Locating Site Selection for Rainwater Harvesting Structure using Remote Sensing and GIS

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Abstract. Rainfall is a key source to diminish the problem of water scarcity in the arid and semi-arid regions. Rainwater harvesting is considered an imperious tool for rainwater conservation. Locating the appropriate location for rainwater harvesting structure plays an important role to increase water availability and improve water resources planning. The main goal of this paper is to recognize the proper location for a rainwater harvesting structure using a suitability model generated with ModelBuilder in ArcGIS. Six thematic layers i.e. soil structure, slope, drainage density, vegetation cover, distance to the roads, and runoff depth, are considered to find the proper site for rainwater harvesting structure. The result shows that 12% represents the suitable zone of the total study area, 42% represents the medium suitable area, and 46% represents not suitable areas to implement rainwater harvesting structure. The application of this scheme should maintain any policy adoption for site selection for rainwater harvesting.

1. Introduction
The scarcity of water resources in the western desert of Iraq is the main concern that limits the application and plans of water management [1]. This has affected the wellbeing of citizens, their productivity, health, and environment. Since rainfall is considered a significant natural resource in dry and semi-dry areas. The benefit of collecting rainwater in these regions, where rain often falls during limited months in the year, is of greater importance than its counterparts in humid regions. Its importance increases in areas where no other sources are existing, such as groundwater or transported water, which makes it the most feasible way to ensure human and animal life. The water harvesting process is the key to the use of rainwater for domestic and agricultural purposes. It reduces the impact of drought, and it helps to use runoff water beneficially.

The selection of suitable sites for rainwater collection in large areas is a challenging matter [2]. Locating site selection requires gathering and extracting different data i.e. hydrology, soil, climate, topography, agronomy, and socio-economic [4]. Tackling all these criteria in consideration of the site selection process may be difficult and time-consuming. The clarity in the decision of making the process for siting rainwater harvesting structure becomes more and more vital; especially in data-limited areas. GIS and remote sensing have the ability to ease the process of site selection and could be an effective tool to get clarity to the decisions revolving around site selection for rainwater harvesting structure [5]. Many studies applied remote sensing data and GIS in selecting the optimal sites for rainwater harvesting in arid and semi-arid regions [6], [7], [8], [9], [10], [11].

GIS and geospatial data have played significant roles in water resources management and planning [12],[13]. Both remote sensing data and GIS are important steps to maxims the availability of water
and the productivity of land [14]. The process of site selection by using GIS is based on support decision rules which specify how to combine a certain feature map to well order alternative decision depending on evaluation criteria[15]. Generally, Boolean operators and Weighted Linear Combination techniques are used decision rules in GIS. The Boolean method provides site selection based on using the OR or the AND operations. Several researchers have been used this method, while the Weighted Linear Combination combines maps via applying a standardized score to each class of a certain parameter [16]. This method is flexible in selecting suitable sites and provides better site selection. Several researchers have been utilized this method [17], [18], and [19].

This study focuses on identifying suitable locations for rainwater harvesting structure based on physical and socio-economic characteristics in the western desert of Iraq called (Wadi Al-Muhammad); using a runoff model combined with GIS and remote sensing data.

2. Study area

Al-Muhammad Valley basin is administratively located within Heat district of Anbar Province, with 39° 38’ 11” to 40° 46’ 46” N latitude and 34° 17’ 41” to 32° 47’ 7” E longitude as shown ‘figure 1’. This area was selected because of its current orientation for rainwater harvesting and the possibility of investment in the future. Al-Muhammad valley is situated to the west of Euphrates River. It is bordered by Al-Baghdadi Valley to the north, by Houran Valley to the northwest, by the Amij Valley to the west, and by Gadaf valley to the south and southwest. Accordingly, it is located in the northern Badia plateau within the lower valleys of the natural divisions of this plateau. Al-Muhammad valley stretches long from southwest to northeast. Its total length is 7117 km, and the basin area of the valley is (5332)〖km〗^2; while the number of the stream is (13238) [20].

The climate of the study area is characterized by its semi-arid climate, low rainfall and great contrast between night and daytime temperatures with low humidity. In summer, the temperature rises to 52°, and in winter it drops to 0°. The wind has northwesterly and southwesterly, sometimes with a top speed of 21 m / s. The average annual rainfall in winter is 115 mm which approximately 49% falls in winter, and the average annual evaporation is 3200 mm. The highest and lowest elevations are 572 and 54 m respectively above sea level [21].

![Figure 1. Study area](image)

3. Material and methods

The data used in this study are divided into three major classes, i.e. satellite images, metrological data. Satellite images consist of Landsat image 8 2019 and Shuttle Radar Topographic Mission (SRTM), provided by United State Geological Survey (USGS). Daily and monthly precipitation data from 1980 to 2013 is also used. The geo-reference of satellite image is WGS-84 datum projected zone 38. The soil data is categorized by reference to the FAO global map.
Locating the proper sites for rainwater harvesting is based on many factors problem and it has many objectives. Remote sensing data is used to prepare the thematic input database using ArcGIS. In this research four main stages are adapted and assumed as follows:

1- Rainwater harvesting criteria selection.
2- Suitability assessment levels of the selected criteria.
3- Weights assignment of this criteria.
4- Generate maps using GIS tools

3.1 Considered criteria
According to six factors listed by Food and Agricultural Organization (FAO) i.e (hydrology, climate, topography, soils, socioeconomic, and agronomy) which mentioned by [3], six of these criteria are used based on available literature review, nature of the study area, and expert judgment. These criteria were adopted to determine the most suitable place for rainwater harvesting using the ArcGIS Software by including soil texture, slope, Runoff, vegetation cover, drainage density, and distance to the roads.

3.1.1 Run off depth
Surface runoff in arid and semi-arid environments is one of the most important water resources for rivers, lakes and streams. It is also considered one of the largest weights in the criteria taken in rainwater harvesting[22]. The integration of hydrological soil map and land use land cover is used to generate curve number map. The runoff depth is calculated by the following formula [23]:

\[ Q = \frac{(P-1a)^2}{(P-1a)+S} \] (1)

Where:
- \( Ia = 0.2S \)
- \( Q = \) runoff depth (mm).
- \( P = \) rainfall (mm).
- \( S = \) potential maximum retention after runoff starts (mm).
- \( Ia = \) initial abstraction (mm).

The soil conservation service (SCS) model relies on the Curve Number (CN). CN is unsurprising by means of soil impact and land spread on the precipitation overflow forms [24]. CN is assessed per pixel for the examination region, by means of land spread guide and soil map that was renamed into Hydrologic Soil Groups and hydrologic condition as ‘figure 2’. High CN value indicates that there is a high runoff in the area [25]. As shown in figure 3a, the runoff map of the study area is classified into three classes. This map was generated using ArcGIS.

![Figure 2. Hydrological soil map of the study area](image)

3.1.2 Slope
The generation of runoff is based on the slope, which is considered as an important role, and thus influences the amount of sedimentation as well as the speed of water [26]. It is recommended that the areas of rainwater harvesting should be < 5% because it needs large earthwork prerequisites and these areas are liable to extraordinary erosion amounts as a result of uneven runoff distribution [27]. DEM represented as raster elevation data (grids) provides measurements, analysis and accurate results for
slopes [28]. The slope map is generated using DEM with 30 m resolution, which generated from Shuttle Radar Topographic Mission (SRTM) data, after flat areas and sinks removed via ArcGIS software. The slope map is classified into four classes as shown in ‘figure 3b’.

3.1.3 Soil texture

Soil is one of the most important criteria that determine the appropriate site for rainwater harvesting, which affects the surface runoff and the rate of infiltration. Medium and fine-textured soils are more desired for the process of rainwater harvesting site location [29]. Clayey soil has the capability to clutch the assembled water and low permeability. Therefore, sites with this type of soils are superlative for water conservation [26]. Thus, soil texture is considered as the most important criterion for choosing sites for rainwater harvesting. The soil texture map is categorized by reference to the FAO global map. This map shows that the basin has four types of soil: clay loam, loam, sand clay loam, and silt loam, as shown in ‘figure 3c’.

3.1.4 Vegetation cover

The vegetation index is a quantitative variable to measure the biomass. It usually, consists of the sum of several spectral ranges, and the indicators are formed through a mixture of spectral values that were added in a way that aims to produce one value to indicate the density of the vegetation in each cell. Vegetation plays an important role in the infiltration of soil [30]. Hence, the amount of runoff can be affected directly via the vegetation cover. The sun sends its rays to the Earth, where everything that can be seen falls under the visible range. However, what matters most in this study is the invisible clot represented in the infrared images of the satellite, which reflects a large part of the plant. NDVI is based on the reflection of near-infrared and red radiation, referring to measuring the vegetation activity. It can be extracted through the following equation [31]:

\[
NDVI = \frac{NIR - RED}{NIR + RED}
\]  

Where:

- \(NIR\) = Near Infrared Spectroscopy.
- \(RED\) = Red light.

\(NDVI\) constantly varies between -1 and +1, and there is not a separate boundary for each kind of parcel cover. The increment in the positive value of NDVI indicates that the amount of green vegetation whereas the negative and near-zero values of NDVI indicate non-regulated features, may include other features such as rock, soil (barrier surfaces), and water. Figure 3d shows the spatial distribution of vegetation cover in spring session for the entire study area.

3.1.5 Drainage density

Drainage configuration reflects the subsurface hydrological formation and surface features. It shows the natures of surface material and the closeness of channel spacing. Less the drainage density means lower runoff and vice versa [32]. The total length of the streams was every (2000x2000) m squares. For the study area, Landsat image 8 used to extract drainage density map. The distribution is different due to the density of water flow in relation to each square, as shown in as ‘figure 3e’.

3.1.6 Distance to the roads

The distance of the site selection for rainwater harvesting from the communications network and the main road is one of the greatest socio-economic criteria for the population. People can move their trucks through these roads or when moving to search grass and water for their livestock. For cost consideration, the site must not be remote from existing roads. Moreover, this increases accessibility to the rainwater harvesting sites. For the study area, there are three roads that pass-through Al-Muhammadi valley. According to scales suggested by [17], [18], and [19], the buffer zones are delineated to the right and left of the road in order to pass through Al-Muhammadi valley. This was applied with a magnitude of (<500, 500-1000, 1000-2000, 2000-2000) m to determine the shortest distance that reaches the most suitable place for building dams, see figure 3f.
3.2 Suitability assessment levels of the selected criteria
Due to different scales and measurements in this study, each criterion has been categorized for all the different criteria suggested. The factors itemized in Table 1 to categorize the pixel values according to scales suggested by [17], [18], and [19] literature. All maps created for each factor have a pixel value. The suitability values are categorized into three classes: suitable, medium and low suitable.

3.3 Assignment of weights to the selected criteria
After creating the criteria for overweight by GIS, each criterion is given according to its priority in the water harvesting process. In the reclassification process, the high number is given to the criterion most affecting the water harvesting. As for giving weights to the considered criteria, the high weights are given to the standards that have a high impact on the determination process for rainwater harvesting, as shown in the table1. The current study adopts the weights and rates utilized by [17], [18] and [19] literature, which have alike environmental and physical conditions to this study.

Figure 3. Spatial analysis for (a) runoff, (b) slope, (c) soil texture, (d) vegetation cover, (e) drainage density, and (f) distance to the road.
3.4 Generate maps using GIS tools

The database adopted for identifying a suitable location for rainwater harvesting is developed using ArcGIS with a raster and vector database. The suitable site model was generated using Model Builder in ArcGIS version 10.2 to apply the process for locating suitable sites. The proper areas for rainwater harvesting are identified via reclassifying all the layers and gathering them by raster calculation tools using the spatial analyst tool model. Each criterion is reclassified to numeric values to the entire study area and assigning suitability ratings based on Table 1 values.

| Criteria                  | Classify | weight |
|---------------------------|----------|--------|
| Runoff (mm):              |          | 6      |
| High                      | 3        |        |
| Average                   | 2        |        |
| Low                       | 1        |        |
| Slope:                    |          | 5      |
| 1) 0-3                    | 4        |        |
| 2) 3-5                    | 3        |        |
| 3) 5-10                   | 2        |        |
| 4) >10                    | 1        |        |
| Soil texture:             |          | 4      |
| Clay loam                 | 4        |        |
| Loam                      | 3        |        |
| Sand clay loam            | 2        |        |
| Silty loam                | 1        |        |
| NDVI:                     |          | 3      |
| Vegetation                | 2        |        |
| Barren soils              | 1        |        |
| Drainage density:         |          | 2      |
| Much order                | 3        |        |
| Average order             | 2        |        |
| Less order                | 1        |        |
| Distant to Roads (m):     |          | 1      |
| <500                      | 4        |        |
| 500 – 1000                | 3        |        |
| 1000 – 2000               | 2        |        |
| >2000                     | 1        |        |

4. Results and Discussion

The selection of proper sites for rainwater harvesting plays an important part in maximum water availability and recharge. The process of locating rainwater harvesting structure relying on the characteristics of the watershed. These characteristics are the source that suggests the process of locating the site in a suitable way. Six thematic layers such as soil structure, slope, drainage density, vegetation cover, distance to the roads, and runoff depth are considered to recognize the proper site for rainwater harvesting structure. The spatial analysis of runoff and slope are correlated. The runoff augmented with slope. The runoff depth enlarged in the direction of the downstream area. Each pixel has various scores for the six main layers when using the ArcGIS model. As shown in ‘figure 4’, the result of this model produced a map that has three categorizes zones aimed at rainwater harvesting: suitable, medium and not suitable. The generated map shows that the downstream zones of the catchment are appropriate to implement rainwater harvesting structures. The suitable zone represents 12% of the total study area. While only 42% represents the medium suitable area for rainwater harvesting and 46% represents no suitable areas to implement rainwater harvesting structure. The
major suitable area has a slope between (1-3) % and the main soil texture varied from clay loam to sandy clay loam as well as which having runoff depth. The results of this study are compatible with the study of [29], who showed that the zones having the soil such as clay loam combined with gentle slope are appropriate for implementing rainwater harvesting structure.

For long time studies, the earth dam is the most suitable and commonly utilized using in the study area. The study area has limited infrastructure, skilled labor force, and financial resources. Hence, the construction should be simple; for example, earthwork and stonework should be given top priority [27]. The application of six criteria and the Model Builder in ArcGIS software are conducted in the appropriate zones for dams. Based on estimating the availability of runoff, potential dam locations could be chosen. To minimize the dam dimensions and costs, suitable locations are selected in suitable areas based on visual interpretation. As shown in ‘figure 5’, the cross-section for each site assist planner in analyzing and calculating the features such as height and requisite length of the dam.

The success of the determination of suitable sites for rainwater harvesting does not only depends on biophysical characteristics, but also on the inclusion of the socioeconomic criteria which is significant for gaining meaningful information to improve the effectiveness of the locating rainwater harvesting structure.

Figure 4. Suitable zones for rainwater harvesting

Figure 5. Cross section for suitable site suggested for rainwater harvesting

4. Conclusion
In this study, locating proper sites for gathering rainwater are suggested developed utilizing ModelBuilder in Arc GIS. Six layers i.e., runoff depth, slope, soil structure, vegetation cover, drainage
density, and distance to the roads, are considered to identify the proper site for rainwater harvesting. The result of this study shows that the suitable zone represents 12% of the total study area, 42% represents the medium suitable area for rainwater harvesting and 46% represents not suitable areas to implement rainwater harvesting structure. This study finds that the GIS tool is a very valuable tool for combining various information to identify a proper location for rainwater harvesting as well as it is a flexible, cost-effective and time-consuming tool for screening large scale areas. The result of a suitable map is very convenient for decision-makers and planners for quickly selecting sites for rainwater harvesting in large areas.

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