AN APPRAISAL OF THE EFFECTIVENESS AND SUSTAINABILITY OF SAND DAMS TO IMPROVE WATER SECURITY AND RESILIENCE IN RURAL SOMALILAND

by

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Abstract

Only 28% of the rural population in Somalia has access to basic water services (UNICEF-WHO, 2019), resulting in water and livelihoods insecurity and high vulnerability to climate variability and recurrent droughts. Existing literature and practitioner experience indicates sand dams and sub-surface dams constitute a low-cost and robust rainwater harvesting technology, capable of enhancing water availability in drylands while strengthening community resilience to the effects of climate change.

Somaliland has favourable climatic and hydrogeological conditions for sand dam development but the technology remains underdeveloped and research limited. Through a study of five communities in Somaliland, this research appraises the effectiveness of sand dams as a rural water supply technology, potentially capable of positively impacting water security and resilience in semi-arid and arid environments in the wider Somali region. This study also explores the technical, environmental, socio-economic and cultural aspects involved in the sustainable and effective management of sand dams.

Keywords: Somalia, climate, drylands, rainwater, harvesting, adaptation.

Executive Summary

Background

Sand dams and sub-surface dams are increasingly recognised as low-cost and robust rainwater harvesting technologies to enhance water availability in drylands and build resilience to the effects of climate change (Maddrell, 2018; GWP/UNICEF, 2017; WWAP/UN-Water, 2018). A sand dam is a reinforced concrete or rubble stone masonry structure built across the riverbed of a seasonal river to increase the accumulation of coarse sand upstream and enlarge the natural storage capacity of the riverbed aquifer (Maddrell, 2018). Sub-surface dams are built below the surface of sandy riverbeds to block the downstream groundwater flow and raise the water level in the alluvial aquifer.

There is consensus among researchers (Chritchley and Di Prima, 2012; Neal and Maddrell, 2013; Tuinhof et al., 2012) that sand dams have a comparative advantage over open water storage infrastructure in rural semi-arid and arid lands. Storage in sediment significantly reduces evaporation-loss while filtration through sand reduces the risk of bacteriological contamination. Extensive research on Kenyan sand dams by Lasage et al. (2008), Pauw et al. (2008) Rempel et al. (2005) and De Bruijn and Rhebergen (2006) provided evidence of the positive impact of sand dams in improving social and economic standards, thereby reducing vulnerability and enhancing capacity of communities to cope with drought and climate variability.

Considering this body of evidence, sand dams could be considered a panacea in drylands highly vulnerable to climate change like Somalia, where only 28% of the rural population has access to water supply (UNICEF-WHO, 2019) and the prevalence of water-related diseases such as acute watery diarrhoea is high. Studies conducted by Mohamoud (1990), Oduor and Gadain (2007) and Altai Consulting (2015) conclude that the Somaliland region has favourable climatic and hydrogeological conditions for sand dams. In the last twenty years, several agencies have piloted sand dams and sub-surface dams as part of resilience and development programmes in Somaliland. With only an estimated 20-25 sand dams in existence in Somaliland, this rainwater harvesting technology remains underdeveloped and relatively unknown (Amier, 2013; Altai, 2015).

While some pilot sand dam projects have been documented by implementing agencies, external evaluations and research remain very limited in this geographical context. The case study of four sand dams by Altai Consulting (2015) is the only recent research on sand dams in the context of Somaliland, following the work of Mohamoud in 1990. This research project aims to expand the available body of evidence through a critical appraisal of additional sand dam experiences in Somaliland.

Research rationale and objectives

The overarching goal of this study is to tangibly contribute to the ongoing efforts of communities, civil society and government to address water scarcity and adapt to climate change. In practice, this research aims to inform resilience programming, which includes potentially piloting new sand dam projects.

This research project aims to determine whether sand dams are an effective and sustainable solution to improve water security and build resilience in rural communities in Somaliland. Its objectives are formulated as four research questions:

1. What key lessons can be learned from sand dam practitioner experiences in the region?
2. Are sand dams an effective solution for domestic water supply in rural areas of Somaliland?
3. Can sand dams contribute to improving water security and resilience in the context of Somaliland?
4. What factors influence the sustainability of sand dam technology in the context of Somaliland?

Methodology

The study reviews best practices and lessons learned from practitioners at regional and national levels through a comprehensive literature desk review and key informant interviews. This information is captured in a learning framework which later facilitates the appraisal of sand dam experiences in Somaliland (research question 1). Effectiveness, sustainability and impact on water security and resilience are appraised through a field study of a heterogeneous sample of five communities with access to sand dams and sub-surface dams in the regions of Awdal and Woqooyi Galbeed in Somaliland.

In each site, quantitative and qualitative data was collected through sand dam field measurements, water sampling, sand sampling, transect walks with GPS data collection and direct observation. Semi-structured group interviews and community mapping were conducted with two distinct group profiles in each community covering 95 men and women.

In addition to the analysis of qualitative data from the semi-structured group interviews, the following quantitative data was generated to inform the research questions:

- Using the formula proposed by Nissen-Petersen (2000), the maximum extractable volume of water of sand dams was compared with the dry season water demand for domestic and livestock use.
- Water samples were analysed for turbidity, TDS, pH and thermotolerant coliforms. The results can be considered only as indicative because the number of sample sites was limited to three and the samples could only be collected once, thus limiting the reliability of the data.
- Capital costs of sand dam construction over a 30-year design life were calculated per person with access to sand dam water supply. Operational and maintenance costs of the dam and the water supply facilities were also identified.

Main findings

The research concludes that **sand dams are an effective solution for improving domestic water supply in rural areas of Somaliland**. Sand dams are a socially acceptable, nature-based technology with potential capacity to fully cover community domestic water demand during the dry season. Proper management and monitoring of sand dams is crucial to prevent over-abstraction for other uses. Failure to do so can result in insufficient water availability for domestic use in the dry season.

Water from covered wells in sand dams is perceived by users to be suitable for drinking without any treatment. While sand filtration can achieve WHO drinking water standards of turbidity, pH and TTC if the source is adequately protected, unprotected wells or poorly maintained water supply facilities can compromise water quality.

Investing in sand dams is cost-effective, requiring an average capital investment of 21-28 USD per capita for a minimum 30-year supply, less than values reported (by Altai, 2015) for earth dams and *berkads*.

The analysis of factors influencing the **sustainability of sand dam technology in the rural context of Somaliland** indicates very high potential for long-term sustainability but also identifies evidence of current shortcomings. In some cases, insufficient knowledge of this relatively new technology in Somaliland hinders communities' ability to participate in the site-selection and design phase in a more informed and proactive manner. Adequate sensitisation through visits to other sand dams and broader community consultation on site-selection can mitigate potential negative impacts on downstream dwellers, such as reduced well yield and increased erosion of unconsolidated riverbanks.

The findings also illustrate the importance of considering pre-existing conditions, community user preferences and willingness to pay when designing sand dam water supply facilities. To be effective and accepted by communities, sand dams need to improve upon pre-existing facilities either by reducing time/distance for water collection or by reducing water expenditure, or both.

Adequate sand dam maintenance over a 30-year lifespan ranges from 0.7 to 1.2 USD per person per year. Maintenance costs of associated water supply facilities range from only 0.1 USD/person/year for manual lifting from wells, up to an average of 3 USD/person/year for solar piped-water systems. The results suggest affordability is not a limiting factor of sand dam maintenance, nor is the availability of technical services, materials and spare parts. The key limiting factors identified are:

- Low sense of community ownership and buy-in; insufficient knowledge of sand dam technology sometimes results in limited community participation in the design process.
- Insufficient community awareness and capacity to conduct essential sand dam maintenance such as the repair of gabions to protect the dam from erosion.
- Low user satisfaction levels and unwillingness to pay where convenience and accessibility is not visibly improved by the new sand dam and facilities.

This research provides evidence that **sand dams contribute to improve water security and community resilience** in four critical ways:

- Safeguarding access to water supply for domestic and livestock use during the long dry season (*Jilal*), with net gains from two to five months of local water supply as a direct result of the increased water storage capacity of the alluvial sand aquifer.
- Reducing the risk of water-borne pollution through sand filtration. The provision of safe drinking water free of coliforms can only be assured through protected water sources and well-maintained facilities.
- Sustaining agro-pastoral and pastoral livelihoods by covering 58-100% of combined domestic and livestock water demand in the dry season as well as supporting income generation through increased irrigated farming and diversifying income sources.
- Increasing riverine vegetation quantity and variety thanks to the rise of the water table. This results in enhanced resilience of the riverine ecosystem and improved adaptive capacity to climate change (Ryan and Elsner, 2016).

The above benefits have direct causal links to improved food security as well as nutrition and health, which in turn contribute towards enhancing individual, household and community resilience capacities to cope with climate-related shocks.

Conclusion and recommendations

The findings of this research are based on a limited sample of sites therefore the results are not statistically representative and cannot be extrapolated to all sand dams in Somaliland. The research however meets its objective of appraising the effectiveness, sustainability and impact of sand dams in Somaliland, directly expanding the limited body of evidence on this topic and in this geographical area by complementing the case study of four sand dams conducted previously by Altai (2015).

This study strongly recommends the piloting of sand dams in new locations of Somaliland based on the analysis of effectiveness, sustainability and positive impacts of sand dams to alleviate water insecurity and shore up community resilience to climate change. Available local technical capacity, a supportive public policy framework, the relative security and stability of Somaliland as well as the favourable climatic and hydrogeological conditions confirmed by Mohamoud (1990), Oduor and Gadain (2007) and Altai (2015) all contribute to a highly conducive environment to realize the potential of sand dams and related water supply facilities.

This study recommends building on the lessons learned from engineers in Somaliland and other experiences in arid environments in Africa, some of which are captured in the learning framework (Chapter 4). In particular, the design of sand dam projects should consider the coverage of domestic and livestock water demand for host and nomadic populations in the dry season (as well as other uses like water trucking). Sand dams built in series can be a suitable option to further enhance storage capacity and meet the projected demand with minimum downstream impact.

To maximise benefits and sustainability, sand dam projects need to be jointly led with communities from the initial decision-making stages of site-selection and design of water supply facilities. This requires investing in building capacity and creating in-depth community awareness around this new technology. To remain effective in the long term, post-implementation support and monitoring is critical to the sustainability of community-managed sand dams and facilities.

Finally, this study also recommends accurately documenting future pilot sand dam projects to record lessons learned and challenges faced. Scaling up and refining this experience in the context of Somaliland has the potential to expand this valuable and innovative technology to benefit communities in other Somali regions where climate-resilient water supply solutions such as sand dams remain underdeveloped.

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Glossary

Aquifer groundwater	A body of permeable rock or sand that can hold or transmit
Berkad	Manmade underground reservoir, lined or un-lined, excavated to store surface runoff
Catchment	An area draining rainwater.
Deyr	Short rainy season in the Northern Somali region, which typically lasts from mid-September to mid-December
Flash-floods	Flooding by rainwater run-off.
Gu	Long rainy season in the Northern Somali region, which typically lasts from mid-March to mid-June
Jilal	Dry season in the Northern Somali region, which typically lasts from mid-December to mid-March
Key	An underground extension preventing seepage.
River banks	The two sides of a sand river.
Riverbed	The area between the river banks.
River floor	The base under the sand in a riverbed.
Run-off	Rainwater running off a surface.
Shoats	Term use in Somalia referring to goats and shoats
Spillway	Overflow for surplus water from a dam.
Throwback	Length of sand reservoir upstream of the dam.
Togga	Seasonal river.
Underground dyke	River floor protruding upwards.
Wadi	Seasonal river.
Wing walls	Extensions of a dam wall into riverbanks.

Acronyms

FAO	Food and Agriculture Organization
FGD	Focus Group Discussions
GWP	Global Water Partnership
HH	Household
IFAD	International Fund for Agricultural Development
KEBS	Kenya Bureau of Standards
KII	Key Informant Interview
MoA	Ministry of Agriculture
MoERD	Ministry of Environment and Rural Development (Somaliland)
MoL	Ministry of Livestock
MoWR	Ministry of Water Resources (Somaliland)
NGO	Non-Governmental Organisation
O&M	Operation and Maintenance
PRA	Participatory Rural Appraisal
RCC	Reinforced concrete
RHW	Rainwater harvest systems
Sh	Somaliland shilling
SSD	Sub-surface dam
SWALIM	Somalia Water and Land Information Management
ToR	Term of Reference
TDS	Total Dissolved Solids
TTC	Thermotolerant coliforms
UNDP	United Nations Development Programme

UNFPA	United Nations Population Fund
UNICEF	United Nations Children Fund
USD	United States Dollar
VC	Village Committee
VSF	Veterinaires Sans Frontiers
WET	Wadi Evaluation Tool
WALP	Water for Agro-pastoral Livelihoods Pilot Project
WASH	Water, Sanitation and Hygiene
WEDC	Water, Engineering Development Centre at Loughborough University
WHO	World Health Organization
WWAP	United Nations World Water Assessment Programme

Units and conversions

Barrel of water	200 litres
Household	6 members per household (UNFPA, 2016).
Jerrycan of water	20 litres
Man height	1.6m (Traditional measure for well depth)
Truck of water	9,000 litres
US$	Equivalent to 8,500 Somaliland Shilling (Generally recognized exchange rate as of July 2019).

Chapter 1. Introduction

1.1 Background

A sand dam is a reinforced concrete or rubble stone masonry structure built across the riverbed of a seasonal river to increase the accumulation of coarse sand upstream and enlarge the natural storage capacity of the riverbed aquifer (Maddrell, 2018; RAIN, n.y.). The sand stored behind the dam is recharged every time rains flood the sandy riverbed (Nissen-Petersen, 2000). The heavier and coarser sand in the run-off deposits behind the wall, while the lighter silt and fine sand flows over the dam spillway (Maddrell, 2018). Water is stored in the pores of the sand reservoir that builds behind the dam. Figure 1 shows a sand dam built in stages and different water abstraction options.

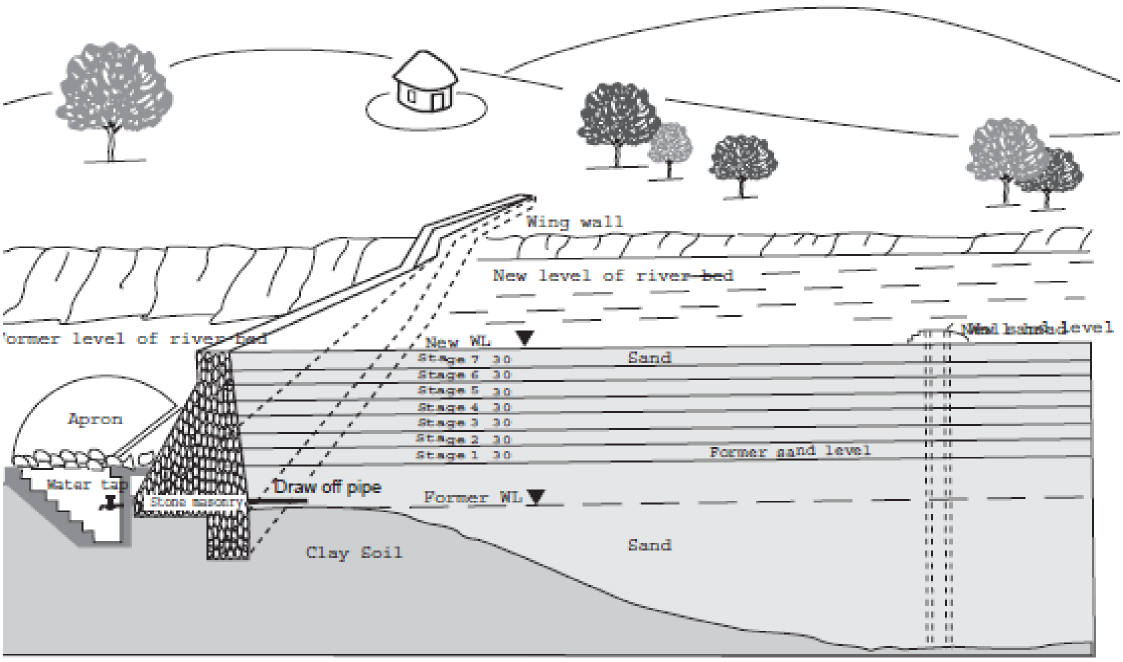

Figure 1. Cutaway model of a sand dam built in stages. The dam is equipped with an infiltration pipe with tap stand*. Source: Nissen-Petersen (2000).*

Sand dams are built several meters above the ground and sub-surface dams are built below the surface of the riverbed to block the downstream groundwater flow and raise the water level in the alluvial aquifer (Figure 2). Sand dams therefore enlarge storage capacity, while sub-surface dams use the existing riverbed storage capacity (VSF, 2006). In general, sand dams are used in narrower sections and where the topographical gradient in relatively high. Sub-surface dams are suitable for wider sections with low topographical gradients usually found in the transition areas from hills to plains.

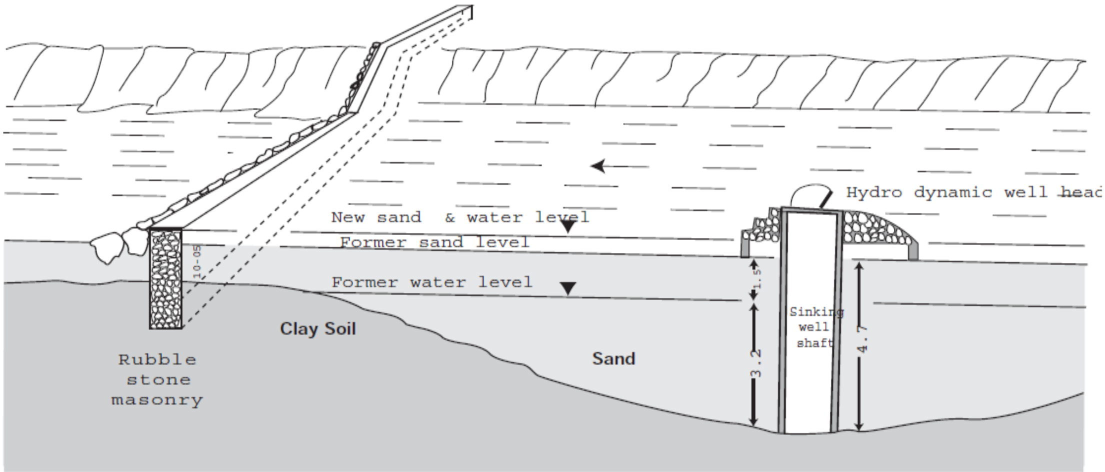

Figure 2. Sub-surface dam and sinking well with hydrodynamic wellhead. *Source: Nissen-Petersen (2000).*

According to Nissen-Petersen (2006), subsurface dams are less expensive and easier to maintain than sand dams, but have less storage capacity. Throughout the study, reference to sand dams includes both sand dams and sub-surface dams, except where specific distinction is made between the two.

Sand dams and sub-surface dams are increasingly recognised as low-cost and robust rainwater harvesting technologies to enhance water availability in drylands while building resilience to the effects of climate change. The UN World Water Development Report (WWAP/UN-Water, 2018) features sand dams as a nature-based storage solution with potential to mitigate the risks related to water availability in arid and semi-arid lands. The Global Water Partnership and UNICEF recognise riverbed infiltration techniques such as sand dams as climate-smart infrastructure (GWP/UNICEF, 2017).

The majority of the research on sand dams has taken place over the last decade. Since 2006, authors have provided evidence of the benefits and positive impacts of sand dams in rural arid and semi-arid areas, mainly in Kenya and Ethiopia. There is consensus among researchers (Chritchley and Di Prima, 2012; Neal and Maddrell, 2013; Tuinhof et al., 2012) that sand dams have a comparative advantage over open water storage infrastructure in the context of semi-arid and arid rural lands. Storage in sediment significantly reduces evaporation-loss and filtration through sand reduces the risk of bacteriological contamination. The construction of a sand dam leads to larger volumes of water stored in the riverbed while simultaneously ensuring higher water quality and availability, usually lasting throughout the dry season when water supply is scarce (Tuinhof et al., 2012). Extensive research on Kenyan sand dams by Lasage et al. (2008), Pauw et al. (2008), Rempel et al. (2005) and De Bruijn and Rhebergen (2006) provided evidence of the positive impact of sand dams in improving social and economic standards, thereby reducing vulnerability and enhancing capacity of communities to cope with drought and climate variability.

Considering this body of evidence, sand dams could be considered a panacea in drylands highly vulnerable to climate change, such as Somalia, where access to rural water supply is extremely low and the prevalence of water-related diseases such as acute watery diarrhoea is high. Somalia is the only country with an urban-rural gap exceeding 50, with 83% of the urban population using basic water services, compared with just 28% of the rural population (UNICEF-WHO, 2019, p.28). More specifically, a household survey completed in January 2014 showed that in rural areas of the semi-autonomous region of Somaliland this gap drops to 3%, which is the lowest access rate in the world (HYDRONOVA, 2019, p.19).

According to Oduor and Gadain´s (2007) report for FAO-SWALIM, Somalia has ephemeral streams that yield adequate amounts of sand that could be used to conserve water for domestic, livestock and irrigation purposes. Yet, despite this apparent potential for development, sand dams remain relatively rare in the country, except for some examples in Somaliland. Somalis are however very familiar with rainwater harvesting techniques. *Berkads* (cement-lined open water reservoirs), *waro* (water pond/earth dams) and *xadlings* (bunds) are testimony to a long history of harnessing rainwater. Rural households mostly rely on rainwater harvesting through *berkads*, earth dams/pans and shallow wells with high seasonal variability, or, the procurement of expensive water from vendors. Groundwater sources in Somaliland are generally underdeveloped: aquifers are limited, mostly deep, and often highly saline or low yielding.

Mohamoud (1990), Oduor and Gadain (2007) and ALTAI (2015) conclude that the Somaliland region has favourable climatic and hydrogeological conditions for sand dams. Somaliland´s National Vision 2030 (MNPD, 2011) also highlights the high potential of harvesting surface water as well as government willingness to raise resources for water supply development. In the last twenty years sand dams and sub-surface dams have been piloted by agencies including Action Aid, IFAD, Somaliland Red Crescent, the World Bank and government line ministries (MoERD and MoWR). Information from key informant interviews suggests there are an estimated number of 20-25 sand dams and sub-surface dams in Woqooyi Galbeed, Sool, Todgheer and Awdal regions of Somaliland. It therefore remains an underdeveloped and relatively unknown rainwater harvesting technology in Somaliland as concluded by Amier (2013) and ALTAI (2015).

1.2 Aim and research questions

This research project aims **to determine whether sand dams are an effective and sustainable solution to improve water security and build resilience in rural communities in Somaliland.** Its objectives are formulated as research questions:

***Question 1*: What key lessons can be learned from sand dam practitioner experiences in the region?**

Insights from selected case studies in Somaliland, Kenya and Ethiopia, as well as relevant manuals and key informant interviews, are summarized into a best practice and learning framework. The framework guides the assessment of the selected sand dam sites in Somaliland and assists in the interpretation of the field research results.

***Question 2*: Are sand dams an effective solution for domestic water supply in rural areas of Somaliland?**

In November 2002, the UN Committee on Economic, Social and Cultural Rights adopted its general comment No. 15 on the Right to Water stating that: "*The human right to water entitles everyone to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses*" (CESCR, 2003). The Human Rights Council (2011) adopted, through Resolution 16/2, access to safe drinking water and sanitation as a human right.

→Are sand dams able to provide sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses in rural contexts of Somaliland?

→Are sand dams a cost-effective technology?

***Question 3*: Can sand dams contribute to improving water security and resilience in the context of Somaliland?**

The dry season is a climate stress for rural households in Somaliland, characterized by food and water scarcity, increased market prices and exposure to human and livestock diseases. Erratic or below-average rainy seasons leading to drought conditions are frequent in Somalia, with the most recent occurring in 2019, 2017 and 2011. Rainy season failure reduces crop productivity, pasture regeneration and water source replenishment, further exacerbating food and water insecurity in the dry season. Water security is defined by UN-WATER (2013) as *"The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability"*.

→Are existing sand dams in Somaliland contributing to improve water security?

→How do sand dams contribute to individual, livelihood and ecosystem resilience to climate-related stresses and shocks?

***Question 4*: What factors influence the sustainability of sand dam technology in the context of Somaliland?**

OECD (2000) defines sustainability as "*measuring whether the benefits of an activity are likely to continue after donor funding has been withdrawn. Projects need to be environmentally as well as financially sustainable*." Sustainability remains a major challenge for rural water supply in Africa.

→What can we learn from the Somaliland experience regarding the technical, social, financial and environmental factors influencing the sustainability of sand dams?

1.3 Scope, structure and use of the study

The study first analyses best practice and lessons learned from documented experiences in Somaliland, Kenya and Ethiopia to develop a best practice and learning framework for the study of sand dam sites. While the scope of this desk review is regional (Horn of Africa), the fieldwork focuses specifically on five communities with access to sand dams in Woqooyi Galbeed and Awdal regions of Somaliland. Located in the northwest of Somalia, bordering Djibouti and Ethiopia, Somaliland is a self-declared autonomous region of Somalia. The five communities studied have a total of four sand dams, two sub-surface dams and one collapsed sand dam.

Chapter 2 sets the scene with a broader analysis of available literature on sand dams and sub-surface dams, focusing on both positive and negative impacts. Chapter 3 presents the methodological approach used to answer the research questions and outlines the scope and limitations of the study. Chapter 4 presents the best practice and learning framework developed from the desk review of documented experiences in Ethiopia, Kenya and Somaliland, practitioner manuals and key informant interviews in Somaliland. Chapter 5 describes the context of the five study sites and presents the field data collected. The discussion of results in Chapter 6 is structured around the research question sub-themes while Chapter 7 presents conclusions and final recommendations.

The overarching goal of this study is to tangibly contribute to the ongoing efforts of communities, civil society and government to address water scarcity and adapt to climate change. In practice, this research aims to inform resilience programming and the piloting of new sand dam projects.

Chapter 2. Literature review

1. Literature search strategy

The literature research was structured around two objectives: firstly, the review of existing academic research on sand dams and practitioners' project documentation, case studies and manuals; secondly, the identification of specific literature on sand storage dams in Somalia and/or Somaliland specifically. Loughborough University´s VPN was used for advanced search through Google Scholar and the Loughborough Library Catalogue using the keywords: `sand´, `dam´, `sand dam´, `sand dams´, `artificial sand aquifers´, `sand storage dams´ and `sub-surface dams´, limiting the search to documents with these keywords in the title. Reference lists from the initial documents found were used to identify other relevant resources. WEDC professors and Excellent Development staff also provided additional references. Most academic studies found in the literature review focus on sand dams in Ethiopia and Kenya. The web search was less productive regarding studies on Somalia and Somaliland. ALTAI´s 2015 report was available online while other relevant documents were provided directly by FAO-SWALIM as well as key informants.

2.2 Sand dams: a rainwater harvesting technology for semi-arid climates

Riverbed infiltration techniques have traditionally been used in sub-Saharan Africa and South Asia for decennia to capture and store run-off in sediment and create 'artificial' sand aquifers (GWP/UNICEF, 2017, p.30). Sand dams have been utilised in India for centuries, and were later developed in the beds of African seasonal rivers in Ethiopia, Burkina Faso, Kenya and Zimbabwe (Nissen-Petersen, 2006, p.45). These have been mainly isolated initiatives built by local NGOs or farmer groups to enhance their water supply (RAIN, n.y., p.2). WWAP/UN-Water (2018, p.39) quotes Lasage et al. (2008) and Love et al. (2011) who find that despite the high storage potential of the seasonal sandy riverbeds in arid and semi-arid lands sand dams are currently under-utilised in many regions of Africa. Indeed, figures from Grey and Sadoff (2006), quoted by Foster and Briceno-Garmendia (2010, pp.279-280), show average storage capacity in Africa is about 200 m^3 per capita, much less than other regions such as North America with 5,961m^3 per capita.

External expertise is recommended for appropriate riverbed survey, siting and design. Bonham Cozens (2017) conducted an exhaustive literature review to produce a technical feasibility framework synthesising the required conditions of precipitation and run-off, storage capacity and affordability for the feasibility of sand dams. RAIN (n.y.), Nissen-Petersen (2006) and Maddrell (2018) provide detailed guidelines, case studies and lessons learned on the implementation of sand dams. Their key recommendations are captured in the learning framework in Chapter 4.

2.3 Advantages of sand dams

Many authors provide evidence of the benefits and positive impacts of sand dams in rural arid and semi-arid areas of Kenya and Ethiopia. There is consensus among researchers and practitioners (ALTAI, 2015; Chritchley and Di Prima, 2012; Tuinhof et al., 2012; GWP/UNICEF, 2017; IRC, 2014; Neal and Maddrell, 2013) that sand dams have comparative advantages over open water dams in the context of semi-arid and arid lands: storage in sediment significantly reduces evaporation-loss while filtration through sand reduces the presence of pathogens. The construction of a sand dam ensures higher water quality and availability, usually lasting throughout the dry season when water supply is scarce (Lasage et al., 2011, p.4; Tuinhof et al., 2012, p.40; HYDRONOVA, 2019, p.67). According to Chritchley and Di Prima (2012, p.47) and Tuinhof et al. (2012, p.40), the storage capacity of sand dams typically varies between 1,000 and 2,000 m^3. An IRC study (2014, p.1) raises the range of storage capacity up to 5,000m^3, while Neal and Maddrell (2013, p.3) and Maddrell (2018, p.18) believe the storage capacity of sand dams can potentially range up to 20,000m^3.

Case studies show that water from sand dams is mainly used for domestic purposes as well as agriculture and other livelihoods. In Kenya, people are known to use sand dam water for kitchen gardens and tree nurseries (SAHEL, 2006, p.3) whereas in Borana (Ethiopia) it is mainly used for livestock watering (Chritchley and Di Prima, 2012, p.47). HYDRONOVA (2019, p.66) describes the increase of small-scale irrigated agriculture as a primary benefit of sand dams in Somaliland.

Lasage et al. (2008) and Pauw et al. (2008) build on previous research from Rempel et al. (2005) and De Bruijn and Rhebergen (2006). They study socio-economic impacts by comparing population groups with and without sand dams in the Kitui District (Kenya). Results of both studies show a reduction in distance to the water source and thus a reduction in time spent fetching water. Lasage et al. (2008, p.71) conclude an average increase in domestic water use of about 20L/day after sand dams construction, whereas Pauw et al. (2008) conclude an average increase of 23.4 L/day. Conversely, neither of the studies records an increase in domestic water use in the population groups without sand dams. SAHEL (2006, p.33), working in Makueni County in Kenya, also report a significant reduction in time spent fetching water, decreasing from 4-8 hours to 15-20 minutes.

Interviews conducted by Lasage et al. (2008, p.71) show a positive effect in the reduction of vector-born disease. Pauw et al. (2008, pp.40-41) conclude suffering of common diseases such as malaria, cold and amoebic dysentery had become worse for households without access to dams, while the majority of households with a dam identified a decrease in disease. However, due to questionnaire bias, the results were rendered inconclusive. Neither of these studies focused on health benefits in depth. It can be assumed that an increase in domestic water use volume will have a direct positive impact on hygiene practices (ALTAI, 2015, p.81).

A HYDRONOVA (2019, p.76) study in Somaliland highlights “improved human health and reduced under-five mortality” as a principal economic benefit of sand dams. If the source is protected from contamination, improved access to safe water supply is also expected to result in reduced water-related disease morbidity (VSF, 2006, p.16). Many authors point at reduction in malaria prevalence compared to surface water storage options, which host mosquito-breeding sites (IRC, 2014, p.2; RAIN, 2008, p.3; SASOL, 2004, p.8; VSF, 2006, p.16). A reduction in breeding sites for the snail hosts of schistosomiasis has also been reported as an advantage of underground storage (IRC, 2014, p.2).

Improved access to water supply after sand dam construction facilitates livestock watering (SAHEL, 2006, p.23) and can also increase the amount of suitable areas permanently accessible for livestock grazing (VSF, 2006, p.46). An increase in water availability and decrease in time spent fetching water can improve agricultural production, creating time for alternative economic activity, which in turn can increase household incomes (SAHEL, 2006, p.33). Due to improved water availability, accessibility and reliability, case studies in the Kitui District in Kenya show an increase in irrigated surfaces, crop diversification and the development of non-agricultural activities such as brick manufacturing and basket weaving.

Results from Lasage et al. (2008, p.73) show the average household total income had risen by 9,000 KSh in 2005 compared to average income in 1995, while the group with no sand dams experienced no change in average income. Pauw et al. (2008, p.39) compare income change in the 5 years following multiple sand dam construction, showing an average income increase of 27,242 KSh for households with access to sand dams and an average decrease of 37,851 KSh for those without sand dams. While using different approaches and methodologies, with their associated biases and limitations, both Lasage et al.’s (2008) and Pauw et al.’s (2008) studies provide evidence of the impact of sand dams in improving social and economic standards and thus in reducing vulnerability and enhancing capacity to cope with drought and climate variability.

The majority of documents studied in this review highlight the cost-effectiveness of sand dams. If the design and construction is of good quality and maintenance is adequate, they have the longest lifespan of any water storage infrastructure and may last for decennia (ALTAI, 2015, p.88). Neal and Maddrell (2013) refer to sand dams as a low-cost rainwater harvesting technology, with a life span of 30-50 years and virtually zero operational and maintenance costs. However, poor construction quality or poor site selection can render sand dams expensive due to high maintenance costs, low storage capacity or low levels of community use (ALTAI, 2015, p.85). Maintenance of dams, hand pumps and wells used for water abstraction need to be factored in, as operating costs may be more than those of surface dams (Lasage et al., 2011, p.3; VSF, 2006, p.17). Tuinhof et al. (2012, p.41) use a cost-benefit approach to study aquifer recharge structures. For the case study of Kitui District (Kenya), they estimate the total investment costs may vary between USD 10,000 - 15,000 USD, including 2-5 dug wells with hand pumps. Annual maintenance and monitoring costs are estimated at about 10% of the investment costs per year. (Tuinhof et al., 2012, p.38)

Several authors have studied sand dam benefits in mitigating land degradation and enhancing resilience to climate hazards such as drought and floods. Ryan and Elsner's (2016) study of historical satellite-imagery indicated that vegetation biomass was significantly higher at sand dam sites during drought periods and that vegetation at sand dam sites recovered more quickly from drought. Ryan and Elsner (2016) concluded that sand dams enhance the resilience of marginal environments and increase the adaptive capacity of drylands. Foster and Briceno-Garmendia (2010) also recognise artificial water storage ensures reliable water supply during droughts and retains excessive water during periods of flooding. Neal and Maddrell (2013, p.4) conclude that a permanent increase in the water table around sand dams allows trees and other vegetation to grow naturally along seasonal riverbanks. Groundwater recharge, improved soil and increased vegetation reduce the loss of biodiversity and the overall ecosystem degradation. The benefit to local vegetation and biodiversity is also echoed by SASOL (2004, p.8) and Maddrell (2018, p.18).

2.4 Challenges and limitations

The main challenges identified by the different authors include site-selection, design, construction and maintenance as well as the sustainable and equitable management of the source while mitigating potential negative impacts on downstream users. A study from Nissen-Petersen (2006, p.45) showed that only about 5% of the dams built during the last forty years in Machakos, Makueni, Kitui, Mwingi, Embu and Meru counties in Kenya were functioning properly. The process of locating suitable sites requires significant expertise and failure due to poor siting considerations is common (IRC, 2014, p.1; HYDRONOVA, 2019, p.83). The complexity of dam design and varied quality of subcontractors can also lead to poor construction quality, resulting in high maintenance costs and failure rates (ALTAI, 2015, p.81; HYDRONOVA, 2019, p.83). Budget concerns due to logistical challenges, unexpected delays and changes in availability of materials are common (IRC, 2014, p.7; VSF, 2006, p.20; HYDRONOVA, 2019, p.90). Maintenance, particularly of abstraction infrastructure, is necessary while difficulties in covering maintenance costs are common (IRC, 2014, p.6). Lack of availability of spare parts and skilled mechanics in rural areas often makes communities dependent on external assistance and can cause infrastructure to fall into disuse (ALTAI, 2015, p.112). Although communities often express their desire to be involved in the maintenance of facilities, lack of funds means that they cannot take responsibility for large-scale repair work (HYDRONOVA, 2019, p.85). Institutionalised sustainable financing models are necessary to cover life-cycle costs and follow-up support from committed external agencies is essential (IRC, 2014, p.6).

Special attention should be given to the robustness of the structure to withstand peak river discharges and erosion (RAIN, 2008, p.20). Careful maintenance and immediate repair is necessary to prevent floodwater eroding the dam and the riverbanks during heavy rains (Nissen-Petersen, 2006, p.53). RAIN (2008, p.22) studied the Kenyan experiences of the local NGO SASOL and concluded higher quality design and construction substantially reduces maintenance needs. Nissen-Petersen (2006, pp.48-53) affirm sand dams have a great potential for supplying water from small riverbeds in semi-arid, arid and semi-desert zones of Africa, provided the criteria of siting, design, construction and maintenance are adhered to.

Water quality largely depends on the abstraction method used as well as the presence of pollution sources. RAIN (2008) noted that one of the main actions for protecting water quality is to prevent human and livestock contamination of the throwback area of the dam and surrounding riverbanks. Two recent studies published in scientific journals analysed water quality of sand dams in south-eastern Kenya and obtained divergent results regarding bacteriological contamination in shallow wells. Quinn et al.'s (2018) assessment in Machakos and Makueni counties showed water from test holes and covered wells had median TTC levels of 0/100 ml while scoop holes had 159/100ml. Turbidity and conductivity for both scoop holes and covered wells however exceeded the WHO guideline values. Ndekezi, James and Patrick´s (2019) study on Kitui-West Sub-County, showed that the majority of assessed physicochemical parameters and trace metals complied with KEBS limits at the rates of more than 90%, except turbidity, Cu and Fe that complied with low overall scores; 44%, 56% and 35% respectively. TTCs were detected at high rates of 94% in scoop holes and 47% in shallow wells.

Challenges can also relate to land ownership issues (Tuinhof et al 2012, p.14), institutional issues in terms of investment (who pays?), priority uses and resource capture (who benefits?) as well as management arrangements (who controls?) (GWP/UNICEF, 2017, p.29-30). Community management with different levels of institutional support seems to be the most common management arrangement documented. Lessons learned from RAIN (2008, p.21) suggest the community must be involved intensively to establish ownership, which has proven to be one of the critical factors for successful construction and sustainable maintenance of sand dams. The benefits of a sand dam are mostly collective but can also provide income through farmland irrigation, livestock watering, brick making and other livelihood benefits. As Pauw et al. (2008, p.47) study of Kitui sand dams in Kenya demonstrates, despite the fact that most people know the community owns the dam, 29% of households believe benefits are not equally shared. This perception is mainly related to the ability to fetch water and the distance to the dam. Inequity in benefit sharing is regularly documented by practitioners such as IRC (2014, p.6). According to Pauw et al. (2008, p.47), without rules regulating use, problems can arise as people start fetching high amounts of water, depleting a dam before the end of the dry season. GWP/UNICEF (2017, p.29-30) also highlights the need to ensure that downstream users do not lose out from upstream water storage. To address these issues, ALTAI (2015, p.9) recommends increased investment in the assessment of power dynamics and community-level water tenure rights prior to project implementation.

2.5 Scalability and resilience to climate change

Ryan and Elsner (2016) used hydrological modelling and satellite imagery to compare normalised difference vegetation index at sand dam sites and control sites in Makui District (Kenya), identifying higher levels of robustness to periods of extended droughts of ecosystems around sand dams.

Aerts et al. (2007) conducted pioneering research studying the robustness of sand dams to climate change using a water balance model-STREAM to simulate water availability in the Kitui District over a period of 100 years. Lasage and Andela (2011) later conducted a comparable study to that of Aerts et al. (2007), applying STREAM model to simulate changes in river discharge under different climate change scenarios in the Dawa river basin in Ethiopia. Their conclusions align with those of Aerts et al. (2007), showing that under future climate scenarios, declining river discharges will cause sand dams to consume a relatively larger part of the discharge, thus affecting downstream users. Lasage and Andela (2011, p.6) estimate the limit to the development of sand dams in 1,000 dams in the Melka Guba catchment and 600 dams in the Mormora catchment, to maintain flow reduction within an acceptable 3% by 2050.

Aerts et al. (2007), Lasage and Andela (2011) and Lasage et al. (2015) agree that, from an hydrological point of view, sand dams are a feasible adaptation strategy to deal with current scarce water resources and to improve water security under climate change. At the same time, all authors show that significant upscaling of sand dams in a catchment has the potential to reduce flows downstream, and that this reduction is further exacerbated in future climate change scenarios studied. Authors differ on what they consider acceptable downstream flow reduction.

For Aerts et al. (2007, p.579) a 20% reduction of flow would result in water shortages to downstream users, while Lasage et al. (2015, p.335) believe a 20% reduction will only have moderate downstream impacts.

The conclusions from these authors converge in the recognition that upscaling sand dam development requires basin-level coordination and development strategies. Development strategies should be informed by specific basin-level research in order to maximise the benefits of sand dams and limit negative downstream impacts in a range of different climate scenarios.

2.6 Sand dams in Somaliland

Mohamoud (1990) analysed rainfall, run-off, evaporation, soil infiltration and topography data sets in Somaliland and suggested that, in most non-flat areas, dams can be built to a height of up to 6m to trap medium-sized sand grains without slowing the flood. The author concludes that sand filled dams are feasible in the region and that they can be an effective method to improve water supply during the dry season. SWALIM's *Potential of Rainwater Harvesting in Somalia* report (Oduor and Gadain, 2007, p.19) also concluded that Somalia has ephemeral streams that can yield adequate amounts of sand to conserve water for domestic, livestock and irrigation purposes.

The WALP project (2015-2018) in Somaliland developed a Wadi Evaluation Tool (WET) allowing for fast and broad spatial analysis of *wadi* water harvesting potential in a selected area, yielding a weighted ranking between the potential sites (Hydroc, 2015). The WET tool cannot be considered as a substitute for the field surveys but can assist in the rapid identification of areas where sand or sub-surface dams might be a viable solution to water harvesting (HYDRONOVA, 2019, p.17).

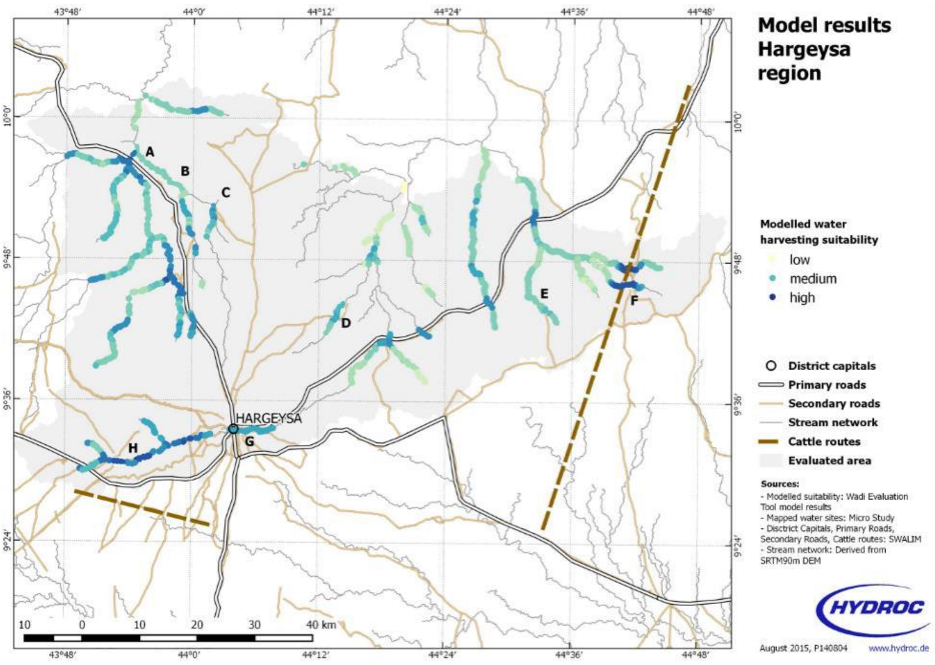

Figure 3. Example of the WET result display with blue dots showing the modelled water harvesting suitability in the light grey assessment area*. Source: Hydroc (2015).*

ALTAI (2015, p.81) evaluation of two sand dams and two weir dams in Somaliland concluded the usage was sub-optimal in three of the sites due to poor site selection, errors in construction calculations and procedures, as well as lack of adequate maintenance. The distant location of the sand dam and presence of private own farms along the riverbanks are highlighted among factors hindering access to water supply in the sand dam. This is the only independent evaluation of existing sand dams identified in Somaliland. By appraising five additional sand dam sites, this study aims to generate additional evidence on the effectiveness, sustainability and impacts of sand dams in the context of Somaliland.

Chapter 3. Methodology

3.1 Research strategy

The study first captured best practices and lessons learned from practitioners at regional and national levels in order to develop a learning framework to facilitate the appraisal of sand dam experiences in Somaliland. Effectiveness, sustainability and impact on water security and resilience are appraised through a field study of a heterogeneous sample of five communities with access to sand dams and sub-surface dams in the regions of Awdal and Woqooyi Galbeed in Somaliland. Field research took place from mid-August to early October 2019 with the support of the Concern Worldwide-Somaliland team. The methodological framework in Table 1 summarises the research questions as well as the data collection and analysis methods employed.

The methodology proposed at the concept note stage considered the selection of two types of case study sites: i) communities with functional sand dams and ii) communities with underutilised or non-functional sand dams. However, during research preparation and site selection it became clear that the boundary between these categories is vague and that the reality on the ground is more complex. Hence, categorising a dam as functional or non-functional/underutilised requires research in itself. Consequently, the analysis of the different factors influencing functionality and success became one of the study outcomes.

A heterogeneous sample of sand dams was selected with the objective of studying the research variables in a variety of contexts in order to identify common trends. Twelve potential sites were identified during the desk review process and key informant interviews with relevant stakeholders in Somaliland in August 2019. Five sites with sand dams and sub-surface dams in the regions of Awdal and Woqooyi Galbeed in Somaliland were selected according to the following criteria:

- Sites located in the regions of Awdal and Woqooyi Galbeed in Somaliland, accessible to the author with logistic support from Concern Worldwide.
- Rural communities of less than 500 households.
- Rural communities with different livelihoods: pastoral, agro-pastoral and irrigated farming.
- Diversity of seasonal river morphology and catchment geology and topography.
- Sand dams built in the period 2000-2018, with a mix of newer and older sand dams.
- Sand dams built by different stakeholders (national NGOs, international NGOs and government).

In each site, quantitative and qualitative data was collected through semi-structured group interviews, community mapping, sand dam field measurements, water sampling, sand sampling, transect walks with GPS data collection and direct observation. The sites were studied from an independent and impartial perspective. The study was not intended as a project evaluation and therefore the names of the implementing organisations are omitted. None of the sand dams studied were implemented by Concern Worldwide.

Research aim: To appraise sand dams as an effective and sustainable solution to improve water security and build community resilience to drought in Somaliland.			
Research question	**Detailed questions**	**Data collection method**	**Data analysis and output**
1) What key lessons can be learned from sand dam practitioner experiences in the region?	Lessons learned/recommendations on: •Siting (hydrogeological and topographical factors)? •Siting (socio-economic factors)? •Design and construction? •Water abstraction, operation and maintenance? •Management arrangements, capacity building and enabling environment? •Risk mitigation?	1/Desk review: analysis of case studies, project reports, studies and manuals to summarise key lessons learned in Somaliland, Ethiopia and Kenya. 2/ Key informant interviews (KII) with practitioners.	Data analysis provides a non-exhaustive compilation of lessons learned and best practice, highlighting the critical issues that determine the success of sand dams in other African contexts. Key documents are referenced for further consultation. This learning framework informs the field study of sand dam sites in W.Galbeed and Awdal (Q2, Q3 and Q4).

2) Are sand dams an effective solution for domestic water supply in rural areas of Somaliland?	• Can sand dams provide access to sufficient, safe, acceptable, physically accessible and affordable water for personal and domestic uses? (15 L/p/day with no faecal coliforms/100ml as per Somalia WASH cluster standards) • Are sand dams cost-effective? What are the total lifespan costs and what is the daily cost per person who gains access to sufficient and safe water supply (15 L/p/day with no faecal coliforms/100ml as per Somalia WASH cluster standards)?	1/ Desk review: project documents, designs, BoQ and materials quotes. 2/ Key informant interviews with practitioners. 3/ Transect walk, field measurements and satellite imagery to collect data on dam dimensions, throwback length, location, wells depth and sand composition, among other. 3/ Water quality analysis (TTC/100ml, pH, turbidity and TDS). 4/ Group interviews to collect data on number of users, daily water demand for domestic use, appraisal of water quality, accessibility, affordability and convenience.	Satellite imagery (Google Earth pro) is used to represent the location of sand dams, wells, distribution points, farmland and settlements. Bacteriological water test results are triangulated with water quality perceptions from group interviews. Extractable water volume, water demand and lifespan costs calculations and assumptions are tabulated. The findings across 5 sites are compared and interpreted considering the specific context of each site and the learning framework (Q1).
3) Can sand dams contribute to improving water security and resilience in the context of Somaliland?	What are the impacts in terms of: • Water availability during the dry season? • Water demand for domestic use? • Amount of money spend in water for domestic use? • Incidence of water-related diseases? • Livelihood security and diversification? • Riverine ecosystems and flood risk?	1/ Group interviews for qualitative data on perceived impacts after sand dam construction.	Qualitative analysis of group interviews comparing data from Group A and B in each site. The findings across 5 sites are compared and interpreted considering the specific context of each site.

4) What factors influence the sustainability of sand dam technology in the context of Somaliland?	What factors influence: •Technical sustainability of the dam infrastructure? •Financial sustainability? •Social sustainability? •Environmental sustainability?	1/ Key informant interviews with practitioners. 2/ Transect walk and observation of sand dam, water abstraction facilities condition and use and surrounding environment. 2/ Group interviews and community mapping for quantitative and qualitative data on preferences and convenience, O&M arrangements, willingness to pay, perceived benefits and disadvantages, excluded groups, etc.	Qualitative analysis of KII and group interviews comparing data from Group A and B in each site. The information is triangulated with transect walk observations. The findings across 5 sites are compared and interpreted considering the specific context of each site and the learning framework (Q1).

Table 1. Methodological framework. *Source: Paz Lopez-Rey (2019)*

3.2 Data collection methods

3.2.1 Desk review

Among the documents cited in the literature review, six documents were selected for further in-depth analysis, with the purpose of capturing lessons learned from sand dam experiences in the region and informing the learning framework (Question 1). These documents include case studies, project endline reports and external projects evaluations:

- Ethiopia : IRC (2014)
- Kenya: SAHEL (2006), SASOL (2004) and VSF (2006).
- Somaliland: ALTAI (2015) and HYDRONOVA (2019).

The learning framework was further complemented with key best practice recommendations from recognised manuals on sand dam technology: Nissen-Petersen (2000) and Maddrell (2018).

3.2.2 Semi-structured key informant interviews

The author conducted three semi-structured interviews with experts on the implementation of sand dams in Somaliland:

- Engineer Mr. AbdiRashid Omar (independent consultant with extensive experience implementing sand dams in Somaliland and Djibouti with IFAD and other organizations).
- Engineer Mr. Hariir Farole (engineer at Somaliland Red Crescent Society with extensive experience implementing sand dams in Somaliland)
- Engineer Mr. Mubarik Rabileh and Ms. Rahma Abdirahman (project engineer and project manager of the WALP project at MoERD).

The interviews were conducted at the early stages of the field research to gain an understanding of existing local knowledge and experience with the technology, in order to inform the learning framework (Question 1) and to assist in the identification of potential sites for study.

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3.2.3 Transect walks, observation and field measurements

GPS references, photographs and observation notes were taken during transect walks from the community to the dam as well as upstream and downstream of the dam. The walks also provided the opportunity to conduct short, informal discussions (2 or 3 quick questions) with community members present at different locations: water point operators, farmers irrigating land onsite, water vendors filling trucks and women collecting water. The field observations and additional information gained through these short informal interviews assisted with the triangulation of the findings from the group interviews and community mapping.

Data on river sediment and morphology, dam dimensions and conditions, and characteristics of the principal wells in the throwback was collected at each site using the technical data collection form in Appendix II. Sand samples at 30cm below the surface were collected from the dam throwback to appraise sediment type and estimate drainable porosity with the volume method proposed by Nissen-Petersen (2000, p.14) and Maddrell (2018, p.53).

3.2.4 Water quality analysis

Five samples were collected in sealed dedicated bottles: three directly from wells in the throwback and two from tap stands. The samples were tested for pH, turbidity and TDS using Wagtech digital pH meter, turbidity meter and conductivity meter available at Concern

Worldwide office. The samples collected could not be analysed for TTC using the Delaqua kit as planned because the vacuum pump was broken and not available in Hargeisa. The MoWR laboratory was under rehabilitation so new samples were taken in December 2019, once the vacuum pump was available. Samples were collected at Aw, Barkhadle, Diinqal and Huluuq, but it was not logistically possible to collect them in Carracad. After preparation of the media, sterilization of the media and petri dishes, and filtration of the samples through the filtration disc, the dishes were placed in the incubator for at 44°C for 18 hours. After the incubation period the petri dishes were observed within 15 minutes. The results can be considered only as indicative because the number of sample sites is limited to three and the samples could only be collected once at each site, thus limiting the reliability of the data.

3.2.5 Semi-structured group interviews and community mapping

Semi-structured group interviews assisted by community mapping was the qualitative data collection method selected to capture community members' perceptions. This approach was considered appropriate in relation to the time and resources available, as well as the need to avoid raising expectations through intense and time-consuming data collection methods. FGD were not deemed relevant due to the amount of information required on a diverse range of themes. As suggested by Denscombe (2010), interviewing more than one person at a time can increase the number and range of participants significantly. The disadvantage is that, in the presence of the group, people may say things that are not representative of what they really do or what they really think, compromising the validity of the data. To minimise this risk and to allow for data triangulation, two distinct groups of 8-10 participants were interviewed at each study site:

- Group A: A gender-mixed group including members from the VC and the water management committee (where these exist), as well as pastoralists (where relevant) and riverine landowners upstream and downstream of the dam site.

- Group B: A group composed exclusively of women, including women-headed households living in the village or in areas upstream and downstream of the dam. This group included women from pastoralist, agro-pastoralist or riverine farming livelihoods.

The participants of both groups were invited through the village committee representative, explaining the composition required for each group. The author facilitated the semi-structured group interviews with simultaneous translation Somali-English provided by Concern Worldwide-Somaliland WASH Engineer (male) and Hygiene Promotion Officer (female). Both staff are experienced in the facilitation of community participatory discussions in rural communities in the region.

A total of 95 individuals (57 women and 38 men) participated in the group interviews held from 25th September to 1st October 2019. Gender and group disaggregation is shown in Figure 2. Further details on the participants and photographs of the group interviews are provided in Appendix IV.

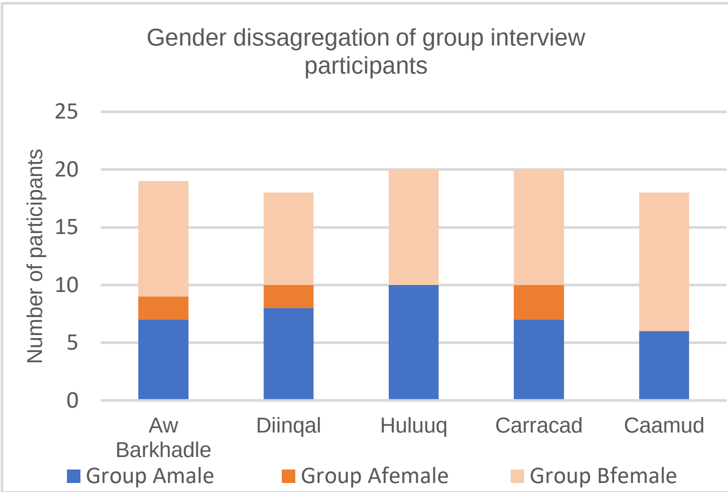

Figure 4. Group interview participants. *Source: Lopez-Rey (2019)*

The answers of the interviewees were recorded in the interview guide (Appendix III), which included a range of potential answers to facilitate subsequent analysis of qualitative data. The option that best represented the group answer was selected and further details, nuances or discrepancies among interviewees were noted. All of the interview questions were open-ended and no closed answer options were proposed to the participants. When only one or two participants replied, other participants were prompted to agree or disagree with the answer given and to provide further explanation.

A community mapping PRA tool was used as an icebreaker to actively engage the participants. Using a flip chart and colour markers the participants were asked to map the settlement area, sand dam, wells, water facilities, land uses and other key features. The map was used by the interviewers to better explain the meaning of some questions (for example the concepts of downstream and upstream) and by the participants to visually represent spatial-related information such as distance, proposed location of sand dam or wells, or location of satisfied and unsatisfied farmers (Appendix IV).

3.3 Data analysis, validity and limitations

3.3.1 Quantitative data

Research questions 2 and 3 required collecting and analysing quantitative data to estimate the following variables:

a. Maximum extractable volume of water from the sand reservoir.

b. Water demand for domestic use in the dry season.

c. Water demand for livestock in dry season.

d. Capital cost of dam and associated facilities

e. Maintenance and wall rising costs of sand dams over a 30-year design period.

f. Operation, maintenance and replacements costs of water supply facilities over a 30-year design period.

In order to produce the following results:

i) % water domestic demand covered by the sand dam supply in the dry season

= a / b x 100

ii) % water domestic and livestock demand covered by the sand dam supply in the dry season

= a / (b+c) x 100

iii) Estimated cost-effectiveness (capital investment per capita)
= d / number of people with access to water supply

iv) Estimated annual recurrent costs (O&M of sand dam and facilities per capita per year for a 30 year design life)

= (e+f) / number of people with access to water supply / 30

Estimated extractable volume of water from the sand reservoir (a)

Hudson (1975) formula for estimating storage capacity of a reservoir considers:

$$Q = (L \times D \times T) / 6$$

Where:
Q= capacity in cubic meters
L= length of the dam wall in meters at full supply
D= maximum depth in meters
T=Throwback in meters

The ALTAI (2015) study applied Hudson's formula with a correction factor of 40% because study comparisons of sand volume calculations using different formulas showed that, on average, Hudson's formula underestimates the sand volume by 40%.

Maddrell (2018) suggests the use of a formula proposed by Nissen-Petersen (2000, pp.16-17):

$$Q = (L \times D \times T) / 3$$

Where:
Q= capacity in cubic meters
L= maximum width of riverbed
D= maximum depth of sand
T=Throwback of the water level in the sand in meters

Nissen-Petersen's (2000) formula reduces the total volume of the rhomboid that makes up L x D x T by a factor of 3 because of the valley shape (Maddrell, 2018, p.27). Nissen-Petersen's formula is applied to estimate storage capacity considering that, in all the sites studied, the maximum width of the riverbed in the throwback section is often much larger than the width at the dam section. The method and limitations in the calculation of these variables are explained below:

- Maximum width of sand in the riverbed (L) estimated with satellite imagery in order to determine the widest section in the throwback.
- Maximum depth of sand below the level of the dyke (D). Probing of the river depth on site was not feasible therefore the depth the communal well behind the dam was used as a reference. The height of the dam wall was not used as reference because only part of the wall is visible above the ground and in general, dams are built on natural rock dykes for cost-effectiveness. Hence, the depth of the sand reservoir behind the dam is assumed to be larger than the dam wall height as shown in Figure 3.

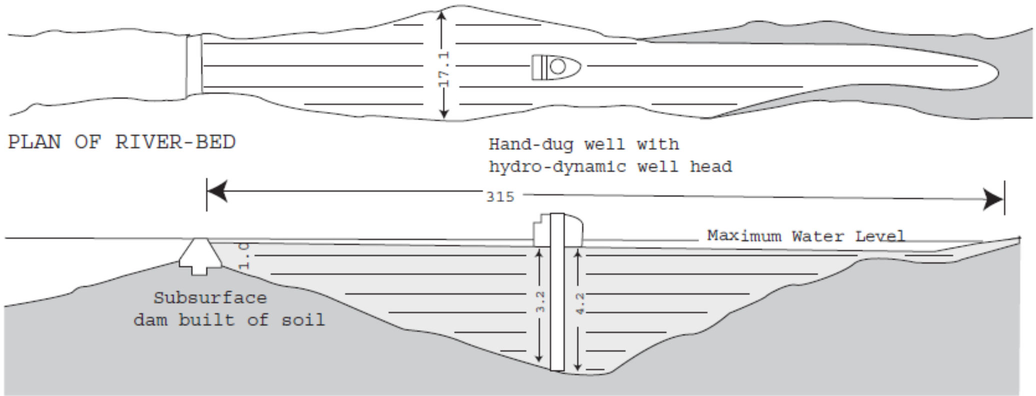

Figure 5. Example of longitudinal profile and plan view of sand reservoir.
Source: Nissen-Petersen (2000, p.24)

Wells are normally built at the deepest point of the sand reservoir. However, where the bedrock is permeable some wells are dug below the bedrock, hence the total well depth can sometimes exceed the sand reservoir depth. In this scenario, the shallow well can also abstract water held in the original riverbed aquifer in addition to the new sand aquifer the dam provides. Community knowledge on the depth of the wells was considered on a case-by-case basis.

- Throwback of the water level in the sand (T). Due to lack of adequate equipment the length of the sand reservoir was estimated based on: i) community members knowledge of the river prior to sand dam construction and ii) presence of physical barriers such as road pillars, other existing sand dams or deposition areas in meanders.

Nissen-Petersen's (2000) formula, also suggested by Maddrell (2018), was used to estimate the extractable volume of water from the sand reservoir.

Volume of extractable water from the sand reservoir = Dam Capacity (Q) x Drainable Porosity

Drainable porosity was estimated by saturating with water a known volume of dry sand collected from the sites (at a depth of 30cm) with a known volume of water and measuring the volume of water drained after 24h (Nissen-Petersen 2000, p.14) and (Maddrell, 2018, p.53).

Drainable Porosity (%) = Volume of water that freely drains ÷ Total volume

The sand collected at a depth of 30cm was very wet and therefore it was not feasible to wait for the sample to dry completely onsite. Due to the limitation in the amount of sediment that could be taken and transported, the drainable porosity could only be calculated for a dry sediment sample of 100ml. This significantly reduces the degree of accuracy compared to results gained using larger volumes. To check the validity of the results, these were compared with the analysis of the sediment type (see Appendix VI) and validated with known drainable porosity values for different sediments published by Nissen-Petersen (2000, p.15).

The maximum extractable volume of water was used to estimate sand dam water supply demand coverage. However, as cited by Hut et al. (2008) and Maddrell (2018), the actual yield of sand dams is normally greater than the water storage capacity of the sand reservoir considering inflows (repeated river flows and base flow) and outflows (seepage to the underlying aquifer and evaporation, which is negligible below 60cm according to Hellwig (1973)). The present study did not aim to calculate the total water availability over the design life period. This would have required the collection of detailed data on rainfall in the catchment area, specific yield of sediments, evaporation and seepage losses, as well as the estimation of the base flow from the sediments and the riverbanks base flow (Borst & de Haas, 2006; Hoogmoed, 2007 and Hussey, 2003).

Current water demand for domestic use in dry season (b)

Average number of jerry cans used per day per household in rainy and dry seasons was informed by the group interviews. UNFPA (2016) average household size of six members per household was considered.

Current water demand for livestock in dry season (c)

Given the large variety in number of livestock owned by each household and the seasonal migration dynamics, livestock water demand estimation is less accurate than domestic water demand. Answers from Group A and B were triangulated in order to estimate the average number of *shoats* and camels or cows per household, as well as the number of nomadic pastoralist households immigrating during the dry season. The WASH cluster-Somalia (2018) standards of 5 L/small animal/day and 20–30 L/large or medium animal/day were considered.

Capital cost, operation, and maintenance costs of dam and facilities over a 30-year period (d, e, f)

The costs of the dam construction and associated facilities were provided by project implementers for three sand dams but could not be obtained for the fourth sand dam and the two SSD. For these, the capital costs of the dam construction, as well as operation and maintenance costs of the dam and water supply facilities over a 30-year design life, were estimated using field data on the dam dimensions, suppliers quotes provided by Concern Worldwide and sand dam bill of quantities examples available from KI1 (2019), KI2 (2019) and

Maddrell (2018). Certain assumptions were considered for the missing information such as the dimension of the key, wall height to the bedrock or reinforcement materials used. Despite these limitations on the accuracy of the results, the consistency in the application of assumptions is considered to provide a reliable estimation for the purpose of appraising total lifespan costs for the different dams and types of facilities.

The detail of the calculations and the assumptions is presented in Appendix VII and VIII.

3.3.2 Qualitative data

The group interviews provided a good account of existing perceptions in the community. Group composition was diverse enough to capture difference of opinions, including from those who felt excluded of the sand dam benefits. Group interview transcripts were analysed question-by-question (Appendix III), triangulating data from Group A and B interviews and the field observations. The qualitative data is presented by theme and sub-theme in narrative, table or quote form in Chapter 5.

The author anticipated the risk of the NGO presence, particularly international staff, creating expectations of future investment in the community and the associated bias. Although it is impossible to completely avoid this risk, clear communication at the start of the interviews (refer to Section 3.4) is believed to have significantly reduced this bias. It is also assumed that conducting interviews in a group dynamic, where responses are heard by fellow participants, produces testimonies closer to reality. Moreover, the atmosphere of the interviews was relaxed and participants were visibly comfortable with the interviewers and the type of questions. In general, it was felt that the community was pleased to have a forum to discuss issues regarding the sand dam and to express advantages and disadvantages externally. Participation was generally very active and the conversation was allowed to flow irrespectively of the interview questions order ensuring all the sub-themes were covered.

Language was a barrier for the author, and despite the fluency in English of the Somali interviewing team, it is expected that some level of nuance and depth to the answers was lost during simultaneous translation. To mitigate this the interview guide was translated to Somali to assist the team in the preparation and interviewing stages.

Another limitation relates to the ability of people to accurately recall past situations. As no baseline information was available, participants were asked to compare the situation before and after the implementation of the dam. Participants could clearly recall changes in very tangible variables such as the number of months wells dry-out before and after dam, but it was harder to evaluate other variables such as vegetation changes.

3.4 Ethics

All participants were clearly informed of the research objectives and contributed voluntarily. To avoid raising expectations and negatively impacting the NGO´s reputation, community groups were informed that the visit had strictly a research and learning purpose. It was clearly communicated that in no case was this an assessment leading to project implementation and that the NGO had no interventions planned in the community. The single exception is Carracad, where Concern Worldwide implements a resilience programme and the research was presented as a separate activity.

Authorisation to interview, record and photograph was obtained before starting, with a written consent form (Appendix IV).

Knowledge and experience of Concern Worldwide local staff was leveraged to support the design of data collection tools using culturally acceptable wording.

Participants remain anonymous except for key informant interviewees who agreed to be cited. Participants were not exposed to any undue danger during this research.

Chapter 4. Learning Framework

A summary of practitioners' best practice and lessons learned

1. Site selection (hydro-geological and topographic factors)

1.1 Lack of emphasis on hydro-geological investigation, soil profiling, infiltration analysis and gradient study prior to implementation can put at risk the long-term sustainability of the infrastructure (KI2, 2019; HYDRONOVA, 2019, p.17).

1.2 Inflow should be sufficient to provide enough sand to fill the dam reservoir and store water in the pores (Maddrell, 2018, p.32; VSF, 2006, p.21). Dense vegetation and local knowledge on tree species can indicate areas with abundant sub-surface water (VSF, 2006, p.19; Nissen-Petersen, 2000, p.8). The presence of waterholes suggests that the riverbed does not leak into the ground below and can be a good indication for siting (Nissen-Petersen, 2006, p.50).

1.3 ALTAI (2015, p.144) KI2 (2019), Maddrell (2018, p.32), SASOL (2004, p.1) and VSF (2006, p.18) recommended topographical gradients between 0.125 and 4%, to ensure adequate flow and reduce silt accumulation. SSD however can be suitable where gradients and velocities are lower (VSF, 2006, p.17).

1.4 Sand dams are recommended for riverbed sections with a maximum width of 25m to reduce the cost of reinforcement while sub-surface dams of natural clay and soil may be more appropriate in wider riverbeds (Nissen-Petersen, 2006, p.49). Well-defined and stable riverbanks of at least 1.5m height decrease the risk of lateral flow and leakages (ALTAI, 2015, p.84; VSF, 2006, pp.18-21). Local knowledge on river morphology and flow during flood episodes should be considered for siting (KI2, 2019) avoiding bends or sections where the watercourse could bypass the dam (Nissen-Petersen, 2006, p.49; VSF, 2006, p.21).

1.5 To minimise costs and maximise water storage, Nissen-Petersen (2006, p.50) recommends to build sand dams and SSD on underground dykes of rock.

1.6 The riverbed should have a solid rock foundation which can support the weight of the dam, and which is not porous (Maddrell, 2018, p.32; VSF, 2006, p.21). Dams built on clay soils may subside (SASOL, 2004, p.11). Dam walls should never be built on fractured rocks or large boulders because such walls cannot be made watertight (Nissen-Petersen, 2006).

1.7 Optimal sites are those with sand and gravel soils with impermeable bedrock at depths of 4-6 metres (Maddrell, 2018, p.45; VSF, 2006, p.18) and permeable river banks to allow base flow recharge the aquifer (KI2, 2019). Thick alluvial deposits such as coarse sand are most optimal (SASOL, 2004, p.22). Low performance of sub-surface dams has been associated with very low infiltration in very fine sands (KI2, 2019; Nissen-Petersen, 2006, p.49).

2. Site selection (socio-economic factors)

2.1 Baseline data on individual and community needs and aspirations should be collected through detailed community assessment to understand water access and utilisation prior to site-selection (IRC, 2014, p.4; SASOL, 2004, p.15). VSF (2006, p.47) identify the inclusion of local livestock keepers in the site selection process as a key success factor in Turkana (Kenya).

2.2 Where the technology is unknown, the community may require sensitization to understand how dams work and take informed-decisions. This can be best done by visiting other sand dams as suggested by KI3 (2019) and KI1 (2019).

2.3 ALTAI (2015, p.145) suggests preliminary assessments to map land ownership and mobilise communities through consultation processes can address power imbalances and ensure infrastructure remains public. Dams should not be constructed on private land and owners of adjacent land should agree to give way to the site (Maddrell, 2018, p.107; VSF, 2006, p.19).

2.4 The site should be easily accessible, preferably in close proximity to dwellings and the main road (SASOL, 2004, p.11; VSF, 2006, p.21). Large distance from local communities is a common cause of disuse of dams (ALTAI, 2015, p.136).

2.5 KI1 (2019) and KI3 (2019) highlight the importance of avoiding sites where there are farmers within 1-2km downstream of the dam because of increased erosion by flash floods and potential reduction in well yields. Further downstream, these effects are negligible.

3. Sand dam design and construction

3.1 Design is sensitive to river morphology, depth to the bedrock, river width, height of the banks, gradient and sediment type. Best practice highlights from interviewed engineers and technical manuals include:

- To avoid silt storing behind the dam, Nissen-Petersen (2006, p.51) and Maddrell (2018, p.130) promote the construction of the dam in stages, with the spillway height raised by 30 cm with each major flooding in order to harvest the heavier coarser sands and allow lighter fine sands and silt to spill over. Other practitioners suggest to start with 1m, then increase the height by 80cm (KI2, 2019).
- Spillway width should be at least the width of the riverbed (KI1, 2019).

- Wing walls should be fully embedded in the river banks, up to 7m for loose soils and about 5m for hard soils (SASOL, 2004, p.43)
- Nissen-Petersen (2006, p.52) states that "*dam walls must be keyed 1 metre into solid and impermeable soil and the thickness of the key should be 0.55 of the height of its dam wall*". When the dam foundation is built on solid bedrock, vertical steel reinforcement bars should be drilled into bedrock (Maddrell, 2018, p.93). Details on trench digging are provided by SASOL (2004, p.45).
- For the dam to support the pressure of sand and water, Nissen-Petersen (2006, p.52) recommends "*the width of the base of the dam to be 0.75 (3/4) of the height of the dam wall. The width of the crest and its height on the downstream side should be 0.2 (1/5) of the height of its dam wall*". Nissen-Petersen (2006, p.52) also suggests the wall on the upstream side should lean in the direction of water flow by a gradient of 0.125 (1/8).
- KI3 (2019) suggests concave dams have greater resistance to the pressure of sand and water.
- The spill-over apron "*should be of the same width as the dam wall and extend up along the wing walls. Large stones should be set into the concrete to break the force of water spilling over*" (Nissen-Petersen, 2006, p.52).

3.2 Detailed guidelines on concrete and stone masonry construction techniques can be found in Maddrell (2018), Nissen-Petersen (2006) and SASOL (2004).

3.3 Construction should take place during the dry season when rain damage to structures is unlikely (IRC, 2014, p.7; VSF, 2006, p.20; HYDRONOVA, 2019, p.90).

3.4 In order to improve work quality and accountability of contractors, HYDRONOVA (2019, p.90) recommends 'prequalification' of companies, and close construction monitoring by a skilled engineer.

4. Water abstraction, operation and maintenance

4.1 To avoid weakening of the structure and maximize water storage KI1 (2019), KI2 (2019), KI3 (2019), Maddrell (2018, p.135) and Nissen-Petersen (2006, p. 53) recommend the following minimum maintenance of dams:

- Replacing the gabions or stone riprap to protect the spillover apron and the base of the wall from erosion.
- Repair erosion damage in the wing walls and the crest caused by big boulders during floods.
- Removing clay top layer every 1 or 2 years to allow good water infiltration.

4.2 The construction and maintenance of the associated water supply infrastructure and requires a high level of technical knowledge (IRC, 2014, p.6). Projects should consider and attempt to quantify maintenance costs, complexity of potential repairs and access to spare parts, paying close attention to water demand and projected use of infrastructure. (ALTAI, 2015, p.92).

4.3 It is important to consider other uses in the design of supply infrastructure (SASOL, 2004, p.9). Separate distribution mechanisms, for example by channelling water from shallow wells to tap stands and livestock troughs, may address contamination issues and improve convenience (HYDRONOVA, 2019, p.86).

4.4 Communal water supply facilities should be placed strategically, acknowledging the groups that may benefit from each (ALTAI, 2015, p.119). The use by non-community members such as nomadic pastoralists and water truckers should be considered in the design of facilities (HYDRONOVA, 2019, p.25).

4.5 Contamination may result from open defecation, animal carcasses and faeces and polluted surface water run-off (Maddrell, 2018, p.72; HYDRONOVA, 2019, p.86). These risks can be mitigated by incorporating sanitation and hygiene promotion and water quality monitoring (HYDRONOVA, 2019, p.83).

4.6 The development of cost-recovery mechanisms is necessary to sustainably finance life-cycle costs if communities are not to receive continued external assistance (ALTAI, 2015, p.88; IRC, 2014, p.6). ALTAI (2015, p.117) and HYDRONOVA (2019, p.94) recommend considering the roles which government, the community and public-private partnerships can play in management and service delivery.

5. Management, capacity building and enabling environment

5.1 The importance of committed local management is recognised as a critical factor for ensuring long-term sustainability and should begin at an early stage, before the site selection process (VSF, 2006, p.47; HYDRONOVA, 2019, p.93).

5.2 Identifying and strengthening existing water management groups can play a key role (HYDRONOVA, 2019, p.93). Supporting existing community-led processes can be more effective to create ownership than externally imposing water committees (ALTAI, 2015, p.85). SAHEL (2006) project evaluation concludes that engaging with Self Help Groups largely contributed to the success of sand dam projects in Kenya and maximized the benefits beyond water supply access.

5.3 The Water Management Committee should be formalised in by-laws defining roles and responsibilities (IRC, 2014, p.4; SASOL, 2004, p.9). All target groups and their aspirations should be included in this process (VSF, 2006, p.19).

5.4 In terms of capacity-building, KI3 (2019), SAHEL (2006, p.30) and HYDRONOVA (2019) recommend exchange visits of community representatives to successful sites, with practical demonstration and community consultations.

5.5 Many practitioners have noted the importance of community sense of ownership and its influence on sustainability (Maddrell, 2018, p.68; SAHEL, 2006, p.31; VSF, 2006, p.48). SAHEL (2006, p.5) note that community groups appreciate an approach which is "*serious, focused and transparent*". Managing budgets transparently and keeping record of all costs and community contributions encourages community commitment to maintain the asset (SASOL, 2004, p.14). K11 (2019) and Maddrell (2018, p.68) highlight that community contribution is essential for sustainability.

6. Risk mitigation

6.1 Interventions which alter communal management dynamics have the potential to reinforce existing power imbalances, disempower specific groups and exacerbate existing conflicts (SAHEL, 2006, p.40). Benefits may not be shared equally and depend largely on land ownership and dam siting, which may render some holdings more accessible for irrigation than others (IRC, 2014, p.6). In order to mitigate conflicts, a participatory assessment of local power dynamics and of the institutions through which grievances are addressed is crucial (SAHEL, 2006, p.40; HYDRONOVA, 2019, p.93). Land tenure issues should be addressed through community dialogue prior to implementation (ALTAI, 2015, p.121; VSF, 2006, p.19).

6.2 Unregulated withdrawals by private water truckers represent a significant threat to the sustainability in areas where water trucking is a growing business (HYDRONOVA, 2019, p.26). Projects must include actions to support communities in controlling appropriation of water, for example by establishing a protected throwback area and by creating regulation to ensure that the Water Management Committee has the right to control non-communal withdrawals (HYDRONOVA, 2019, p.17).

6.3 Quality control and technical backstopping during construction is essential both in mitigating against the failure of dams and in ensuring the safety of labourers. Insufficient knowledge and skill can lead to poor site choice, errors in hydrological calculation and design work and poor execution of construction procedures, which have been noted as the most important reasons for sand dam failure by ALTAI (2015, p.81) and Maddrell (2018, p.131).

6.4 Several practitioners have also noted that the application of short-term 'value for money' measures of success can undermine longer-term project outcomes such as creating strong community ownership and sustainable water management structures (ALTAI, 2015, p.82; SAHEL, 2006, p.40).

6.5 Project design should be informed by an assessment of the potential environmental impacts and necessary mitigation measures, including risk of flooding and erosion (KI2, 2019).

Chapter 5. Case studies in Somaliland

5.1 Area of study

Carracad and Camud sites are located in Borama district (Awdal region), Aw Barkhadle and Diinqal in Hargeisa district and Huluuq in Gabiley district (Woqooyi Galbeed region). All five sites are located in the Dur-Dur watershed which is covered by igneous (basalts and rhyolites) and a wide range of metamorphic rocks (Paron and Vargas, 2007). Carracad and Camud, located in the highlands southward of the Al Mountains, have narrow river valleys, whereas Huluuq, Aw Barkhadle and Diinqal are located in plateaus with wide alluvial plains.

The study area lies at the extremity of the sub-Saharan semi-arid zone. The rainfall pattern is bimodal with primary *Gu* rains between March and June and short *Deyr* rains between August and October followed by a cool long dry *Jilal* period from November to February. It is subject to high potential evapotranspiration (PET) with an annual average between 2,000 and 3,000 mm, exceeding the mean annual rainfall of 500-600mm in Borama highlands and 400-500mm in the plateaus in Woqooyi Galbeed (Paron and Vargas, 2007). As a result, the area experiences a water deficit during most of the year. Ephemeral rivers (locally called *togga* or *tug*) only contain water during flash floods in the two rainy seasons, making them suitable for sand dam construction.

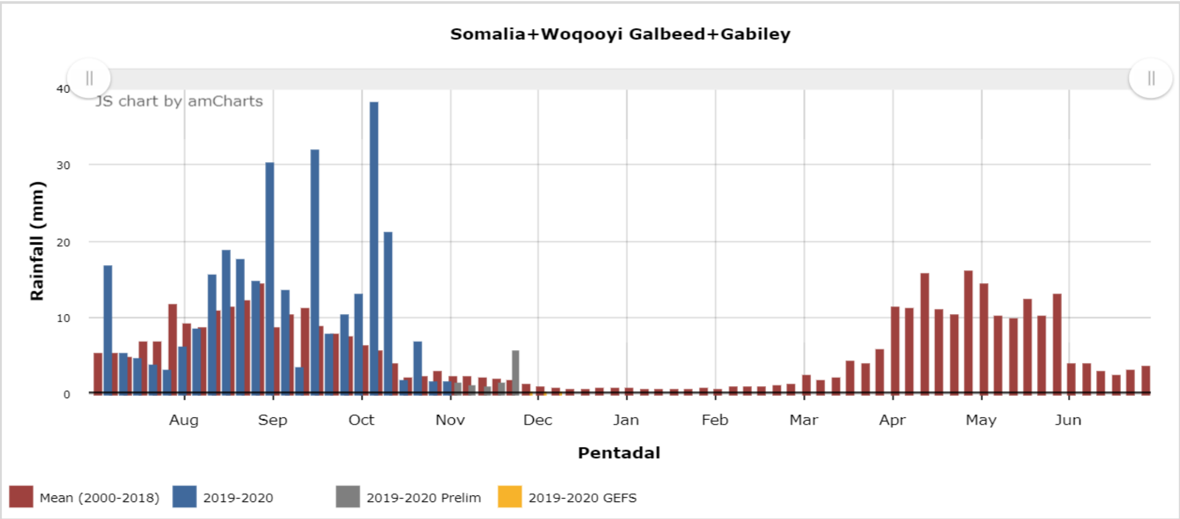

Figure 6. Pentad rainfall 2000-2018 mean and 2019 mean in Woqooyi Galbeed. *Source: USGS (no date).*

The field visit took place from 24th September to 4th October 2019, towards the end of a significantly above average Deyr rainy season as shown in Figure 5. In all studied sites the water table was very high and the sand was fully saturated at depths of only 30cm.

Figure 7. Location of the five study sites in Somaliland. *Source: Google Earth image 14/12/2015 © 2018 Google*

The following sections present the qualitative and quantitative data collected from the semi-structured group interviews, field measurements, transect walks and direct observation in each study site.

5.2 Aw Barkhadle sand dam

Aw Barkhadle lies at the confluence of two seasonal rivers 30 km northeast of the capital Hargeisa. Pastoralism is the main livelihood of the population, estimated at 400 households. Vegetables and fruits are cultivated in the fertile riverbanks but rain-fed cereal farming is not practiced due to soil acidity.

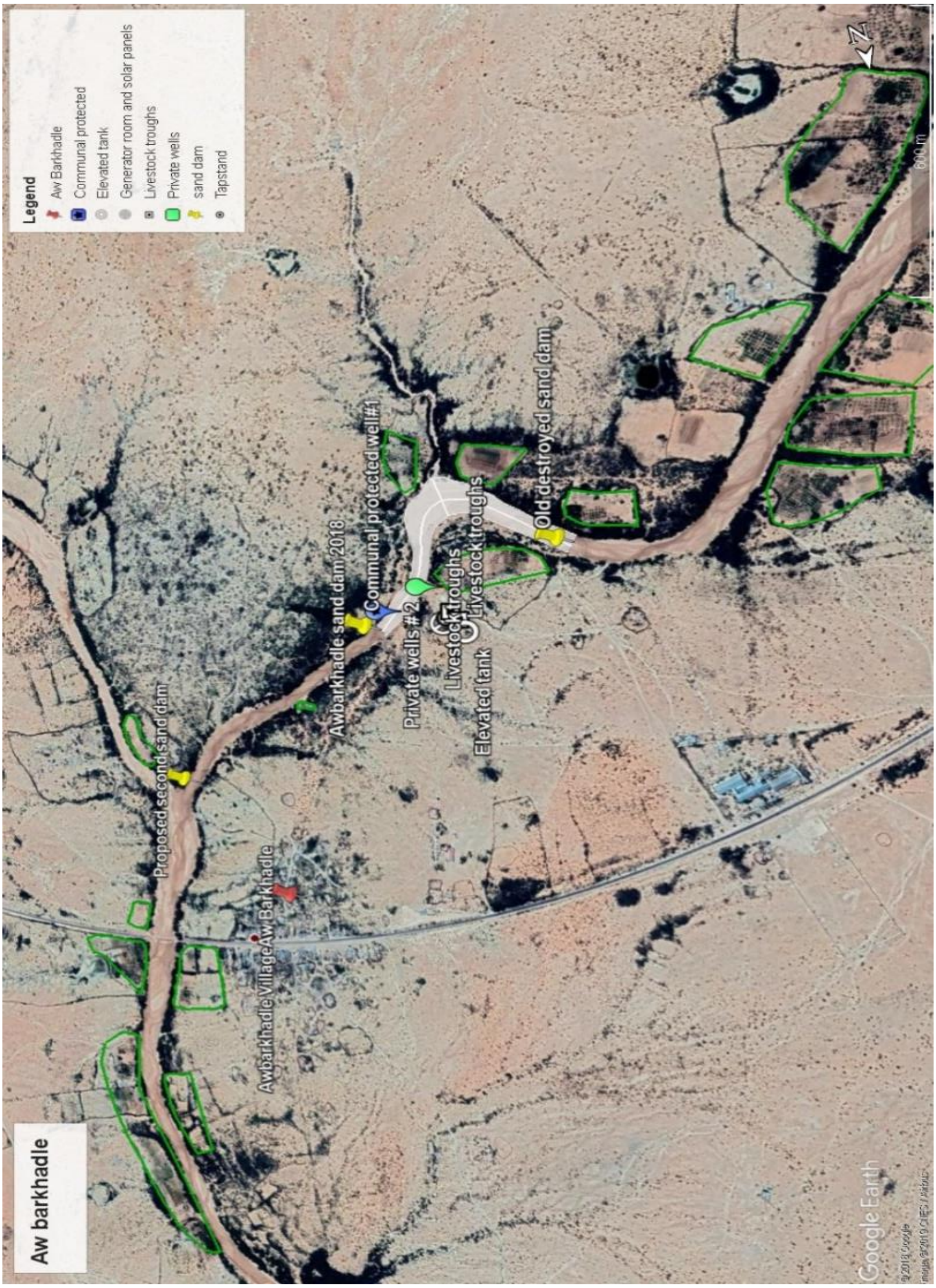

Figure 8. Aw Barkhadle village and sand dam location. *Source: Google Earth image © 2019 CNES/Airbus.*

Sand dam siting, design, construction and condition

A sand storage dam was built in 2018 on the seasonal river Nakhal, approximately 1.5 km south-west of the centre of Aw Barkhadle community, cutting across a river section 55m wide. The river gets an average of five large flash floods per year and up to twenty smaller higher smaller floods. The aquifer of permeable rock is located 2- 4 meters under the riverbed. Irrigated farming is practiced upstream of the dam and further downstream at the confluence with the river Rift Dogor (Figure 8). The implementing agency and the community jointly selected the site after a comprehensive consultation process. The site selected is close to a previous dam washed away by floods. The dam built as a road crossing in 1972 as part of the Hargeisa-Berbera road construction project.

The contractor hired local unskilled labour but the community did not contribute directly to the sand dam construction. The group interviewed was however aware of the materials used and the total cost of the entire project. The project endline report reflects a total cost of 67,387 USD for dam construction and 57,796 USD for appurtenant structures.

The dam has a concave shape, with a total length of 55.3m, a main spillway 30m long and a crest 1.12-1.19m wide. The height of the visible wall is 1.60m with an estimated additional 40cm under the sand reaching the bedrock. The wall is made of concrete reinforced with 12mm and 6mm steel bars. The top layer of the crest exhibits erosion and exposure of the steel bars in the middle section. It was also observed that the top layer of gabions had been fully washed away and the wings do not extend fully up the riverbanks. The community members interviewed also identified the damage to the crest and the gabions after the first heavy floods but explained that they did not have the resources to conduct the repairs. At the time of the visit, the dam was fully filled with coarse, medium and fine sand (Appendix VI).

Figure 9. Aw Barkhadle sand dam. *Source: Lopez-Rey (2019)*

Figure 10a and 10b. Fully eroded gabion and exposed steel bars on the crest of Aw Barkhadle sand dam. *Source: Lopez-Rey (2019)*

Associated infrastructure

A protected concrete lining well was built 65m behind the dam with an estimated depth of 7m and a diameter of 2m.The well slab was completely covered by sand at the time of the visit. A solar pumping unit pumps water to a 15m^3 masonry tank uphill and is then distributed by gravity to three concrete animal troughs and one public tap stand with washing facilities. A caretaker room and VIP latrines were also built by the project. At the time of the visit, the system was functional but the facilities were not in use. According to the operator and community members interviewed, utilisation of this water point is low in the rainy season because water vendor prices are low and households have access to scoop holes and domestic RHW. The frequentation in the dry *Jilal* season is reported to be very high.


Figure 11a and 11b.Tap stand and livestock trough next to Aw Barkhadle sand dam. *Source: Lopez-Rey (2019)*

There are at least 180 wells in Aw Barkhadle surroundings, mainly used for vegetable crops irrigation as well as water trucking. The wells located behind the sand dam have increased their yield significantly after the sand dam construction. Private well owners generate additional income selling water to vendors at 6USD/truck off $9m^3$, who in turn sell water in Hargeisa at 1.06-1.41 USD/200L, thus generating an average income of 55.6 USD per truckload. During the field visit, trucks were collecting water from a 7m deep masonry private well located 180m upstream of the dam. The well owner reported a yield of 2,000L/minute. The community estimates at least 40% of the water from the sand dam is sold in Hargeisa.

Ownership, operation and maintenance

The sand dam and facilities were handed over to the community water committee. Currently the system is operated by two operators and the implementing agency continues to provide monthly incentive for one of them. Community members received training on how to operate the solar pump and training on water fees collection but no cost-recovery system is currently in place. The water committee plans to implement cost-recovery in the second phase of the project when they expect water will be piped from the tank to the village. The committee expects households in the village will be willing to pay a fee if water can be accessed close to their premises.

Uses, accessibility and preferences

The public water supply facilities built with the sand dam can be currently accessed free of cost with no access or quantity restriction although they are operational on the dry seasons only. The two limiting factors identified by the interviewees are long distance from the village to the water point and long queuing times during the dry season. Community members estimate 200 households living in the surrounding of the sand dam use the new communal well and facilities, which represents 50% of the population. The majority of households in the village, 1.5km away from the dam, prefer to buy water from vendors because the walking round trip is very long (40 min) and they lack donkey carts or other transportation means.

During the rainy season, when the water table is very high, everyone is free to take water from scoop holes in the riverbed. This water is considered unsafe and is used for livestock or washing only. The community drinks water from vendors or from covered wells in the upstream and downstream sections of the dam with no prior treatment because they perceive water is of good quality. The groups interviewed reported a low frequency of diarrhoeas before and after the sand dam.

	Rainy season	**Dry season**
Preferred option for domestic use	Water vendors at 800 Sh/jerry can (0.09 USD) due to convenience. Rainwater harvesting at household level.	Water vendors at 1200-2000 Sh/ jerry can (0.14- 0.23 USD) due to convenience.
Second preferred option for domestic use	Sand dam communal well, used mainly by households living in the proximity. Not preferred option in the village because of long walking round trip (up to 40 minutes).	Sand dam communal well used mainly for livestock watering due to low pressure in tap stand and overcrowding in the dry season.
Other livelihood uses	Shallow wells and scoop holes in the riverbed as well as RWH at household level.	Shallow wells and scoop holes dry. Communal well and facilities behind sand dam used for livestock watering, including nomadic pastoralists.
Average domestic demand	8 jerry cans/HH/day. (26.6 L/p/d)	6 jerry cans/HH/day. (20 L/p/d)
Average cost domestic demand	6,400 Sh or 0.75 USD/day/HH.	7,200 – 12,000 Sh or 0.85-1.4 USD/day/HH.

Table 2. Seasonal variability of water sources, demand and preferences in Aw Barkhadle. *Source: Semi-structured interviews, 25/09/2019.*

Perceived impacts

Dry season water availability	Before: wells will often dry in the period from December to March (4 months). After: Wells yield reduced in the dry season but never completely dry. Net gain: 4 months.
Water used per day in the dry season	A little bit more, mainly due to price reduction compared to 2016-2017 drought years.
Water expenditure in the dry season	A little bit less, only for those living around the water kiosk at the sand dam site.
Frequency of diarrheal disease	No change perceived. Low frequency of diarrhoeas in Aw Barkhadle in general.
Surface of irrigated land	Large increase for upstream farmers. Decrease for downstream farmers.
Livestock number and condition	Slight reduction in livestock emigration due to increased water availability during the dry season. No change in livestock immigration.
Livelihoods diversification	No change in type of livelihoods activities.
Riverine vegetation	No change observed.
Flood risk	Reduced risk upstream. Increased risk downstream.

Table 3. Perceived impacts after Aw Barkhadle dam construction in 2018. *Source: Semi-structured interviews, 25/09/2019.*

> *"The new well on the dam never dries in the dry season but the amount of water is less than the rainy season".* Aw Barkhadle female participant.

Unintended negative effects

Downstream farmers complain of reduced yield in their wells and reduced volume of alluvial sediment. Some downstream dwellers also expressed concern about increased erosion damaging the structure of their wells. No other groups were identified as negatively affected and no environmental negative impacts were observed or mentioned by the interviewees besides erosion downstream.

> *"Upstream households have much more water now but the ones downstream have less water and less sand".* Aw Barkhadle female participant.

Users overall satisfaction

Opinions on the sand dam are divided between upstream farmers (approximately 80%), who express total satisfaction with the significant increase in well yields and improved income from irrigated farming and water selling, and downstream farmers (approximately 20%), who are generally very dissatisfied due to reduced water yield and increased erosion. During the group interview, one woman living downstream expressed her preference for the dam to be removed or to have a second dam downstream of the current one in order to benefit as well. The proposed location of the second dam is shown in Figure 6 and the community map in Appendix V.

Community member´s living close to the sand dam expressed satisfaction with the new facilities and increased yield in the private wells upstream. However, those living in the village feel they will benefit if water is piped to the village.

Overall, the community will recommend this technology if the negative effects on downstream users can be mitigated and if water can be supplied closer to dwellings. The group consisting of women (Group B) also recommended investing in new communal wells with water kiosks.

5.3 Diinqal sand dam

Diinqal is located close to the road connecting Hargeisa with Berbera, 37 km northeast of Hargeisa and 6km north of Aw Barkhadle. The community has an estimated population of 280 households, mainly pastoralists. Vegetables and fruits such as guava, papaya, tomato, onion and okra are cultivated in the riverbanks. Cereal farming is not practiced due to soil acidity.

Figure 12. Diinqal village and sand dam location. *Source: Google Earth © 2019 CNES/Airbus.*

Sand dam siting, design, construction and condition

A sand storage dam was built in 2018 across a section 44m wide on Yayne seasonal river, approximately 1.2 km northeast of Diinqal village. No farming is practiced downstream of the site. The river gets an average of 3 to 4 large flash floods per year, along with smaller flash floods. A sub-surface aquifer of permeable rock is located 2-4 meters under the riverbed.

The community members interviewed stated that the site of the dam and the new well is not suitable. They had suggested to the contractor an alternative site approximately 450m upstream of the current location, where they believe the yield would have been much higher. The contractor hired unskilled local labour from Diinqal, but the community was not directly involved in the construction and is not aware of the materials used or the cost of the project. The final project report states the total cost of the dam construction was 57,393 USD and the appurtenant structures 43,582 USD. The plot of land where the facilities are located was private land and the VC compensated the landowner with another land plot.

The dam has a concave shape and a slightly sloping downstream wall with a total length of 44m, a main spillway 26.5m long and a crest 1.10m wide. The height of the visible wall is 1m, which extends approximately 50cm below the sand to the bedrock. The wall is made of reinforced concrete and covered with a layer of cement. No erosion and exposure of the steel bars was observed. The wing walls extend sufficiently on the riverbanks, with no risk of over-spilling on the steep right bank and medium-low risk on the flatter left bank. A riprap of flat stones joined with cement extends 9m from the wall for erosion protection and is in good condition one year after completion of the works. The dam was fully filled with sand at the time of the visit. A mix of gravel, coarse, medium and fine sand compose the sediment at a depth of 30cm while a thin layer of silt deposit was present in the top layer (Appendix VI).

Figure 13. Diinqal sand dam. *Source: Lopez-Rey (2019)*

Figure 14. View of the left wing wall and riprap in Diinqal dam *Source: Lopez-Rey (2019)*

Associated infrastructure

A new, concrete-lined, protected well was built alongside the dam. It has an estimated depth of 4m and a diameter of 2m. The community believes it should have been dug to 9m (expressed as 6-man heights) to reach the bedrock aquifer, but it could not be dug deeper than 4m because the contractor found hard rock. The community had suggested another location for the well further upstream, close to an old masonry well 7m deep that has good yield. Overall, there are five communal wells and over thirty private irrigation wells upstream of the dam.

The new well is equipped with a solar system pumping system with a 15m^3 masonry tank, three concrete animal troughs and one public tap stand with washing facilities. A caretaker room and VIP latrines were also built as part of the project. At the time of the visit, the system was functional but the facilities were not in use. According to the operator and community members interviewed, the pump had not been activated since March. The new communal well and facilities are only used by the community in the 2 months following the rainy season. The rest of the year, the yield is too low and it is only used by nearby farmers to manually irrigate their plots.

Figure 15. View of the new well 10m upstream of Diinqal sand dam. *Source: Lopez-Rey (2019)*

Figure 16. Livestock troughs and public tap stand next to Diinqal sand dam. *Source: Semi-structured interviews, 26/09/2019.*

Ownership, operation and maintenance

The sand dam and facilities were handed over to the community water committee. Two operators were trained on the operation of the pump and the system is currently operated by one operator/watchman paid by the implementing agency. The water community committee does not see the need to collect fees, since the current yield of the well is low and it benefits only a few people. The committee plans to implement a cost-recovery system if water is piped to the village in a second phase of the project, as there is willingness to pay for water delivered close to the homesteads.

No maintenance works have been conducted so far for the dam or the associated facilities, but if required, the farmers and pastoralists benefiting from the dam would be willing to fund dam repairs if the cost is low.

"We don't have knowledge and experience about how to maintain the dam. If small repairs needed we can contribute, but if more complex and expensive repairs we need assistance" Diinqal male participant.

Uses, accessibility and preferences

Community members estimate that 220 households in Diinqal use the five communal wells upstream of the dam directly, or buy water from vendors accessing the private wells upstream of the dam. The public communal well is accessed free of cost with no restriction other than distance and yield limitations.

Everyone is free to abstract water directly from scoop holes in the river bed during the rainy season when the water table is very high, but there is an awareness of disease risk and water from scoop holes is only used for livestock or washing. The community drinks water from vendors or from communal wells in the upstream sections of the dam directly with no prior treatment, as they perceive it is of good quality.

	Rainy season	**Dry season**
Preferred option for domestic use	Rainwater harvesting at household level or water vendors at 800 Sh /jerry can (0.09 USD) due to convenience.	Free water from communal wells (1h - 1h30 walking round trip, water transported with wheelbarrow).
Second preferred option for domestic use	Free water from communal wells (1h-1h30 walking round trip, water transported with wheelbarrow).	Water vendors from Aw Barkhadle at 1,200-2,000 Sh /jerry cans barrel (0.14-0.23USD).
Other livelihood uses	Earth dams (surface water) and public and private wells behind the dam.	Public and private wells behind the dam.
Average domestic demand	5 jerry cans/HH/day. (16.6 L/p/d)	3-4 jerry cans/HH/day. (11.7 L/p/d)
Average cost domestic demand	1,500 Sh or 0.17 USD/day/HH.	1,400 Sh or 0.49 USD/day/HH.

Table 4. Seasonal variability of water sources, demand and preferences in Diinqal. *Source: Semi-structured interviews, 26/09/2019.*

Perceived impacts

Dry season water availability	Before: wells dry completely in the period from February to March (2 months). After: some wells dry up in the period February-March, others do not dry completely but have low yield. Net gain: 2 months (partially).
Water used per day in the dry season	A little more.
Water expenditure in the dry season	Less money spend in water due to increased water availability in in communal wells.
Frequency of diarrheal disease	No change perceived. Low frequency of diarrhoeas.
Surface of irrigated land	No change perceived.

Livestock number and condition	Small increase in immigration of households with livestock from the East during the dry season. Improved body condition in the wet season due to increased water availability.
Livelihoods diversification	No change perceived.
Riverine vegetation	More vegetation /more diversity upstream of the dam.
Flood risk	No change perceived upstream or downstream.

Table 5. Perceived impacts after Diinqal dam construction in 2018. *Source: Semi-structured interviews, 25/09/2019.*

Unintended negative effects

There are no farmlands downstream and no other groups were identified as negatively affected. No environmental negative impacts were observed or mentioned by the interviewees.

Users overall satisfaction

Both groups interviewed expressed satisfaction regarding the sand storage dam, as they recognise that it has brought benefits in terms of improved yield in upstream wells. On the other hand, the new communal well did not meet their expectations due to low yield at the selected location and the community expressed they were not sufficiently involved in deciding the location of the dam and new communal well. Overall, the community will recommend this technology but would suggest that communities must have a greater role in planning to maximize the number of people benefiting from the project.

"The dam is important for us but it also has some problems. The dam is only useful for us in the rainy season because the well is not deep enough and does not have enough yield in the dry season" Diinqal male participant.

5.4 Huluuq sand dam and sub-surface dams

Huluuq is a small village located 0.5 km from Arabisyio town and 36 km northeast of Hargeisa in the region of Woqooyi Galbeed. The community has a relatively small population of 120 households but hosts up to 450 nomadic pastoralist households during the dry season. The predominant livelihood is rain-fed and irrigated farming practiced along the riverbanks.

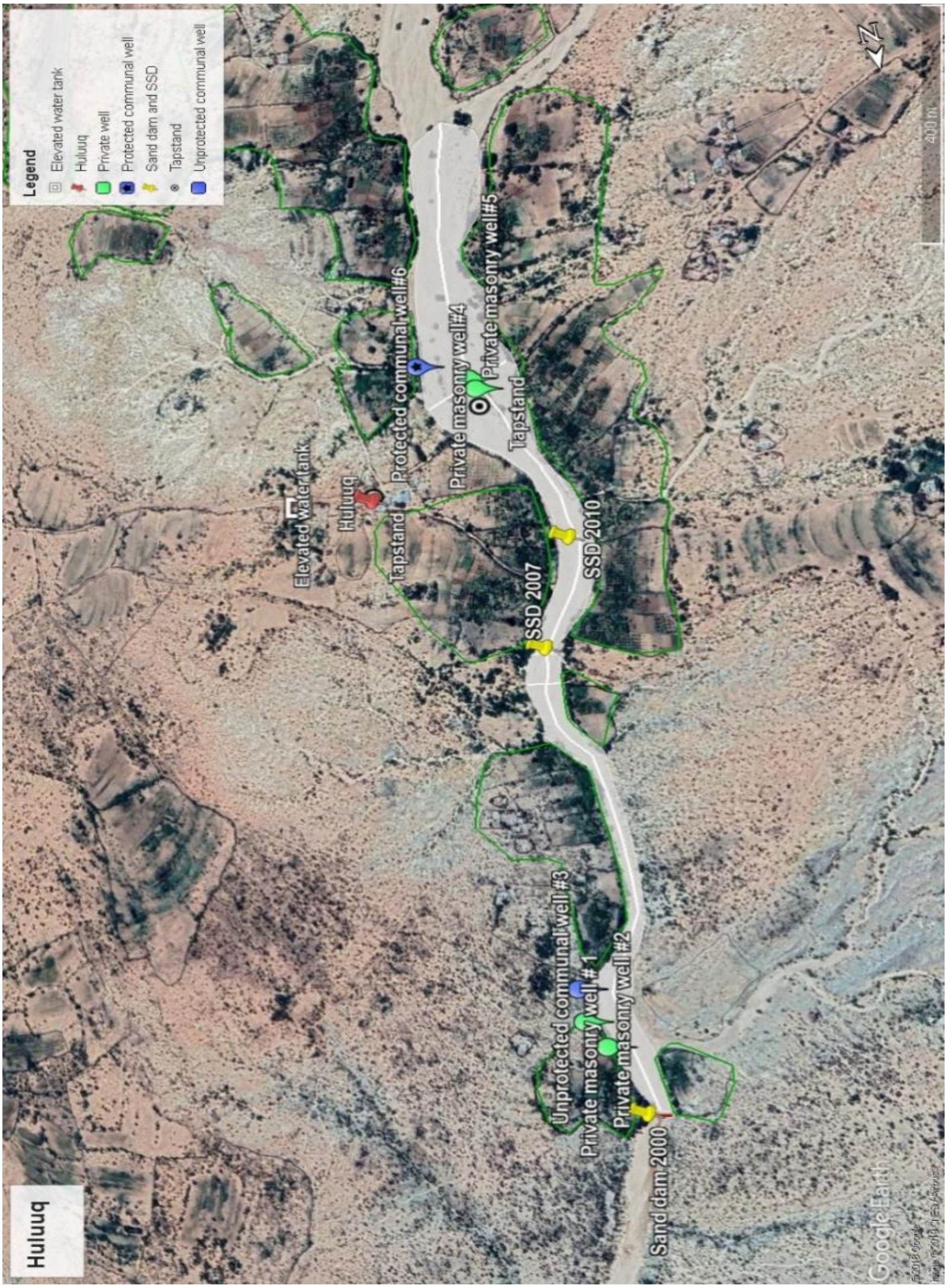

Figure 17. Huluuq village, sand dam and sub-surface dams location. Source: Google Earth image © 2019 CNES/Airbus.

Sand dam siting, design, construction and condition

The seasonal river at Huluuq has a wide sandy riverbed with three dams: one sand storage dam built in 2000 in a narrow section 26m wide and two sub-surface dams built in 2007 and 2010 in the upstream wider section of the seasonal river (63m and 69m respectively).

The community, represented by the VC, was actively involved in deciding the location of all three dams, proposing sections of the river where wells had lower yields and where no downstream farmers would be negatively affected. The community contributed providing sand, rubble stone and water for construction but were not aware of the total construction cost.

The two sub-surface dams are not visible from the surface. The sand dam, made of rubble stone masonry covered with cement, has a curved shape and visible height of up to 1m above the sand. The length of the spillway covers the full length of the riverbed, 26.4m, and the crest is 60cm wide. The crest shows slight erosion but the dam is overall in good condition, considering it is 19 years old. A sloping concrete riprap stretches 2m downstream with a height of 60cm above the ground. The dam was fully filled with sand at the time of the visit. The sediment samples showed a mixture of gravel, very coarse, coarse, medium and fine sand (Appendix VI).

Figure 18. Panoramic picture of the riverbed upstream of the two sub-surface dams in Huluuq built in 2000. *Source: Lopez-Rey (2019)*

Figure 19. Rubble stone sand dam in Huluuq built in 2000. *Source: Lopez-Rey (2019)*

Associated infrastructure

There are three masonry private wells and two masonry communal wells used mainly for livestock upstream of the oldest sand dam built in 2000. Two additional private masonry wells and one protected communal well are located upstream of the two sub-surface dams (Figure 17). All of the wells have a diameter of 3m and average depth of 6.5m (expressed as 4-man heights). The wells located in the throwback have masonry wellheads 1.5m high for flood protection. The protected communal well # 6 (Figure 21a.) behind the two sub-surface dams has a depth of 16m (10 man heights) and is equipped with a solar pump feeding a 20m^3 tank and a gravity flow water distribution system with three community tap stands. In addition to the main masonry wells, there are over 70 traditional hand dug wells in the river banks used for irrigation (Figure 22).

Figure 20. Masonry communal and private wells in the throwback of the oldest sand dam in Huluuq built in 2000. *Source: Lopez-Rey (2019)*

Figure 21 a. and b. Protected masonry communal well used for domestic water supply and tap stand in the community centre of Huluuq. *Source: Lopez-Rey (2019)*

Figure 22. Open well in the riverbank used for irrigation of citrus trees. *Source: Lopez-Rey (2019)*

Ownership, operation and maintenance

A community water committee, sitting under the VC, is responsible for the dams and the communal wells. The committee received training on the operation of the pump but did not receive training on dam maintenance.

Water is accessed free of cost. The community has a funding system whereby farmers allocate a portion of their harvest to pay for communal infrastructure and services, including pump maintenance and school repairs. No maintenance has been carried out so far for any of the three dams or the facilities because the community considers they are in good condition.

Uses, accessibility and preferences

All 120 households from Huluuq community use water from the piped water system for domestic purposes and the other wells for irrigation and livestock. The interviewees estimate 450 nomadic pastoralist households immigrate with their livestock to Huluuq and other riverine communities searching for water in the dry season.

Water from the covered wells in the dam throwback is considered safe to drink without prior treatment. Communal wells are accessed for free and without quantity limitation. No groups were identified as excluded from the service.

	Rainy season	**Dry season**
Preferred option for domestic use	Free water from community tap stand (10-30 min walking round trip) or private wells on the dam throwback.	Free water from community tap stand (10-30 min walking round trip) or private wells on the dam throwback.
Second preferred option for domestic use	Rainwater harvesting at household level for domestic use.	
Other livelihood uses	Private wells used for irrigation. Communal and private wells used for livestock.	Private wells used for irrigation. Communal and private wells used for livestock.
Average domestic demand	8 jerry cans/HH/day. (26.6 L/p/d)	6 jerry cans/HH/day. (20 L/p/d)
Average cost domestic demand	No cost.	No cost.

Table 6. Seasonal variability of water sources, demand and preferences in Huluuq. *Source: Semi-structured group interviews, 29/09/2019.*

Perceived impacts

	After dam construction in 2000, 2007 and 2010
Dry season water availability	Before: wells often dry in the period from January to March (3 months). After: water is available all year round. In drought conditions with failure of the rainy season wells exceptionally dry-out in March. Net gain: 3 months.
Water used per day in the dry season	A little more.
Water expenditure in the dry season	No fees charged for water before and after the dam.
Frequency of diarrheal disease	No major change because water did not cause illness before. Low frequency of diarrhoeas. Improvement in hygiene thanks to the tap stands in the community and the school.
Surface of irrigated land	Large increase in the surface of irrigated land upstream of the dams. No farms within 1 km downstream of the last dam.
Livestock number and condition	Large increase in immigration of nomadic pastoralists attracted by water availability and mineral composition during the dry season. No change in the number of animals owned by Huluuq community (mainly farmers with few animals for milk supply at the household level). Good animal condition all year round.
Livelihoods diversification	Community shifted from rain-fed crop to large scale irrigated vegetable and fruit cash crops (mango, papaya, lemon, orange, okra, tomato, onion, garlic, etc.) which generate a greater income. Sale of food, drinks, snacks to an increasing number of nomadic pastoralists during the dry season.
Riverine vegetation	More vegetation/more diversity upstream of the dam.
Flood risk	Less flooding upstream. Less flooding downstream. Some farmers build gabions on the riverbanks to protect farmland from erosion and flooding.

Table 7. Perceived impacts after the construction of the three dams in Huluuq (2000, 2007 and 2010). *Source: Semi-structured group interviews, 29/09/2019.*

"We have more water now in the house because the sand dam increases water".
Huluuq woman participant.

Unintended negative effects

No groups were identified as negatively affected in Huluuq community. There is at least 1km distance from the last dam to the next farmland in a village further downstream, thus, it is unlikely that they are negatively affected (Figure 17).

Users overall satisfaction

The community is highly satisfied with the three dams in series because they have seen the water table in the riverbanks rise significantly, allowing considerable expansion of irrigated farming and increased income. Improved water availability during the dry season has also increased the influx nomadic pastoralists, which is positively perceived by the community as an opportunity to generate income through petty trade and food sale. The interviewees also acknowledge health improvements. Water from the protected communal well is perceived to be safe and increased water availability and accessibility has improved hygiene practices. The members interviewed recommend this technology for riverine communities to improve water availability for livestock and farming and expressed their willingness to have two more dams further upstream.

"Even in 2017 drought the wells had water, it was low but they never dried".
Huluuq woman participant.

5.5 Carracad sand dam

Carracad village is located in a remote mountain valley in Borama district (Awdal region). Although the community is only 30km away from the district capital, road conditions are poor and the community remains isolated from markets and basic services. The community has an estimated population of 250 households dispersed in the valley. Subsistence rain-fed farming and sale of goat and camel milk are the main livelihood activities in the community. Irrigated farming is marginal.

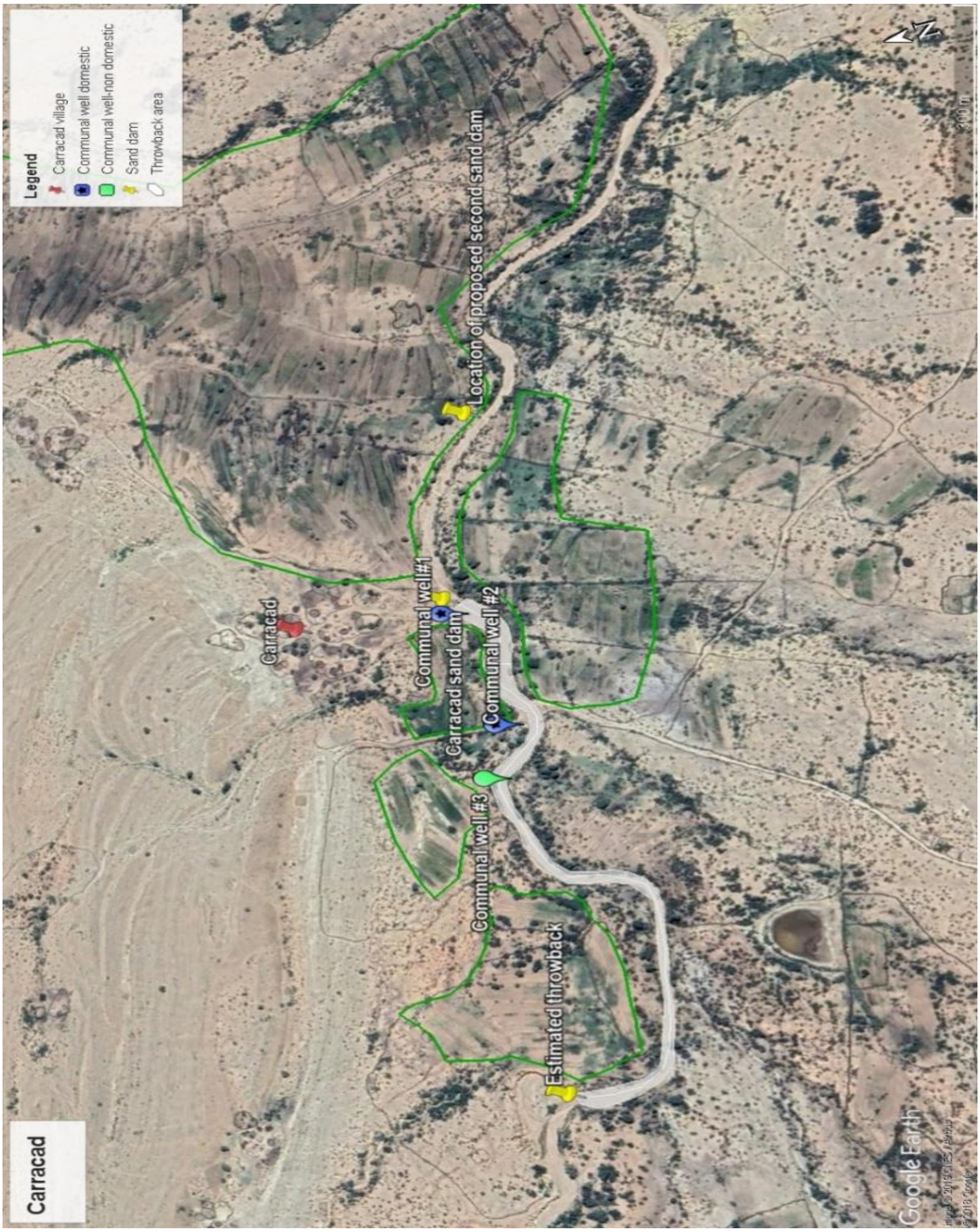

Figure 23. Carracad village and sand dam location. *Source: Google Earth © 2019 CNES/Airbus.*

Sand dam siting, design, construction and condition

The seasonal river at Carracad is located in a narrow mountain valley and is formed of coarse sand deposits on top of a layer of white clay. The village takes the name from the Somali word *Carra* meaning clay. A sand storage dam was built in 2003 and rehabilitated in 2017. It is located in a river section 30m wide, just 100 metres from the community centre.

The community members were not involved in the site selection, as they were not familiar with the technology, but contributed to the construction by excavating the trench and providing rubble stone and water. The implementing agency reports an estimated cost of 18,000 USD in 2003.

The dam wall has a straight shape and is made of reinforced concrete covered with a layer of cement. It has a total length of 30.8m with a spillway 23.2m long covering the full width of the riverbed. The right wing wall extends sufficiently into the rocky steep bank but the left wing does not extend sufficiently on the shallow sandy bank, where there is visible signs of water overflow around the wing wall (Figure 24). The crest is only 78cm wide and exhibits slight erosion with exposure of the reinforcement bars at the central section. The height of the visible wall is 1m with approximately 50cm extending to the bedrock and is keyed 1m below the bedrock. In 2016 the implementing agency repaired the gabions and raised the wall by 20cm, but strong flash floods in 2018 partially washed away the gabions (Figure 25). At the time of the visit, the dam was fully filled and the sand sample taken at a depth 30cm showed a heterogeneous composition of gravel, very coarse and coarse sand, medium, fine and very fine sand (Appendix VI).

Figure 24. Panoramic downstream view of Carracad sand dam and gabions. *Source: Lopez-Rey (2019)*

Figure 25. View of insufficiently extended wing wall on the left bank and partially washed-away gabions in Carracad dam. *Source: Lopez-Rey (2019*

Figure 26 a and b. Well # 1 used for domestic purposes and well # 2 used for livestock watering in Carracad sand dam throwback. *Source: Lopez-Rey (2019)*

Associated infrastructure

There are three communal masonry wells in the throwback. All of them have concrete slabs and a metal cover for manual water lifting. The wells have a diameter of 3m and are lined with rocks intercalated by 20mm PVC infiltration pipes. Communal well #1, closest to the dam wall, is used for domestic purposes including drinking. The well was dug 4m until reaching a white clay impermeable layer, however well # 2 has a total depth of 14m and was dug below the clay layer 9m into the permeable bedrock. Well #2 has a good yield and is mainly used for livestock watering. Well # 3 is 9m deep but has lower yield and is occasionally used for livestock and irrigation.

Ownership, operation and maintenance

The community, through its committee of village elders, owns the dam and is responsible for the maintenance. The community received training on how to maintain the gabions and there is a sense of awareness on its importance to prevent erosion and eventual wall collapse. The community feels adequately skilled to conduct the repair of gabions using locally available boulders and is willing to collect community contributions to procure the iron wire needed. However, the gabions damaged by 2018 floods have not been repaired at the time of the visit in October 2019. Overall, the community considers the dam is in good condition and functioning well.

Uses, accessibility and preferences

The population of surrounding villages like Qol Qol and Culacuule collects water from the sand dam during the rainy season. There is no restriction on accessing water from the communal wells, all community members can access water for free and without quantity limitation. No groups were identified as excluded. The community considers water from the covered wells in the dam throwback is safe to drink directly.

	Rainy season	**Dry season**
Preferred option for domestic use	Free water from community well. Community is very scattered and the roundtrip varies from 5-90min.	Free water from community well. Community is very scattered and the roundtrip varies from 2-90min)
Second preferred option for domestic use		When the wells have very low yield the community collects water free of cost from a mountain spring in Nadhi village located 16km away (2h round trip by donkey)
Other livelihood uses	Communal and private wells used for livestock.	Nadhi spring (same as for domestic use)
Average domestic demand	6-8 jerry cans/HH/day. (23.3 L/p/d)	4 jerry cans/HH/day. (13.3 L/p/d)
Average cost domestic demand	No cost.	No cost.

Table 8. Seasonal variability of water sources, demand and preferences in Carracad. *Source: Semi-structured group interviews, 30/09/2019.*

Perceived impacts

Dry season water availability	Before: wells provide water 4 months per year (in rainy seasons and immediately after). After: wells provide water 9 months per year and dry out during the 3 months of Jilal (January-March). Net gain: 5 months.
Water used per day in the dry season	Significantly more because more water is available and for a longer period. In the dry season months the quantity of water used remains very limited.
Water expenditure in the dry season	No fees charged for water before and after the dam.
Frequency of diarrheal disease	Low frequency of diarrhoeas.
Surface of irrigated land	Large increase in the surface of irrigated land upstream of the dams. Small decrease in water availability for irrigation downstream.
Livestock number and condition	Large increase in number of households from surrounding villages who collect water from the wells in Carracad dam. Many livestock heads were lost with cyclone *Sagar* in 2018 and numbers are recovering. Livestock drinking from Carracad wells are in good health condition.
Livelihoods diversification	Home gardening introduced.
Riverine vegetation	More vegetation/higher biodiversity upstream of the dam.
Flood risk	Less flooding upstream. More flooding downstream as riverbanks expanded.

Table 9. Perceived impacts after Carracad dam construction in 2003. *Source: Semi-structured group interviews, 30/09/2019.*

"Drought times were longer and we had to collect water from Nadhi spring during 8 months of the year but after the dam it is only 3 months". Carracad female participant

"Households from other four surrounding villages, Jir, Qol Qol, Abase and Culacuule also get water from Carracad now". Carracad male participant.

Unintended negative effects

Decreased sediment downstream of the dam has exposed the unconsolidated soil riverbanks causing them to collapse. Farmers downstream complain of loss farming land due to erosion of the riverbanks. The VC has identified the need to build a second dam approximately 300m downstream (Figure 23) to mitigate further erosion and to benefit downstream farmers. There is no farmland downstream of the proposed site.

Users overall satisfaction

Overall, the community expresses high satisfaction with the dam because of the extended period of time water is now available locally, reducing the number of months people need to collect water from Nadhi spring located 16km from Carracad. The community recommends this technology to other communities and has expressed desire to build a second dam downstream to increase water availability.

"When it was first build the community was not aware how important the dam was" Carracad man participant.

5.6 Camud sand dam (collapsed)

Camud village is located 4km northeast of Borama town in the district of Borama (Awdal region) and has an estimated population of 260 households. It is an agro-pastoral community with some irrigated agriculture. Due to its close proximity to the town of Borama the community benefits from access to basic services, markets and labour opportunities.

Figure 27.Camud village and sand dam locations in Camud and Damug rivers. *Source: © 2019 CNES/Airbus.*

Sand dam siting, design, construction and condition

A sand storage dam was built in 2007 in a section 33m wide on Camud seasonal river, located approximately 1km north-east from Camud village centre. The dam collapsed and was washed away by heavy flooding during Sagar cyclone in 2018. Three additional RCC dams were also built in Damug river to enhance aquifer recharge for Borama town water supply (Figure 27).

Camud community was not involved in the site selection or the construction of Camud sand dam in 2007, as they were not familiar with the technology. The dam was built with rubble stone and, according to the interviewees, the total wall height was 5m, half of it below the bedrock. The wing walls did not extend fully in the riverbanks and there was no gabion or riprap for erosion protection behind the wall. The community had seen the base of the wall suffering from erosion and had requested support from different stakeholders as they did not feel they had the knowledge or the means to conduct the works. Excessive abstraction of sand for construction in Borama town is also believed to have accelerated erosion.

"We saw erosion was happening and had requested support several times but we never thought we will lose the dam". Camud male participant.

Figure 28a and b. Camud sand dam remains in the left riverbank and exposed concrete-ring well next to the collapsed dam. *Source: Lopez-Rey (2019)*

Associated infrastructure

No specific water abstraction and distribution infrastructure was developed with the dam project. Several masonry communal wells and private wells exist upstream of the dam. The exposed structure of a masonry well located behind the collapsed dam (Figure 28b) shows the original height of the sand reservoir, now washed away by consecutive flash floods. Other wells visited in the riverbank were functional but showed low water levels at the time of the visit despite the above-average seasonal rains.

Ownership, operation and maintenance

The community did not have a committee in place to manage the dam and lacked awareness on how to maintain the dam. However, stones and boulders were placed on the gap between the wings and the bank to avoid flow diversion and further erosion of the banks.

Uses, accessibility and preferences

Before the dam collapsed 260 households from Camud were using water from the wells behind the dam all year round. Water abstracted from the wells behind the dam was perceived to be of good quality and suitable for drinking. No water sample was taken in Camud as the sand dam is currently not functional.

Public communal wells were accessed for free with no restriction of access. During the dry season 200-230 households of nomadic herders used to settle in this area to access the 20 wells in the riverbanks. After the collapse of the wall lower well yields have reduced the frequentation of nomadic pastoralists and negatively impacted 45 upstream farmers.

	Rainy season	Dry season
Preferred option for domestic use	New boreholes with tap stands in Borama town located at 300m.	New boreholes with tap stands in Borama town located at 300m.
Second preferred option for domestic use	Communal wells and private wells in the riverbanks.	Communal wells and private wells in the riverbanks.
Other livelihood uses	Communal wells and private wells in the river banks	Communal wells, private wells or cement-lined catchments *(berkads)*
Average domestic demand	5 jerry cans/ HH/ day. (16.6 L/p/d)	4 jerry cans/ HH/day. (13.3 L/p/d)
Average cost domestic demand	No cost.	No cost.

Table 10. Seasonal variability of water sources, demand and preferences in Camud. *Source: Semi-structured group interviews, 31/09/2019.*

Perceived impacts

Dry season water availability	Before: wells will dry from November to March. After: wells normally provide water throughout the dry season January-March, except in abnormally below average rainy seasons. Net gain: 5 months.
Water used per day in the dry season	Significantly more in both the rainy and the dry season.
Water expenditure in the dry season	No fees charged for water before and after the dam. Borehole water in Borama town free of charge.
Frequency of diarrheal disease	No change perceived. Occasional diarrhoeas during the dry season.
Surface of irrigated land	Large increase in the surface of irrigated land upstream of the dams. No change in surface irrigated downstream. Less erosion observed.
Livestock number and condition	Large increase in number of nomadic herders accessing wells behind the dam in Camud during the dry season. Improved livestock body condition due to water availability in the dry season.
Livelihoods diversification	Development of irrigated farming of lemon and guava, considered drought-resistant trees, as well as vegetables like beetroot, okra, tomato and onion. Since the dam collapses of the dam households shifting from farming to raising cows and shoats. Sale of sand for construction in Borama town (observed during the field visit).
Riverine vegetation	No change perceived.
Flood risk	More flooding upstream. Less flooding downstream.

Table 11. Perceived impacts after Camud dam construction in 2007 (and before dam collapse in 2018). *Semi-structured group interviews, 31/09/2019.*

Unintended negative effects

Downstream farmers were not negatively affected by the construction of the dam due to the presence of a sub-surface dam further down in Camud river. During the 2018 floods, upstream farmers believe to have been more severely affected by farmland flooding than those downstream.

"Up to 230 nomadic herder with an average of 45 camels each were coming to Camud during Jilal. When the wall fell they moved to the boreholes in Borama". Camud male participant.

Users overall satisfaction

Overall, the community was highly satisfied with the sand dam due to increased water availability all year round, the development of vegetable and fruit farming as well as small business associated to the presence of nomadic herders. Riverine farmers have been the most affected by the collapse of the wall and reduced wells yield. The community strongly recommends sand dam technology and is seeking support for the construction of a new sand dam. The community has identified four potential sites in narrower sections of the river, which they believe are suitable for sand dam development.

"The sand dam helped us have water for longer times than before". Camud female participant.

5.7 Summary of quantitative results

The quantitative results for all sites are presented in this section and discussed in chapter 6.

Table 12 shows the results of maximum volume of extractable water, coverage of water demand for domestic use and coverage of water demand for livestock, illustrated in the graphic in Figure 29. In all four locations, the maximum extractable volume of water at the beginning of the dry season is theoretically sufficient to cover 100% of the current average domestic water needs (20 l/p/d) during the 5-month dry season (150 days). In Diinqal dam the extractable volume is twice the domestic dry season demand, in Aw Barkhadle and Carracad it is three times the demand and in Huluuq dam it is 29 times the domestic demand. The detailed calculations and the assumptions are presented in Appendix VII.

	Aw Barkhadle	Diinqal	Huluuq sand dam	Huluuq two SSDs	Carracad	Average
Throwback length (m).	700	435	933	1,160	1,000	
Maximum width riverbed (m)	103	41	62	170	35	
Maximum depth of sand (m)	4	4	6	6	4	
Dam storage capacity (m^3)	96,133	23,780	123,405	420,693	46,667	
Drainable porosity (%)	18%	30%	25%	25%	20%	
Estimated maximum volume of extractable water from sand deposit (m^3)	**17,203**	**7,134**	**30,851**	**105,173**	**9,333**	**28,282**
Estimated water demand domestic use in dry season (m^3)	7,200	3,960	10,260		4,500	**6,480**
Estimated water demand livestock (m^3)	15,000	8,250	62,550		9,000	**23,700**
Water demand coverage in dry season (domestic)	**100%**	**100%**	**100%**		**100%**	**100%**
Water demand coverage in dry season (domestic and livestock)	**77%**	**58%**	**187%**		**69%**	**98%**

Notes:
Calculations could not be carried out for Camud site where the sand dam collapsed in 2018.
The average of maximum extractable volume is calculated for 6 dams considering Huluuq has one sand dam and two SSD.
Demand in the dry season includes nomadic pastoralists.
Details of the calculations and assumptions is provided in Appendix VII.

Table 12. Maximum extractable volume of water and dry season demand coverage. *Source: Lopez-Rey (2019)*

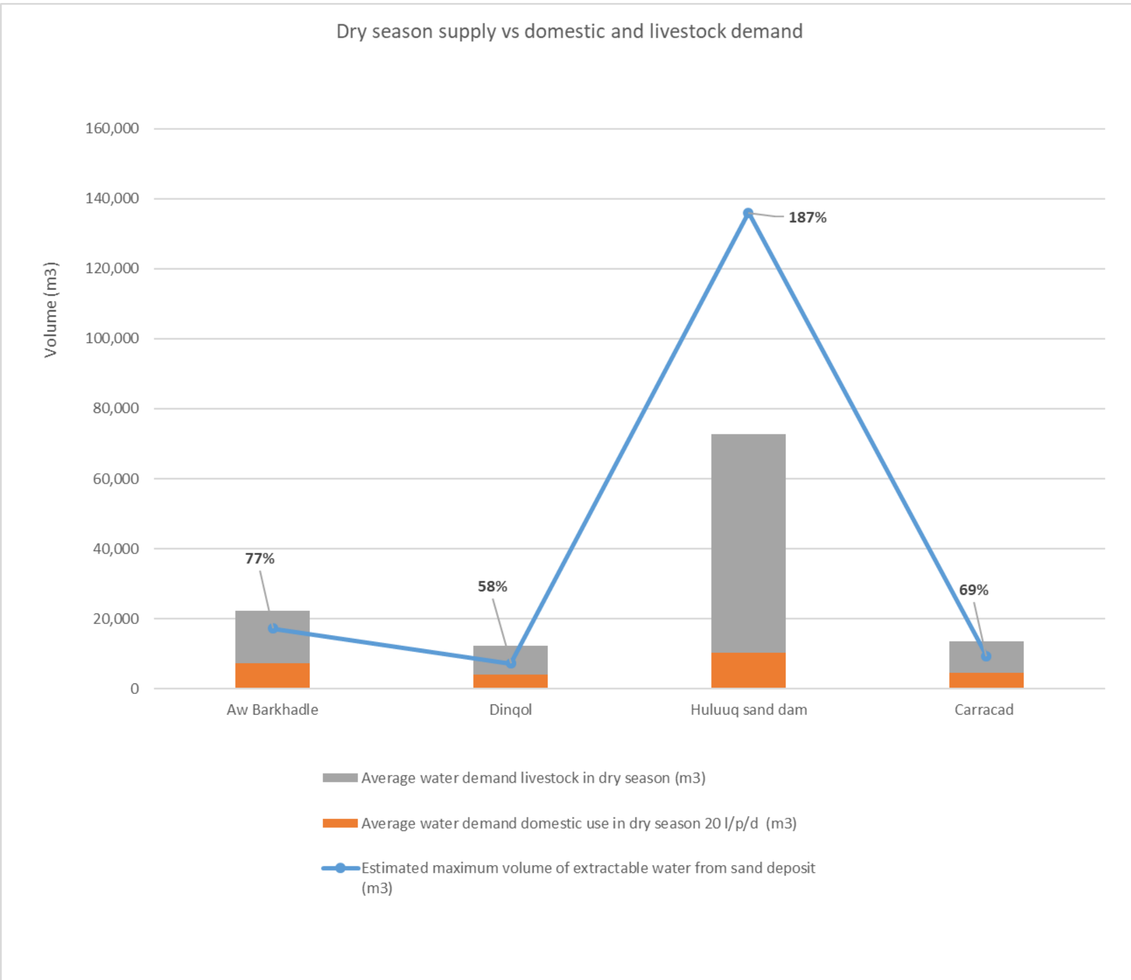

Figure 29. Dry season sand dam supply vs domestic and livestock demand. *Source: Lopez-Rey (2019)*

All the samples analysed (Table 13) show relative low levels of mineralization with TDS below 1,000 mg/L. Total dissolved solids can affect water acceptability but is not considered a health concern in WHO drinking water guidelines. pH values in all samples are within the WHO (2017) range 6.5-8.5. Turbidity is also below the 5 NTU maximum WHO standard in all samples except in Diinqal well#1, where it is above the standard. The measurement was taken three times recording differences of +/- 0.1. TTC was positive in two of the three samples analysed and the control petri dish showed no contamination.

Sample	**pH**	**TDS (ppm)**	**Turbidity (NTU)**	**TTC (CFU/100ml)**
Aw Barkhadle tap stand	6.90	439	1.20	>100
Diinqal well #1	6.92	660	14.17	>100
Huluuq village tap stand	6.18	739	0.74	0
Carracad well # 1	7.28	618	0.53	Not analysed
Carracad well# 2	7.14	739	2.03	Not analysed

** Does not include Camud sand dam which collapsed in 2018.*

Table 13. Water quality test results. *Source: Lopez-Rey (2019)*

Figure 30 shows seasonal water availability in the studied wells before and after sand dam construction. After sand dam construction wells provide water throughout the dry season in four of the five sites studied. Yields are significantly reduced towards the end of the dry season in March, except for Huluuq, which has three dams. Overall, the results show that the sand dam resulted in net gains of two to five months of local water availability. It is worth noting that the interviewees' responses consider normal rainfall years and not drought years.

	Gu			Hagaa		Deyr			Jilal			
	April	May	June	July	August	September	October	November	December	January	February	March
Aw Barkhadle	X	X	X	X	X	X	X	X	>>	>>	>>	>
Dinqol	X	X	X	X	X	X	X	X	X	X	>	>
Huluuq	X	X	X	X	X	X	X	X	X	>>	>>	>>
Carracad	X	X	>>	>>	>>	X	X	>>	>>	0	0	0
Camud (before collapse)	X	X	X	X	X	X	X	>>	>>	>>	>>	>

X	Wells supply before dam
>>	Wells supply after dam
>	Wells supply after dam (low yield)
0	Wells dry after dam

Figure 30.Seasonal water availability in riverbed wells before and after dam construction. *Source: Lopez-Rey (2019)*

Table 14 summarises capital construction costs and maintenance costs of the sand dams studied for a design life period of 30 years. The detailed calculations and assumptions are presented in Appendix VIII.

	Aw Barkhadle RCC dam	Diinqal RCC dam	Huluuq rubble stone dam and two SSD***	Carracad RCC dam	Average RCC dam	Average rubble stone dams/SSD
Number of people with access to sand dam water supply (host and nomads) *	2400	1320	2700	1500		
A) Initial construction costs of sand dam and SDD **	$67,387	$57,393	$15,893	$32,120	**$52,300**	**$15,893**
Capital cost per person with access to water supply per year (host and nomads)	$0.9	$1.4	$0.2	$0.7	**$1.0**	**$0.2**
Capital cost per person with access to water supply (host and nomads)	$28.1	$43.5	$5.9	$21.4	**$31.0**	**$5.9**
Capital cost per cubic meter	$314.1	$470.0	$68.6	$454.4	**$412.8**	**$68.6**
B) Construction costs of raising sand dam wall by 60cm **	$13,227	$14,560	$660	$5,766	**$11,184**	**$660**
Capital cost per person with access to water supply per year (host only)	$0.18	$0.37	$0.03	$0.13	**$0.2**	**$0.03**
C) Maintenance costs of sand dam erosion protection infrastructure over 30 year design life period****	$55,742	$44,352	$26,611	$31,046	**$43,714**	**$26,611**
Maintenance cost per person with access to water supply per year (host only)	$0.8	$1.1	$1.2	$0.7	**$0.9**	**$1.2**

Notes:

** The number of people with access to sand dam water supply considers seasonal pastoralist immigration in Huluuq durig the dry season (450HH) but only host population (120HH) is considered in maintenance costs per capita.*

*** Costs exclude surveying and project monitoring costs but include an estimate of 25% for civil works, transportation and administration costs of service contract.*

**** Wall not considered for Huluuq sub surface dams (SSD)*

***** Considers full repair every 10 years of 3m wide rip-rap over the bedrock with gabions on top along the entire length of the wall in all dam sites. Detail of maintenance and replacement cost calculations is provided in Appendix VIII.*

Table 14. Summary of capital and maintenance cost of sand dams. *Source: Lopez-Rey (2019)*

Table 15 summarises the capital construction costs and operation and maintenance costs of the water supply facilities for a design life period of 30 years. The detailed calculations and assumptions are presented in Appendix VIII.

	Aw Barkhadle	Diinqal	Huluuq	Carracad	Average
Number of people with access to sand dam water supply (host and nomads) *	2,400	1,320	2,700	1,500	
Option A) protected communal well, solar pumping unit, elevated tank and facilities					
A.1) Initial construction costs	$57,796	$43,582	$45,000	NA	**$48,793**
Capital cost per person with access to water supply per year (host and nomads)	$0.8	$1.1	$0.6	NA	**$0.8**
A.2) Maintenance and replacement costs over 30 year design life period	$104,360	$104,360	$104,360	NA	**$104,360**
Maintenance cost per person with access to water supply per year (host only)	$1.4	$2.6	$4.8	NA	**$3.0**
Option B) Communal masonry wells and manual lifting					
B.1) Initial construction costs	NA	NA	NA	$16,500	**$16,500**
Capital cost per person with access to water supply per year (host and nomads)	NA	NA	NA	$0.4	**$0.4**
B.2) Maintenance and replacement costs over 30 year design life period	$0	$0	$0	$3,600	**$3,600**
Maintenance cost per person with access to water supply per year (host only)	NA	NA	NA	$0.1	**$0.1**

**** The number of people with access to sand dam water supply considers seasonal pastoralist immigration in Huluuq durig the dry season (450HH) but only host population (120HH) is considered in maintenance costs per capita.***
Detail of maintenance and replacement cost calculations is provided in Appendix VIII.

Table 15. Summary of capital, operation and maintenance cost of communal water supply facilities associated to sand dams. Source: Lopez-Rey (2019)

Chapter 6 Discussion and Recommendations

6.1 Effectiveness of sand dams for domestic water supply

6.1.1 Water quantity

The method for calculating water demand coverage during the dry season has several limitations. The maximum depth of the sand reservoir was estimated based on the depth to the bedrock in the wells in the throwback, rather than by probing, which would have provided more accurate maximum extractable volume results. In the absence of a hydrological survey, the supply vs demand analysis only considers the water stored in the sand reservoir and not the groundwater in the permeable bedrock below the sand reservoir. The values obtained are therefore likely to be underestimated.

During the dry season the recharge of the sand aquifer is considered nil, assuming any inflow from base flow is offset by outflows from evaporation and seepage. Assuming the sand aquifer is fully replenished at the end of a normal rainy season, the study appraises if the maximum extractable volume is sufficient to cover domestic water demand during the long 5-month dry season.

Huluuq and Aw Barkhadle communities reported the use of 20 l/p/d during the dry season. Carracad and Diinqal reported the use of only 13.3 l/p/d, below the minimum SPHERES standard of 15 l/p/d for drinking, cooking and personal hygiene. The study considers 20 l/p/d as the minimum sufficient amount to cover domestic water supply in this context.

The results in Table 12 show that the maximum extractable volume is sufficient to cover 100% of the current domestic water demand in the long dry season and therefore throughout the year, when recharge takes place. However, group interviews revealed that at one of the sites, the wells dry three months before the end of the dry season and at three sites the yield is very low in the last month of the dry season (Figure 30). This is likely to be explained by the high demand for livestock watering of local and nomadic pastoralists, as well as other uses, during the peak of the dry season. Table 12 shows livestock demand is on average 3.5 times domestic demand considering nomadic pastoralists immigration. As there is no regulation on quantities abstracted, the availability of water for domestic use cannot be guaranteed until the end of the dry season at those sites where demand for livestock or water trucking exceeds the maximum extractable volume of the dam.

6.1.2 Water quality and acceptance

The SPHERE water supply Standard 2 on water quality states that water should be "*palatable and of sufficient quality to be drunk and used for cooking and personal and domestic hygiene without causing risk to health*" (SPHERE PROJECT, 2011, p.100). Qualitative data obtained from the group interviews showed low frequency of diarrhoeas at all five sites, with no significant change in diarrhoeal diseases before and after the construction of the dam. Drinking water extracted from the sand is considered culturally acceptable since digging wells on the sandy riverbeds is a traditional way of accessing water for domestic and other purposes. All groups interviewed shared the view that water from the covered wells behind the sand dam is of good quality, palatable and safe to drink without any prior treatment. Water for drinking is collected exclusively from covered wells, while open wells and scoop holes are used for washing, livestock or irrigation. This clearly indicates community awareness of the contamination risk in non-protected sources and illustrates the importance of equipping sand dams with protected water sources for domestic use.

The sand reservoirs in the throwback of the studied dams are not protected and livestock faeces was observed at several sites. At two of the sites water for livestock is lifted manually from the wells in the riverbed and numerous animals enter the sand dam throwback area for drinking. This increases the risk of faecal contamination, particularly during the wet season, due to increased run-off and infiltration. The increase in the water table also limits the depth available for sand filtration of pathogens.

The water quality results in Table 13 show Huluuq water sample collected in the tap stand meets WHO standards for pH, turbidity and TTC. Diinqal well #1 sample´s high turbidity and positive TTC is explained by the fact that the solar piped-water system is not used in the rainy season and the communal well is used for irrigation by neighbouring farmers. During the two visits the well was found open and the metal lid does not seal the manhole properly. It is therefore likely that surface run-off has entered the well, which could explain the high turbidity and TTC results. The observed layer of silt on the surface of the riverbed also explains the high turbidity. Aw Barkhadle sample collected in the tap stand has pH and turbidity within the standards but positive TTC. The communal well feeding the piped water system is protected, although it could not be observed directly because the well head is fully buried below the sand. Considering the depth of the sand deposit and the high proportion of fine sand (Appendix VI), it seems unlikely that the surface run-off is the source of bacteriological contamination. A more plausible explanation is the proliferation of bacteria in the stagnant water leftover in the tank, given the fact that the system was not running on daily basis during the rainy season and the pump was only activated at the time of the visit to collect samples from the tap stand.

The qualitative data on water quality provided by the group interviews cannot be triangulated with quantitative data from the water quality analysis because the reliability of the results is very limited. The same sampling and testing process should be repeated at different points in time to validate the results. Nevertheless, it can be concluded that while sand may filter pathogens, the risk of contamination can be high in unprotected wells or poorly maintained water systems. Further research on the water quality of sand dams is recommended, in addition to post-implementation water quality monitoring.

6.1.3 Accessibility

All five sites have at least one communal well, often more, accessible by all community members. Communal wells can be accessed for free and with no restriction throughout the year, whenever water is available. In some cases, communal wells are also accessed by non-community members such as nomad seasonal pastoralists in Huluuq or neighbouring valley communities in Carracad. No groups were identified as excluded from accessing communal wells for domestic and livestock use.

In Somaliland, the WASH cluster and SPHERE standard *“Maximum distance to nearest water point is 500 metres*” is rarely achievable in peri-urban or IDP settlements, let alone in rural areas, where the population is dispersed over a large area. The results are therefore not compared against this standard, but in terms of users’ perception of physical accessibility and convenience. The results can be classified in two categories:

1) Off-site distribution, where water is piped to tap stands in the village. This is the case of Huluuq, where accessibility and convenience are positively perceived and the use of tap stands is the preferred water source for domestic use all year round.

2) On-site distribution, where water is accessed directly from the communal well (Carracad and Camud), or from tap stands located next to the sand dam well (Aw Barkhadle and Diinqal). In the case of Carracad, the community is used to travelling up to 16km with donkeys to fetch water from a spring in the dry season so the increased local water availability is perceived as a critical advantage. On the other hand, Aw Barkhadle and Diinqal are used to paying for water delivered by vendors close to their premises. Hence, the installation of tap stands at 1.2-1.5km from the village centre is not perceived by the interviewees as a more convenient option, despite water being free. In this scenario, the community considers that accessibility would be improved if water was piped to tap stands in the village at lower fees than the current vendors’ prices.

Accessibility and convenience are context-based and largely dependent on pre-existing circumstances, user preferences and willingness to pay for different levels of service, all of which need to be factored in to the design of water abstraction and distribution facilities. The consideration of social aspects in design is further discussed in section 6.3.1.

6.1.4 Affordability

In-kind community contribution with materials and labour was identified at two sites only. At all sites, the construction costs of the dam and wells were almost fully subsidised by external agencies with no capital investment cost-recovery.

No formal O&M cost-recovery mechanism is in place at any of the sites. Water is accessed free of charge at all communal facilities and therefore affordability is not a limitation for users. Table 14 shows that sand dam maintenance costs per person per year for a 30-year project life are actually very low and affordable. The water supply facilities O&M costs vary from 0.1 to 3 USD/person/year depending on the level of technology selected (Table 15). The financial aspects of sustainability are further discussed in section 6.3.2.

6.1.5 Cost –effectiveness

The initial capital cost of reinforced concrete (RCC) sand dams varies between 32,120USD and 67,397USD, with riverbed width as the main variable influencing the total cost. The cost per cubic meter of dam ranges from 312 to 470USD for RCC, with smaller dams having higher cost per cubic meter. For the rubble stone sand dam and SSD in Huluuq, the estimate cost was only 69USD/m^3 (Table 14).

Cost-effectiveness, considered as the comparison between capital investment costs and the number of people with access to water supply, largely varies with the type of sand dam and population served. The highest cost-effectiveness is recorded in Huluuq, at 5.0USD per person, due to the relatively low investment costs of three rubble stone dams compared to the large population of host community and nomads served in the dry season. The lowest cost-effectiveness was recorded in Diinqal, at 43.5USD per person, due to the high cost/volume ratio of a relatively small RCC dam and smaller number of users. A reasonable average to consider is illustrated in the results for Aw Barkhadle and Carracad, with a range from 21-29USD per person, equivalent to 0.7-0.9USD/person/year considering a 30-year project life. This is less than the capital costs per person reported by ALTAI (2015, pp.74-80) for small earth dams (33USD/person) and *berkads* with a storage capacity of 500m^3 (103USD/person). ALTAI's

(2015, pp.85-87) study of four sand dams shows values from 16.4-74USD per person, with the highest cost recorded for a 175m long weir dam.

6.2 Contributions to resilience and water security

6.2.1 Individuals resilience

A positive impact of sand dams cited by interviewees across all sites is the improvement in water availability during the dry season, with a net gain of two to five months of local water supply, as shown in Figure 36. This translates to improved self-reliance and many direct benefits for communities. Firstly, reduced time to fetch water, as illustrated in the example of Carracad. Secondly, lower expenditure on water during the dry season, as mentioned by Diinqal community. Thirdly, an increase in the amount of water used by households (slight to large increase reported by all communities). Fourthly, extended availability of water for livestock resulting in improved animal health and body condition (reported by all communities). Indirect benefits of the above include; more time available to women for childcare and income generation, increased household savings and better hygiene practices.

6.2.2 Livelihoods resilience

The results show a general improvement in the yield of irrigation wells located upstream of the dam, except in Diinqal, where the interviewees do not appreciate any change. However, this dam is just over 1-year old and it may take several years for the sand dam to reach its full storage capacity. Improved yield results in improved productivity and income for upstream farmers. The results also evidence that farmers located downstream can be negatively affected by a reduction in wells yield and alluvial sediment. This negative impact is evidenced by the dissatisfaction of downstream famers in two communities. In the other three, there is either no presence of farmers 1km downstream, or farmers downstream benefit from a second dam (Camud). These results confirm the learning framework recommendation 2.6, regarding the need to avoid siting of dams where irrigated farming exists within 1-2 km downstream (KI1, 2019 and HYDRONOVA, 2019). Alternatively, several sand dams in series can be proposed, as in the case of Huluuq and Camud.

The results also show a positive impact on livestock husbandry activities. All five communities reported good livestock body condition during normal dry seasons, which is partially attributed to increased water availability. Aw Barkhadle community perceived a slight decrease in emigration during the dry season. Huluuq and Camud, which are traditional seasonal immigration sites, have witnessed an increased influx of nomads after the dams' construction.

Table 12 shows that in Huluuq the maximum extractable volume of the three dams in series is 187% of the domestic and livestock demand in the dry season (including estimated demand from nomadic pastoralists). Thanks to this surplus, Huluuq farmers are able to irrigate large surfaces of fruit trees and vegetable crops even during the dry season. In the other three sites, the coverage of domestic and livestock demand varies from 58% to 77%, hence alternative water sources are still required. These results are likely to be underestimated, as only water stored in the sand reservoir is considered and not the groundwater in the permeable bedrock (see section 3.3.1).

Livelihood diversification is more remarkable in Huluuq and Camud (before the wall collapse), where farmers have introduced new vegetable and fruit cash crops such as guava and citrus. In Carracad, where cereal rain-fed agriculture is predominant, some households with access to the riverbed wells have introduced home gardens. Other new sources of income include petty trade with nomadic pastoralists, sale of sand for construction and sale of water to private vendors. Sand and water sale was only observed in the two communities located closer to urban centres; Aw Barkhadle and Camud. This represents a source of additional income for a handful of households but it can also lead to accelerated depletion of the community resource in the absence of regulation.

6.2.3 Ecosystems resilience

Three communities report a visible increase in natural riverine vegetation and biodiversity upstream, likely to be attributed to an increase in the water table. Aw Barkhadle and Camud interviewees did not observe any significant change in vegetation, however this could be due to the fact that one dam is only 1 year- old and the other collapsed in 2018. No negative impacts on the downstream natural riverine vegetation were observed at the studied sites or cited by the interviewees.

Further research on the potential of sand dams for ecosystem-based adaptation is highly relevant in the climate change vulnerable context of Somaliland. As concluded by Ryan and Elsner (2016) increased biomass enhances ecosystems' resilience to climate variability and increases drylands´ adaptive capacity.

6.3 Factors influencing sustainability of sand dam technology in Somaliland

The results of on-site observation and group interviews clearly show shortcomings in the sustainability of sand dams and associated facilities. At two sites, Aw Barkhadle and Carracad, the gabions damaged during 2018 cyclone floods had not been repaired. The Diinqal dam, only one-year old, is still in good condition. Huluuq's rubble stone sand dam is in good condition despite being almost 20 years old, but the eroded crest has never been maintained. Finally, Camud collapsed dam illustrates potential deficiencies in design and construction but also lack of adequate maintenance. This section discusses the potential reasons: Lack of awareness or capacity? Lack of resources or willingness to pay? Lack of interest or satisfaction with the sand dam? Lack of sense of ownership and responsibility?

This discussion is structured around social, technical, financial and environmental aspects identified as factors influencing the sustainability of sand dams and the associated water supply infrastructure. Findings are discussed against the backdrop of the recommendations captured in the learning framework in Chapter 4.

6.3.1 Social aspects

Participation in the siting decision-making process was hindered by a general lack of understanding on how sand dams work and the associated benefits and risks. Only two communities actively participated in the siting process. Other communities stated that they were not familiar with this new technology and therefore relied on the engineers to select a suitable location. One community expressed clear dissatisfaction with the final site chosen, which shows that technical aspects may not have been sufficiently explained. Learning 2.3 (p.47) highlights the importance of community sensitisation and technology awareness prior to the start of the project. As suggested by the author, KI1 (2019) and HYDRONOVA (2019), visits to other communities with access to sand dams would be the most appropriate way, as people can more easily relate to the experience of similar communities.

Despite the initial lack of knowledge, all five communities interviewed concluded that they are satisfied or very satisfied with the sand dam impacts and will recommend the technology to other communities. This confirms a high level of social and cultural acceptance of the technology. Upstream farmland owners are clearly the most satisfied with the significant increase in well yields and the resulting benefits. However, the potential negative effect on downstream dwellers discussed in section 6.2.2 must be mitigated. A sensitisation phase can also assist the community in taking better-informed site selection decisions to mitigate these risks and avoid conflicts in the community. In the opinion of this study, sensitisation and siting consultation are more effective in mitigating risks and conflicts where they involve the broader community and not only the village committee or water user committee members. As highlighted in section 2 of the learning framework, socio-economic factors must be considered along with the topographic and hydrogeological factors to identify suitable riverbed sections. If the community preferred option is not technically viable or not the option with highest water storage capacity, the technical justifications must be communicated to communities. Following joint agreement on the selected site, land tenure issues must be resolved before implementation (learning 2.4, p.47). In Diinqal for example, a landowner was compensated with land elsewhere in order to construct the project water supply facilities.

Participation in the design of the associated water supply facilities is also identified as a critical factor influencing community user satisfaction and thus willingness to maintain the facilities. The findings illustrate the importance of considering pre-existing circumstances and user preferences. The designed facilities must improve the convenience of pre-existing facilities either by reducing time or distance for water collection as in the case of Carracad or Huluuq, or by reducing water-related expenditure as in the case of Diinqal. This highlights the importance of informing design through participatory assessment of existing water sources, seasonal availability, prices and user preferences. In Aw Barkhadle for example, the water supply facilities constructed next to the sand dams are of very good quality but the majority prefer to buy water delivered closer to households rather than transporting water 1-1.5km. In this case there is little incentive to contribute to the maintenance costs. Contributions may be limited to those living close to the facilities and upstream farmers directly benefiting from the dam.

As for any rural water supply project, considering the appropriateness and affordability when selecting technology is also good practice in the case of sand dam facilities. In communities located closer to towns like Diinqal and Aw Barkhadle, spare parts and technical skills are readily available for maintenance and replacement of solar-powered piped water systems, whereas in isolated communities such as Carracad, maintaining such facilities could prove challenging. Considering that the responsibility for the operation and maintenance of facilities falls on communities, they must be provided with a costed range of options. Cost analysis should consider operation, recurrent maintenance and replacement costs for the design period, prorated per year or month and per user, to provide a clear picture of the contributions that will be required to sustain each technological option. Further analysis regarding financial sustainability is discussed in section 6.3.2 below.

Participation and contribution to construction was generally low, with only two communities actually providing in-kind contribution of construction materials or labour. Only one of the communities interviewed had an estimated idea of the total construction cost. Although it is not common practice for agencies to share detailed information of the costs of a project and to provide a value to community contributions, in the authors' experience, awareness of external capital investment and valued community contributions clearly enhances a sense of ownership and self-reliance in communities, which can positively influence sustainability. This recommendation is supported by SASOL (2004), KI1 (2019) and Maddrell (2018) and captured in learning 5.5 (p.49).

At all sites the sand dam and associated facilities have been handed-over by implementing agencies to the community, represented by the village committee (VC). In two communities, a specific Water User Committee was formed during the project but at the time of the interview the community did not make a distinction between this committee and the VC. At the five sites the management of the sand dam and facilities falls within the responsibility of the VC or a sub-committee within this body. Therefore, building the capacity of the existing traditional local governance structures, rather than creating new bodies, seems a more sustainable approach in the context of small rural communities in Somaliland. Only one of the five committees received training on how to maintain the dam and gabions. The three communities with solar pumping systems received training only on the operation and maintenance of the system but not of the dam itself. These findings show a significant knowledge gap regarding how to protect the sand dam structure in the longer term.

Decentralised community-based management in rural African contexts with low presence and capacity of public and private stakeholders is often the most suitable approach. However, some level of external support and regulation is often required for the sustainability of community-managed systems. In the case of the studied sand dams, a regulatory and supportive role from government is recommended by the author in order to regulate over-abstraction, monitor water quality and provide maintenance technical support. The author also recommends to align sand dam planning processes with multi-year grants timelines, when possible, to ensure post-implementation monitoring and capacity building on sand dam maintenance.

6.3.2 Financial aspects

The cost analysis summarised in Table 14 shows that the cost of adequate dam and gabions maintenance over a 30-year project life can range between 0.7 and 1.2USD per person per year. Investing in increasing the wall height by an additional 60cm would represent an average cost 0.2USD per person per year for RCC dams. The analysis assumes that all the host community accessing water supply contribute to maintenance costs. These values suggest that affordability is not the main limiting factor for sand dam maintenance.

Regarding the operation and maintenance of water supply facilities, the cost analysis summarised in Table 15 shows that figures can vary from an average of 3USD per person per year for solar water pump systems to only 0.1USD per person per year for the maintenance of covered wells with manual lifting. While motorised water lifting is recommended to protect water quality, this technology may not be appropriate or affordable in more remote communities. Aw Barkhadle and Diinqal spend an average of 19USD per person per year buying water from vendors, hence an annual fee of 3USD would be affordable and result in household savings. In Huluuq, the costs are relatively higher than the average at 4.8USD, due to the small host population numbers, but this cost may still be affordable given the high productivity of the cash crops in this community.

None of the five sites has a cost-recovery system in place to cover operation and maintenance costs. Community-based cost recovery is not common practice in the study region and fees are only paid to private service providers such as water vendors or owners of facilities such as *berkads*. Paying fees for a community owned resource is not a common practice in Somaliland. In these specific case studies, there are no “visible” expenditures such as fuel consumption and therefore the collection of periodic fees or fees on jerry cans is unlikely to be successful.

Solar pumping system daily operation costs are limited to the salary of operators, which are either partially subsidised by government or paid by the community. Recurrent maintenance is not required, as opposed to fuel generators. The costs to be covered are therefore punctual repairs of the sand dam (gabions, crest, wing walls) and the repair or replacement of solar panels, pump, pipes and batteries. As these costs are not recurrent but punctual expenses, the collection of community contributions when repairs are required is likely to be more effective than regular water fee collection, which involves more complex administration and risks associated to cash management.

This is illustrated by the case of Huluuq, where community contributions are collected from harvests to repair community infrastructure when required. No repairs have been done since construction in 2000 because the community considers the dam is in good condition, not due to lack of financial resources. In Carracad the community expressed willingness to contribute to iron wire and the collection of rocks but technical support is required to repair the gabions. In Aw Barkhadle, the committee cited lack of resources as the reason for not repairing the fully washed-away gabions. However, according to the group interviews, well owners upstream have increased their income selling water and irrigated cash crops and Aw Barkhadle households spend an average of 19USD per year buying water from vendors. Hence, rather than affordability, the problem is likely to be lack of awareness on how to maintain the dam or the expectation that the implementing agency will conduct necessary repairs. These factors are strongly linked to the social aspects of project ownership and capacity building described above.

6.3.3 Technical aspects

All the sand dams visited were built in ephemeral rivers at riverbed sections with widths ranging from 26.4-55.3m, above the 25m width recommended by Nissen-Petersen (2006) to reduce costs of reinforcement (learning framework point 4.1). Indeed, Aw Barkhadle dam with a total length of 55.3m wide has the highest cost (67,387 USD). A SSD could have been a less expensive option for this wide and flat river section. However, given the high water demand for livestock and water trucking in this site a greater investment is justified. Huluuq SSDs are located in sections 63-69m wide.

Estimated average slope of the throwback section provided by Google Earth (Appendix VII) shows values in the range of 1.5% to 4.8%. Only Diinqal has a topographical gradient above the 0.125 - 4% range recommended by several authors (learning 1.3, p.46), which may partially explain why this was the only site with a silt layer covering the entire throwback surface.

Drainable porosity varied from 18% to 30% (see Appendix VII). Considering the measurement limitations explained in section 3.3.1, these values have low accuracy, but they do correlate with sand particle sizes inventoried in Appendix VI. Aw Barkhadle, with the lowest value, shows high proportion of fine and very fine sands, whilst Diinqal records the highest value due the high presence of coarse sand and gravel (the sample was collected 30cm below the surface thus avoiding the top silt layer).

None of the dams were built in stages during construction (Figure 1). Only Carracad sand dam was raised by 20cm during rehabilitation works. According to the recommendations of Maddrell (2018) and Nissen-Petersen (2006), building in stages can increase the proportion of coarser sands and reduce the content of fine sands, thus increasing drainable porosity and water storage. Building the dam in stages can be a suitable method to increase the volume of extractable water in riverbeds with very high content of fine sand like Aw Barkhadle.

Some deviations from the technical design recommendations captured in learning 3.1 (p.47) include:

- Two of the four sand dams did not have wing walls sufficiently embedded in the riverbanks and showed signs of water overflow.
- The width of the base could not be appraised visually. However, one of the four sand dams has a straight wall, rather than a sloping downstream wall, suggesting the base

and the crest have similar width. This can compromise the capacity of the sand dam to withstand the pressure of water and sand.

- The spill over apron downstream of the dam extends sufficiently at only one of the sites but is not protected with gabions. At two sites, the spill over apron was not visible but the gabions on top had been fully or partially washed away. KI3 (2000) suggests the use of stone riprap downstream and Nissen-Petersen (2006) suggest covering the apron with large stones or gabions. None of the sites presented the combination of both riprap apron and gabions to minimize the risk of erosion and structural damage. The case of Camud rubble stone sand dam described in section 5.6 clearly illustrates how erosion at the base of the wall can weaken the dam structure and result in collapse during above normal flood episodes.

Key informant interviews and field visits confirmed the existence of strong engineering expertise in sand dam siting and design in Somaliland, as well as construction contractors with experience in this type of infrastructure. Onsite monitoring by engineers is essential to ensure the designs and technical specifications are respected.

6.3.3 Environmental aspects

Sand dam rainwater harvesting is a sustainable water resource because it is recharged every rainfall episode. The technology allows communities to cope with water scarcity in the dry season. However, the reliability of the source can be compromised in drought years with below average recharge and increased demand. The carbon footprint of the technology is limited to the manufacturing and transport of constructions materials. Manual water lifting or solar pumping have zero emissions.

Consideration of environmental impacts and mitigation measures in the design phase is strongly recommended (learning 6.5, p.50). In Camud, flood risk upstream of the dam was perceived to be higher than before dam construction, though this could have been influenced by the 2018 Sagar cyclone floods that caused the collapse of the wall. At all the other sites, flood risk was perceived to have decreased or not changed upstream of the dam. Flood risk downstream is perceived to be higher after the construction of the dam in two communities, Carracad and Aw Barkhadle, due to increased erosion of unconsolidated riverbanks. Gabions in the riverbanks like those present in Huluuq and tree planting for soil stabilisation are possible mitigation measures.

Chapter 7. Conclusion

The research concludes that sand dams are an effective solution to improve domestic water supply in rural areas of Somaliland. Sand dams are a socially acceptable technology with potential to cover 100% of communities' domestic water demand during the dry season. Considering the methodological limitations described for the supply and demand calculations, a conservative approach was taken when estimating values for which accurate data was not available or could not be collected in this study. Therefore, the percentage coverage of domestic demand and livestock demand are likely to be underestimated and can be considered as minimum values. Effective management and regulation of sand dams is however crucial to prevent over-abstraction for other uses. Failure to do so can result in insufficient water availability for domestic use in the dry season. Where demand exceeds supply in the dry season, sand dams constructed in series can further increase storage capacity to meet domestic, livestock and other uses all year round.

There is a general perception among users that water from covered wells in the sand dams is of good quality and can be consumed directly without any treatment. However, despite the pathogen filtration capacity of the sand reservoir, preliminary water quality test results show bacteriological contamination in unprotected wells or poorly maintained water supply facilities. With adequately protected water supply systems sand dam water can meet WHO water quality standards for bacteriological contamination (TTC), pH and turbidity.

The findings show that investment in sand dams is cost-effective, requiring an average capital investment of 21-28 USD/person for a minimum 30-year supply. This is less than small earth dams at 33USD/person and *berkads* with storage capacity of 500m^3 at 103USD/person (ALTAI, 2015, pp.74-80).

The analysis of factors influencing the sustainability of sand dam technology in the rural context of Somaliland indicates very high potential for long-term sustainability but also evidences shortcomings. For example, insufficient knowledge of this relatively new technology in Somaliland hinders communities' ability to participate in the site selection and design phase in a more informed and proactive manner. However, as highlighted in section 2 of the learning framework, it is essential that socio-economic factors are given equal consideration to technical factors. Adequate community sensitisation through visits to other sand dams and broader community consultation on site selection can mitigate potential negative impacts on downstream dwellers, such as reduced well yield and increased erosion of unconsolidated riverbanks.

The findings also illustrate the importance of considering pre-existing conditions, community user preferences and willingness or ability to pay when designing sand dam water supply facilities. To be effective and accepted by communities, sand dams need to visibly improve pre-existing facilities either by reducing time/distance for water collection or by reducing water expenditure, or both.

The cost analysis suggests affordability is not a limiting factor for sand dam maintenance, nor is the availability of technical services, materials and spare parts. Three factors are identified as the most important limiting factors to sustainability: firstly, a low sense of community ownership, caused by insufficient knowledge of technology often resulting in limited participation in the design process and resulting in the lack of community contribution; secondly, insufficient community awareness and capacity to conduct essential sand dam maintenance such as gabions repair and; thirdly, where convenience and accessibility is not visibly improved, users satisfaction and willingness to pay is low. Community based cost-recovery mechanisms based on punctual contribution for specific repairs are likely to be more successful than recurrent collection of fees in this context.

This research provides evidence that sand dams contribute to improve water security and community resilience in four critical ways:

- Safeguarding access to water supply for domestic and livestock use during the long dry season (*Jilal*), with net gains from two up to five months of local water supply resulting from increased water storage capacity of the alluvial sand aquifer.
- Reducing the risk of water-borne pollution through sand filtration. However, the provision of safe drinking water free of coliforms can only be assured through protected water sources and well-maintained facilities.
- Sustaining agro-pastoral and pastoral livelihoods by covering 58%-100% of combined domestic and livestock water demand in the dry season, supporting income generation through increased irrigation capacity for fruit and vegetable cash crops and diversifying income sources.
- Increasing riverine vegetation quantity and variety thanks to the rise of the water table. This results in enhanced resilience of the riverine ecosystem and improved adaptive capacity to climate change (Ryan and Elsner, 2016).

The above benefits have direct causal links with improved food security, nutrition and health. In turn, these factors contribute to enhance individual and community resilience capacities to cope with climate-related shocks.

The findings of this research are based on a limited sample of sites: five communities with a total of four sand dams, two sub-surface dams and one collapsed dam. This is estimated to be 1/5 of the number of sand dams in Somaliland. Therefore, the results are not statistically representative and cannot be extrapolated to all sand dams in Somaliland. The research however meets its objective of appraising the effectiveness, sustainability and impact of sand dams in Somaliland, directly expanding the limited body of evidence in this geographical area by complementing the study of four sand dams conducted by ALTAI (2015). The learning framework produced in Chapter 4 is not intended to be an exhaustive collection of sand dam best practices, as it is limited to a succinct review of two practitioner manuals and six case studies, and as such does not represent an in-depth review and analysis of best practice. Nonetheless, the learning framework fulfilled its objective of assisting in the interpretation of field results and serves as guidance for Concern Worldwide team and other practitioners piloting sand dams.

Based on the analysis of effectiveness, sustainability and positive impacts of sand dams to alleviate water insecurity and shore up community resilience to climate change, this study strongly recommends the piloting of sand dams in new locations of Somaliland. Available local technical capacity, a supportive public policy framework, the relative security and stability of Somaliland as well as the favourable climatic and hydrogeological conditions confirmed by Mohamoud (1990), Oduor and Gadain (2007) and Altai (2015), all contribute to a highly conducive environment to realize the potential of sand dams.

This study recommends building on the lessons learned from engineers in Somaliland and other experiences in arid environments in Africa, some of which are captured in the learning framework (Chapter 4). In particular, the design of sand dam projects should consider the coverage of domestic and livestock water demand of host and nomadic populations in the dry season (as well as other uses like water trucking). Sand dams built in series can be a suitable option to further enhance storage capacity and meet the projected demand with minimum downstream impact.

To maximise benefits and sustainability, sand dam projects need to be jointly led by communities from the initial decision-making stages of site-selection and design of water supply facilities. This requires investing in building capacity and creating in-depth community awareness around this new technology. To remain effective in the long term, post-implementation support and monitoring is critical to the sustainability of community-managed sand dams and facilities.

Finally, this study also recommends accurately documenting future pilot sand dam projects to record lessons learned and challenges faced. Scaling up and refining this experience in the context of Somaliland has the potential to expand this valuable and innovative technology to benefit communities in other Somali regions where climate-resilient water supply solutions such as sand dams remain underdeveloped.

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Appendices

I. Data collection tools: Key informant interview guide

II. Data collection tools: Technical assessment form

III. Data collection tools: Semi-structured group interview guide

IV. Informed consent form

V. Group interview photographs and community maps

VI. Sand samples

VII. Calculations of extractable volume and water demand coverage

VIII. Calculations of capital investment, operation and maintenance costs.

IX. Bacteriological test results

Appendix I. Data collection tools- Key informant interview guide.

Name:
Location:
Date:

- Introduction
- Summary of research objectives and methodology
- Purpose of the KII and consent.

1) Could you please share an overview of your experience implementing sand storage in Somaliland?

Prompt questions

How many?

Where?

When?

What was the implementation modality?

- *Directly through a contractor? –from where? –is there local expertise?*
- *What was the role of the community? –siting, construction, management…*
- *Government role?*

2) Have the results been as expected?

3) Are you still implementing sand dams or planning to do so in the near future?

If yes: Where?

If no : Why?

4) Do you find the technology is cost-effective in the context of Somaliland? (Estimated cost per sand dam?)

5) Do you find sand dams are a sustainable solution for rural water supply in the long term?

6) What major challenges did you encounter during the project? And what challenges do you foresee regarding the long-term good functioning of sand dams?

Prompt questions

- *Acceptance of the technology by communities?*

- *Technical capacities for construction and maintenance?*

- *Financial cost of maintaining the dams?*

- *Conflict with excessive abstraction from water trucking vendors?*

7) What are the main learnings from previous sand dams projects and what would be your key recommendations for stakeholders engaging in sand dam development?

➢ Open discussion for other inputs or questions on the study.

➢ Request consent to cite this interview in the MSc research dissertation report.

THANK YOU FOR YOUR TIME

.

Appendix II. Data collection tools- Technical assessment form.	
Date :	**Sand dam:**
Community description	
District	
Community	
GPS point community “center”	
Estimated population (data source)	
Community description and livelihoods	
River/area description	
River morphology	
River width at sand dam site (meters)	
River bank height (m) and composition	Upstream Downstream
River bed composition	Upstream Downstream
Type of vegetation and activities upstream/downstream	
Sand dam description	
Year construction	
Organization constructed	

Year rehabilitation	
Organization rehabilitated	
GPS coordinates at the dam	
GPS coordinates at the end of the sand throwback	
Total length sand dam (including wing walls)	
Total length of main spillway.	
Width of the crest	
Estimated height of the main wall (From crest of spillway to bedrock)	
Estimated height of the wing walls (From highest wing to bedrock)	
Gradient (Slope) from wall – to visible throwback point.	
Materials of the main wall	
Condition of the main wall	
Materials of the wing walls	
Condition of the wing walls	
Does the dam confine the flow of sand and water or is flood diverted around the dam?	
Materials of the crest	
Condition of the crest	
Materials used for dam erosion mitigation (rip-rap, gabions..)	
Condition of the erosion protection measures	

Description of top layer sand	Type: Silt < 0.5mm Fine sand 0.5-1mm Medium sand 1-1.5mm Coarse sand 5-19mm Fine gravel 5-19 Gravel 19-70mm
Description of sand 60 cm below	Type: Silt < 0.5mm Fine sand 0.5-1mm Medium sand 1-1.5mm Coarse sand 5-19mm Fine gravel 5-19 Gravel 19-70mm
Water sampling in new scoop hole upstream of the dam (if hand auger available and water within < 80cm)	
Sanitary conditions upstream of the dam	
Transect view drawing	
Bird view drawing	

Water abstraction	
Well # 1 **Main public/communal well with:** 1) Windlass/manual lifting 2) Handpump 3) Pumping system to reservoir and tap stand. 4) Other, specify	GPS: Type of well: Estimated depth: Diameter: Water level: Water aspect: Water lifting device: Associated facilities (livestock trough, irrigation pump, etc.) Main use of the wells: domestic/ irrigation/ livestock /multipurpose Ownership: Observations on sanitary conditions: Water sampling:
Well # 2 Secondary private/public wells	GPS: Type of well: Estimated depth: Diameter: Water level: Water aspect: Water lifting device: Associated facilities (livestock trough, irrigation pump, etc.) Main use of the wells: domestic/ irrigation/ livestock /multipurpose Ownership: Observations on sanitary conditions: Water sampling:

Well # 3 Secondary private/public wells	GPS: Type of well: Estimated depth: Diameter: Water level: Water aspect: Water lifting device: Associated facilities (livestock trough, irrigation pump, etc.) Main use of the wells: domestic/ irrigation/ livestock /multipurpose Ownership: Observations on sanitary conditions: Water sampling:
Description of other water sources in the community (protected/unprotected)	

Appendix III. Data collection tools- Semi-structured group interview guide.

SECTION I COMMUNITY MAPPING EXERCISE

1. Village center and location of settlements (estimated total population)
2. Community buildings (School, mosque, health facility, market)
3. Road
4. River/s,
5. New and old sand dam/s,
6. Communal wells
7. Private wells
8. Other water sources
9. Farmland
10. Other livelihood zones, landmarks
11. Satisfaction of community groups in different locations (i.e upstream/downstream)

Additional notes:

SECTION II GROUP INTERVIEW: Sustainability- siting, design & construction quality, community participation, ownership and O&M

12. When was the dam built?

13. Who built it?

14. Did the community decide the location?

    - If yes: Who was involved in the decision? ____________________________________

      Why did you decide to locate it there?__________________________________
    - If no: why?____

15. Did the community participate/contribute in the construction?

    - If yes: How did you participate/contribute? ____________________________________
    - If no: Why you didn't participate?

      ____

16. Do you know what was the cost of building the sand dam?______________________

17. What materials were used for construction?

    ____

    ____

18. Was the trench build below the river bedrock or above the river bedrock?

    ____

19. Is the sand dam in good condition or is it damaged?

- Good condition
- Damaged. What is the damage?

  ____

  ____

20. Who is responsible for the maintenance of the dam?

____

21. Did you receive any training on utilization and maintenance of the dam?

- If yes: what do you know about use and maintenance of the dam

  ____

  ____

- No

22. Has the dam been repaired since construction?

- If yes: What repair?

  ____

  Who repaired? ____

  What was the cost?____

  Who paid? ____

- If no: Why?

  ____

23. Has the height of the dam been raised since construction?

  If yes: By how much? ____

  Who did the works? ____

  What was the cost? ____

  Who paid? ____

- If no: Why?

____

24. Is money collected to pay for maintenance/repair of dam?

- If yes:

  Who pays?____

  Who administers money collected?___________________________________

With which frequency is money collected? ______________________________

What is the money used for?____

____

- If no: Why?
  ____
  ____

Additional notes:

SECTION III. Group interview: resilience, equity and effectiveness of sand dams in terms of water availability, access and quality.

1. In the **rainy seasons** Gu and Deyr, where do you get water for drinking, cooking, washing and small animals in the house?
   Do not list options, mark most relevant answers. Ask for all sources available and mark for principal source with 1, secondary source with 2 and any tertiary source with 3.

- Sand dam wells: Communal well, private well, scoop hole? _________
  Water depth _________Walking time (round trip) ?____________ Price per jerrycan? ____________
- Water vendors. Price per jerrycan?______________
- Berkads – Walking time (round trip) ? ___________Price per jerrycan?
- Earth pan – Walking time (round trip) ? ___________Price per jerrycan? ___________
- Borehole – Walking time (round trip) ? ___________Price per jerrycan? ____________
- Other, specify__________ Walking time (round trip) ? _________Price per jerrycan?___________

Why?____

____

1. **Xilliyada roobka** Gu ga iyo Deyrta, xaggee baad ka heshaan biyaha la cabbo, wax lagu karsado, dharka lagu dhaqo iyo kuwa la siiyo xoolaha yaryar ee guriga jooga?
   Ku calaamadi isha biyood ee ugu muhiimsan 1, isha xigta 2, isha ugu hoosaysana 3

- Ceelasha biyo xidheenka: Ceel la wadaago, ceel gaar loo leeyahay, laas? ________
  jooga biyaha________ wakhtiga loo lugaynayo (round trip) ? ____________ Qiimaha hal ka Jirikaan? ____________
- Biyoole – Qiimaha hal ka Jirikaan _________________

- Barkaddaha – wakhtiga loo lugaynayo (round trip) ? _________ Qiimaha hal ka Jirikaan?______
- Balay – wakhtiga loo lugaynayo (round trip) ? _________ Qiimaha hal ka Jirikaan?________
- Ceel Riig – wakhtiga loo lugaynayo (round trip) ? _________ Qiimaha hal ka Jirikaan?
- Wax kale, sheeg ___________ wakhtiga loo lugaynayo(round trip) ? _________ Qiimaha hal ka Jirikaan? ________

Sababta sheeg?

____

____

2. During the rainy seasons Gu and Deyr, how many jerry cans (big 20L) you use in your household every day?

____

2. Xilliyada roobka Gu ga iyo Deyrta, imisa Jirikaan (20Litir) ayuu qoyskiinu isticmaalaa maalin walba?

____

3. After the construction of the sand dam, has there been any change in the amount of water you use per day during during Gu and Deyr?
Select option that best matches the group answers:
   - Much more water
   - Little bit more
   - No change
   - Little bit less
   - Much less water

   Comments: ____

3. Dhismihii biyo xidheenka dib, miyey wax iska beddeleen xaddiga biyaha aad isticmaasho maalin kasta inta lagu guda jiro Gu'ga iyo Deyrta?
Dooro jawaabta ugu fiican ee ku haboon jawaabaha kooxda
   - Biyo aad uga badan
   - Biyo woxoogaa ka badan
   - Is badal ma jiro
   - Biyo woxoogaa ka yar
   - Biyo aad uga yar

   Comments: ____

4. In the **dry season** during the last months of Jilal, how do you access water for drinking, cooking, washing and small animals in the house?
Do not list options, mark most relevant answers. Ask for all sources available and mark for principal source with 1, secondary source with 2 and any tertiary source with 3.

- Sand dam wells: Communal well, private well, scoop hole? __________ Water depth __________Walking time (roundtrip) ?_______________ Price per jerrycan? ____________
- Water vendors. Price per jerrycan?_______________
- Berkads – Walking time (roundtrip)? ____________Price per jerrycan? ______________
- Earth pan – Walking time (roundtrip)? ____________Price per jerrycan? _____________
- Borehole – Walking time (roundtrip)? ____________Price per jerrycan? _____________
- Other, specify___________ Walking time (roundtrip)? __________Price per jerrycan?____________

Why?____

____

4. Xilliga lagu jiro bilaha ugu dambeeya ee Jilaalka, sidee baad ku heshaan biyaha la cabbo, wax lagu karsado, dharka lagu dhaqo iyo kuwa la siiyo xoolaha yaryar ee guriga jooga? Ku calaamadi isha biyood ee ugu muhiimsan 1, isha xigta 2, isha ugu hoosaysana 3

- Ceelasha biyo xidheenka: Ceel la wadaago, ceel gaar loo leeyahay, laas? _________jooga biyaha _________ wakhtiga loo lugaynayo (roundtrip)? _____________ Qiimaha hal ka Jirikaan? _____________
- Biyoole. Qiimaha hal Jirikaan __________
- Barkaddaha – wakhtiga loo lugaynayo (roundtrip)? __________ Qiimaha hal ka Jirikaan?
- Balay – wakhtiga loo lugaynayo (roundtrip)? __________ Qiimaha hal ka Jirikaan?
- Ceel Riig – wakhtiga loo lugaynayo (roundtrip)? __________ Qiimaha hal ka Jirikaan?
- Wax kale, sheeg ____________ - wakhtiga loo lugaynayo(roundtrip)? __________ Qiimaha hal ka Jirikaan? _________

  Sababta sheeg?

  ____

  ____

5. During the dry season (Jilal), how many jerry cans (big 20L) do you use in your household every day ?

   ____

5. Xilliyada Jilaalka, imisa Jirikaan (20Litir) ayuu qoyskiinu isticmaalaa maalin walba?

   ____

6. After the construction of the sand dam, has there been any change in the amount of water you use per day in the Jilal dry season?

   Select option that best matches the group answers:
   - Much more water
   - Little bit more

- No change
- Little bit less
- Much less water

Comments____

6. Dhismihii biyo xidheenka ka dib, miyey wax iska beddeleen xaddiga biyaha aad isticmaasho maalin kasta inta lagu guda jiro Jiilaalka?

Dooro jawaabta ugu fiican ee ku haboon jawaabaha kooxda

- Biyo aad uga badan
- Biyo woxoogaa ka badan
- Is badal ma jiro
- Biyo woxoogaa ka yar
- Biyo aad uga yar

Comments____

7. After the construction of the sand dam, has there been any change in the amount of money you spend buying water from private vendors during the dry season (Jilal)?

Select option that best matches the group answers:

- More money spend
- No change
- Less money spend
- No water bought to vendors

Why?____

7. Dhismihii biyo xidheenka ka dib miyey wax iska beddeleen qiimaha lacagta aad biyaha kaga iibsato biyoolaha xiliga jiilaalka lagu jiro?

Dooro jawaabta ugu fiican ee ku haboon jawaabaha kooxda

- Lacag ka badan ku iibsaday
- Is badal ma jiro
- Lacag woxoogaa ka yar
- Wax Biyo ah biyoole maba keeno

Sababta sheeg?

____

8. How many livestock heads (camels/cows) are drink water from the sand dam during the dry season (Jilal)? *(estimation)*

____

8. Imisa neef oo xoolo ah (Awr/Saco) ayaa laga waraabiyaa biyaha biyo xidheenka xiliga Jiilaalka lagu jiro?

____

____

9. Do the wells in the sand dam completely dry-out at any point of the year?

- If Yes: in which months are they dry?

____

- No, they have water all year round

9. Miyey Ceelasha biyo xidheenku gabi ahaanba qalalaan xiliyo ka mida sanadkii?
- Haday haa tahay, Bilahee ayey qalalaan?______________________________
- Maya, sanadka dhan way ku jiraan biyuhu.

10. Before the sand dam, did the wells in the river bed dry at any point of the year?

- If Yes: in which months are they dry?

  ____

- No, they had water all year round

10. Ka hor biyo xidheenka, miyey ceelasha ku yaal dooxu qalali jireeen xiliyo ka mida sanadkii?
- Haday haa tahay, Bilahee ayey qalalaan?_____________________________
- Maya, sanadka dhan way ku jiraan biyuhu.

11. How many households in the community get water from:

- Public /communal wells upstream of the dam _______________
- Private wells upstream of the dam _________________

11. Imisa qoys oo bulshada ka mid ah ayaa biyo ka hela:
- Ceelasha bulshadu wadaagto eek u yaal xaga sare ***(upstream)*** ee biyo xidheenka __________________
- Ceelasha gaar ka loo leeyahay ee ku yaal xaga sare ***(upstream*** *)* ee biyo xidheenka ___________________

12. Are there any groups in the community who cannot use the wells in the sand dam? If so, why?

____

____

12. Ma jiraan dad bulshada ka mida oo aan isticmaali Karin ceelasha ku yaal biyo xidheenka ka? If so why?

____

____

13. Are there any restrictions to the amount of water that can be collected from the public/communal wells in the sand dam?

____

____

13. Miyey jirtaa in la xadido xaddiga biyaha ee laga dhaansan karo ceelasha bulshada ka dhexeeya ee ku yaala biyo xidheenka**?**

____

____

14. Is there a water fee to collect water from the public communal wells in the sand dam?

- Yes - How much per jerrycan? _________
  Are you able to easily pay this amount?
  - Yes
  - No
- No, water is free.

14. Miyaa wax lacag ah laga qaadaa biyaha laga dhaansado ceelasha bulshada ka dhexeeya ee ku yaala biyo xidheenka**?**

- Haday haa tahay, imisa lacaga halkii jirikaanba__________________
- Ma awoodaan in aad si fudud u bixisaan qadarka lacagtaas?
- Haa
- Maya
- Maya, biyuhu waa lacag la'aan

____

____

15. Is there a water fee to collect water from the private wells in the sand dam?

- Yes - How much per jerrycan? _________
  Are you able to easily pay this amount?
  - Yes
  - No
- No, water is free

____

____

15. Miyaa wax lacag ah laga qaadaa biyaha laga dhaansado ceelasha bulshada ka dhexeeya ee ku yaala biyo xidheenka**?**

- Haday haa tahay, imisa lacaga halkii jirikaanba__________________
- Ma awoodaan in aad si fudud u bixisaan qadarka lacagtaas
- Haa
- Maya
- Maya, biyuhu waa lacag la'aan
- ____

____

16. Do you use the sand dam water to drink?

- Yes. Do you do anything before drinking the water?
  Select option that best matches the group answers:
  - No water treatment –drink directly
  - Boiling
  - cloth filtering
  - ceramic filter
  - sun exposure

- water purification tablet. If yes, where did they procure ___________ at what cost? ________
- Other ______________________________

- No, we don’t drink water from the dam. Why?__________________________________

16. Miyaad biyaha biyo xidheenka u isticmaashaan cabitaan ahaan?
   - Haa. Cabitaanka biyaha ka hor miyaad wax uun ku samaysaan biyaha?
     Dooro jawaabta ugu fiican ee ku haboon jawaabaha kooxda
     - No water treatment-drink directly
     - Kar Karin
     - Maro ku miirid
     - Dhoobo ku miirid
     - Cad ceed u dhigid
     - Biyo sifeeye
     - Kuwa kale _______________________________
   - Maya, biyaha kama cabno biyo xidheenka? Sababta ______________________

17. Has there been a change in the frequency of disease, vomits and diarrhoeas in the family since you drink and cook with water from the sand dam?
Select option that best matches the group answers:

- More frequent – what type of disease is more frequent? _________________________
- No change
- Less frequent -what type of disease is less frequent? ___________________________

Is there any difference in illnesses between the rainy season and the dry season?

____

____

17. Miyey wax iska bedaleen soo noqnoqoshada cudurada, shubanka iyo mataga/hunqaacada ee ku dhaca qoyska maadama aad cabtaan waxna ku karsataan biyaha laga soo dhaamiyo biyo xidheenka?
Dooro jawaabta ugu fiican ee ku haboon jawaabaha kooxda
- Aad u soo noqnoqda – xanuun noocee ah ayaa soo noqnoqda?
- Wax is bedala ma jiro
- Yaraaday - xanuun noocee ah ayaa soo noqnoqdkoodu yaraaday? ____________________________________

18. After the construction of the sand dam, has there been any change in the amount of irrigated land upstream of the dam?
Select option that best matches the group answers:

- Large increase
- Small increase
- No change
- Small Decrease
- Large decrease

____

____

18. Dhismaha biyo xidheenka ka dib, miyuu wax is bedal ahi ku yimid xadiga biyaha waraabka dhulka ee xaga sare *(upstream)* ee biyo xidheenka?
Dooro jawaabta ugu fiican ee ku haboon jawaabaha kooxda

- Aad u kordhay
- In yar kordhay
- Is bedal ma jiro
- In yar hoos u dhacay
- Aad hoos ugu dhacay

---

19. After the construction of the sand dam, has there been any change in the amount of irrigated land downstream of the dam?
Select option that best matches the group answers:

- Large increase
- Small increase
- No change
- Small Decrease
- Large decrease

---

19. Dhismaha biyo xidheenka ka dib, miyuu wax is bedal ahi ku yimid xadiga biyaha waraabka dhulka ee xaga hoose (**downstream)** ee biyo xidheenka?
Dooro jawaabta ugu fiican ee ku haboon jawaabaha kooxda

- Aad u kordhay
- In yar kordhay
- Is bedal ma jiro
- In yar hoos u dhacay
- Aad hoos ugu dhacay

---

20. After the construction of the sand dam, has there been any change in the number of livestock in the community?
Select option that best matches the group answers:

- Large increase
- Small increase
- No change
- Small decrease
- Large decrease

---

20. Dhismaha biyo xidheenka ka dib, miyuu wax is bedal ahi ku yimid tirada xoolaha ee bulshadu haysato
Dooro jawaabta ugu fiican ee ku haboon jawaabaha kooxda

- Aad u kordhay
- In yar kordhay
- Is bedal ma jiro

- In yar hoos u dhacay
- Aad hoos ugu dhacay

21. After the construction of the sand dam, has there been any change in the livestock health and body condition during the dry season?

Select option that best matches the group answers:

- Less animal disease — Better weight/body condition
- No change — No change
- More animal disease — Worst body condition/weight loss

Open answers

21. Dhismaha biyo xidheenka ka dib, miyuu wax is bedal ahi ku yimid caafimaadka xoolaha iyo xaalada jidheed inta lagu jiro jiilaalka?
Dooro jawaabta ugu fiican ee ku haboon jawaabaha kooxda

- Xanuunada xoolaha oo yaraaday — Xaaladooda jidheed oo wanaagsanaatay
- Is bedal ma jiro — Is bedal ma jiro
- Xanuunada xoolaha oo batay — Xaaladooda jidheed oo sii xumaatay

Jawaabo furan

22. Has the presence of the sand dam changed migration of people and livestock during the dry season or periods of drought?

Open answer

22. Miyuu dhismaha biyo xidheenku wax ka bedalay guur-guuritaanka dadka iyo xoolaha xiliga lagu jiro abaaraha?

Jawaabo furan

23. After the construction of the sand dam, have new livelihood activities developed in the community?
Select option that best matches the group answers:

- Vegetables/ home gardening
- cash crops (cowpea, groundnut, sesame, etc)
- Brick making
- Other

____

____

23. Dhismaha biyo xidheenka ka dib, miyaa dhaqdhaqaaq dhaqan dhaqaale oo cusub laga bilaabay bulshada dhexdeeda?
Dooro jawaabta ugu fiican ee ku haboon jawaabaha kooxda

- Khudaar/ beerta guriga dhexdiisa
- cash crops (cowpea, groundnut, sesame, etc.)
- Jaajuur samayn
- Kuwo kale

____

____

24. Has the presence of the dam changed the natural vegetation on the riverbanks?

- More vegetation/more diverse
- The same
- Less vegetation

____

____

24. Miyuu dhismaha biyo xidheenku wax ka bedalay khudaarta dabiiciga ah ee ka baxda dooxa qarkiisa?

- Khudaar aad u badan
- Isku mid uun
- Khudaar aad uga yar

25. Has the presence of the dam changed the risk of flooding in neighbouring farmland/houses?

Upstream of the dam:

- More flooding
- No change
- Less flooding

Downstream of the dam:

- More flooding
- No change
- Less flooding

____

____

25. Miyuu dhismaha biyo xidheenku wax ka belay khatarta daadadka ee beeraha/guryaha ka ag dhaw?

Xagga sare (*Upstream*) ee ka biyo xidheenka
- Daadad badan
- Is bedal ma jiro
- Daadad yar

Xagga hoose (*Downstream*) ee ka biyo xidheenka
- Daadad badan
- Is bedal ma jiro
- Daadad yar

26. Has the presence of the sand dam affected negatively some members of the community or brought problems in the community?

____

____

____

26. Miyuu dhismaha biyo xidheenku wax saamayn taban ah ku yeeshay qaar ka mid ah dadka ama wax dhibaato ah uu ku keenay bulshada?

____

____

____

27. Are you overall satisfied with the sand dam?

- Yes. Why?

  ____

- No. Why ?

  ____

27. Guud ahaan ma ku qanacsan tihiin biyo xidheenka?
- Haa, Sababta?______________________________
- Maya, Sababta?______________________________

28. Would you recommend sand dams to other communities in the region?

- Yes. Why?

  ____

- No. Why ?

  ____

28. Miyaad kula talin lahayd biyo xidheeno deegaanada kale ee gobolka ku yaal?

- Haa, Sababta ____
- Maya, Sababta _______________________________________

Additional notes:

Appendix IV. Informed consent form

INFORMED CONSENT FORM

MSc research "Sand dams in Somaliland: cost-effective and sustainable solutions for rural water supply and drought resilience?"

Taking Part	**Please initial to confirm agreement**
The purpose and details of this study have been explained to me. I understand that this study is designed to further scientific knowledge.	---------------------
I have had an opportunity to ask questions about my participation.	---------------------
I understand that taking part in the project will involve being photographed, interviewed and recorded by audio to facilitate information gathering.	---------------------
I understand that I am under no obligation to take part in the study, have the right to withdraw from this study at any stage for any reason, and will not be required to explain my reasons for withdrawing.	---------------------
Use of Information	
I understand that all the personal information I provide will be processed in accordance with Concern Worldwide data protection policy.	---------------------
I understand that information I provide will be used for learning and research reports only.	--------------------
I understand that personal information collected about me that can identify me, such as my name or where I live, will not be shared beyond the study team.	---------------------
I agree that information I provide can be quoted anonymously in research outputs (the name will not be cited).	---------------------

Consent to Participate

I voluntarily agree to take part in this study.

______________________	______________________	__________
Name of participant [printed]	Signature	Date
______________________	______________________	__________
Researcher [printed]	Signature	Date

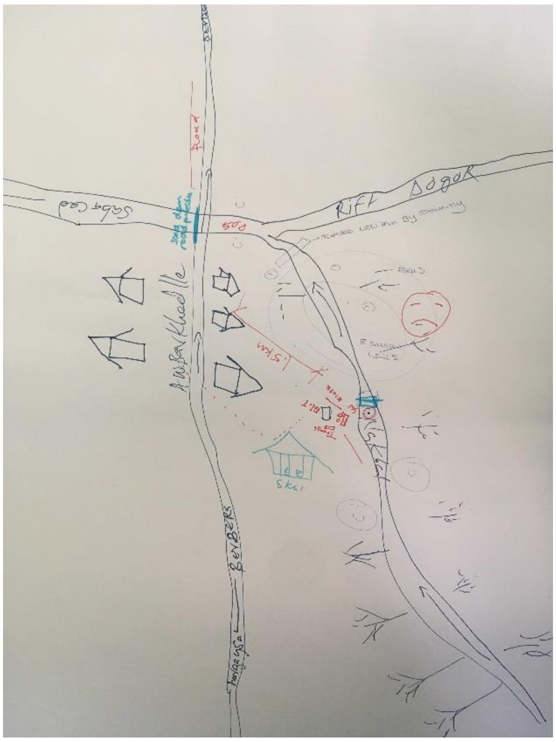
Appendix V. Group interview photographs and community maps.

Site	Group A	Group B
Aw Barkhadle	9 participants (7 men and 2 women), including 3 VC members, water point operator, 1 pastoralist , 2 farmer upstream, 2 farmer downstream and police offer as observer.	10 women from different locations in Aw Barkhadle village (pastoralist and farmer households),
Diinqal	10 participants (8 men and 2 women), including 3 VC members, water point operator, 1 pastoralist , 2 farmer upstream, 1 person living downstream and 2 women from the village).	8 women from different locations in Diinqal (pastoralist and farmer households),
Huluuq	10 men, including 2 VC members, 2 school staff, 5 upstream farmers and 1downstream farmer.	10 women from different locations in Huluuq village (farmer households),
Carracad	10 participants (7 men and 3 women, including 4 VC members and households living upstream and downstream),	10 women from different locations in Carracad (farmer households).
Camud	6 men, including 2 VC and 4 farmers.	12 women from different locations in Camud village (farmer households.
Total interviewed	**45 participants (38 men and 7 women)**	**50 participants (all women)**

Summary of participants in the group discussions held from 25th September to 1st October 2019.

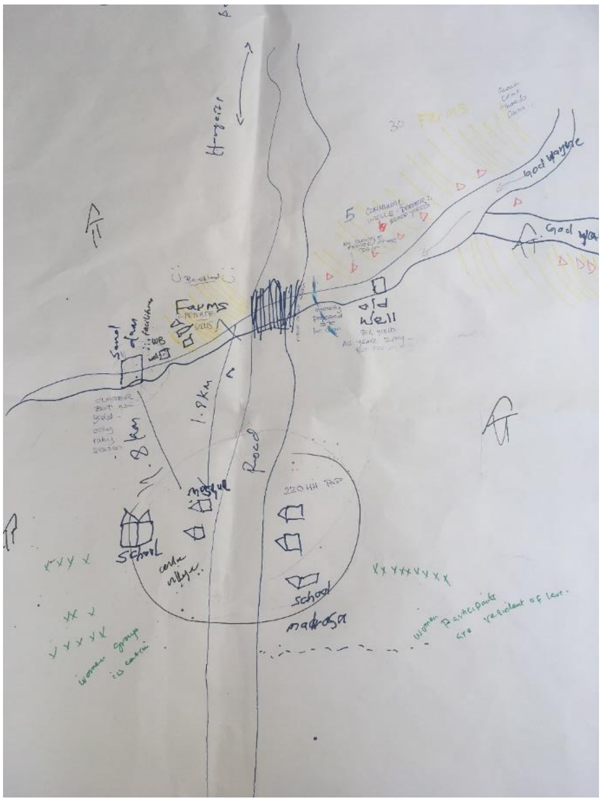
Aw Barkhadle community map and group interview pictures (25/09/2019)

Source: Paz Lopez-Rey (2019)



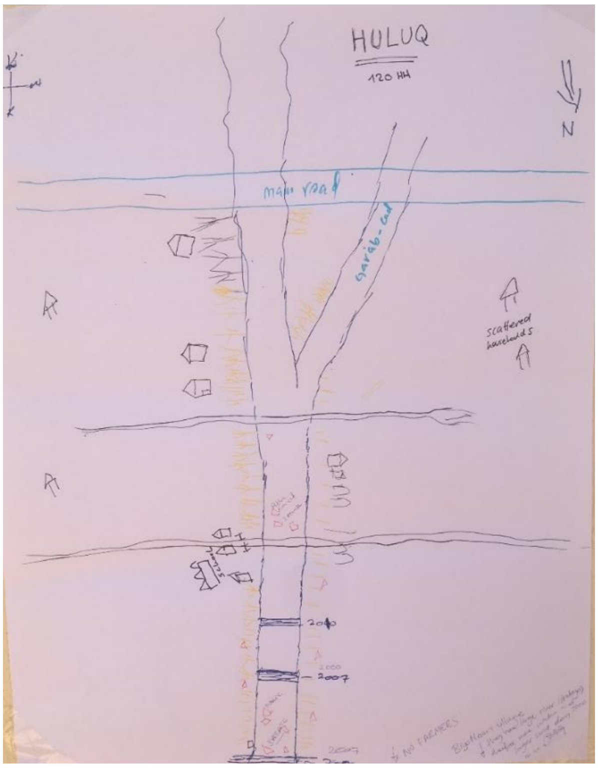
Diinqal community map and group interview pictures (26/9/2019)

Source: Paz Lopez-Rey (2019)



Huluuq community map and group interview pictures (29/09/2019)

Source: Paz Lopez-Rey (2019)



Carracad community map and group interview pictures (30/9/2019)

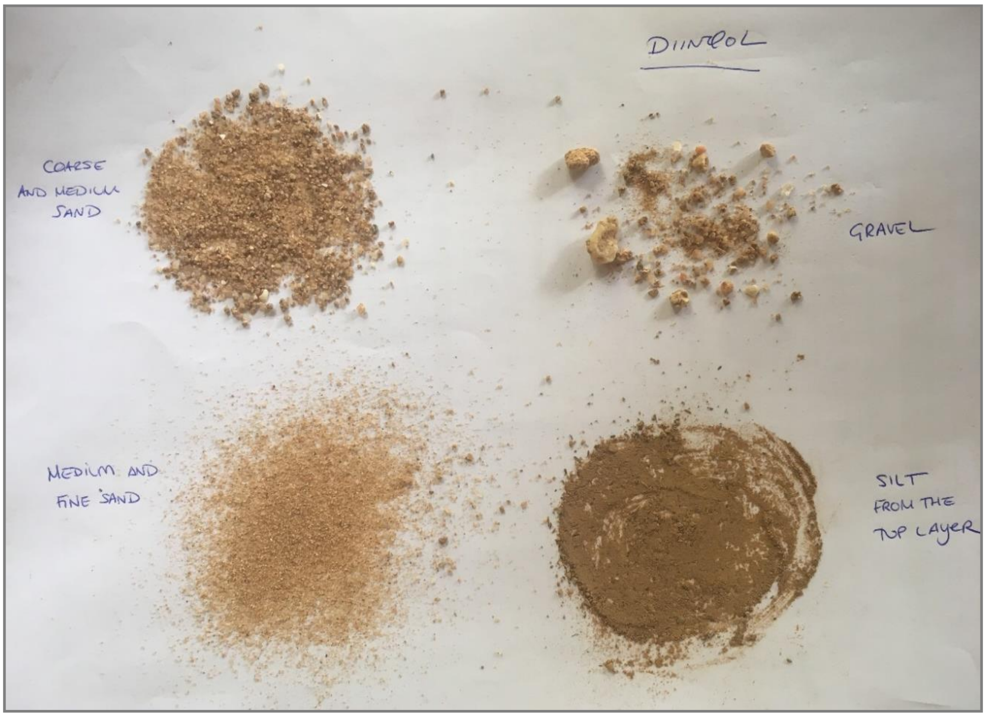
Source: Paz Lopez-Rey (2019)

Camud community map and group interview pictures (31/09/2019)

Source: Paz Lopez-Rey (2019)

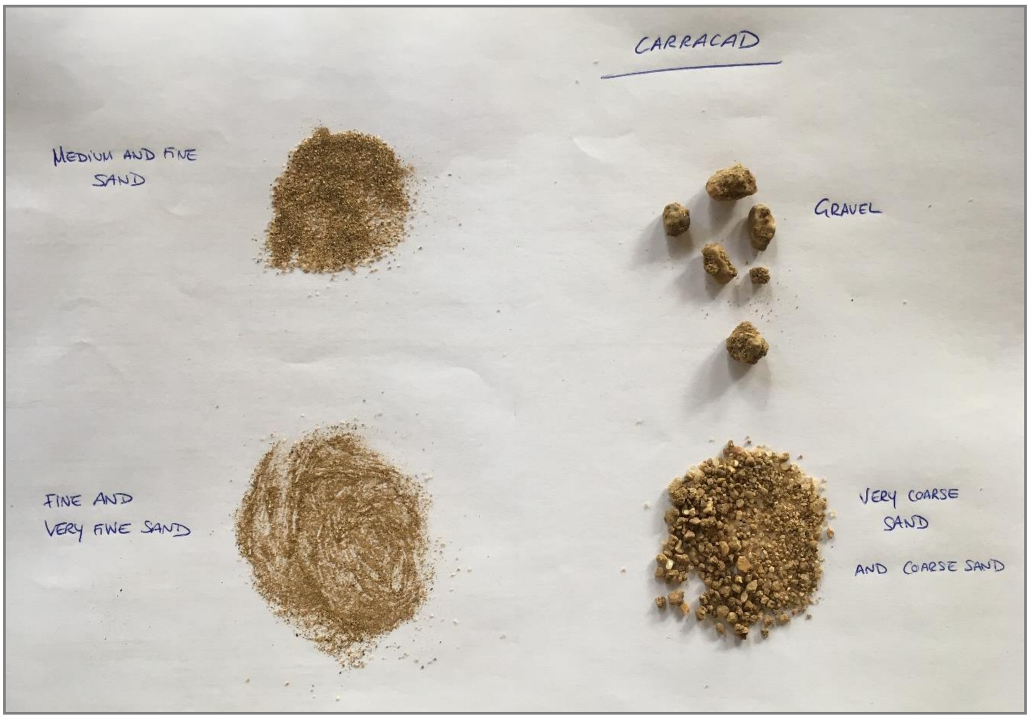
Appendix VI. Sand samples

Aw Barkhadle sand sample taken at a depth 30cm in the dam throwback.



Diinqal sand sample taken at a depth 30cm in the dam throwback and the top dry silt layer.

Huluuq sand sample taken at a depth 30cm in the dam throwback.



Carracad sample taken at a depth 30cm in the dam throwback.

	Silt	Fine sand	Medium sand	Coarse sand	Fine gravel	Coarse gravel
Diameter of particles	<0.5 mm	0.5 to 1.0 mm	1.0 to 1.5 mm	1.5 to 5.0 mm	5.0 to 19.0 mm	19 to 70.0 mm
Volume of sand	20.0 litres	20.0 litres	20.0 litres	20.0 litres	20.0 litres	20.0 litres
Porosity	1.52 litres 38%	1.58 litres 40%	1.63 litres 41%	1.80 litres 45%	1.87 litres 47%	2.05 litres 51%
Extracted water	0.90 litres 5%	3.75 litres 19%	5.00 litres 25%	7.00 litres 35%	8.25 litres 41%	10,00 litres 50%

Porosity and extractable volume of water (Nissen –Petersen 2000, p.15)

Appendix VII. Calculations of extractable volume and water demand coverage

Aw Barkhadle sand dam		Information sources and assumptions
Maximum extractable volume of water		
Average slope of the throwback	2.3%	Google Earth elevation profile for the georeferenced throwback.
Throwback length (m).	700	Throwback delimited by old sand dam site.
Maximum width riverbed (m)	103	Satelite imagery
Maximum depth of sand (m)	4	7m depth of communal well #1 dug below the bedrock. Sand depth deposit estimated to 4m.
Estimated dam storage capacity (m^3)	96,133	
Drainable porosity (%)	18%	Volume of water that freely drains per 100ml dry sediment sample. Sediment mainly composed of fine sand with medium and very fine sand. Value in range with drainable porosity for fine sand (19%) published by Nissen-Petersen (2000,p.15). See Appendix VI.
Estimated maximum volume of extractable water from sand deposit (m^3)	**17,203**	
Water demand in the dry season November - March (5 months)		
Average water demand domestic use in dry season (m^3)	7,200	Based on community estimation 6 jerrycan 20L/ HH average in dry season for the total population of 400 HH for 5 months (150 days).
Estimated water demand livestock (m^3)	15,000	Based on community estimation 20 goats + 5 camels/HH. Majority of households in Aw Barkhadle have less number of heads but due to inmigration of nomadic herders during Jilal season, this number of heads/HH is estimated for a total population of 400 HH. Somalia WASH cluster standards apply: 5 litres per small animal/ day and 20–30 litres per large or medium animal/day.
Estimated total water demand domestic and livestock dry season (m^3)	22,200	
Water demand coverage in dry season (domestic and livestock)	**77%**	This % coverage considers only additional abstractable water stored in the sand deposit behind the dam, not the water held in the original river basin which can be abstracted shallow well dug below the permeable river bed rock.
Balance of water for irrigation in the dry season (m^3)	0	Vegetable crop production mainly during April -October. Minor vegetable crop production during the Jilal season.

Diinqal sand dam		Information sources and assumptions
Maximum extractable volume of water		
Average slope of the throwback	4.8%	Google Earth elevation profile for the georeferenced throwback.
Throwback length (m).	435	Throwback delimited by road pillars and river meander.
Maximum width riverbed (m)	41	Satellite imagery.
Maximum depth of sand (m)	4	4m depth of ommunal well #1 reaching the bedrock
Estimated dam storage capacity (m^3)	23,780	
Drainable porosity (%)	30%	Volume of water that freely drains per 100ml dry sediment sample. Sediment includes mainly by coarse sand, as well as gravel, medium and fine sand. A layer of silt was found in the top layer only. Value in range with drainable porosity for medium sand (25%) and coarse sand (35%) published by Nissen-Petersen (2000,p.15). See Appendix VI.
Estimated maximum volume of extractable water from sand deposit (m^3)	**7,134**	
Water demand in the dry season November - March (5 months)		
Average water demand domestic use in dry season (m^3)	3,960	Current water use in the dry season reported by community is 4 jerrycan 20L/ HH average which is below the standard 15 l/p/d. A minimum water demand of 20 l/p/d is considered for 220 HH during 5 months (150 days)
Estimated water demand livestock in dry season (m^3)	8,250	Based on community estimation 20 goats + 5 camels/HH. Majority of households in Diinqal have less number of heads but due to immigration of nomadic herders during Jilal season, this number of heads/HH is estimated for a total population of 220 HH. Somalia WASH cluster standards apply: 5 litres per small animal/ day and 20–30 litres per large or medium animal/day.
Estimated total water demand domestic and livestock dry season	**12,210**	
Water demand coverage in dry season (domestic and livestock)	**58%**	This % coverage considers only additional abstractable water stored in the sand deposit behind the dam, not t water held in the original river basin which can be abstracted shallow well dug below the permeable river bed rock.
Balance of water for irrigation in the dry season (m^3)	0	Vegetable crop production mainly during April -October. Minor vegetable crop production during the Jilal season.

Huluuq sand dam		Information sources and assumptions
Maximum extractable volume of water		
Sand dam 2000		
Average slope of the throwback	1.5%	Google Earth elevation profile for the georeferenced throwback.
Throwback length (m).	933	Throwback delimited by sub-surface dam 2007
Maximum width riverbed (m)	62	Satellite imagery
Maximum depth of sand (m)	6.4	Wells #1, #2, #3 dug below the bedrock with a total of 4 man's height equivalent to 6.4m
Estimated dam storage capacity (m^3)	123,405	
Sub-surface dams 2007 and 2010		
Average slope of the throwback	2.0%	
Throwback length (m).	1160	Based on community knowledge.
Maximum width riverbed (m)	170	Satellite imagery
Maximum depth of sand (m)	6.4	Wells #4, #5, #6 dug below the bedrock at total depth 10 man's height equivalent to 15 m. Depth of the sand reservoir considered to be also 6.4 m.
Estimated dam storage capacity (m^3)	420,693	
Total dams storage capacity (m3)	544,098	
Drainable porosity (%)	25%	Volume of water that freely drains per 100ml dry sediment sample. Sediment mainly composed medium sand as well as coarse sand and some fine gravel. Value in range with drainable porosity for medium sand (25%) published by Nissen-Petersen (2000,p.15). See Appendix VI.
Estimated maximum volume of extractable water from sand deposit (m^3)	**136,025**	Total storage capacity x drainable porosity.
Water demand in the dry season November - March (5 months)		
Average water demand domestic use in dry season (m^3)	10,260	Based on community estimation 6 jerrycan 20L/ HH average in dry season for all local Huluuq population and up to 450 nomadic households(570 HH) for 5 months (150 days).
Estimated water demand livestock in dry season (m^3)	62,550	Majority of households in Huluuq are farmers with few goats/sheep (estimated at 20 heads per HH for a local population of 120HH). However during the Jilal season up to 450 nomadic pastoralist HH immigrate with their livestock estimated at 120 goat or sheep/HH and 10 camels/HH. Somalia WASH cluster standards apply: 5 litres per small animal/ day and 20–30 litres per large or medium animal/day.
Estimated total water demand domestic and livestock dry season	**72,810**	
Water demand coverage in dry season (domestic and livestock)	**187%**	This % coverage considers only additional extractable water stored in the sand deposit behind the dam, not the water held below the bedrock which can be abstracted by shallow wells dug below the bedrock.
Balance of water for irrigation in the dry season (m^3)	63,215	Irrigated orchards during the Jilal season include citrus and mango trees. There are approximately 52 hectares of orchards bordering the sand deposits of the three dams in Huluuq (satellite imagery).

Carracad sand dam		Information sources and assumptions
Maximum extractable volume of water		
Average slope of the throwback	1.9%	Google Earth elevation profile for the georeferenced throwback.
Throwback length (m).	1000	Throwback delimited by deposition area in wide river meander and community knowledge.
Maximum width riverbed (m)	35	Satellite imagery
Maximum depth of sand (m)	4	2m total wall height. 4m depth communal well #1 reaching the clay layer
Estimated dam storage capacity (m^3)	46,667	
Drainable porosity (%)	20%	Volume of water that freely drains per 100ml dry sediment. Sediment includes a variety of particle sizes including gravel, very coarse and coarse sand, medium sand, fine and very sand, as well clay content which may reduce permeability of the coarse sand. (Appendix VI) . Value within the drainable porosity range for fine sand (19%) and medium sand medium sand (25%) published by Nissen-Petersen (2000,p.15).
Estimated maximum volume of extractable water from sand deposit (m^3)	**9,333**	Volume of water that freely drains per 100ml dry sediment sample. Sediment mainly composed medium sand as well as coarse sand and some fine gravel. Value in range with drainable porosity for medium sand (25%) published by Nissen-Petersen (2000,p.15). See Appendix VI.
Water demand in the dry season November - March (5 months)		
Average water demand domestic use in dry season (m^3)	4,500	Current water use in the dry season reported by community is 4 jerrycan 20L/ HH average, which is below the standard 15 l/p/d. A minimum water demand of 20 l/p/d is considered for 250 HH for 5 months (150 days) is considered.
Estimated water demand livestock in dry season (m^3)	9,000	Based on community estimation: 40 goats/sheep, 2-5 camel and cow 6-10/HH. Majority of households in Carracad have significantly less number of heads and there is no immigration of nomadic herders. Hence this average number of heads is estimated for 50% of total population of 250 HH. Somalia WASH cluster standards apply: 5 litres per small animal/ day and 20–30 litres per large or medium animal/day.
Estimated total water demand domestic and livestock dry season	**13,500**	
Water demand coverage in dry season (domestic and livestock)	**69%**	This % coverage considers only additional abstractable water stored in the sand deposit behind the dam, not water held in the original river basin which can be abstracted by shallow wells dug below the permeable river bedrock.
Balance of water for irrigation in the dry season (m^3)	0	Vegetable crop production mainly during April -October. No water available for fruit tree irrigation in the dry season

Appendix VIII. Calculations of capital investment, operation and maintenance costs

VIII.1 Sand dam construction and maintenance costs

Dam	Date of implementation	Mehtodology for cost calculation
Aw Barkhadle RCC dam wall	2018	Total construction cost in 2018 reported by implementing agency. Unit cost per m3 estimated from total cost reported (excluding surveying and management costs).
Diinqal RCC dam	2018	
Huluuq rubble stone dam	2000	Total current cost estimated based on current on current prices of materials in Hargeisa for rubble stone with mortar 1:4, steel Y20 and barbed wire.
Huluuq rubble stone SSD	2007	
Huluuq rubble stone SSD	2010	
Carracad RCC dam	2006	Total cost reported by implementing agency 18,000 USD in 2003. Present cost for similar construction based on current cost per m3 of vibrated RCC 1:2:4 with 16mm steel bar with 12 mm stirrups 200 mm C/C 14mm stirrups 200mm.
Ali Haydh	2019	Design, BOQ and quotation of an RCC sand dam built in Borama district as example and for triangulation of estimated costs.

Assumptions

- The number of people with access to sand dam water supply considers seasonal pastoralist immigration in Huluuq during the dry season (450HH) but only host population (120HH) is considered for the coverage of maintenance costs per capita.

- The key below the bedrock is assumed to be 1m deep and 75% the height of the wall above the bedrock as per suggested by KI1 (2019) in the design of Ali Haydh sand dam and recommended in learning 3.2 by Nissen-Petersen (2006).

- Erosion protection maintenance costs consider a 3m wide riprap over the bedrock with gabions on top along the entire length of the wall in all dam sites. Cost are based on current estimated prices in Hargeisa (Somaliland).

- Masonry dam in Huluuq considered to be rubble stone and mortar 1:4

- Estimation of steel bars and barbed wire required for masonry dam in Huluuq based on Maddrell (2018,p.111):

  Number of Y20 Steel bars (12m long) = (TW ÷ 1.2 x H) ÷ 12, where;

  TW = Total width of the dam (m^3)

  H=Height of foundation and spillway (m).

Number Barbed Wire Rolls 250m length = (Number of Layers x Each Layer Length) ÷ 250, where;

Each layer uses 2 x 1.5m length for every 1.2m width of the dam [Each Layer Length (m) = (TW ÷ 1.2 x 1.5) x 2]

Layers every 0.5m in height, starting from base and finishing at spillway. [Number of Layers = (H ÷ 0.5) + 1]

1. Sand dam initial construction costs (2018-2019 prices)	**Aw Barkhadle RCC dam**	**Diinqal RCC dam**	**Huluuq rubble stone dam**	**Huluuq rubble stone SSD 2007**	**Huluuq rubble stone SSD 2010**	**Carracad RCC dam**	**Ali Haydh sand dam RCC example 2019**	
Wall (A)							section AA	section BB
L (m)	55.3	44.0	26.4	63.0	69.0	30.8	30.0	15.0
W (m)	1.2	1.1	0.6	0.6	0.6	0.8	1.0	1.0
H (m)	2.0	1.5	1.5	1.0	1.0	1.5	1.5	0.6
Total A (m3)	131.6	72.6	23.8	37.8	41.4	36.0	45.0	9.0
Key (B)								
L (m)	55.3	44.0	26.4	63.0	69.0	30.8	30.0	15.0
W (m)	1.5	1.1	1.1	0.8	0.8	1.1	1.0	1.0
H (m)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.6
Total B (m3)	83.0	49.5	29.7	47.3	51.8	34.7	30.0	9.0
Total volume A + B (m3)	214.6	122.1	53.5	85.1	93.2	70.7	93.0	
Total 20mm twisted steel bar x 12m -- for masonry dams	0.0	0.0	4.6	8.8	9.6	0.0	0.0	
Total 12.5 gauge barbed wire (100m rolls) - for masonry dams	0.0	0.0	4.0	7.9	8.6		0.0	
Cost per m3 of vibrated RCC 1:2:4 with 16mm steel bar with 12 mm stirrups 200 mm C/C 14mm stirrups 200mm.	235.5	352.5	0.0	0.0	0.0	340.8	340.8	
Cost per m3 of rubble stone with mortar 1:4 cost	0.0	0.0	50.0	50.0	50.0	0.0	0.0	
Cost 20mm twisted steel bar x 12m	0.0	0.0	12.0	12.0	12.0	0.0	0.0	
Cost 12.5 gauge barbed wire (100m roll)	0.0	0.0	3.0	3.0	3.0	0.0	0.0	
Total cost materials	50540.3	43044.8	2739.9	4381.1	4798.4	24089.8	31695.0	
% Other civil works, labour and administration costs	25%	25%	25%	25%	25%	25%	25%	
Total cost USD	**$67,387**	**$57,393**	**$3,653**	**$5,842**	**$6,398**	**$32,120**	**$42,260**	
Number of people with access to sand dam water supply	2400	1320		2700		1500		
Cost per person per year (USD)	**$0.9**	**$1.4**		**$0.2**		**$0.7**		
Cost per m3 (USD)	**$314.06**	**$470.05**		**$68.6**		**$454.40**	**$454.41**	

2. Sand dam wall 30 cm rise (2018-2019 prices)	Aw Barkhadle RCC dam	Diinqal RCC dam	Huluuq rubble stone dam	Carracad RCC dam
Wall (A)				
L (m)	55.3	44.0	26.4	30.8
W (m)	1.2	1.1	0.6	0.8
H (m)	0.3	0.3	0.3	0.3
Total A (m3)	19.7	14.5	4.8	7.2
Total 20mm twisted steel bar x 12m -- for masonry dams	0	0	0.6	0
Total 12.5 gauge barbed wire (kg) - for masonry dams	0	0	1.1	0
Cost per m3 of vibrated RCC 1:2:4 with 16mm steel bar with 12 mm stirrups 200 mm C/C	251	376	0	300
Cost per m3 of rubble stone with mortar 1:4 cost	0	0	50	0
Cost 20mm twisted steel bar x 12m long	0	0	12	0
Cost 12.5 gauge barbed wire (100m)	0	0	3	0
Total cost materials	4960	5460	247	2162
% Other civil works, labour and administration costs	25%	25%	25%	25%
Total cost USD per 30 cm rise	**$6,614**	**$7,280**	**$330**	**$2,883**
Total cost USD per 60 cm rise	**$13,227**	**$14,560**	**$660**	**$5,766**
Number of people with access to sand dam water supply	2400	1320	720	1500
Cost per person per year (USD)	**$0.18**	**$0.37**	**$0.03**	**$0.13**

3. Maintenance of erosion protection structures 30-year design life (2018-2019 prices)	Aw Barkhadle RCC dam wall	Diinqal RCC dam	Huluuq rubble stone dam	Carracad RCC dam
A.1 Rip rap repair - (every 10 years)				
L (m)	55.3	44.0	26.4	30.8
W (m)	3	3	3	3
H (m)	0.6	0.6	0.6	0.6
Total A (m3)	99.54	79.2	47.52	55.44
Estimated cost per m3 rip-rap below gabions including cement, stone and labour (with 10% slope)	50	50	50	50
Total cost rip-rap repair	**4977**	**3960**	**2376**	**2772**
A.2 Gabion repair - (partial repair every 3 years equivalent to total repair every 10 years)				
L (m)	55.3	44.0	26.4	30.8
W (m)	3	3	3	3
H (m)	0.6	0.6	0.6	0.6
Total A (m3)	99.54	79.2	47.52	55.44
Estimated cost per m3 gabion including wire mesh, rubble stone and labour.	90	90	90	90
Total cost rip-rap repair	**8958.6**	**7128**	**4276.8**	**4989.6**
% Other civil works, labour and administration costs	25%	25%	25%	25%
Total cost materials - 30 years (USD)	**$55,742**	**$44,352**	**$26,611**	**$31,046**
Number of people with access to sand dam water supply	2400	1320	720	1500
Cost per person per year (USD)	**$0.8**	**$1.1**	**$1.2**	**$0.7**

VIII.2 Sand dam water supply facilities construction, operation and maintenance costs

Site	Date of implementation	Methodology for cost calculation
Aw Barkhadle	2018	Total cost of communal well, solar-piped system and facilities built in 2018 reported by the implementing agency.
Diinqal	2018	
Huluuq	2016	Total cost of communal well, solar-piped system and facilities built in 2016 estimated based on the present cost of similar facilities.
Carracad	2006	Total cost of masonry lined well of 2m diameter and 4m depth based on the present cost of similar facilities.

Assumptions

- The number of people with access to sand dam water supply considers seasonal pastoralist immigration in Huluuq during the dry season (450HH) but only host population (120HH) is considered for the coverage of maintenance costs per capita.
- Costs estimations are inclusive of transport, labour and administrative costs
- Maintenance and replacement costs are based on quotes collected by Concern Worldwide for similar infrastructure and equipment in the past two years in Hargeisa (Somaliland)

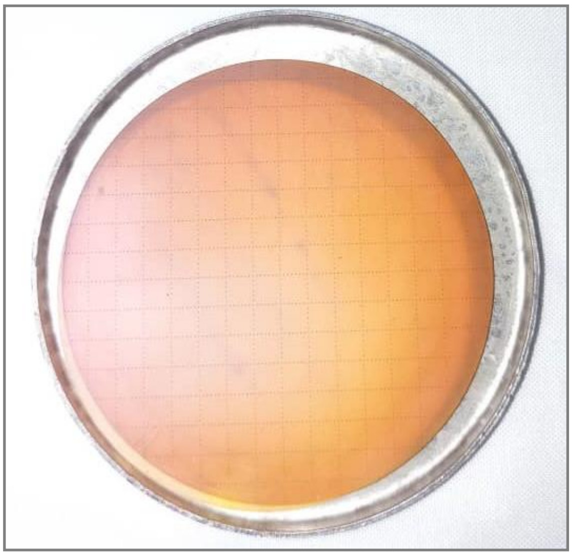
1. Initial capital cost of communal water supply infrastructure (2018-2019 prices)	**Aw Barkhadle**	**Dinqol**	**Huluuq**	**Carracad**
Cost concrete-lined communal well, solar pumping unit, elevated tank and facilities	$57,796	$43,582	$45,000	NA
Cost of 3 masonry-lined communal wells 3m diameter x 4m depth (lined to full depth) and concrete slab with manhole	NA	NA	NA	$16,500
Number of people with access to sand dam water supply	2,400	1,320	2,700	1,500
Cost per person per year (USD)	**$0.8**	**$1.1**	**$0.6**	**$0.4**
2.Operation, maintenance and replacement costs of communal water supply infrastructure in 30-year design life (2018-2019 prices)	**Times in 30Y**	**Units**	**Unit cost (USD)**	**Total (USD)**
Option A: Solar pumping systems				
Replacement of solar pump unit (15 years lifespan)	2	1	$2,400	$4,800
Replacement of photovoltaic panels (25 years lifespan)	1	1	$2,600	$2,600
Replacement of batteries 24v (7 years lifespan)	4	2	$120	$960
Fittings and general maintenance costs (annual)	30	1	$800	$24,000
Operator costs (monthly) -average cost for 30 years	360	1	$200	$72,000
Total cost - 30 years (USD)				**$104,360**
Option B: Communal masonry wells and manual lifting				
Lining and slab rehabilitation for wells 2m diameter and 4m depth (once every 1	2	1	$1,800	$3,600
Total cost - 30 years (USD)				**$3,600**
3. Operation, maintenance and replacement costs of communal water supply infrastructure in 30-year design life (2018-2019 prices)	**Aw Barkhadle**	**Dinqol**	**Huluuq**	**Carracad**
Total cost maintenance option A solar pumping systems and tap stands	$104,360	$104,360	$104,360	NA
Total cost maintenance option B Manual lifting from masonry wells	NA	NA	NA	$3,600
Number of people with access to sand dam water supply	2,400	1,320	720	1,500
Cost per person per year (USD)	**$1.4**	**$2.6**	**$4.8**	**$0.1**

Appendix IX. Bacteriological tests results

Control dish 12/12/2019

Aw Barkhadle tap stand water sample 12/12/2019

Diinqal well# 1 water sample 12/12/2019



Huluuq tap stand water sample 12/12/2019