GIS- based approach for rainwater harvesting site selection

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Abstract. The main obstacle to development in arid areas is the scarce and intermittent rainfall. Water harvesting is considered one of means to grantee the sustainability of water for use in domestic, irrigation and even industry. The current study carried out on Haqlan valley basin in western part of Iraq. The selection of suitable location for rainwater harvesting is based on different key determinates such as environment, hydrology, socio-economic, and topography as well as the estimation of the storage volume and the surface area. This study aims to identify the suitable location for rainwater harvesting using Geographical Information System (GIS) and remote sensing with multi-criteria decision techniques in the study area. Many thematic maps were extracted such as soil map, vegetation cover, land use/land cover, slope, and digital elevation model. The drainage network and the contour line map were used to suggest six sites in the study area. The result shows that the total suitable area for water harvesting was 28% of the study area, while 21% indicated moderate suitability. The proposed method is relatively supportive in analyzing geospatial data to determine and select the optimal site for rainwater harvesting and minimize evaporation losses.

1. Introduction
Water resources are one of the most important criteria for societies building and their development. Only 1% is existing for human consumption, out of 2.5% global fresh water [1]. According to United Nations Development Programme (UNDP) report, Iraq will be in water stress zone because the available water resources have reduced in the year 2000 and 2010[2]. UNESCO has suggested integrated water management in arid and semi-arid areas as high precedence [3]. Planning, Evaluation and management of water resources became one of the most important issues in the humans life, especially in an arid region that characterized extremely limited precipitation and uneven spatially distributed. The west desert of Iraq is one of the biggest arid regions in country which has suffered from severe water shortage, mainly due to its climate condition and lack of water resources planning and management. Therefore, an innovative and cost-effective water conservation alternative should be introduced in the region. Rainwater harvesting structure is considered as one of the best solution to increase the accessibility and availability of freshwater to enhance the quality of life in these regions, and it ensure continuous supply throughout the year.

The selection of rainwater harvesting location is relying on six crucial factors, i.e., hydrology, climate, soil, agronomy, topography, and socio-economic conditions [4]. The consideration of all these factors may increase the difficulty of the site selection process besides making it more time consuming, especially when a large watershed is involved. GIS and remote sensing technology have enabled the simplification of the site selection procedure for rainwater harvesting structures by dropping the number of proposed sites and selecting only optimal locations. Geospatial data and GIS
have been applied in many studies in selecting the sites for rainwater harvesting [5], [6], [7], [8], [9], [10], and [11].

Both geospatial data and GIS have played vital roles in planning and management [12], [13], and [14]. GIS permits the combination of remote sensing maps data and other collateral information, which aids to make decisions that are scientific [15]. Basically, the site selection process of rainwater harvesting using GIS methods rely on support decision rules depending on an evaluation criterion [16].

The main objective of this study is to present a methodology for better decision making to identify suitable site for rainwater harvesting in the west desert of Iraq based on GIS and remote sensing. The highlight of this study that uses the area volume elevation curve as well as other criteria should be useful to identify and determine the most susceptible areas and selecting the most suitable site for rainwater harvesting in the western desert of Iraq. The proposed approach was efficient in terms of cost and time, especially for large study areas.

2. Location of the study
The study area is Haqlan valley basin located in Al-Anbar governorate in the west of Iraq, which in the east of the Euphrates river is located between 33° 53’ 44” to 34° 12’ 00” north and 41° 37’ 53” to 42° 33’ 26” east. It has a catchment area of 452.6 km², as shown in Figure 1. The study area bounded from the south and south east Horan valley, from the north of Haditha lake, and from west Al-Fahami valley.

The climate of the study area is extremely hot, dry in summer and comparatively cold with humid winter. All precipitation occurs in the winter and spring months (October- May). It is noted that all areas of the valley are arid desert lands. The mean annual rainfall of the study area is 116 mm. Despite the lack of and fluctuated rainfall it is falling in heavy rainfall from that result flash floods in drainage stream. The monthly average temperature is 21.6º. The minimum monthly temperature recorded is 8º in January, while the highest monthly temperature recorded is 33 in July. The mean annual evaporation is 3300 mm.

The study area lies within the Euphrates formation and that its components of solid limestone and flint stone. Generally, the rock formations located in the study area are quartz, sandstones, and clays.
3. Data requirement
In this study, three types of data used are: meteorological data, satellite images, and soil characteristics. Satellite images consist of Landsat image 8 and ASTER DEM, and Shuttle Radar Topographic Mission (SRTM) were provided by United State Geological Survey (USGS). Daily and monthly precipitation data from 1980 to 2013 is also used. The geo-reference of the satellite image is UTM-WGS-84 datum projected zone 38. Soil samples are collected throughout the study area and the soil characteristics are determined using laboratory tests.

4. Methodology
The ArcGIS environmental has good tools to support planning and decision making to choose and select suitable areas. The hydrological parameters i.e. flow accumulation stream network and slope were derived from the DEM with 30 m resolution. All sinks were removed in order to keep the continuity of flow to the catchment outlet. Satellite imagery (Landsat 8) with a spatial resolution of 30 m was used to extract land use/land cover.

The model builder of ArcGIS program was developed to find a suitable map for rainwater harvesting. This model generates suitability maps for rainwater harvesting by integrating different criteria maps using weight overly process. All criteria do not have the same importance for determination of potential rainwater harvesting areas. Thus, different weight was identified for these criteria. Site suitability for rainwater harvesting relies on the determination of the best site from a set potential sites by analyzing all characteristics of the candidate sites. To estimate the weight of criteria, the Analytical Hierarchy Process (AHP) method was used. This method based on the pairwise comparison. This method was developed by Satty [17]. All criteria are combined by applying a weight to each followed by a summation of the results to yield a suitability map.

For this study, pairwise comparison was used. The weights of criteria in Saaty technique are computed by applying the main eigenvector of the square reciprocal matrix. The results of relative weights of each criterion are illustrated in table 1.
The purpose for suitable sites for small dam and medium dam can be found based on the suitability map for rainwater harvesting. The features of selected dams i.e. a profile of the dam, length and the height of dams, basin area, and storage capacity were considered. The contour lines per 5m interval and drainage network were used to determine the appropriate locations of the dams. The capability of ArcGIS tool was used to estimate the storage capacity of the dams using the Triangular Irregular Network layer. The length of the dam was derived from DEM while the height derived from the area elevation curve derived from ArcGIS tool.

5. Result and discussion
To identify the potential sites for rainwater harvesting, a short description of the criteria extracted and stored, after defining the catchment characteristics inside the platform of GIS, are discussed below.

5.1. Slope map
Based on 30 m pixel size ASTER DEM in GIS environment as shown in Figure 2, slope map was derived. The slope map is considered an important map in runoff suitability analysis for the catchment area. It effects on recharge and infiltration. Based on guidelines that taken from FAO slope classification, the study area is suitable analysis for potential runoff [18]. The rainwater harvesting is not recommended with average slope of more than 5% [19] Five slope classes and spatial distribution can be distinguish in the study area as shown in Figure 2. The first class (0%-1.2%) and second class (1.2%-2.2%) are represent about 86% of the whole area while the other classes represent about 14%.

5.2. Land use/ land cover map
The land use /land cover map was derived from Landsat satellite images taken in 2014 with spatial resolution 30m. The unsupervised classification was used to classify the study area into two classes i.e., urban and bare soil as shown in Figure 3. These types were recognized depending on the interpretation of the satellite imagery. The overall accuracy of the classification is (99.7%) of each class. Details description for each classes are difference with the time have a large effects on surface runoff. The denser vegetation is highly correlated with higher rates of interception and infiltration, and thus lower runoff [20].

![Table 1. Pairwise comparison matrix.](image-url)
5.3. Soil texture map
Soil is considered a vital input in the selection of a suitable site for rainwater harvesting. The study area lacks an elaborate soil map that shows the variability of soil characteristics among different land use system. Thus, soil samples were taken from some sites which were selected based on unsupervised classification (clustering) classification method were used for the image classification process. GIS capability was used to create a soil map is a main input component to the runoff site suitability. The percentage of clay, silt, and sand were conducted for soil samples. Generally, medium and fine textured soil were more desired for rainwater harvesting because of sites with clay soil are the best for water storage due to low permeability of clay and to hold the harvested water [21]. The soil of the study area ranging between silty sand and sandy loam as shown in Figure 4. This type of soil acceptable for agriculture. This soil regular porosity and its sediments subjected frequently to consolidation at various depths by limestone layer [22].

5.4. Drainage network map
The stream network characteristics of the catchment have an important role in estimating the amount of surface runoff that results from rainfall. The drainage network map determined by the boundary of the basin based on topographic maps by connecting each cell to its neighbor in the direction of principle slope. Two major effects of increasing the resolution coarseness are drainage length and slope. The effect of slope flattening and drainage length on hydrograph response may be compensating [23]. The shorter drainage length accelerates concentration times at the outlet, while flatter slope delay arrival times. Figure 5 illustrates the distribution of the streams in the study area.
5.5. Runoff depth map
The runoff depth is a vital criterion for choosing appropriate sites for rainwater harvesting. The curve number is used to define the runoff properties for definite soil and land use land cover. The soil conservation service runoff equation utilizes the curve number value as input factors. The curve number is a function of hydrological soil group, land use and antecedent moisture content. The basic structure of the soil conservation service curve number method with 5 day yields runoff for any value of the potential maximum retention. The physical description of curve number using dynamical concept of infiltration and attributed its dependence on hydraulic conductivity and soil sorptivity besides others by Singh [1]. The curve number is assessed for the study area on a pixel basis using the hydrological soil map. Infiltration relies on the soil property, which in turn affects the relationship between rainfall and runoff. The high value of curve number denotes to an area with high runoff potential and low infiltration [24]. The rainfall data and curve number map are used to derive the runoff depth layer in term hourly maximum rainfall height for the entire study area, as presented in figure 6.
5.6. Rainwater harvesting potential map

The multi-layer integration of slope, soil texture, land use / land cover, drainage network and runoff depth were presented suitability for determining rainwater harvesting sites in the study area. The suitability map of rainwater harvesting sites was developed, displaying the potential locations for water harvesting in the west desert of Iraq. Analysis of the multi criteria evaluation has aided in determining general suitability areas for rainwater harvesting. Five comparable units were representing the potential sites for rainwater harvesting namely, high suitability, medium, and low suitability. Figure 7 illustrates potential sites for rainwater harvesting and the percentage of area which covered by different suitability zones for rainwater harvesting. It is clear that the suitable zone concentrated in the area with a gentle slope and dense hydrological network. The main areas were more strongly influenced by runoff depth as well as other criteria. The suitability map shows that the total suitable area for water harvesting was 28% of the study area, while 21% indicated moderate suitability.

The length of the dam was derived from DEM, while its height was derived from the area elevation curve based on ArcGIS tools as shown in the figure 8.
The appropriate locations of the dam do not represent all the possible rainwater harvesting sites, but only represent the best locations based on the data derived from area elevation curve. The preferred sites for rainwater harvesting are located where drainage is narrow to get a minimum cost for the structure. Six sites are chosen to implement rainwater harvesting techniques based on thematic maps derived and the volume of runoff at the basin outlet. The simulation method gives a clear idea about how to select these natural reservoirs and what will be the shape form.

A vital analysis carried out in this study is the shape the reservoir based on the area elevation curve extracted using remote sensing data integrated with GIS application [9]. The main assumption of this analysis relies on the storage capacity that can be estimated by computing the surface area at each level. According to nature of study area, the shape of the reservoir has an impact on the evaporation process. Therefore, this analysis able to decrease the evaporation rate as the surface area of storage water is minimized. Since, all the meteorological i.e. precipitation pattern, relative humidity, temperature, solar radiation, and velocity of wind distribute equally with only slight differences throughout of the study area, they had a similar effect on the evaporation rate. Thus, this analysis present in this study. The proposed method is relatively supportive in analyzing geospatial data to determine and select the optimal site for rainwater harvesting and minimize evaporation losses.

6. Conclusion
Remote sensing data and GIS are the necessity in water resources planning and management, especially for developing countries. This approach proved their efficiency according to the nature of the study area. Additionally, the proposed approach was efficient in terms of cost and time, especially for large study areas. The results shows that the total suitable area for water harvesting is 28% of the study area, while 21% indicated moderate suitability. The result of the proposed approach can be used in determining and selecting the most appropriate site for rainwater harvesting, where evaporation losses are minimized.

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