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The potential of in situ rainwater harvesting in arid regions: developing a methodology to identify suitable areas using GIS-based decision support system

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Abstract The first step in any rainwater harvesting system involves methods to increase the amount of water stored in the soil profile by trapping or holding the rain where it falls. This may involve small movements of rainwater as surface runoff in order to concentrate the water where it is wanted most. This paper presents a geographic information system (GIS) methodology based on a decision support system (DSS) that uses remote-sensing data, filed survey, and GIS to delineate potential in situ rainwater harvesting areas. The GIS-based DSS implemented as well as evaluated the existing rainwater harvesting structures in the study area. The input into the DSS included a map of rainfall surplus, slope, potential runoff coefficient (PRC), land cover/use, and soil texture. The outputs were map showing potential sites for in situ water harvesting (IWH). The spatial distribution of the suitability map showed that 1.5 and 27.8 % of the study area have excellent and good suitability for IWH, relatively, while 45 % of the area has moderate suitability. Validation of the existing IWH structures was done during a field survey using collected data and the suitability map. The validation depends on comparing rainwater harvesting/recharge dam's locations in the generated suitability map and the location of the surveyed IWH structures using the proximity analysis tool of ArcGIS 10.1. From the proximity analysis result, all the exiting IWH structures categorized as successful (99 %) were within the good suitable areas.

Keywords In situ water harvesting · Remote sensing · Geographic information system · Decision support system

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Introduction

In the last few decades, most of the world's irrigated agriculture areas faced a limitation of water resources. This is particularly in the Kingdom of Saudi Arabia (KSA) where the agriculture use is almost dependent on groundwater as the main source of irrigation, which is difficult and costly to access. In addition, domestic water use depends on desalinated sector, which is highly costly. Such limitations in water resources and the increase of the potential cultivated area, it is necessary to develop an alternative supplementary water source for use in agriculture and domestic sectors. Rainwater harvesting (RWH) could be one of the indispensable water supplies for the sustainability of water. RWH technique can be considered as one of the most important means to make each drop of water valuable and is worth collecting to be exploited by any means due to water shortage in KSA. Accordingly, this important source now is being considered in many urban areas for various purposes as well as groundwater recharges. Recently, the officials and legislators of water resources in KSA have encouraged promoting RWH to avoid severe drought conditions. In this country, exploiting of RWH is gaining great importance to revive life in areas suffering from water scarcity.

In the past, different forms of RWH have been practiced through diversions using spate flow from normally dry watercourses (Wadi) into an agricultural area in the Middle East. Among others, examples are the Negev Desert (Evenari et al. 197l) and the desert area of Arizona and Northwest Mexico (Zaunderer and Hutchinson 1988) and Southern Tunisia (Arnold and Adrin 1986). Critchley and Reij (1989) recognized the importance of traditional, small-scale systems of RWH in sub-Sahara Africa and, more recently, for buildings in urban areas (Gould and Nissen-Petersen 1999). Huge number of systems and structures of RWH are currently in use for a wide variety of applications (Fewkes 1999; Gould and Nissen-Petersen 1999; Weiner 2003). RWH has numerous advantages

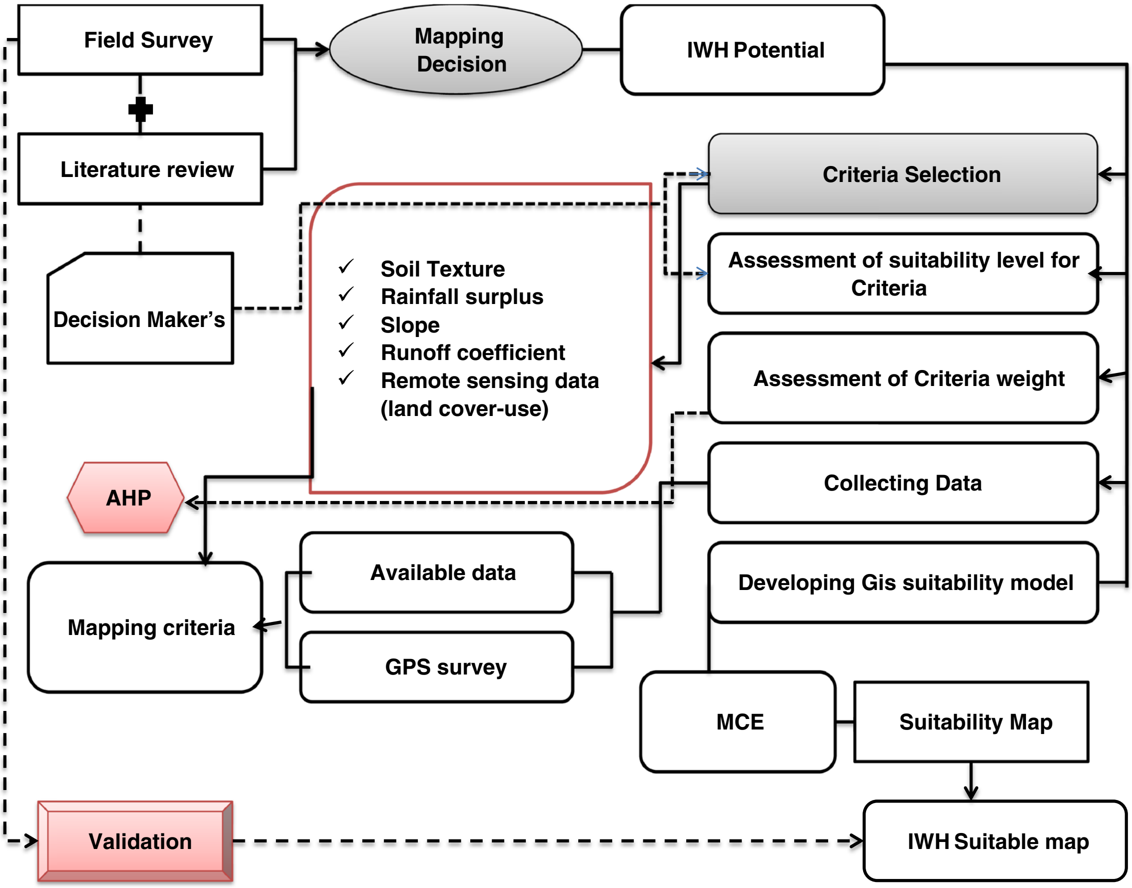


Fig. 1 Workflow chart

and benefits as described by previous researchers (Jackson 2001); this is sufficient to put RWH as a supporter for water management solutions under the climate change. Studies on the ecological and hydrological interaction determine the resource use and influence vegetation composition and diversity (Ludwig et al. 2005; Yu et al. 2008). Identification of potential sites for RWH (PRWH) is an important step towards maximizing water availability and land productivity in the semi-arid areas (Mbilinyi et al. 2007). In recent days, an integrated study of runoff modeling, remote sensing, and geographic information system (GIS) has gained significance in targeting suitable sites for water recharging/harvesting structures (Padmavaty et al. 1993; El-Awar et al. 2000; Ravishankar and Mohan 2005; De Winnaar et al. 2007). The cited literature on RWH structures showed that there are huge research and development works, but a few cited literatures are available on research works using information technologies (remote sensing (RS) and GIS) for delineation suitable sites for water harvesting structures in arid regions. A study conducted by Singh et al. (2009) in Soankhad Watershed, Punjab uses remote sensing and geographical information system (RS-GIS). The satellite images of the Soankhad Watershed (IRS-1C, P6) was used in addition to land use map, soil map, slope map, and digital elevation model (DEM) hydro processing. Similarly, Bothale et al. (2008) presented a decision support system "WARIS" as a case study for the identification of suitable sites for water harvesting structures for upper Betwa Watershed of Betwa Basin, which covers 1,385.61 km^2 area. In another case study presented by Ramakrishnan et al. (2008) of the Kali Sub Watershed, Gujarat, India as a part of the Mahi River Watershed, the parameters used to identify suitable sites for the RWH were runoff potential, slope fracture pattern, and micro-watershed area. Mbilinyi et al. (2007) presented a GIS-based decision support system (DSS) that utilizes RS and limited field survey to identify potential sites for RWH technologies. Furthermore, Jabr and El-Awar (2005) presented a methodology for siting water harvesting reservoirs in a 300-km^2 area of Lebanon to improve the agriculture potential characterized by low and erratic precipitation. This methodology was done in three steps in hydro spatial analytical hierarchy process (AHP):

1. ArcGIS software was used to produce pertinent spatial coverage,
2. Watershed modeling system (WMS) was used to simulate the runoff in the watersheds,
3. Decision hierarchical structure using the AHP was developed and implemented to rank various potential

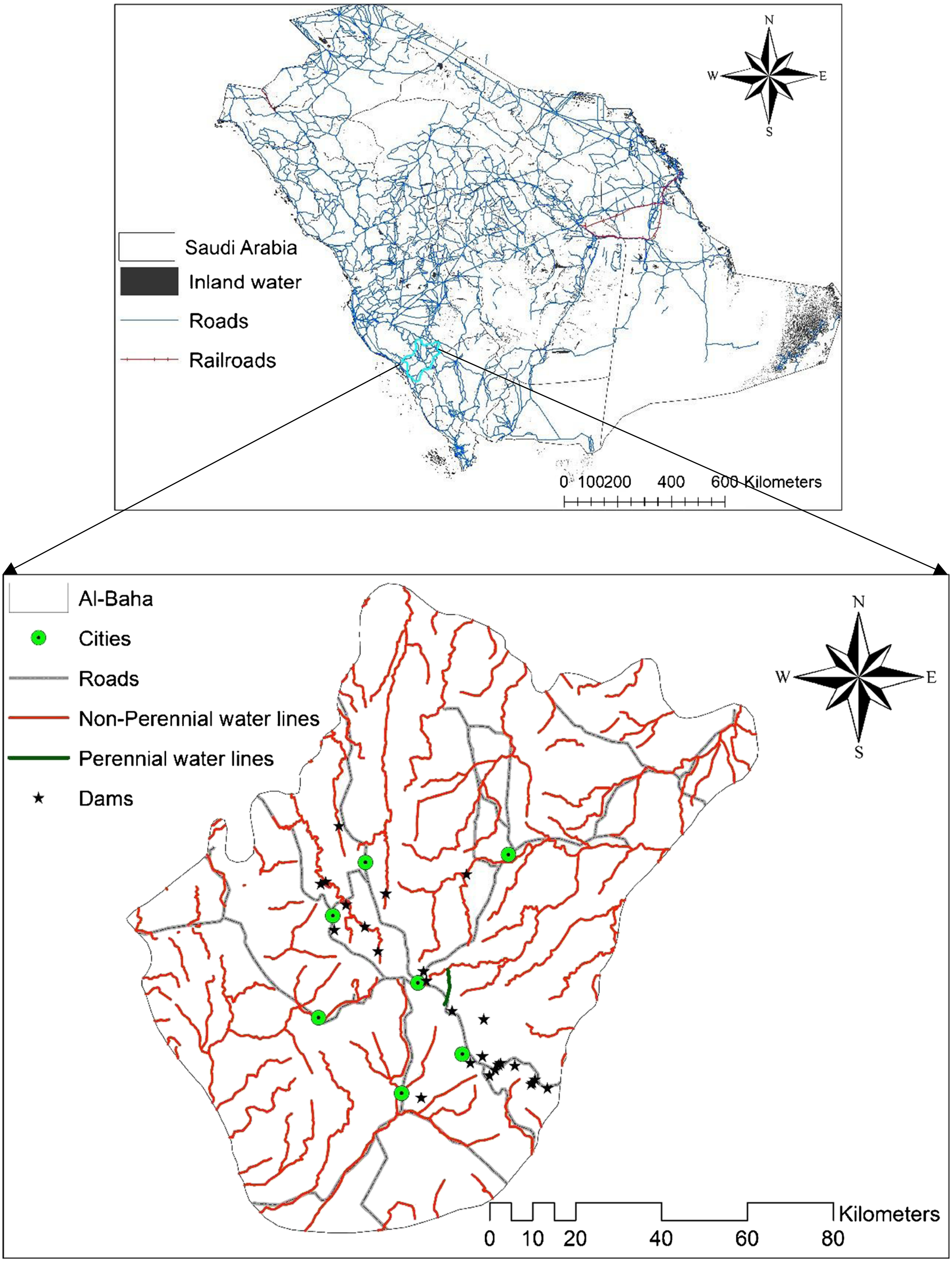


Fig. 2 Location map of the studying area

reservoir sites according to their suitability expressed in terms of a reservoir suitability index.

The outcome of this sketch was the excavation below the water harvesting reservoir at the outlet of the highest ranking watershed. However, Gupta et al. (1997) developed a water harvesting strategy in the semi-arid area of Rajasthan, India by using GIS. Information on topography and soils were digitized to form the GIS database. Land cover information was derived from remote-sensing satellite data (IRS-1A) in the

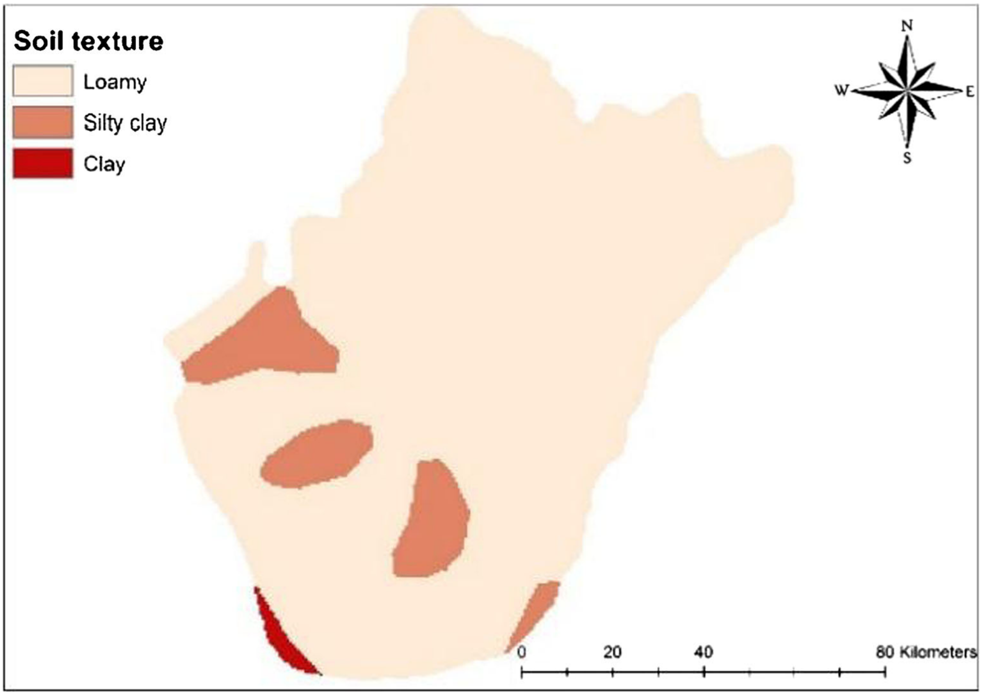


Fig. 3 Soil texture for Al-Baha region (Mahmoud et al. 2014)

form of the normalized difference vegetation index (NDVI). Six basins were delineated using a DEM, and the total acreage in different slope classes was estimated. These maps were used as input to derive a modified Soil Conservation Service (SCS) runoff curve number. The results demonstrate the capability of GIS and its application for water harvesting planning over larger semi-arid areas.

The selection of potential areas depends upon several factors including biophysical and socioeconomic conditions (Mahmoud 2014a and Mahmoud et al. 2014). Different studies used different parameters, for instance, FAO (2003) as cited by Kahinda et al. (2008) listed the key factors to be considered when identifying RWH sites, which include climate, hydrology, topography, agronomy, soils, and socioeconomic criteria. More emphasis is made on the importance of social, economic, and environmental conditions when planning and implementing RWH projects (Arnold and Adrin 1986). Ramakrishnan et al. (2008) used slope, porosity and permeability, runoff potential, stream order, and catchment area as criteria to select suitable sites for various RWH/recharging structures in the Kali Watershed, Dahod district of Gujarat of India by using RS and GIS techniques. Mahmoud (2014b) conducted a study to estimate the potential runoff coefficient (PRC) and determine the runoff volume for Egypt using geographic information system (GIS) based on the area's hydrologic soil group (HSG), land use, and slope. Rao et al. (2003) identified land use, soil, slope, runoff potential, proximity, geology, and drainage as criteria to identify suitable sites for RWH. Kahinda et al. (2008) used physical, ecological, and socioeconomic factors (land use, rainfall, soil texture and soil depth, ecological importance, and sensitivity category).

Table 1 Areas covered by different soil classes (Mahmoud et al. 2014)

Soil texture	Area (km^2)	% of total area
Loamy	10,476.9	85.8
Silty clay	1,028.8	8.4
Clay	701.4	5.7
Total	12,207.1	100

Multi-criteria decision making (MCDM) plays a vital role in many real-life problems. It is not an exaggeration to argue that almost any local or federal government, industry, or business activity involves, in one way or the other, the evaluation of a set of alternatives in terms of a set of decision criteria. Very often, these criteria are conflicting with each other. Even more often, the pertinent data are very expensive to collect (Triantaphyllou and Mann 1995).

AHP is a multi-criteria decision-making approach introduced by Saaty (1977, 1994). AHP is one of a GIS-based MCDM that combines and transforms spatial data (input) into a result decision (output). The procedures include the utilization of geographical data; the decision maker's preferences and manipulation of the data and preferences according to specified decision rules referred to as factors and constraints.

Malczewski (2004) cited the key considerations that are of critical importance in decision making which are (1) the GIS

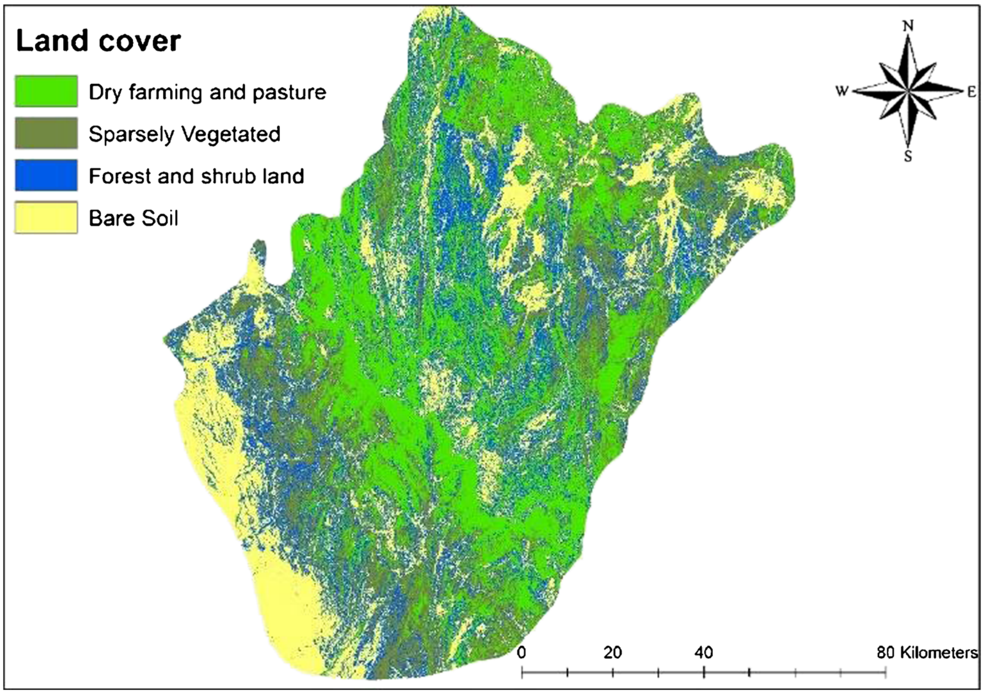


Fig. 4 Classified land cover for Al-Baha region

capabilities of data acquisition, storage, retrieval, manipulation, and analysis, and (2) the MCDM capabilities for combining the geographical data analysis and the decision maker's preferences into uni-dimensional values of alternative decisions.

AHP is a key decision-making tool that was used in this study to assist in obtaining appropriate solutions over suitability assessment for RWH. Saaty (1990) noticed that the process will include the structuring of factors that are selected in a hierarchy starting from the overall aim to criteria, sub-criteria, and alternatives in successive levels. Saaty (2008) outlined four steps as key factors in undertaking AHP in an organized method in order to make a decision over alternative as following:

1. Definition of the issue to be considered,
2. Identifying the goal,
3. Developing a pairwise comparison matrix,
4. Weight priorities for each element with priorities obtained from the comparison matrix to obtain priority that will form the basis of decision making for alternatives at the bottom of the hierarchy.

Table 2 Areas covered by the different land cover and land use

Land cover/land use	Area (km^2)	% of total area
Dry land cropland and pasture	2,870.7	23.5
Sparsely vegetated	2,769.3	22.7
Forest and shrub land	3,703.2	30.3
Bare soil	2,863.9	23.5
Total	12,207.1	100

This paper presents a GIS methodology based on a DSS that uses RS data, filed survey, and GIS to delineate potential water conservation sites. The GIS-based DSS will be implemented as well as evaluated existing RWH structures in the study area.

Material and methods

A field study of past and recent RWH structures in Al-Baha was taken through three different approaches, namely, a review of the literature, data collection through observations, and interviews with farmers using a semi-structured questionnaire. In order to identify the suitable areas for in situ water harvesting (IWH), five criteria were selected where are:

1. Soil map
2. Land cover and land use (derived from available RS data).
3. Slope (topography)
4. Run off coefficient
5. Rainfall surplus precipitation

The criteria used during the GIS analysis are presented in workflow chart (Fig. 1). Because of the different scales on which the criteria was measured, SMCE requires that the values contain in the criterion map are to be converted into

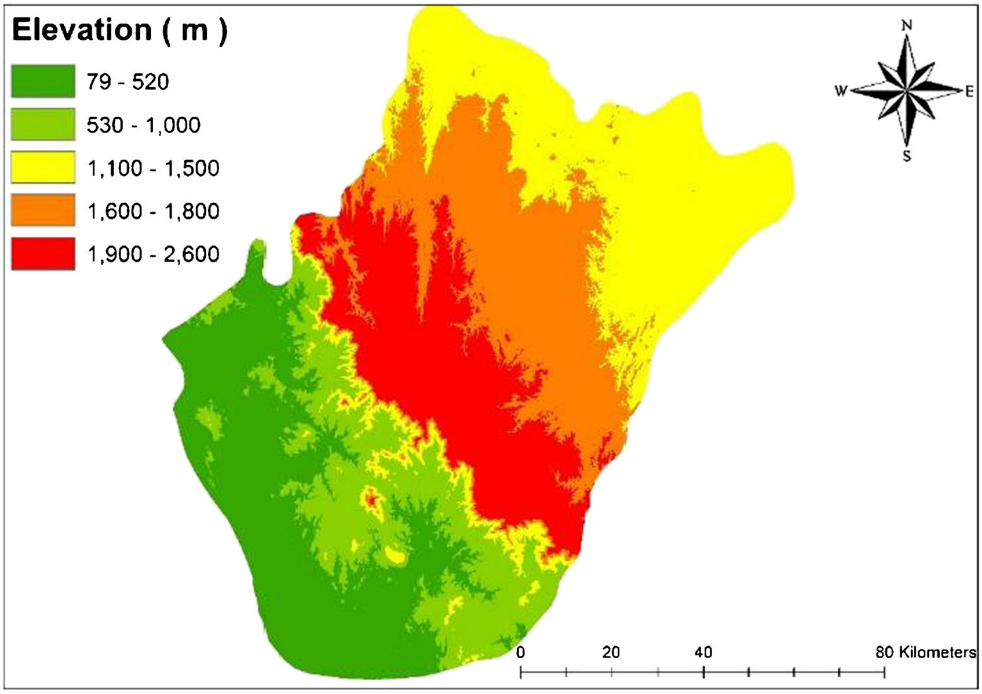


Fig. 5 The exploitation of DEM for Al-Baha

similar units. Therefore, the criteria maps were reclassed into four comparable units, i. e., suitability classes, namely: 5 (“excellent”), 4 (“good”), 3 (“moderate”), 2 (“poor”), and 1 (“unsuitable”). The suitability classes were then used as a base to generate the criteria map. The methodology used to determine the potential IWH sites within the study area using RS and GIS is indicated in the flow charts in Fig. 1.

Study area

Al-Baha region was selected to implement this study due to its considerable divergence in its topography and climate. The climate, in general, falls in the arid zone classification. Relative humidity varies between 52 and 67 % with temperatures ranging between 12 and of 23 °C as minimum and maximum,

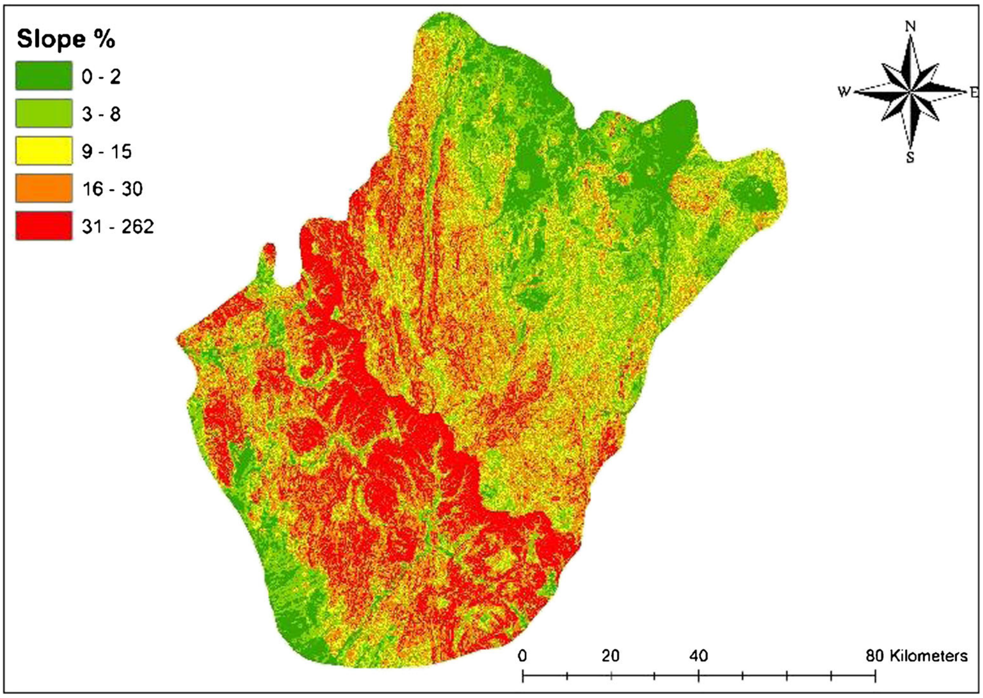


Fig. 6 Slope map for identifying potential IWH sites

respectively. Rainfall is much higher than Saudi average, yet it ranges between 200 and 600 mm/year. Al-Baha region is situated in Hejaz, western part of KSA (41°42 E and 19° 20 N) between the Holy Makah and Asser (Fig. 2). It is the smallest of the Kingdom's provinces 12,000 km^2 (Saudi Geological Survey 2012).

Data input and pre-processing

Soil map

The soil map developed by Mahmoud et al. (2014) for the study area using GPS data with the support of soil experts to identify the soil texture in the site. In this study, GPS points for soil texture covered all the area during field survey, following the soil texture map for the study area, this map (Fig. 3). The soil map was classified into three classes: loam, clay, and silty clay. As noticed from Table 1, 85.8 % of the area is loamy soil with a moderate infiltration rate once thoroughly wetted and is classified as mainly or moderately deep infiltration, moderately to well-drained soils with moderately fine to moderately coarse textures. In addition, 8.4 % from the area is silty clay with low infiltration rates and 5.7 % of the entire area is clay soil with the lowest infiltration rates.

Land cover and land use (derived from available RS data)

Landsat 5/7 TM/ETM image was obtained in the year 2000 from the King Abdul-Aziz City for Science and Technology (KACST). This image was incorporated with collected data from the specified region and was ultimately utilized in categorizing land use and land cover (LULC). Erdass Imagine Software 2013 was used for mosaic the collected satellite images. Iso Cluster unsupervised classification and Maximum likelihood classification function was used in the ArcGIS spatial Analyst for the unsupervised classification. Training samples were collected during field survey to create spectral signatures (i.e., reflectance values) for the supervised classification to identify what the cluster represents (e.g., water, bare earth, dry soil, etc.). The LULC map was classified into four main classes' cropland, sparsely vegetated, forest and shrub land, and bare soil as shown in the map (Fig. 4). The area covered by each land cover and land use is presented in Table 2.

Table 2 shows the different land cover/land use classes in the study area where forest and shrub land represent the biggest ratio of the area. According to their percentages, 30.3 % of the study area is forest and shrubland while 23.5 % of the total area is dry land; cropland and pasture have the same ratio of bare soil while the low ratio is for sparsely vegetated land. The result shows that land cover classes logically fit a mountain area like Al-Baha.

Slope (topography)

DEM obtained from KACST was used to generate the slope map for Al-Baha. The DEM was analyzed to remove sinks and flat areas to maintain continuity of flow to the catchment

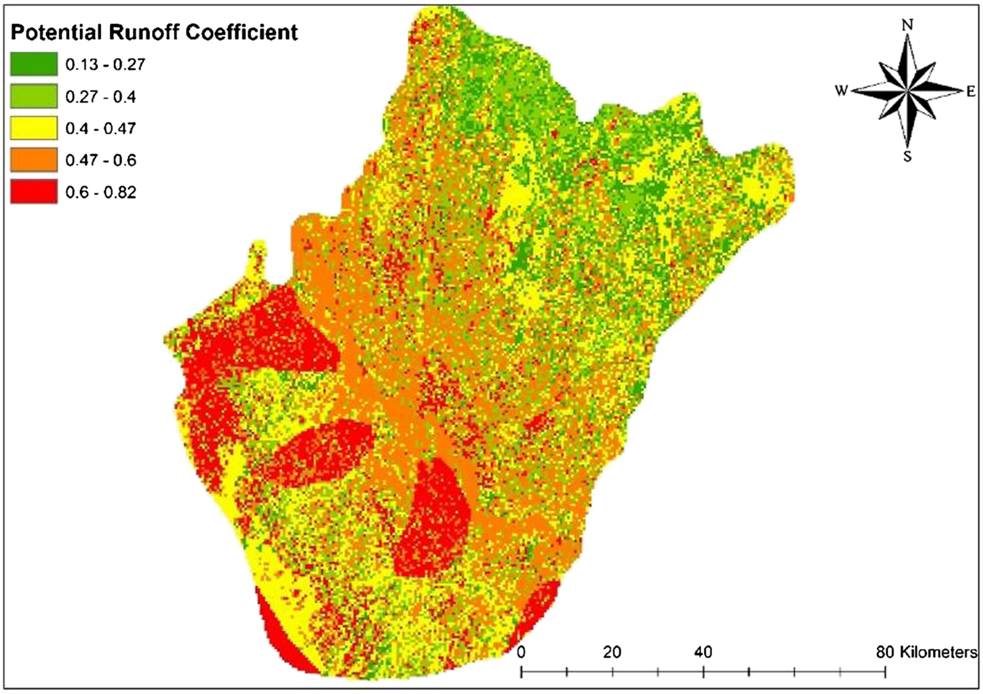
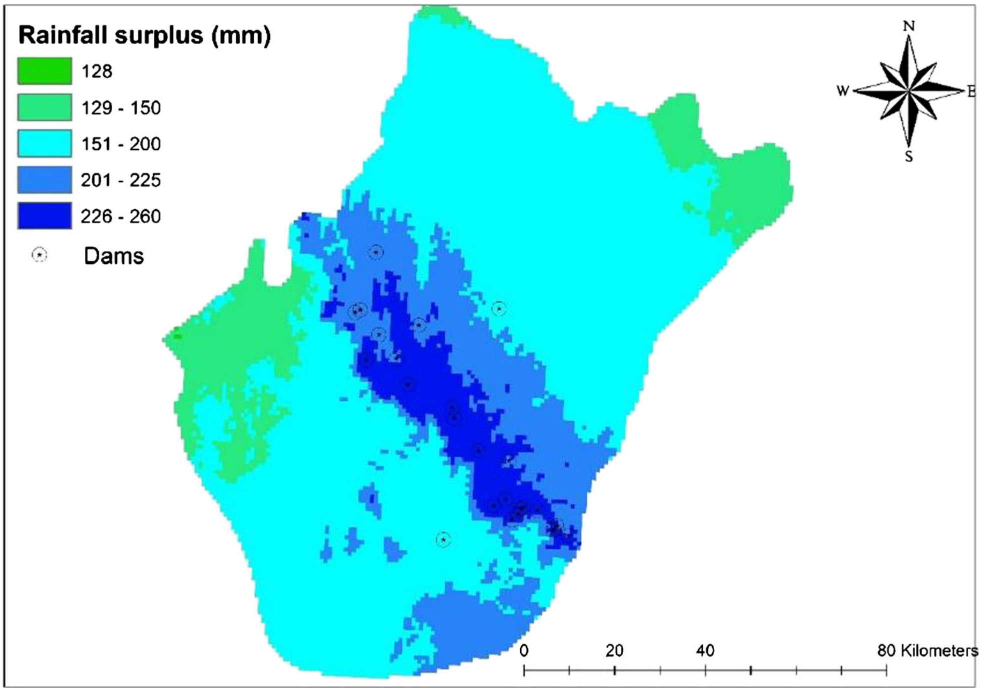


Fig. 7 Distribution of potential runoff coefficient (Mahmoud et al. 2014b)

Fig. 8 Rainfall surplus map for the study area



outlets. GIS was used for DEM preparation by filling the sink areas so the DEM is ready for the next step as presented in Fig. 5. Slope map (Fig. 6) for the study area was generated from Al-Baha filled DEM. The slope map was created for the entire area and given an impression of the steepness of the terrain.

The slope of the catchment affects how quickly water will runoff during a rain event. A steep area will shed runoff quickly. A less-steep, flatter area will cause the water to move more slowly, raising the potential for water to remain on the soil surface, while the size of the soil particles will determine how much rainwater can be stored in the soil profile that can increase the opportunity for rain-fed agriculture and in situ water harvesting technique, which is the diversion of rainwater into a collecting area to a cropping area, thereby increasing the quantity of water available for crop growth.

Potential runoff coefficient

Mahmoud et al. (2014) conducted a study to estimate the PRC using GIS-based on the area's hydrologic soil group (HSG), land use, and slope in Al-Baha region, Saudi Arabia. Mahmoud et al. (2014) noticed an indication that in the absence of reliable ground measurements of rainfall product, PRC can satisfactorily be applied to estimate the spatial rainfall distribution based on values of R and R^2 (0.9998) obtained. The potential runoff coefficient generation from this study ranged from 0 to 82 % of the total rainfall and is presented in Fig. 7.

Rainfall surplus

Even by revising the climatic data obtained from Meteorological Department, Ministry of Agriculture, and Ministry of Water and Electricity, these data were still insufficient to meet the requisites of this study, and so, these data were interpolated by utilizing the following sources:

1. Satellite images for monthly global precipitation from (1979 to 2009) obtained from the World Data Center for Meteorology.

Table 3 Suitability ranking for soil texture

No.	Soil texture class	IWH suitability
1	Fine	2
2	Fine and medium	3
3	Medium	5
4	Medium and coarse	4
5	Coarse	2

Table 4 Suitability ranking for rainfall surplus

IWH suitability	Rainfall surplus class	No.
1	Very large deficit	1
2	Large deficit	2
3	Medium deficit	3
4	Small surplus	4
5	Large surplus	5

Table 5 Suitability ranking for slope

IWH suitability	Slope %	Slope class	No.
5	0–2	Flat	1
4	2–8	Sloping	2
3	8–15	Strongly sloping	3
2	15–30	Moderately steep	4
1	>30	Mountainous	5

Table 6 Suitability ranking for land cover

IWH suitability	Land cover type	Land cover class	No.
5	Intensively cultivated	Very high	1
5	Moderately cultivated	High	2
1	Forest, exposed surface	Medium	3
1	Mountain	Low	4
Restricted	Water body, urban areas	Very low	5

2. NASA Tropical Rainfall Measuring Mission (TRMM) Monthly Global Precipitation Data from (1998–2010) obtained from NASA GES Distributed Active Archive Center.

The rainfall surplus (P-ET) map generated by subtracting long-term average monthly evapotranspiration values of the precipitation for all meteorological stations covering the period from 1950 to 2012. The annual rainfall surplus calculated at each meteorological station by adding only the positive values of the difference (P-ET), spatial distribution of rainfall surplus map (Fig. 8) generated by interpolating previous data values using ArcGIS.

Data processing and analysis

Assessment of suitability level of criteria for IWH

The suitability level of criteria for IWH developed using DSS and expert decision for each factor. Table 3 shows the soil texture suitability ranking for IWH according to soil texture in Al-Baha.

Table 4 exhibited areas with large rainfall surplus, and this will take high suitability rank as it ensures the availability of runoff to be harvested.

IWH structure is generally more appropriate in areas having a rather flatter slope; however, a slight slope is needed for better harvesting of the runoff. Areas with slope ranging from 2 to 8 % are given higher suitability rank. The criteria used in Table 5 are for slope classification.

As this study focuses on IWH for improving the environmental situation, the land cover and land use were employed as criteria to identify potential areas for IWH. The classification is provided in Table 6.

Runoff index (Table 7) was used when PRC was greater than 0.5 as it is better for suitable potential areas.

Assignments of weights to these criteria

The weights were assigned to the criteria by applying the pairwise ranking and rank sum methods. The final weight calculation requires the computation of the principal eigenvector of the pairwise comparison matrix to produce a best-fit set of weights. The weight module of IDRISI Selva software was used for this calculation. In IDRISI, the weighting procedure is based on AHP. The first step was to make a judgement of the relative importance of pairwise combinations of the factors involved. In making these judgments, a nine-point rating scale is used as follows:

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely	Very strongly	Strongly	Moderately	Equally	Moderately	Strongly	Very strongly	Extremely
Less important					More important			

The expected value method calculates the weight, W_k, for criterion k according to Eq. 1 (Janssen and Van Herwijnen 1994).

$$W_k = \sum_{i=1}^{n+1-k} \frac{1}{n(n+1-i)} \tag{1}$$

where n=the number of criteria and k=criterion.

The rank sum method calculates the weight, W_k, for criterion k according to the following equation:

$$W_k = \frac{n+1-k}{\sum_{i=1}^{n}(n+1-i)} \tag{2}$$

where n=the number of criteria and k=criterion.

The accuracy of pairwise comparison was assessed through the computation of the consistency index (CI). This determines the inconsistency in the pairwise judgments and, hence, allows for re-evaluation of comparative. The CI, which is a

Table 7 Suitability ranking for PRC

PRC index	IWH suitability
0–0.27	1
0.27–0.4	2
0.4–0.6	3
0.6–0.7	4
0.7–0.82	5

Table 9 Pairwise comparison matrix for IWH areas

	Texture	Land cover	Slope	Rainfall surplus	Runoff
Texture	1	7	4	3	2
Land cover	1/2	5	3	2	1
Slope	1/3	4	3	1	1/2
Rainfall surplus	1/7	1	1/2	1/4	1/5
Runoff	1/4	2	1	1/3	1/3

measure of departure from consistency based on the comparison matrices, is expressed as:

$$\mathrm{CI} = (\lambda - n)/(n-1) \tag{3}$$

where λ is the average value of consistency vector and n is the number of columns in the matrix (Garfi et al. 2009; Saaty 1990; Vahidnia et al. 2008a, b). The consistency ratio (CR) is then calculated as:

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \tag{4}$$

The random index (RI) is an index that depends on the number of elements that are being compared (Garfi et al. 2009). Table 8 shows the RI of matrices of order 1–15 as derived from Saaty (1980).

The pairwise rating procedure has several advantages. First, the ratings are independent of any specific measurement scale. Second, the procedure, by its very nature, encourages discussion, leading to a consensus on the weights to be used. In addition, criteria that were omitted from initial deliberations are quickly uncovered through the discussions that accompany this procedure. Experience has shown, however, that while it is not difficult to come up with a set of ratings by this means, the ratings are not always consistent. Thus, technique of developing weights from these ratings also needs to be sensitive to these problems of inconsistency and error. To provide a systematic procedure for pairwise comparison, a matrix was created by setting out one row and one column for each factor in the problem (Table 9). The rating is then calculated for each cell in the matrix. Since the matrix is symmetrical, ratings were provided for one-half of the matrix and then inferred for the other half.

Table 8 Random indices (RI) for n=1, 2… 15 (Saaty 1980)

n	RI	n	RI	n	RI
1	0.00	6	1.24	11	1.51
2	0.00	7	1.32	12	1.48
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.01	10	1.49	15	1.59

The consistency rational (CR) of the matrix, which shows the degree of consistency that has been achieved during comparing the criteria or the probability matrix's rating that was randomly generated, was 0.02 which was less than 0.10 (Saaty 1977), and so, the rating is consistency.

Development of a GIS-based suitability model

The entire processes in finding IWH suitability map were implemented in a suitability model developed in the model builder of ArcGIS 10.1. The suitability model generates suitability maps for IWH by integrating different input criteria maps using Weighted Overlay Process (WOP), by utilizing both vector and raster databases. With a weighted linear combination, criteria combined by applying a weight to each followed by a summation of the results to yield a suitability map using The weight module of IDRISI Selva software was used in the calculation, and the final weight was presented in Table 10.

Results and discussion

The Kingdom of Saudi Arabia is one of the hottest and driest subtropical desert countries across the world. With an average of 112 mm of precipitation per annum, much of the Kingdom falls within the standard definition of a desert: an area with a

Table 10 Weight (Percent of Influence)

No.	Criteria	Weight	Weight %
1	Soil texture	0.426	42.6
2	Land cover/use	0.049	4.9
3	Slope	0.085	8.5
4	Rainfall surplus	0.178	17.8
5	Potential RC	0.262	26.2
	Sum	1	100

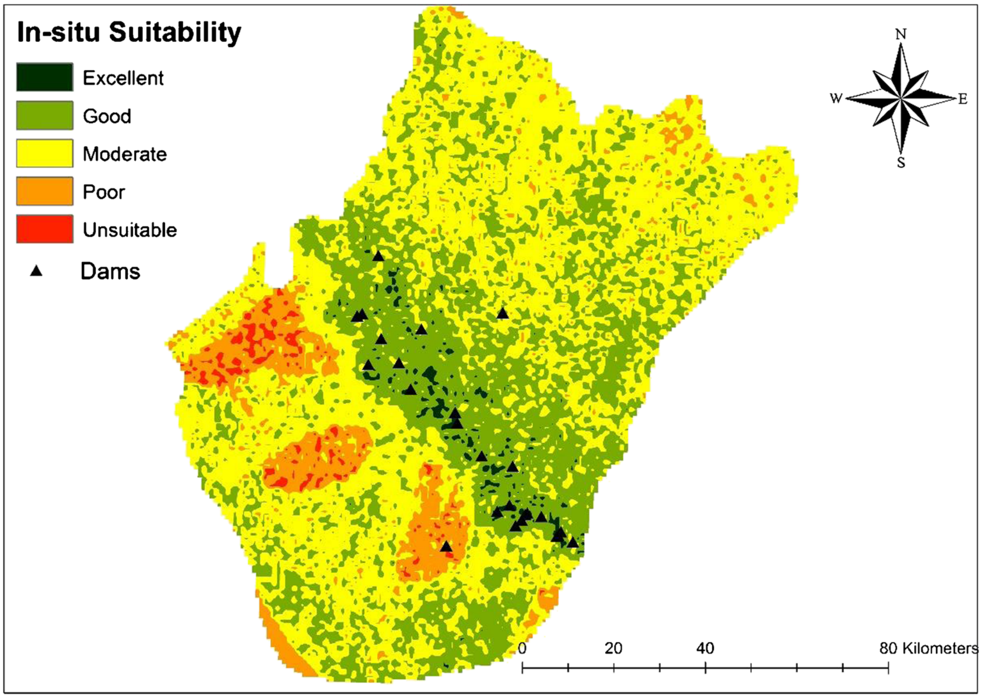


Fig. 9 In situ suitability map

precipitation rate of less than 250 mm/year, compared with the global average of 800 mm. The amount of rainwater in Saudi Arabia estimated to be 130 billion m^3/year. More than 90 % of this precipitation is lost to runoff, a problem that is compounded by the lack of IWH practices. The exploitation of subsurface water from deep aquifers also depletes resources that have taken decades or centuries to accumulate and on which the current annual rainfall has no immediate effect. Undoubtedly, execution RWH projects in various regions of the country will have a huge impact on social life and environmental development such as forest conservation and many other benefits. Al-Baha region was selected to implement this study due to its considerable divergence in its topography and climate. The climate, in general, falls in the arid zone classification. Relative humidity varies between 52 and 67 % with temperatures ranging between 12 °C and of 23 °C as minimum and maximum, respectively. Rainfall is much higher than Saudi average, yet it ranges between 200 and 600 mm/year.

Table 11 Areas under different suitability classes

Suitability	Percent of total area
Excellent	1.5
Good	27.8
Moderate	45
Poor	5.2
Unsuitable	20.5

Table 12 Existing dams in Al-Baha area

No.	Dam name	Dam area	Purpose	Actual capacity m^3
1	Al-Khalah	Beljarshy Province	Recharge	200,000
2	Al-Ssadr	Almendq Province	Irrigation	650,535
3	Al-Talkiah	Beljarshy Province	Recharge	42,960
4	Tharwah	Beljarshy Province	Recharge	70,881
5	Matwa	Beljarshy Province	Recharge	41,231
6	Al-Morba'a	Beljarshy Province	Recharge	85,340
7	Al-Haijah	Beljarshy Province	Recharge	38,012
8	Zagat	Beljarshy Province	Recharge	55,146
9	Shaba	Baha	Recharge	27,906
10	Qoub	Baha	Recharge	32,795
11	Al-Kama'a	Beljarshy Province	Recharge	49,846
12	Al-Habis	Beljarshy Province	Control	5,873
13	Sabihah	Almendq Province	Recharge	162,335
14	Al-Mathlamat	Almendq Province	Recharge	139,754
15	Al-Karrar	Almendq Province	Recharge	90,622
16	Dabdab	Almendq Province	Control	15,990
17	Al-Mleh	Makhwah Province	Control	21,312
18	Baidah	Yadh Province	Recharge	1,294,621
19	Medhas	Almendq Province	Recharge	418,799
20	Al-Marzook	Almendq Province	Recharge	677,947
21	Al-Aqiq	Garnet Province	Drinking	22,500,000
22	Al-Jahafin	Beljarshy Province	Recharge	36,032
23	Al-Heliah	Beljarshy Province	Recharge	22,913
24	Al-Dhahyan	Almendq Province	Recharge	320,000
25	Arada	Baha	Drinking	68,000,000

Identifying suitable IWH sites was implemented in the ArcGIS model environment using the model builder of ArcGIS 10.1. Based on AHP analysis taking into account five layers, the special extents of IWH suitability areas were identified using Multi-criteria decision (MCE). Different spatial analysis tools were used in the model to solve spatial problems during the process of identifying suitable areas, as the identification process in this study was considered as a multi-objective and multi-criteria problem.

The suitability model generated a suitability map for IWH with four suitability classes, i.e., excellent, good, moderate, poor, and unsuitable suitability (Fig. 9). The spatial distribution of the suitability map (Table 11) shows that 1.5 and 27.8 % of the study area have excellent and good suitability for IWH, respectively, while 45 % of the area is moderate.

The majority of the areas with excellent to good suitability have slopes between 2 and 8 % and with an intensively cultivated area. The major soil types in the excellent to the good suitable area are loam and clay loam, and the rainfall ranges from 150 mm up to 260 mm.

During field survey, 25 dams were found within the study area (Table 12). According to their percentage, 70 % of existing dams were established for groundwater recharge. This is justified because the groundwater resources are depleted in the area around the dams before the construction initiated. Such depletion across the years hindered all the agriculture activities in the area since the main source of water is that obtained from groundwater wells. Furthermore, it was revealed that only 4 % of dams are for irrigation purposes and other activities, which taking place around the dams' lake, and 12 % for flood control. In addition, 14 % of the dams were established for drinking purposes, where desalinated water is somewhat difficult to be obtained. In general, the main purpose of existing dams in the study area is to recharge groundwater to support agriculture sector in the study area, which give an indication of the importance of this study.

Validation of the existing IWH structures was done during a field survey using collected data and the suitability map. The validation depends on comparing rainwater harvesting/recharge dam locations in the generated suitability map and the location of the surveyed IWH structures using proximity analysis tool of ArcGIS 10.1. From the proximity analysis result, most of exiting IWH structures categorized as successful (99 %) were within the good suitable areas. The fact that most of the existing IWH structures are categorized as successful was because most of them were located in the good and excellent suitable areas. The validation results showed that the database and methodology used for developing the suitability model including the suitability levels of the criteria and the criteria's relative importance weights have given great results.

Conclusion and recommendations

Identification of potential sites for in situ water harvesting (IWH) is an important step toward maximizing water availability and land productivity in arid and semi-arid regions. Therefore, IWH can be used to provide water for agricultural use in arid regions where there is no surface water available for human activities. Agriculture sector in Saudi Arabia is almost dependent on groundwater as the main source of irrigation, which is difficult and costly to access. In addition to domestic water, use depends on desalinated sector, which costs highly. With such limitations in water resources and the increase of the potential cultivated area, it is necessary to develop an alternative supplementary water source for use in agriculture and domestic activities. Hence, RWH could be one of the indispensable water supplies for the sustainability of water, and development means using this source efficiently.

This study presented a GIS methodology based on a DSS that uses RS data, filed survey, and GIS to delineate potential IWH areas. The GIS-based DSS implemented as well as evaluated existing RWH structures in Al-Baha region- Saudi Arabia that may be used in the development and management of agriculture areas. Identifying suitable IWH sites was implemented in the ArcGIS model environment using the model builder of ArcGIS 10.1. Based on AHP analysis taking into account five layers, the spatial extents of IWH suitability areas were identified using MCE. The suitability model generated a suitability map for IWH with four suitability classes, i.e., excellent, good, moderate, poor, and unsuitable. Therefore, IWH can be used to provide water for agricultural in arid regions where there is no surface water available for human activities.

Despite the great results of suitability model, including the suitability levels of the criteria, and of the criteria's relative importance weights, environmental and socioeconomic factors have to be given due consideration to increase its usefulness. It is therefore recommended that more work be carried out to improve the model and to include other percent ancillary data like environmental and socioeconomic factors.

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