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ORIGINAL PAPER

Robust approach for optimal positioning and ranking potential rainwater harvesting structure (RWH): a case study of Iraq

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Abstract Rainwater harvesting (RWH) structure is considered as the best solution to conserve water for arid regions. The selection of RWH location is based on several key determinants such as hydrology, environment, topography, and socio-economic. This study proposed a robust methodology to identify and select the location of RWH using geographical information systems (GIS) and remote sensing (RS) with multi-criteria decision techniques in areas where data are scarce. Several thematic maps were extracted such as vegetation cover, soil group, slope, land use, and digital elevation (DEM). The RWH sites were ranked based on four major indexes: evaporation, cost-benefit, sediment, and hydrological index. Sensitivity analysis shows that the variance inverse (VI) and rank order method (ROM) considered all indices that effect ranking as compared to the analytic hierarchy process (AHP) and fuzzy-AHP. Sensitivity analysis also proved that the proposed method is suitable to be used for RWH site selection in arid regions.

Keywords Rainwater harvesting structure · GIS · Remote sensing · Multi-criteria decision techniques

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Introduction

Water is one of the most valuable resources on Earth, especially in regions where rainfall is scarce. Water stress is a global issue where many regions suffer from severe water shortage. Western desert of Iraq is one of these regions, which is classified as an arid region, and it is facing tremendous pressure to deliver and manage water resources. Additionally, water is an important resource that has a direct effect on both socio-economic development and ecosystem health. The nature of most arid regions is generally characterized by the lack of precipitation, high temperature and evaporation, and limited surface water and groundwater resources. Effective water resource planning and management for arid regions is important in order to increase accessibility and availability of freshwater, as well as to enhance the quality of life for this region. However, this region has limited hydrological and climatic data to perform water resource analyses. Therefore, there is a need for an effective solution to tackle the issue of water availability. Recently, rainwater harvesting (RWH) came out as an imperative tool for water conservation. RWH has the ability to provide safe, accessible, and affordable water for many types of use such as drinking, agriculture, livestock, and small-scale industries and domestic uses (Agarwal et al. 2001; Samra et al. 2002).

RWH can be defined as the collection of runoff for its productive use (FAO 2001). Availability of an RWH structure has several advantages including increasing water availability, reduces the risk of production failure, enhances livestock and crop productivity, improves water use efficiency, provides access to water (for drinking and irrigation), reduces off-site damage including floods, reduces erosion, and improves surface water and groundwater recharge.

For any RWH sites, there are six main factors that should be considered, i.e., hydrology (rainfall–runoff relationship and intermittent watercourses), climate (rainfall), soil (texture,

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structure, and depth), agronomy (crop characteristics), topography (land slope), and socio-economic condition (population density, workforce, people's priority, people's experience with RWH, land tenure, water laws, accessibility, and related costs) (FAO 2003). The site selection process may be difficult and time-consuming when all these factors are taken into consideration, especially in a large watershed with limited data. Geographic information system (GIS) and remote sensing (RS) have the ability to ease the process of site selection for RWH structures. GIS and RS could be used effectively as tools in site preselection by reducing the number of suggested sites and selecting the best locations. GIS and RS as geospatial techniques have been applied in many studies in selecting the optimal site of RWH in arid and semi-arid regions (Sekar and Randhir 2007; Winnaar et al. 2007; Forzieri et al. 2008; Jasrotia et al. 2009; Pandey et al. 2011; Kadam et al. 2012; Jamali et al. 2014; Krois and Schulte 2014).

Additionally, GIS and RS have played significant roles in planning and management of water resources (Mwenge Kahinda et al. 2008; Ziadat et al. 2012; Bulcock and Jewitt 2013). RS and GIS observations from the satellites provide physical and socio-economic information and its natural resources in spatial format. GIS allows the integration of RS maps, non-spatial (socio-economic) data, and other collateral information, which helps to make a decision that is scientific and people-oriented (Machado 2002). Generally, there are a lot of vital information that can be extracted using RS for the purpose of site selection, such as site resource evaluation and real-time site monitoring. Basically, the process of site selection by using GIS techniques is based on support decision rules which specify how to combine a certain criterion maps into good order alternative decisions (i.e., locations) depending on the evaluation criterion (Malczewski 2004).

This study identifies suitable sites for rainwater harvesting in the western desert of Iraq using several site selection criteria and high-quality digital satellite images. The main objective of this research is to present a robust methodology based on GIS and RS to improve the decision-making process. The proposed methodology consists of three phases, where each phase has certain utilities and techniques to reduce the number of suggested sites and rank it depending on the priority and benefits. The highlight of this method is that the area-volume curve for the RWH structure sites is developed from GIS. In addition, four main indexes, i.e., evaporation, cost-benefit, sediment, and hydrological, derived from a combination of the main criteria, were also considered. These indices have a significant role in the ranking of RWH structure sites.

Study area

Wadi Horan is the largest valley in the western desert of Iraq, which extends from the Saudi border at the southwest corner and also the Jordanian and Syrian borders at the west and northwest, respectively. This valley is geographically located in the south of Euphrates River, and its coordinate is 32° 10′ 44″ to 34° 11′ 00″ north, 39° 20′ 00″ to 42° 30′ 00″ east, as shown in Fig. 1. Wadi Horan has a catchment area of 13,370 km^2, the total length of 362 km, the perimeter of 1307 km, the width of 49.3 km, and shape coefficient of 0.13. The western desert of Iraq is characterized by its severe arid climate.

The main climate characteristics of this region are extremely low and erratic rainfall with seasonal variations of temperatures, high wind, and storm dust. Generally, it is cold in winter and very hot in summer. Average annual temperature is slightly different from year to year, where the highest record in July and August is (42.8 °C) while the lowest is from December to February (2.6 °C). Despite its high altitude, rainfall is scarce (Iraqi Public Authority 2014).

The rainy season is during winter through spring (December to May) while the dry season is in summer (June to September). The average annual rainfall for this catchment is 115 mm, and about 49.5% of the time occurs in winter, 36.3% in spring, and 14.2% in fall. The mean annual runoff is 900 million m^3. The relative humidity is low with an annual mean of 46.2% and it varies significantly over the year. The highest relative humidity is about 76%, recorded in December, while the lowest is in July (~21%). The area is most humid in the period between November and April. The annual distribution of humidity, evaporation, temperature, wind speed, sunshine, and rainfall were distributed equally with slight differences throughout the study area. Therefore, these climatic factors have a similar effect on the evaporation rate.

The high temperature and low humidity lead to high evaporation rate, about 3200 mm annually. The value of dryness coefficient (evaporation/rainfall) is between 25 and 35. This value shows that the water losses in the catchment are mostly due to evaporation. The ground water level of the area is deep, therefore resulting in no recharge to the surface runoff, and forms artesian conditions represented by some wells constructed in this area (Kamel and Mohammed 2010).

The topography of the study area had a minor change in elevation, where 600 m is the difference between the upstream and the downstream of the catchment, while the land also inclines gently towards the Euphrates river valley. There are eight orders of stream types. The soils are mostly shallow over limestone, gypsum, gravel, lime hardpan, or gypsum hardpan. The availability of these types of sandstones, quartz, and clays will serve the region as the base to the dam construction. Wadi Horan is located in the stable zone of Iraq. The major stratigraphic formation in Horan valley is the Zor Horan formation which consists of a sequence of limestone and marl layer (AL-Furat Center for Studies and Designs of Irrigation Projects 1994). Most of the area has a population of fewer than four people per square kilometer.

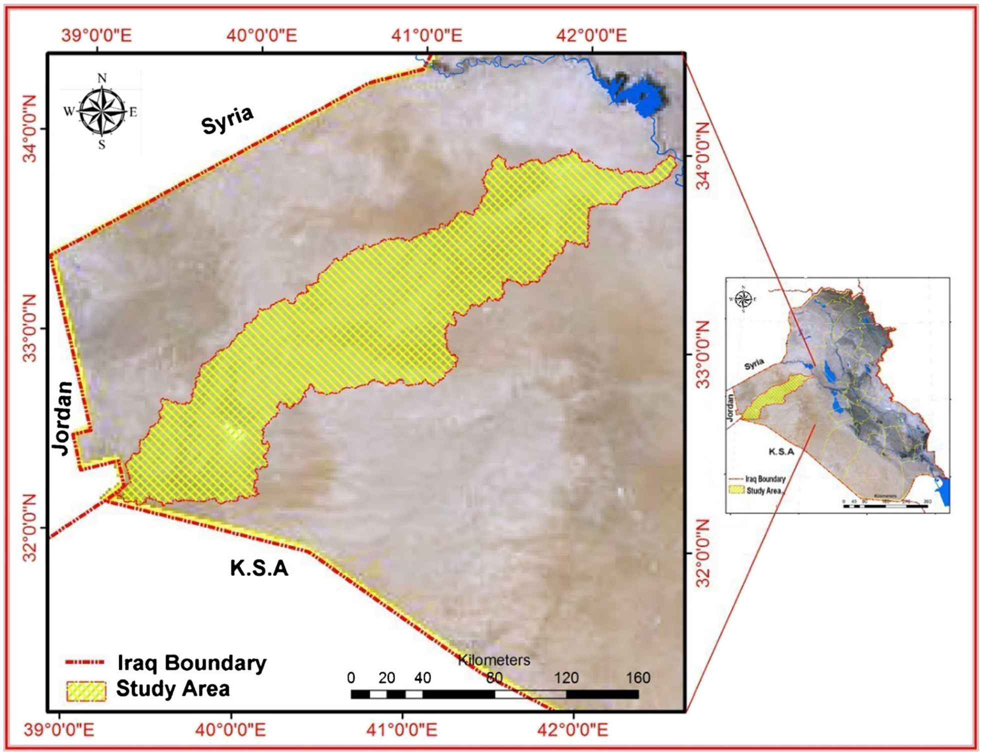


Fig. 1 Location of study area

Methodology and data preparation

The site preselection is a sophisticated process due to the parameters and constraints that directly affect the decision of site section. Therefore, this study proposed a methodology to simplify this process that consists of three phases, i.e., preliminary site selection, qualitative selection, and site ranking. The methodology is summarized in Fig. 2. Each phase is based on certain criteria, and the details are given in the following paragraphs.

In the first phase, the preliminary site selection is based on the width of the valley, the height of the walls, and narrow canyon. These conditions play an important part to reduce the dimension of the structure (Nilsson 1985, 1988). Valley slope was also considered because it affects the site selection (Stephens 2010). Less than 3% of the slope give the reservoir better storage efficiency with economical earthwork required (Critchley and Siegert 1991; Al-Adamat 2008). GIS was used to select the most suitable valley, where the Shuttle Radar Topography Mission (SRTM) and Quickbird satellite images taken in 2006 are used as the input data.

The second phase utilized the Boolean overlay method to simplify the sieving mapping. The Boolean method used logical operators, i.e., AND for the intersection, OR for the union, and NOT for the exclusion of areas (Jones 2014). The limitations of the socio-economic and physical criteria are given in terms of 0 (not allowed) and 1 (allowed). According to the constraints and their justification suggested by Baban and Wan-Yusof (2003), Shatnawi (2006), Al-Adamat (2008), and Al-Adamat (2012), the distances of site selected as socio-economic criteria considered in this study are from faults larger than 1000 m, from road is more than 250 m and less than 5000 m, from agricultural activities are more than 500 m, and from village areas is more than 250 m and more than 5000 m for the uninhabited area. Quickbird satellite images in 2006 and Landsat 8 satellite image in March 2013 were the input data in GIS to determine these criteria.

The Landsat 8 satellite image in March 2013 was classified as unsupervised classification and rectified with correct ground points. Four types of land use patterns in spring were identified for the study area, which include agricultural land, bare land, built, and water and moisture soil, as shown in Fig. 3. The type of land covers and use can provide important information for runoff estimation. Vegetation plays a significant role on the infiltration capacity of the soil. Thus, the runoff amount can be directly affected by the vegetation index. The normalized vegetation index (NDVI) is used primarily for vegetation identification and to determine the lushness of vegetated land surfaces (as shown in Fig. 3).

Watershed Modeling System (WMS) is used to determine several geometry parameters for the catchment. Many researchers have found that the hydro-morphometric criteria are highly correlated with runoff volume and peak discharge (Wolman 1974; Elewa et al. 2012; Oweis et al. 2013). The main criteria used in this screening phase included the volume of annual flood, basin area, basin length, maximum flow distance, drainage frequency density, lineament frequency

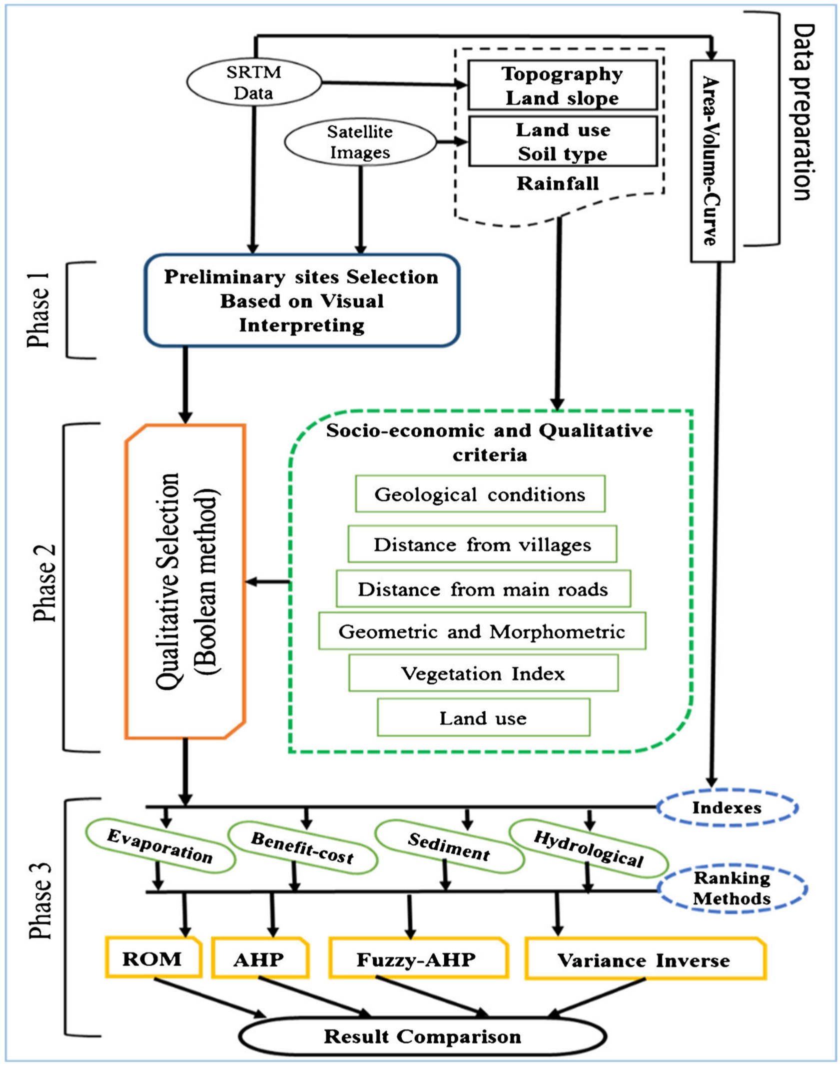


Fig. 2 A schematic chart for the proposed methodology

density, basin slope, and stream order to determine the suitable site for runoff water harvesting.

The third phase is considered as the most important part of this study where the analysis and ranking of the potential sites are produced. The main focus of this phase is the functionality of each RWH site in terms of storage and operation. A comparison among these sites is performed based on four major indexes, i.e., evaporation, cost-benefit, sediment, and hydrological. These derived indexes rely on a physically based incorporation of the main reference criteria. These indexes were extracted from the area-volume curve for each RWH site and geometrical properties. In this step, the integration of GIS with digital elevation model (DEM) that was extracted from the SRTM data is utilized to develop the thematic maps of the area-volume curves (Sayl et al. 2016). In this study, the area was measured for every 2 m of water level while the volume was calculated from area and height. The intersection of the area-volume curve represents the ideal height for the dam where it has a direct effect on the values of all indexes. The detailed methodology of the four main indexes, i.e., evaporation, cost-benefit, sediment, and hydrological, is described in the following sections.

Evaporation index

Evaporation index is defined as the mean ratio between the volume storage and surface area at any level. The main merit of this evaluation refers to the shape of reservoir body, and it will have an impact on the evaporation process which is extremely high with the increase of surface area of the stored water. Theoretically, the main assumption of this index is that the capacity of a reservoir represents the volume of a pyramid at any level, whose base is the water surface (Sawunyama et al. 2006). Hence, it is most recommended that the reservoir is deep and narrow to reduce evaporation losses due to the nature of this study area (Stephens 2010). The climate conditions such as wind speed, temperature, relative humidity, and the sunshine do not change significantly in the study area.

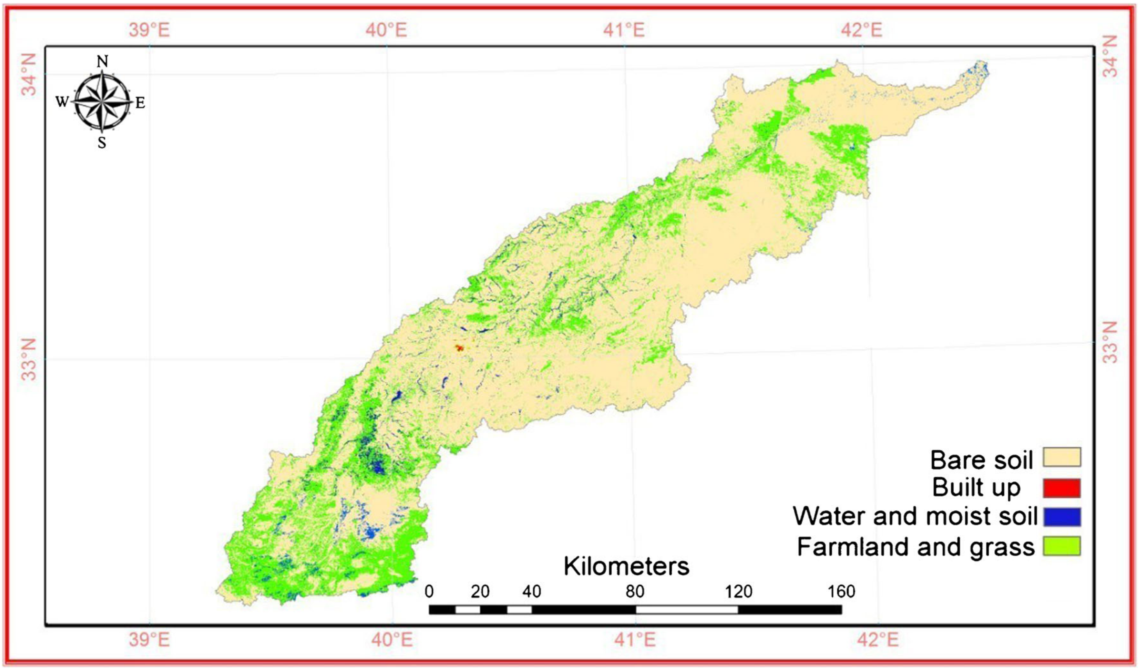


Fig. 3 Land use/cover for the study area

Therefore, only surface area and depth are considered in this index (Sayl et al. 2017).

Benefit-cost index

This is an important index in terms of economic feasibility. This index is defined as the ratio between the potential volume of storage water and the volume of the RWH structure. This parameter indicates the quality of narrows in a quantitative way. Basically, the water storage represents the benefit aspect while the cost of RWH structure construction is a function of the volume of the embankment. This study area has limited infrastructure, skilled labor force, and financial resources. Hence, the construction should be simple; for example, earthwork and stone work should be given top priority (Critchley and Siegert 1991). A gross estimation of the ratio of cost-benefit associated to the structure realization can be represented by this index. The estimation of this index is based on the real equations for the embankment cross section and longitudinal sections (Stephens 2010).

Sediment index

Sediment is the result of an erosion process in the catchment. The sedimentation process is affected by many factors that can reduce or increase it such as soil type, slope, land cover/use, rainfall intensity, geological formation, and catchment extent. Sedimentation is considered as a future problem on the RWH structure, where the storage decreases and the cost of maintenance increases. AL-Furat Center for Studies and Designs of Irrigation Projects (1994) mentioned that the total annual sediment of the study area is 60 t/km^2 every year. Therefore, it is essential for this parameter to be considered in site classification and evaluation. Sediment index represents the ratio between the volume of potential storage and quantity of sediment (t/year). The WMS 9.1 was used to extract the properties of spatial and morphological basins, using a modeling tool known as the Soil and Water Assessment Tool (SWAT). The SWAT model was linked to GIS to find the amount of sediment for each proposed site. SWAT is a physically based continuous-event hydrologic model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large watersheds (Arnold et al. 1998). This model is based on the following input data: a DEM, a land use/cover map, a soil map, a daily measured time series of the climate parameter precipitation, minimum/maximum temperature, relative humidity, solar radiation, and wind speed. From DEM (after filling sinks), flow direction, and accumulation, slope are calculated, and the watershed boundaries and the river network (stream definition) are derived (Winchell et al. 2010; Neitsch et al. 2011).

Hydrological index

The hydrological index in this study refers to the volume of water from precipitation collected by the catchment area. The effective rainfall depth is the ratio between the volume of water storage and the catchment area that is sufficient to fill the reservoir. The assumption made in order to estimate this index is that the number of effective storm water events has higher significance as compared to the amount of annual rainfall. The curve number (CN) developed by the USDA Natural Resources Conservation Service was used to estimate the runoff depth and derived from Eqs. (1) and (2) (Maidment 1992):

$$Q = \frac{(P-0.2\,S)^2}{(P+0.8\,S)} \tag{1}$$

$$S = \frac{25,400}{CN} - 254 \tag{2}$$

where Q is the runoff depth in mm, P is the precipitation in mm, S is the potential maximum retention after runoff starts in mm, and CN is the runoff curve number.

CN represents the runoff properties for a certain soil and land cover/use. In this study, remote sensing was used to develop the land cover maps and interpolate the rainfall data with soil map. Figure 4 illustrates the runoff depth values over the study area, where the largest area has runoffs between 27 and 45 mm. Losses of water by infiltration are excluded from the hydrological index estimation because all the aspects about infiltration had a similar effect, with only slight differences throughout all sites suggested for RWH in the study area (Consortium-Yugoslavia 1977; Hamza 2007). The effective rainfall depth is an important index for the site ranking as it is a direct indicator of the amount of rainfall that can be harvested for each site. Furthermore, it is an indicator of the capability of filling the dam storage. Therefore, the rainfall depth is an inverse value for the hydrological index, where the lowest value of rainfall depth is sufficient to fill the dam storage that represents the highest value of the hydrologic index. The frequency of occurrence can play a significant role for the hydrological index value, and that is quite important to give an idea of how to manage and operate the dam in the future. For example, the rainfall frequency occurrence of less than 10 mm/h is 27 times in a year, and higher than 10 mm/h is seven times in 1975/1976 for this study area (Kamel and Mohammed 2010).

The ranking process is performed based on four methods of weighting criteria, i.e., analytic hierarchy process (AHP), fuzzy-AHP, rank order method (ROM), and variance inverse (VI). These methods were chosen because it is quite difficult to practice any site classification with multi-criteria without giving weight to each index. AHP is a multi-criteria decision method that uses hierarchical structures proposed by Saaty (1980). The weights for the decision-making criteria are derived from the pairwise comparisons of the relative importance between each of these two criteria. The steps of AHP procedure include defining the unstructured problem, developing the AHP hierarchy, pairwise comparison, calculating the relative weights, checking the consistency, and obtaining the total weights and overall rating (Safari et al. 2010). Fuzzy-AHP is a method based on the fuzzy set theory proposed by Zadeh (1965). This approach allows decision makers to make interval judgments, where this approach has the ability to capture a human's appraisal of ambiguity (Tsiko and Haile 2011). ROM is another multi-criteria decision method, and it is simpler than AHP. This method orders all criteria from the most important to least important. All these methods depend on decision maker's judgment where

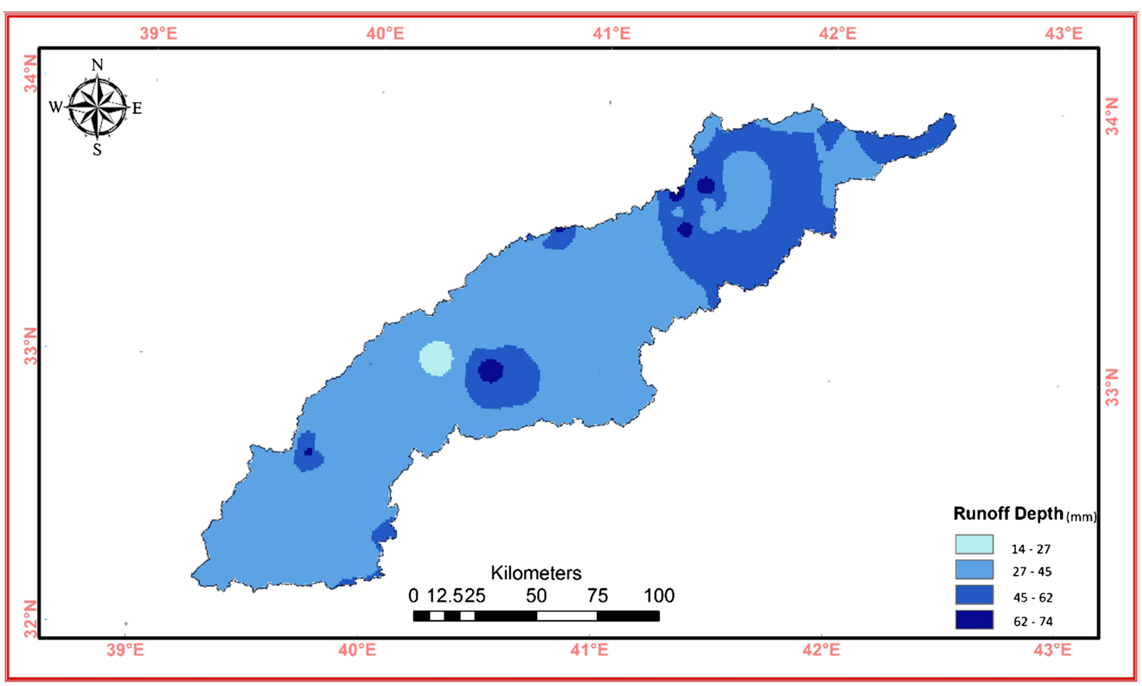


Fig. 4 Thematic map of distribution of runoff depth

these decisions have some inherent uncertainty. VI is a statistical method that has been used to give the criteria weighting based on the inverse relationship closer to the best value. Logically, it can be concluded that a difference between the best value and the value for each site for each criterion will have a small standard deviation or variance, and thus should be weighted more heavily (held close to its value) (Wolf and Ghilani 2012). This method defines the variance as the summation of the square of the difference between the site criteria value, and the best value of the criteria for all sites and the relative weights are inversely proportional to variances. Additionally, the sensitive analysis is crucial in the evaluation of the robustness of model and the extent of output difference when criteria are systematically diverse over a range of interest (Chen et al. 2009). To investigate how sensitive the ranking of these alternatives is to any changes in the importance of the criteria, a sensitivity analysis was performed to test the robustness and uncertainties of the output (result) for each method.

Result and discussion

In the preliminary site selection phase, the site selection is based on the most important characteristics, as mentioned previously in the methodology. The selection procedure in this phase depends on visual identification. As a result, 53 site locations were selected over the study area. The second phase is a screening process for the suggested sites, depending on the physical and socio-economic criteria. Figure 5 represents the result of qualitative selection phase the areas in the thematic map were assigned a simple binary number, i.e., 0 or 1, which means to exclude or include for location selection. With reference to Fig. 5, the red areas show allowable areas of RWH structure construction. However, only 32 out of 53 sites are located in the allowable areas. The 32 sites are considered as potentially suitable in terms of qualitative selection (they fulfill the socio-economic and physical criteria). Additionally, some existing sites have been selected for the validation process (i.e., site no. 30). It is recommended to construct the RWH structure where the total annual storage of this site does not exceed 200 million m^3, while the annual runoff for the study area is around 900 million m^3.

The final phase is the main part of this study where the candidate sites were ranked using AHP, fuzzy-AHP, ROM, and VI depending on four indexes. A summary of the results is given in Table 1. From Table 1, the value of indexes is not on the same scale. The weighting process for these methods was performed after standardizing all values. The standardization or normalization was derived by assigning the same dimensionless continuous scale (i.e., 0 to 1). The first method has been set as an equal weight for all indexes in the ranking process. This method is characterized by the simplicity and employed for comparison with AHP, fuzzy-AHP, ROM, and VI methods.

Table 2 presents the weight values for AHP, fuzzy-AHP, ROM, and VI for the four indexes. It is noticeable that all methods are given the highest weight for evaporation index, followed by benefit-cost, sediment, and hydrological index.

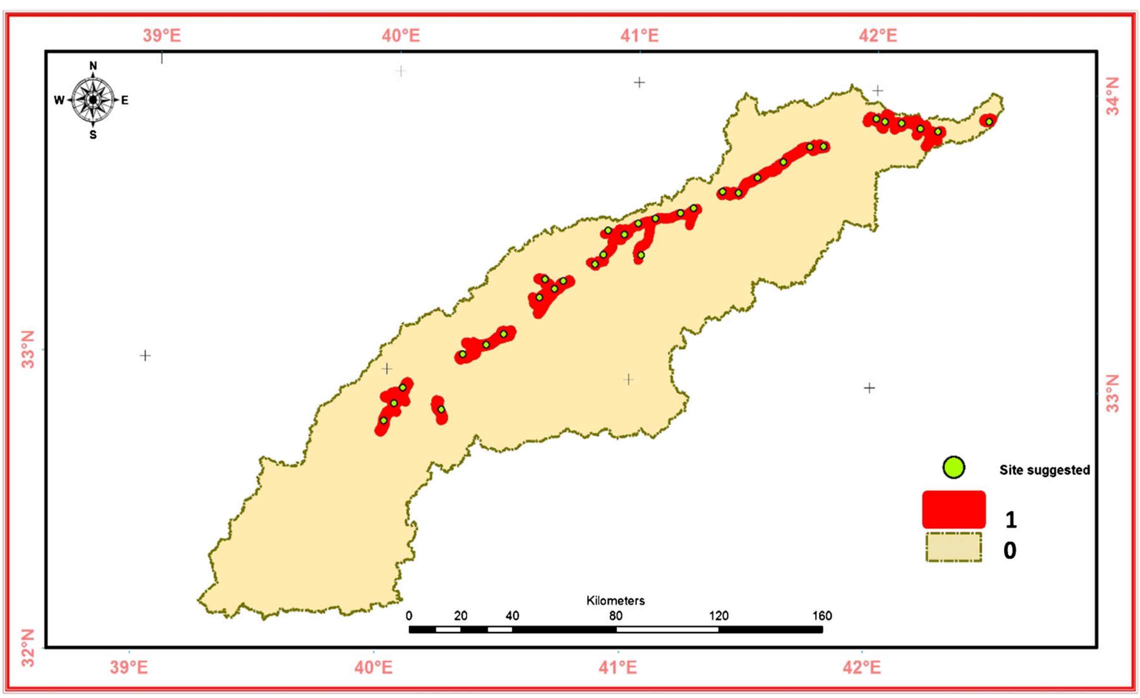


Fig. 5 The final thematic map for phase 2 showing the allowable area of site construction

Table 1 Ranks, indexes, and location for the 32 candidate dam sites

Code	Site location		Indexes				Ranks				
	Longitude (E)	Latitude (N)	Evaporation	Benefit-cost	Sediment	Hydrological	Equal	AHP	ROM	Fuzzy-AHP	VI
1	42.42144	33.92855	2.25	7.61	3.35	6.03	17	28	30	28	27
2	42.25638	33.86908	1.98	6.52	3.42	5.88	28	32	32	32	32
3	42.18277	33.87777	2.36	21.80	14.36	1.42	23	23	22	24	23
4	42.10432	33.89357	2.64	16.78	8.45	2.42	18	19	18	21	20
5	42.03424	33.89789	2.12	19.74	6.66	3.10	25	30	28	29	29
6	41.99692	33.90625	2.38	12.44	12.10	1.71	31	26	29	30	24
7	41.77822	33.81171	3.60	21.19	25.29	0.81	4	2	3	2	2
8	41.72391	33.8054	2.89	11.36	10.92	2.05	20	14	15	16	15
9	41.61457	33.75036	3.39	17.70	12.97	1.69	8	4	5	5	3
10	41.50907	33.69491	2.36	15.45	14.98	1.46	30	25	27	27	25
11	41.43116	33.64195	2.77	25.76	32.37	0.67	10	11	7	11	16
12	41.36391	33.64339	1.99	19.39	18.69	1.16	32	31	31	31	31
13	41.24602	33.58462	2.93	5.47	7.32	2.92	21	16	21	19	14
14	41.19207	33.56646	2.21	21.6	14.77	1.42	29	27	26	26	26
15	41.08821	33.54545	3.21	9.97	4.94	4.32	7	7	10	8	8
16	41.01743	33.52603	2.92	8.28	6.09	3.44	16	13	17	13	13
17	40.96254	33.48766	2.97	2.34	5.11	4.00	19	15	23	18	12
18	40.87706	33.41605	2.77	2.40	5.04	5.25	15	20	25	22	18
19	40.84494	33.38292	3.23	9.57	11.56	1.85	13	10	12	10	7
20	40.7142	33.32392	3.36	10.39	9.27	2.30	11	6	8	7	5
21	40.68003	33.30662	3.33	26.02	49.21	0.46	2	3	2	3	4
22	40.89329	33.49887	3.26	11.08	103.83	0.10	3	5	4	4	6
23	41.03449	33.4204	3.20	8.05	61.33	0.18	12	8	9	9	9
24	40.63865	33.32663	2.41	17.07	109.39	0.10	9	21	11	12	22
25	40.6189	33.26507	2.05	22.59	103.82	1.65	6	24	13	17	30
26	40.47635	33.13571	2.09	24.67	37.68	0.57	24	29	24	25	28
27	40.4057	33.10345	2.50	19.31	16.93	1.26	22	22	20	23	21
28	40.31074	33.06174	2.80	12.08	19.78	1.08	26	17	19	20	17
29	40.06835	32.94038	3.06	5.50	27.29	0.82	27	12	16	14	11
30	40.03646	32.88597	3.50	33.37	109.27	0.20	1	1	1	1	1
31	40.23177	32.8728	2.99	13.86	102.49	0.10	5	9	6	6	10
32	39.99599	32.82596	2.63	17.6	50.46	0.45	14	18	14	15	19

This is reasonable because it represents the nature of the study area, where the evaporation is the main issue in this arid region.

The results in Table 1 show that all methods indicate that site no. 30 is the best location for RWH structures, as shown in Fig. 6a–e, where this suggested site has the highest evaporation index and benefit-cost index. The highest evaporation index is an indicator of the ability to save water in the reservoir over the years. This indicator is very significant to manage water storage in the reservoir. Imaginary satellite images, as

Table 2 Index weights for AHP, ROM, fuzzy-AHP, and variance inverse

Weight/method	Evaporation index	Benefit-cost index	Hydrological index	Sediment index
AHP	0.60	0.20	0.09	0.11
ROM	0.40	0.30	0.10	0.20
Variance inverse	0.34	0.28	0.20	0.18
Fuzzy-AHP	0.45	0.24	0.13	0.18

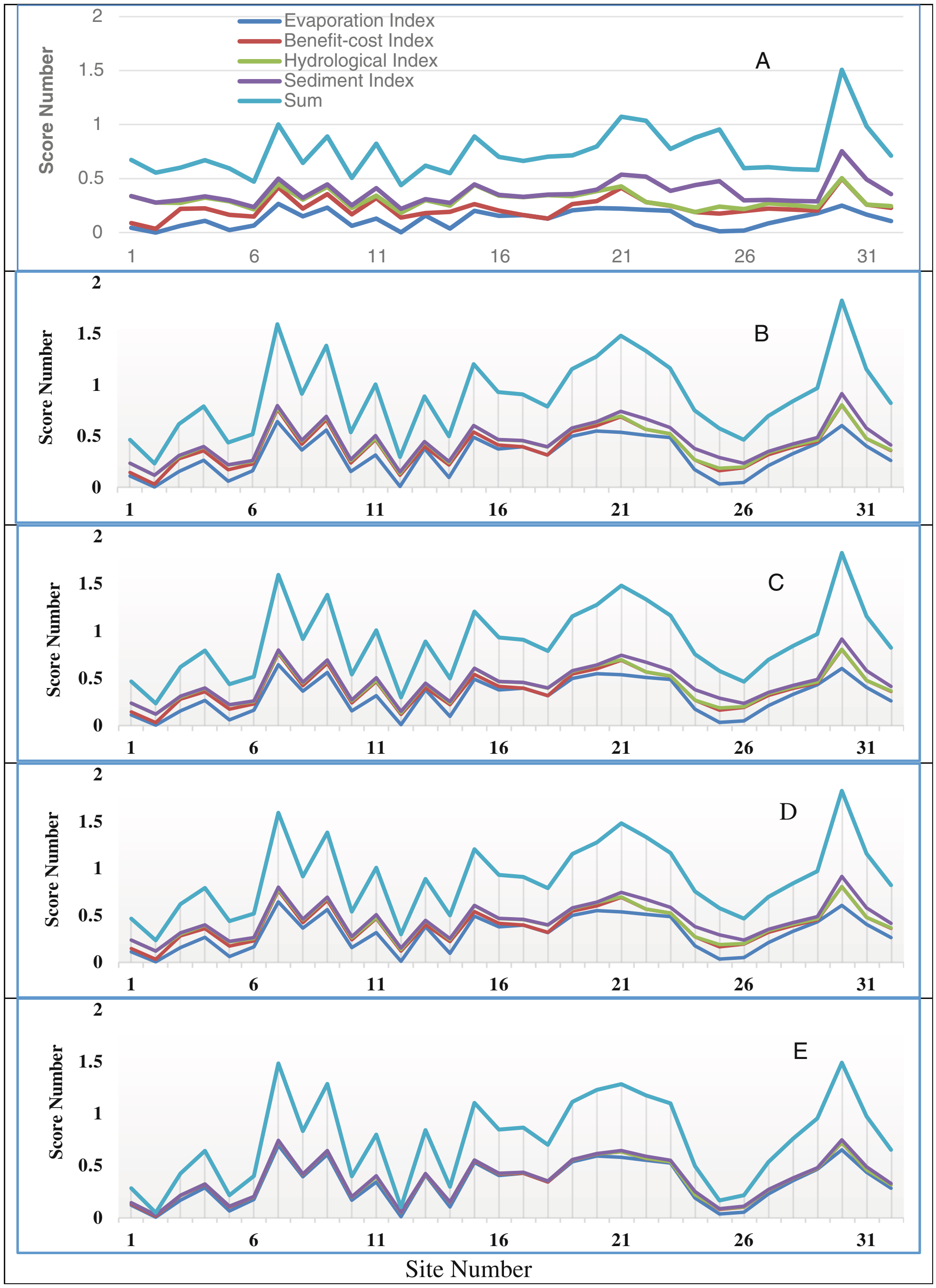


Fig. 6 Site ranking. **a** Equal weight. **b** AHP. **c** ROM. **d** Fuzzy-AHP. **e** VI methods

shown in Fig. 7, represent site no. 30, where these images were taken during rainy and dry seasons of 2013. This figure reflects water storage over the year, which is the main purpose of a RWH structure. In addition, this is an indicator of how the selection of indexes is valid in this study.

ROM, AHP, fuzzy-AHP, and VI produced almost the same results in the site order ranking. However, the result produced by fuzzy-AHP is closer to the result of VI, as compared to other methods. Figure 6a–e illustrates the distributions of the four indexes after applying the weights for each method. The summation of index value refers to the score of each site which gives the rank; highest summation wins the first rank. The four indexes do not have the same weight effect on the priority of site ranking. Therefore, it is important to set the optimal value of weights for each one.

Figure 6a–d shows high fluctuation in distribution indexes for the sites because of the weight values and that is clear from Fig. 6a that the weight is equal. However, Fig. 6e shows good consistency between the indexes for all sites. Even though the agreement between AHP, fuzzy-AHP, ROM, and VI is in the sequence of index priority, it is very important to set the optimal weight selection that can reduce this fluctuation. The

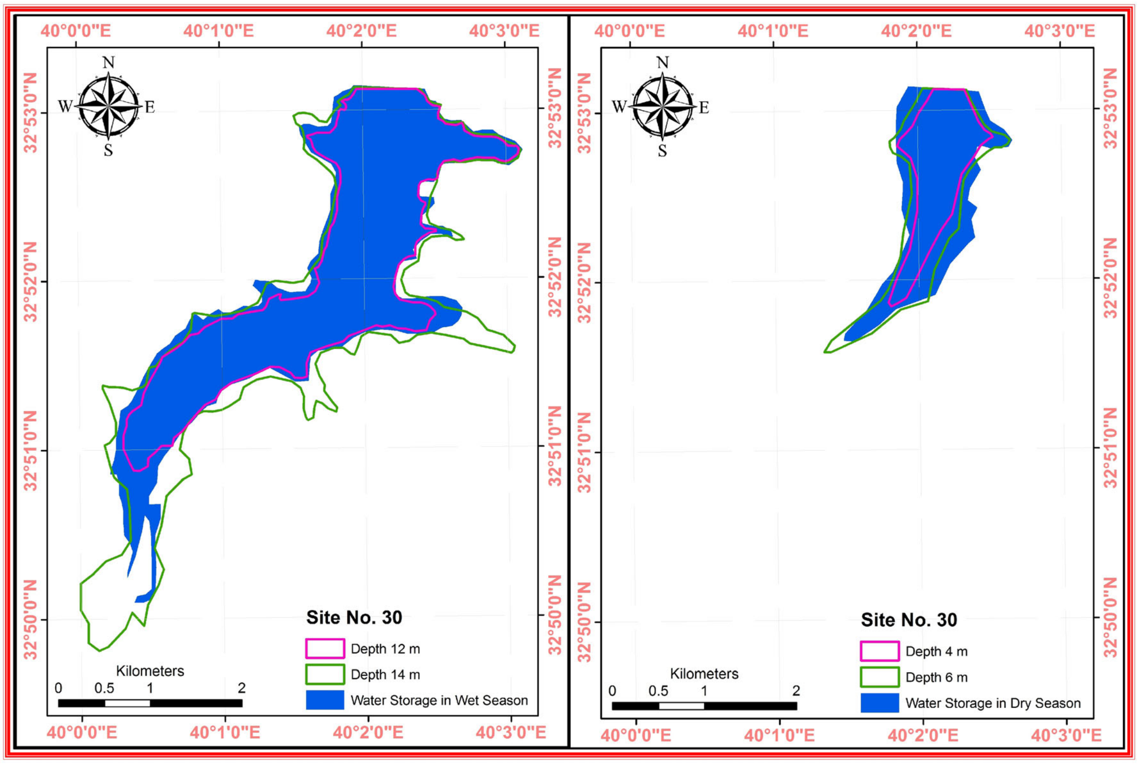
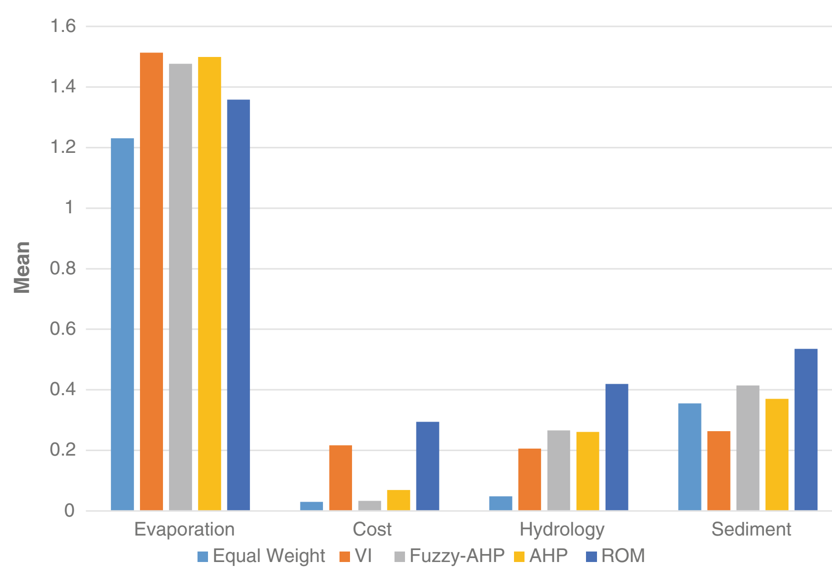


Fig. 7 Water storage at certain level for **a** rainy and **b** dry seasons (March and August) using Landsat 8 imagery, 2013

reduction of fluctuation between the indexes could lead to optimal site ranking. The VI is a statistical method where it sets the weight depending on the values of each index which is more suitable than AHP, fuzzy-AHP, and ROM for site ranking. AHP, fuzzy-AHP, and ROM are methods that depend on decision maker's judgments where these decisions have some inherent uncertainty. In addition, the site selection and ranking processes contain uncertainty because they are based on measurements of hydrological, socio-economic, and geological parameters.

The sensitive analysis about mean has been carried out to determine the reliability of the models through assessment of uncertainties in the output. The sensitivity analysis plot against rank is given in Fig. 8. For all methods, the evaporation index represents the highest effectiveness as compared to other indexes. This is because it represents the nature of the study area, where the evaporation is the main issue in this arid region. Although the fuzzy-AHP approach permits the decision makers to give interval judgments to create weights, it was found that fuzzy-AHP and AHP reduced the cost effect

Fig. 8 Sensitivity analysis



index as compared to other indexes. The ROM and VI methods have affected the priority of ranking, particularly on evaporation index. Therefore, the statistical method is considered as the most suitable method to reduce the uncertainty, where it distributes the parameter effect equally during ranking process.

Conclusion

RWH structure is one of the best solutions for managing water resources in arid regions. This study presented a robust methodology for optimal RWH site selection in remote areas where the availability of qualitative and quantitative data is scarce. This method consists of three phases, i.e., preliminary site selection, qualitative selection, and ranking, which are based on several criteria. The RS and GIS played significant roles in providing the study area with high-quality data where many thematic maps were extracted. The results show that only 32 out of 53 potential sites identified in phase 2 passed the sieving mapping (Boolean overlay), and these selected sites are suitable for RWH in Wadi Horan. The result of ranking site illustrates that the evaporation index has the highest weight than other indexes due to the nature of the study area. The ROM and VI methods have affected the priority of ranking, particularly on evaporation index. Therefore, the statistical method is considered as the most suitable method to reduce the uncertainty, where it distributes the parameter effect equally on the ranking process. In conclusion, the integration of RS and GIS with multi-criteria decision techniques proved to be suitable for site selection in the arid regions and help in preselection process so that field survey can be done more effectively. Finally, the use of GIS and RS in water resource planning and management is significant in the development of remote areas.

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References

Agarwal A, Narain S, Khurana I (2001) Making water everybody's business: practice and policy of water harvesting. Centre for Science and Environment, New Delhi

Al-Adamat R (2008) GIS as a decision support system for siting water harvesting ponds in the basalt aquifer/Ne Jordan. J Environ Assess Policy Manag 10:189–206. https://doi.org/10.1142/S1464333208003020

Al-Adamat R (2012) The combination of indigenous knowledge and geo-informatics for water harvesting siting in the Jordanian Badia. J Geogr Inf Syst 4:366–376. https://doi.org/10.4236/jgis.2012.44042

AL-Furat Center for Studies and Designs of Irrigation Projects (1994) Western desert dams design report of Horan dam H-2

Arnold JG, Srinivasan R, Muttiah RS, Williams JR (1998) Large area hydrologic modeling and assessment part I: model development. J Am Water Resour Assoc 34:73–89. https://doi.org/10.1111/j.1752-1688.1998.tb05961.x

Baban SMJ, Wan-Yusof K (2003) Modelling optimum sites for locating reservoirs in tropical environments. Water Resour Manag 17:1–17. https://doi.org/10.1023/A:1023066705226

Bulcock LM, Jewitt GPW (2013) Key physical characteristics used to assess water harvesting suitability. Phys Chem Earth 66:89–100. https://doi.org/10.1016/j.pce.2013.09.005

Chen Y, Yu J, Shahbaz K, Xevi E (2009) A GIS-based sensitivity analysis of multi-criteria weights. In: Proceedings of the 18th World IMACS/ 13–17.

Consortium-Yugoslavia (1977) Hydrogeological explorations and hydrotechnical work—western desert of Iraq. Blook7, Directorate of western desert development projects. Republic of Iraq (Unpublished)

Critchley W, Siegert K (1991) Manual of water harvesting. Water 154

Elewa H, Qaddah A, El-Fel A (2012) Determining potential sites for runoff water harvesting using remote sensing and geographic information systems-based modeling in Sinai. Am J Environ 8:42–55

FAO (2001) Water harvesting in western and central Africa. Food and Agriculture Organization of the United Nations, Rome

FAO (2003) Training course on water harvesting. L. Water Digit. Media Ser. ;Food Agric. Organ. United Natios

Forzieri G, Gardenti M, Caparrini F, Castelli F (2008) A methodology for the pre-selection of suitable sites for surface and underground small dams in arid areas: a case study in the region of Kidal, Mali. Phys Chem Earth 33:74–85. https://doi.org/10.1016/j.pce.2007.04.014

Hamza NM (2007) Geomorphology of the Iraqi western desert. Iraqi Bull Geol Min 1:9–27

Iraqi Public Authority (2014) Meteorological and seismic monitoring of Iraq

Jamali IA, Mörtberg U, Olofsson B, Shafique M (2014) A spatial multi-criteria analysis approach for locating suitable sites for construction of subsurface dams in northern Pakistan. Water Resour Manag 28:5157–5174. https://doi.org/10.1007/s11269-014-0800-2

Jasrotia AS, Majhi A, Singh S (2009) Water balance approach for rainwater harvesting using remote sensing and GIS techniques, Jammu Himalaya, India. Water Resour Manag 23:3035–3055. https://doi.org/10.1007/s11269-009-9422-5

Jones C (2014) Geographical information systems and computer cartography. Routledge, Abingdon

Kadam AK, Kale SS, Pande NN et al (2012) Identifying potential rainwater harvesting sites of a semi-arid, basaltic region of western India, using SCS-CN method. Water Resour Manag 26:2537–2554. https://doi.org/10.1007/s11269-012-0031-3

Kamel A, Mohammed A (2010) Determination of water harvesting regions in Iraqi western desert using GIS system

Krois J, Schulte A (2014) GIS-based multi-criteria evaluation to identify potential sites for soil and water conservation techniques in the Ronquillo watershed, northern Peru. Appl Geogr 51:131–142. https://doi.org/10.1016/j.apgeog.2014.04.006

Machado ME (2002) Concepts in space science. Universities Press

Maidment DR (1992) Handbook of hydrology. University of Texas at Astin, Texas

Malczewski J (2004) GIS-based land-use suitability analysis: a critical overview. Prog Plann 62:3–65. https://doi.org/10.1016/j.progress.2003.09.002

Mwenge Kahinda JM, Lillie ESB, Taigbenu AE et al (2008) Developing suitability maps for rainwater harvesting in South Africa. Phys Chem Earth 33:788–799. https://doi.org/10.1016/j.pce.2008.06.047

Neitsch S, Arnold J, Kiniry J, Williams J (2011) Soil & water assessment tool theoretical documentation version 2009. Texas Water Resour

Institute, College Station, pp 1–647. https://doi.org/10.1016/j.scitotenv.2015.11.063

Nilsson A (1985) Siting of groundwater dams for rural water supply in developing countries, hydrogeologiacal and planning aspects In: Proceedings of the Fifth World Congress on Water Resources, vol. 3, pp. 1287–1296

Nilsson A (1988) Groundwater dams for small-scale water supply

Oweis T, Prinz D, Hachum A (2013) Water harvesting; indigenous knowledge for the future of the drier environments. J Chem Inf Model 53:1689–1699. https://doi.org/10.1017/CBO9781107415324.004

Pandey A, Chowdary VM, Mal BC, Dabral PP (2011) Remote sensing and GIS for identification of suitable sites for soil and water conservation structures. Land Degrad Dev 22:359–372. https://doi.org/10.1002/ldr.1012

Saaty (1980) The analytic hierarchy process. McGraw-Hill International, Columbus

Safari M, Ataei M, Khalokakaie R, Karamozian M (2010) Mineral processing plant location using the analytic hierarchy process—a case study: the Sangan iron ore mine (phase 1). Min Sci Technol 20:691–695. https://doi.org/10.1016/S1674-5264(09)60264-7

Samra JS, Sharda VN, Sikka AK (2002) Water harvesting and recycling

Sawunyama T, Senzanje A, Mhizha A (2006) Estimation of small reservoir storage capacities in Limpopo River basin using geographical information systems (GIS) and remotely sensed surface areas: case of Mzingwane catchment. Phys Chem Earth 31:935–943. https://doi.org/10.1016/j.pce.2006.08.008

Sayl KN, Muhammad NS, Yaseen ZM, El-shafie A (2016) Estimation the physical variables of rainwater harvesting system using integrated GIS-based remote sensing approach. Water Resour Manag 30:3299–3313. https://doi.org/10.1007/s11269-016-1350-6

Sayl KN, Muhammad NS, El-Shafie A (2017) Optimization of area–volume–elevation curve using GIS–SRTM method for rainwater harvesting in arid areas. Environ Earth Sci 76:368. https://doi.org/10.1007/s12665-017-6699-1

Sekar I, Randhir TO (2007) Spatial assessment of conjunctive water harvesting potential in watershed systems. J Hydrol 334:39–52. https://doi.org/10.1016/j.jhydrol.2006.09.024

Shatnawi G (2006) Determine the best sites for water harvesting projects (Dams & Hafirs) in northeastern Badia using GIS applications. Al al-Bayt University, Mafraq

Stephens T (2010) Manual on small earth dams a guide to siting, design and construction

Tsiko RG, Haile TS (2011) Integrating Geographical Information Systems, Fuzzy Logic and Analytical Hierarchy Process in Modelling Optimum Sites for Locating Water Reservoirs. A Case Study of the Debub District in Eritrea. Water 3:254–290. https://doi.org/10.3390/w3010254

Winchell M, Srinivasan R, Luzio M Di, Arnold J (2010) ArcSWAT interface for SWAT 2009. Users' guide. Temple, Blackland Research Center, Texas Agricultural Experiment Station and Grassland

Winnaar G, Jewitt GPW, Horan M (2007) A GIS-based approach for identifying potential runoff harvesting sites in the Thukela River basin, South Africa. Phys Chem Earth 32:1058–1067. https://doi.org/10.1016/j.pce.2007.07.009

Wolf P, Ghilani C (2012) Elementary surveying—an introduction to geomatics, Thirteenth

Wolman MG (1974) Drainage basin form and process. In: Gregory KJ, Walling DE (eds) A geomorphological approach. Halsted (Wiley), New York

Zadeh LA (1965) Fuzzy sets. Inf Control 8:338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

Ziadat F, Bruggeman A, Oweis T et al (2012) A participatory GIS approach for assessing land suitability for rainwater harvesting in an arid rangeland environment. Arid Land Res Manag 26:297–311. https://doi.org/10.1080/15324982.2012.709214