.682	25.0%	1	-0	1	70	1	1	1	0.12	0	6	28.1	0.6	1	0.5	3.497E-05	1		1	339	0.538	4.87	0.33	7
9/9/2016	SASOL	Mangya	0.675	100.0%	1	0.01	0	250	1	1	4	0.68	0.5	5	16.5	0.9	1	1	0.000203975	0.5	###	0	3767	0.44	6.46	0.64	3
9/7/2016	SASOL	Kyakuthu	0.675	44.4%	1	0		60	1	0.75	2	0.17	1	6	16.5	0.5	1	0.7	0.000795466	0.5	###	0.5	3529	0.49	7.22	0.64	2
8/18/2016	UDO	Ngomeni	0.646	0.0%	1	0.02	0	100	1	1	3	0.25	0	3	32.8	0.5	0.25	0.5	0.006829596	1	###	1	1524.2	0.519676	4.41	0.40	
9/13/2016	SASOL	Musalani	0.645	75.0%	1	-0	0.5	120	1	0.5	4	0.37	1	3	18.9	0.9	0.75	0.75	0.000176031	1	170	0.5	5931	0.4	5.71	0.64	3
8/26/2016	UDO	Matondoni	0.628	100.0%	1	-0	1	15	1	0.75	3	0.49	1	4	26.3	1	1	1	0.005463067	0	###	0.5	6271.542	0.355381	11.00	0.30	2
9/14/2016	SASOL	Kyangiti	0.623	100.0%	1	0.01	1	200	1	0.75	0	0.00	0.5	6	23.6	1	1	1	1.36499E-05	0.5	278	1	6730	0.39	5.65	0.64	
9/15/2016	SASOL	Kyalo	0.623	50.0%	1	0.01	1	200	1	0.5	0	0.00	0	6	20.7	0.7	1	1	0.000274006	1		1	825	0.525	6.31	0.65	3
8/19/2016	UDO	Walanio	0.619	75.0%	1	0	1	275	1	0.75	0	0.00	0	3	27.7	0.4	1	0.7	5.99495E-05	0	###	0.5	935.5062	0.62813	4.92	0.32	
9/19/2016	SASOL	Mutavi	0.616	75.0%	1	-0	0.5	200	1	0.5	2	0.39	0.5	5	30	0.7	1	0.7	0.000184868	1	534	0.5	2456	0.316	6.29	0.64	4
9/2/2016	UDO	Pioneer	0.616	80.0%	1	-0	0.5	300	1	0.5	0	0.00	1	4	37.7	0.35	0.5	1	0.000467033	0	###	0	3520.55	0.281573	5.87	0.61	4
9/30/2016	UDO	Wendo wa Ngc	0.611	58.3%	1	0	1	6	1	0.75	0	0.00	1	5	29.3	1	1	1	0.001204936	1	442	1	1524.357	0.536991	6.55	0.53	6
8/26/2016	UDO	Matondoni	0.609	100.0%	1	0.01	1	150	1	0.75	3	0.41	0	3	32.6	0.4	1	1	4.2153E-05	0	###	0	5551.441	0.351888	14.10	0.35	1
9/19/2016	SASOL	Ituloni	0.607	90.9%	1	0.01	1	200	1	0.75	1	0.03	0	5	16	0.4	0.75	0.5	0.000597023	0.5	653	0	3363	0.286	5.01	0.64	10
9/14/2016	SASOL	Kakunike	0.595	40.0%	1	-0	1	30	1	0.25	2	0.16	0.5	6	18.3	0.9	1	0.7	4.11945E-05	1	###	0.5	744	0.54	5.61	0.50	3
9/7/2016	SASOL	Kanduu	0.582	0.0%	1	-0		10	1	0.25	0	0.00	1	5	22.3	0.5	1	0.7	0.001065481	0	###	0.5	2854	0.52	4.61	0.64	1
9/28/2016	UDO	Mutangavuni	0.553	100.0%	1	-0	1	200	1	0.75	0	0.00	0	3	26.7	1	1	0.7	0.000715648	0.5	###	0.5	2309.679	0.510989	5.42	0.27	2
9/22/2016	SASOL	Kalimu Munyur	0.545	0.0%	1	-0	1	30	1	0.25	0	0.00	0	3	22.5	0.6	1	1	0.000391763	0.5	813	0	3723	0.419	6.41	0.64	3
9/6/2016	SASOL	Kavuti B	0.543	50.0%	1	-0	0.5	60	0.5	0.5	3	0.66	0.5	4	19.9	1	0.5	1	0.001657779	1	714	1	4938	0.41	6.03	0.64	4
9/20/2016	SASOL	Kakunike A	0.532	90.9%	1	0.01	0.5	50	1	0.5	1	0.09	1	5		0.8	0.5	0.5	0	0.5	###	1	3690	0.44	5.90	0.64	1
9/26/2016	UDO	Kisesi	0.53	41.7%	1	0.01	0.5	250	0.5	0	0	0.00	1	5	19.4	0.8	1	0.9	0.000546449	1		1	1378.909	0.440196	5.89	0.65	1
9/13/2016	SASOL	Kyambua	0.526	83.3%	1	0.02	0	150	1	0.5	0	0.00	1	6	20.2	0.8	1	0.5	4.82684E-05	0.5	163	0	9531	0.38	5.78	0.64	4
8/19/2016	UDO	Ukuno	0.525	71.4%	1	-0	1	100	1	0.75	0	0.00	0	1	21.8	0.4	1	0.7	0.000117836	0	432	0	979.0132	0.558645	4.11	0.27	3
8/17/2016	UDO	Watema	0.524		1	-0	0	200	0	0.25	0	0.00	1	3	31.1	0.3	0.5	1	0.001080283	0		1	6246.879	0.267516	8.06	0.30	3
9/6/2016	SASOL	Katumi	0.521	45.5%	1	-0	0.5	50	1	0.5	0	0.00	0.5	4	25.4	0.8	1	0.5	0.000179122	0.5	174	1	6240	0.4	5.62	0.64	2
10/4/2016	UDO	Mbodoni	0.517	100.0%	1	-0	1	20	1	0.5	2	0.36	0	5	24	1	1	1	0.000203732	0.5	384	1	2303.678	0.330875	10.10	0.20	3
8/22/2016	UDO	Kithito	0.485	100.0%	1	0.02	1	230	0.5	0.5	0	0.00	0	4	28.5		1	0.7	0.000326682	0	703	0.5	3749.949	0.285861	11.70	0.40	1
8/25/2016	UDO	Kwakika	0.474	100.0%	1	0.03	0	120	1	0.5	0	0.00	1	4	24.6	0.9	1	0.9	0.000180175	1	465	1	1130.942	0.475608	5.26	0.57	1
9/21/2016	SASOL	Milinga	0.468	0.0%	0	0	0.5	50	0	0.5	2	0.41	1	6	18	0.6	1	0.7	0.002765771	0.5	797	0.5	2871	0.527	6.64	0.64	
10/7/2016	UDO	UDO	0.454	16.7%	1	-0	1	50	0	0	0	0.00	1	5	24.1	1	1	0.7	0.000523945	0	593	1	4939.547	0.26699	13.50	0.42	2
10/24/2016	SASOL	Kalova	0.434	91.7%	1	0.02	0.5		0.5	0	0	0.00	0	6	22.2	0.9	0.75	0.9	0.000112706	1	###	1	1081	0.528	4.83	0.33	
8/22/2016	UDO	Kithito	0.422	100.0%	1	0.03	1	230	0	0.5	0	0.00	0	4	25		1	0.9	0.000759035	0	634	0.5	3807.052	0.282815	13.30	0.40	2
10/24/2016	SASOL	Kitooni	0.418	0.0%	0	0.01	0.5	70	0.5	0	0	0.00	1	6	24.1	0.35	1	0.5	9.70851E-06	1	###	1	423	0.59	5.66	0.67	1
8/30/2016	UDO	Wikwayo	0.406	83.3%	1	-0		40	0	0.25	3	0.35	1	5	24.4	0.75	1	0.5	0.001887309	0	443	1	3290.027	0.321633	6.90	0.30	5
9/28/2016	UDO	Miamba	0.401	25.0%	1		0	100	0	0	1	0.06	1	5	32.9	0.5		0.7	0.000328653	1	910	0.5	1674.529	0.507068	5.50	0.27	1
8/31/2016	UDO	Kithito	0.397	100.0%	1	-0	0.5	90	0	0.75	1	0.03	0.5	5	32.7	0.75	1	0.7	0.000474854	0	478	0.5	3285.894	0.258373	14.10	0.42	6
9/15/2016	SASOL	Mbaluka	0.391	0.0%	0	-0	0.5	5	0.5	0	2	0.10	0.5	6	21.2	0.5	1	0.7	0.000109304	1	843	1	1038	0.42	5.58	0.65	1
9/2/2016	UDO	Mbondoni	0.387	100.0%	1	-0	0.5	200	0	0.25	1	0.60	0.5	3	27.8	0.2	0.25	1	0.001138851	0	402	1	1669.767	0.224465	6.40	0.64	8
9/20/2016	SASOL	Metika	0.387	58.3%	0	-0	1	250	0	0	1	0.44	0.5	4	23.2	0.85	1	0.9	0.000190593	1	372	0	6429	0.394	6.02	0.64	5
10/7/2016	UDO	UDO	0.383	83.3%	1	0.02	1	20	0	0.25	2	0.47	0	4	29.1	0.9	1	1	0.000425885	0.5	972	1	4797.597	0.272717	15.40	0.41	9
10/27/2016	SASOL	Nugulini	0.379	100.0%	1	-0			0	0	0	0.00	1	4	13	1	1	1	2.19242E-05	0.5	65	1	548	0.6	22.00	0.70	9
9/29/2016	UDO	Kalovoto	0.377	50.0%	1	-0	0.5	80	0	0	0	0.00	1	5	27.1	0.8	1	1	0.006612658	1		1	1635.676	0.534617	6.29	0.19	5
10/10/2016	UDO	Matika	0.368	0.0%	0	-0	1	200	0	0	0	0.00	0	4	24.3	0.5	1	1	0.002074029	1		1	4999.882	0.375006	10.30	0.30	1
9/26/2016	UDO	Kisesini	0.368	16.7%	1	-0	0	70	0	0	0	0.00	1	5	25	0.6	1	0.5	0.00022897	1		1	956.7516	0.416278	5.58	0.64	1
8/29/2016	UDO	Kithuluni	0.361	100.0%	1	-0		120	0	0	3	0.28	1	3	42.2	0.3	1	1	0.001903179	0	452	0.5	3292.958	0.280694	8.80	0.42	1
10/5/2016	UDO	Yikiuku	0.356	0.0%	0	0.03	0	200	0	0	0	0.00	1	5	26.4	1	1	1	0.000532635	1		1	882.1825	0.445679	4.95	0.27	3
9/21/2016	SASOL	Ngelesani	0.355	75.0%	1	0.01	0.5	50	0.5	0	0	0.00	0.5	4	22.5	1	1	0.5	9.97872E-05	1	699	1	2001	0.59	7.05	0.68	1
10/26/2016	SASOL	Ngali	0.339		0	-0		30	0	0	0	0.00	1	4	28.5	0.25	1	1	0.001180012	0.5	18	1	69	0.63	6.62	0.57	
10/14/2016	SASOL	Mukumbu	0.334	37.5%	1		0	10	0.5	0	0	0.00	0	6	20.7	0.9	1	0.5	6.75768E-05	1		1	840	0.421	5.42	0.64	4
9/27/2016	UDO	Munandani	0.324	0.0%	0	0.02		30	0	0	2	0.21	0.5	5	35.5	0.9	1	0.7	9.6587E-05	1		0.5	1501.364	0.514714	5.78	0.43	3
8/29/2016	UDO	Manzaa	0.324	100.0%	1	0		120	0	0.5	0	0.00	0.5	3	44.4	0.5	1	0.7	0.000694439	0	259	0.5	3232.53	0.259065	13.80	0.42	1
10/18/2016	SASOL	Ngui	0.316	27.3%	1	0.04	0	10	0.5	0	0	0.00	0	3	28.8	0.9	1	0.5	0.000228386	1		1	953	0.451	6.95	0.65	4
10/18/2016	SASOL	Wathe	0.313	0.0%	0	-0	0.5	15	0.5	0	0	0.00	0	5	23.6	0.75	1	0.9	7.26806E-05	1		1	1049	0.528	4.43	0.66	0
10/14/2016	SASOL	Kivuva	0.307	0.0%	0	-0	0.5	20	0.5	0	0	0.00	0	4	13.3	0.4	1	0.9	0.001187328	1		1	914	0.415	5.26	0.65	5
11/3/2016	SASOL	Kithayuni	0.307	100.0%	1	-0	1	24		0	0	0.00	0	5	20.8	1	1	0.7	0.000180899	1		0	742	0.505	5.58	0.66	1
8/18/2016	UDO	Miamba	0.304	75.0%	1	-0	0.5	60	0	0	0	0.00	1	2	24.4	0.4	1	0.9	0.001097585	1		0.5	2084.073	0.506569	5.20	0.27	5
9/1/2016	UDO	Ngatho	0.302	100.0%	1	-0	1	50	0	0	0	0.00	0.5	4	30.2	1	1	0.7	0.000117811	0	338	0.5	3643.339	0.286907	11.80	0.40	2
10/25/2016	SASOL	Kithongo	0.301	0.0%	0	0.04		0	0.5	0	0	0.00	0	5	27.4	0.2	1	0.9	0.000164805	1	###	1	475	0.651	5.58	0.66	4
10/14/2016	SASOL	Kinyali	0.299	66.7%	1	0.01		10	0.5	0	0	0.00	0	4	22.7	1	1	1	0.000326796	1		1	914	0.415	5.25	0.65	3
10/5/2016	UDO	Nguumo	0.297	16.7%	1	-0		10	0	0	0	0.00	0	5	25	1	1	0.5	0.01418976	1		1	1566.159	0.418353	5.50	0.64	2
9/29/2016	UDO	Kyeni	0.293		0	0.01	0.5	15	0	0	0	0.00	0	5	28.2		0.5	0.9	0.000132661	1		1	2145.889	0.515387	4.99	0.34	7
10/3/2016	UDO	Kwa tuta	0.288	77.8%	1	-0	1	10	0	0	0	0.00	0	5	33.5	1	1	1	6.29289E-05	1			5056.917	0.323231	19.00	0.41	7
9/27/2016	UDO	Munandani	0.285	50.0%	1	0.01	0.5	12	0	0	0	0.00	0	5	19.9	0.8	1	0.5	5.771E-05	1		1	1505.998	0.517486	5.82	0.43	3
9/15/2016	SASOL	Katitiva	0.283	0.0%	0	0.02		2	0.5	0	0	0.00	0	4	24.6	0.8	1	0.7	9.07149E-05	1		1	917	0.441	5.29	0.65	5
9/30/2016	UDO	Kalovoto	0.275	50.0%	1	-0	0.5	15	0	0	0	0.00	0	5	24.2	1	1	0.9	0.000557887	1		0	1422.749	0.532897	6.96	0.19	5
9/15/2016	SASOL	Matheka	0.275	0.0%	0	0	0	30	0.5	0	0	0.00	0	5	22.8	0.7	1	0.5	0.000144603	1		1	98	0.752	6.26	0.65	6
11/3/2016	SASOL	Kilikuni	0.259	0.0%	0	-0	0	150	0	0	0	0.00	0	5		1	1	0.5	0	1		1			6.20	0.62	4
8/31/2016	UDO	Kithito	0.258	100.0%	1	-0	0.5	85	0	0	0	0.00	0.5	3	45.8	0.2	0.5	0.5	0.000272895	0	535	0.5	3251.902	0.258373	14.10	0.42	6
8/25/2016	UDO	Munathi	0.247	0.0%	0	-0	0.5	0	0	0	0	0.00	0.5	3	14.3	0.4	1	0.9	0.002346208	1		0.5	723.8294	0.622149	4.19	0.27	
9/22/2016	SASOL	Kalikuvu	0.24	83.3%	1	-0	0	150	0	0	0	0.00	0	4	17.1	0.65	1	0.5	0.000118856	1		0	2992	0.439	5.82	0.64	
10/10/2016	UDO	Matika	0.236	75.0%	1	-0	0.5	30	0	0	0	0.00	0	3	18.8	1	1	0.9	0.001651039	1		1	5328.759	0.387855	8.50	0.30	3
10/18/2016	SASOL	Mutinda	0.229	0.0%	0	-0	0	5	0.5	0	0	0.00	0	2	32.5	0.9	1	1	0.000167672	1		1	927	0.447	4.73	0.65	2
10/14/2016	SASOL	Malimbani	0.227	75.0%	1	0.02	0	10	0	0	1	0.07	0	5	25.5	1	1	1	0.000464488	1		1	652	0.414	5.59	0.65	3
10/25/2016	SASOL	Maviani	0.225	11.1%	0	-0		20	0	0	0	0.00	0.5	4	31	1	1	0.7	3.28911E-05	1		1	414	0.562	5.66	0.61	0
10/4/2016	UDO	Matika	0.209	100.0%	1	0.03	0.5	20	0	0	0	0.00	0	3	18.9	1	1	1	0.003643389	1			4843.333	0.382488	13.80	0.38	1
8/25/2016	UDO	Munathi	0.201	0.0%	0	-0			0	0	0	0.00		0	18.5	0.4	1	0.9	0.004901104	1			744.305	0.614107	5.32	0.27	1
9/26/2016	UDO	Wendo	0.193	83.3%	1	0	0	14	0	0	0	0.00	0	5	19.3	0.4	1	0.7	0.000217096	1		1	1339.969	0.439126	4.93	0.66	1
9/19/2016	SASOL	Musivi	0																								
9/20/2016	SASOL	Mutua	0																								
9/21/2016	SASOL	Kyanguni	0																								
10/27/2016	SASOL	Nzaa	0																								
9/29/2016	UDO	Ngatho	0																								

Conclusions: Dams rated as more functional (presence and/or usage of water) did not show a strong overall correlation with physical factors (siltation, watershed slope, etc).

4.2. Statistical correlation of physical parameters with dam functionality

Multivariate analysis (multiple regression) was carried out to determine which of the measured physical factors[19] correlated best with the functionality index (Table 9). A total of 89 dams had all data for these parameters (Excel cannot handle missing data for multiple regression). The overall regression was statistically significant at a p value of 0.002, and the variables included explain about ¼ of the observed variance in dam functionality (r^2=0.253).

Table 9 Potential drivers of dam functionality.

Parameter	***P-value***	***Units***	***Coefficients***
Degree of sedimentation, calculated reduction in water volume using low estimate	0.079	Percent	-0.0056
Observed degree of sand/sediment filling	0.261	0 to 1; empty to full	-0.1303
Erosion	0.725	0 to 1; max to min erosion	0.0358
Leakage evidence	0.001	0 to 1; max to min leakage	-0.1763
Population nearby	0.069	population within 2km radius of dam	2.27E-05
Poverty levels	0.288	fraction of population within 2km below poverty level	0.2509
Slope suitability	0.695	median percent slope	0.0024
Soil suitability	0.425	percent silt and clay	0.1010

These can be considered on two levels: 1) factors external to the dam which predict the functionality of the dam prior to its being built, such as watershed slope, and 2) factors about the dam itself once it is in existence, such as degree of erosion at the dam.

4.2.1. Factors external to the dam

4.2.1.1. Adjacent population

For the items analyzed, adjacent population correlated weakly with dam functionality (Fig. 18). Selection of areas with larger populations logically would increase the pool of beneficiaries. As noted earlier, these denser areas were not those areas with the higher living standards, so it is possible to choose areas with more people while still targeting the needier populations.

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[19] Eight parameters were included: measured degree of sedimentation (as percent decrease in potential water held in dam), observed degree of sediment filling, erosion, leakage evidence, population, poverty level, slope, and soil suitability. Observed degree of sedimentation (visual rating of sand, silt, clay) was not included as it is not an independent parameter from the measured sedimentation (rather, it is another way of estimating the same parameter), and water salinity was not included as it was only measured in dams containing water.

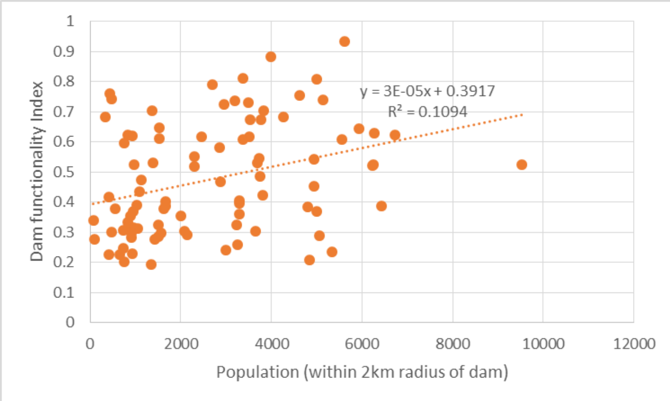


Figure 17. Correlation of adjacent population with dam functionality.

4.2.1.2. Soil texture from soil maps

Since the degree of siltation correlated weakly with dam functionality, we looked for whether siltation rates can be predicted. Soil maps allow one to analyze relative amounts of clay, silt and sand in potential dam watersheds. Thus, one might be able to avoid higher amounts of siltation by looking for sites for which the watersheds have relatively less silt and clay. In the multiple regression analysis, soil suitability (as % silt/clay based on soil maps) was not correlated with the dam functionality index (Table 9). Measured siltation at dams did not increase in areas with higher silt/clay (Fig. 19).[20] Particles which accumulate in the dam are unlikely to come from the entire watershed, and thus the considerable variation is not surprising.

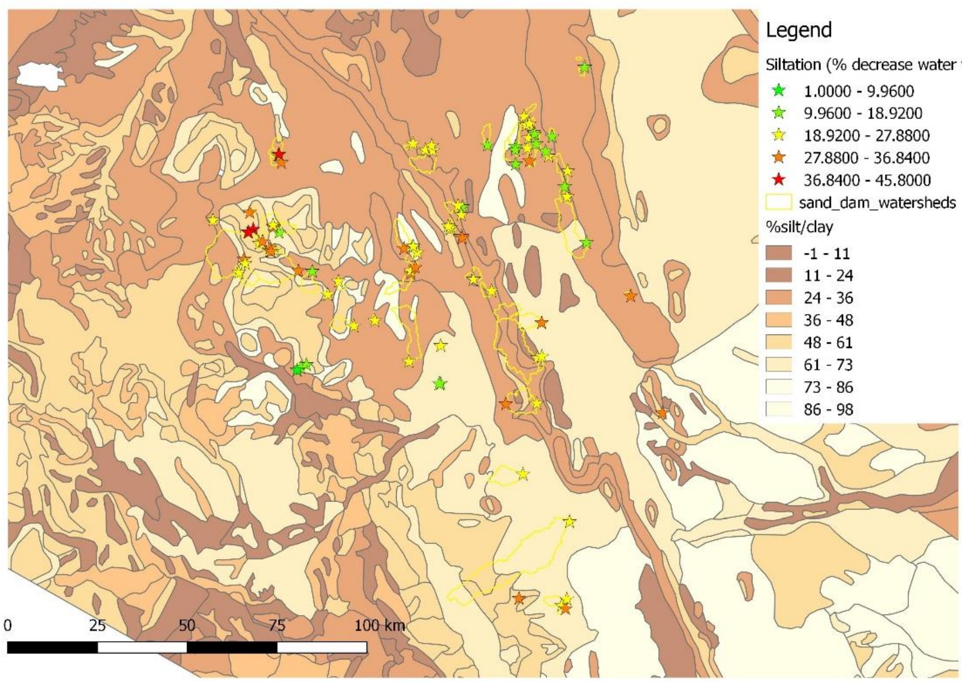


Fig 19. Distribution of sand dams showing their degree of siltation (color of stars) relative to percent of sand in soil (from soil survey maps)

4.2.1.3. Slope.

[20] There was a statistically significant decrease in siltation with increased silt/clay based on the soil maps – an opposite result of what would be expected. However, the regression coefficient is low suggesting that any actual correlation has little impact on silt at the dam. See addendum for data.

Slope was not correlated with overall dam functionality (Table 9). In a separate correlation analysis, slope did predict siltation at the dam (p=0.03; see addendum) (Fig. 20). This is consistent with the study of Viducich (Viducich 2015) that found watershed slope is predictive of siltation. Restricting the analysis to an area within a closer distance of the dam may be more predictive, and further analysis might be more helpful in finding a way to further predict the potential level of siltation.

These results suggest that reported soil texture in the region, at least at the resolution of the map that was used, is not useful in predicting good dam sites map. Elevation models (for slope) at the level of the whole watershed can give some guidance on potential dam sites with respect to future siltation of dams, although this was still a relatively weak predictor of siltation.

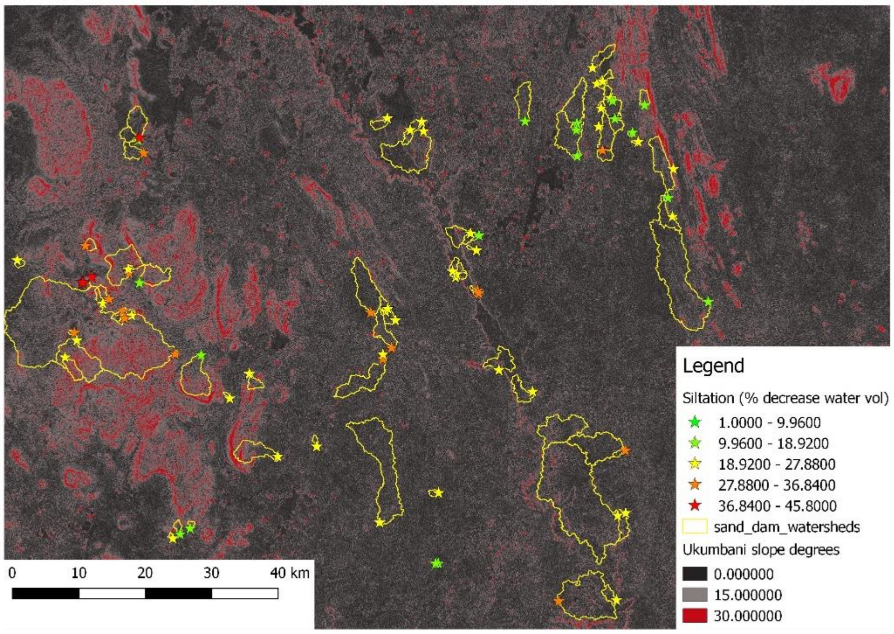


Fig 20. Location of sand dams relative to slope of land.

4.2.2. Factors after dam construction

4.2.2.1. Structural integrity and dam filling.

Neither the presence of erosion at the base or ends of the dam (which was common), nor underfilling of dams (which was not common) was correlated with dam functionality (Table 9). These factors did not seem to be significant drivers of which dams in the region were more or less successful.

There was a strong correlation between evidence of possible leakage and dam functionality, with increased evidence of leakage in the more functional dams. Since leakage was mostly evident as the presence of pools of water below the dam, this parameter actually is an indicator of both a negative attribute (leakage of water), and a positive attribute (presence of water, in the dam and/or the water table). It is not surprising, therefore, that increased presence of water below the dams is found at dams that are more functional. In many cases, these pools were obviously well used by the community, in fact often more people were present below the dam than on the dam itself. The pools are easier to access than scoop holes, and thus used for a variety of purposes.

In addition, we emphasize that “leakage” here refers to movement of water out of the storage component (whether the dam itself or the adjacent water table), and would not necessarily indicate a failure of the dam structure (such as a crack). Depending on the situation, water could move out of the sand, into the water table, and then into the riverbed downstream of the dam, circumventing the dam entirely. (Hoogmoed 2007) Indicators of actual structural compromise of the dam were not adequately recorded, and could not be assessed in this study. In addition, not all communities view leakage as bad. For instance, the dam at Kamumbani shows obvious leakage (a stream of water from under an eroded side), but the dam is left unrepaired as downstream users strongly object to losing water sources below the dam that are the result of this leakage (Fig. 21).

Fig. 21. Sand dam showing large degree of pooling below dam, seen actively flowing from a large hole in the dam (right panel).

4.2.2.2. Siltation.

Our measurements of sediments showed that siltation generally does not severely decrease the water volume held by dams (section 1.1.2). There was a weak correlate of the degree of siltation with the calculated functionality index (Table 9). This suggests that siltation has some impact on the success of a dam, but that it is not the primary determinant, and thus is one of a variety of factors that has a smaller impact.

4.2.2.3. Social components.

Numerous social factors might drive whether or not dams are functioning well. We did not have detailed data on most potential social factors. The only factors for which we have data related to dam functionality are estimations of management: there was no significant difference in functionality between dams that reported active management (functionality 0.51 ± 0.21; N=22) and those that had no active management (0.47 ± 0.17; N=57). As dams were mostly functioning well in their physical aspects (for instance, water was largely present), we suspect that social factors are more important drivers of successful dams. The nature of such social factors cannot be established by this evaluation.

Conclusions: No factors analyzed in this evaluation were singly responsible for a large proportion of a dam's success. Dams which are most successful probably have 1) a combination of individual factors (such as reduced siltation, high nearby population) that each contribute a small but important amount to the dam success and 2) a psychosocial context that encourages dam usage, such as strong motivation and planning on the group or individual level.

Discussion

As a technology, sand dams are designed to hold water where water in a location would otherwise not be held for a long period. As an activity, sand dams rely on the organization of a group of motivated residents, and/or on individuals with access, resources and initiative. *As a technology, the dams largely succeed.* Although there has been concern about siltation as a critical limitation of sand dams in general, evidence from this study suggests that siltation is not the primary barrier to the success of most sand dams.[21] Water was present in the majority of dams visited. Structural issues (e.g. erosion) were observed, but did not appear to be the primary impediments to using the dams. *As an activity, sand dams vary considerably in their success.* Signs of robust usage of water, either as direct evidence of harvesting or as indirect evidence in the utilization for a diversity of activities was less obvious than its presence. The case study below illustrates this main conclusion.

These results underline and confirm many of the points elaborated by other published studies and unpublished evaluations, while also extending understanding of sand dams in several critical ways. For instance, the most recent evaluation in the region ((Woodring 2014)) concluded that dam siting is important, that sand dams are not always coordinated with other water projects in the region, and that water is sometimes unusable because of high salt – results of our study are consistent with those conclusions. Consistent with other studies, we found general enthusiasm for the dams and a good understanding of the broad range of benefits associated with sand dams.

This built on previous studies in a number of ways:

1. The study was designed with a higher sample size (97) to give results representative of the general population of sand dams in the region. Dam selection was based on a random selection design in order to avoid any unconscious bias at choosing dams that were particularly successful, or particularly unsuccessful. We believe this gives a higher degree of confidence that parameters that were measured are representative of sand dams in the region.

2. The study design was particularly useful in defining some of the physical characteristics such as the degree of siltation, and the presence of water (or water harvesting evidence). Concerns that siltation is a fundamental flaw in sand dam construction (at least when built in stages) are not supported by our results. However, there were two ways in which the physical functioning of dams may be limiting. First, the calculated volume of water may not be large enough for the reported number of beneficiaries, over a longer dry period. This estimate critically depends on the volume of adjacent groundwater which supplements water held in the dam itself. Second, satellite data did not show general greening around most sand dams, suggesting that claims of general ecological benefits such as greening in the vicinity of dams may be overstated. Attention to continued improvement on sand dam siting or construction is therefore warranted, but not the primary consideration in improving sand dam usage.

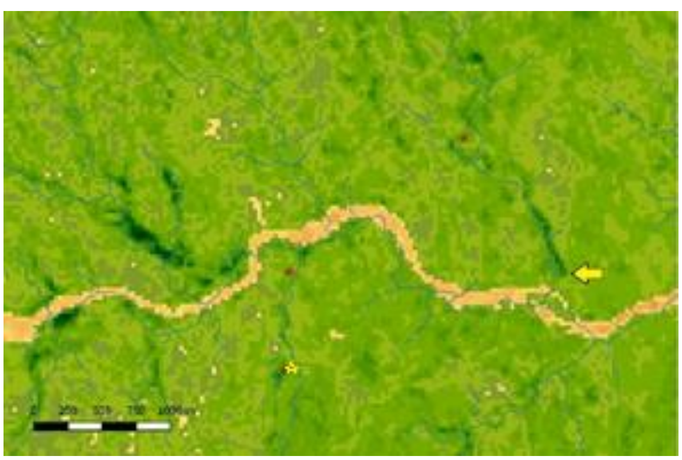
[21] http://www.samsamwater.com/library/Sand_dams_or_silt_traps.pdf

Case Study : Munandani, Makueni

Two dams were built at Munandani, in Makueni County, on tributaries of the Thwake River. Dam #622 was built in 2010 at the request of a group, which rapidly made good use of the water for a variety of activities such as a thriving tree nursery. When visited on August 27, 2016 (late in the dry season), this was no longer the case. The group had ceased collaborative activities at the dam, and there was no evidence of water harvesting, or of activities adjacent to the dam that were supported by water from the sand dam.


Dam #622, Munandani; surface has sand, but no evidence of usage late in the dry season.

Why did use of the dam stop after a promising start? The structure was intact, albeit with notable erosion on the edges of the structure. The dam area was filled with medium and coarse sand – there was no indication that siltation was a problem. Water was found in half of cores from the dam, at depths of less than ½ meter. Satellite images show greening of vegetation along the waterway during the previous Jan-Feb dry season, albeit less than other nearby locations with sand dams. Thus in general, the dam itself seemed functional, and it seems likely that even in late dry season of Aug 27, 2016, that there would have been harvestable water deep in the sand.




Satellite analysis showing greening along waterways, especially at several dams. Dam #622 is located at the yellow star, lower center. Other dams are at red stars and yellow arrow. Thwake River runs through the center, at right scoop hole shows abundant water shallow in the sand.

These dams are located within easy walking distance of the Thwake River, which had abundant and easily accessible water. Interviewees report that only 12 households currently use the sand dam, as most residents in the region prefer to go to the Thwake River. The group still actively cooperates on activities, such as with table banking and building terraces. Interviewees easily list a wide range of benefits from using the dam. They have stopped, however, in collaborating on using the sand dam.

3. The study relied on observational data in an attempt to "groundtruth" questionnaire data. Questionnaire data is important, but susceptible to unconscious or conscious biases by either respondents or interviewers. In fact, observational data (for example, recording water harvesting activities observed) gave a different picture of the extent of sand dam usage than the self-reported responses. Although questions remain about the full degree of sand dam usage, these results do suggest relying on self-reported data from users (in this study, or other studies) could result in an overestimation of how much sand dams are actually used. Self-report data may be most helpful in evaluating user knowledge of how sand dams can be used, or to evaluate how communities aspire to use sand dams.

So are sand dams fundamentally working to provide water in the region, and are they worth continued promotion? This study points toward sand dams as good solutions when focusing on water challenges, if they are carefully sited and constructed, and utilized to their potential. Water continues to be a major concern and determinant of the well-being of communities and individuals, and solutions are needed for water limitations in the region. As a solution to this, sand dams are estimated to have the lowest lifecycle cost of water provision methods (Batchelor, Fonseca et al. 2011). However, it is critical that sand dams are viewed in the local context (see below), and that they are not seen as "silver bullets" – they have not definitively solved livelihood challenges of communities they serve. Perhaps sand dams are a component of "silver buckshot" – one needed component out of many that together can make an impact on livelihoods.

Recommendations:

- Continue to optimize sand dam design and siting.

Although it would be naïve to assume that performance can be exactly predicted, using the most robust method possible to screen potential sand dam sites and groups could help ensure that locations are appropriate for sand dams, both from a biophysical and a social perspective. A model for this might be A.P.A. Insurance Company's current insistence on careful screening for dams they fund at UDO. A.P.A. dams were not on our list of randomly selected dams, however anecdotally these dams seem to more consistently show success. Consideration of factors such as the density of the nearby population, the land slope of the watershed, and the presence of other water sources help to predict dam function and would help to refine siting decisions. The results of this study suggest that social factors are particularly critical to the success of sand dams. Although not quantitatively assessed, experience from evaluation suggests that dams have the best chance of success when groups have a good history of working together to achieve common goals, and individuals with initiative are respected by the community and thus can inspire the community (see below for additional comments on psychosocial factors).

Recent concerns about the possibility of extensive and debilitating siltation in sand dams have prompted calls to build dams with a staged approach to raising the height of dams. The theory behind this recommendation is solid, and it is possible that siltation is reduced by staging construction. Definitive evidence for this could be shown by rigorous comparison of dams constructed in stages with those built at a single time – to date such a comparison has not been done. Although issues of siltation should be considered, the results of this study suggest that any siltation has not fundamentally compromised those dams built thus far (which were not built in stages). Since groups and partner organizations prefer the ease of building dams at a single time, we question whether it is advisable to push groups to do something which might be an additional barrier to successfully completing a dam.

- Emphasize ongoing work with communities utilizing sand dams. Link sand dam projects more closely with promoting associated activities.

Sand dam communities, and indeed sand dams themselves, are dynamic entities. We found examples, for instance, of dams which had turned into subsurface dams, or had filled with sand and then had the sand washed away (and then refilled, in some cases). There were examples of groups which had previously had a wide range of activities associated with sand dams, but had subsequently stopped those activities and made little sustained use of the dam. In other cases, groups were adjusting to changes in the dams (e.g. fixing erosion), or to the local cultural context (changing population or local markets). These observations, and the conclusion that the physical functioning of sand dams is generally not the primary barrier to optimal use, suggests that external engagement with sand dam communities after construction could boost the utilization of existing sand dams.

Although the study did not rigorously survey how best to encourage sand dam use, general observations point toward a number of possibilities. First, there should be continued emphasis on a **strong promotion of activities associated with dams**. Both UDO and SASOL have worked with communities in the past on integrating activities (e.g. agricultural production) with sand dams. As an example, there is opportunity for integrating water harvesting into the current emphasis on promoting sustainable agricultural methods (such as conservation agriculture).[22] Increasing water harvesting for the purpose of agriculture has been identified as a key means to increase resilience during drought conditions, and particularly in the face of climate change. Reviews of water management in drylands (Molden, Oweis et al. 2010, Rockström, Karlberg et al. 2010, Bouma, Hegde et al. 2016), for instance, make a case that water management through such harvesting techniques is critical for increasing resilience, particularly in the face of continued climate changes.

A local model for close integration of sand dam construction with associated activities is in the current CEFA project with SASOL which promotes sustainable livelihood diversification. A number of activities (including WaSH, income generation, agricultural production, etc) are promoted as a holistic package of activities occurring at new sand dam sites[23]. Integrating sand dams with agricultural activities would also address a fundamental structural barrier often present at the government level, where water ministries tend to focus on water for domestic consumption or industry, while agricultural ministries focus on dryland agricultural issues like soil fertility (Rockström, Karlberg et al. 2010).

Second, **more attention to management plans** could improve usage. A sand dam is an intermediate-scale water provision stategy – they avoid the complexity and investment of large scale water projects, but requiring local management at the catchment level (Rockström, Karlberg et al. 2010). Sand dam groups did not appear to have detailed mechanisms for attending to management of dams. While a somewhat laissez faire attitude towards dam use was working to a point, a more intentional effort at articulating community plans for sand dam use could catalyze groups to be more visionary in their plans.

Third, **a fuller understanding of the social context of sand dams** would lead to better understanding of what strategies are most effective at promoting use. This point is considered in more detail below.

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[22] Rockstrom Rockström, J., et al. (2010). "Managing water in rainfed agriculture—The need for a paradigm shift." Agricultural Water Management **97**(4): 543-550.

makes an interesting point on the link between agricultural and water management practices - that those with good in situ water harvesting practices (i.e. level of the field, like terracing) also tend to be the best at ex situ practices (like sand dams).

[23] http://eeas.europa.eu/archives/delegations/kenya/documents/20151002.pdf

- Work to better understand the social context of sand dams, and the psychosocial barriers to use.

Of the four questions originally outlined at the start of the study, the question relating to social context ("what are the social dynamics of management and conflict at sand dams?") remains mostly unanswered. In general, the question of community management (and conflict) related to sand dams is in need of investigation, as there are fewer rigorous studies addressing these questions[24]. The successful use of sand dams involves not just the provision of material resource, but involves behavioral adjustment to the new context. Motivation and organization, either on the group or individual level, appears to be a challenge to achieve large benefits from sand dams. Lessons from other sectors that rely on both effective technology and behavioral change (e.g. WaSH – water, sanitation and hygiene) points towards the critical importance of two social components: 1) the local context and traditions, and 2) the broader nature of decision-making processes in humans at the individual and group levels.

Using WaSH in the African context, there are good examples of the importance of these components. For instance, Akpabio and Takara (Akpabio and Takara 2014) argue that social norms and habits play a key role in how well WaSH behaviors are followed, and thus the success of efforts to improve health. In particular, traditional beliefs, myths, or taboos about excreta, cleanliness and beauty, or about water in the environment, have complex interplays that impact the end behavior of communities. The WaSH sector has also benefited from generalizable insights into human behavior (e.g. (Marshall and Kaminsky 2016)) – for instance, the importance of social status aspirational values (as opposed to health messaging) in motivating behavior change.

To take one example of the importance of understanding social context, it was not clear from the data itself whether promoting sand dam use on the group level, or the individual level, is most effective (or indeed whether they are mutually exclusive). Our observations are that sand dams are still viewed as primarily a group activity, and that they are viewed more as a public good rather than something more akin got a business investment. This is not surprising in the context of Kamba (and indeed Kenyan) traditional culture, where communal works are a normal aspect of life. There were good examples of active groups which were instrumental in making sand dams successful. In fact, this is the model successfully for both UDO and SASOL in the construction phase, when communities are asked to work together in constructing the dam. Maintaining group cohesion is not without effort, however, and external encouragement/assistance to sand dam groups could be instrumental in catalyzing greater usage of dams.

There are also examples were individuals are benefiting well from sand dams outside of a group context, and social forces are pushing local culture towards a less communal way of living (for instance, the tradition of households pooling labor in crop fields is diminishing). Conceivably, encouraging particularly motivated individuals could encourage benefits to entire communities – an adjacent land owner, for instance, might benefit personally from vegetable production while the community also benefits from increased availability of affordable vegetables. Such entrepreneurial endeavors have potential and should be encouraged but with care – the conflicts that were reported in our survey most often revolved around individuals that are perceived to monopolize access to sand dam resources. In fact the issue of disagreements and conflicts around sand dams is not well understood, and deserves more attention. A better understanding of what conflicts arise, and how they are resolved (or not) would help determine the best way to encourage optimal sand dam usage.

[24] The thesis by Cruikshank Cruickshank, A. (2010). These are our water pipes, Faculty of Environmental Studies in partial fulfillment of the requirements for the degree of Master in Environmental Studies, York University, Toronto.
is one good starting point for what is understood about social dynamics

- Explore new options for how to improve or use dams

Communities and organizations should be open to exploring new options for how sand dams are structured, and how users make the best use of them. We mention here several examples, not to advocate for these as good specific solutions, but as illustrations of possible solutions which address identified barriers (such as convenience).

As one example, there were several dams with pipes embedded in the dam face, which potentially provide easier access to water from deep within the sand (which may in fact be cleaner; see water quality study). Although there are identifiable challenges to this approach (water may not be palatable, a spigot to control flow would be subject to breakage, etc), experimenting with possible ways of using such pipes would be worth investigating. Similarly, pump wells are popular solutions which provide convenience and (somewhat) higher quality water. However, maintenance issues with pump wells are notoriously difficult to address (an estimated 30-40% of handpump wells throughout sub-saharan Africa are not functioning[25]). We likewise noted a high number of nonfunctional wells. For instance, of some 7 pump wells visited in one area of Kitui in May of 2017, only one was functional (wells were built around 2009). The pumps had been vandalized for scrap metal, washed away by floods, or suffered mechanical failure. Given their advantages, pump wells probably do represent good value addition, if these issues with maintenance can be successfully addressed. More sustainable arrangements for using pump wells at dams is therefore worth exploration. Finally, there is some evidence that dam volume could be limiting (see section 1.1.1), and increasing volumes at existing by increasing the height of dams might help (indeed, in an extensive groundwater modeling study, (Hoogmoed 2007) suggested raising dam height would have the greatest impact on improving sand dam function). This is especially important to consider in the context of changes of local climate, where the amounts or distribution of rainfall are changing unpredictably.

- Attend to issues of water, sanitation and hygiene could improve the impact of sand dams

In a separate report, we outline findings related to water quality and possible impacts on health. In short, although water from sand dams is often assumed to be clean, bacteria levels were high enough to present a possible health risk. Specific recommendations are outlined in that report.

Limitations

Sample Selection

We chose a random selection design for assessing the dams. However, random selection was not entirely possible due to a lack of records. Locations for the majority of dams are not, to our knowledge, recorded. We also restricted dam selection to those recorded by two organizations – SASOL and UDO – aside from the 8 colonial dams. Results are therefore bias towards the designs used by these organizations in the last two decades. Dams constructed earlier, or by other organizations (e.g. newer dams from African Sand Dams Foundation, UDO and ASDF were originally a combined organization) likely have some different characteristics. These results therefore represent a "closest approximation" of sand dams in general.

Particle size, siltation and water volume

Getting deep cores for sediment samples on dams was difficult and usually not possible with the equipment that we had. Thus, the core samples here are relatively shallow, which potentially limits its utility in describing the

[25] RWSN (2009) Handpump Data 2009. Selected Countries in Sub-Saharan Africa, RWSN, St Gallen, Switzerland

level of siltation in the entire dam. For instance, Trincheria et al (DE TRINCHERIA, NISSEN-PETERSEN et al.) suggest that when dams are not built in stages, silt will accumulate especially at lower levels because water pools behind the higher dam structure, causing the silt settle. Viducich (Viducich 2015) did find the presence of a silt/clay layer ("bedset") in many of the dams he analyzed, although the degree to which this bedset affects water storage was not quantified.

We acknowledge that we have no data on whether lower layers of the dam sediments are different from those sampled, and that our calculations may therefore be an overestimation. However, there are several lines of evidence that suggest we can make general conclusions based on the top layers:

1) Deep scoop wells were present at many of the dams – to a depth of 4 or more meters in some cases. For our purposes, these essentially represent existing deep cores of the dam sediments. Although we did not collect quantitative data on these scoop holes, observations at these wells did not show obvious evidence of different sediment texture at the bottom.

2) The particle distribution in dams from this study appears similar to the 11 analyzed by Viducich (Viducich 2015), in which coring was about twice as deep as ours (1.5m). The overall particle distribution in the 11 dams of Viducich is similar to ours; for instance, in our study an average of 27% of particles in dams are fine sand or smaller, which is similar to what Viducich found (see figure 4.8 in Viducich's document). D_{50} for the dams in Viducich's study averaged 0.465 mm, which was close to the 0.440 mm found for our study. Although samples from Viducich's study did show some silt/clay bedset (from figures it appears that 18 out of 33 cores that went deeper than our average core depth had smaller particles at the bottom than at the top), it did vary considerably, with some cores having larger particles at the bottom. This suggests that while bedsets likely are present in our dams also, it did not have a large effect on our estimation.

3) Because of the geometry of area containing sand behind the impoundment, most of the sand held by dams is relatively shallow. Despite an average depth of the dam of 2.2 m vs sampling depth of 0.7 m, the geometry of the dam is such that our samples represent on average 60% of the volume of sediment in the dam – most of the sediment is nearer the surface in the area that was sampled.

4) The pattern of siltation – which dams are more silted than others – is unlikely to be affected by sampling depth. In other words, if it is more likely a layer of silt occurs in the bedset, it is also more likely the top layers have some silt in them. Thus, correlations of siltation with other parameters like slope are valid even if there is uncertainty about the absolute degree of siltation.

As mentioned earlier in this document, there are several other uncertainties in making estimations of water volumes. First, we could not estimate the water volume of adjacent groundwater. This is a more technically demanding measurement to make, and we hope others are able to better define this in the future. Second, average particle size distribution at a location does not accurately describe the behavior of water at the site. For instance, a small upper layer of hard silt could block water movement to the larger lower sand layers where water could be stored. Again, further rigorous study of these factors would be welcomed.

Vegetative Index

In principle, measuring the greening of vegetation should be a good way of objectively assessing effects of water available via its impact on vegetation. In practice, further analysis will be needed to choose the best scale and method in which to do this. The simple analysis done here is therefore a first estimation. We note that if greening occurs only narrowly close to the dam, this analysis may have been too broad to clearly see differences. Alternatively, if greening occurs much more broadly, our control sites may actually be reflecting greening due to the dams also. In addition, we relied on satellite images to choose control sites, in order to make sure the control sites did not have an adjacent dam. Dams are mostly visible on satellite images, although it is possible some smaller ones were missed, and that some control sites could actually represent adjacent dam sites. In retrospect, control sites should have been chosen while on the ground. None-the-less, it is unlikely that this represents a significant bias.

Dam usage – challenges with self-reported and observational data

Collecting accurate data for dam usage, and in general for social factors associated with dam usage, is methodologically challenging. We collected both self-report and observational data on dam usage. Self-report data can be notoriously subject to bias and must be interpreted with care. Observational data was taken in an attempt to reduce bias, and pointed to a lower level of activities at sand dams than indicated by self-reported data. However, this left open the question of whether activities are simply dispersed in time and thus hard to observe, or if the lower amount of observational data showing activities represented a relatively small quantity of activities (even if the breadth of activities was larger). Parameters such as the number of beneficiaries (the median of which was quite high, 80 households/dam) proved difficult to define and collect – probably that number represents the number of potential beneficiary households.

Cultural context

This study takes an unapologetically scientific approach, with a focus on attempting to get unbiased objective data. Thus it falls within the current trend towards evidence-based decision making, with a heavy focus on monitoring and evaluation. Although we maintain that there are critical strengths to this approach, we recognize there are weaknesses also. In particular, the study did not try to deeply assess the cultural context of sand dams. Arguably, without knowing how sand dams fit into traditional Kamba society, any evaluation is incomplete at best, and misleading at worst. It is critical to acknowledge this component is missing, and look forward to others articulating this better in the future. In the meantime, we're confident that the current scientific approach contributes to the overall understanding of sand dams, and can helpfully guide their future use.

And finally…some reflections on things not exactly addressed by the study, but related

Some concerns which have been raised regarding sand dams include 1) lack of good evidence that food security was impacted, 2) lack of sustainability (no spontaneous adoptions), 3) the relatively high price compared with other interventions, and 4) there are a high number of dams in the region. Although this study did not directly address these aspects of sand dams, conversations and observations did touch on these subjects, and personal reflections on those concerns are included here.

Do they increase food security? Probably. Although there are some good studies on general benefits (e.g. (Cruickshank 2010) (Pauw, Mutiso et al. 2008)), to our knowledge the impacts on common measures of food security (food consumption score, dietary diversity score, etc) have not been measured. There are indications in studies, though, that food security is impacted (for example, the UDO evaluation of 2014 does state "The evaluation revealed that there are positive food security outcomes due to the promotion of sand dams…") So while the evidence isn't definitive, the adage may apply here that "absence of evidence is not evidence of absence".

Finally, there were two unanticipated benefits of doing this evaluation. First, being based in Nairobi, it gave a depth of interaction with these organizations, and the region, which would not have otherwise happened. Spending many hours with staff from these organizations, and with community members at the sand dams, was invaluable as an MCC service worker. I presume they likewise valued that opportunity to interact at a deeper level. Second, we visited many communities that had not received visits from SASOL or UDO for some time. Many times their responses were "We've not seen you in a long time, where have you been?!" Communities clearly valued being visited, and it gives them encouragement to do better with their sand dams.

Will they be spontaneously adopted? Doubtful, at least on any substantial scale. One of the primary goals of development projects such as sand dams has the degree to which the projects are "sustainable" (unfortunately, a somewhat confusing term due to its multitude of uses and its often nebulous definition). In this case, sustainable refers to the ability of the activity to spread spontaneously through communities, in the absence of external assistance.

Although a few examples were found of individual land owners funding and building their own small sand dams, and of groups funding their own repairs, it seems unlikely that this is an activity that will ever be "sustainable" in the sense that communities find their own ways to build sand dams without outside financial assistance. The cost of sand dams is simply beyond the reach of most individuals.

However, one could question the assumption that ultimate goal of sand dams is to make them sustainable in this sense. Some social improvements might inherently require something more akin to public works. Although imperfect analogies, community improvements in road systems, or in public health efforts such as vaccinations, might be a more appropriate way to think about water provision. In fact, communities seemed to view sand dams more as a public good, rather than something more akin to a business investment. These types of projects are traditionally seen as more the purview of government obligations. In this respect, it is heartening to see interest by some local governments in Kenya in helping to make sand dams (although there are some mixed messages on this, and the strategy considered by governments is quite different in a manner that could affect the effectiveness of the efforts). In fact, while sand dams are heavily dependent on external funding at the construction stage, it is important to recognize that communities have invested as well (e.g. providing food and labor during construction). In this view, sand dams are in essence subsidized by external funds (albeit heavily), and are somewhat analogous to a situation such as bed net provision, where the full price is not paid by the user (a generally agreed upon approach to get good usage).

Are they expensive? Yes, compared to other development activities. No, when compared to other ways of harvesting water (at least when sand dams are well utilized). Material costs per dam run ~$8000, and with many communities having multiple dams, investment in dams therefore run around $30,000 per community (Woodring 2014). When viewed across their lifecycle rather than just up-front costs, sand dams are one of (if not the) cheapest ways to provide a volume of water (e.g. (Batchelor, Fonseca et al. 2011)).

Is the area saturated with dams? Probably not. Although it is difficult to even estimate how many dams are present, anecdotally there are still areas that are "unreached" by sand dams. For example, an MCC work and learn tour helped UDO with a dam in the Masii region of Machakos recently, which was the first sand dam in that area. There continues to be high demand for sand dams from communities. However, although there are probably areas that would benefit from new sand dams, that does not imply that new dams is the highest development priority, and there is no denying that there is a higher density of sand dams in Ukambani than in any other location, at least to our knowledge.

Methods

Selection of sand dams

In order to avoid biases, and in an attempt to get a representative sample of the population of sand dams in Ukambani, sites were selected on a random basis. Initial sand dam sites were selected from lists of dams that SASOL (505 dams) and UDO (448 dams) had constructed. Because records of sand dams constructed from earlier (early 1990) were not kept, selected sites mostly represented dams that were not older than 20 years. The entire lists were randomly ordered using Excel, and the first 40-50 dams from each of the UDO and SASOL lists were taken as the initial selections. Several alternations were needed on those randomized lists. In particular, there were 12 cases dams could not be located or records were otherwise inaccurate. If in the field with community members, this normally involved searching a number of sites for the correct dam, which was not found. In those cases, we selected the last site searched, as a substitute for the original dam sought. In other cases, there was no clear information on where to search for a dam; these sites were dropped and the next on the list (for example, starting at the fifty-first on the randomized list) was added to the selection. Due to time constraints, we visited 49 UDO dams, and 40 SASOL dams. In addition, eight colonial-era sand dams (1950's or early) were selected in Kitui. Eight colonial dams were selected, based on SASOL's familiarity knowledge of their presence, their historical work with communities adjacent to these dams, and as a broad representation of the location of these dams.

Randomly selected dams were analyzed together with colonial-era dams. Estimates of sand dams in Ukambani are as high as 5000, and the total of 98 sites visited would also be at the 10% confidence interval[26] for this total number of dams in the region, although the dams visited are not a truly representative sample from that entire population (since there are not records for the earlier dams constructed in the region, and therefore no means of making a list from which to sample them).

General site information
GPS coordinates were collected for each site, at the centerpoint of the sand dam structure, and at the drawback point. Interviewers recorded the reported locational information as subcounty, ward, sublocation and village. Since administration units and boundaries in Kenya have changed in the last decade, some reported names may reflect previous names rather than the current system.

Volume of Sand Dam
The volume held behind a sand dam was estimated using a simple geometric model based on field measurements of the actual dam structure (height and width), incremental widths of the area behind the dam, and the drawback (distance upstream from the dam having sand accumulation as a direct effect of the dam).

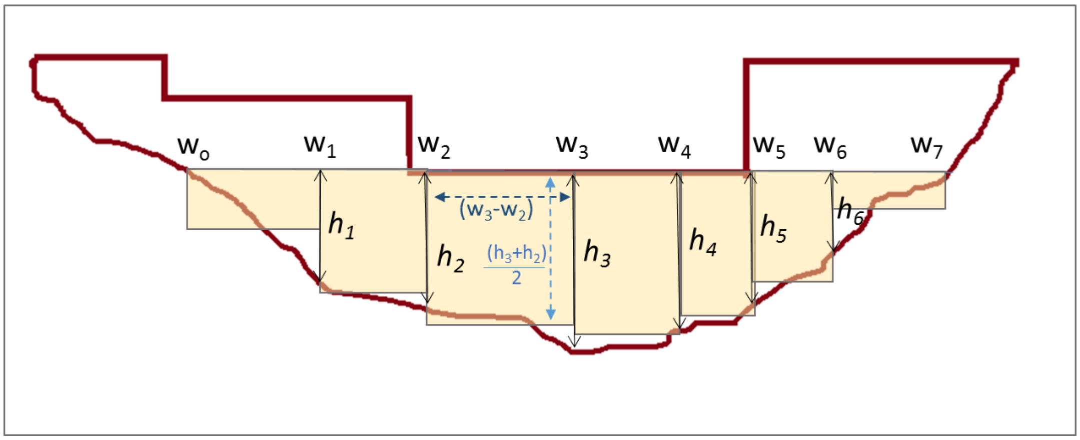
Dam structure: The actual concrete dam structure was assessed using a laser distance finder (Bosch GLM 80) and a conventional tape measure. Dams often have a notched spillway, and/or raised wings; all dimensions of these structures were collected. The depth of the dam structure was measured on the downstream side at approximately 5 meter intervals.

Width and length of accumulated sand: The width of the area accumulating sand behind the dam was measured starting immediately upstream from the dam structure, and then at intervals of 10 to 50 meters (depending on

[26] https://www.surveymonkey.com/mp/sample-size-calculator/

the drawback of the dam; shorter dams had closer measurement intervals). The lateral boundaries were judged as the transition from sand to soil, and/or a bench where the ground was obviously raised. The drawback was normally estimated as a constriction in the channel, often with the presence of rocks, that signaled a transition from flat sand or soil, to a more rocky or uneven channel that appeared to have been unaffected by substrate accumulation. In a minority of cases, the channel itself was even sand or other substrate, and a definitive drawback was more difficult to identify. Usually these were in dams with a long drawback (more than 400 meters, for instance), and we made a judgment on an approximate transition from the dam to the unaltered river bed.

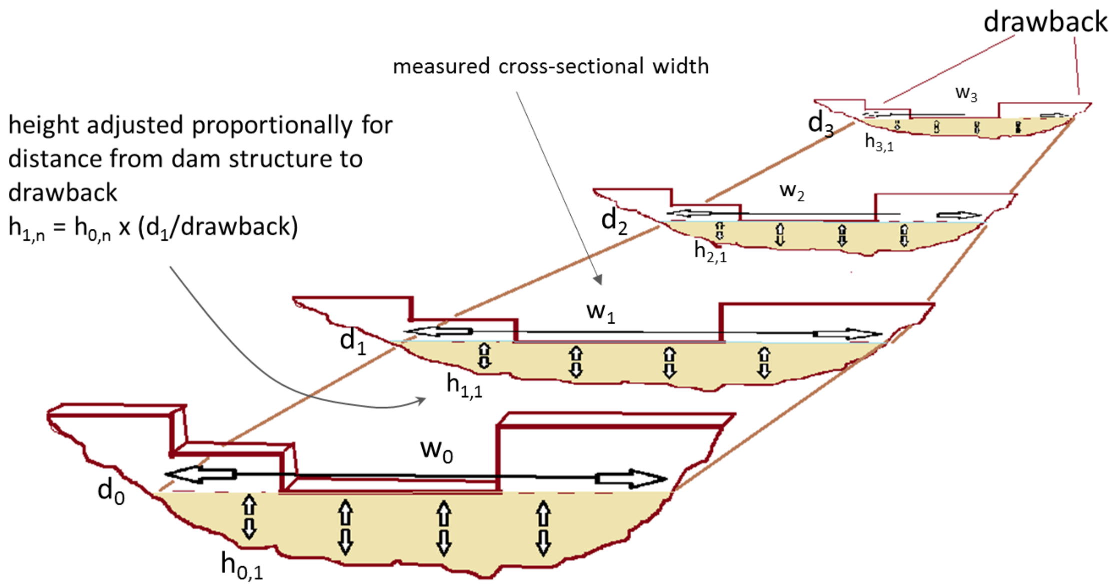
Calculation of volume: We used a geometrical model based on that used by Teel[27], in which a 2-dimensional shape is projected from the dam structure to the drawback. Rather than using a trapezoid, we used the 2-D shape outlined by the dam structure itself, taking the spillway level as the top surface (of the theoretically fully-filled dam), and the measured dam structure depths to define an irregular polygon. The surface area of this irregular polygon was estimated in a manner analogous to the midsection method commonly used in estimating cross-sectional area in streams.[28]



The polygon shape was taken as representing the geometry at the measured intervals back to the drawback. At each interval, the width of the polygon was adjusted to the measured width of the dam, and the height of the polygon was adjusted linearly based on the distance from the dam structure to the drawback (for example, the depth of the dam at half the distance from dam structure to drawback is assumed to be half the full depth at the dam structure).

[27] "Storage capacity, basic water chemistry and impact of sand dams in Kenya: the sand dams of Utooni Development Organization", unpublished document by Wayne Teel, James Madison University.

[28] https://www.msudenver.edu/media/content/earthandatmosphericsciences/documents/researchpapers/Accuracy%20of%20the%20Cross%20Section%20Method%20of%20Determining%20Stream%20Discharge%20with%20Variance%20in%20Current%20Meter%20Selection%20and%20Number%20of%20Vertical%20Sections.pdf



Sand Dam Cores/Particle Size

A soil corer with extender was used to sample the substrate in sand dams to a maximum of 1.5m. In most cases, it was not possible to get a sample to this depth, due to the hard nature of the substrate (such as compacted dry silted sand, coarse sand making it difficult to use corer, etc). In cases where substrate was very loose, or very crusted, a shovel was used to dig an initial hole. Substrate removed from the hole was mixed and then filled the corer to the depth of the hole, as a roughly representative sample.

Four cross-sectional sites were selected at the dams for substrate coring. The first site was approximately two meters upstream from the dam structure. The other three sites were roughly ¼, ½ and ¾ the distance from the dam structure to the drawback. At each cross-sectional site, three cores were taken, at roughly ¼, ½ and ¾ across the width of the dam at that site. Observations of particle class (sand, silt, clay) across the cored depths were made each cross-sectional site, and moisture depth noted. The three cores at each site were then pooled and stored in a plastic bag. Sample bags were transported to the labs at SASOL or UDO and held until analysis. Samples were thoroughly air-dried prior to analysis. Dried samples were separated in a set of 6 particle sieves (Ben Meadows; mesh for 0.063, 0.125, 0.250, 0.500, 2.0, 4.0 mm) by manual shaking for 10 minutes, and collected particles in the separate sieve trays were weighed to the nearest 0.1 g on a portable scale (Ohaus). All samples were then saved in the original sample bags. Because the initial weighing missed the clay fraction (<0.063 mm), samples were reanalyzed in the sieves to include this fraction, and were measured as broader size classes (0-0.063 mm, 0.063-0.250, 0.25-0.5 mm, and >0.5mm).

Estimation of Water Quantity

Sand dam volume and particle size distribution were combined to estimate the volume of water stored in the dam. The estimated volume containing available water was based on (Johnson 1967)[29] who report minimum and maximum estimates. The adjacent sediments and water table could, of course, represent a source or sink for sand dam water – as there is no easy way to estimate the effects of this compartment, we did not consider this in the estimates. We note, however, that the consensus is that there is recharge of the adjacent water table,

[29] https://pubs.usgs.gov/of/1963/0059/report.pdf

providing additional water storage and which can be considered an additional benefit of dams (Borst and De Haas 2006).

Specific yields of various materials
[Rounded to nearest whole percentage]

Material	Number of determinations	Specific yield		
		Maximum	Minimum	Average
Clay	15	5	0	2
Silt	16	19	3	8
Sandy clay	12	12	3	7
Fine sand	17	28	10	21
Medium sand	17	32	15	26
Coarse sand	17	35	20	27
Gravelly sand	15	35	20	25
Fine gravel	17	35	21	25
Medium gravel	14	26	13	23
Coarse gravel	14	26	12	22

Reproduced from Johnson, 1966

Substrate material class sizes are by international standard[30], which is close to those used by Johnson.

Class	Particle size (mm)
Fine Gravel	2.0-6.3
Coarse Sand	0.63-2.0
Medium Sand	0.2-0.63
Fine Sand	0.063-0.2
Silt & Sand	<0.063

Observational Data

Condition of Sand Dam Structure

The general condition of the sand dam structure was assessed subjectively. Any evidence of damage, leakage (*e.g.* staining, or pooling of water below dam), or erosion was noted. It some cases, photographs were taken to document specific problems with the sand dam structure.

Photographic evidence

A series of standard photographs were collected for each dam:

- View of entire dam site (from a vantage point up a bank from the dam)
- Face of dam (from downstream, facing upstream); for visual record of the general geometry of the dam structure, and the condition of the dam.
- Informational plaque (if present)
- Side view showing area immediately upstream of the dam (and including the dam); for visual record of extent of filling in dam, and general condition of the substrate.
- View looking upstream (towards drawback) from the center of the dam structure (take from standing position)
- View looking downstream from dam structure, showing the stream downstream

[30] http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=25260

- Proceed 1 dam length downstream, view of stream bed with banks facing downstream (view from center of stream, plus view of the banks)
- View of the estimated end point (drawback point) of the dam

Sand Dam Impacts

Observational data was collected on visual impacts of the sand dam. Land use on the banks was recorded at the locations where width of dams was measured (transects). Records of land use were categorized as bushland, unused cropland, presently used cropland (dryland crops - maize, beans, etc), vegetable fields (requiring irrigation – cabbage, etc), cultivated grass (e.g. napier grass), fruit trees (e.g. mango, papaya, etc.).

Any evidence of use of water use was recorded, such as scoop holes (used or unused), observed visits by community members, presence of water pumps or other equipment, livestock presence, etc. Relative quantities of manure was estimated by estimating the number of manure piles within 1 m along transects on the dam surface, and within a 5 m radius of water sources where bacteria tests were performed.

GIS Analysis

QGIS was used to collect the following data:

- Watershed area draining to location of sand dam (digital elevation model)
- Average slope in watershed (digital elevation model)
- Vegetative index, average calculated within 100m buffer of dam length (normalized difference vegetative index; NDVI calculated from opensource Landsat 8 images[31], resolution 30m, NDVI = (IR – R) / (IR + R) where IR is the infrared band (band 5) and R is the red band (band 4))
- Percent sand, silt, clay in soil of watershed (opensource soil data)
- Average rainfall in watershed for April and November (long and short rains), and July (dry season)
- Total population and average poverty rate within 2km of dam structure

Questionnaire

Two project staff were selected as interviewers, one for Kitui and one for Machakos/Makueni. Community members were normally identified and contacted in advance. In some cases, individuals to interview were identified once at the site. A single interview session was conducted at each of the 97 sites site, with the group size varying between a single individual and larger groups of around 10 individuals (the median number of people present was 3). The lead interviewees (primary contact for the group present, and the lead spokesperson in the interview) were female in 47% of interviews conducted; median age of the lead interviewee was 51. Normally in groups there was a lead individual who led responses to questions. Individuals and groups were those that used the dam, or were part of the groups that made and managed the dam. All interviews were conducted in the local language, Kikamba, by native Kikamba speakers. Answers were recorded in English, and interviews normally lasted approximately 30 minutes. Interviews therefore largely represented single (or single group) perspectives on the sand dam; we did not perform multiple interviews at each dam.

Dam Functionality Index

We categorized measured parameters as those describing 1) the current function of the dam (whether there was evidence of water and its use) and 2) potential drivers of the function of the dam –in other words, factors that might account for differences in the functionality of the dam. For the first category, each parameter was scaled to a 0-1 rating (0=”worse”, 1=”better”, in terms of functionality) (Table 10). An overall rating (0-1; “dam

[31] https://libra.developmentseed.org/

functionality index") was calculated as a measure of how successful each dam has been. Each parameter used to calculate this functionality index was subjectively weighted according to its estimated importance.

Table 10 Parameters describing current dam function

Parameter		Data collection and unit	Weighting used to calculate functionality index
Is there evidence of water in the dam?	Observed presence of water directly in the sand	Core samples; % of cores at dam showing water	1
	Direct or indirect evidence of water	Observational data; Presence of water in sand, below dam, or from wells (0=no, 1=yes)	0.75
	Impacts on vegetation index	Satellite images; NDVI of dam site vs nearby control; 0-0.5 indicating degree of greening	0.2
	Reported water presence in dam during dry season	Questionnaire; reported number of months in dry season when water is present (0=short or not time; 0.5=1-3 mo; 1=more than 3 mo.)	0.75
Is the water being used?	Reported number of beneficiary households	Questionnaire; # of households	1
	Evidence of scoop hole or well usage	Observational data from dam site (0=no evidence; 0.5=past use, currently dry; 1=current use)	1
	Observed evidence of current water usage activities	Observational data from dam site (0=no use; 0.25=1 type of use; 0.5=2 types; 0.75=3 types; 1=4 or more types)	1
	# of observed agricultural activities	Observational data; Number of types of activities (e.g. grain/legume crops, fruit trees, vegetables…)	0.5
	Fraction of adjacent land area currently used as agricultural activities	Observational data; % land with any current agricultural activities, calculated from transects	0.5
	Reported dam usage during dry season for domestic/drinking	Questionnaire; 0=not used; 0.5=used, other sources also used; 1=used as only water source	0.5
	Self-reported usage of dam from list of primary benefits	Questionnaire; number of uses from list of primary uses (drinking, domestic,	0.5

		irrigation, livestock, brickmaking, sand harvesting)	

Table 11 Parameters that are potential drivers of dam functionality

Is there potential for holding water in the dam?	Degree of sedimentation, by water volume reduction	Calculated % reduction in water volume based on particle size analysis
	Degree of sedimentation by observation rating	Core samples rated based on type and pattern of sediment observed (see below for more details)
	Observed degree of sand/sediment filling	Degree of sediment filling behind dam structure
	Erosion	Observational rating of severity of erosion
	Watershed supply of water during April	Calculated total rain falling in watershed, based on GIS-defined watershed area and average rainfall for April for that watershed
	Leakage evidence	Observational rating based on pools downstream from dam
Is the water usable?	Measured salinity	Measured conductivity converted to ppm scale
	Reported problems with water	Questionnaire for any problems with water that limit use
What potential does the dam location have?	Population nearby	GIS analysis of 2015 estimated population within 2km of dam structure
	Poverty levels	GIS analysis of 2008 estimated % in poverty within 2km of dam structure
	Slope suitability	Median slope in degrees for watershed
	Soil suitability	Average % silt or clay in soil of watershed area, based on GIS soil survey data
	Nearby dam or other water sources	Questionnaire, reported dams nearby or other water sources such as pipes or boreholes

Degree of siltation by observational rating

A subjective classification of sample cores was also recorded. A pattern was established for the two core transects nearer the dam, and a separate pattern recorded for the two core transects nearer the drawback. Based on the patterns observed, a rating system was used to convert the observations to a numerical value, with lower values representing more siltation and higher values representing less siltation. For each of the two patterns, the following adjustments were made to the base value of 1 (no siltation):

some silt	-0.1
sandy silt	-0.25
multiple silt layers	-0.2
hard sand crust on top	-0.05
thin sand on top of silt	-0.3
hardpan layer	-0.15
hard silt	-0.4
silt hardpan	-0.2
hard sand/silt	-0.3
silt/clay	-0.4

Example: A dam with sandy silt near the dam, and multiple silt layers near the drawback would be given a value of 0.55 (= 1 - 0.25 - 0.2).

Addendum

Additional data is provided here by number in the results section.

1.1.1.

For all correlations, r calculated from r^2 in excel. p values calculated from Pearson product (r) from, http://www.socscistatistics.com/pvalues/pearsondistribution.aspx.

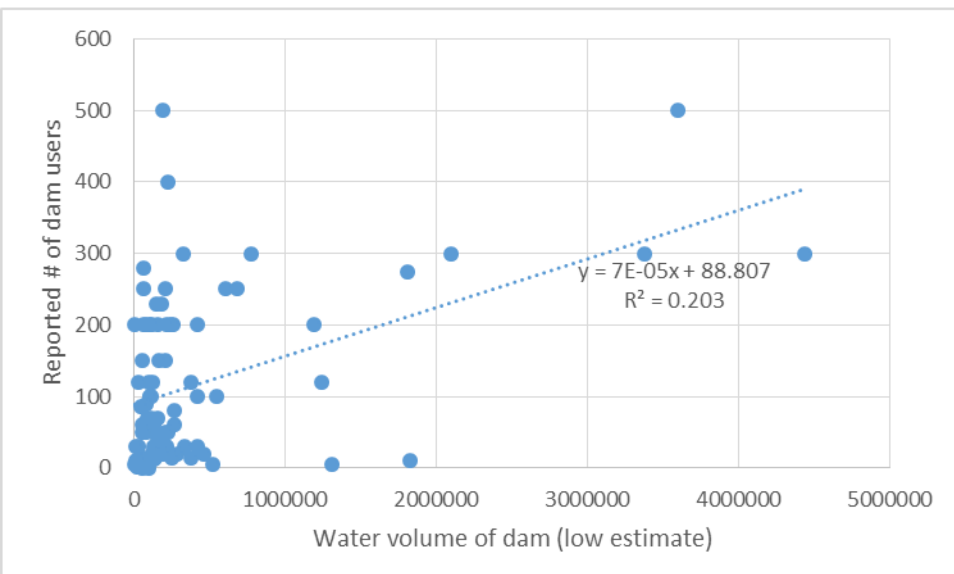


Figure 18. Correlation of an increase in number of dam users with increased dam size (as estimated by water volume).

1.1.2

Data for clay/silt component was clearly non-normal distribution (chi-square; http://excelmasterseries.com/D--Loads-Review/New_Manuals/Normality_Testing_in_Excel.pdf). We therefore report median rather than mean. D_{50} calculation was performed using excel from https://water.ohiodnr.gov/portals/soilwater/data/doc/Calculating_D50.doc.

Silt was measured in two ways: using the sieve/mass method reported in results, and by subjective classification. Subjectively classified observations of the degree of siltation are consistent with the general conclusion from measured particle sizes – most dams do not suffer from a large degree of silt accumulation.

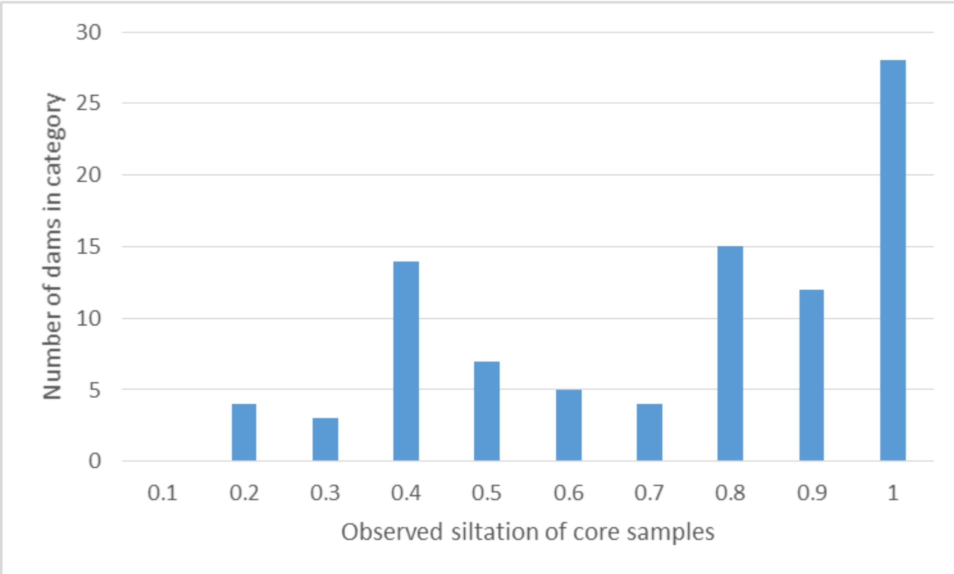


Figure 19 Subjectively categorized degree of siltation, with 0 = maximal siltation and 1 = no siltation

However, the subjective ratings of siltation did not correlate with measured median particle sizes. Visually judging siltation may overestimate how much silt is present (for instance, a small amount of dark silt could make the entire sample seemed silted, even though most of the sample is sand).

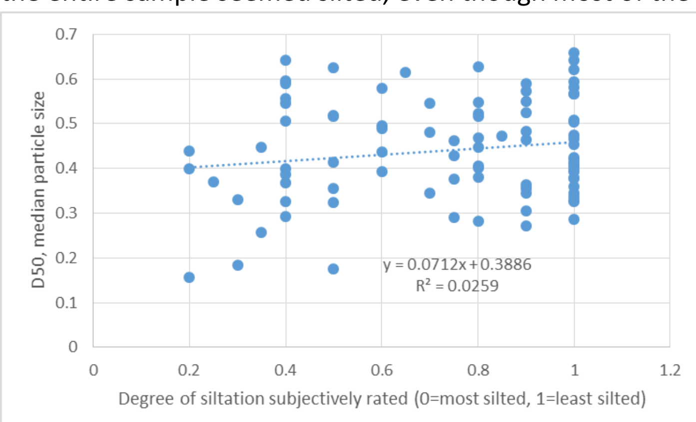


Figure 20 Subjectively rated siltation compared to measured D50 values.

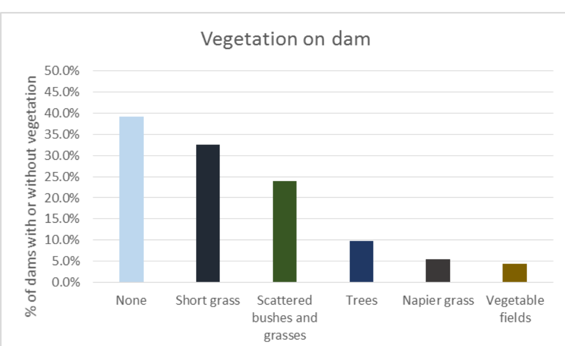


Figure 21 Percent of dams showing each vegetation type. Dams can have more than one type of vegetation.

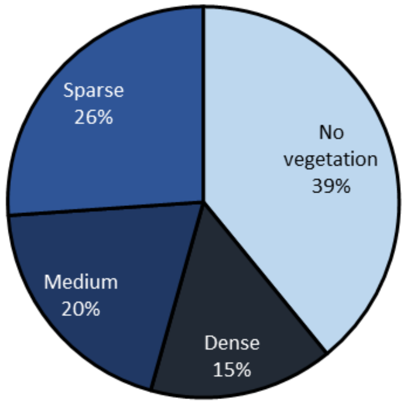


Figure 22 Density of vegetation on dams.

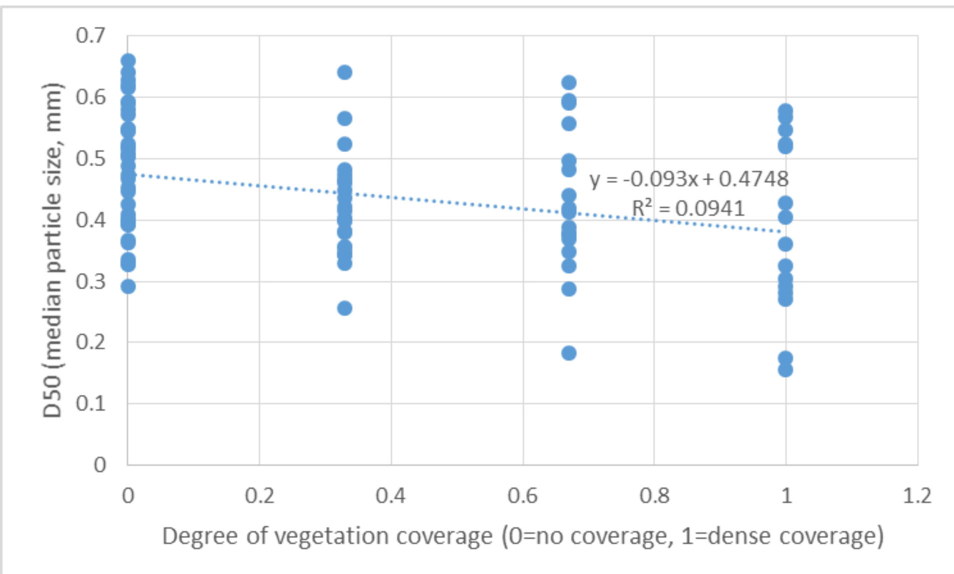


Figure 23 Smaller particle size associated with increased vegetation coverage.

1.1.3.

Leakage was assessed mostly by observing water at the base of the dam; data for actual damage (e.g. cracks) to the dam structure was inconsistently collected. As noted in results, leakage measured in this sense could be both a positive and negative aspect of the dam – it shows that water is present in the dam (or groundwater), but it indicates the possible presence of leakage from the dam structure.

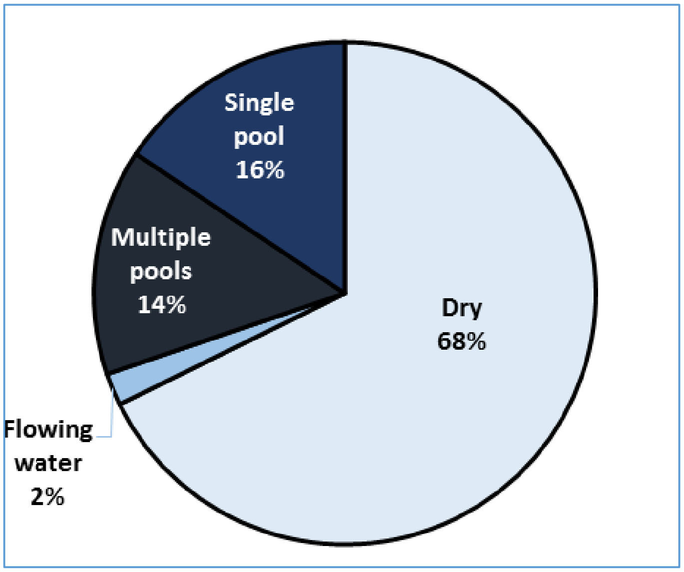
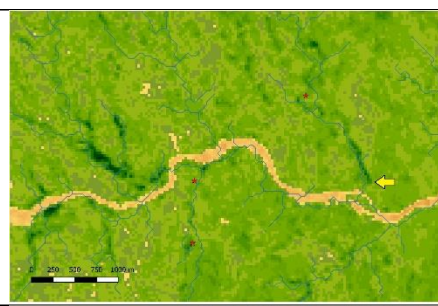
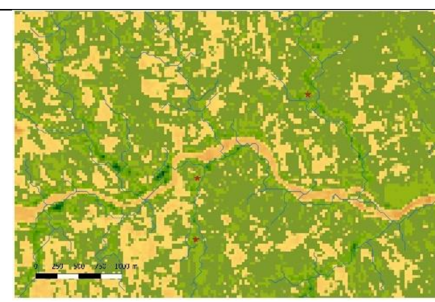
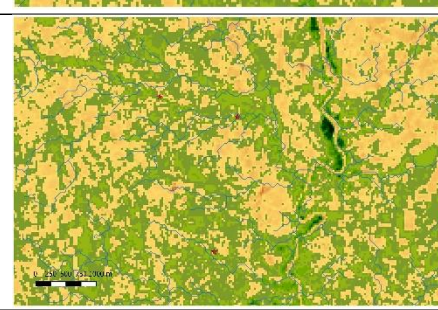


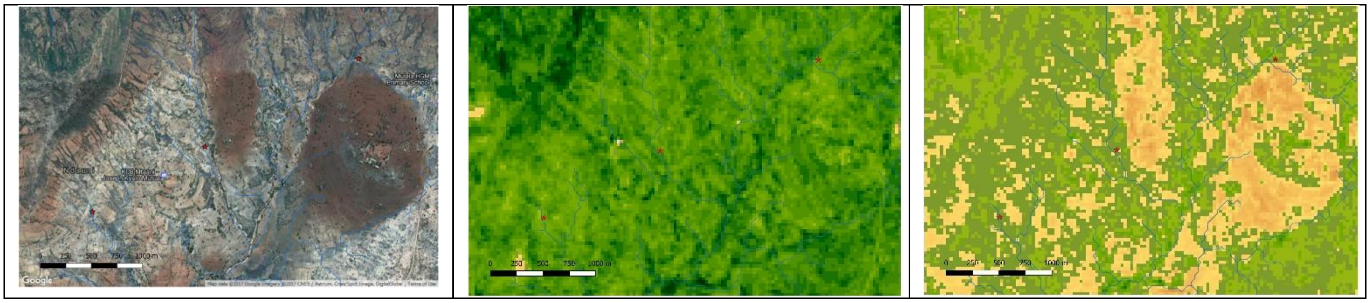
Figure 24 Presence of water at base of dam.

2.1

NDVI data are normally distributed, and therefore analyzed with paired t-test. The calculated p values for Jan-Mar and Aug-Oct dry seasons were 0.92 and 0.20, respectively. This is well above the usual 0.05 cutoff for statistical significance.

Table 12 Additional vegetation index examples



2.3.

Table 13 Dam functionality index, showing values for individual parameters used to aggregate the index

				Is there evidence of water in the dam?				Is the water being used?						
				Observed presence of water directly in sand	Direct or indirect evidence of water	Impacts on vegetative index	Reported water presence in dam during dry season	Reported number of beneficiary households	Evidence of scoop hole or well usage	Observed evidence of current water usage activities	# of observed agricultural activities on adjacent land	Fraction adjacent area currently as agriculture activities	Reported dam usage during dry season for domestic/drinking	Self-reported usage of dam from list of primary benefits
8/24/2016	UDO	Kitandi	**0.934**		1	-0	1	100	1	1	2	0.56	1	4
8/17/2016	UDO	Makanda	**0.884**		1	-0	1	500	1	0.5	0	0.00	1	4
8/23/2016	UDO	Kyeni	**0.811**	100.0%	1	0.01	1	500	1	1	3	0.69	1	5
8/23/2016	UDO	Ikankanu	**0.808**	100.0%	1	0.01	1	280	1	1	4	0.68	1	4
10/4/2016	UDO	Kilili	**0.79**	75.0%	1	0	1	200	1	1	3	0.55	1	5
10/25/2016	SASOL	Matinga	**0.761**	8.3%	1	0.01	1	300	1	0.5	0	0.00	1	4
9/22/2016	SASOL	Mitauni	**0.755**	100.0%	1		0.5	400	1	1	4	0.38	0.5	6
10/26/2016	SASOL	Nzamba	**0.741**	0.0%	1	0.01	1	200	1	0.5	0	0.00	1	5
8/30/2016	UDO	Ngatho	**0.739**	100.0%	1	0	1	300	1	0.75	2	0.34	1	5
9/1/2016	UDO	Kloni	**0.737**	100.0%	1	0	1	120	1	1	3	0.76	1	5
9/7/2016	SASOL	Makongwe	**0.73**	83.3%	1	0	0	300		1	4	0.74	1	6
9/13/2016	SASOL	Ikindu	**0.724**	58.3%	1	-0	0.5	100	1	1	3	0.55	1	6
9/8/2016	SASOL	Ndunda	**0.705**	91.7%	1	-0	0	300	1	1	3	0.27	1	6
8/24/2016	UDO	Kithito	**0.703**		1	-0	0.5	50	1	0.25	1	0.50	1	3
9/8/2016	SASOL	Kamumbuni	**0.683**	100.0%	1	0	0	250	1	1	3	0.56	1	5
10/24/2016	SASOL	Kasina	**0.682**	25.0%	1	-0	1	70	1	1	1	0.12	0	6
9/9/2016	SASOL	Mangya	**0.675**	100.0%	1	0.01	0	250	1	1	4	0.68	0.5	5
9/7/2016	SASOL	Kyakuthu	**0.675**	44.4%	1	0		60	1	0.75	2	0.17	1	6
8/18/2016	UDO	Ngomeni	**0.646**	0.0%	1	0.02	0	100	1	1	3	0.25	0	3
9/13/2016	SASOL	Musalani	**0.645**	75.0%	1	-0	0.5	120	1	0.5	4	0.37	1	5
8/26/2016	UDO	Matondoni	**0.628**	100.0%	1	-0	1	15	1	0.75	3	0.49	1	4
9/14/2016	SASOL	Kyangiti	**0.623**	100.0%	1	0.01	1	200	1	0.75	0	0.00	0.5	6
9/15/2016	SASOL	Kyalo	**0.623**	50.0%	1	0.01	1	200	1	0.5	0	0.00	0	6
8/19/2016	UDO	Walanio	**0.619**	75.0%	1	0	1	275	1	0.75	0	0.00	0	3
9/19/2016	SASOL	Mutavi	**0.616**	75.0%	1	-0	0.5	200	1	0.5	2	0.39	0.5	5
9/2/2016	UDO	Pioneer	**0.616**	80.0%	1	-0	0.5	300	1	0.5	0	0.00	1	4
9/30/2016	UDO	Wendo wa Ngo	**0.611**	58.3%	1	0	1	6	1	0.75	0	0.00	1	5
8/26/2016	UDO	Matondoni	**0.609**	100.0%	1	0.01	1	150	1	0.75	3	0.41	0	3
9/19/2016	SASOL	Ituloni	**0.607**	90.9%	1	0.01	1	200	1	0.75	1	0.03	0	5
9/14/2016	SASOL	Kakunike	**0.595**	40.0%	1	-0	1	30	1	0.25	2	0.16	0.5	6
9/7/2016	SASOL	Kanduu	**0.582**	0.0%	1	-0		10	1	0.25	0	0.00	1	5
9/28/2016	UDO	Mutangavuni	**0.553**	100.0%	1	-0	1	200	1	0.75	0	0.00	0	3
9/22/2016	SASOL	Kalimu Munyur	**0.545**	0.0%	1	-0	1	30	1	0.25	0	0.00	0	3
9/6/2016	SASOL	Kavuti B	**0.543**	50.0%	1	-0	0.5	60	0.5	0.5	3	0.66	0.5	4
9/20/2016	SASOL	Kakunike A	**0.532**	90.9%	1	0.01	0.5	50	1	0.5	1	0.09	1	5
9/26/2016	UDO	Kisesi	**0.53**	41.7%	1	0.01	0.5	250	0.5	0	0	0.00	1	5
9/13/2016	SASOL	Kyambua	**0.526**	83.3%	1	0.02	0	150	1	0.5	0	0.00	1	6
8/19/2016	UDO	Ukuno	**0.525**	71.4%	1	-0	1	100	1	0.75	0	0.00	0	1
8/17/2016	UDO	Watema	**0.524**		1	-0	0	200	0	0.25	0	0.00	1	3
9/6/2016	SASOL	Katumi	**0.521**	45.5%	1	-0	0.5	50	1	0.5	0	0.00	0.5	4
10/4/2016	UDO	Mbodoni	**0.517**	100.0%	1	-0	1	20	1	0.5	2	0.36	0	5
8/22/2016	UDO	Kithito	**0.485**	100.0%	1	0.02	1	230	0.5	0.5	0	0.00	0	4
8/25/2016	UDO	Kwakika	**0.474**	100.0%	1	0.03	0	120	1	0.5	0	0.00	1	4
9/21/2016	SASOL	Milinga	**0.468**	0.0%	0	0	0.5	50	0	0.5	2	0.41	1	6
10/7/2016	UDO	UDO	**0.454**	16.7%	1	-0	1	50	0	0	0	0.00	1	5
10/24/2016	SASOL	Kalova	**0.434**	91.7%	1	0.02	0.5		0.5	0	0	0.00	0	6
8/22/2016	UDO	Kithito	**0.422**	100.0%	1	0.03	1	230	0	0.5	0	0.00	0	4
10/24/2016	SASOL	Kitooni	**0.418**	0.0%	0	0.01	0.5	70	0.5	0	0	0.00	1	6
8/30/2016	UDO	Wikwayo	**0.406**	83.3%	1	-0		40	0	0.25	3	0.35	1	5
9/28/2016	UDO	Miamba	**0.401**	25.0%	1		0	100	0	0	1	0.06	1	5
8/31/2016	UDO	Kithito	**0.397**	100.0%	1	-0	0.5	90	0	0.75	1	0.03	0.5	5
9/15/2016	SASOL	Mbaluka	**0.391**	0.0%	0	-0	0.5	5	0.5	0	2	0.10	0.5	6
9/2/2016	UDO	Mbondoni	**0.387**	100.0%	1	-0	0.5	200	0	0.25	1	0.60	0.5	3
9/20/2016	SASOL	Metika	**0.387**	58.3%	0	-0	1	250	0	0	1	0.44	0.5	4
10/7/2016	UDO	UDO	**0.383**	83.3%	1	0.02	1	20	0	0.25	2	0.47	0	4
10/27/2016	SASOL	Nugulini	**0.379**	100.0%	1	-0			0	0	0	0.00	1	4
9/29/2016	UDO	Kalovoto	**0.377**	50.0%	1	-0	0.5	80	0	0	0	0.00	1	5
10/10/2016	UDO	Matika	**0.368**	0.0%	0	-0	1	200	0	0	0	0.00	0	4
9/26/2016	UDO	Kisesini	**0.368**	16.7%	1	-0	0	70	0	0	0	0.00	1	5
8/29/2016	UDO	Kithuluni	**0.361**	100.0%	1	-0		120	0	0	3	0.28	1	3
10/5/2016	UDO	Yikiuku	**0.356**	0.0%	0	0.03	0	200	0	0	0	0.00	1	5
9/21/2016	SASOL	Ngelesani	**0.355**	75.0%	1	0.01	0.5	50	0.5	0	0	0.00	0.5	4
10/26/2016	SASOL	Ngali	**0.339**		0	-0		30	0	0	0	0.00	1	4
10/14/2016	SASOL	Mukumbu	**0.334**	37.5%	1		0	10	0.5	0	0	0.00	0	6
9/27/2016	UDO	Munandani	**0.324**	0.0%	0	0.02		30	0	0	2	0.21	0.5	5
8/29/2016	UDO	Manzaa	**0.324**	100.0%	1	0		120	0	0.5	0	0.00	0.5	3
10/18/2016	SASOL	Ngui	**0.316**	27.3%	1	0.04	0	10	0.5	0	0	0.00	0	3
10/18/2016	SASOL	Wathe	**0.313**	0.0%	0	-0	0.5	15	0.5	0	0	0.00	0	5
10/14/2016	SASOL	Kivuva	**0.307**	0.0%	0	-0	0.5	20	0.5	0	0	0.00	0	4
11/3/2016	SASOL	Kithayuni	**0.307**	100.0%	1	-0	1	24		0	0	0.00	0	5
8/18/2016	UDO	Miamba	**0.304**	75.0%	1	-0	0.5	60	0	0	0	0.00	1	2
9/1/2016	UDO	Ngatho	**0.302**	100.0%	1	-0	1	50	0	0	0	0.00	0.5	4
10/25/2016	SASOL	Kithongo	**0.301**	0.0%	0	0.04		0	0.5	0	0	0.00	0	5
10/14/2016	SASOL	Kinyali	**0.299**	66.7%	1	0.01		10	0.5	0	0	0.00	0	4
10/5/2016	UDO	Nguumo	**0.297**	16.7%	1	-0		10	0	0	0	0.00	0	5
9/29/2016	UDO	Kyeni	**0.293**		0	0.01	0.5	15	0	0	0	0.00	0	5
10/3/2016	UDO	Kwa tuta	**0.288**	77.8%	1	-0	1	10	0	0	0	0.00	0	5
9/27/2016	UDO	Munandani	**0.285**	50.0%	1	0.01	0.5	12	0	0	0	0.00	0	5
9/15/2016	SASOL	Katitiva	**0.283**	0.0%	0	0.02		2	0.5	0	0	0.00	0	4
9/30/2016	UDO	Kalovoto	**0.275**	50.0%	1	-0	0.5	15	0	0	0	0.00	0	5
9/15/2016	SASOL	Matheka	**0.275**	0.0%	0	0	0	30	0.5	0	0	0.00	0	5
11/3/2016	SASOL	Kilikuni	**0.259**	0.0%	0	-0	0	150	0	0	0	0.00	0	5
8/31/2016	UDO	Kithito	**0.258**	100.0%	1	-0	0.5	85	0	0	0	0.00	0.5	3
8/25/2016	UDO	Munathi	**0.247**	0.0%	0	-0	0.5	0	0	0	0	0.00	0.5	3
9/22/2016	SASOL	Kalikuvu	**0.24**	83.3%	1	-0	0	150	0	0	0	0.00	0	4
10/10/2016	UDO	Matika	**0.236**	75.0%	1	-0	0.5	30	0	0	0	0.00	0	3
10/18/2016	SASOL	Mutinda	**0.229**	0.0%	0	-0	0	5	0.5	0	0	0.00	0	2
10/14/2016	SASOL	Malimbani	**0.227**	75.0%	1	0.02	0	10	0	0	1	0.07	0	5
10/25/2016	SASOL	Maviani	**0.225**	11.1%	0	-0		20	0	0	0	0.00	0.5	4
10/4/2016	UDO	Matika	**0.209**	100.0%	1	0.03	0.5	20	0	0	0	0.00	0	3
8/25/2016	UDO	Munathi	**0.201**	0.0%	0	-0			0	0	0	0.00		0
9/26/2016	UDO	Wendo	**0.193**	83.3%	1	0	0	14	0	0	0	0.00	0	5
9/19/2016	SASOL	Musivi	**0**											
9/20/2016	SASOL	Mutua	**0**											
9/21/2016	SASOL	Kyanguni	**0**											
10/27/2016	SASOL	Nzaa	**0**											
9/29/2016	UDO	Ngatho	**0**											
	Weighting			*1*	*0.75*	*0.2*	*0.75*	*1*	*1*	*1*	*0.5*	*0.5*	*0.5*	*0.5*

3.1. Population near dam

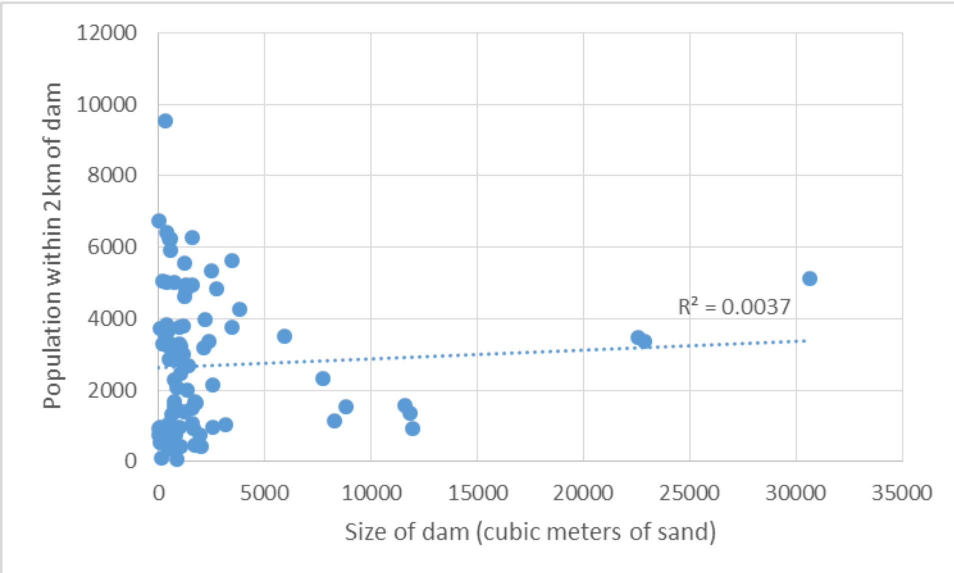


Figure 25 Correlation of dam size, and population within 2 km of dam

Data details for population and poverty given below:

AfriPop (www.afripop.org) dataset details

____

DATASET: Alpha version 2010 and 2015 estimates of numbers of people per grid square, with national totals adjusted to match UN population division estimates (http://esa.un.org/wpp/) and remaining unadjusted.
REGION: Africa
SPATIAL RESOLUTION: 0.000833333 decimal degrees (approx 100m at the equator)
PROJECTION: Geographic, WGS84
UNITS: Estimated persons per grid square
MAPPING APPROACH: Random Forest
FORMAT: Geotiff (zipped using 7-zip (open access tool): www.7-zip.org)
FILENAMES: Example - AGO_popmap10adj_v2b.tif = Angola (AGO) population count map for 2010 (10) adjusted to match UN national estimates (adj), version 2b (v2b). Population maps are updated to new versions when improved census or other input data become available.
DATE OF PRODUCTION: July 2013

AfriPop (www.afripop.org) dataset details

____

DATASET: Alpha version 2008 estimates of proportion of people per grid square living in poverty, as defined by the Multidimensional Poverty Index (http://www.ophi.org.uk/policy/multidimensional-poverty-index/), and associated uncertainty metrics.
REGION: Africa
SPATIAL RESOLUTION: 0.00833333 decimal degrees (approx 1km at the equator)
PROJECTION: Geographic, WGS84
UNITS: Proportion of residents living in MPI-defined poverty (poverty dataset); 95% credible interval (uncertainty dataset)
MAPPING APPROACH: Bayesian model-based geostatistics in combination with high resolution gridded spatial covariates applied to GPS-located household survey data on poverty from the DHS and/or LSMS programs.
FORMAT: Geotiff (zipped using 7-zip (open access tool): www.7-zip.org)

FILENAMES: Examples - ken08povmpi.tif = Kenya (ken) MPI poverty map for 2008. ken08povmpi-uncert.tif = uncertainty dataset showing 95% credible intervals.
DATE OF PRODUCTION: January 2013
CITATION: Tatem AJ, Gething PW, Bhatt S, Weiss D and Pezzulo C (2013) Pilot high resolution poverty maps, University of Southampton/Oxford.

4 Predicting dam function

Table 14 ANOVA with Tukey's posthoc test for potential drivers of dam functionality.

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.502721							
R Square	0.252729							
Adjusted R Square	0.178002							
Standard Error	0.169744							
Observations	89							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	8	0.779	0.097	3.382	0.0022			
Residual	80	2.305	0.028					
Total	88	3.084						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.582	0.22937	2.536	0.013	0.125	1.038	0.125	1.038
Degree of sedimentation, calculated reduction water volume using low estimate	-0.0056	0.00315	-1.781	0.079	-0.012	0.0007	-0.012	0.0006
Observed degree of sand/sediment filling	-0.130	0.1152	-1.131	0.261	-0.360	0.099	-0.360	0.100
Erosion	0.0358	0.1013	0.353	0.725	-0.166	0.237	-0.166	0.237
Leakage evidence	-0.176	0.0511	-3.447	0.0009	-0.278	-0.074	-0.2781	-0.075
Population nearby	2.27E-05	1.23E-05	1.844	0.069	-1.8E-06	4.72E-05	-1.8E-06	4.72E-05
Poverty levels	0.2509	0.234	1.0704	0.288	-0.216	0.718	-0.216	0.717
Slope suitability	0.0024	0.0061	0.393	0.695	-0.010	0.014	-0.010	0.015
Soil suitability	0.101	0.126	0.802	0.425	-0.150	0.352	-0.150	0.352

4 Rainfall

Average wet season rainfall is shown for the two wet seasons, taking Nov and Apr is representative for the short and long rains, respectively. Dam functionality is shown by color coding in dam location.

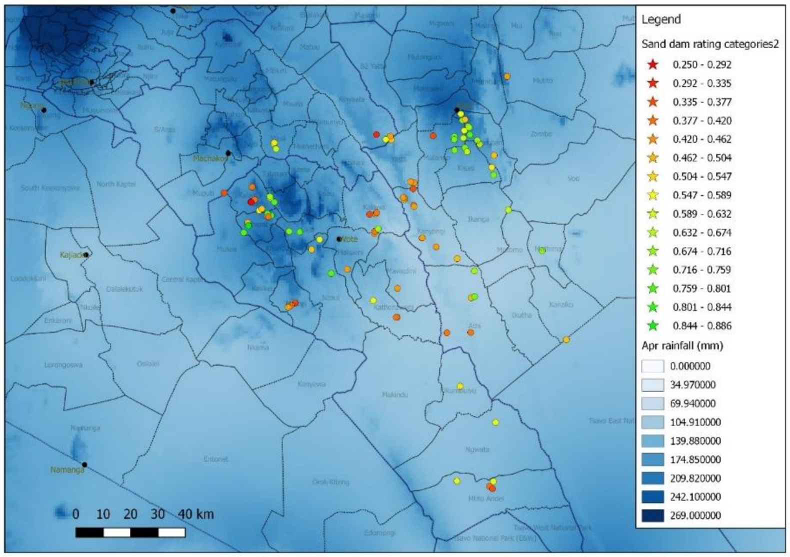


Figure 26 Average rainfall in long rains (mm, month of Apr)

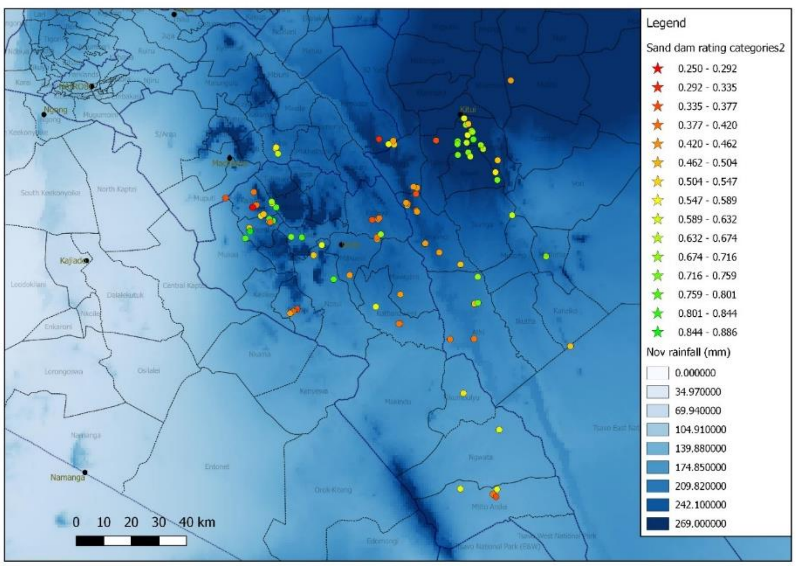
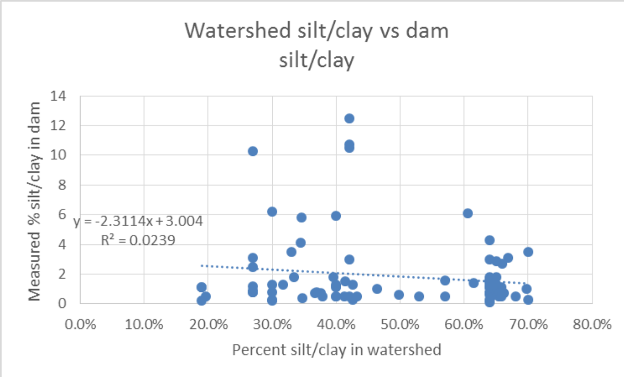
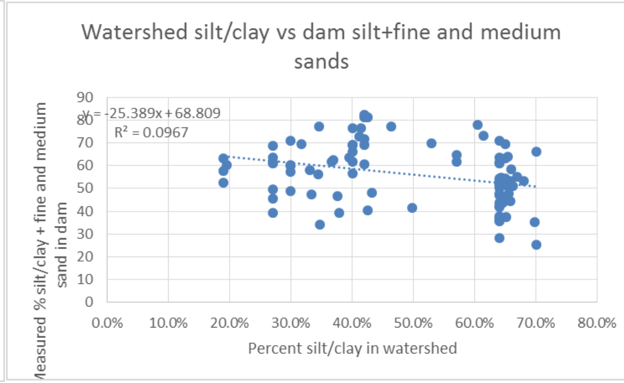


Figure 27 Average rainfall for short rains (mm, month of Nov)

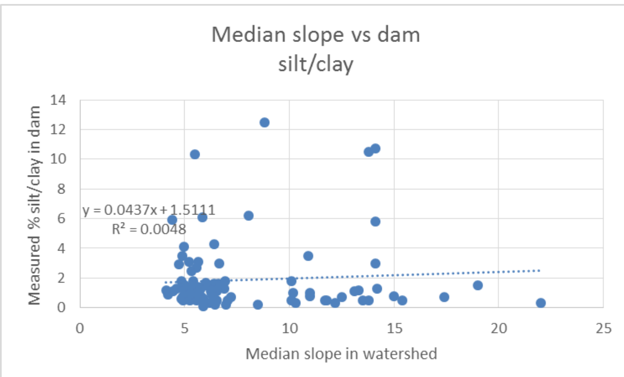
4.2.1.2.

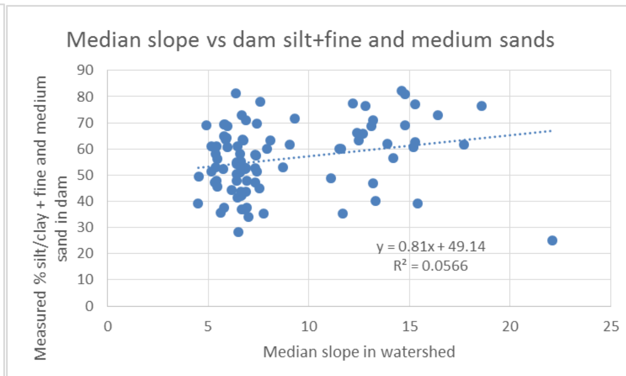
Additional analysis was performed to relationships between measured sediment characteristics at dam, sediment characteristics in the watershed as reported by GIS data. Data analyzed by clay/silt fractions, or the clay/silt plus fine and medium sand (corresponding to the finer fraction as used by de Trincheria).



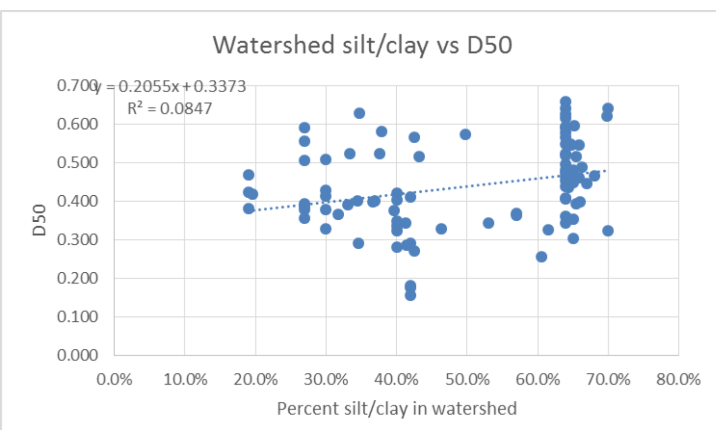


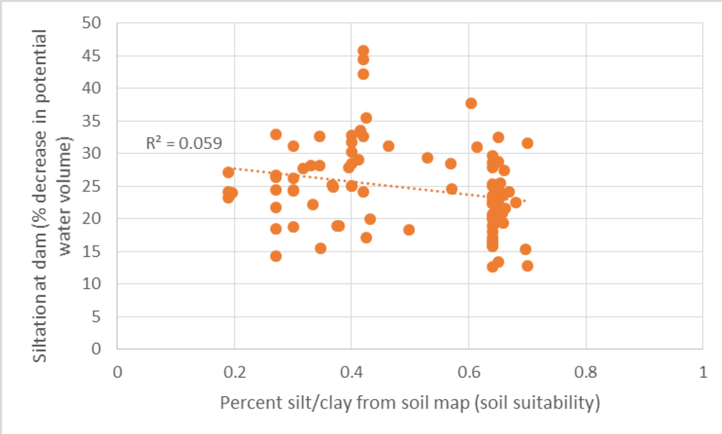
Relationship of slope to siltation:



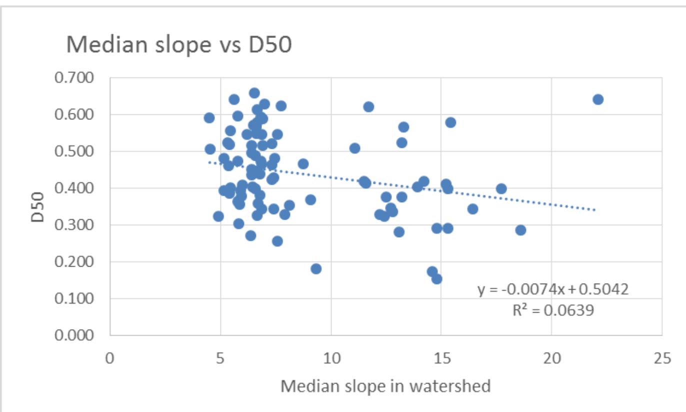


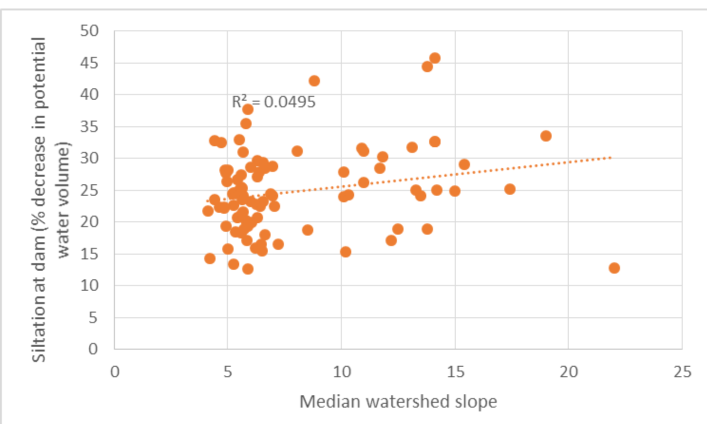
For existing dams in this study, there was a statistically significant correlation ($p=0.005$) between the D_{50} (median particle size), and the amount of silt/clay in the total watershed. Similarly, this relationship holds when analyzing with measured siltation (% reduction in potential water volume) rather than D_{50}. These relationships (less silt in the region = more silt at dam) are opposite what is expected, although the effect is low (a small regression coefficient).





Median particle size (D_{50}) was negatively correlated ($p=0.016$) with watershed slope as it was for Viducich's smaller sample size.





Checklist of needed field items

- ☐ Survey sheet, pen
- ☐ GPS unit
- ☐ Camera
- ☐ Tape measures
- ☐ Laser distance finder
- ☐ Soil corer
- ☐ Soil sample bags, labels
- ☐ Permanent markers
- ☐ Shovel
- ☐ Conductivity meter
- ☐ Conductivity Standard
- ☐ pH paper
- ☐ Bacteria test cards
- ☐ Water sampling pipet
- ☐ Tweezers
- ☐ Dark container

Survey by: ______________________________________ Date: __________________

1. Coordinates at center of dam structure:

Name of Dam: ____

Latitude (Southing) in decimal degrees __________________

Longitude (Easting) in decimal degrees __________________

2. Photographic record (Record first picture number in series for this dam:_______)

a. View of entire dam site (from a vantage point up a bank from the dam)____________
b. Face of dam (from downstream, facing upstream)____________
c. Informational plaque ____________
d. Side view showing area immediately upstream of the dam (and including the dam)____________
e. View of drawback from the center of the dam structure (take from standing position)____________
f. Downstream view from dam structure, showing the stream downstream ____________
g. Proceed at least 1 dam length downstream, view of stream bed with banks (view from center of stream, plus view of the banks)_____________
h. View of the end point (drawback point) of the dam ________________

3. Indicate extent of:

a. Standing water downstream from dam:

b. Evidence of erosion at dam base:

c. Structural failure of dam:

d. Evidence of leakage from the dam:

4. Dam structure Sketch the dam face, include all relevant dimensions. Include total dam height (meters, to the nearest cm) for at least 5 places along the front of the dam.
Indicate right side on sketch. Right side is define as facing: ☐ upstream *or* ☐ downstream?

5. Estimated Drawback

Distance from dam along estimated thalweg (deepest part of the channel): ____________________

Latitude (Southing) in decimal degrees ___________________

Longitude (Easting) in decimal degrees ___________________

6. Width & Adjacent land use & characteristics

Sketch the surface of the dam site, including measured width (meters, to the nearest cm) at 30 m intervals (or a minimum of 4 locations) along the length of the dam. Sketch location of vegetation, animal waste, extraction/scoop holes, pump wells, etc. (any evidence of human usage). Along dam surface, record presence of animal waste or vegetation along transect line.

Record land cover/activities in transects away from dam site, at 20-50 meter intervals along each bank. Record distance from edge of bank for each location.

7. Sand/Soil Cores Soil cores to maximum depth of sampler at 3 locations (dividing width into quartiles): 2 meters behind dam (A), ¼ (B), ½ (C), and ¾ (D) distance to drawback. (see example in appendix). Record observations from the cores (such as layers of sand/silt). Indicate how deep the core was taken.

A - near dam

Right

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

Center

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

Left

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

B - 1/4 from dam

Right

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

Center

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

Left

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

C - 1/2 from dam

Right

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

Center

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

Left

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

D - 3/4 from dam

Right

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

Center

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

Left

Moisture	Sand	Silt	Clay	
				0.1
				0.2
				0.3
				0.4
				0.5
				0.6
				0.7
				0.8
				0.9
				1.0
				1.1
				1.2
				1.3
				1.4
				1.5

Pool 3 samples (for instance, the 3 from section A) from each location into a bag for later analysis

7. Water Sample – Conductivity (uS/cm) and pH

	Conductivity (duplicate samples)	Temperature	pH
Pump well			
Scoop well(s)			
Surface water			

8. Water Sample – Bacteria

At each selected site for bacteria measurements. Label cards, and indicate here the labels:

Approx. time of plating on cards: ______________________

	Label	Volume of water plated	Purple colonies, indicate time and date read	Blue colonies, indicate time and date read	Manure piles within 5 m radius of source
Negative Control [1; clean, filtered water]					
☐ Scoop Hole ☐ Pump Well ☐ Open Well ☐ Surface Water					
Describe location and appearance. Is it being used as a drinking source?					
☐ Scoop Hole ☐ Pump Well ☐ Open Well ☐ Surface Water					
Describe location and appearance. Is it being used as a drinking source?					

☐ Scoop Hole ☐ Pump Well ☐ Open Well ☐ Surface Water					
Describe location and appearance. Is it being used as a drinking source?					

9. Water Sample – Nutrients

10. Observations

Were there people utilizing the dam at the time of the survey? (describe number of people/animals and activities; indicate whether this was at scoop holes, pump wells, downstream etc)

Was there any water observed? (for example, pooled water, or wet sediment in dam cores) Indicate the number of scoop holes present with water. *We want a sense of whether water is currently stored in the dam.*

Double check:

- When leaving, is all equipment with you?!
- Are bacteria cards covered from the sun? Are they flat for 15-30 minutes after plating?
- Is all information recorded on the sheets?

11. Questionnaire **Date ________________________**

Name of Dam___________________________ **Name of interviewer______________________**

Identify at least two people in the region to interview. Preferably these are users of the dam, who have lived in the area for the duration of the dam.

> Hello! My name is _________________________, I am one of the researchers working with ________________________________. You were selected as a potential participant in this study because you are currently residing near this sand dam. We wish to understand the usefulness and limitations that sand dams pose in this region of Kenya. We will be asking some questions on sand dam function and usefulness. Participation in this interview is voluntary. The interview will take about 20 minutes. You can choose to stop the interview at any time or not to answer any question. If you decide not to participate in the interview or in answering questions, there will be no repercussions.

Name: ____ M/F Age__________

Were other people present during the interview? If so, how many?

Information about interviewee's relationship to the dam (such as: do they live near the dam? are they a group member?) ____________________

Does the respondent use the dam? Y / N How long has the respondent lived in the area? _________

Subcounty_____________ Ward________________

Sublocation ____________ Village________________

A. Questions about the surveyed sand dam

1. Does the dam run out of water? When? (how many months?)

2. Who uses the dam? (about how many households? Indicate if this number includes users of nearby dams)

3. Who is allowed to take water from the dam? How is water use managed? (if there is a management committee, what do they do?)

4. Is there (or has there been) any conflict over use of water? (or has conflict changed since building the sand dam?) What impact have you observed on **community relations** due to the sand dams? (positive or negative)

5. Is sand harvested from the dam? By whom and for what purpose? (Is there a policy on sand harvesting?)

B. Water Use

1. What are the main uses of water from the sand dam? (household, drinking, irrigation, cattle, etc.) Identify the use that requires the most water. (circle)

2. Is the water clean for drinking? (How clean is the water?) Why or why not?

3. Are there issues with color, taste, odor of the water?

4. Do you treat water before it is used for drinking? If so, how is it treated?

5. What is the main source of drinking water during the dry season?

6. What is the main source of drinking water during the wet season?

7. [for selected households, at dams where bacterial testing is performed]. "May we take a sample of water from your household that you use for drinking, in order to test for bacterial contamination?"

Time of plating on card: _______________________

	Label	Volume of water plated	Purple colonies, indicate time and date read	Blue colonies, indicate time and date read
Household water source [2]; duplicates				

C. Benefits and Costs

1. Briefly describe how this sand dam was built. What was the level of the community involvement in the construction process?

3. How is the sand dam impacting the surrounding communities? Which do you consider the most important impact? Has that impact changed over time?

4. Has the sand dam impacted women, men, boys, and girls differently? If so, how does it impact these groups differently?

5. What are the main challenges to adoption of sand dams by a community? Was there a cost to communities in adopting a sand dam? (either financial cost, or any other cost)

D. Nearby sand dams

1. Are there other sand dams in the region?

2. Where are they located? (Give a distance if possible) *If other sand dams are easily reached, take GPS coordinates for those sites.*

3. Is anything known about the history of the other dams (such as when it was built)?

4. Are the other sand dams being utilized? What for?

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