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ORIGINAL ARTICLE

GIS-based approach for identification of potential rainwater harvesting sites in Arsi Zone, Central Ethiopia

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Abstract
Water plays a crucial role in fulfilling basic human needs, for socio-economic developments and for ecosystem services. Ethiopia is experiencing pressure on water shortage for agricultural and domestic uses. Arsi Zone frequently faces drought and crop failure due to lack of water sources. Eleven physical characteristics of the study area layers were adopted integrating multi criteria decision analysis, which uses analytical hierarchy processes with a fuzzy logic approach and geographical information system. Soil conservation service model was used to estimate the runoff depth layer of the study area. Weighting was made based on environmental, socio-economical and hydro-geological characteristics of the study area, and available literature. Results show that potential suitability class was not suitable with constraints 5769.8 km^2 (27.88%), less suitable 3104.34 km^2 (15%), suitable 5695.42 km^2 (27.52%), very suitable 4097 km^2 (19.8%) and extremely suitable 2027.38 km^2 (9.8%). The area coverage of constraints were 4540.37 km^2 (21.94%) of the study area. Outcome of this study emphasized the importance of geospatial modeling in assessing rainwater harvesting potential sites, proposed to assist in planning water facility and to address water scarcity problem in the study area. The model developed in this research can be used in other areas to determine the potential of rainwater harvesting and integrate rainwater as an alternative water source to ensure availability for domestic, agricultural and industrial uses. It is recommended that detailed ground validation and socio-economic factors should be analyzed to increase its effectiveness before implementation.

Keywords Analytic hierarchy process · Fuzzy logic · Geographical information system · Remote sensing · Rainwater

Introduction

Water is one of the vital resources required for every living organism, and for sustainability of ecosystems. However, there is considerable water shortage all over the world (Gowing et al. 1999; Ramakrishnan et al. 2009; Conway and Schipper 2011; Tarun Kumar and; Jhariya 2017). In the developing world, many rural communities are located in water scarce areas, where there is uneven distribution of hydrological resources and economic and/or political barriers to lay pipe and distribute water from the ground surface (UN 2014; Mosello et al. 2015). The problem of accessing availability of fresh water is more costly and difficult, even in developed countries (Prinz 1996; Rosegrant et al. 2002; Tarun Kumar and Jhariya 2017). Climate change and developing water resource interest for agricultural and urban development are increasing the making on water resources and variability of the hydrological regime. It is expected that by the year 2020 between 75 and 250 million people will be exposed to highly increased water stress in Africa. In some regions of the continent, 50% of the agricultural productivity is expected to be severely compromised as a result of food shortage (Ammar et al. 2016).

There are several benefits of rainwater harvesting, such as to control excessive runoff, flood in the downstream catchment, and to improve soil moisture and for soil conservation (Madan et al. 2014; Ammar et al. 2016; Li et al. 2018). Rain Water Harvesting (RWH) has been practiced in many areas as a practical solution for reducing water shortage, and to maximize water quality. In addition, it is a measure to address climate change effects on precipitation variability (Barron 2009; Ndiritu et al. 2011). To overcome the problem of water shortage, it is believed that rainwater harvesting is one of the best options. The term 'rainwater harvesting' is generally used to describe

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collection, storage, distribution and use of rainwater for household or agricultural purposes (Mutekwa and Kusangaya 2006; Barron 2009; Singh et al. 2009; Fitsum et al. 2014; Hafizi et al. 2018; Tamaddun et al. 2018). It refers to the collection and storage of natural precipitation and also other activities aimed at harvesting surface and groundwater, prevention of losses through evaporation and seepage and all other hydrological and engineering interventions (Rockstrom 2000; Sutherland and Fenn 2000; Rockström et al. 2009; IFAD 2013).

Geographical information system (GIS) and Remote Sensing (RS) are playing significant role in hydrological modeling in view of its capacity to handle enormous amount of spatial data (Cheng et al. 2005; De Winnaar et al. 2007; Mahmoud and Alazba 2015; Tarun Kumar and; Jhariya 2017). Some of its features, such as map overlay and analysis help to derive and aggregate hydrologic parameters from different sources like soil, land-cover and rainfall data. In recent years, integrated studies of RS, GIS and run-off modeling have advanced in targeting suitable sites for water recharging/harvesting structures (Ramakrishnan et al. 2009; Tiwari et al. 2018). Remote sensing data have been useful in the determination of land-cover thematic mapping, providing valuable information for delineating the extent of land-cover classes, as well as analyzing hydrological data at various scales. Several studies in 1990s (Padmavathy et al. 1993; Van Dijk and Reij 1994; Prinz 1996; Gupta et al. 1997; Prinz et al. 1998; Getachew 1999) focused on biophysical criteria such as slope, soil type, drainage network and land-use. Most of the recent studies have tried to integrate socio-economic parameters with the biophysical components as the main criteria for selecting suitable sites for RWH (Prinz and Singh 2000; Efe 2006; Mbilinyi et al. 2007; Ramakrishnan et al. 2009; Margulis et al. 2010; Maina and Raude 2016; Omar et al. 2017; Shaheed et al. 2017). Common technical steps Weighted Linear Combination follows are preparing layers, standardizing suitability layers, assigning weights of relative importance to the suitability layers, combining weights and standardizing suitability layers and obtaining the overall suitability score for the delineation of artificial recharge zones and for the identification of suitable sites for artificial recharge (Tabor and Hutchinson 1994; Baban and Wan-Yusof 2003; Malczewski 2004; Ayalew and Yamagishi 2005).

Arsi Zone of Central Ethiopia has promising, sensitive and complex geological systems. Geospatial data handling and analysis techniques bring out significant attention for locating potential RWH sites selection. This study was aimed to develop spatial GIS modeling using Fuzzy modeling approach and Analytical Hierarchical Process (AHP) for potential sites selection for RWH in the Arsi Zone, Central Ethiopia.

Materials and methods

The study area

Arsi Zone is one of the Zones of the Oromia Regional State of Ethiopia bordered by the Adama Special Zone on the north, East Shewa Zone on the northwest, Bale Zone on the south, West Arsi Zone on the southwest and West Hararghe on the east. The administrative center of the Zone is Asella town located 175 km southeast of Addis Ababa, the capital of Ethiopia. Abomsa, Assasa, Bokoji, Sagure, Kersa, Dhera, Etaya, Arsi Robe and Huruta are other major towns in this Zone. Arsi Zone is bounded by latitude 7°10′34″–8°42′46″N and longitude 38°41′14″–40°43′58″E, covering a total area of 20,694.41 km^2 (Fig. 1). Altitudes of Arsi Zone range from 881 to 4287 m asl. According to the Central Statistics Agency (CSA 2008) national census report, there were 2,637,657 people in this Zone, of whom 1,323,424 were men and 1,314,233 were women with the population density of 127.45 km^2. The average minimum and maximum temperature of Arsi Zone is 10 °C and 24 °C, respectively. The rainfall of the Zone is characterized by a bimodal pattern. The annual average rainfall in the Arsi Zone is 1000 mm. The main rainy season, which accounts for approximately 60% of the annual precipitation is between June–September, while the short rainy season is during March–May. Land-use types of the study area are classified into eight major classes such as bareland, forest, farmland, grassland, settlement, shrubland, water body and wetland with farm land and shrubland types have higher proportions.

Methodology

Data collection and softwares used

Primary data such as cloud free Landsat 8 image (spatial resolution of 30 m) and Shuttle Radar Topography Mission (SRTM), and Digital Elevation Model (DEM, 30 × 30 m and DEM, 1 × 1 km) were acquired from the United States Geological Survey Global Visualization Viewer Website (https://earthexplorer.usgs.gov). Secondary data used were from published and unpublished documents from different organizations. Interpolated rainfall satellite data were collected from National Meteorological Agency (NMA), which include mean annual precipitation and temperature for all 15 metrological stations in the study area for 25 years (1990 – 2015). Demographic characteristics, geological topographic and other data were gathered from

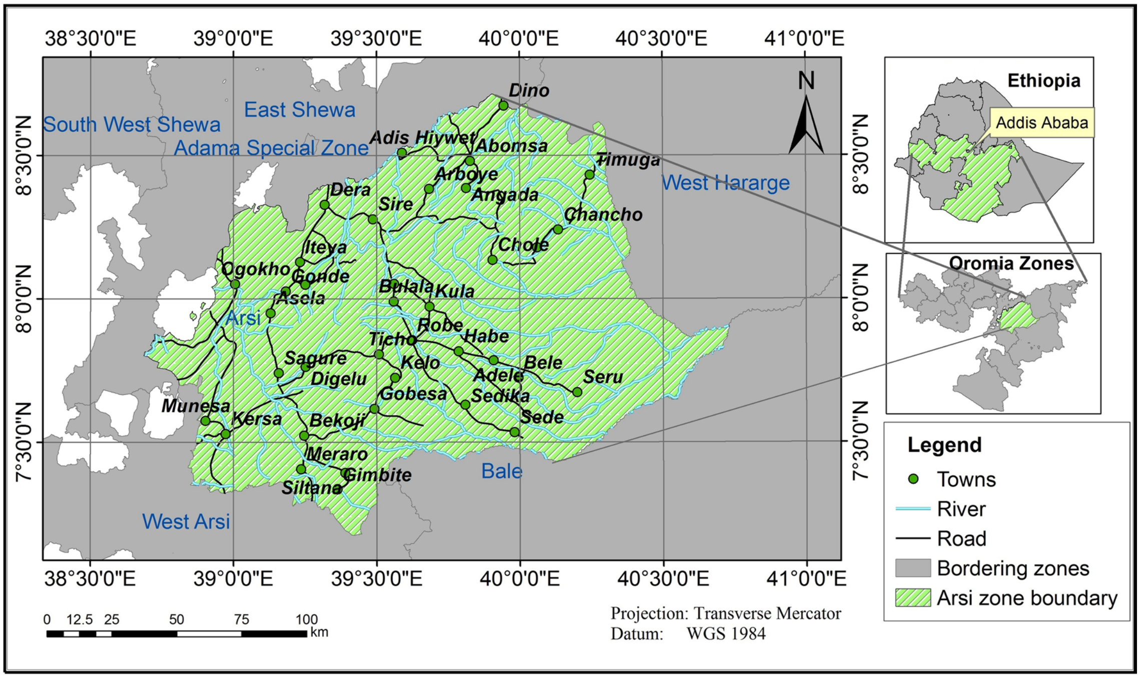

Fig. 1 Location map of the study area

CSA and Geological Survey of Ethiopia. Resampled soil property data were acquired from world soil information center Harmonized soil database geoportal (http://www.isric.org).

Softwares used were ERDAS Imagine 2014 for satellite image pre-processing and post-processing including layer stacking and mosaic for LU/LC classification. ArcGIS 10.3 was used for storing and managing geographic data in geodatabase package, compile and edit GIS datasets and display and analyze spatial data in both vector and raster format. Geomatica 2015 was used for geological lineament extraction of satellite image for lineament proximity layer preparation. IDRISI Silva was used for decision support and uncertainty management of weighting criteria, fuzzy standardization, and an extensive set of criteria aggregation based on weighted linear combination.

Selection of thematic layers

Basic thematic layers such as land-use and land-cover, rainfall, slope, soil digital elevation model, slope and drainage density were prepared. Different land-use and land-cover classes were applied through supervised classification, with a combination of three consecutive bands as False Color Composite (FCC) of Band 3, Band 4 and Band 5. Different land-use/land-cover classes such as bareland, farmland, forest, grassland, shrubland, wetland and settlement have different impacts on the conversion of rainfall to runoff. Appropriate layers were prepared using Landsat 8 OLI Satellite data, Digital elevation model and other thematic and collateral data. Depending on the layers prepared in stage one, digitization, data editing, field verification, data validation, data integration, attribute table design and entry were done. Consecutive procedures undertaken to finalize the model were standardizing criteria, reclassifying input layers, fuzzification, comparison, aggregation, considering constraints, running the model and identifying the potential RWH sites (Fig. 2). Flow direction, flow accumulation, stream order and lithology were also prepared and used for the selection of suitable sites for farm ponds, percolation tanks and check dams.

Computation of runoff by Fuzzy Logic model

The decision hierarchy model of RWH site was structured as shown in Fig. 3. The hierarchy consists of the main objective at the top (RWH), followed by three levels. The 11 criteria (also known as factors) used were divided into three main groups; environmental, hydrological and socio-economic factors, to form the second hierarchy. These were further split into eight factors, of which four were environmental (topography, geology, soil texture and land-use/land-cover), two were hydrological (runoff depth and drainage density) and two were socio-economical (distance from roads and distance from settlements) to form the third hierarchy. The final hierarchy was formed by dividing the topography and geology factors. Topography was divided into slope and elevation sub-factors and

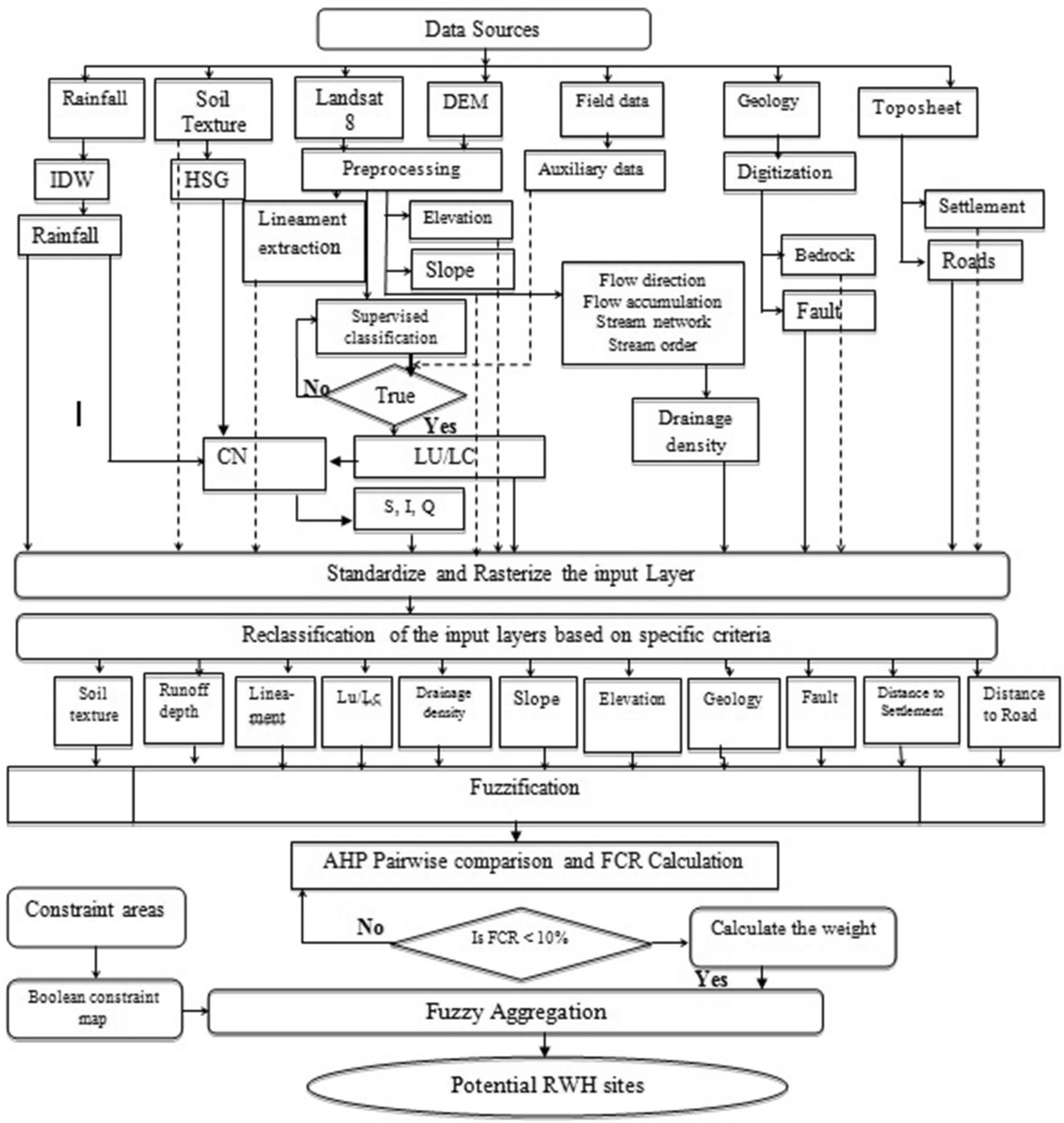

Fig. 2 Flow chart of the methodology for the delineation of rainwater harvesting potential zones

geology was divided into lithology, faults and lineaments proximity sub-factors. The layer in the higher hierarchical level was considered as a major influential layer because major influential layer has an effect directly or indirectly to the lower one (Baban and Wan-Yusof 2003). In addition, in a complete hierarchy, every layer in the lower hierarchical level affects every element in the upper hierarchical level. Therefore, elements in the lower hierarchical level were compared to each other based on their effects on the major influential layer above.

Triangular fuzzy and AHP pair-wise comparison

Standardized layer reclassification and rating were done each determine the relative importance of the criterion layers. Each criteria layer had its own impact on the outcome, through a

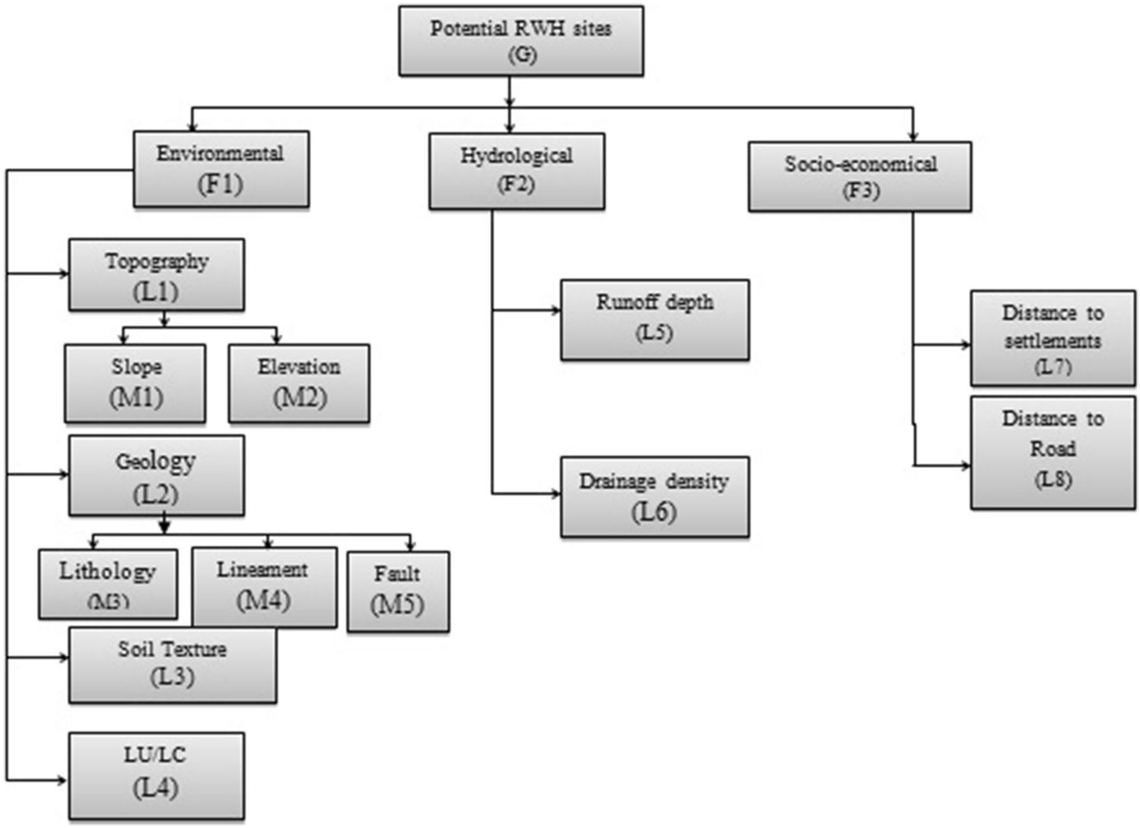

Fig. 3 The interactive influence of factors and rank

quantitative rating. Pair-wise comparison method was used for the assignment of weight for criteria layers (Drobne and Lisec 2009). This decision matrix was expressed as integer values ranging from 1 to 9 (Table 1). Fuzzy TFN approach was used to assign interval judgments that allows and minimize the decision making process ambiguity and complexity, expressed as *l, m* and *u*. Triangular fuzzy number membership functions is represented as follows:

$$\mu A(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \le xm \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x > u \end{cases}. \quad (1)$$

Table 1 Triangular Fuzzy Numbers (TFNs), linguistic variables used

Saaty's scale of relative importance	Definition	Membership function	Domain	TFNs scale (*l*,m,u)	Reciprocal-of triangular-fuzzy numbers
1	Just equal			(1.0,1.0,1.0)	(1.0,1.0,1.0)
	Equal importance	$\propto_A(x)=(3-x)/(3-1)$	$1 \le x \le 3$	(1.0,1.0,3.0)	(1.0/3.0,1.0,1.0)
3	Moderately importance	$\propto_A(x)=(x-1)/(3-1)$	$1 \le x \le 3$	(1.0,3.0,5.0)	(1.0/5.0,1.0/3.0,1.0)
		$\propto_A(x)=(5-x)/(5-3)$	$3 \le x \le 5$		
5	Essential or strong importance	$\propto_A(x)=(x-3)/(5-3)$	$3 \le x \le 5$	(3.0,5.0,7.0)	(1.0/7.0,1.0/5.0,1.0/3.0)
		$\propto_A(x)=(7-x)/(7-5)$	$5 \le x \le 7$		
7	Demonstrated importance	$\propto_A(x)=(x-5)/(7-5)$	$5 \le x \le 7$	(5.0,7.0,9.0)	(1.0/9.0,1.0/7.0,1.0/5.0)
		$\propto_A(x)=(9-x)/(9-7)$	$7 \le x \le 9$		
9	Extreme importance	$\propto_A(x)=(x-7)/(9-7)$	$7 \le x \le 9$	(7.0,9.0,9.0)	(1.0/9.0,1.0/9.0,1.0/7.0)
2,4,6,8	Intermediate	–	–	–	–

Using TFN, the fuzzy decision matrices $\tilde{A}(\tilde{a}_{ij})$ was used to construct pair-wise comparisons for criteria layers at each level of the decision hierarchy as follows:

$$\tilde{A} = (\tilde{a}_{ij})_{nXn}\begin{bmatrix} (1.0,1.0,1.0) & (l_{12},m_{12},u_{12}) & \cdots & \cdots & \cdots & (l_{1n},m_{1n},u_{1n}) \\ (l_{12},m_{12},u_{12}) & (1.0,1.0,1.0) & \cdots & \cdots & \cdots & (l_{2n},m_{2n},u_{2n}) \\ (l_{n1},m_{n1},u_{n1}) & (l_{n2},m_{n2},u_{n2}) & \cdots & \cdots & \cdots & (1.0,1.0,1.0) \end{bmatrix}, \tag{2}$$

where, $\tilde{a}_{ij} = (l_{ij},m_{ij},u_{ij}) = \tilde{a}_{ij}^{-1} = (1/u_{ji}, 1/m_{ji}, 1/l_{ji})$ *for* $i,j = 1,\ldots.n$ *and* $i \neq j$.

The number of comparisons at each decision hierarchy level was determined by the formula $n(n-1)/2$, where, n is the total number of criteria layers.

Determining weights of criteria

Fuzzy Extent Analysis (FEA) method was followed to get the weight of each criteria layer (Chang 1996), which was applied after pair-wise fuzzy comparison decision matrix was done. Consecutive methodological steps followed for criteria weight determination were:

Fuzzy synthetic extent value or normalized values of row sums calculated for each of the of fuzzy TFN decision matrices using a fuzzy arithmetic operations as formulated in Eq. 3,

$$\hat{S} = \sum_{j=1}^{n} \tilde{a}_{ij} \otimes \left[\sum_{k=1}^{n}\sum_{j=1}^{n} \tilde{a}_{ij}\right]^{-1}, \tag{3}$$

where, $\otimes$ represents the extended multiplication of two fuzzy numbers.

$\sum_{j=1}^{n} \cap ij$ fuzzy addition operation was done to the fuzzy numbers in the fuzzy decision matrices as:

$$\sum_{j=1}^{n} \cap_{ij} = \left(\sum_{j=1}^{n} l_j, \sum_{j=1}^{n} m_j, \sum_{j=1}^{n} u_j\right). \tag{4}$$

To find $\left[\sum_{k=1}^{n}\sum_{j=1}^{n} \tilde{a}_{kj}\right]$ the fuzzy addition operation was used to the column values in the matrix obtained from Eq. 4, followed by computation of the inverse of the resulting vector as:

$$\left[\sum_{k=1}^{n}\sum_{j=1}^{n} \tilde{a}_{kj}\right]^{-1} = \left(\frac{1}{\sum_{k=1}^{n} u_k}, \frac{1}{\sum_{k=1}^{n} m_k}, \frac{1}{\sum_{k=1}^{n} lk}\right). \tag{5}$$

This can be equivalently expressed as:

$$V\left(\hat{S}_i \geq \hat{S}_j\right) = \begin{cases} 1 & if \quad m_i \geq m_j \\ \frac{l_j - u_j}{(m_i - u_i) - (m_j - l_j)} & if \quad l_j \geq u_j \\ 0 & 0 \quad Otherwise, \end{cases} \tag{6}$$

where, $\hat{\mathbf{S}}_i = (l_i, m_i . u_i)$ and $\hat{\mathbf{S}}_j = (l_j, m_j . u_j)$.

In order to compare, $\hat{\mathbf{S}}_i$ and $\hat{\mathbf{S}}_j$, both the value of $V(\hat{\mathbf{S}}_i \geq \hat{\mathbf{S}}_j)$ and $V(\hat{\mathbf{S}}_j \geq \hat{\mathbf{S}}_i)$ were computed.

The basic principles in Step 2 were extended to calculate the degree of possibility of $\hat{\mathbf{S}}_i$, of one criterion, being greater than all the other (n- 1) convex fuzzy numbers, $\hat{\mathbf{S}}_j$, of other criteria, defined as:

$$V\left(\hat{S}_i \geqslant \hat{S}_j \mid j = 1, \ldots, n; j^1 i\right). \tag{7}$$

The normalized weight vectors for each fuzzy comparison matrix, $\tilde{A}$, at each level of the hierarchy were then determined by normalizing the weight vector, w, dividing each value in the weight vector (w) by their total sum as:

$$W_i = \frac{V(\hat{S}_i \geqslant \hat{S}_j \mid j = 1, \ldots, n; ji)}{\sum_{k=1}^{n} V(\hat{S}_i \geqslant \hat{S}_j \mid j = 1, \ldots, n; jk)}, \quad i = 1, \ldots n. \tag{8}$$

Analytic hierarchy process

Analytic Hierarchy Process is a decision-support model to identify optimal decision making in complex through a hierarchical structure made target, criteria and alternatives (Satty 1980). Composite weights were detected by aggregating the weights according to the hierarchy. The final result is a standardized vector of the overall weights of the system to examine the consistency of the comparison matrix (Satty 1980).

The CR was then calculated using the following formula:

$$\text{Consistency ratio } (CR) = \frac{CI}{RI}. \tag{9}$$

In which, CI is consistency index, and RI is random consistency index of a comparison matrix. If CR is greater than 0.1, then the set of judgment is consistent; if CR equals 0, then the judgment is wholly consistent. In Eq. (9), CI is computed as:

$$CI = \frac{\lambda \max - n}{n - 1}. \tag{10}$$

In which, λ_{max} is the largest eigenvalue of the composition matrix and n is the number of criteria or factors.

Results

Results of the present study area have revealed that the central and southern parts of the study area are suitable potential areas for rainwater harvesting. Those proposed rainwater harvesting sites are generated from extremely and

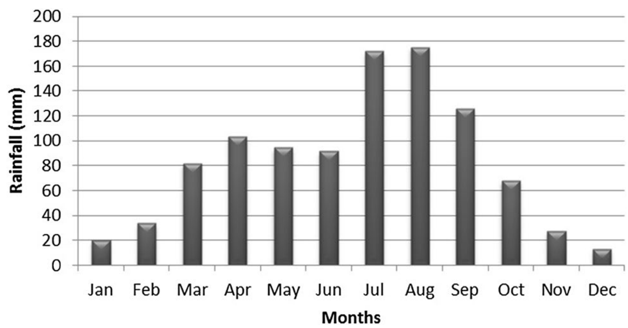

Fig. 4 Average of monthly rainfall in the study area (1990–2015)

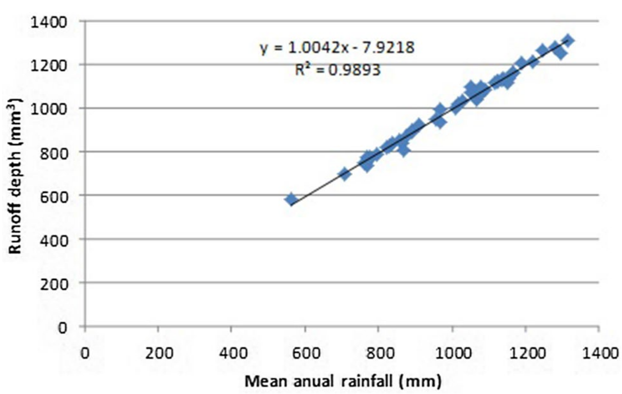

Fig. 5 Correlation between mean annual rainfall and annual runoff depth

very suitable areas. However, eastern, some part of southwestern and northwestern parts of the study area are classified under less suitable and unsuitable zones. Such areas are not recommended for RWH sites. But of the total extent of 20694.41 km^2 study area 5769.8 km^2 (27.88%) is not suitable, 3104.34 km^2 (15%) is less suitable, 5695.42 km^2 (27.52%) is suitable, 4097 km^2 (19.8%) is very suitable and 2027.37 km^2 (9.8%) is extremely suitable extents for rainwater harvesting sites. The excluded constraints area, buffered as not suitable accounts for 4541 km^2 (21.95%) of the study area.

Rainfall and Runoff characteristics

The result of monthly average rainfall for the 25 year period (1990–2015) shows that the rainy season begins in July and ends in September, and the dry season is from October to February (Fig. 4). Rainfall was lowest in December, with monthly average of 13.13 mm, while highest in August, with monthly average of 175 mm. The short rainfall season is during October–February 16.12% of the total mean annual runoff. The correlation between rainfall and runoff depth layers was 0.98, which was near to one. This indicates that the two criteria have high positive correlation in most part of the study area (Fig. 5). The result of standardized and fuzzified suitability map of each criteria layer of soil texture, slope, elevation, geology, lineament proximity, fault, land-use/land-cover, runoff depth, drainage density, settlement proximity and major road proximity are presented standardized attribute values based on potential RWH suitability sites (Table 2; Fig. 6).

Soil

The soil map of the study area reveals four major classes such as sandy loam, sandy clay loam, clay loam and clay.

Table 2 Fuzzy standardized attribute values based on suitability for the RWH

	Not suitable	Less suitable	Suitable	Very suitable	Extremely suitable
Fuzzy Score	0	0.2	0.5	0.8	1
Soil texture (clay content (%))	< 10	10–25	25–30	30–35	> 35
Slope (%)	S > 30	10% < S ≤ 30	5% < S ≤ 10	2% < S ≤ 5	S < 2
Elevation (m)	< 1,300 OR > 2,600	1300–1600	1600–2,000	2000–2,400	2400–2600
Geology	–	High permeable			
Sandstone	Permeable and high grain size limestone and sedimentary	Felsic ignimbrite and tuffs	Basalt		
Lineament	< 3	2.5–3	1.5–2.5	0.75–1.5	> 0.75
Fault (Km)	< 1	1–3	3–5	5–10	> 10
LU/LC	Settlement	Forest	Shrubland	Agricultural land	Bareland
Runoff (mm)	< 250	250–600	600–750	750–1000	> 1000
Drainage density (Km/Km^2)	< 1.5	1.5–1.7	1.7–1.8	1.8–2	> 2
Towns Proximity (m)	< 1000	1000–5000	5000–10,000	10,000–15,000	> 15,000
Major Road Proximity	< 0.5	0.5–1	1–1.5	1.5–2	> 2

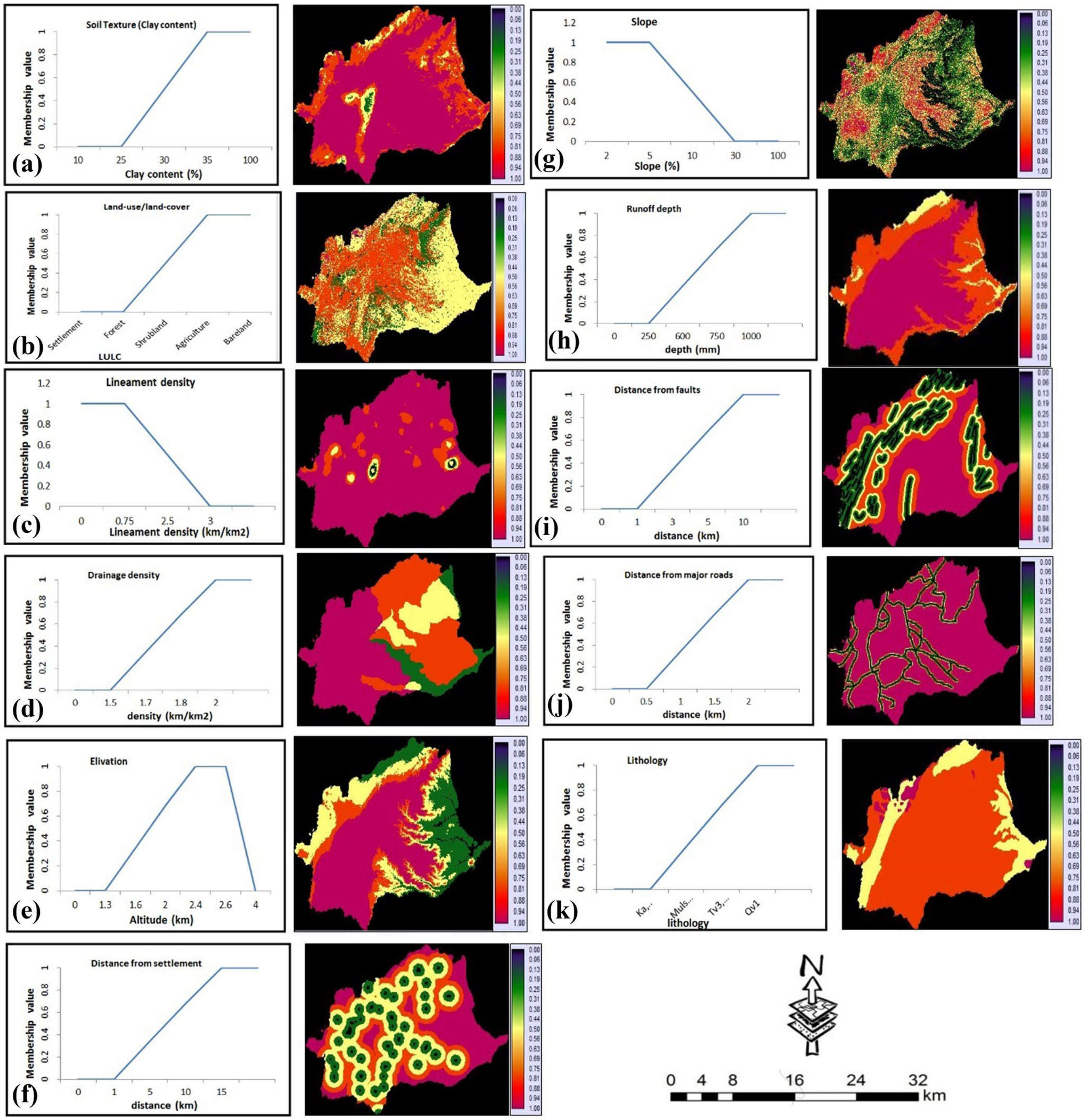

Fig. 6 Thematic maps

Major portion of the study area was occupied by clay loam, spread in the central and north portions of the study area encompassing an area of 12607.87 km^2. The next major soil classes are sandy clay loam and clay, which cover a major portion of the western part of the study area in areal extents of 3523.83 km^2 and 3456.25 km^2, respectively. Sandy loam soil exits in a patch covering an area of 1106.51 km^2 in the eastern part of the study area. The fuzzified soil texture result revealed that most parts of the study area are under extremely suitable class for RWH, except in the central mountainous area, northern, north eastern and some western part of the study area (Fig. 6).

Elevation and slope

Tthe fuzzification elivation result shows most central and southern part of the study area are rated at >0.8, which is suitable for RWH. But, large extents in the eastern, western and north western parts of the study area have < 0.5 fuzzification values. Fuzzified slope layer result show that the study area has erratic topography that make most part under sloping level. The topographic slope of the area ranges between 0 and 35%. The slope of the area were divided in to six slope classes such as nearly level 0–1%, gentle 1– 3%, moderately gentle 3–5%, steep 5– 10%, moderately steep 10–15% and very steep 15– 30%, respectively. The eastern, southern and part of central part of the study areas are covered with higher altitude mountains such as Chilalo Mountain that generate highly steep slopes, such areas are not suitable and less suitable for rainwater harvesting. Some central southwestern parts of the study area are suitable for RWH (Fig. 6).

Land-use/land-cover

The land-use/land-cover map of the study area were classified into eight classes, such as bareland, farmland, forest, grassland, settlement, shrubland, waterbody and wetland. Major portion of the study area (43.30%) is covered by farmland, followed by shrubland (36.91%) and forest (12.97%). Fuzzified land-use/land-cover map shows central part of the study area represent agricultural/cropland and bareland, which are suitable for rainwater harvesting. The area under settlement is fuzzified as not suitable with membership value 0.

Runoff potential

The runoff potential in the study area for the normal rainfall years were grouped into five lassses such as not suitable (< 250 mm), less suitable (250–600 mm), suitable (600–750 mm), very suitable (750–1000 mm) and extremely suitable > 1000 mm. Fuzzified runoff depth layer map shows that most part of the study area is under the range of very suitable to extremely suitable (0.8–1) classes. Hence, most part of the study area is suitable for rainwater harvesting in terms of runoff depth. However, some eastern, northern and wester part of the study area are less suitable for rainwater harvesting (Fig. 6).

Lineament and faults

The fuziification result of lineament proximity/density shows that several part of the study area are exposed for lithological discontinuities. Eventhogh, most part of the study area is suitable for RWH, some western, central and eastern part of the study area are not suitable. The fuzzified fault layer result shows that most part of the study area is exposed to nearby faults, especially the area lies inside main Ethiopian Rift Vally and eastern part of the study area where large altitudinal difference exists, and hence not suitable for rainwater harvesting. Central part of the study area located far from nighbouring fault lines is rated at > 0.8 is extremely suitable for rainwater harvesting.

Drainage density

Drainage density in the study area varies from < 1.5 to > 2/km^2. On the basis of drainage density, watershed of the study area were grouped in the five classes such as not suitable 0-1.5/km^2, less suitable 1.5–1.7/km^2, suitable 1.7–1.8/km^2, very suitable 1.8–2/km^2 and extremely suitable 2– 3 km^2. The result of drainage density fuzzification reveals that southern and western part of the study area are extremely suitable, and most northern and eastern part of the study area are very suitable. However, particular areas in southeastern and northern part of the study area to less suitable. Area with high surface drainage density is less favorable for rainwater harvesting on the land surface, and hence the area having low surface drainage density is preferred as per rainwater harvesting viewpoint.

Settlement and road proximity

Some of the central, western and northern parts of the study area are less suitable and not suitable having a fuzzification value of less than 0.5. An area located 1.5 km away from settlements, in the eastern and central parts of the study area is very suitable and exteamely suitable, respectively. Large portion of the study area is suitable, scoring fuzzification value of > 0.8. Some part of a study area is less suitable, where a land unit is close to 1 km from major road.

Rainwater harvesting potential

Using fuzzy AHP analysis that took into account various physical layers, potential site suitability areas for RWH were identified in the spatial extents of the study area. All the factors and group of factors were integrated to produce five suitability classes based on Weighted Linear Combination (WLC) of fuzzy aggregation suitability index values (Fig. 7). The potential sites for RWH as identified reflect specific suitability levels of parameters and weight of factors applied in the analysis. Not suitable class has higher proportion of sand content in the soil and with very less drainage density. Western part of the study area, where the main Ethiopian Rift Valley crosses and eastern part where minimum soil clay content exists belong to this class. Most of the area classified under this class contains many faults, high lineament density and constraint areas. Not suitable class covers 1976.5 km^2 (9.55%) of the study area. Less suitable class has less proportion of clay content in a soil (10–25%) and with minimum drainage density. An area belongs to this class exists not far from settlement and major road. The area is covered mainly with forest

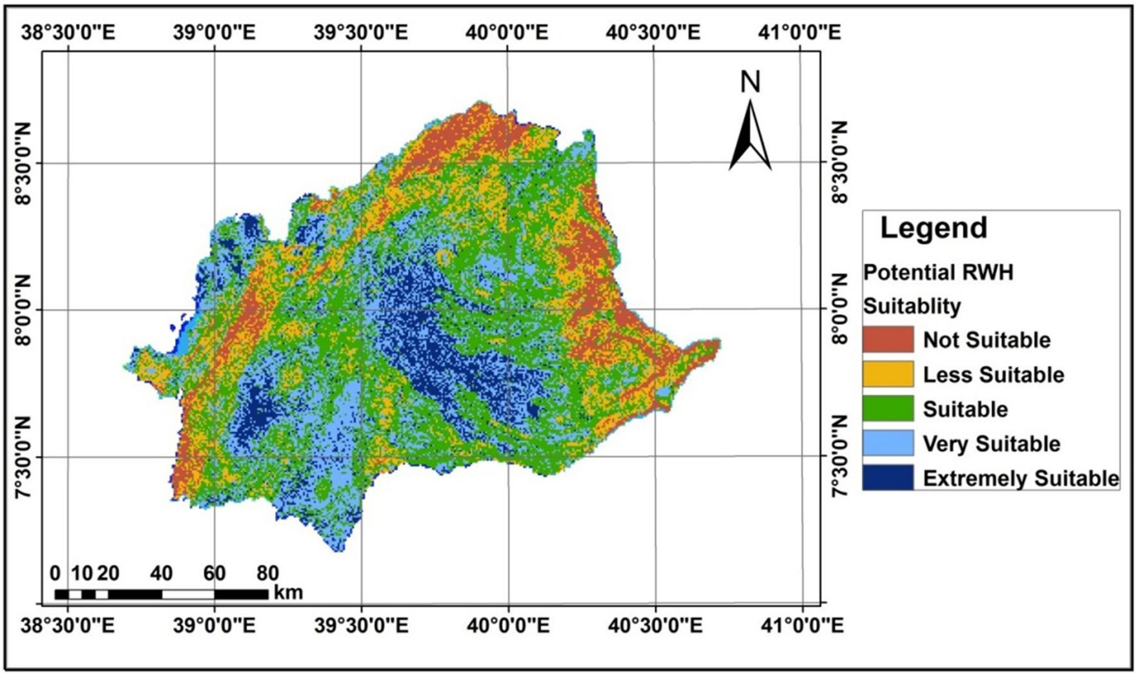

Fig. 7 Potential rainwater harvesting suitability map of the study area

Table 3 Constraint and restricted area factors

Factors	Distance (m)	Rank	Classification
Distance to settlement	> 1000	1	Suitable
	≤ 1000	0	Not Suitable
Distance to road	> 500	1	Suitable
	≤ 500	0	Not Suitable
Fault	> 1000	1	Suitable
	≤ 1000	0	Not Suitable

and steep slope. Less suitable class covers 4425.20 km^2 (21.38%) of the study area. Suitable class has good proportion of clay content in the soil (25–30%) and runoff depth ranges between 250 and 750 mm with better drainage density. Such areas are covered mainly by grassland and shrubland with moderate slope covers 6,721.92 km^2 (32.48%) of the study area. Very suitable class has higher proportion of clay content in the soil having runoff depth between 750 and 1000 mm with better drainage density. Most part of this class is agricultural land way from settlements and major road with very gentle slope, and covers 5,003 km^2 (24.18%) of the study area. Extremely suitable class has the highest proportion of clay content in the soil having runoff depth was > 1000 mm with drainage density > 2 km^2. Geologically it is located on quaternary basalt and away from faults, settlements and major roads. These are agricultural and bare lands with almost level slope, which class covers 2,569 km^2 (12.41%) of the study area.

Constraints layer map

The constraint Boolean layer was multiplied with the final rainwater harvesting suitability layer with the same resolution of the study area (Table 3). From the total study area, 4,540.37 km^2 (21.94%) of the study area was kept as a constraint. Out of this, major roads, faults and settlements cover 2,367.37 km^2 (52.14%), 1873 km^2 (41.25%) and 300 km^2 (6.6%), respectively. After the removal of constrains from the total suitability classes, 5769.8 km^2 (27.88%) is less suitable, 3104.3 km^2 (15%) is less suitable, 5695.42 km^2 (27.52%) is suitable, 4097 km^2 (19.8%) is very suitable and 2027.38 km^2 (9.8%) is extremely suitable for rainwater harvesting (Fig. 8).

Rainwater harvesting suitability sites check dam, percolation tanks and farm ponds

Based on the results 57% of the total study area is suitable for farm pond (16%), percolation tank (9%) and check dam (32%). The remaining 43% of the study area is less and not suitable for selected rainwater harvesting structure types (Fig. 9). The proposed rainwater harvesting construction sites are located across small streams having gentle slope, hard rock as well on alluvial formation bedrock. Most part of the study area is suitable for check dam construction.

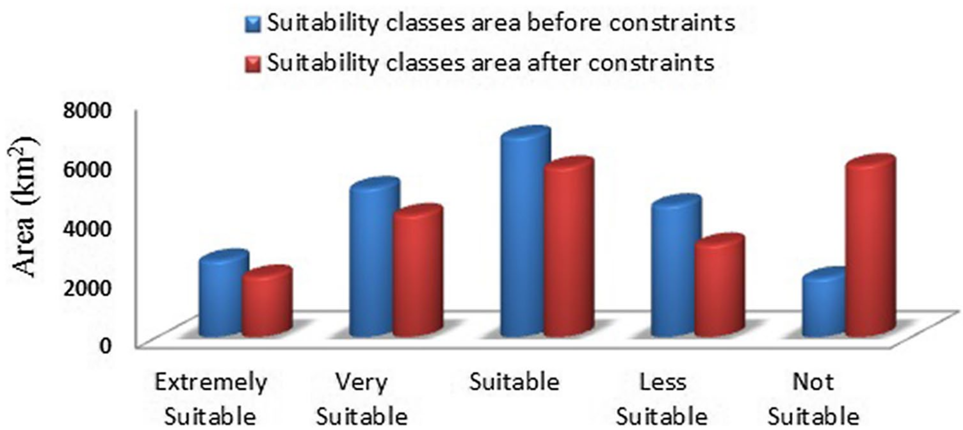

Fig. 8 Potential rainwater harvesting suitability area class of the study area

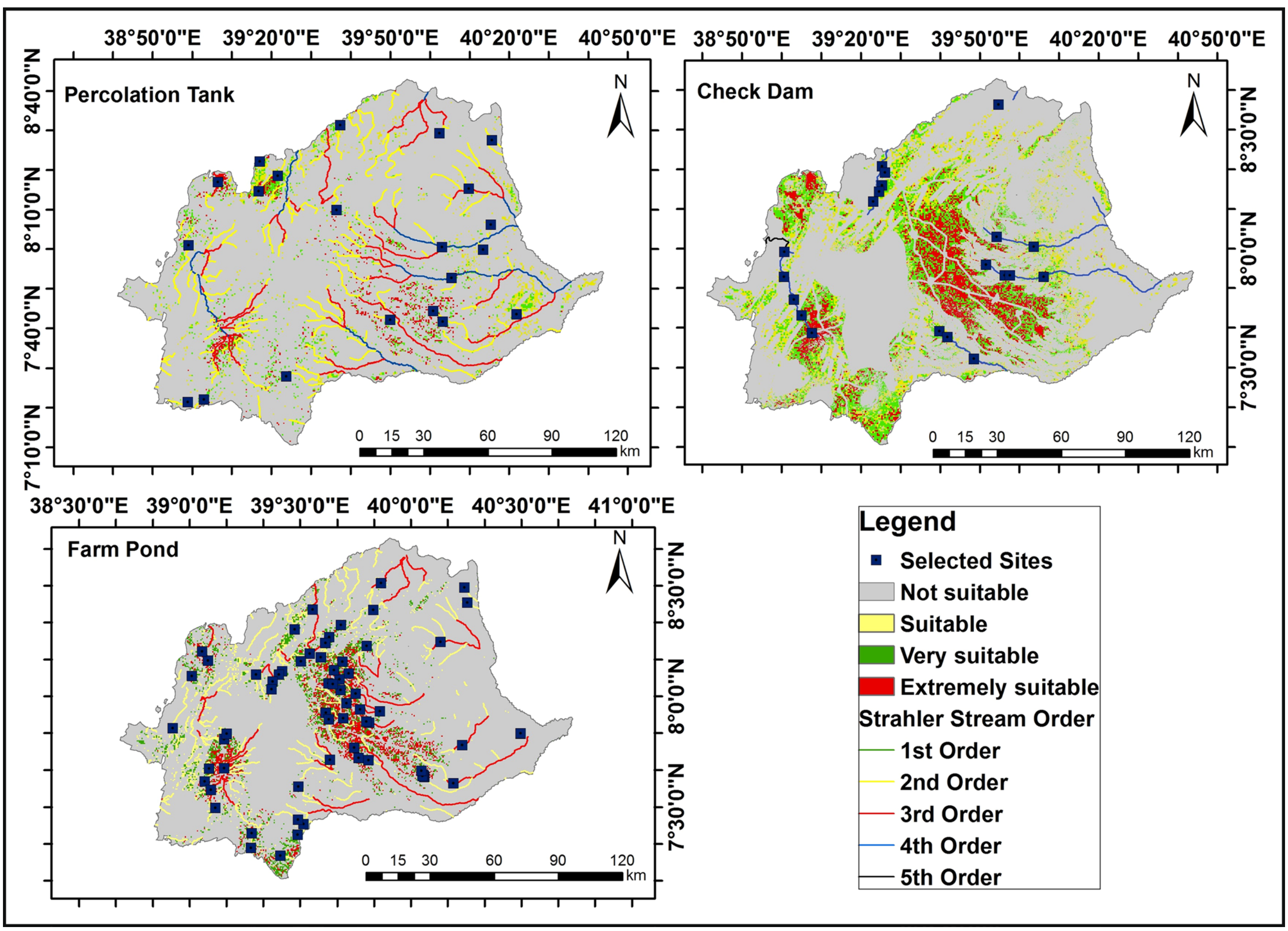

Fig. 9 Percolation tank, Check dam and Farm pond suitability maps and proposed sites in the study area

From the 6,642.86 km^2 check dam suitable area, 19 rainwater harvesting check dam sites are proposed for supplementing irrigation during the dry season. Percolation tanks are constructed across streams and bigger gullies in order to impound part of the run-off water and such sites are located in uncultivated, moderate slope, sandy and fracture rocks and across 4th and 5th order stream to provide better water access for the community and for recharging the groundwater. From the extent of 1,838 km^2 percolation tank suitable area, 21 rainwater harvesting percolation tank sites were proposed for this watershed. From the total area of Arsi Zone, 3,339 km^2 area of land is suitable for farm ponds, and where

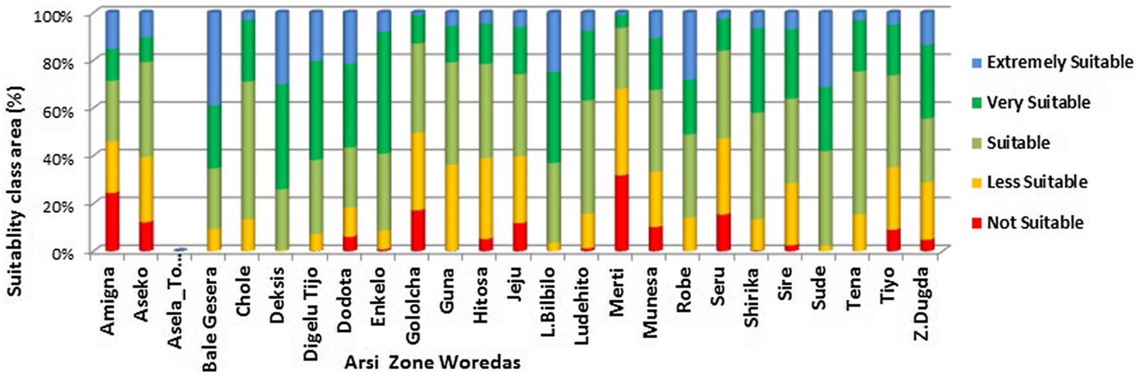

Fig. 10 Percent of rainwater harvesting suitability classes for each District

60 farm pond sites distributed in the central plains, agricultural land and nearly level slope area with 2nd and 3rd order streams were proposed.

Model validation

Details of the existing rainwater conservation structure in the study area were gathered in order to validate classification of the potential sites for rainwater harvesting, reveled using fuzzy approach. Proposed rainwater harvesting sites may not spatially fit with the existing harvesting sites. In addition to that, required assessment was not held in the evaluation and potential of existing rainwater harvesting structures. The result of this research proves that 80.72% of the area is under suitable class (suitable is 34.12%, very suitable is 34.68% and extremely suitable is 11.92%) (Figs. 10, 11). This indicates that the developed model is valid for the study area. Potential rainwater harvesting site selection done in this and neighboring Zones indicates that Tiyo, Lude hitosa, Digelu tijo, Hitosa, L.bilbilo, Z. dugda and Munesa districts were classified under very high and high suitability classes covering 645 km^2 (99%), 229 km^2 (93%), 872 km^2 (93%), 536 km^2 (90%), 380 km^2 (75%) and 627 km^2 (60%), respectively.

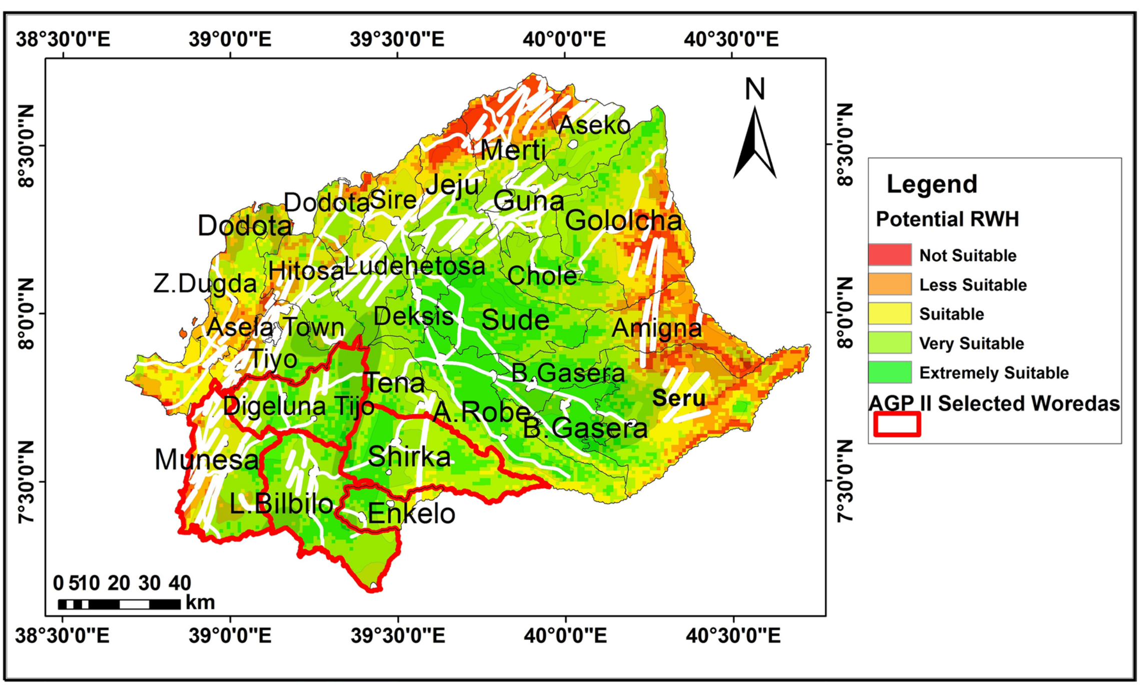

Fig. 11 Proposed rainwater harvest sites and AGP II selected Districts

Discussion

Climate change is bringing tremendous difficulties for sustaninence of socio-economic developments worldwide (Chang 1996; Vahidnia et al. 2008). Its effects will excessively influence sub-Saharan African nations, where economies are highly depending on climate conditions such as rainfed agriculture. The Ethiopian agriculture is characterized by extreme dependence on the annual rainfall (Tadesse 2002). Arsi Zone farmers are facing erratic rainfall with temporal and spatial variabilities. In order to make available water for agricultural and related activities, rainwater harvesting is an identified and globally accepted solution.

Potential rainwater harvesting sites selection model was developed in the present study through fuzzy modeling approach of fuzzy set theory (Zadeh 1965) by identifying more influential and appropriate factors for selection of potential sites. Correlation coefficient calculation done between each identified influential factors was near to zero for most of the factors, which indicates that no systematic co-varying exist between the variable, except rainfall-runoff correlation (Glass and Hopkins 1996). Surface runoff is an essential hydrologic criteria used in many water resource and related studies. The rainfall runoff progression is a non-linear, dynamic and complex process, which is affected by many physical and often interrelated factors. The runoff estimation from conventional methods is difficult, error prone, costly and time consuming due to unreachable areas (Ebrahimian et al. 2009). Runoff depth estimation requires detailed and accurate spatial information of the study area (Munyao 2010). The present study provides an integrated approach to model the spatio-temporal pattern of run-off potential areas using SCS CN model with remote sensing-derived inputs and ancillary data in GIS (Tarun Kumar and Jhariya 2017). Integrating RS and GIS is an effective solution in the application in this kind of hydrological studies (Lyon 2003; Shamsi 2005; Elangovan and Selva Kumar 2018).

All criteria layers identified for the analysis were not equally influential and important to select potential RWH sites in the study area. This difference can be managed by multifactor evaluation of weighted linear aggregation method for weight calculation to give weight to each criterion to reflect their relative importance. This can be effective because it forces the decision makers to give thorough consideration to all elements of a decision problem. By assigning quantitative weights, it is possible to make important criteria have a greater impact on the outcome than other criteria. Though the selected criteria's were weighted, it was necessary to consider restricted and unacceptable areas for implementation as constraints. In this study, socio-economic and environmental constraint considered was 1 km radius of faults, 1 km radius of settlements and 0.5 km radius of main road. Weighted Linear Combination technique is most used and preferable technique for better decision making processes and for constraint aggregation (Baban and Wan-Yusof 2003; Destiny 2015). This research suggests and identifies suitable sites for some commonly used rainwater harvesting strictures (check dam, percolation tank and farm pond), based on common criteria of each structure types.

Proposed check dam sites were selected across a drainage channel to lower the speed of runoff for a certain design range of rain events. Check dams reduce the effective slope of the channel, by minimizing the momentum of flowing water, allowing sediment to settle and reduce erosion. This helps in soil and water conservation (Zhang et al. 2010). Proposed percolation tank sites were also identified downstream of runoff zone with a land slope gradient of 3–5%, which allows water to percolate through layers. Percolation tank benefits the community to get better clean water, as water flow slowly downward and eventually reaches an underground aquifer (Limaye 2011). Proposed farm pond sites were also identified for irrigation, watering cattle, fish production and related agricultural practices, where the sites with no excessive seepage losses exist and nearly level slope area in order to irrigate with gravity flow (Singh et al. 2009; Chou et al. 2013). To ascertain the reliability of the model adopted, validation was done based on existing data and reviewed literature of (KOICA 2008; Girma 2009; MoA 2015), confirming 90% of the model valid.

Conclusion

Rainwater harvesting and artificial recharge are promising techniques to effectively tackle water scarcity problems by augmenting water supplies on a long-term basis. To tackle this challenge, the present study demonstrated a robust methodology for rainwater harvesting potential sites using fuzzy and AHP techniques. The technique will be more effective and helpful, if accurate data are available, especially in inaccessible areas where rainwater harvesting practice is required for better development and water security. Application of rainwater harvesting technologies directly help the community to minimize water crisis. Based on the results of this study, runoff and soil texture, the central and the south western parts of the study area are very suitable for rainwater harvesting. Suitability of this area for RWH gives a good opportunity to store rain water and to irrigate nearby agricultural lands. Total suitable class that ranges from extremely suitable to very suitable areas covers 29.59% of the area, while suitable area is 27.52%. The remaining part, representing less and not suitable is 42.88%. Implementation of rainwater harvesting should be done in connection with a field survey, because the spatial resolution of the analysis does not guarantee that every site in an area classified as low suitable areas is indeed low suitable areas. Any location in an area classified as suitable does not guarantee that it is suitable as some of these locations may be socially by restricted areas, small villages or influenced by other factors preventing implementation of hydraulic structures.

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