



Regional-scale planning of water harvesting interventions in Somali arid areas: A multicriteria approach

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ABSTRACT

Somalia is one of the most arid countries in the world. In its northern part, Water Harvesting (WH) - the collection and storage of runoff water for productive use - can represent a viable solution for combating the effects of limited and erratic rainfall, and subsequent water shortages. A major barrier to WH implementation is the difficulty of selecting suitable sites, especially for large areas where this approach has never been implemented. This study presents a multi-criteria analysis for selecting the best sites for WH Ponds and Sand Dams for seven regions of northern Somalia. Criteria and weights for the analysis were based on existing literature and expert consultation with FAO-SWALIM officers. The Analytical Hierarchy Process (AHP) was used to minimize uncertainty in weights selection, and the analysis was validated using over 100 existing WH structures. Finally, the biophysical suitability of different catchments in the study area was evaluated, showing good potential in the north-western side along the eastern coast. This approach, covering half of the country, represents a baseline and a starting point for any lower-scale investigation, and can be replicated in any similar context.

1. Introduction

Water scarcity is an ever-greater challenge for agriculture, especially in drylands (Prävalie, 2016). Drylands are characterized by scarce and erratic precipitation that is unable to support local needs, especially agricultural production (Farooq and Siddique, 2016). Climate change is exacerbating water scarcity in many drylands, including Central and Southern Africa (Stringer et al., 2021). However, climate projections foresee an expected increase in precipitation, runoff, and soil moisture in some key dryland regions, like the Horn of Africa (Piemontese et al., 2019).

Even where water might be available, economic water scarcity – namely the impossibility to access water due to economic conditions – does not allow the local population to access and use water for food security (Rosa et al., 2020). Increasing access to water is therefore of paramount importance. Water infrastructure is a key adaptation measure to alleviate current and projected water scarcity, especially when relying on non-conventional waters, like water harvesting (Greve and

Seneviratne, 2015). Water Harvesting (WH) is the collection and storage of rainfall or runoff water for productive use (Rockström and Malin, 2015). Different WH technologies have been developed in different contexts to decrease surface runoff, limit soil evaporation, and increase infiltration and soil moisture retention (Rockström et al., 2002). The positive effect of WH has been largely documented, especially its positive impact on reducing dry spells (Barron and Okwach, 2005; Ellis-Jones and Tengberg, 2000), together with its potential to increase agricultural production globally (Piemontese et al., 2020).

In pastoral drylands, the most common WH structures are sand dams and water ponds, which are widely used by pastoral communities for farming, pastoral and domestic use (Ritchie et al., 2021). Sand dams are concrete barriers built in seasonal sandy rivers to create sand reservoirs and water storage and increase water quality (Castelli et al., 2022), while water ponds are simpler structures, often dug-out on clay soils to collect runoff water from a small catchment area (Forzini et al., 2022).

These WH infrastructures have been promoted in Somalia, which is particularly affected by water scarcity. Somalia's arid and semi-arid

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parts, which make up about 80% of its territory, are highly vulnerable to the risks of climate change and extreme weather conditions, particularly in the regions of Awdal, Bari, Nugaal, Sanaag, Sool, Togdheer, and Woqooyi Galbeed. According to national development plans, these regions experienced five consecutive failed rainy seasons from 2018 to 2022. More than 70% of livelihoods in the livestock and agriculture sectors were affected, while 54.4% of the Somali population lives below the poverty line (Somalia National Bureau of Statistics, 2022).

The Somaliland National Disaster Preparedness Strategy (NADFOR (Somaliland National Disaster Preparedness and Food Reserve Authority), 2019) included mechanisms to improve drought resilience. In line with this strategy, various soil and water conservation programs were embarked on, including the rehabilitation of 30 berkhads (rectangular water harvesting basins) in Togdheer, 11 berkhads in Sanaag, the establishment of four sand dams in the Woqooyi Galbeed region, and two earth dams in Ceel-Afwayn and Balli-Gubadle districts (Somaliland National Development Plan III, 2023-2027). Moreover, during the Revised Puntland Development Plan (2017-2019) implementation period, 23 sand/earth dams and 152 water catchments were constructed (Puntland State of Somalia, 2021). Nevertheless, a countrywide plan and clear best-siting guidelines for water harvesting measures are lacking.

In this study, we provide a large-scale site suitability assessment for sand dams and water ponds based on Multi-Criteria Decision Making (MCDM). MCDM is a common tool used to evaluate and prioritize multiple, sometimes conflicting, criteria in complex situations. MCDM has been used to evaluate the suitability of different WH technologies (Adham et al., 2016; Al-Adamat et al., 2010), including sand dams (Piemontese et al., 2023). The two types of WH techniques were selected strategically: WH ponds to be in line with national and sub-national water development plans; and sand dams, since they represent a technology piloted in Somalia and with considerable potential in the country (Piemontese et al., 2025). Moreover, the two techniques have different suitability criteria, allowing the exploration and assessment of different areas.

Our results can help guide national and local plans for the implementation of sand dams and water ponds in Somalia and support local communities in adapting to climate change and droughts, creating the evidence for the more efficient and sustainable development of such structures.

2. Materials and methods

2.1. Study area

The study area includes the regions of Awdal, Bari, Nugaal, Sanaag, Sool, Togdheer, and Woqooyi Galbeed of Somalia (Fig. 1).

Rainfall in the area is low and erratic, and is driven by the monsoon

dynamics of the Indian Ocean, creating two rainy seasons, interrupted by two dry seasons, every year. The main or long rainy season, called Gu, occurs between April and June, and the short rainy season, called Deyr, from October to December. The two dry seasons are Jilaal and Haggai, which occur between January and March and July and September (Muchiri, 2007).

CHIRPS (Funk et al., 2015) annual rainfall average data for the period 1981 to 2022 showed a range from 10 to 817 mm/y in the study area. However, more than 75% of the area received less than 250 mm/y in the period, while only less than 1% received more than 500 mm/y. Evaporation is very high, exceeding rainfall in all the regions. Annual potential evapotranspiration ranges from 1800 mm to 3000 mm (Oduor and Gadain, 2007).

2.2. Water harvesting (WH) technologies

The technologies selected for the study were water ponds and sand dams. Although the term WH ponds can refer to a wide range of systems, we refer here specifically to the design proposed by FAO-SWALIM for Somalia (Oduor and Gadain, 2007). Ponds are conceived as open surface reservoirs constructed by communities, consisting of a catchment area, an inlet canal, and a live fence to break the wind and protect animals and humans. The surface area for ponds is approximately 1000 m² with depths ranging from 2.5 to 6 m. The height of the embankments usually ranges from 2 to 3 m. Sand dams, on the other hand, work with a different principle: they are barriers built across the riverbed of a seasonal sand river. The sedimentation of coarse sand upstream of the structure enlarges the natural storage capacity of the riverbed aquifer, which fills with water during the wet season, creating additional groundwater storage for the community (Piemontese et al., 2023, 2025).

2.3. Multicriteria Decision-Making (MCDM)

Spatial MCDM allows the comparison of different kinds of data by converting them into spatial maps classified on a common scale and then overlaid to obtain a single final output (Krois and Schulte, 2014).

For the analysis of site suitability for WH structures, different spatial layers in raster format were analysed and reclassified, and the final suitability maps were obtained by applying Eq. (1):

$$S = \sum w_i x_i \quad (\text{Eq.1})$$

where S is the final suitability score, w_i is the weight of factor i , and x_i is the suitability score of each factor i (Dile et al., 2016). Following the methodology provided by Krois and Schulte (2014), the pixel values of each criteria map were reclassified into five suitability classes, according to a 1-9 suitability scale. Values corresponding to class 1 are marked as

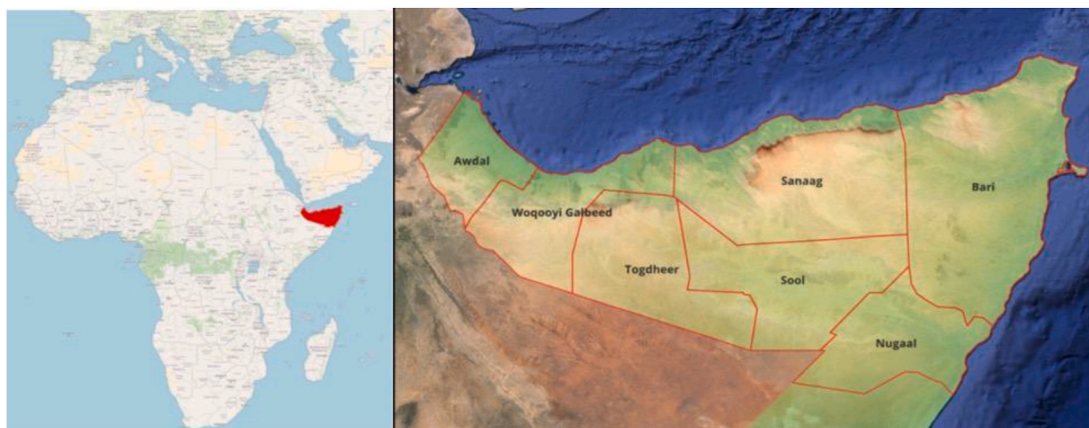


Fig. 1. Location of the regions of the study.

unsuitable, increasing numbers mean higher suitability up to value 9, which marks optimally suitable pixels (Table S1). Different combinations of criteria were created for WH Ponds and Sand Dams (Table 1), following the approach by Krois and Schulte (2014), Adham et al. (2016), Grum et al. (2016), Piemontese et al. (2023).

The reclassification algorithm for each criterion was based on a literature analysis, as shown in Tables 2 and 3.

2.3.1. Weights selection

The Analytic Hierarchy Process (AHP) was used to assign the weights. AHP allows the calculation of w_i for each factor by using the pair-wise comparison matrix method (Saaty, 1980) and validating the results with a consistency check. The procedure for creating the matrix is based on the comparison of pairs using a scale of relative importance in the range 1 to 9. The AHP scale of paired comparisons with its description is listed in Table S2. The pairwise matrix is computed by rows. Each criterion is considered for a row and a column. If the criterion in row n is more important than the criterion in column m , the element (n,m) of the matrix has a value equal to the Numeric Scale (Table S2), in relation to the relative importance of n with respect to m . The element (m,n) is the reciprocal of (n,m) . Criteria should be ordered in the same way for rows and columns. Therefore, the elements of the diagonal (n,n) are always 1. The vector of the weights is then calculated as the normalized Eigenvector of the matrix. By definition, the sum of w_i is then equal to 1.

The relative importance given to one parameter over another is acceptable if the consistency ratio (CR) of the matrix is less than 10%. If the consistency ratio is over 10%, the pair-wise comparison matrix should be recalculated. CR is computed as:

$$CR = CI/RI \quad (\text{Eq.2})$$

Where.

- CI is the Consistency index, calculated as

$$CI = (\lambda - n) / (n - 1) \quad (\text{Eq.3})$$

- λ_{max} is the Principal Eigenvalue
- RI is the Randomness Index derived from a sample size of 500 of a randomly generated reciprocal matrix (Saaty, 1987, Table S3).

2.3.2. Generation of pair-wise comparison matrices and validation

Typically, pair-wise comparison matrices are generated by expert evaluation or directly by decisionmakers (Saaty, 1980; Masi et al., 2024). For the present case study, however, due to the difficulty of gathering a pool of experts for the entire area of study, a mixed approach was adopted. Three different pair-wise matrices were generated for WH ponds, and one for Sand Dams in 2 different online meetings with FAO-SWALIM officers between May and September 2024. Maximizing the availability of ground data, the resulting suitability maps were validated using the geolocations of existing Ponds and Sand Dams.

Suitability maps were then reclassified into quartiles as follows.

- Quartile 0 (Q0) – minimum pixel of the distribution

Table 1

Criteria combinations for Ponds and Sand Dams siting.

ID	Ponds	Sand dams
1	Slope	Slope
2	Rainfall	Rainfall
3	Land Cover	Land cover
4	Soil Texture	Soil texture
5	Potential Runoff/Curve Number	Geology
6		Drainage Order

- First quartile (Q1) - the suitability value below which 25% of pixels fall.
- Second quartile (Q2) - the suitability value below which 50% of pixels fall, equal to the median.
- Third quartile (Q3) - the suitability value below which 75% of pixels fall.
- Fourth quartile (Q4) – maximum pixel of the distribution.

For each map, the percentage of existing structures found in each interval between quartiles was calculated. The position of the structures was retrieved in a file in.kml format provided by FAO-SWALIM containing 102 existing and functioning WH structures (99 ponds and 3 sand dams). Five more Sand Dams were gathered by Lopez-Rey (2019). To simplify the analysis, the following result classes were created for each map (Table 4).

2.4. Watershed analysis

Raster-based suitability maps are often difficult to use for planning interventions on the ground. To overcome this practical issue, in the present paper we propose a ranking of project area basins based on the morphoclimatic and land cover vocation for Ponds and Sand Dams structures. The baseline information provided in the HydroBASINS database (Lehner and Grill, 2013) was used to delineate such areas. HydroBASINS comprises a series of vectorized polygon layers that depict sub-basin boundaries at a global scale. The goal of this dataset is to provide seamless global coverage of consistently sized and hierarchically nested sub-basins at different scales (from tens to millions of square kilometres). HydroBASINS has been extracted from the gridded HydroSHEDS core layers at a resolution of 15 arc-seconds.

Based on the dimensions of the basins for the scope of our analysis, it was decided to use HydroBASINS level 5 data, including 20 basins within the project area. Finally, two new columns were created. The average suitability was calculated for each basin, with reference to the full area for the WH Ponds and the stream length for the Sand Dams.

2.5. Data collection

The following data were retrieved and used for the analysis (Table 5). Data processed in a QGIS environment.

3. Results

3.1. Multicriteria Decision-Making (MCDM)

3.1.1. Generation of weights and validation

Tables S4-S7 show the results of the three AHP combinations for Ponds and of the AHP for Sand Dams. During the meetings with FAO-SWALIM staff, a request was made to test an equal weights combination for Ponds (Table S6), for which the CR is not calculated. All computed CRs were within the limits.

Tables 6 and 7 show the results of the validation for WH Ponds and Sand Dams respectively. Table 6 shows that the weights combination of test 2 represents the best solution for ponds, highlighting worse results for the equal-weights combination. The Validation for Sand Dams also shows good results for the sole pair-wise matrix generated, despite the analysis being limited to a much lower number of existing Sand Dams.

3.1.2. Suitability maps

The results of suitability maps are shown in Figs. 2 and 3.

The best sites for both types of structure are in the northwest of the study area, e.g. the Woqooyi Galbeed region, favoured by topography and relatively higher rainfall amounts. The eastern regions, on the other hand, have a moderate potential for the construction of ponds, but a very limited potential for the creation of new sand dams, considering that most of the area is flat, with river systems characterized by very large

Table 2

Suitability classes for best siting of WH Ponds. Note: the interval always includes the minimum value of the range and does not include the maximum value.

Suitability Classes for Water Ponds	9	7	5	3	1	References
Slope (%)	1-5	0-1	5-8	8-15	>15	Critchley et al. (1991); Al-Adamat (2008).
Annual Rainfall (mm)	750-1000	500-750 and 1000-1200	250-500	200-250	<200 and >1200	Mati et al. (2007); Toosi et al. (2020); Al-Adamat (2008).
Land cover	Bare/sparse vegetation; Cropland	Grassland	Shrubland	Tree cover	Built up; Permanent water bodies; Mangroves; Herbaceous wetland	Adham et al. (2016); Forzini et al. (2022).
Soil texture	Clay, Sandy Clay	Sandy Clay Loam; Clay loam	Loam	Sandy loam	ND	Al-Adamat (2008), Adham et al. (2016).
Potential Runoff/ Curver Number (CN)	>70	61-70	54-61	ND	ND	Krois and Schulte (2014); Ahmad and Verma (2018).

Table 3

Suitability classes for best siting of Sand Dams. Note: the interval always includes the minimum value of the range and does not include the maximum.

Suitability classes for Sand Dams	9	7	5	3	1	References
Slope (%)	1-6	0-1	6-10	10-15	>15	Maddrell (2018); Adham et al., 2016.
Annual Rainfall (mm)	750-1000	500-750 and 1000-1200	250-500	200-250	<200 and >1200	Mati et al. 2007; Toosi et al., 2020; Al-Adamat (2008).
Land cover	Bare/sparse vegetation;	Grassland; Shrubland	Cropland	Tree cover	Built up; Permanent water bodies; Mangroves; Herbaceous wetland	Adham et al., (2016); Maddrell (2018); Said (2021).
Soil texture	Sandy loam	Loam	Sandy Clay Loam	Clay loam	Sandy Clay; Clay	Adham et al., (2016); Maddrell (2018); Said (2021).
Lithology	Metamorphic	Intermediate volcanic rocks; Siliciclastic sedimentary rocks, Basic plutonic rocks	ND	Carbonate sedimentary rocks	Unconsolidated sediments	Dai (2016); Said (2021).
Drainage Network/ Order	Order 3	Order 2	Order 1	Order 4	Order 5-6	Dai (2016); Maddrell (2018)

Table 4

Relation between quartiles and result classes.

Interval	Result class
Equal to Q0	1
Higher than Q0, lower or equal than Q1	3
Higher than Q1, lower or equal than Q2	5
Higher than Q2, lower or equal than Q3	7
Higher than Q3, lower or equal than Q4	9

stream orders. A more comprehensive evaluation is given in [Tables 8 and 9](#).

Table 5

Data sources and utilization.

Layer type	Data format	Name of the dataset	Ponds	Sand Dams	Reference
DTM	Raster (30 m resolution)	FABDEM (Forest and Buildings removed Copernicus DEM)	X	X	Hawker et al. (2022) .
Administrative Boundaries	Vector	Administrative Regions Within Somalia	X	X	UNOCHA (1998) .
Rainfall	Raster (5 km resolution)	Precipitation (average) – CHIRPS (climate hazards infrared precipitation with stations)	X	X	Funk et al. (2015)
Land cover	Raster (10 m resolution)	ESA Worldcover	X	X	Zanaga et al. (2022)
Soil	Vector	Somalia Soil Map - Scale of 1:250,000	X	X	FAO-SWALIM (2019)
Curve number	Raster (250 m resolution)	Curve Number - GCN250 Average antecedent conditions	X		Jaafar et al. (2019)
Drainage Network/ Order	Vector	HydroRIVERS V 1.0		X	Lehner and Grill (2013)
Basins	Vector	HydroBASINS V 1.0	X	X	Lehner and Grill (2013)
Lithology	Vector	GLiM - Global Lithological Map		X	Hartmann and Moosdorf (2012)

3.2. Watershed analysis

The result of the watershed analysis is in [Table 10](#) and [Fig. 4](#), which also shows the positions of level 5 watershed boundaries from Hydro-BASINS ([Lehner and Grill, 2013](#)).

To provide suitable information for the future implementation of WH systems, the following rule was adopted: the watersheds ranking in the top ten positions for both Sand Dams and WH Ponds were suggested as those having a higher biophysical suitability for Ponds and Sand Dams structures. This analysis, by design, does not represent a fully integrated study, as several pieces of information are missing, such as the socio-economic setting and the possible presence of other WH technologies.

Table 6

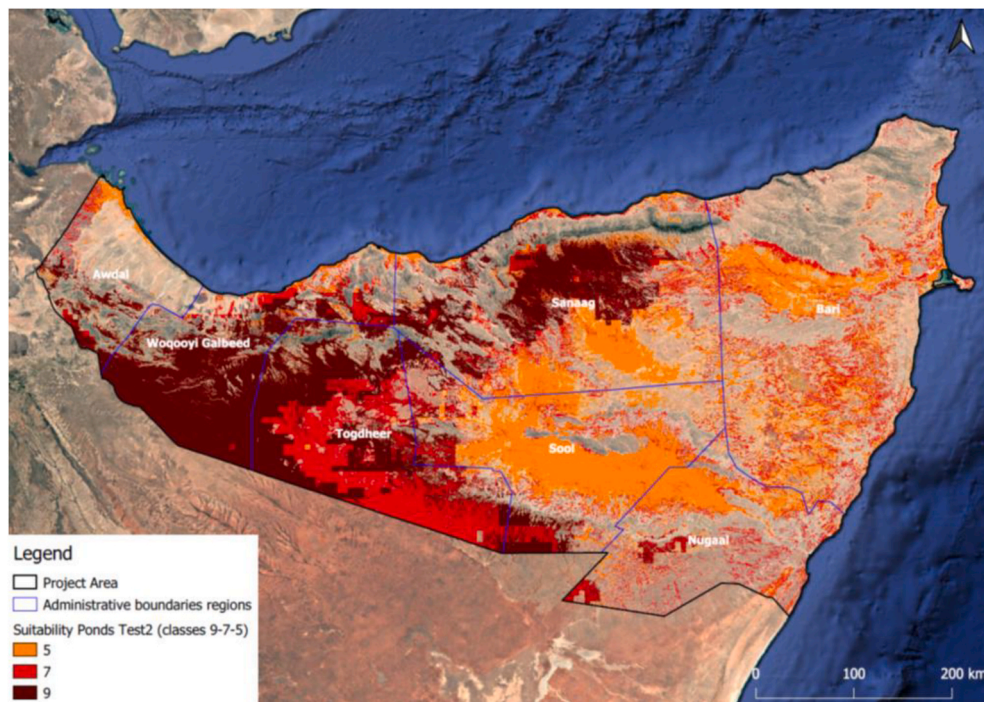
Validation results for WH Ponds best siting.

ID	Description	9	7	5	3	1	Sum Classes 9 + 7+5	Sum Classes 3 + 1
Test1	N° of WH structures per class	40	29	7	5	6	76	11
	% of WH structures per class	46%	33%	8%	7%	7%	87%	13%
	Area per class	20%	29%	16%	15%	20%	66%	34%
Test2	N° of WH structures per class	46	12	20	3	6	78	9
	% of WH structures per class	53%	14%	23%	3%	7%	90%	10%
	Area per class	20%	20%	23%	18%	19%	63%	37%
Test3	N° of WH structures per class	39	0	34	14	0	73	14
	% of WH structures per class	45%	0%	39%	16%	0%	84%	16%
	Area per class	45%	0%	21%	13%	21%	66%	34%

Table 7

Validation results for Sand Dams best siting.

Description	9	7	5	3	1	Sum Classes 9 + 7+5	Sum Classes 3 + 1
N° of WH structures per class	6	1	1	0	0	8	0
% of WH structures per class	75%	12.50%	12.50%	0%	0%	100%	0%
Length per class	19%	20%	19%	23%	19%	58%	42%

**Fig. 2.** Final suitability map for WH Ponds considering test 2 wt

However, the analysis represents a fundamental first step, since the missing information can be retrieved only at a smaller scale.

4. Discussion

4.1. Multicriteria Decision-Making (MCDM), weights and pairwise scoring

The analysis of pair-wise comparison matrices for WH Ponds (Tables 9 and 10) shows that the most important parameter is the runoff potential evaluated using the Curve Number (CN) method. This is also coherent with similar studies considering the runoff potential as a parameter (Alene et al., 2022). Other relevant parameters for Ponds include rainfall and slope, and this is in line with a wider range of studies such as Forzini et al. (2022), Taher et al. (2022), Adham et al. (2016) and Grum et al. (2016). For Sand Dams, runoff generation potential is

not often considered, while the watershed potential for the siting is mostly expressed by the stream order, similar to that done by Piemontese et al. (2023)). Our approach introduces the use of lithology as a relevant parameter, with a $w = 0.160$, in line with a few other studies investigating Sand Dams siting using this parameter (Dai, 2016; Said, 2021). Also of interest is the siting of different types of structures with the same database and a common study area but different systems of weights, such as that proposed by Haddad et al. (2024).

To the best of our knowledge, the input data selected in our analysis represent the state-of-the-art for similar studies in the region. If, in the future, any more accurate datasets are available, the whole MCDA analysis could be replicated simply by recalculating the criteria related to these new data. In this sense, the main limitation of the analysis is the limited sample size of our validation dataset, which should cover the whole study area to guarantee the consistency of the analysis. To overcome this issue, it should be noted that in-depth WH suitability

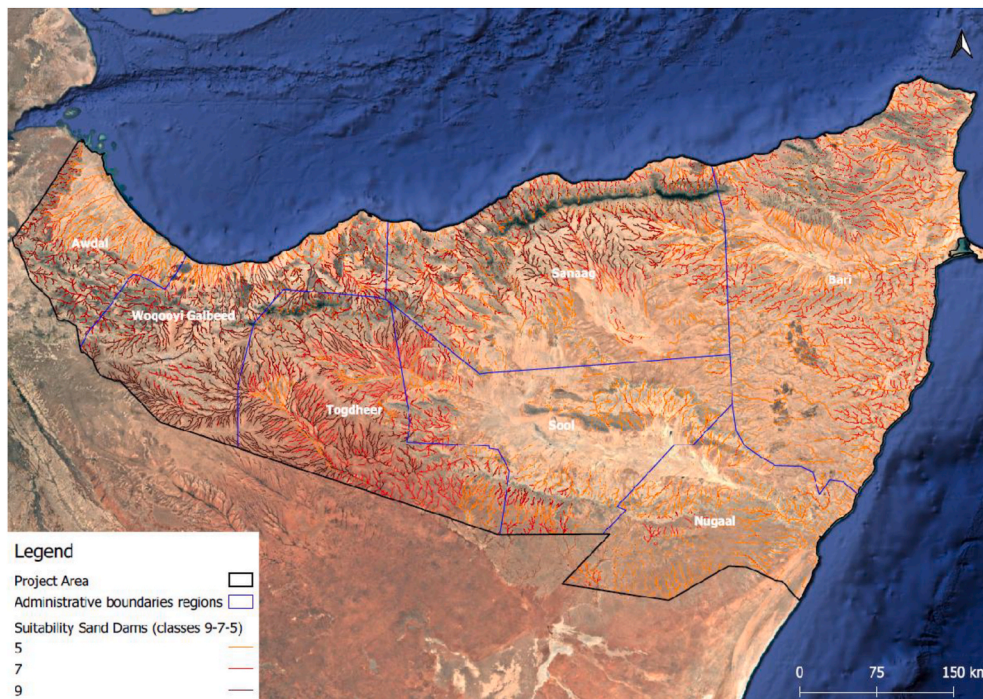


Fig. 3. Final suitability maps for Sand Dams.

Table 8
Summary of the suitability score per region for WH Ponds.

ID	Region	Description
1	Awdal	Class 9 areas are mainly in the south and southwest. Class 7 areas are mainly in the south and west Class 5 areas are mainly in the north and west
2	Bari	A fragmented pattern of classes 7 and 5 characterizes the central and southern areas Class 9 areas cover only small parts of the north Classes 7 and 5 areas also cover some coastal areas in the north and northeast
3	Nugaal	Classes 9 and 7 areas are mainly in the centre and southwest Class 5 areas are mainly in the north and in a fragmented pattern with classes 7 and 9 in the centre and the south
4	Sanaag	Class 9 areas are mainly in the centre, in the west and some spots along the coast Class 7 areas are mainly in the centre, east and west Class 5 areas are mainly in the south, east and some spots along the coast
5	Sool	Class 9 areas are mainly in the northwest, west and southwest Class 7 areas are mainly in the northwest, west and southwest Class 5 areas are mainly in the north, centre, east and southeast
6	Togdheer	Class 9 areas are mainly in the north, centre, west and southwest Class 7 areas are mainly in the centre, east, southeast Classes 9 and 7 areas cover a great part of the region Class 5 areas are only present in a fragmented pattern
7	Woqooyi Galbeed	Class 9 areas cover a great part of the south and centre and are present in some spots in the north and northeast Class 7 areas are mainly in the north and northeast Class 5 areas are mainly in the northeast and the coastal

mapping, taking advantage of more accurate data sources, yet limited to much smaller areas, could be performed with our methodology in the future.

Despite several attempts, it was also not possible to include socio-economic information. This relates again to the difficulty in including representative data for a regional-scale siting like the one presented in

Table 9
Summary of the suitability score per region for Sand Dams.

ID	Region	Description
1	Awdal	Class 9 streams are mainly in the south and west. Class 7 streams are mainly in the south and centre Class 5 streams are mainly in the north and centre
2	Bari	Class 9 streams are only in limited spots in the north Classes 7 streams are mainly in the north, centre and east Classes 5 streams are mainly in the centre, west and south
3	Nugaal	Classes 9 and 7 streams are mainly in the centre and east Classes 5 streams cover the north, centre and south
4	Sanaag	Class 9 streams are mainly in the centre, west and in some coastal areas Class 7 streams are mainly in the centre, east and west and some coastal areas Class 5 streams are mainly in the south, east and some spots along the coast
5	Sool	Class 9 streams are mainly in the northwest and southwest Class 7 streams are mainly in the northwest, west and southwest Class 5 streams are mainly in the west, east and south
6	Togdheer	Class 9 streams are mainly in the north, centre, west and southwest Class 7 streams are mainly in the centre, east, southeast Classes 9 and 7 streams form the majority of the region's streams Class 5 streams are mainly in the southwest, east and southeast
7	Woqooyi Galbeed	Class 9 streams cover a great part of the south, centre, west and east Class 7 streams are mainly in the centre, west and northeast Class 5 streams are mainly in the northwest and the coastal

this study. Other studies that include socio-economic data target much smaller areas (Piemontese et al., 2023; Masi et al., 2024).

The comprehensive database of water sources provided by FAO-SWALIM allowed us to conduct a solid validation for both Sand Dams and WH ponds, with a much higher number of validation points than other validation-performing studies (Piemontese et al., 2022; Forzini et al., 2022).

Table 10

Results of the watershed analysis for the 20 watersheds from HydroBASINS selected for the study area. The watersheds highlighted are those in the top ten positions in both the Sand Dams and WH Ponds rankings.

PONDS				SAND DAMS			
Basin ID	Suitability mean value	Basins Rank	Area km ²	Basin ID	Suitability mean value	Basins Rank	Area km ²
18	6.82	1	1,606.73	18	5.38	1	1,606.73
17	6.78	2	34,851.20	17	4.94	2	34,851.20
1	6.35	3	5,314.73	20	4.87	3	31,601.80
3	6.26	4	4,777.14	1	4.83	4	5,314.73
20	6.22	5	31,601.80	3	4.45	5	4,777.14
19	6.18	6	1,989.42	5	4.35	6	4,153.59
15	6.12	7	64,513.50	2	4.16	7	2,993.20
5	6.06	8	4,153.59	12	4.09	8	699.51
11	6.06	9	26,063.60	10	4.08	9	6,972.81
14	6.02	10	7,759.97	11	4.03	10	26,063.60
16	6.00	11	6,851.96	6	3.99	11	14,145.60
12	5.91	12	699.51	9	3.98	12	28,658.00
13	5.83	13	6,524.76	19	3.97	13	1,989.42
10	5.73	14	6,972.81	4	3.96	14	456.23
9	5.72	15	28,658.00	15	3.95	15	64,513.50
4	5.62	16	456.23	13	3.83	16	6,524.76
6	5.44	17	14,145.60	14	3.73	17	7,759.97
2	5.36	18	2,993.20	16	3.73	18	6,851.96
8	5.29	19	10,975.90	8	3.64	19	10,975.90
7	4.88	20	4,796.53	7	3.46	20	4,796.53

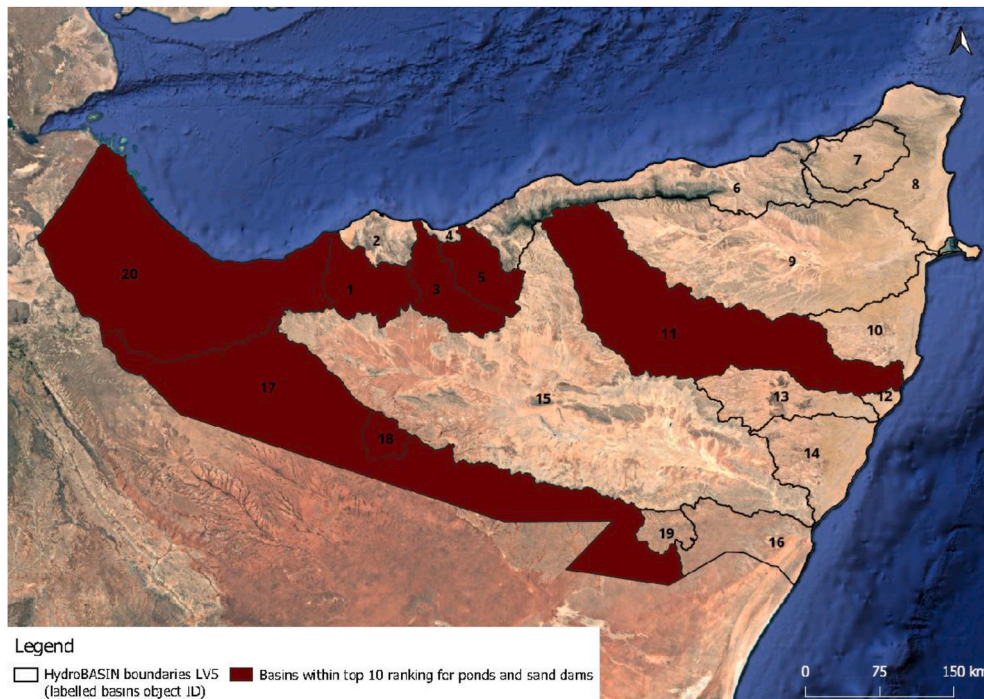


Fig. 4. Geographical locations of the watersheds identified. The watersheds highlighted are those in the top ten positions in both Sand Dams and WH Ponds rankings.

4.2. Watershed analysis and further developments

The results of watershed analysis (Table 10 and Fig. 4) are in line with standard MCDM results (Figs. 2 and 3). The most suitable watersheds are still in the west of the study area, but the subdivision into hydrological units also highlights the possibility of working in the east, with coastal watershed number 11. The analysis was carried out using the HydroBASINS database (Lehner and Grill, 2013), but not formally referencing Somalia's water management policy. Nevertheless, the same approach can be used with a different set of watersheds. It should be

noted, however, that the watershed analysis performed is an indication of the biophysical suitability of each watershed for Ponds and Sand Dams, and not a ranking of intervention priorities, which can only be evaluated after a more detailed analysis, including other water structures, socio-economic data, including – for example – land tenure (Forzini et al., 2022), technical skills and level of education (Piemontese et al., 2020), including field visits in the local communities to double-check the desk-study findings (Piemontese et al., 2020). The development of such analyses requires an in-depth knowledge of the local context, with field data collection and participatory planning of

water management infrastructure with local actors, which is virtually impossible at our scale of analysis. In this sense, this study can be seen as a key first step to identify priority areas for further action and field data collection that requires a higher investment, also considering the difficulty of working in the North of Somalia.

5. Conclusion

The present study has developed a regional-scale best siting of WH structures, Sand Dams and Ponds, for Northern Somalia, using MCDM and pairwise comparison through AHP. The analysis was fully validated using over 100 existing structures, most of them falling in the suitable areas identified with the spatial MCDM. The regions with the highest potential for WH are Togdheer and Woqooyi Galbeed, while an analysis based on hydrologically sound boundaries revealed that the most suitable watersheds for WH under a biophysical profile are mostly located in the north-west of Somalia, with also a relatively high potential in a large coastal watershed in the east of the study area. The results represent a starting point for future planning of WH structures.

CRediT authorship contribution statement

Marco Sirigu: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Paolo Paron:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Luigi Piemontese:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Ugo Leonardi:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Flavian Muthusi:** Writing – review & editing, Methodology. **Michael Makokha:** Writing – review & editing, Methodology. **Awo Osman:** Writing – review & editing, Data curation. **Abdullahi Ali:** Writing – review & editing, Data curation. **Elena Bresci:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Giulio Castelli:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jaridenv.2026.105753>.

Data availability

Data will be made available on request.

References

Adham, A., Riksen, M., Ouassir, M., et al., 2016. Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: a review. *Int. Soil Water Conserv. Res.* 4, 108–120. <https://doi.org/10.1016/j.iswcr.2016.03.001>.
 Ahmad, I., Verma, M.K., 2018. Application of analytic hierarchy process in water resources planning: a GIS based approach in the identification of suitable site for water storage. *Water Resour. Manag.* 32, 5093–5114.

Al-Adamat, R., 2008. GIS as a decision support system for siting water harvesting ponds in the basalt Aquifer/NE Jordan. *J. Environ. Assess. Pol. Manag.* 10, 189–206. <https://doi.org/10.1142/S1464333208003020>.
 Al-Adamat, R., Abdullah, D., Shatnawi, G., 2010. Combining GIS with multicriteria decision making for siting water harvesting ponds in Northern Jordan. *J. Arid Environ.* 74 (11), 1471–1477. <https://doi.org/10.1016/j.jaridenv.2010.07.001>.
 Alene, A., Yibletal, M., Abera, A., et al., 2022. Identifying rainwater harvesting sites using integrated GIS and a multi-criteria evaluation approach in semi-arid areas of Ethiopia. *Appl. Water Sci.* 12, 238.
 Barron, J., Okwach, G., 2005. Run-off water harvesting for dry spell mitigation in maize (*Zea mays* L.): results from on-farm research in semi-arid Kenya. *Agr. Water Manage.* 74 (1), 1–21. <https://doi.org/10.1016/j.agwat.2004.11.002>.
 Castelli, G., Piemontese, L., Quinn, R., et al., 2022. Sand dams for sustainable water management: challenges and future opportunities. *Sci. Total Env.*, 156126 <https://doi.org/10.1016/j.scitotenv.2022.156126>.
 Critchley, W., Siegert, K., Chapman, C., 1991. Water Harvesting, A Manual Guide for the Design and Construction of Water Harvesting Schemes for Plant Production. FAO, Rome. www.fao.org/docrep/u3160e/u3160e07.htm.
 Dai, X., 2016. Dam site selection using an integrated method of AHP and GIS for decision making support in Bortala, Northwest China. Lund University GEM thesis series 14. https://webapps.itc.utwente.nl/librarywww/papers_2016/msc/gem/dai.pdf.
 Dile, Y.T., Rockström, J., Karlberg, L., 2016. Suitability of water harvesting in the upper Blue Nile Basin, Ethiopia: a first step towards a mesoscale hydrological modeling framework. *Adv. Meteorol.*, 5935430 <https://doi.org/10.1155/2016/5935430>.
 Ellis-Jones, J., Tengberg, A., 2000. The impact of Indigenous soil and water conservation practices on soil productivity: examples from Kenya, Tanzania and Uganda. *Land Degrad. Dev.* 11 (1), 19–36. [https://doi.org/10.1002/\(SICI\)1099-145X\(200001/02\)11:1<19::AID-LDR357>3.0.CO;2-2](https://doi.org/10.1002/(SICI)1099-145X(200001/02)11:1<19::AID-LDR357>3.0.CO;2-2).
 FAO-SWALIM, 2019. Somalia Soil Map - Scale of 1:250,000.
 Farooq, M., Siddique, K.H.M., 2016. Research and developmental issues in Dryland Agriculture. In: Farooq, M., Siddique, K.H.M. (Eds.), *Innovations in Dryland Agriculture*. Springer International Publishing, Cham, pp. 31–46. https://doi.org/10.1007/978-3-319-47928-6_2.
 Forzini, E., Piemontese, L., Bresci, E., et al., 2022. Identification of suitable sites for traditional pokhari water harvesting in mountain rural communities of the Himalaya. *Hydrol. Res.* 53 (11), 1340–1356. <https://doi.org/10.2166/nh.2022.027>.
 Funk, C., Peterson, P., Landsfeld, M., et al., 2015. The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Sci. Data* 2, 150066.
 Greve, P., Seneviratne, S.I., 2015. Assessment of future changes in water availability and aridity. *Geophys. Res. Lett.* 42 (13), 2015GL064127. <https://doi.org/10.1002/2015GL064127>.
 Grum, B., Hessel, R., Kessler, A., et al., 2016. A decision support approach for the selection and implementation of water harvesting techniques in arid and semi-arid regions. *Agr. Water Manage.* 173, 35–47. <https://doi.org/10.1016/j.agwat.2016.04.018>.
 Haddad, M., Worqlul, A.W., Strohmeier, S., et al., 2024. Suitability mapping of micro and meso scale rain water harvesting for vegetation-based restoration in arid degraded areas of Jordan. *Catena* 246, 108461.
 Hartmann, J., Moosdorf, N., 2012. The new global lithological map database GLiM: a representation of rock properties at the Earth surface. *G-cubed* 13, Q12004. <https://doi.org/10.1029/2012GC004370>.
 Hawker, L., Uhe, P., Paulo, L., et al., 2022. A 30 m global map of elevation with forests and buildings removed. *Environ. Res. Lett.* 17, 024016.
 Jaafar, H.H., Ahmad, F.A., El Beyrouthy, N., 2019. GCN250, new global gridded curve numbers for hydrologic modeling and design. *Sci. Data* 6, 145. <https://doi.org/10.1038/s41597-019-0155-x>.
 Krois, J., Schulte, A., 2014. GIS-based multi-criteria evaluation to identify potential sites for soil and water conservation techniques in the Ronquillo watershed, northern Peru. *Appl. Geogr.* 51, 131e14.
 Lehner, B., Grill, G., 2013. Global river hydrography and network routing: baseline data and new approaches to study the world's large river systems. *Hydrol. Proces.* 27 (15), 2171–2186. <https://doi.org/10.1002/hyp.9740>.
 Lopez-Rey, P., 2019. An Appraisal of the Effectiveness and Sustainability of Sand Dams to Improve Water Security and Resilience in Somaliland. MSc. Thesis. Loughborough University, UK. <https://admin.concern.net/sites/default/files/documents/2020-12/MSc%20final%20research%20report-%20Sand%20dams%20Somaliland-Lopez-Rey%202020%20%28003%29.pdf>.
 Maddrell, S., 2018. Sand dams: a practical & technical manual. Excellent Development. <https://www.cyrho.com/data/Sand%20Dam%20Manual%20-%20Maddrell.pdf>.
 Masi, M., Arrighi, C., Piragino, F., et al., 2024. Participatory multi-criteria decision making for optimal siting of multipurpose artificial reservoirs. *J. Environ. Manag.* 370, 122904.
 Mati, B., Tanguy, D.B., Maimbo, M., et al., 2007. Mapping the potential of rainwater harvesting technologies in Africa: a GIS overview on development domains for the continent and ten selected countries. Technical Manual No.7, World Agroforestry Centre (ICRAF). Netherlands Ministry of Foreign Affairs and Swedish International Development Cooperation Agency (SIDA).
 Muchiri, P.W., 2007. Climate of Somalia, Technical Report No W-01. FAO-SWALIM, Nairobi, Kenya.
 NADFOR (Somaliland National Disaster Preparedness and Food Reserve Authority), 2019. National Disaster Preparedness Strategy. Government of Somaliland, Hargeisa, Somaliland.
 Oduor, A.R., Gadain, H.M., 2007. Potential of rainwater harvesting in Somalia, A planning, design, implementation and monitoring framework. Technical Report NoW-09. FAO-SWALIM, Nairobi, Kenya.

- Piemontese, L., Castelli, G., Fetzter, I., et al., 2020. Estimating the global potential of water harvesting from successful case studies. *Glob. Environ. Change* 63, 102121. <https://doi.org/10.1016/j.gloenvcha.2020.102121>.
- Piemontese, L., Castelli, G., Limones, N., et al., 2023. Large-scale siting of sand dams: a participatory approach and application in Angolan drylands. *Land Degrad. Dev.* 34 (3), 844–858. <https://doi.org/10.1002/ldr.4500>.
- Piemontese, L., Fetzter, I., Rockström, J., et al., 2019. Future hydroclimatic impacts on Africa: beyond the Paris agreement. *Earths Future* 7 (7), 748–761. <https://doi.org/10.1029/2019EF001169>.
- Piemontese, L., Villani, L., Limones, N., et al., 2025. Global dataset of sand dam features and geographical distribution across drylands. *Sci. Data* 12, 1929. <https://doi.org/10.1038/s41597-025-06197-w>.
- Prävalie, R., 2016. Drylands extent and environmental issues. A global approach. *Earth Sci. Rev.* 161, 259–278. <https://doi.org/10.1016/j.earscirev.2016.08.003>.
- Puntland State of Somalia, 2021. Puntland 5 YEAR Dev Plan - Jan 28 2021. <https://doi.org/10.13140/RG.2.2.21416.70401>.
- Ritchie, H., Eisma, J.A., Parker, A., 2021. Sand dams as a potential solution to rural water security in drylands: existing research and future opportunities. *Front. Water* 3, 651954. <https://doi.org/10.3389/frwa.2021.651954>.
- Rockström, J., Barron, J., Fox, P., 2002. Rainwater management for increased productivity among small-holder farmers in drought prone environments. *Phys. Chem. Earth, Parts A/B/C* 27 (11), 949–959. [https://doi.org/10.1016/S1474-7065\(02\)00098-0](https://doi.org/10.1016/S1474-7065(02)00098-0).
- Rockström, J., Malin, M., 2015. Agriculture: increase water harvesting in Africa. *Nature* 519 (7543), 283. <https://doi.org/10.1038/519283a>.
- Rosa, L., Chiarelli, D.D., Rulli, M.C., et al., 2020. Global agricultural economic water scarcity. *Sci. Adv.* 6 (18), eaaz6031. <https://doi.org/10.1126/sciadv.aaz6031>.
- Saaty, T.L., 1980. The analytic hierarchy process (AHP). *J. Oper. Res. Soc.* 41 (11), 1073–1076.
- Saaty, T.L., 1987. Principles of the analytic hierarchy process. In: Mumpower, J.L., Renn, O., Phillips, L.D., Uppuluri, V.R.R. (Eds.), *Expert Judgment and Expert Systems*, NATO ASI Series, 35. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-86679-1_3.
- Said, M.A., 2021. Selection of Suitable Sites for Sand Dams in Upper Biji Catchment, Northern Somalia. MSc. Thesis. University of Florence.
- Somalia National Bureau of Statistics, 2022. Somalia Integrated Household Budget Survey (SIHBS). Somalia National Bureau of Statistics. <https://microdata.nbs.gov.so/index.php/catalog/59>.
- Stringer, L.C., Mirzabaev, A., Benjaminsen, T.A., et al., 2021. Climate change impacts on water security in global drylands. *One Earth* 4 (6), 851–864. <https://doi.org/10.1016/j.oneear.2021.05.010>.
- Taher, J.K., Najim Nasimi, M., Najim Nasimi, M., et al., 2022. Identifying suitable sites for rainwater harvesting using GIS & Multi - Criteria Decision Making techniques in Badghis Province of Afghanistan. *Central Asian J. Water Res.* 8 (2), 46–69.
- Toosi, A.S., Tousi, E.G., Ghassemia, S.A., et al., 2020. A multi-criteria decision analysis approach towards efficient rainwater harvesting. *J. Hydrol.* 582, 124501.
- UNOCHA, 1998. Somalia Country Administrative Boundary Admin 2 (Regions of Somalia).
- Zanaga, D., Van De Kerchove, R., Daems, D., et al., 2022. ESA WorldCover 10 m 2021 v200. <https://doi.org/10.5281/zenodo.7254221>.