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ORIGINAL ARTICLE

Identifying rainwater harvesting sites using integrated GIS and a multi-criteria evaluation approach in semi-arid areas of Ethiopia

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Abstract

In recent years, East Africa has been suffering from severe droughts. The availability of water is crucial to socioeconomic development and ecosystem services in the region. In order to address the pressing issue of water scarcity in the Wag Himra zone, a study will identify viable rainwater harvesting (RWH) sites. Geographical Information System with a multi-criteria evaluation system was used to identify suitable RWH sites based on land use and cover, soil texture, runoff depth, slope, drainage density, and considering road and town constraints. The runoff depth was estimated using the soil conservation service curve number model, and the land use/cover image classification was undertaken using ArcGIS. By using weighted overlay analysis, sites that are potentially suitable for RWH were identified. Based on the hydrological and socioeconomic characteristics of the study area and available literature, the weight of the criteria was determined using the Analytical Hierarchical Process. The findings of the study indicate that only 0.02% of the study area is considered highly suitable, 2.59, 12.26, 61.76, and 21.1% are rated as moderately suitable, marginally suitable, less suitable, and not suitable for RWH, respectively, and 2.29% is labeled a constraint for RWH. It is possible to harvest and store rainwater in the study area to meet increasing water demand. These findings aim to assist decision-makers, planners, and managers to find sites, invest in water resources, and use RWH as an alternative water source.

Keywords Semi-arid area · Rainwater harvesting · Analytical hierarchical process · Multi-criteria evaluation · Water scarcity

Introduction

Water scarcity is a severe problem in many countries, particularly in developing nations (Ibrahim et al. 2019). Agricultural and urban expansion are putting pressure on water supplies due to climate change and rising water demand (Hagos et al., 2022a; Andualem et al. 2021). Many people in Africa will likely be exposed to rising water stress by 2020, and agriculture, especially food access, may become more challenging (Adham et al. 2016). Ethiopia is a developing country in the Horn of Africa with an agricultural economy reliant heavily on rain. More than 80% of the country's population depends on agriculture for their livelihood. Many Ethiopian smallholder farmers who depend on rainfed agriculture face food insecurity because of climate change (Ayahu and Yibeltal 2016). Agriculture is more susceptible to the effects of climate change as rainfall varies both in space and over time (Dile et al. 2013).

Ethiopia has abundant surface and groundwater resources as well as potential irrigable land, despite the fact that only 4–5% of the available land has been developed (Worqlul et al. 2015). The annual surface runoff potential is approximately 122 billion m^3, but much of this water is exported through transboundary rivers (Ketsela 2009). In this study area, water is scarce, and rainfall is irregular and unreliable

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due to water constraints in the Tekeze basin. Water stress is the main factor that limits the supply of residential water, livestock watering, and agricultural productivity (Wale et al. 2021). Utilizing water resources can provide full-season irrigation and supplemental irrigation to compensate for agricultural productivity losses. These efforts include harvesting surface and groundwater, preventing loss through evaporation and seepage, and other engineering and hydrological interventions (Rockstrom 2000, Rockström et al. 2009; Sutherland et al. 2000; IFADU 2013). Using rainwater harvesting (RWH) to use runoff water is critical because much of it leaves the catchment as surface runoff (Adham et al. 2016). There is a growing interest in rainwater harvesting as a low-cost irrigation alternative (Tolossa et al. 2020). Rainwater harvesting is the practice of collecting and recharging groundwater wells, and flood control, rainwater harvesting is the practice of collecting and storing rainwater for later use (Bera and Ahmad 2016).

In addition to reducing excessive runoff, rainwater harvesting reduces flooding in downstream catchments and improves soil moisture (Ammar et al. 2016; Li et al. 2018; Madan et al. 2014). In many locations, rainwater harvesting has been used as a cost-effective method to reduce water scarcity and improve water quality. Further, it addresses the effects of climate change on precipitation variability (Barron 2009; Ndiritu et al. 2011). There is no doubt that rainwater collection is one of the best solutions to the problem of water scarcity. Ex-situ and in-situ RWH structures can be used to collect, store, and utilize rainfall runoff. In ex-situ RWH systems, water is detained outside the point of storage (Sakthivadivel and Vennila 2021). These detention areas include farm ponds, dams, open tanks, cisterns, runoff farming systems, and small reservoirs (Hagos et al. 2022b). In contrast, in-situ RWH systems hold rainwater in the root zone of the soil where it falls (Rockström et al. 2010). Various in-situ RWH systems are available, such as pitting, *Fanya juu*, stone lines, conservation tillage, etc. Through these practices, farmers can store some of the rain and reduce crop failure due to rainfall variability or unavailability during dry periods and droughts (Wale et al. 2021). Moreover, they can be used to maintain a farmer's livelihood, which would otherwise be lost due to evaporation, interception, and surface runoff (Dile et al. 2016).

RWH systems are successful primarily when suitable sites and technologies are identified (Ejegu and Yegizaw 2020). The most common method for identifying potential sites for RWH is by conducting a field survey in a small area. Alternatively, geographic information systems (GIS) and remote sensing (RS) are used for areas of greater size (Adham et al. 2016). The use of GIS and RS data is now becoming more common for assessing the biophysical environment and identifying suitable RWH sites (Adham et al. 2016; Bera and Ahmad 2016). When the decision-making process was taking place, RWH was recommended to use GIS as a decision-making and problem-solving tool. The GIS-MCE combination provides a cogent, objective, and simple approach for choosing suitable sites for RWH technologies by integrating the identified factors (Isioye et al. 2012). Many factors influence the identification of the RWH site, such as physical factors or a combination of physical and socioeconomic factors (Tolossa et al. 2020; Worqlul et al. 2015). Using FAO standards and Integrated Mission for Sustained Development (IMSD) guidelines, the researchers determined the criteria that could affect the potential RWH site (Ramakrishnan et al. 2008). Several factors are listed by FAO for identifying RWH potential areas, cited by Adham et al. (2016), for example: climate (rainfall), hydrology (runoff and drainage density), topography (slope), agronomy (land use/cover), soils, and socioeconomic factors (distance to stream, main road, settlement etc.).

A water-scarce region like Wag Himra requires more water resource management measures for various purposes. Hence, the objective of this study is to identify suitable rainwater collection sites in order to construct rainwater harvesting technologies to meet the region's water needs using GIS and multi-criteria decision analysis.

Materials and methods

Study area description

A study was conducted in the Wag Himra zone of Ethiopia's Amhara state, Tekeze basin. It is located at 38°20' E–39°18' E and 12°07' N–13°18' N (Fig. 1), having a difference in elevation of 989 to 4021 m above sea level and covering about 9004 4 km^2. The area's climate was described as having mean minimum and maximum temperatures of 12.4–26.8 °C, measured from Sekota station (Wale et al. 2021). The main rainy season, which accounts for approximately 80% of the annual precipitation, takes place between June and September, while the short rainy season takes place between March and May. We extracted the soil map of the study area from the Tekeze basin soil map, which contains twelve textural class features (Fig. 5a). The soil texture data were collected from the Amhara design supervision and construction work enterprise. Loam and sandy loam soils dominated over 70% of the area. Land use/land cover (LU/LC) maps were derived from image classification. In the area, seven different types of LU/LC class features were identified, including bare land, grazing land, farmland, forest, shrub land settlements, and water bodies.

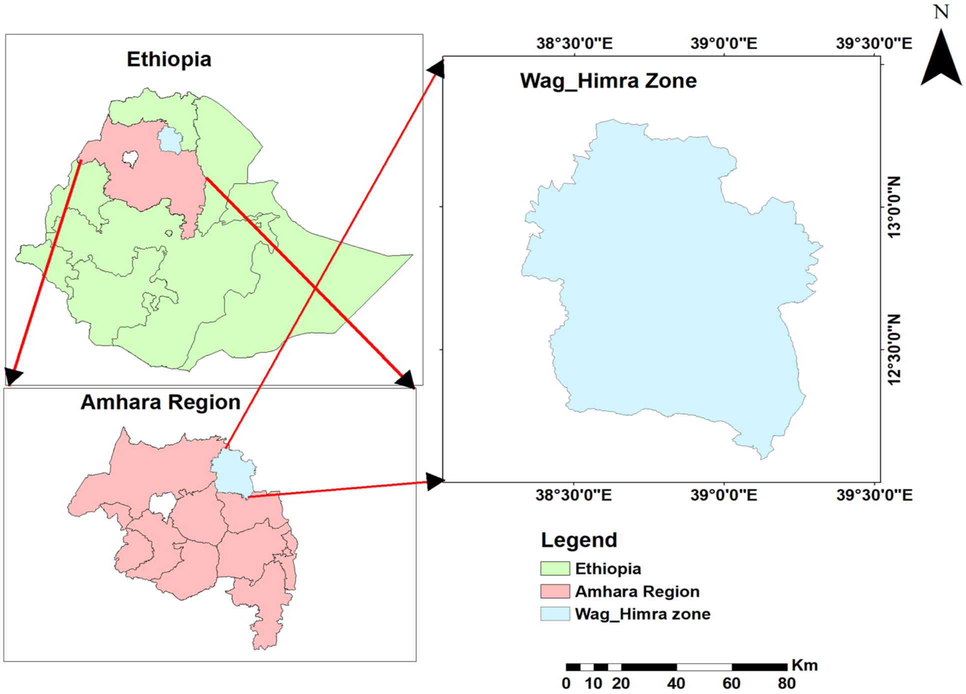

Fig. 1 Study area description of Wag Himra Zone

Datasets

The Shuttle Radar Topographic Mission (SRTM) digital elevation model (DEM) and the Landsat 8 satellite image are both from the USGS's open-source geo-database. Rainfall records for nine sites within and near the research area were provided by the Ethiopian National Meteorological Station from 2008 to 2017. Soil maps for the study area were collected from the Amhara design and supervision works enterprise. The main processes used to select suitable rainwater

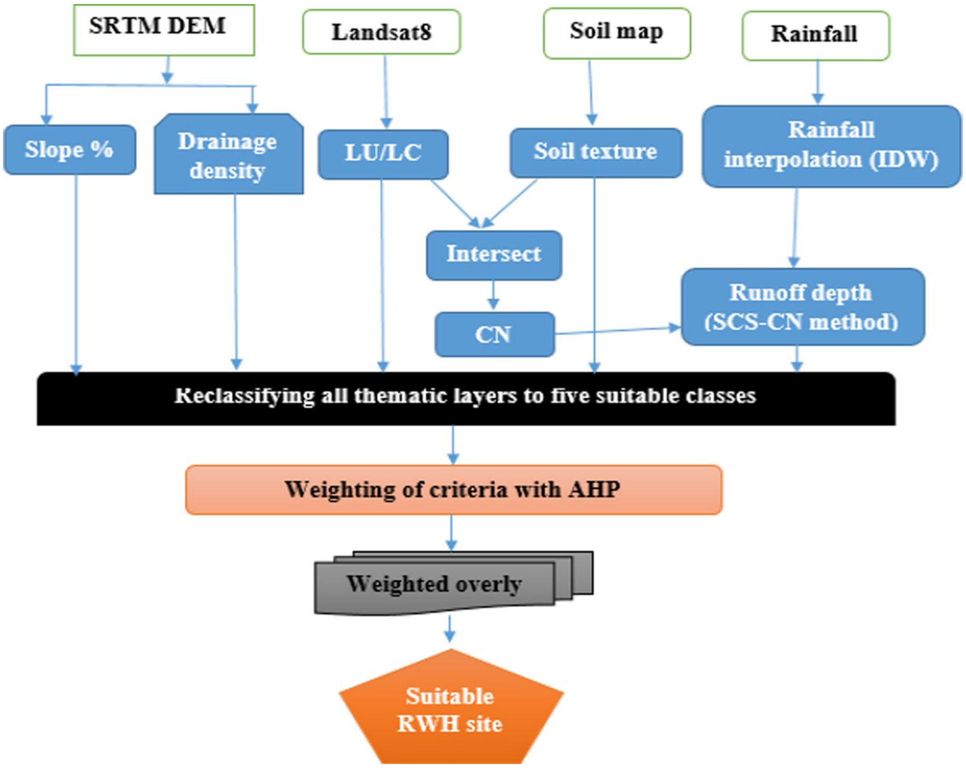

Fig. 2 Flowchart for the selection of RWH site in the Wag Himra zone

Table 1 Soil group. Source: (Ibrahim et al. 2019)

Soil group	Runoff description	Soil texture
A	Low runoff potential because of high infiltration rates	Sand, loamy sand, and sandy loam
B	Moderately infiltration rates lead to a moderate runoff potential	Silty loam and loam
C	High/moderate runoff potential because of slow infiltration rates	Sandy clay loam
D	High runoff potential with very low infiltration rates	Clay loam, silty clay loam, sandy clay, silty clay, and clay

harvesting sites in the Wag Himra region were identifying criteria, organizing input data, analyzing, reclassifying criteria according to literature, and integrating factors with weighted overlay analysis by assigning weight to each factor (Fig. 2).

Criteria selection and data processing

RWH sites were selected using layers based on literature, climatic and physical characteristics of watersheds, and data availability (Adham et al. 2016). RWH sites are identified using FAO standards and Integrated Mission for Sustained Development (IMSD) guidelines (Ramakrishnan et al., 2008). FAO identified climate, hydrology, topography, agronomy, soils, and socioeconomic factors as factors influencing RWH potential areas (Adham et al. 2016). In 48 studies conducted in arid and semi-arid areas, slope (83%), land use/land cover (75%), soil type (75%), and rainfall (56%) were the most commonly used criteria to detect potential RWH sites. Distance from settlements (25%), distance from streams (15%), distance from roads (15%), and cost (8%). (Ammar et al. 2016). Thus, this study used the following criteria to identify suitable RWH sites: land use/cover, slope, soil texture, runoff depth, and drainage density. In addition to those requirements, distances from major roads and settlements were considered a constraint or restricted area. All of the primary and secondary data that were collected and analyzed were processed at the same resolution (30 m × 30 m).

Land use/land cover

The land use/cover map was prepared based on Landsat 8 OLI/TIS released on October 13, 2020, with a spatial resolution of 30 m. For LU/LC mapping, Landsat8 has a minimum accuracy difference of 5% compared to Sentinel-2 (Forkuor et al. 2018). Landsat8 was included in a recent publication by Haile and Suryabhagavan (2019), Wondimu and Jote (2020). In addition, LANDSAT8 was selected due to its compatibility with secondary data collected. Three bands, 4, 3, 2, were used as a true color composite in ArcGIS 10.4. An ArcGIS supervised classification algorithm was applied for the LU/LC map. Ground control points were collected using GPS and Google Earth from physically known areas to create a signature file. The site's acceptability for RWH technologies was determined by using the kappa coefficient and classified into five acceptable categories based on the effects of LU/LC (Table 2).

Slope

Slope was a key consideration in selecting the ideal location for water harvesting and storage in the channel and pond. RWHs with slopes greater than 8% should not be considered because they are prone to high erosion rates due to irregular runoff distribution and excessive earthworks (Adham et al. 2016; Ibrahim et al. 2019). In ArcGIS, slope maps of the study area in percent were extracted from 30 m DEMs and reclassified into five classes (Table 2).

Soil texture

A soil's texture is determined by the proportion of silt, sand, and clay in the particles. It has a significant impact on infiltration and surface runoff. RWH is generally more suitable for fine- and medium-textured soils due to their higher water-holding capacity (Ibrahim et al. 2019). According to its capacity to hold water and to infiltrate it, it was reclassified into five suitable RWH classes (Table 2).

Runoff depth

Runoff depth plays the most significant role in determining which locations are best suited for RWH. During the rainy season, these data are used to calculate the potential water supply from surface runoff (Buraihi and Shariff 2015). In order to identify a potential runoff site, the Soil Conservation Service Curve Number (SCS-CN) technique was combined with average annual rainfall and curve number (Ejegu and Yegizaw 2020). The runoff depth was computed as:

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \tag{1}$$

Table 2 Criteria, classes, suitability and their source

Criteria	Class	Suitability	References
Land use/land cover	Bare land	S1	Ejegu and Yegizaw (2020) and Haile and Suryabhagavan (2019)
	Agricultural and grazing-land	S2	
	Shrub land	S3	
	Forest	S4	
	wetlands, urban and water bodies	S5	
Slope (%)	< 5	S1	Hameed (2013), Islam et al. (2020) and Mugo and Odera (2019)
	8-May	S2	
	8–15	S3	
	15–30	S4	
	> 30	S5	
Soil texture	Clay	S1	Adham et al. (2016) and Hameed (2013)
	Silty clay	S2	
	Sandy clay, loam, silty clay loam, clay loam	S3	
	Sandy clay loam & sandy loam, loamy sand	S4	
	Others	S5	
Runoff depth	> 900	S1	Mugo and Odera (2019)
	700–900	S2	
	600–700	S3	
	500–600	S4	
	< 500	S5	
Drainage density	> 2	S1	Adham et al. (2018)
	1.8−2	S2	
	1.7−1.8	S3	
	1.5−1.7	S4	
	< 1.5	S5	
Road proximity	> = 500	Suitable	Haile and Suryabhagavan (2019)
	< 500	Not Suitable	
Town Proximity	> = 1000	Suitable	
	< 1000	Not Suitable	

S1, highly suitable; S2, moderately suitable; S3, marginally suitable; S4, less suitable and S5, not suitable

$$Ia = 0.2 \times S \tag{2}$$

where Q is runoff depth (mm), P is precipitation (mm), which is prepared by using the inverse distance weight (IDW) interpolation method (Gaikwad 2015). The spatial rainfall was thus calculated by interpolating the mean annual rainfall data collected from nine weather stations between 2008 and 2018. In the equation below, S represents the potential maximum retention after runoff (mm) and Ia represents the initial abstraction (mm) that includes all losses prior to runoff, infiltration, evaporation, and vegetation contact with the water.

Table 3 Scale value of AHP (Saaty 1980)

Intensity of importance	Degree of preference	Explanation
1	Equally	Two factors contribute equally to the objective
3	Moderately	Experience and judgment slightly to moderately favor one factor over the other
5	Strongly	Experience and judgment strongly to moderately favor one factor over the other
7	Very strongly	A factor is strongly favored over another and its dominance is shown in practice
9	Extremely	The evidence of favoring one factor over another is of the highest degree possible
2, 4, 6, 8	Intermediate	Used to represent compromises between the preferences in weights 1, 3, 5, 7 and 9
Reciprocals	Opposites	Used for inverse comparison

$$S = \frac{25400}{CN} - 254 \tag{3}$$

where CN is the curve number calculated per pixel in the research region by combining the soil map with the LU/LC. The curve number (CN) is a measure of how much rainwater contributes to surface runoff from a rainfall event after considering rainfall, land cover types, Hydrologic Soil Groups (HSG), and prior moisture conditions. Infiltration and runoff potential of the soil in the area can be used to classify its HSG. In Table 1, the soil groups assigned to the various soil textures are listed.

Drainage density

RWH structures are useful only for harvesting runoff at the proper depth if wads are harvested accordingly. There is a high potential for runoff depth in areas with high drainage densities since it is supplied by a number of streams. Adham et al. (2018) extracted drainage density from the DEM, and then they performed a standardized reclassification according to Table 2. Several studies have concluded that RWH is best suited to locations with high drainage densities Wondimu and Jote (2020).

Distance from settlement and road

It is possible to move trucks around using access roads to make life more convenient for people (Khudhair et al. 2020). Thus, having an access road was one of the criteria used to identify a suitable site for RWH. As there is ponding of water at RWH, the environment is conducive to mosquito growth. As a consequence, the chosen site is located away from the metropolitan area. This is in order to ensure the health of the population and reduce the possibility of backwater submersion costs. Due to this, the selection of RWH sites has been constrained by road and settlement factors. A map of town and road proximity was made by using a raster calculator from a specific analyst and Euclidian distance.

In ArcGIS, a raster calculator was used to classify the area into two categories by assigning a code of "0" as restricted and "1" as acceptable for rainwater collection (Ejegu and Yegizaw 2020). To eliminate constraint layers from the potential RWH site, we multiplied the constraint layer map with the RWH map.

GIS analysis and potential RWH site identification

GIS-based multi-criteria evaluation (MCE) was carried out to identify potential RWH sites by integrating different thematic layers. Several studies have shown that Remote

Table 4 IMSD guidelines to select potential locations for RWH structures. Source: (Adham et al. 2016; Saha et al. 2018)

Selected criteria/ structure	Slop (%)	LU/LC	Soil texture	Stream order
Farm pond	< 5	Agricultural land	Fine-textured soil	1st and 2nd
Cheek dam	< 15	Barren and shrub land	Fine-textured soil	3rd and 4th

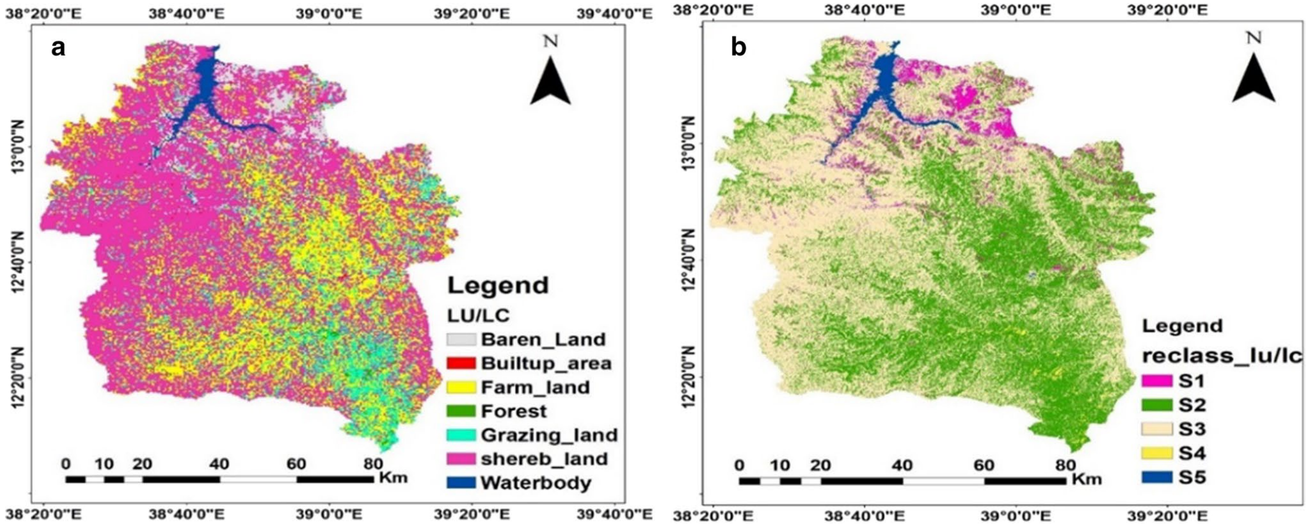

Fig. 3 Land use/cover dataset, **a** represent classified LU/LC, **b** represent reclassified LU/LC for RWH suitability. S1, highly suitable; S2, moderately suitable; S3, marginally suitable; S4, less suitable and S5, not suitable

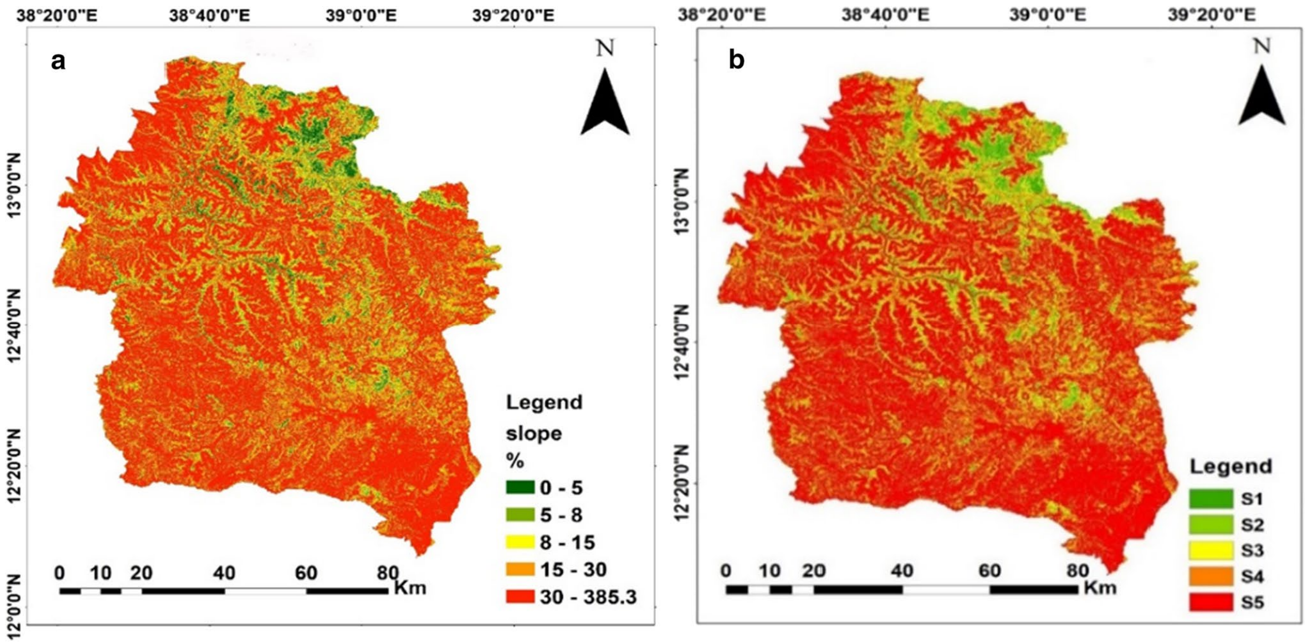

Fig. 4 Classified slope map **a** and reclassified slope map for RWH suitability **b**. S1, highly suitable; S2, moderately suitable; S3, marginally suitable; S4, less suitable and S5, not suitable

Table 5 Slope suitability area percent coverage

Suitability classes	S1	S2	S3	S4	S5
Area (%)	4.2	5	12.3	25.1	53.4

Sensing Data and GIS tools are very useful for identifying potential sites for Water Harvesting (Bakir and Xingnan 2008). Field surveys by experienced people are the best method of selecting the RWH site in relatively small areas. For larger areas, GIS and RS could be the most relevant means to select RWH sites (Ziadat et al. 2012). GIS-MCE methodology combines multiple factors in a flexible manner and applies a weight to each factor. The weight influence of each of the criteria for RWH site suitability was used to determine the significance of each criterion. We assigned weights based on a pairwise comparison called the Analytical Hierarchy Process (AHP), developed by Saaty (1977). Hameed (2013) and Ketsela (2009) used the AHP method to weigh the criteria used to determine the most appropriate regions for rainwater harvesting. A pairwise comparison matrix compares each factor to all the other factors in pairs in order to determine which factor is most essential. As stated by Saaty (1980), a scale from 1 to 9 is suggested, with 1 indicating that all criteria are equally relevant and 9 indicating that the criterion under consideration is extremely relevant in comparison to all other criteria (Table 3).

The rating of criteria 1 to 9 was assigned based on consultation of professional experts and suggestions from people with knowledge on the study area and current state of existing RWH in order of select and label the priority of criteria. Hereafter, evaluate the relative importance of one over all the selected factors. Furthermore, literature review of related works was made the purpose of comparing the result from AHP (Ejegu and Yegizaw 2020). After assigning the weight, the consistency of the matrix was evaluated with the consistency ratio (CR).

$$CR = \frac{CI}{RI} \tag{4}$$

$$CI = \frac{\lambda\max - n}{n - 1} \tag{5}$$

where CI is the consistency index, RI is the random index, is the maximum eigenvalue, and n is the number of factors in the matrix.

Once the weight of the criteria was determined, the potential RWH site was obtained by overlying all the weighted criteria in the ArcGIS environment.

Site identification for RWH structures

In addition to the overall suitability of RWH site selection, additional studies were conducted to find sites for artificial RWH storage structures. In the study region, acute water scarcity is a significant problem that requires fast action to alleviate. As a result, a check dam and a farm pond were

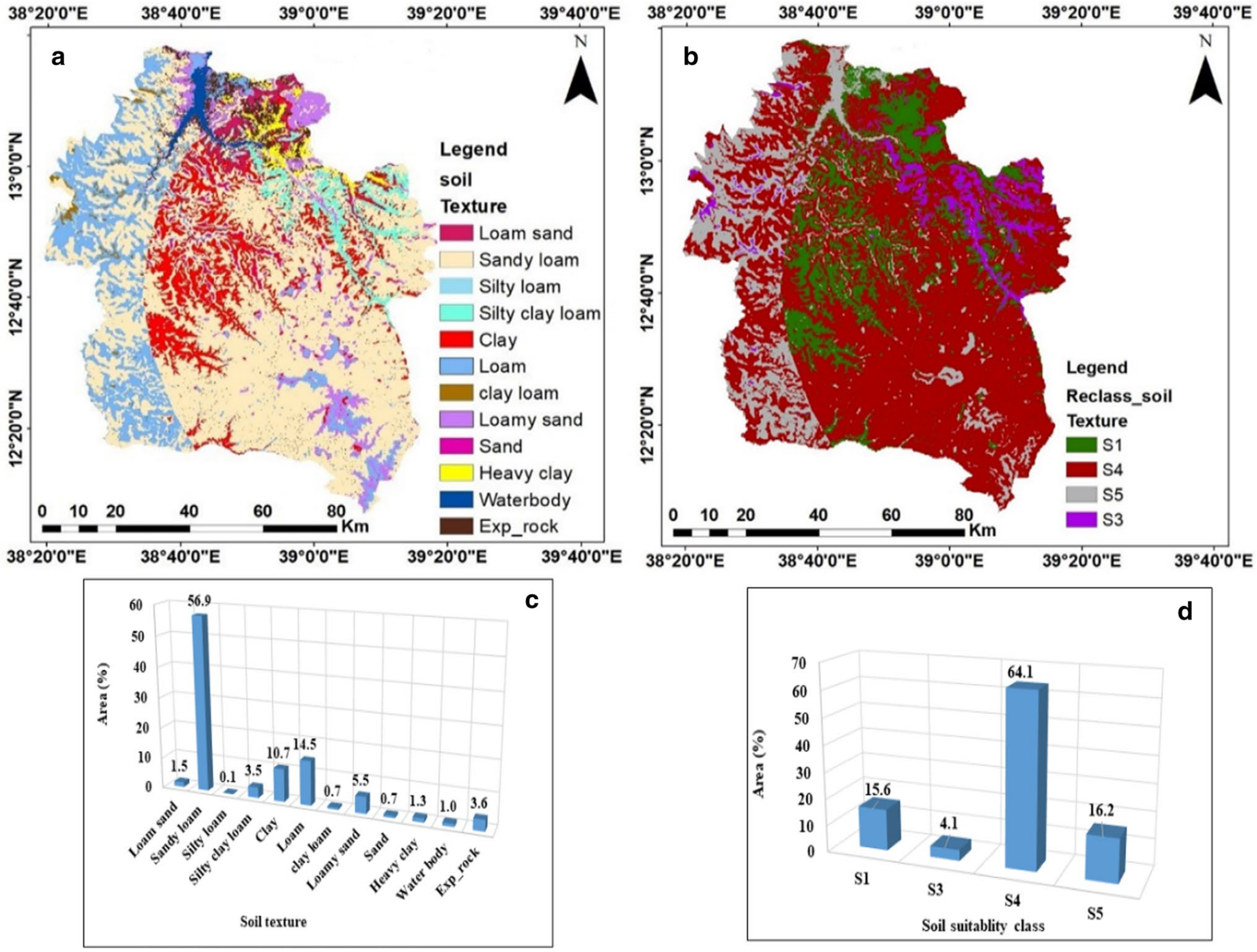

Fig. 5 Soil texture map **a** soil texture area coverage **b** soil texture suitability map **c** and area coverage of soil texture suitability for RWH **d**. S1, highly suitable; S2, moderately suitable; S3, marginally suitable; S4, less suitable and S5, not suitable

chosen for the study. The check dam is a common form of water harvesting structure that is used more for livestock watering and supplemental irrigation. It is also used for augmentation of ground water and the control of soil erosion or sedimentation. In addition to ponds, full or supplemental irrigation was recommended for agricultural lands. According to IMSD (1995) and Fraenkel (1986) guidelines, a suitable location has been selected for the check dam and farm pond (Saha et al. 2018). The selected criteria for this study were integrated into ArcGIS, and the probable placement of RWH structures was determined (Table 4).

Results and discussion

Land use/land cover

The LU/LC of the study area was classified as: bare-land, built-up areas, farmlands, grazing lands, forests, shrub lands, and water bodies. Overall accuracy and kappa coefficient of classified LU/LC maps were 80.1% and 76.2%, respectively. According to Bharatkar and Patel (2013), LU/LC image classification was accurate enough to warrant further investigation when the kappa coefficient was > 75%. As shown in Fig. 3a, shrub land accounted for 57% of the study area, followed by farmland (24.1%), grazing-land (11.9%), bare land (4.9%), water bodies (1.4%), forest (0.6%), and built-up areas (0.1%). In terms of suitability of land use/cover for RWH, the analysis shows that about 4.9% of the land was classified as highly suitable since the area was covered with barren land and facilitates extraction by eliminating the need for initial abstraction, infiltration through vegetation, and site clearance or land improvements (Toosi et al. 2020). In the study area, 36.6% were moderately suitable, 56.4% were marginally acceptable, 0.6% were less suitable, and only 1.5% were not suitable for RWH because of the presence of water and urbanization, which made them unsuitable,

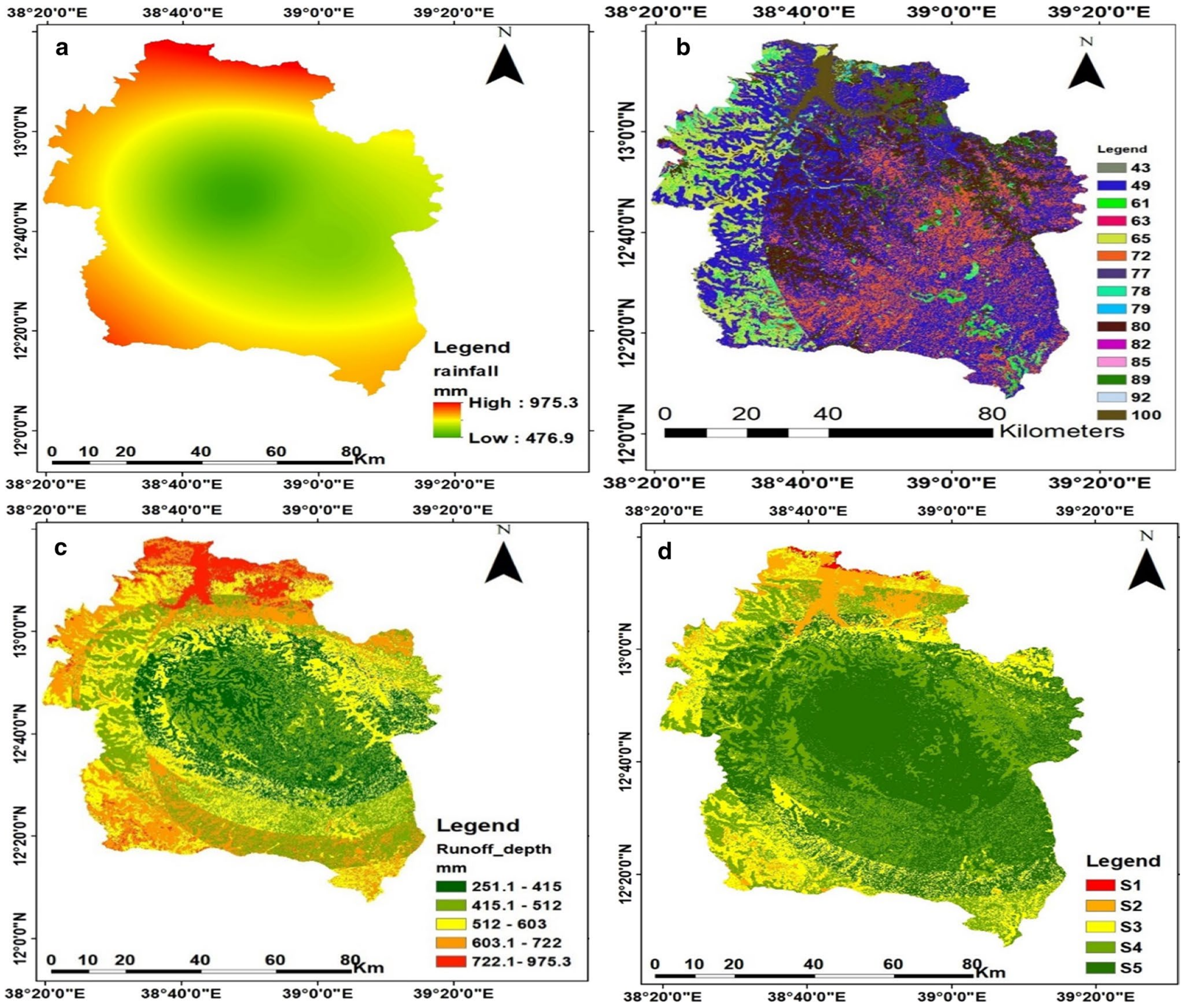

Fig. 6 Rainfall map **a**, CN map **b**, runoff depth layer map **c**, and suitability of runoff depth for RWH **d**. S1, highly suitable; S2, moderately suitable; S3, marginally suitable; S4, less suitable and S5, not suitable

uneconomical, and difficult to use as an RWH site (Ahmad 2016, Ejegu and Yegizaw 2020).

Table 6 Curve number (CN) value. Source: (Ejegu and Yegizaw 2020)

Land use type	Hydrologic soil group			
	A	B	C	D
Urban	61	85	90	92
Water bodies	100	100	100	100
Shrub Land	49	65	75	80
Agricultural	72	78	85	89
Grass Land	49	61	74	80
Forest	43	63	75	82
Bare Land	77	79	86	89

Slope

Using the slope analysis, a maximum of 53.4% of the area was leveled using RWH classes with a slope of > 30% (Fig. 4a, b and Table 5), which means that the natural topography of the area requires large earthworks that are uneconomical. In this study area, approximately 4.2% of the area is classified as highly appropriate because the slope of the region is 0–5%. As a result, Mugo and Odera (2019) study revealed that the topography of the area is nearly level, allowing rainwater harvesting with minimal earthwork.

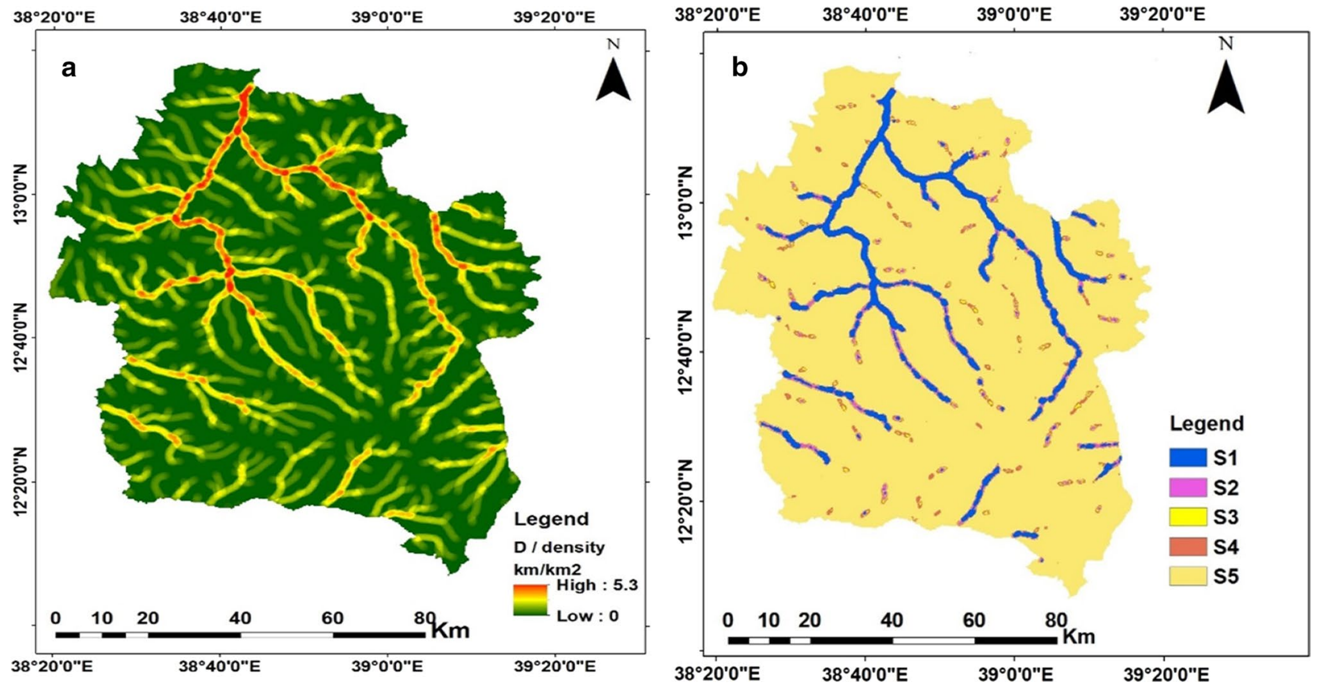

Fig.7 Drainage density map **a** and suitable map of drainage density for RWH **b**. S1, highly suitable; S2, moderately suitable; S3, marginally suitable; S4, less suitable and S5, not suitable

Table 7 AHP criteria pairwise comparison

Criteria	Runoff	Slope	Stream order	Soil texture	LULC	Weight
Runoff	0.44	0.49	0.44	0.38	0.33	0.42
Slope	0.22	0.24	0.29	0.29	0.27	0.26
Soil texture	0.14	0.12	0.15	0.19	0.20	0.16
Drainage density	0.11	0.08	0.07	0.10	0.13	0.10
LU/LC	0.09	0.06	0.05	0.05	0.07	0.06
Total						1

Soil texture

Figure 5b shows a classification of the research area's retrieved soil map into five suitable classes, which are based on the twelve textural features (Fig. 5a). The sandy loam soil texture covered more than 50% of the research area, while the silty loam covered no more than 0.1% (Fig. 5c). When the soil map was reclassified for RWH suitability, no moderately suitable soils were found in the region because silty soil was not included. A total of 64% of the study area was considered unsuitable for RWH. This was because it was covered in sandy loam and sandy clay loam, which did not retain water long enough to be beneficial and lost to infiltration. In contrast, 15.6% of the research area was classified as very favorable for RWH due to high-water-holding capacity soils (Fig. 5d).

Runoff depth

According to the meteorological data, the areas near Woldia, Lalibela, and Ebenat receive higher rainfall than the middle part of the study area, which is shown by the IDW interpolation method (Fig. 6a). Using soil information, an HSG ranges from low runoff potential (Group A) to high runoff potential (Group D), and the curve number values range from 43 to 100 in the study area (Fig. 6b and Table 6). The higher the curve number, the higher the percentage of rainfall that is carried on surface runoff. With a low curve number, water can easily permeate into the soil and minimal runoff occurs.

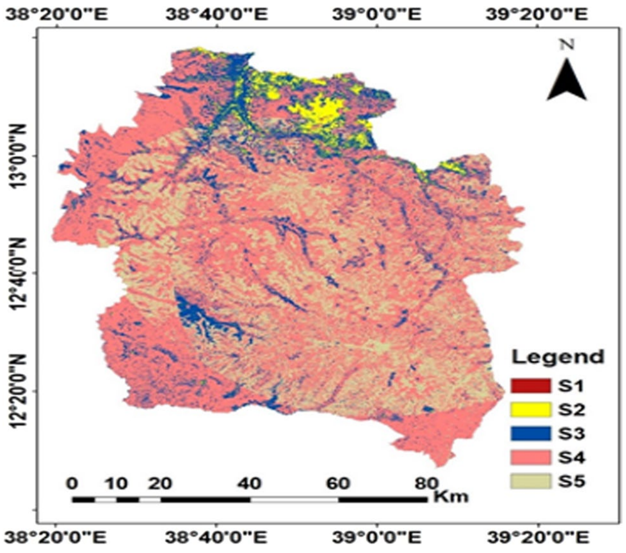

Fig. 8 Potential RWH map without constraint**.** S1, highly suitable; S2, moderately suitable; S3, marginally suitable; S4, less suitable and S5, not suitable

In the middle of the study area, the runoff depth was 251 mm. This indicates a site with high vegetation cover, low water retention soils, and hilly topography. There was scant vegetation cover in the research area's lower rich, low infiltration capacity soils and generally flat topography, as indicated by the maximum runoff depth of 975.3 mm (Fig. 6a). According to the literature and analysis results, the acceptability of runoff depth was divided into a range of highly suitable to not suitable categories (Fig. 6d). Thus, the study area was deemed unsuitable for RWH in at least 44.9% of the cases. This indicates the site has a low runoff depth of less than 500 mm. In addition, there is an initial loss of water due to dense vegetation cover, low water-holding capacity soils, and slopes greater than 30%. Among the regions, 30.3% were deemed less suitable, 17.8% marginally suitable, and 6.7% fairly suitable. There was only 0.3% deemed a highly suitable unit, indicating a runoff depth of > 900 mm and bare-land soils with a slope of less than 5% (Mugo and Odera 2019).

Drainage density and stream

In the area, drainage density ranged from 0 to 5 km km–2. Accordingly, a scale measuring the RWH's suitability was developed (Fig. 7b and Table 2). An area with a red hue in Fig. 7a indicates a high drainage density and is evaluated as having higher suitability for RWH as it has a greater depth of runoff from the upper watershed. Due to the low density of the areas with deep green color, it is not an ideal site for RWH processing due to low runoff depth Wondimu and Jote (2020).

Identification of potential RWH site

The highest weight given to runoff depth was 42% in this study (Fig. 8 and Table 7). Therefore, it may have a stronger effect on the selection of acceptable RWH sites, as LU/LC thematic layers were given a minimum weight of 6% (Table 7). According to the comparison matrix, consistency is at 2%, which is less than 10%. Therefore, the comparison between the theme layers was satisfactory (Bascetin 2007).

Several types of RWH sites were assessed in the study area according to their suitability for RWH. Thus, only 0.02% of the area is highly suitable for RWH. It means that 0.02% of the land has considerable runoff depth potential, reasonably flat topography, clay soils with high water retention characteristics, and other characteristics. Thus, RWH intervention does not require any physical changes or technological advancements. There were 2.7% and 13.4% of marginally acceptable and marginally suitable class units in the research region, respectively. The application of RWH technologies and related activities will require improvement in terms of physical and technological factors such as water availability, slope, LU/LC type, soil texture, and others. However, the majority of the area studied, 61.8%, and 22%, respectively, was rated as less acceptable and not suitable by the RWH (Ammar 2017). In a weighted overly analysis, all factors and groups of factors were integrated and potential rainwater collection sites were discovered (Table 7). RWH requires considerable flat topography to harvest runoff and reduce earthwork costs (Adham et al. 2016; Ibrahim et al. 2019). The study area is dominated by mountainous and rugged topography (Fig. 4a), making finding flat areas challenging. Based on this, the maximum weight assignment for runoff depth and slope agreed with (Ejegu and Yegizaw 2020; Haile and Suryabhagavan 2019; Hameed 2013; Wondimu and Jote 2020).

Constraint layer map

In the constraint layer map, the black color-coded "0" represents the restricted area, while the yellow color-coded "1" represents the non-restricted area (Fig. 9a and b). It was found that the restricted area covered around 2.9% of the total of 9004 km^2, and it was deducted from the total RWH classes (Ejegu and Yegizaw 2020; Haile and Suryabhagavan (2019); Wondimu and Jote 2020).

Suitable location of RWH farm pond and check dam

Farm ponds and check dams were located optimally based on the combination of identified criteria (Table 4). In order to reduce the severity of recurrent drought impacts, 47 RWH farm ponds and 12 RWH check dams were proposed in the study area (Fig. 10a, b). This study agrees with Ali (2018)

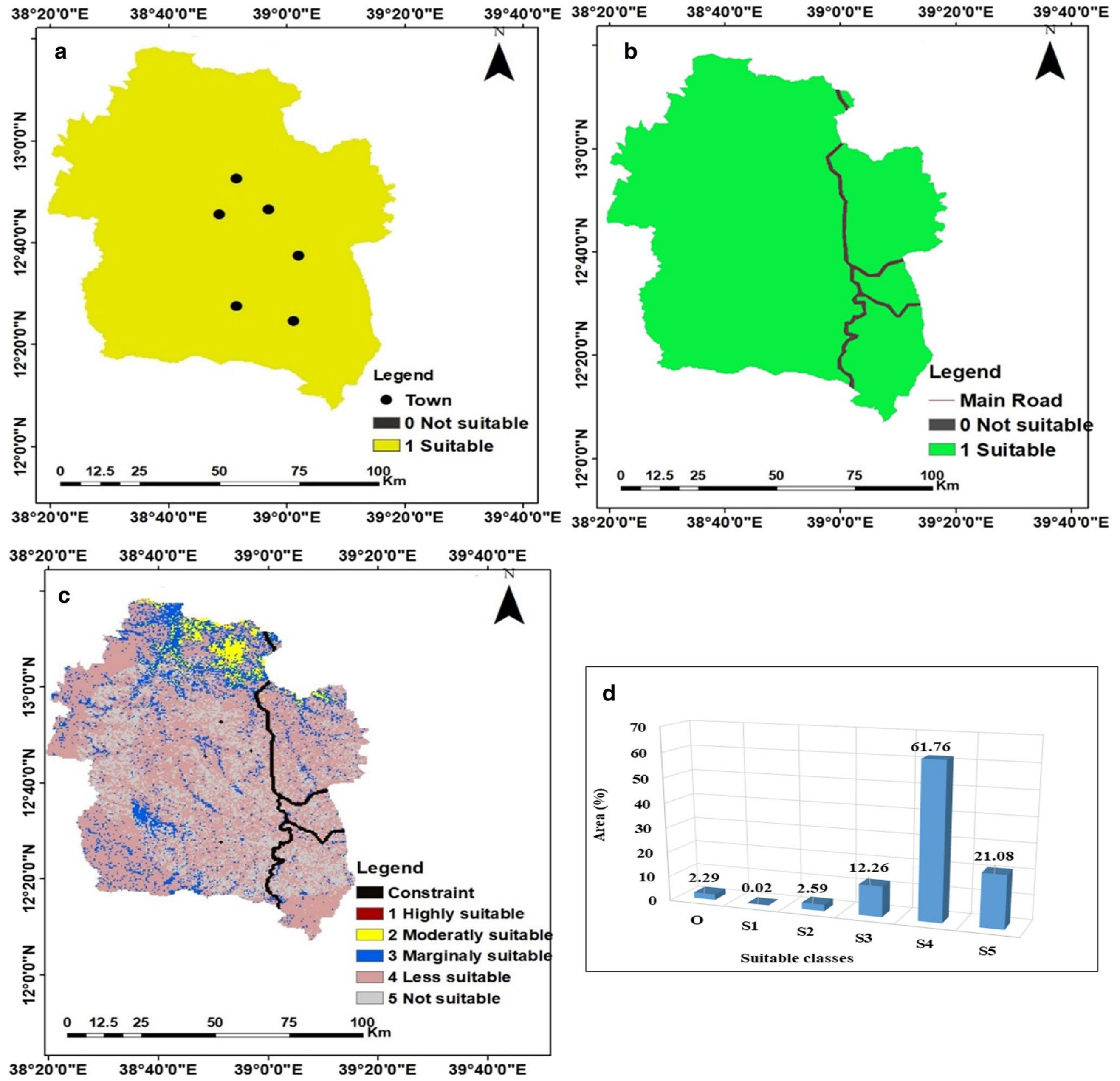

Fig. 9 Town layer map **a**, road layer map **b**, potential RWH map after the removal of constraint **c**, and RWH area coverage after constraint **d**

and Gavit et al. (2018), which found that areas of high soil water retention capacity and gentle to moderate slopes were suitable for the construction of rainwater harvesting systems. According to Ejegu and Yegizaw (2020), areas with gentle to moderate slopes and high water-holding capacities are ideal for RWH structures.

Validation of potential RWH sites

In order to assess the suitability of rainwater harvesting sites, the coordinates of existing functional and non-functional RWH structures in the research area were collected (Table 8). The point data for existing RWH structures were exported and overlaid on the suitability map of RWH (Fig. 11). Among the five remaining functional farm ponds, three were constructed with S3, one with S4, and one lay within the restricted area of RWH. Previously, all failed farm ponds were fitted with S4. Based on the overlay results of existing check dams, three were fitted with S3, one with S4 and the remaining was in the restricted area of RWH.

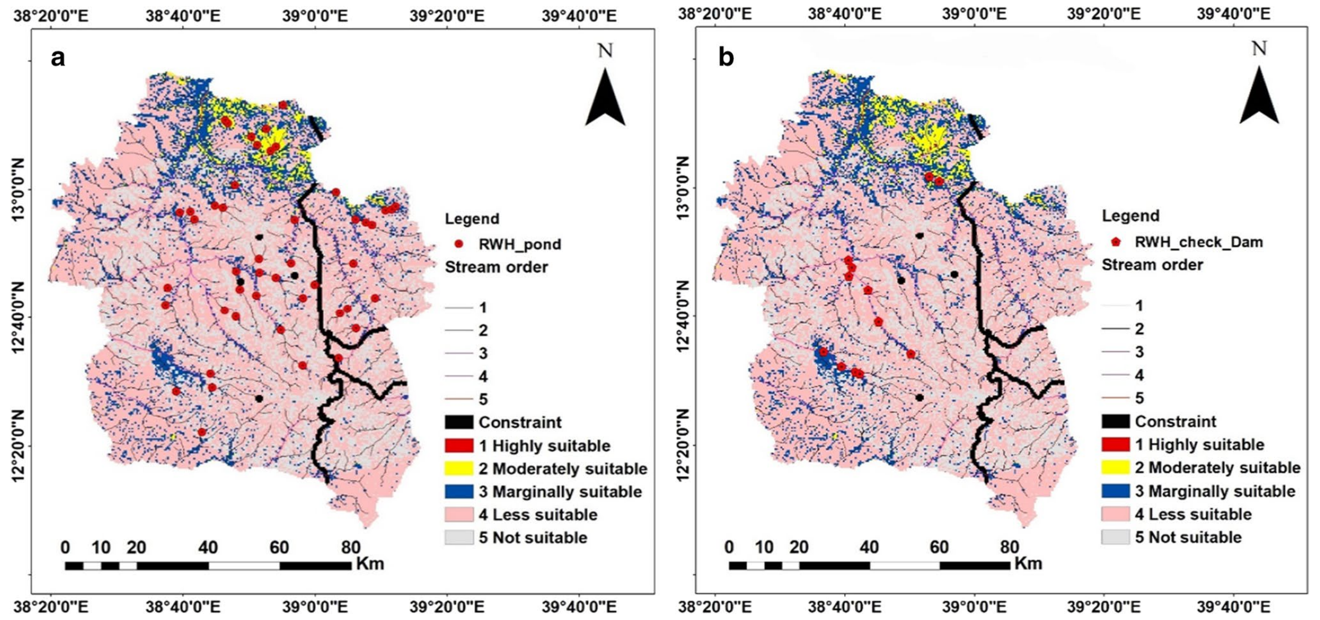

Fig. 10 Location of the farm pond **a** and location of the check dam **b**

Table 8 Ground truth data for validation of RWH site. Source: Sekota dry land agricultural research institute

S.No	Kebele	X	Y	Structure type	Remark
1	Ruvariya	503,573.7	1,413,820.0	Pond	Functional
2	Tiya	507,205.5	1,387,281.7	Pond	Functional
3	Tiya	506,967.2	1,386,927.2	Pond	Functional
4	Ruvariya	501,574.0	1,411,304.0	pond	Functional
5	G/mariyam	504,098.0	1,396,735.0	Pond	Functional
6	Tiya	509,135.0	1,384,602.0	Pond	Failed
7	Ruvariya	502,353.0	1,414,229.0	Pond	Failed
8	Dura	443,891.3	1,371,462.6	Check dam	Functional
9	Akegne	444,698.0	1,428,804.0	Check dam	Functional
10	Hawar-eyaw	501,227.0	1,374,591.0	Check dam	Functional
11	Wuker	488,365.0	1,392,569.0	Check dam	Functional
12	Ruvereya	503,639.2	1,415,414.6	Check dam	Functional

Conclusion

Water is the most remarkable natural resource, essential to maintaining a functioning ecosystem supporting all forms of life. Due to severe water shortages around the world, it is imperative that rainwater harvesting methods are explored that include sound methods for alleviating droughts. The purpose of this project is to identify locations where rainwater harvesting structures can be constructed for effective and efficient rainwater harvesting management in drought-prone areas of Wag Himra. A weighed overlay analysis was applied to identify a possible appropriate RWH location by allocating weight to each factor. AHP was applied to assign weight to each criterion. Rainwater harvesting areas were classified into four categories: highly suitable, moderately suitable, marginally suitable, and not suitable. Using GIS-based MCEs, RWH locations based on five criteria were identified: land use/land cover, slope, soil, runoff depth, and drainage density, together with road constraints. The observed runoff depth using the SCS-CN method ranged from 251.1 to 975.3 mm, with the appropriateness of the RWH unit varying from highly appropriate to not suitable. A weighted overlay analysis of the RWH map determined that 0.02, 2.59, 12.26, 61.76, and 21.1% of the study area were classified as highly suitable, moderately suitable, marginally suitable, less suitable, and not suitable for RWH, while 2.29% was classified as a restricted area for proposing RWH structures. The potential locations for RWHs using check dams and farm ponds are about 12 and 47 sites, respectively. This study is intended to assist decision-makers, water resource planners, and managers in rapidly finding appropriate sites, making water resource investments, and informing RWH as an alternative water supply.

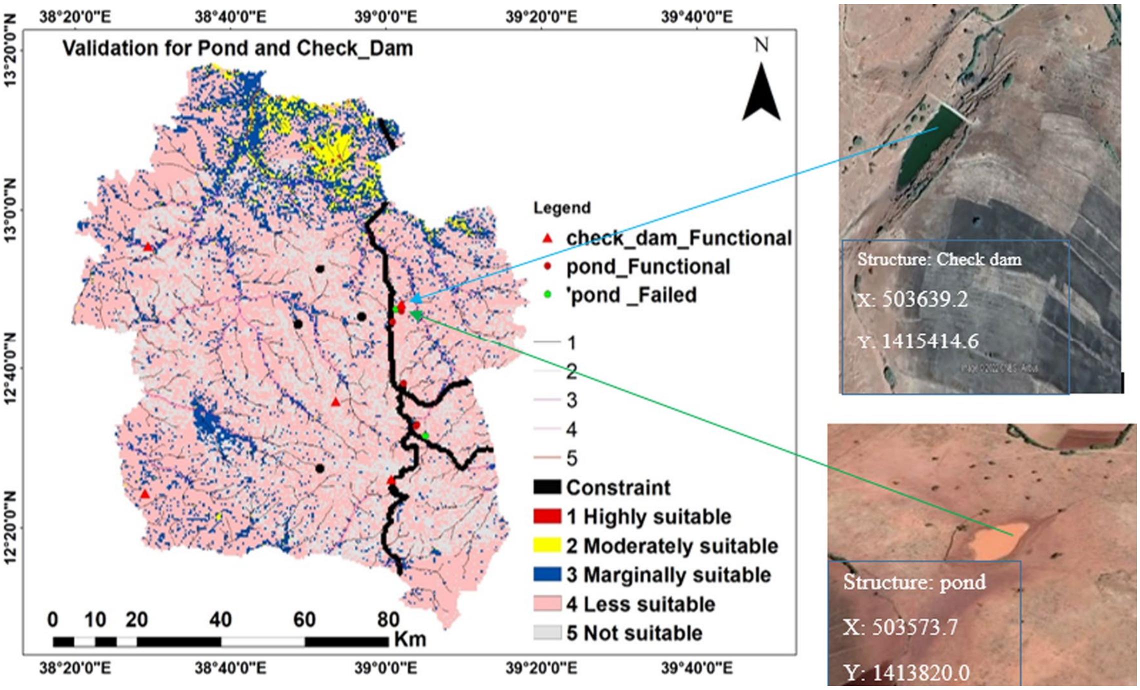

Fig. 11 Validation map of potential RWH site

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Declarations

Conflict of interest The authors declare no competing interests.

Ethical approval Not applicable.

Consent to participate All authors give their consent to participate.

Consent to publish All authors give their consent to be published.

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