Large-scale siting of sand dams: a participatory approach and application in Angolan drylands

Luigi Piemontese[1], Natalia Limones[2], Giulio Castelli[1], Alice Grazio[3], and Elena Bresci[1]

[1]Università degli Studi di Firenze
[2]Universidad de Sevilla
[3]COSPE Onlus

October 24, 2022

Abstract

Sand dams are simple and effective structures built across ephemeral riverbeds in arid/semi-arid regions to harvest water within sand pores and increase water availability and quality for rural communities. The complex morphological, hydrological, social and economic conditions that make sand dams a beneficial tool for water resilience are largely influenced by the siting phase. Proper location of a sand dam can reduce community's travel time to water points, reduce water conflicts and increase food security through expansion of irrigated agriculture. On the other hand, a misplacement of sand dams can, at worst, increase disparities in water access and increase local conflicts. To approach a viable siting of sand dams, most projects are developed and delivered with the community through a bottom-up approach. However, in case of large-scale project, remote sensing and biophysical analysis are the dominant approach, leaving the socio-economic component at the margins of the siting strategy and eventually affecting the benefits to local communities. In this paper, we propose a large-scale participatory methodology to sand dams siting, which draws on mixed-methods connecting the conventional top-down biophysical analysis with bottom-up participatory research. We first describe the generic approach developed for sand dams siting in Namibe, a semi-arid region of South-west of Angola, then we draw on our case to propose a generic approach to large-scale participatory siting beyond Namibe.

Introduction

Water scarcity is one of the major threats to human wellbeing and a central challenge to achieving the milestones of the sustainable development goals (Gain et al., 2016) and ecological restoration (Fischer et al., 2021). Drylands are particularly vulnerable areas characterized by extreme water scarcity, variable rainfall and sparse vegetation, covering almost 40% of global land surface (Safriel et al., 2005). Because of the unstable and uncertain natural resources, drylands are often home to marginalised populations (Sietz et al., 2011), who have adapted to resources scarcity and uncertainty, thus developing resilience to environmental changes (Ifejika Speranza, 2010). However, climate change is expected to expand drylands by changing precipitation patterns and intensity (Feng and Fu, 2013), with serious consequences of increasing populations out-migrations and armed conflicts (Neumann et al., 2015; Sterzel et al., 2014). For example, Southern African drylands are expected to see a decrease in precipitation, runoff and soil moisture, which will likely affect the resilience of millions of agro-pastoralists (Piemontese et al., 2019).

Retaining water in the landscape has a critical role for increasing resilience of drylands to climate change "by avoiding major regime shifts away from stable environmental conditions, and in safeguarding life-support systems for human wellbeing" (Rockström et al., 2014). Harvesting rainwater through small-scale and distributed interventions can be a crucial strategy to increase water retention in the landscape, increasing pasture and water availability for agro-pastoralists (Descheemaeker et al., 2010; Strohmeier et al., 2021).

Within the broad spectrum of water harvesting technologies, sand dams represent a particularly interesting and promising technology to harvest water in dry rivers. Sand dams are barriers built along ephemeral rivers, which trap coarse sediments (mostly sand), creating a small reservoir filled in sand (Ritchie et al., 2021). The sand trapped behind the dam serves as a water storage – up to 40% of the sand volume are pores that can be filled in water (Lasage et al., 2015). Sand dams have demonstrated successful in providing additional water points along ephemeral rivers and increasing communities wellbeing (Teel, 2019). In Kenya, where the majority of the research on sand dam is focused, sand dams have decreased the water collection time from more than 3 hours per day to as little as 15 minutes (Teel, 2019). Other benefits of sand dams include increased water use of about 3 times, increased irrigation water, thus increased food security (Ritchie et al., 2021; Villani et al., 2018).

Replicating and transferring water harvesting (WH) solutions like sand dams to other areas of the world could boost land and water restoration targets and contribute to strengthening social-ecological resilience of drylands (Ammar et al., 2016; Grum et al., 2016; Piemontese et al., 2020). However, especially in areas with no previous experience, planning the most appropriate location for implementation is a key step to ensure the usefulness and effectiveness of the technology. In fact, some 80% of the WH implementations fail because of wrong siting for both failed water retention and scarce involvement of local communities, who are the ones using and benefiting from the technologies (Ngugi et al., 2020).

This is the case of Angola drylands, where sand dams have not been documented in the scientific literature (Ritchie et al., 2021), but the successful experience of places with similar hydro-climatic conditions in Kenya and in the near Namibia (Hartley, 1997), makes it an appealing solution to water scarcity. However, especially in a new context, exploring the feasibility of such technology requires a deep understanding and careful inclusion local communities perceptions and knowledge, not only for selecting a suitable site, but also for ensuring a long-lasting beneficial use (Ziadat et al., 2012).

Conventionally, the siting of sand dams for large areas (regional to national) is approached as a top-down, data-driven analysis to highlight the areas, or river sections, with adequate biophysical conditions for sand dams construction (Forzieri et al., 2008). These large-scale biophysical studies have the advantage to effectively reduce the time and resources for a more detailed field inspection in large areas, but they require high resolution spatial data and often lack socio-economic information on technology viability and use. On the other hand, higher details of suitability analysis can be reached with local participatory approaches, which include a more thorough socio-economic enquire and community participation, but are limited in spatial scale (Ertsen et al., 2005). Although these two approaches seem polarized, and in fact they have been applied in silo, an integration is still possible and desirable to produce insightful large-scale assessments.

Here, we present a mixed-method approach to large scale siting considering both the biophysical requirements of a sand dam site and the needs, constraints and preferences of local communities. We apply the approach to Namibe, a semi-arid Province in Southwest Angola, by using a participative enquiry to assess the water security problems of the communities, analysed to incorporate the socio-economic conditions for the best siting of sand dams. The twofold contribution of this work tackle both the generic research gap on large-scale participatory planning of water harvesting technologies and contributes to expanding the geographical understanding of sand dams in a data-scarce and understudied region as the Angolan drylands.

Data and Methods

2.1 Methodological framework

To identify the sites with highest potential for sand dams in the province of Namibe, we use a mixed-methods approach building on quantitative and qualitative methods applied to ten communities in the two *municípios* of Virei and Bibala. This approach was specifically developed to meet two major challenges in the siting of water harvesting in drylands. First, drylands, especially in Sub-Saharan Africa, are often areas with poor data availability and difficult access to information (Prinz et al., 1998). Lack of high resolution spatial biophysical data is a major limitation to estimating a complex water harvesting technology as sand dams. A suitable river section for sand dams construction must have specific characteristics such as presence of high rocky riverbanks, adequate size of the stream, shallow bedrock, coarse and little clayish sediments and low salinity (Beswetherick et al., 2018; Ngugi et al., 2020). Although some of these data might be available, they usually come from global-scale datasets, rarely tested in Sub-Saharan Africa and at a coarse resolution, which could compromise the reliability of the analysis. The second challenge is represented by the complete lack of socio-economic data. Although with some uncertainty, the literature on best-siting of water harvesting structures suggests the use of socio-economic parameters as distance to communities, rivers, roads, land tenure, population density, workforce availability or prior community experience with similar infrastructures. However, these kinds of data are rarely available and particularly lacking in Angola, where most of scientific and technical work is outdated and definitely neglected remote areas such as rural Namibe (Amado et al., 2020).

2.2 Knowledge integration

To overcome these problems, instead of aiming for the exact location of such a complex technology, we first performed a classic top-down siting with few essential biophysical criteria to narrow down the suitable river sections with the basic biophysical requirements for sand dams construction and then we used this preliminary points to guide the local participatory research, which completes the overall social-ecological suitability. In this, we diverge from conventional top-down large-scale siting which seldom, if ever, include a local participatory process to "validate" the top-down methodology and do not fully integrate local perception or indigenous knowledge (Ziadat et al., 2012). With our methodology (see Figure 1), we build on qualitative GIS to map communities' needs, constraints and use their knowledge of local hydrology to integrate out top-down biophysical analysis with missing local social and hydrological information which constitute the "useful knowledge" (Robinson et al., 2016), which is essential to select the sites with the best overall suitability for sand dams construction (Forrester et al., 2015). Particularly relevant for the knowledge integration phase was the field inspection. After the focus group discussions, we showed the map with the biophysically suitable points to a group of key informants (usually the *soba,* the local administrator, and/or other distinguished community members), asking whether the points were located in *mulola* (i.e. local term for ephemeral rivers) with high rocky river banks and if they had good sand. Also, we asked which are the main *mulola* with *cacimbas* (i.e. scoop holes), which is a good indicator of potential for sand dams (Beswetherick et al., 2018). Apart from refining the selection of biophysical points in this way, we also asked directly to the community whether they had ideas or suggestions for selecting a site. Although this approach is subjected to individuals' own interest and convenience (for example recommending a river section near their settlements or *kimbos*), it was a useful exercise to allow the community for a more active engagement, build trust and reciprocity and let the community show their priorities and preferences without constraints.

2.3. Study area

Case study selection

The province of Namibe is located Southwest of Angola, bordering Namibia, and hosts about 1,200,000 people. The main activity of rural people is animal farming, mostly goats and cows, with official statistics estimating the cattle size to 500.500 heads (Angola, 2013). However, the remote location of the largest cattle keepers and their semi-nomadic nature linked to mobile transhumance practices make it difficult to reliably quantify. In this area, cows are considered much more than a subsistence mean or a financial and capital, but they represent a "spiritual capital", connecting people to their ancestors (Bagnol and Verhoesel, 2009). For this reason, taking care of the animals is the main activity of the Namibian pastoral communities, who also keep animals in close proximity to their families. Farms (*sambos*) are usually embedded within the clans' settlements (*kimbos*), surrounded by a larger area where family houses and other facilities are spread. Within the *Mukubal*, the largest cattle keepers populating mostly the Virei area, the lives of people and animals are so intertwined and co-dependent that the settlements are even called just *sambos*.

The scarce and increasingly unpredictable rainfall make Namibe prone to long droughts and extensive water scarcity, which are already severely affecting the livelihood of local communities (Limones et al., 2020). Local communities have traditionally been practicing transhumance to cope with water scarcity and land degradation, by seasonally reaching locations with higher availability of resources for their livestock (Carvalho, 1974). However, climate change is worsening the hydro-climatic conditions of the areas, forcing local communities to change and prolong their transhumance routes with increasing risk of failure (Herrero et al., 2016).

The ten communities involved in this study are located in three different sub-municipal divisions (the *comunas* of Cainde, Capangombe and Lola), spanning across different socio-economic and agro-climatic areas in a north-south gradient, from the southern semi-arid livestock-based communities of Cainde, to the agro-pastoralist communities of sub-humid Lola. Capturing the social-ecological gradient of the ten communities is fundamental to understand the different socio-economic conditions for siting sand dams along the most important transhumance route of the Province. The three *comunas* are in fact connected by the virtual cattle road that brings pastoralist from drier areas to greener and more humid areas. The light grey area in Figure 2 is the official administrative territory of the communities, which have their own local *soba*, but it often extends further beyond those boundaries to include further pasture and water points, which transhumant pastoralists are extremely dependent on (Mufinda et al., 2015).

2.4 Biophysical suitability: multivariate analysis

The first step of our approach is the selection of biophysically suitable location in the province of study. This step is necessary to identify a first set of location with the necessary biophysical condition for the large area of the ten communities. Moreover, being mobile pastoralists, the communities could make good use of water points located even tens of kilometres far from the core of their villages. Selecting suitable location in such a large area would be impossible with a pure participatory work. We then use Multi-criteria Decision Analysis (MCDA) to select a first set of points for the participatory phase. MCDA uses a set of parameters to discriminate between suitable and unsuitable conditions leading to a certain result. It is a consolidated approach in siting suitability analysis of water harvesting structures (Al-Adamat et al., 2010; Forzieri et al., 2008; Grum et al., 2016). In a recent review of siting methods, Ammar et al. (2016) reports MCDA as one of the most reliable approaches, especially when combined with spatial analysis tools, since it allows to analyze several spatial indicators for large areas in a quick and inexpensive way.

Given the uncertainty in selecting the most adequate parameters for the biophysical suitability of sand dams (Ngugi et al., 2020) and the mentioned lack of reliable and high resolution data, we adopted a conservative approach using a simple set of parameters representing the minimum requirement of measurable variables for the construction of sand dams, including the slope, the salinity and the stream order. The purpose of the analysis is therefore to narrow down the potential number of water stream sections to be inspected during the second phase in the field.

The analysis included the delineation of the stream and the calculation of the stream order (or Strahler order), and the subsequent selection of the points along the stream with appropriate conditions of stream order, slope and salinity. Hereinafter we report the analytical steps with some explanatory figures.

To select the final set of water stream sections we have first produced the hydrographic network (i.e. water streams) starting from the Digital Elevation Model (DEM), using the GIS functions slope, aspect and exposition applied at pixel level from the DEM grid. From the slope and exposition layers, we then calculated the flow accumulation, which is the number of upstream cells draining into each cell of the grid. From the flow accumulation we then reconstructed the stream network by selecting the threshold of 1000 cells from the flow accumulation layer. After reconstructing the river layer, we broke the stream lines into sections 30m apart, technically by converting the stream lines into points. We yield a total of 1813428 points, which represent all the stream sections in Namibe, then we narrowed down the selection of suitable point by excluding the points located in areas with slope higher than 2 degrees, stream order higher than 2 and soil salinity higher than 40Hz. The stream order is a proxy for stream dimensions, since sand dams are most suited for river sections below 25m (Beswetherick et al., 2018). Finally, soil electrical conductivity below 40Hz is a common acceptable salinity value for drinking use (following the FAO guidelines for maximum electrical conductivity values: http://www.fao.org/3/x5871e/x5871e04.htm).

2.4.1 Field calibration of biophysical criteria

The field inspection for the model calibration involved the selection of 3 random analysis points located in an easily accessible location. The purpose of the field inspection was to check whether the dimensions of the selected stream order (between 1 and 2) actually correspond to stream dimensions which are feasible for the construction of small sand dams. The characteristics checked in the field where thus the slope and the cross section between 10 to 20 meters. During the participatory research with the communities, we had further proof that the *mulola* with section range 10-20 m are the most suitable because smaller *mulola* (with section below 10 m) were not used by locals since they are too small to accumulate water in the sand for a reasonable time to make the digging work worth it.

2.5 Qualitative data collection and analysis

To understand the context-specific socio-economic criteria for the best-siting of sand dams, we have conducted qualitative research with the 10 communities in Namibe, collecting information on water availability, water use and needs based on participants perception. We performed three focus group discussions in each community, including a representation of participants of both sexes and all ages (Figure 3). The groups were previously engaged and initiated in participatory work by the NGO leading the cooperation project TransAgua, to build a certain degree of trust and collaboration throughout the participatory activities. Focus group discussions were held in August 2021 and facilitated by the first author and local facilitators of the NGO, who also helped with the logistics and translation from Portuguese to the local language. The topics of the focus groups concerned water availability (i.e. length and intensity of the rainy season and stream water availability and timing), water use and needs of transhumant pastoralism (i.e. animal water consumption and dynamics related to water needs and availability during transhumance) and domestic water (i.e. quantity, quality and location of local water sources and water and domestic water use).

During the group discussions, we also asked about the familiarity of the communities with water harvesting structures and the possible presence of small dams in the area. The presence of sand dams in the area has not been reported in scientific or grey literature, but we were expecting the presence of colonial water structures to provide water to the "modern" large-scale livestock ranching in Namibe during the late colonial time (Carvalho, 1974).

The focus group discussions were facilitated using the semi-structured interview guide available in supplementary material. Interviews were reported using edited transcription to avoid repetitions and to increase readability and clarity, particularly useful when translating answers between English, Portuguese and the different local languages. The lead author then coded the transcripts using a mix of deductive and inductive coding. The scope of the qualitative analysis was to identify the socio-economic criteria to be considered for the siting of sand dams. To come up with a list of criteria that would account for the communities water needs and priorities, we first identified the main water security themes of the communities. The water security themes were first deductively coded guided by the water security framework proposed by Loring et al. (2013), which is broad enough to include other potential emerging themes specific to the local context (Penn et al., 2017). The framework categorises water security based on availability, accessibility, utility, and stability of water resources. Water availability is the water considered to be extractable in and around the community; accessibility concerns the degree of access the water points (e.g. having a well in the village makes water more accessible than having to dig a hole in a sandy river far away from the village); utility refers to the level of safety in water accessibility and use (e.g. polluted or salty water); finally, stability indicates reliability of water resources over time, including the presence of water shortage periods or natural disasters (e.g. droughts and floods).

Starting with coding for these themes we then inductively added other potential water security categories emerging from the interviews. The lead author coded the focus group discussions and reviewed sections of the coded interviews with the local facilitator to make sure to properly interpret the transcripts and to discuss preliminary themes.

After the identification of the themes related to water security problems, we gave a 5-grade score to each problems based on their severity from none, to low, medium, high and very high according to participants' perception. Finally, based on the set of problems identified with the communities and their severity score, we associate a socio-economic criteria for the best-siting of sand dams addressing the identified problems.

During the whole participatory process, we triangulated the results from the focus groups with notes from participant observations (Hertel, 1974), field visits with key informants from the communities as well as conversations with other experts involved in development projects with pastoral communities based in Namibe.

Results

3.1 Biophysical suitability

After applying the filters of the multivariate analysis to the total river sections, we obtained 2106 suitable points in the whole Namibe province (Figure 4, left). This number goes down to 121 points if we only consider the ones located within the territory of the 10 communities (Figure 4, right). This is the final set of points used as a guidance in the participatory phase. It is important to notice that, given the small number of conditions included in the analysis, many of these points might not present all of the specific site conditions required for a dam construction; for example strong rocky riverbanks. Moreover, many of these points are likely to be located in remote areas that would not be useful in providing water to local communities, such as in the large Namibe desert covering the southern part of the province, bordering Namibia. For this reason, integrating this analysis with local communities knowledge and socio-economic constrains and requirements is a fundamental integration to the final siting of sand dams in this case.

3.2 Socio-economic conditions for best siting of sand dams in Namibe

The main themes related to water security emerged from the qualitative analysis of focus group discussions are the following:

1. Water scarcity: The overall water quantity available for the community is not enough for the different uses.

2. Few water points: The community has access to a limited number of water points, including larger *mulola* for *cacimbas*, wells and other non-conventional sources.

3. Difficult access: The water sources are hard to access. For example the community have to dig several or very deep *cacimbas* to collect water.

4. Unequal access: Families within the community are located far from the water points and have to walk for considerably longer time compared to the families living in the proximity of water points.

5. Human-animal conflict: The water points are for both human and animal water consumption, thus creating conflict between the quantity of water available to both and create potential health risk from water contamination.

6. Violent conflict: Particular conditions about the water points create conflict between members of the community, groups of the same community or between the local community and other communities (for example pastoralists from elsewhere transiting in the community).

Although the environmental conditions vary, especially from the drier southern communities in Virei compared to the wetter ones in Bibala, the prevalence and severity of these water-related problems strongly depend on the specific socio-economic conditions of each community. In fact, the natural water availability is mostly related to the presence of larger *mulola* able to retain water in the sandy riverbed for relatively long periods, albeit particular conditions apply to places like Nascente, which stands next to a water spring (the term "nascente" is, in fact, the Portuguese for "water spring"). The main differences in water availability between the communities are determined by the socio-economic access, which makes the better served communities (e.g. with more wells) more resilient to hydroclimatic water stress. This condition is reflected in the themes "Few water points", "Difficult access" and "Unequal access". In fact, apart from Munhino and Tchitemo, which are the most economically developed and best served communities with several wells along the main mulola, all the other communities score between high and very high in these three water-related problems

(Table 1). Human-animal conflicts are quite common in all of the communities, while violent conflicts are particularly sever in Nascente, with the conflictual relationships with transhumant pastoralists transiting in the community and often occupying the only water point at the expanses of the local community (see table S1 in supplementary material for a more extensive description of the severity of water-related problems).

Based on the community-specific water-related problems, we identified the main conditions to account for during the siting on a sand dam. Although the characteristic change depending on the local conditions and local population needs, they can be overall summarized in:

1. Proximity to *kimbos*: important to plan for a location that can serve a large part of the community.

2. Proximity to non-served locations: selecting sites in places without other water sources to increase the coverage, thus promoting equal access to water.

3. Proximity to roads: To allow easy access for transporting materials mechanized vehicles and reduce the costs of construction. It is secondary in case the local community is willing to open the way by clearing the vegetation and/or self-construct the dams..

4. Proximity to strategic places: for example located in pasture areas if the purpose is to serve animals or close to arable land or community farms in case of agricultural use.

5. Proximity to transhumance routes: Where mobile pastoralism is the main characterizing conditions of local communities, planning the sand dams in areas frequently used by herders during seasonal mobilizations can help them save time when fetching water points and increase the chance of survivor for their cattle.

Ideally, these socio-economic conditions would be integrated into the quantitative multicriteria analysis to refine the selection of suitable points. However, the generic problem of data scarcity in SSA, worsened by the long and recent civil war history, together with the intrinsic nature of mobile pastoralists make these data impossible to quantify statistically and even more so at the spatial level. For example, parameters like "Proximity to *kimbos*" is hardly quantifiable because *kimbos* are temporary construction made with locally available material (mostly wood, bushes and mud) and they change place depending on pasture availability and informal clan rules managing the distribution of the land within the community. For these reasons, the abductive approach proposed in this study provides a viable way to integrate local perspective and necessities with top-down biophysical conditions for sand dams suitability.

3.3 Final set of suitable sites

The final set of suitable sites include 16 locations spread across the 10 communities, with distribution depending on the considered water-related problems (Figure 5).

The distribution of the final set of chosen suitable sites is uneven and was determined by the severity of the water-related problems in each community, the presence and direction of transhumance fluxes and the general trade-off between the need of this technology and potential other water solutions. First, not all the communities present biophysically suitable sites for sand dams construction strictly within their territory. This is for example the case of Tchitemo and Nascente. However, there are other water solutions which could be more fit for their conditions and resources. For example Nascente has a water spring that could be better managed and, to solve their high human-animal and violent conflict problems, some other animal-specific water points could be used – for example *chimpacas*, which are the local water harvesting micro-basins for animal use. On the other hand, a larger number of suitable points were selected in the Virei communities of Tchicueya and Sayona (four in each community), because there is no other better suited water harvesting technology in such an arid environment – apart from flood wells built along the sandy rivers, which serve to use the water harvested in the sand. Other suitable points are located in strategic areas to serve both the local communities and the transhumant herders passing by during the seasonal *caminho*. This is, for example, the case of SD4, which is located in the northern part of Tchicueya and it serves both some local *kimbos* and the other herders coming from the south and directed to Bibala area.

The abductive approach has demonstrated to pragmatically deliver the identification of a fair number of suitable points integrating both scientific and indigenous knowledge. In some occasions, allowing the community to freely suggest suitable suites was a successful strategy. For example in the SD12 site in Munhino, we let the key informants (a group of elder herders) guide us to a suitable location based on their experience and knowledge of the place. They first led us to a not-functioning sand dams, which was a sign that they understand the type of water harvesting technology that they were called to support us to identify. They also asked for the rehabilitation of the not-functioning dam, because it used to be a key water point for the cattle. After then, they took us to a point near a biophysically suitable one, which represents the ideal combination of bottom-up and top-down approaches to site identification. However, not always communities' indications provided useful insights. In other occasions, the points suggested by the community were in areas of larger *mulola* were there is high water accumulation in the sand, but the dimensions of the *mulola* were often too large for the type of small sand dams assessed here, or there were no rocky banks. Also most of these larger *mulola* are subject to floods during intense rainfall (which was noted during the focus group discussions and confirmed during field inspections), therefore possibly not suited for sand dams. This indicated that the bottom-up approach relying on indigenous knowledge is much more insightful when communities are familiar with (or well trained and informed on) the technology and they had seen or used it in the past. This is particularly important considering that, regardless of the methodology for sand dams siting that is followed, there is still a significant geomorphological and geophysical assessment work to be performed – increasing the costs to refine the top-down selection.

Discussions

4.1 Integrated large-scale suitability analysis

The mixed-methods approach, presented in this study for sand dams siting, represent a valuable methodological contribution for a broader set of water harvesting practices. In fact, the range of integration of biophysical and socio-economic assessments is still largely underexplored, although widely recommended (Ammar et al., 2016; Bulcock and Jewitt, 2013; Castelli et al., 2022), and most water harvesting siting approaches are relying only on biophysical MCDA. The limitations of such top-down MCDA approaches are multiple. First, MCDA is very sensitive to the input data, which are often scares or have inadequate resolution in most drylands, and particularly in Angola (Amado et al., 2020). This affects the quality of the results, requiring a careful validation or, preferably, an integration with local analysis. For example, Forzieri et al. (2008), Fuentes and Vervoort (2020) and Vishwakarma et al. (2021), among others, developed analyses for similar infrastructures based on engineering and technical perspectives, recognized their limitations when the results were validated, and stressed the importance of incorporating socio-economic aspects related to local and regional dynamics, which are difficult to measure without an interdisciplinary perspective. Bulcock and Jewitt (2013) concluded that the existing guidelines for determining suitable locations for water harvesting base on biophysical MCDA tend to represent only the optimal conditions, claiming that complementing the assessment with a local participatory approach, like the one presented in this study, can be instrumental.

In fact, especially when imbedded in broader water resilience strategies for small communities, following top-down approaches fail to consider knowledge and motivation to adopt the proposed technologies, as well as other political and socio-economic local circumstances that influence adaptation choices (Grum et al., 2016, Van Aalst et al., 2008). debating with the communities and facilitating their internal discussions from the early siting phase can increase local awareness about long-term water supply needs and water harvesting options (Rajabu, 2005; Everard, 2019) and allow the researchers to incorporate useful criteria to siting modeling. This has resulted in increased integration of biophysical and sopcio-economic components in suitability analysis at different scales, from local to national and even global (Al-Adamat et al., 2012; Piemontese et al., 2022, 2020), although the depth of integration between the social and the ecological components varies (Ammar et al., 2016). These integrated assessments often rely on indicators, which provide a quantitative and scalable measure. For example, Piemontese et. al. proposed a social-ecological systems approach for a global suitability of water harvesting using both biophysical and socio-economic indicators. At the local scale, Lasage and Verburg (2015) validate and recommend a similar mix of biophysical and socioeconomic conditions to be considered in order to focus on pertinent characteristics and to ensure an integrated approach when evaluating water harvesting investments.

Our contribution adds to this literature by providing a practical framework to explicitly integrating local knowledge, which is a major frontier in integrated assessments (Al-Adamat et al., 2012; Hart and Mouton, 2005; Robinson et al., 2016). Also, particularly relevant is the application to sand dams, for which such integrated approach was still missing, although highly recommended by experts (Castelli et al., 2022). Our approach thus contributes to expanding the frontiers of knowledge integration on water harvesting implementations and providing a specific guidance on sand dams large-scale siting to increase the spread and the applicability of such a promising technology.

4.2 Insights into sand dams viability and overall fit in Namibe

To support the rapid interest and prospective investments on sand dams in Angola (World Bank, 2022), Serrat-Capdevila et al. (2022) have recently investigated the potential for constructing sand dams in the area, although without providing a specific potential location for sand dams construction. Our final results (the 16 locations assessed with the integrated approach) can thus provide concrete support to investments on sand dams in the area, supporting local water development projects with both our quantitative and qualitative results. In fact, another key finding is that colonial sand dams have been largely used by indigenous people and are considered an asset for the communities (e.g. the colonial dam of Panguelo is the only reliable water point of the community), as opposed to other colonial structures like wells and houses who fell into disrepair or were even vandalized by local herders to reconquer their territory or because of their symbolic meaning of colonial power (Ramazzotti, 1991). The fact that sand dams became embedded in local water use traditions represent thus a peculiar situation, in contrast with most experiences also from larger dams (Liu et al., 2019). This provides new evidence on the viability of sand dams, not only as a biophysically suitable, but also socio-economically and culturally fit technology, encouraging the development of small, distributed and community driven dams for increasing water security in Namibe.

Apart from the territory of the 10 communities (municipalities of Bibala and Virei), our analysis can be used to support other pastoral communities, especially considering that water scarcity is a problem that affects people beyond community's boundaries given the mobile nature of pastural traditions and the increasing climate change-driven migratory trends (Neumann et al., 2015; Sterzel et al., 2014). With our province-scale analysis, other communities could benefit from sand dams construction as adaptation and mitigation strategy to address the increasing impact of climate change and water scarcity. The 2106 biophysically suitable points in the whole province might seem quite a large number considering the time and resources required for a complementary in-field socio-economic assessment. However, other large-scale studies provide a comparable number of suitable points, recommending the integration of local participatory work or at least a local cross-check/validation of the approach, though mostly leaving the in-field part unmet for technical, costs and/or time constraints (Ammar et al., 2016). Nonetheless, we recommend considering our biophysically suitable points as a first selection to be complemented by participatory work, given the possible biases related to the small set of parameters used in the MCDA conceived for a complementary community engagement.

Challenges and way forward

The process of developing a mix-method approach and the extensive field experience open up reflections on a range of challenges and opportunities related to a) the ideal balance between data-driven, top-down biophysical analysis and qualitative participatory research, b) the usefulness and necessity of participatory work beyond the best-siting phase and finally c) a more generic reflection on the fit and implications of sand dams development for frugal, semi-nomadic pastoralists.

Knowledge integration

A critical part of the methodological process was identifying the level of integration between the biophysical assessment and the participatory phase. The criteria for the biophysical analysis were kept to a minimum set of variables, which rendered a coarse first identification of points. Many of these points are likely not overall suitable given the further biophysical requirement that were not accounted in this work for lack of good quality data, but which could be integrated in future analysis. For example, with a higher resolution DEM (i.e.5m or less) it would be possible to estimate the riverbanks height and slope and the throwback area. However, over-reliance on top-down MCDA could lead to downgrading the role of participatory analysis, which should remain central to guarantee a proper inclusion of local stakeholders in the study and the follow up decision process on the implementation (Kallis et al., 2006). Thus, a methodological dilemma remains: Is it more appropriate to include coarse quantitative estimates of biophysical variables or rely on less uncertain estimates from fieldwork? The advantage of the first option is to provide a quick and inexpensive set of suitable points for guiding a more focused in-field inspection. However, the accuracy of the findings might be lower compared to a more extensive in-field participatory phase. The balance between these two approaches is a common struggle that require a good knowledge of the place and careful planning. We suggest tuning the balance between the two research phases depending on spatial data availability, knowledge of the place and level of community engagement.

Participatory research beyond best-siting of sand dams

Beyond the scope of sand dam siting, the participatory engagement helped convening local communities to raise awareness, debate about their needs and experiences and uncover essential matters to take into account for water resources development projects. In this sense, the participatory research approach described here can be useful to a wider research community, since small scale interventions that engage communities have better chances to achieve more engagement in the construction process, ownership of the outcomes, and even foster diffusion of innovations (Mansuri and Rao, 2004; Mulligan et al., 2011). Furthermore, the discussions on why some water points and structures fail or are vandalised was valuable to debate about the importance of maintenance of infrastructure and care within beneficial communities. The focus group discussions promoted a debate on technical matters that helps changing the focus from covering immediate water security needs to developing a longer-term view from the communities, with more emphasis on medium and longer-term needs and more debate on operation and maintenance of the introduced infrastructures (Garfias Royo et al., 2018). More generally, these engagements, facilitated by NGOs, can promote the creation of Water and Sanitation Groups (Grupos de Água e Saneamento), which are local consumer associations or councils, and the implementation of more or less organized models of community water management like the MOGECA model, which is active in some rural municipalities of Angola, but not enough widespread in the south (Baptista and Rall, 2021). A lesson learnt in this work, and highly recommended in other water resources development projects in similar contexts, is the need to guide communities towards a deep understanding of the long term sustainability approach of water harvesting infrastructure and shift the focus from short-term to long term benefits, with the corresponding change in expectations, approach and mentality.

Fixed water resources for mobile pastoralists

A final reflection concerns the epistemological approach to water resources development. It is clear that climate change is increasing resources variability and uncertainty, with negative consequences on local communities. Nonetheless, the solutions proposed by outsiders development projects must acknowledge the diverse universe of point of views and approaches to face such changes and support a really sustainable development (Pisor et al., 2022). The model, although generally positive, of increasing water points and introduce effective water harvesting infrastructure learning from elsewhere experience, should critically reflect on the compatibility with existing mechanism used by local communities, even outside of the scientific literature and debate. Some recent studies on pastoralism and vulnerability suggest mobility as an adaptation of pastoralist to uncertainty and variability, which constitute the very nature of dryland livelihoods. Mobility is seen as an adaptation strategy, which make pastoralists resilient to climatic and other changes (Turner et al., 2014). Under this point of view, supporting such communities with fixed water points might introduce a factor of disturbance in pastural mobility, with the possible consequence of fixing communities because of the initial benefit in availability and accessibility of water, but which might disrupt the mobile arrangement leading to a long term reduction in resilience (Scoons, 1995). These dynamics needs to be further investigated in relation to water harvesting development projects, requiring a dedicated data collection and participatory engagement.

Conclusions

In this work, we introduced a mixed-method approach combining top-down biophysical suitability with bottom-up participatory research to approach large-scale siting of sand dams. While the introduced analytical framework can be used as a general approach to any integrated, large-scale water harvesting siting, the application to sand dams in drylands Angola helped revealing the presence of existing sand dams, which were not reported in previous scientific literature. The existing sand dams well match the potential site identified with the biophysical assessment, confirming the validity of the proposed approach. Overall, the approach has proved to successfully guide the quick identification of 16 potential sites matching the socio-economic requirements investigated during the participatory phase and validated with the local population. However, challenges do exist. The participatory approach should be central, requiring a careful knowledge integration and constant engagement of local people, which is key for ensuring sustainability beyond the siting phase and the project timeframe. Being this research embedded in a cooperation and development project, a follow-up of the case study could monitor and report on the actual functioning and beneficial use of the sand dams to be built in the selected sites, complementing the scarce literature on the complete life-cycle of sand dams implementations, especially relevant for data-scarce regions like dryland Angola.

Acknowledgments

”The work was developed within the project “TransAgua: valorização das boas práticas dos pastores transumantes em gestão dos recursos hídricos e adaptação às mudanças climáticas”, funded within the FRESAN (FED/2017/389-710 - FORTALECIMENTO DA RESILIÊNCIA E DA SEGURANÇA ALIMENTAR E NUTRICIONAL EM ANGOLA”), by the Istituto Camões – Instituto da Cooperação e da Língua).”

References

Al-Adamat, R., AlAyyash, S., Al-Amoush, H., Al-Meshan, O., Rawajfih, Z., Shdeifat, A., Al-Harahsheh, A., Al-Farajat, M., 2012. The Combination of Indigenous Knowledge and Geo-Informatics for Water Harvesting Siting in the Jordanian Badia 2012. https://doi.org/10.4236/jgis.2012.44042

Al-Adamat, R., Diabat, A., Shatnawi, G., 2010. Combining GIS with multicriteria decision making for siting water harvesting ponds in Northern Jordan. Journal of Arid Environments 74, 1471–1477. https://doi.org/10.1016/j.jaridenv.2010.07.001

Amado, M., Rodrigues, E., Poggi, F., Pinheiro, M.D., Amado, A.R., José, H., 2020. Using Different Levels of Information in Planning Green Infrastructure in Luanda, Angola. Sustainability 12, 3162. https://doi.org/10.3390/su12083162

Ammar, A., Riksen, M., Ouessar, M., Ritsema, C., 2016. Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: A review. International Soil and Water Conservation Research 4, 108–120. https://doi.org/10.1016/j.iswcr.2016.03.001

Angola, 2013. Plano de Desenvolvimento Provincial Do Namibe 2013-2017. Luanda, Angola.

Bagnol, B., Verhoesel, K., 2009. O gado: capital simbolico. Relações de genero nas comunidades de pastores. Provicncia de Huíla, Cunene e Namibe.

Beswetherick, S., Carrière, M., Legendre, V., Mather, W., Perpes, T., Saunier, B., 2018. Guidelines for the siting of sand dams. School of Water, Energy and Environment (SWEE).

Bulcock, L.M., Jewitt, G.P.W., 2013. Key physical characteristics used to assess water harvesting suitability. Physics and Chemistry of the Earth, Parts A/B/C 66, 89–100. https://doi.org/10.1016/j.pce.2013.09.005

Carvalho, E.C.D., 1974. “Traditional” and “Modern” Patterns of Cattle Raising in Southwestern Angola: A Critical Evaluation of Change from Pastoralism to Ranching. The Journal of Developing Areas 8, 199–226.

Castelli, G., Piemontese, L., Quinn, R., Aerts, J., Elsner, P., Ertsen, M., Hussey, S., Filho, W.L., Limones, N., Mpofu, B., Neufeld, D.G., Ngugi, K., Ngwenya, N., Parker, A., Ryan, C., de Trincheria, J., Villani, L., Eisma, J., Bresci, E., 2022. Sand dams for sustainable water management: Challenges and future opportunities. Science of The Total Environment 156126. https://doi.org/10.1016/j.scitotenv.2022.156126

Descheemaeker, K., Mapedza, E., Amede, T., Ayalneh, W., 2010. Effects of integrated watershed management on livestock water productivity in water scarce areas in Ethiopia. Physics and Chemistry of the Earth, Parts A/B/C, 10th WaterNet/WARFSA/GWP-SA Symposium: IWRM - Environmental Sustainability, Climate Change and Livelihoods 35, 723–729. https://doi.org/10.1016/j.pce.2010.06.006

Ertsen, M.W., Biesbrouck, B., Postma, L., Westerop, M. van, 2005. Community organisation and participatory design of sand-storage dams in Kenya. Coalitions and Collisions 175–185.

Feng, S., Fu, Q., 2013. Expansion of global drylands under a warming climate. Atmos. Chem. Phys. 13, 10081–10094. https://doi.org/10.5194/acp-13-10081-2013

Fischer, J., Riechers, M., Loos, J., Martin-Lopez, B., Temperton, V.M., 2021. Making the UN Decade on Ecosystem Restoration a Social-Ecological Endeavour. Trends in Ecology & Evolution 36, 20–28. https://doi.org/10.1016/j.tree.2020.08.018

Forrester, J., Cook, B., Bracken, L., Cinderby, S., Donaldson, A., 2015. Combining participatory mapping with Q-methodology to map stakeholder perceptions of complex environmental problems. Applied Geography 56, 199–208. https://doi.org/10.1016/j.apgeog.2014.11.019

Forzieri, G., Gardenti, M., Caparrini, F., Castelli, F., 2008. A methodology for the pre-selection of suitable sites for surface and underground small dams in arid areas: A case study in the region of Kidal, Mali. Physics and Chemistry of the Earth, Parts A/B/C, Hydrological Assessment and Integrated Water Resources Management with Special Focus on Developing Countries 33, 74–85. https://doi.org/10.1016/j.pce.2007.04.014

Fuentes, I., Vervoort, R.W., 2020. Site suitability and water availability for a managed aquifer recharge project in the Namoi basin, Australia. Journal of Hydrology: Regional Studies 27, 100657. https://doi.org/10.1016/j.ejrh.2019.100657

Gain, A.K., Giupponi, C., Wada, Y., 2016. Measuring global water security towards sustainable development goals. Environ. Res. Lett. 11, 124015. https://doi.org/10.1088/1748-9326/11/12/124015

Garfias Royo, M., Parikh, P., Mutwiri, F., Harper, J., Bukachi, V., Mulligan, J., 2018. Using Future Scenario Planning as a tool for informed decision making on infrastructure interventions in Kibera, Nairobi in Kenya. Habitat International 79, 30–41. https://doi.org/10.1016/j.habitatint.2018.07.009

Grum, B., Hessel, R., Kessler, A., Woldearegay, K., Yazew, E., Ritsema, C., Geissen, V., 2016. A decision support approach for the selection and implementation of water harvesting techniques in arid and semi-arid regions. Agricultural Water Management 173, 35–47. https://doi.org/10.1016/j.agwat.2016.04.018

Hart, T., Mouton, J., 2005. Indigenous Knowledge and its Relevance for Agriculture: A case study in Uganda. INDILINGA– African Journal of Indigenous Knowledge Systems 4, 249–263.

Hartley, P.A., 1997. Sand-storage dams: an alternate method of rural water supply in Namibia. University of Cape Town, Master thesis.

Herrero, M., Addison, J., Bedelian, C., Carabine, E., Havlik, P., Henderson, B., van de Steeg, J., Thornton, P., 2016. Climate change and pastoralism: impacts, consequences and adaptation: -EN- -FR- Le changement climatique et le pastoralisme : effets, conséquences et adaptation -ES- Cambio climático y pastoreo: efectos directos, repercusiones y adaptación. Revue Scientifique et Technique de l'OIE 35, 417–433. https://doi.org/10.20506/rst.35.2.2533

Hertel, B., 1974. Review of Field Research: Strategies for a Natural Sociology. International Review of Modern Sociology 4, 102–104.

Ifejika Speranza, C., 2010. Drought Coping and Adaptation Strategies: Understanding Adaptations to Climate Change in Agro-pastoral Livestock Production in Makueni District, Kenya. Eur J Dev Res 22, 623–642. https://doi.org/10.1057/ejdr.2010.39

Kallis, G., Videira, N., Antunes, P., Pereira, Â.G., Spash, C.L., Coccossis, H., Quintana, S.C., del Moral, L., Hatzilacou, D., Lobo, G., Mexa, A., Paneque, P., Mateos, B.P., Santos, R., 2006. Participatory Methods for Water Resources Planning. Environment and Planning C: Government and Policy 24, 215–234. https://doi.org/10.1068/c04102s

Lasage, R., Aerts, J.C.J.H., Verburg, P.H., Sileshi, A.S., 2015. The role of small scale sand dams in securing water supply under climate change in Ethiopia. Mitig Adapt Strateg Glob Change 20, 317–339. https://doi.org/10.1007/s11027-013-9493-8

Lasage, R., Verburg, P.H., 2015. Evaluation of small scale water harvesting techniques for semi-arid environments. Journal of Arid Environments 118, 48–57. https://doi.org/10.1016/j.jaridenv.2015.02.019

Limones, N., Marzo-Artigas, J., Wijnen, M., Serrat-Capdevila, A., 2020. Evaluating drought risk in data-scarce contexts. The case of southern Angola. Journal of Water and Climate Change 11, 44–67. https://doi.org/10.2166/wcc.2020.101

Liu, D., Liu, H., Wang, X., Kremere, E., 2019. World Small Hydropower Development Report 2019. United Nations Industrial Development Organization; International Center on Small Hydro Power.

Loring, P.A., Gerlach, S.C., Huntington, H.P., 2013. The New Environmental Security: Linking Food, Water, and Energy for Integrative and Diagnostic Social-ecological Research. Journal of Agriculture, Food Systems, and Community Development 3, 55–61. https://doi.org/10.5304/jafscd.2013.034.005

Mansuri, G., Rao, V., 2004. Community-Based and Driven Development: A Critical Review. World Bank, Washington, DC. https://doi.org/10.1596/1813-9450-3209

Mufinda, F., Boinas, F., Nunes, C., 2015. Prevalence and Factors Associated with Cattle Brucellosis in Animal Herds of the Namibe Province in Angola. Alexandria Journal of Veterinary Sciences 47, 7–17.

Mulligan, J., Tompsett, A.L., Guthrie, P.M., 2011. An 'engineer–client' framework for participation in community-scale infrastructure projects. Proceedings of the Institution of Civil Engineers - Engineering Sustainability 164, 35–47. https://doi.org/10.1680/ensu.2011.164.1.35

Neumann, K., Sietz, D., Hilderink, H., Janssen, P., Kok, M., van Dijk, H., 2015. Environmental drivers of human migration in drylands – A spatial picture. Applied Geography 56, 116–126. https://doi.org/10.1016/j.apgeog.2014.11.021

Ngugi, K.N.K., Gichaba, C.M.M., Kathumo, V.M.V., Ertsen, M.W.M., 2020. Back to the drawing board: assessing siting guidelines for sand dams in Kenya. Sustain. Water Resour. Manag. 6, 58. https://doi.org/10.1007/s40899-020-00417-4

Penn, H.J.F., Loring, P.A., Schnabel, W.E., 2017. Diagnosing water security in the rural North with an environmental security framework. Journal of Environmental Management 199, 91–98. https://doi.org/10.1016/j.jenvman.2017.04.088

Piemontese, L., Castelli, G., Fetzer, I., Barron, J., Liniger, H., Harari, N., Bresci, E., Jaramillo, F., 2020. Estimating the global potential of water harvesting from successful case studies. Global Environmental Change 63, 102121. https://doi.org/10.1016/j.gloenvcha.2020.102121

Piemontese, L., Fetzer, I., Rockström, J., Jaramillo, F., 2019. Future Hydroclimatic Impacts on Africa: Beyond the Paris Agreement. Earth's Future 7, 748–761. https://doi.org/10.1029/2019EF001169

Piemontese, L., Kamugisha, R.N., Barron, J., Tukahirwa, J.M.B., Harari, N., Jaramillo, F., 2022. Investing in sustainable intensification for smallholders: quantifying large-scale costs and benefits in Uganda. Environ. Res. Lett. https://doi.org/10.1088/1748-9326/ac5ae0

Pisor, A.C., Basurto, X., Douglass, K.G., Mach, K.J., Ready, E., Tylianakis, J.M., Hazel, A., Kline, M.A., Kramer, K.L., Lansing, J.S., Moritz, M., Smaldino, P.E., Thornton, T.F., Jones, J.H., 2022. Effective climate change adaptation means supporting community autonomy. Nat. Clim. Chang. 12, 213–215. https://doi.org/10.1038/s41558-022-01303-x

Prinz, D., Oweis, T., Oberle, A., 1998. Rainwater harvesting for dry land agriculture - developing a methodology based on remote sensing and GIS., in: International Congress Agricultural Engineering, XIII. ANAFID, Rabat, Morocco.

Ramazzotti, M., 1991. IL PROBLEMA DELL'ACQUA NEL SUD DELL'ANGOLA. Africa: Rivista trimestrale di studi e documentazione dell'Istituto italiano per l'Africa e l'Oriente 46, 375–402.

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

Robinson, C.J., Maclean, K., Hill, R., Bock, E., Rist, P., 2016. Participatory mapping to negotiate indigenous knowledge used to assess environmental risk. Sustain Sci 11, 115–126. https://doi.org/10.1007/s11625-015-0292-x

Rockström, J., Falkenmark, M., Allan, T., Folke, C., Gordon, L., Jägerskog, A., Kummu, M., Lannerstad, M., Meybeck, M., Molden, D., Postel, S., Savenije, H.H.G., Svedin, U., Turton, A., Varis, O., 2014. The unfolding water drama in the Anthropocene: towards a resilience-based perspective on water for global sustainability. Ecohydrology 7, 1249–1261. https://doi.org/10.1002/eco.1562

Safriel, U., Adeel, Z., Niemeijer, D., Puigdefabregas, J., White, R., Lal, R., Winslow, M., Ziedler, J., Prince, S., Archer, E., King, C., Shapiro, B., Wessels, K., Nielsen, T.T., Portnov, B., Reshef, I., Thornell, J., Lachman, E., McNab, D., 2005. Dryland systems, in: Hassan, R., Scholes, R., Ash, N. (Eds.), Ecosystems and Human Well-Being: Current State and Trends. Island Press, pp. 623–662.

Scoons, I., 1995. Living With Uncertainty: New Directions in Pastoral Development in Africa. London.

Serrat-Capdevila, A., Limones, N., Marzo-Artigas, J., Marcus, W., Petrucci, B., 2022. Water Security and Drought Resilience in the South of Angola. World Bank. https://doi.org/10.1596/37189

Sietz, D., Lüdeke, M.K.B., Walther, C., 2011. Categorisation of typical vulnerability patterns in global drylands. Global Environmental Change, Special Issue on The Politics and Policy of Carbon Capture and Storage 21, 431–440. https://doi.org/10.1016/j.gloenvcha.2010.11.005

Sterzel, T., Lüdeke, M., Kok, M., Walther, C., Sietz, D., de Soysa, I., Lucas, P., Janssen, P., 2014. Armed conflict distribution in global drylands through the lens of a typology of socio-ecological vulnerability. Reg Environ Change 14, 1419–1435. https://doi.org/10.1007/s10113-013-0553-0

Strohmeier, S., Fukai, S., Haddad, M., AlNsour, M., Mudabber, M., Akimoto, K., Yamamoto, S., Evett, S., Oweis, T., 2021. Rehabilitation of degraded rangelands in Jordan: The effects of mechanized micro water harvesting on hill-slope scale soil water and vegetation dynamics. Journal of Arid Environments 185, 104338. https://doi.org/10.1016/j.jaridenv.2020.104338

Teel, W.S., 2019. Catching Rain: Sand Dams and Other Strategies for Developing Locally Resilient Water Supplies in Semiarid Areas of Kenya, in: Bamutaze, Y., Kyamanywa, S., Singh, B.R., Nabanoga, G., Lal, R. (Eds.), Agriculture and Ecosystem Resilience in Sub Saharan Africa: Livelihood Pathways Under Changing Climate, Climate Change Management. Springer International Publishing, Cham, pp. 327–342. https://doi.org/10.1007/978-3-030-12974-3_15

Turner, M.D., McPeak, J.G., Ayantunde, A., 2014. The Role of Livestock Mobility in the Livelihood Strategies of Rural Peoples in Semi-Arid West Africa. Hum Ecol 42, 231–247. https://doi.org/10.1007/s10745-013-9636-2

Villani, L., Castelli, G., Hagos, E.Y., Bresci, E., 2018. Water productivity analysis of sand dams irrigation farming in northern Ethiopia. Journal of Agriculture and Environment for International Development (JAEID) 112, 139–160. https://doi.org/10.12895/jaeid.20181.726

Vishwakarma, A., Goswami, A., Pradhan, B., 2021. Prioritization of sites for Managed Aquifer Recharge in a semi-arid environment in western India using GIS-Based multicriteria evaluation strategy. Groundwater for Sustainable Development 12, 100501. https://doi.org/10.1016/j.gsd.2020.100501

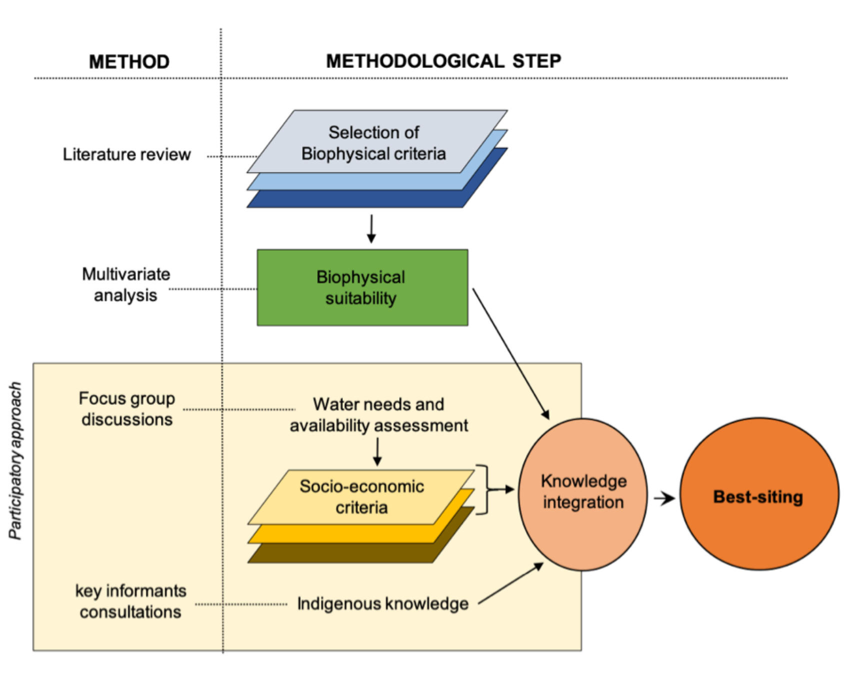
World Bank, 2022. World Bank Injects $300 Million to Support Climate Resilience and Water Security in Angola [WWW Document]. World Bank. URL https://www.worldbank.org/en/news/press-release/2022/03/30/world-bank-injects-300-million-to-support-climate-resilience-and-water-security-in-angola (accessed 5.25.22).

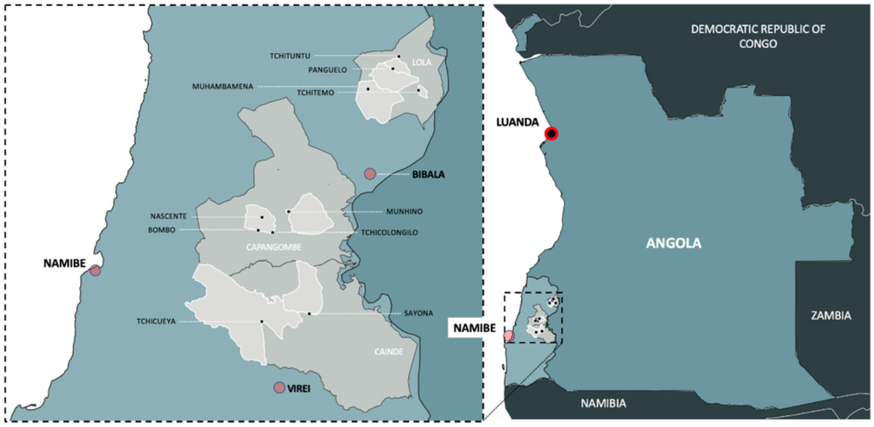
Ziadat, F., Bruggeman, A., Oweis, T., Haddad, N., Mazahreh, S., Sartawi, W., Syuof, M., 2012. A Participatory GIS Approach for Assessing Land Suitability for Rainwater Harvesting in an Arid Rangeland Environment. Arid Land Research and Management 26, 297–311. https://doi.org/10.1080/15324982.2012.709214

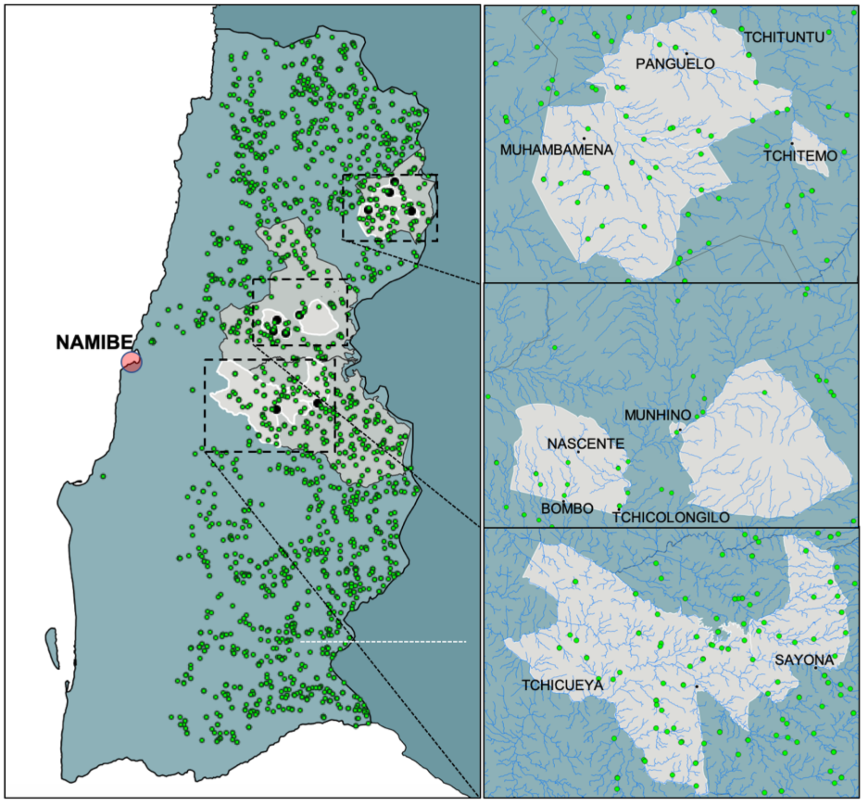
Table 1. Severity score of water-related problems for the 10 communities.

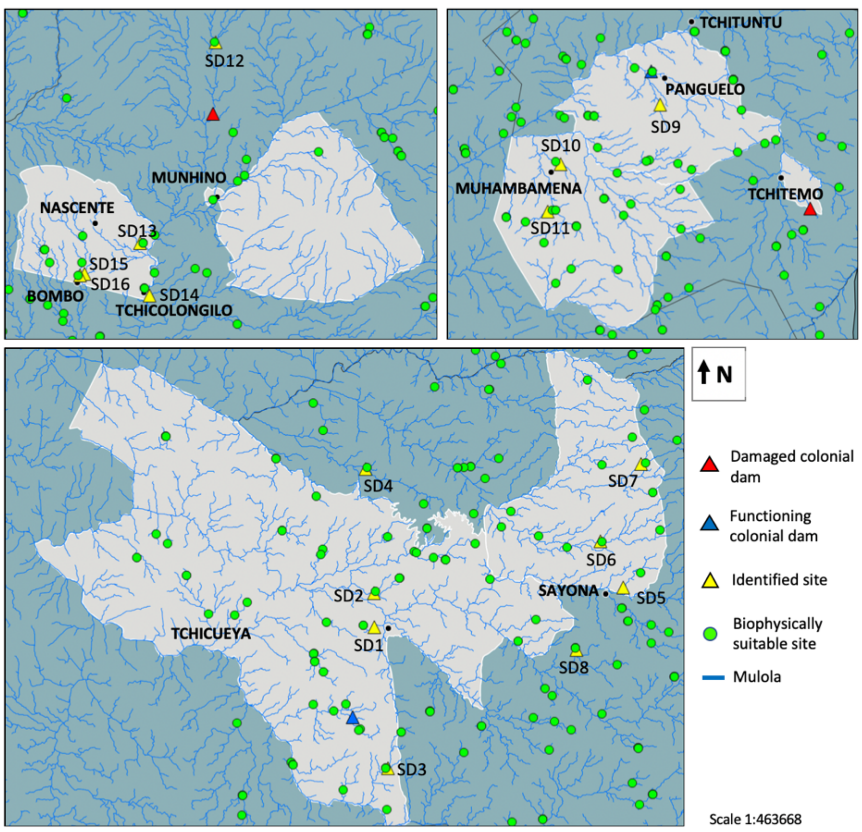
Hosted file

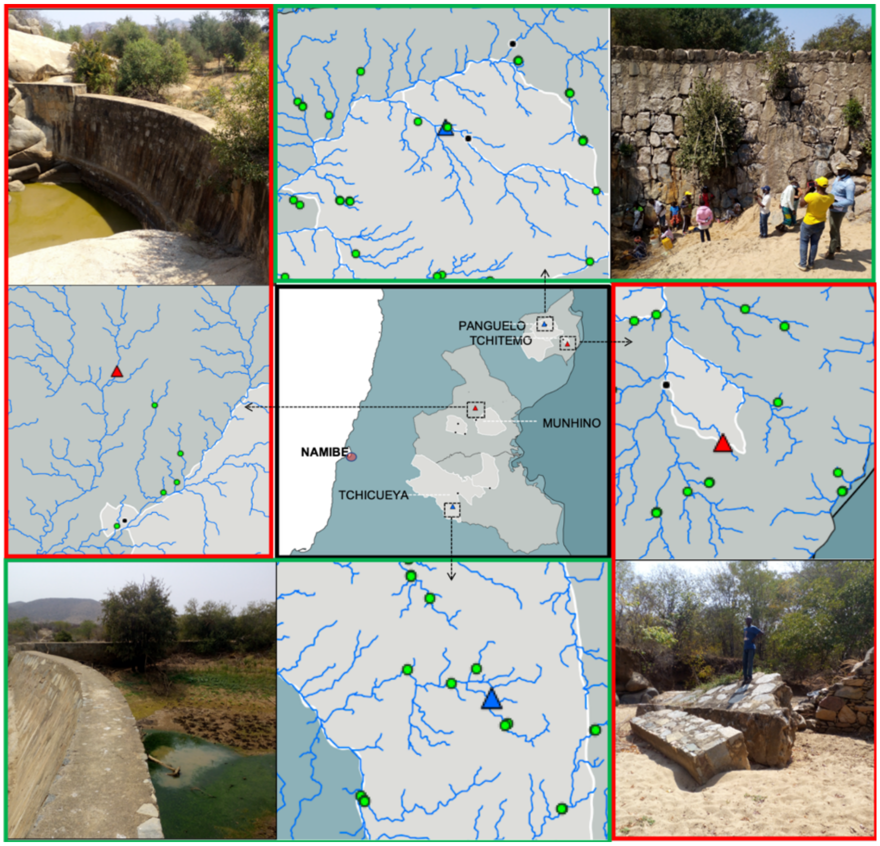
`image1.emf` available at https://authorea.com/users/452589/articles/556451-large-scale-siting-of-sand-dams-a-participatory-approach-and-application-in-angolan-drylands




TCHITUNTU
PANGUELO
LOLA
MUHAMBAMENA
TCHITEMO
BIBALA
NASCENTE
BOMBO
MUNHINO
TCHICOLONGILO
CAPANGOMBE
NAMIBE
TCHICUEYA
SAYONA
CAINDE
VIREI
DEMOCRATIC REPUBLIC OF CONGO
LUANDA
ANGOLA
ZAMBIA
NAMIBE
NAMIBIA


NAMIBE
TCHITUNTU
PANGUELO
MUHAMBAMENA
TCHITEMO
MUNHINO
NASCENTE
BOMBO
TCHICOLONGILO
SAYONA
TCHICUEYA


SD12
MUNHINO
NASCENTE
SD13
SD15
SD16
BOMBO
SD14
TCHICOLONGILO
TCHITUNTU
PANGUELO
SD9
SD10
MUHAMBAMENA
SD11
TCHITEMO
N
SD4
SD7
SD6
SAYONA
SD5
SD2
TCHICUEYA
SD1
SD8
SD3
Damaged colonial dam
Functioning colonial dam
Identified site
Biophysically suitable site
Mulola
Scale 1:463668


PANGUELO
TCHITEMO
MUNHINO
NAMIBE
TCHICUEYA