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MULTI-CRITERIA ANALYSIS FOR SELECTING SUITABLE SITES OF WATER HARVESTING IN NORTHERN AL THARTHAR WATERSHED

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Abstract: Water scarcity in Iraq is becoming a critical issue as demand increases, particularly in arid and semi-arid regions. In response, water harvesting (WH) is a promising technique that can effectively catch surface runoff and thus it could cover different water needs and mitigate droughts. The study objective is to identify and select potential suitable sites for theerection of dams for water harvesting in the northern Al-Tharthar watershed. The study focuses on building an integrated GIS-based multi-criteria model and by using Analytic Hierarchy Process (AHP), where relative importance is obtained from (AHP) through use of ArcGIS 10.5. The model combines 7 Biophysical criterions including: slope, elevation, stream orders, annual rainfall, soil texture, land cover/land use, and runoff zones. However, 4 socio-economic criteria include: settlements and roads, population and rural density, agriculture density, and livestock water demand. Biophysical criteria importance weighted around 84.62% whereas socio-economic importance is 15.38% in the model. The final score for the degree of suitability is produced by using Raster Calculator, it includes 5 classes, from very high suitability to very low suitability. The results demonstrated that the middle and northern part has medium and higher degree of suitability for water harvesting. Furthermore, in the research area the medium and higher degree of suitability covers around 64.013% in contrast to 35.987% which is less suitable for water harvesting. Three potential dams have been identified as highly suitable with storage capacity from the first to the third 37,359,680.5 m^3, 76,273,409.9 m^3 and 9,690,685.6 m^3 respectively.

Keywords: Water harvesting, Iraq, GIS, multi-criteria, AHP.

Introduction

Water scarcity of freshwater has dramatically increased globally (Shadmehri *et al.,* 2020). It is becoming a major threat in several countries, particularly in developing ones (Ibrahim *et al.,* 2019). A possible suitable and sustainable alternative water resource for many activities could be harvested rainwater (Ibrahim *et al.,* 2019). Harvesting could effectively capture the surface runoff. It is also a system which is used to collect precipitation around catchment periphery rather than release it as runoff (Hari *et al.,* 2018). Building structures within the catchment to harvest income water, and therefore increase water availability, has become widely used in recent years and has become a success and acceptable practice, especially in arid and semi-arid regions (Adham *et al.,* 2018).

Water harvesting (WH) structures act as a barrier to soil erosion, prevent flooding and ponds for farming (Hari *et al.,* 2018). Among other considerations, local stakeholders prefer water harvesting techniques (Campisano *et al.,* 2017). WH structures act as surface storage and can increase ecosystem productivity (Lloyd & Dennison, 2018). There are ample advantages of using WH techniques in agriculture (Terêncio *et al.,* 2018). such as reliable water source for livestock and provides a clean and renewable water resource (Sarzaeim *et al.,* 2017).

The success of a water harvesting system heavily depends on selecting criteria and features of sites (Lee *et al.,* 2016). Consequently, the main factors chosen for the model of site selection are extremely important and they will be the key to WH system success (Terêncio *et al.,* 2018; Wu *et al.,* 2018). The key role for the success of the water harvesting system is choosing optimal locations to use later in dry seasons. Appropriate site selection in large areas is a great challenge (Adham *et al.,* 2018).

Delineation of possible sites for water harvesting by using an integrated model of different environmental variables and Geographic Information System (GIS) can provide very precise, accurate and powerful procedure for decision makers (Salman *et al.,* 2017; Selamat *et al.,* 2019). Optimal sites for WH and estimating of runoff in large areas are the greatest challenge (Inamdar *et al.,* 2018). The technique of choosing suitable sites through GIS model is based on two different groups of criteria (Socio-economic and Biophysical). GIS can provide very important reliable and accurate information at large spatial scales to estimate and manage water resources (Sagar & Chauhan, 2017). GIS has proven to be successful and is considered to be a robust scientific tool to deal with large multi-spatial data (Al-Jarjees, 2020; Parkinson *et al.,* 2018). It's also an attractive, effective tool in selecting suitable sites for catchment water harvesting (Varade *et al.,* 2017). Analytical Hierarchy Process (AHP) is a technique for multi-criteria analysis. Currently, many researchers depend on GIS and AHP in using multi-environmental criteria and spatial factors to select optimal zones of water collecting (Alkhatib *et al.,* 2019). Combining GIS and AHP methods in selecting sites have shown highly accurare results (Wu *et al.,* 2018). GIS-based multi-environmental criteria and AHP approach for assessing and selecting sites of water harvesting have become widely used. Integrated models can successfully choose the best possible sites for collecting water, on the other hand it can cope with challenges of missing some data (Haile & Suryabhagavan, 2019).

Water shortage becomes a serious issue in arid and semi-arid regions (Alwan *et al.,* 2020). In those regions' rainfall patterns are unpredictable in both quantity and frequency, thus measuring and managing produced runoff is very important. Water harvesting in arid and semi-arid regions has been introduced as an alternative approach which participated in an increase of water availability. Understanding the nature of the catchment regarding hydrological behaviour is the most important step to plan water harvesting strategy (Campisano *et al.,* 2017)

Generally, Iraq is located in arid to semi-arid zones, but it has unstable precipitation trends (Ibrahim *et al.,* 2019). Until 1970, Iraq was classified as a country rich in water resources because of the Tigris and Euphrates rivers running through it (Adham *et al.,* 2018). Water scarcity in Iraq became a critical issue after years of war lack of water policies and management. Moreover, a high proportion of its water discharges directly into the Gulf (Alwan *et al.,* 2020). This one of the most promising techniques for increasing water availability in Iraq (Saleh *et al.,* 2018).

Little attention has been paid on exploring the reliability of implementing water harvesting strategies in arid and semi-arid areas on large spatial scales (Campisano *et al.,* 2017). No research has been done on this scale of criteria, and on socio-economic criteria. The aim of this study is to identify potential sites for water harvesting in northern Al-Tharthar watershed, through using integrated GIS-based model and AHP method, including a comprehensive multi biophysical, environmental and socio-economics criteria analysis.

Materials and Methods

Study Area

Al-Tharthar valley catchment is one of the biggest watersheds in the Nineveh governorate the northwest desert of Iraq (H. Al-Ardeeni, 2018). The catchment includes the Tharthar lake (depression), which is located between the Euphrates and Tigris rivers (Rahi & Halihan, 2018). The catchment is in arid and semi-arid zones with hot summers and cold winters (H. Al-Ardeeni, 2018). The geographic location of the study area stretches from 35° 17' 45.4" to 36° 31' 7.7" N latitude and from 41° 52' 20.4" to

43° 03’ 7.3” E longitude. The catchment covers an area of 6135.77 km^2 as shown in Figure 1.

The catchment is mostly dry all year, however, the rainy season triggers short concentrated floods (Adham *et al.,* 2018). The mean monthly temperature varies from 33.9ºC in summer to 7.8ºC in winter. The annual average rainfall is less than 350 mm. The majority of rainfall, about 49%, occurs in winter, while rains in spring and autumn are at 36% and 15% respectively. The rainy season extends from November to April. The main water resource of the catchment is rainfall (Saleh *et al.,* 2018) which is used for irrigation (Thair *et al.,* 2017) and various agricultural activities, mainly cultivation of barley, wheat and ranching livestock (Al-Ozeer *et al.,* 2020; H. Al-Ardeeni, 2018).

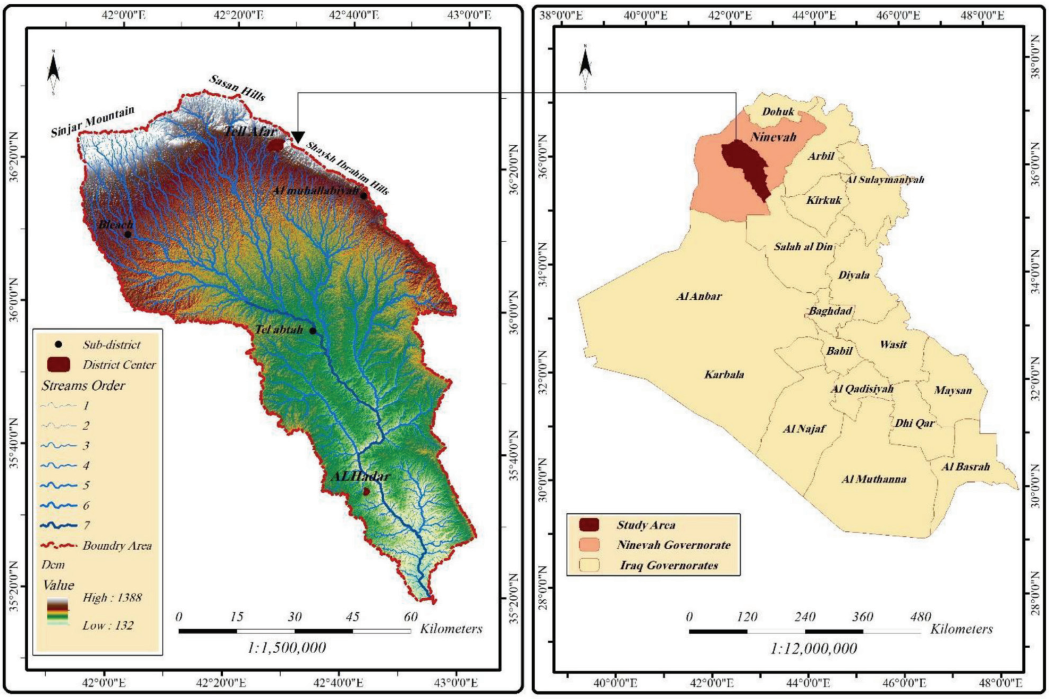


Figure 1: Location of the study area (North AL-Tharthar watershed)

Dataset Collection

Collecting the spatial dataset is an important step in building a GIS model (Alwan *et al.,* 2020). The study used maps produced by using various datasets as illustrated in Table 1.

Table 1: Dataset sources

#	Criteria	Source
1	Slope	Digital Elevation Models (DEM) with 12.5 m resolution obtain from Alaska Satellite https://asf.alaska.edu/
2	Elevation	
3	Stream orders	
4	Annual rainfall	Iraqi Meteorological Organization & Seismology (coverage 2000 to 2014). As measured of 6 meteorological stations. http://www.meteoseism.gov.iq/
5	Soil texture classes	The Digital Soil Map of the World, FAO/UNESCO, Version 3.6, January 2006 and (Buringh, 1960)
6	Land cover/land use	landsat8, LC08_L1TP_170036_20140321, Earth Explore(USGS), https://earthexplorer.usgs.gov
7	Runoff depth	Land cover, Soil map and rainfall data were adopted to produce the runoff depth
8	Settlement centers and roads	Iraqi ministry of Transportation https://www.motrans.gov.iq/
9	Population rural and agricultural density	Directorate of Nineveh Agriculture and Iraqi Central statistical origination http://cosit.gov.iq/
10	Livestock water demand	

Dataset Processing

FAO has listed six essential factors for water harvesting site selection (Inamdar *et al.,* 2018). However, this study integrated seven biophysical and four socio-economic criteria**.** According to literature reviews. socio-economic criteria enhance the process of optimal site selection. Acts as catalyst for sustainable water management, particularly in agriculture areas (Wu *et al.,* 2018). These groups of criteria have not been considered in studies by H. Al-Ardeeni, 2018; *Ibrahim et al.,* 2019. The criteria of the study area have been processed by using ArcGIS 10.5.

Biophysical Criteria

Slope

Slope is the variation between two points within the catchment divided by a horizontal line (Tiwari *et al.,* 2018). Slope is a key parameter in site selection for water harvesting. It has direct impacts on runoff generation, surface water velocity and dams' locations (Ibrahim *et al.,* 2019). Location with slope less than 2% gives higher storage efficiency with low earthwork needs (Walega & Salata, 2019). The slope map is shown in Figure 2 (A1) where it has been classified into six categories according to Zuidam *et al.* (1979).

Elevation

It's also a criterion that plays a key role in selecting potential water harvesting sites. Elevation has a direct relation with water harvesting because higher elevations are less preferable as they will need many earthworks (Adham *et al.,* 2016). Elevation variations that are susceptible to floods provide very important information for more applicable water harvesting process (Mahmoud & Gan, 2018). A map is shown in Figure 2 (A2) that classifies elevations into seven classes.

Stream Orders

The order of streams in the catchment denotes the hierarchical links between stream segments (Adham *et al.,* 2018). It allows the classification of the drainage basin based on their size

Table 2: Soil hydrological group

Soil Group	Potential Runoff	Soil Texture	% in Study Area
A	Low runoff	Sand, Loamy sand and sandy loam	3.992
B	Moderately low runoff	Silty loam and loam	51.977
C	Moderately high runoff	Sand clay loam	44.031

(Ibrahim *et al.,* 2019). Stream order is a critical element in the water harvesting process because higher stream orders have lower permeability and infiltration (Abdulla & Thomas, 2016). The study area has 7th drainage orders as depicted in Figure 2 (A3), with a total length of 11212.84 km.

Annual Rainfall

Rainfall is the most influential factor to identify suitable water harvesting. It's a prerequisite for large-scale harvesting infrastructure (Shadmehri *et al.,* 2020). Rainfall is not only the most important parameter in water harvesting mapping, but also is the base and main source of recharge in the catchment (Adham *et al.,* 2018). It has a direct and indirect impact on the majority of other criteria in planning for water harvesting in arid and semi-arid areas. The map in Figure 2 (A4) illustrates the six zones of rainfall.

Soil Texture Classes

Soil texture classes refer to the percentage of clay, silt and sand in the soil (Rana & Suryanarayana, 2020). It is one of the key parameters in designing and assessing reliability of water-harvesting processes (Shadmehri *et al.,* 2020). Soil suitability is a critical criterion for water-harvesting site selection ast controls regular hydrological response (Adham *et al.,* 2018). Fine and medium soil textures are typically more preferable for water harvesting because of their higher ability to retain water (Lee *et al.,* 2016). The study area has three soil hydrological groups as depicted in Table 2 and in Figure 2 (A5). The data of soil texture classes taken from the FAO and (Buringh, 1960).

Land Cover/Land Use

Land cover use is a key criterion for water-harvesting processes. It can affect the hydrological response of streams in a catchment; thus, it will have a sensitive effect on runoff (Ibrahim *et al.,* 2019). Land cover refers to the vegetation cover in an area. It's linked directly to a high proportion of infiltration and low runoff.(Shadmehri *et al.,* 2020). The land use is considered as a key element in selecting and implementing water-harvesting processes (Shanableh *et al.,* 2018). The map of land cover/ land use is in Figure 2 (A6).

Runoff Depth

Runoff is a significant element in identifying suitable sites for water harvesting (Ibrahim *et al.,* 2019). The runoff estimation the SCS-CN method (NRCS, 2004). The SCS-CN method used widely (Tiwari *et al.,* 2018). Hydrological soil groups (Rana & Suryanarayana, 2020), land cover / land use and rainfall were used to derive curve numbers to estimate runoff depth in the study area (Maizi *et al.,* 2020). The potential runoff depth of the study area was divided into nine zones and is shown in Figure 2 (A7) . The high runoff starts in the north and gradually lowers to the south.

Socio-economic Criteria

Settlement Centers and Roads

Proposed sites of water harvesting have to be reasonably accessible for construction, usage and maintenance. However, they should be some distance from main roads. Very close locations to main roads might increase the possibility for

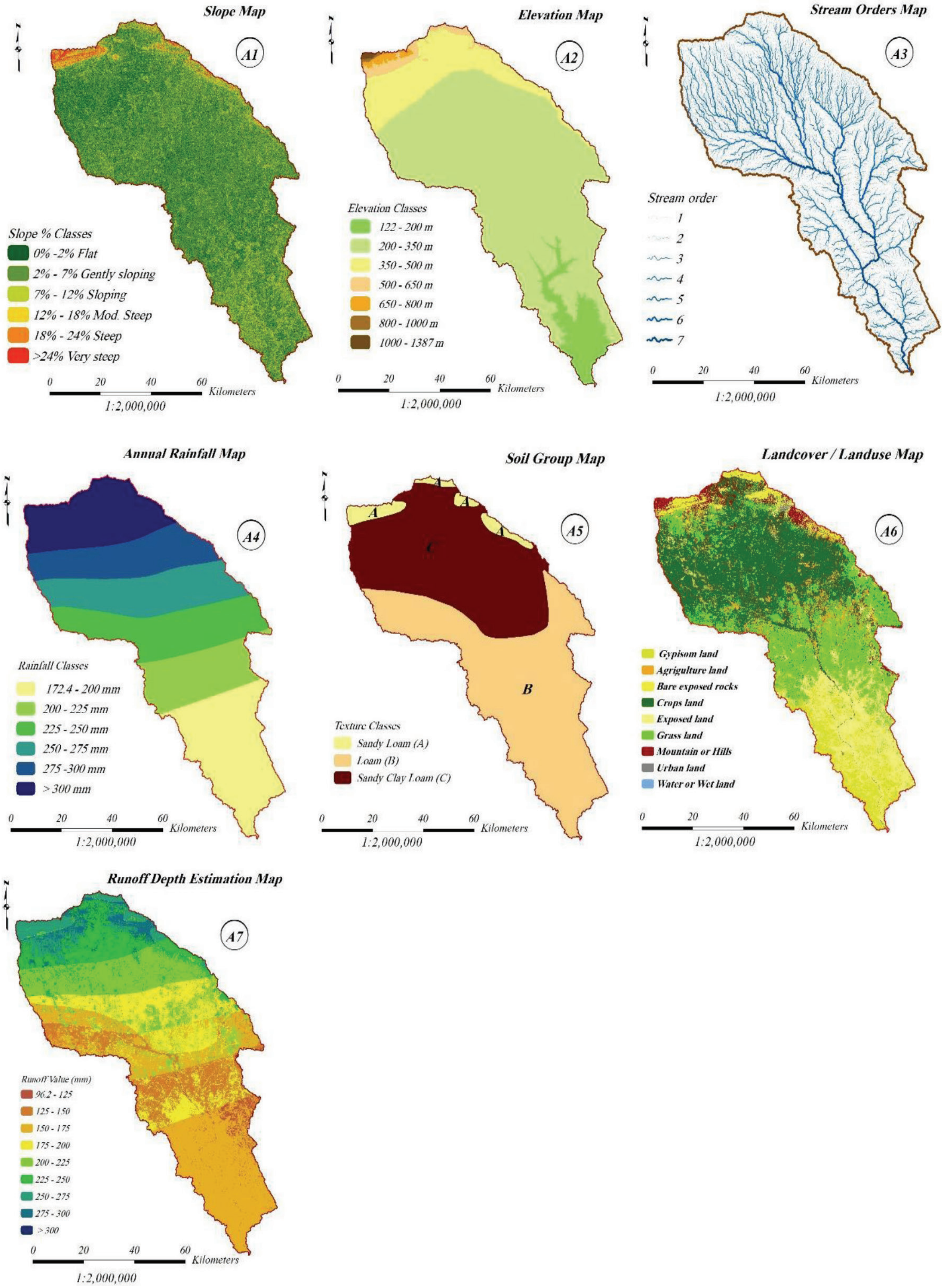


Figure 2: (A1, A2, A3, A4, A5, A6 and A7) of biophysical criteria

surface water pollution (Wu *et al.,* 2018). The study area has two districts, three sub-districts and 67 villages, which is shown in Figure 3 (B1). The area has a total 55.23 km and 219.95 km respectively of main and secondary roads.

Population and Agricultural Density

The distance from settlements is a key socio-economic criteria for selecting optimal water-harvesting sites. Proposed sites close to residential areas and agriculture activities are most likely advantageous (Lloyd & Dennison, 2018). Stored water is a vital potential source for agriculture and population settlement. Moreover, nearby locations will reduce the distance of pumping and diversion systems, thus it would be preferable for stakeholders as it is cost effective. Distance from agriculture is also an important factor for sustainable water-harvesting and it generally follows the same pattern of distance to population density (Wu *et al.,* 2018). Figures 3 (B2) and (B3) illustrate them.

Livestock Water Demand

The Figure 3 (B4) illustrates the livestock water demand. The water demand refers to the water requirements for many purposes including

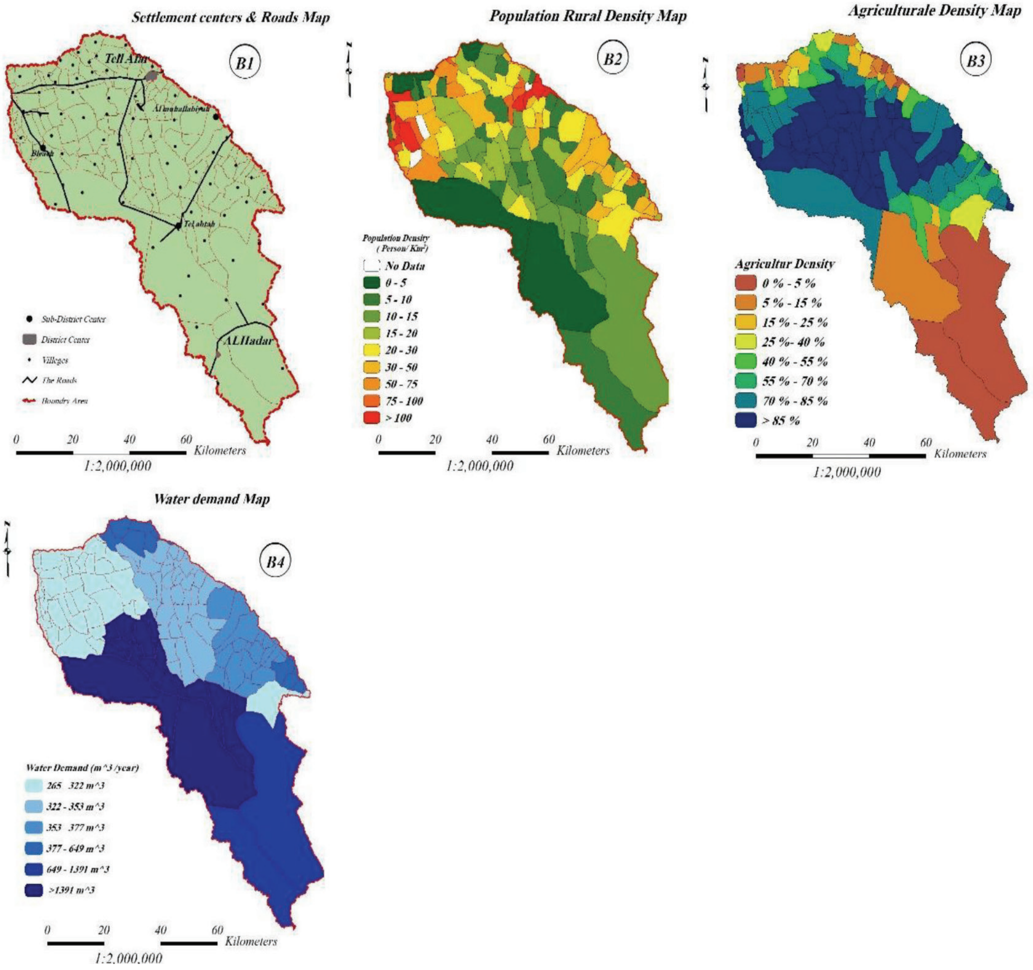


Figure 3: (B1, B2, B3 and B4) socio-economics criteria

agriculture, domestic use and livestock (Singh *et al.,* 2017). The study area is mainly agricultural, mostly barley and wheat, which consumes about 89% of its water. Sheep rearing is also a major user. Water demand is estimated based on daily average needs for livestock and crops (Al-Furaiji *et al.,* 2016).

Analytic Hierarchy Process (AHP)

AHP is a statistics tool for multi-criteria decision analysis. It is used to weigh different parameters to prioritize choices among criteria (Saaty, 2008). AHP allows researchers to assign weights of criteria against others (Tupenaite *et al.,* 2017). It iss utilized to weigh criteria separately according to their importance even though they are tangible or intangible (Shanableh *et al.,* 2018). The principle of AHP, according to Ochir *et al.* (2018), stands on the concept of "Decomposition, comparative judgment and synthesis of priorities". The weights are given from 1-9, where 1 refers to equally important, while 9 means that the parameter has much more importance than others (Saaty, 2008). The AHP method in this study used to weigh and rate input criteria for selecting suitable water-harvesting locations. The weight of certain study criteria was based on experts' opinions, discussion with local authorities and literature review as shown in Table 4. The Table 3 demonstrates 14*14 of pairwise comparisons. First, set a hierarchy system of variables (Faisal & Ahmed, 2018). Second, is to derive weights from a pairwise comparison of the importance between each two relevant parameters. Finally, the consistency ratio is calculated according to pair-wise comparison (Ochir *et al.,* 2018). Super Decision **(**SD) software 20.8 is used to assess weighting accuracy (Faisal & Ahmed, 2018). The consistency ratio of our AHP matrix is 0.0123. The criteria weight of the study is acceptable because consistency ratio is less than 0.1 (Alkhatib *et al.,* 2019; Faisal & Ahmed, 2018; Ochir *et al.,* 2018; Saaty, 2008; Tupenaite *et al.,* 2017)

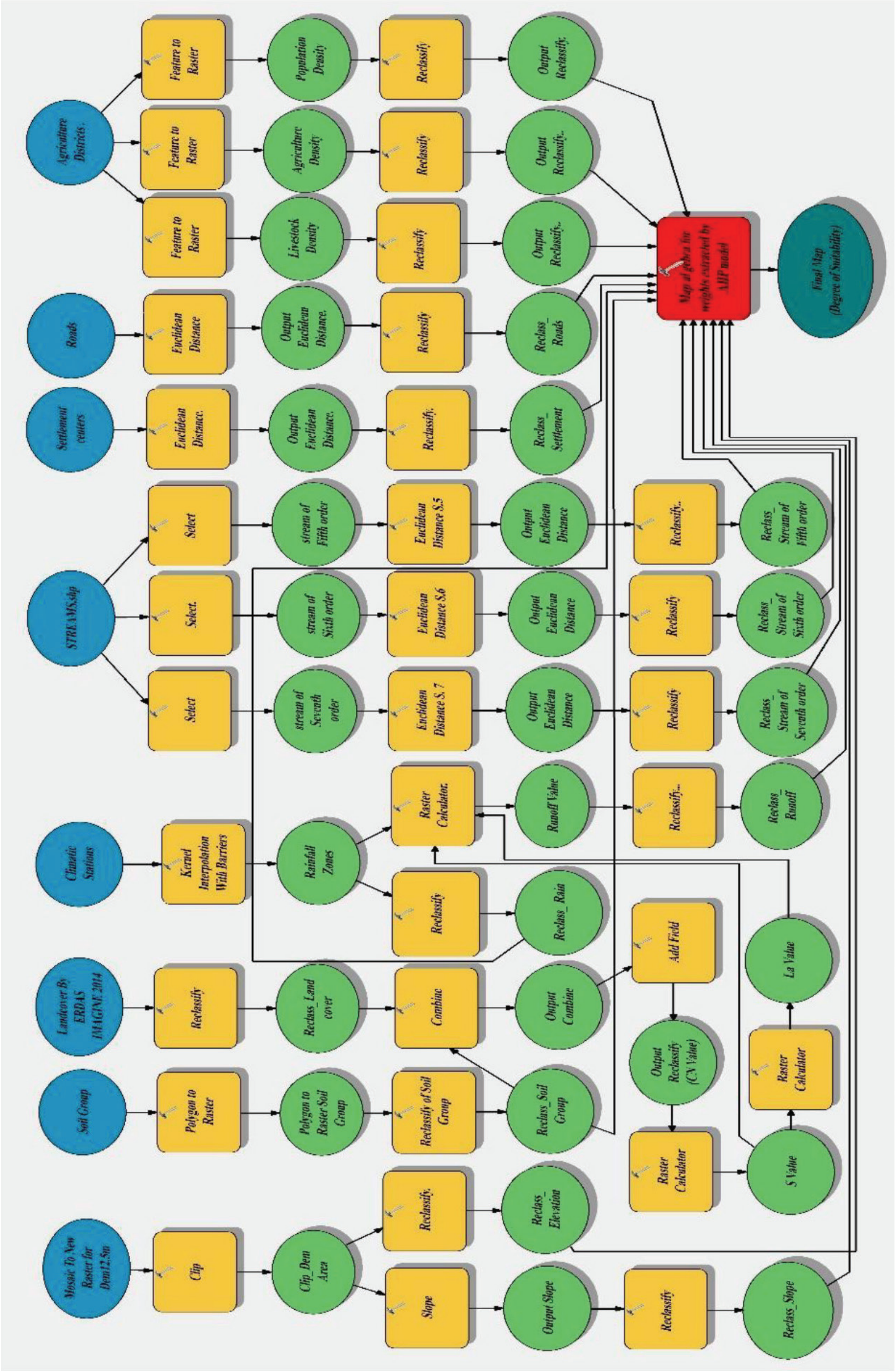
GIS Model Building

The suitability model developed using ArcGIS 10.5 creates a water-harvesting map by merging compatibility criteria of both vector and raster databases using a weighted linear combination process. The criteria that were prepared to input into the model includes re-classification of criteria according to the degree of impact and relative importance in Table 3 to obtain criteria weight. Then, after converting the formulas of all parameters from the Vector data to the Raster data weights to each category of these variables as shown in Table 4 were assigned. The model aims to extract the Suitability Degree map by using the approach of average weighted, where it's prepared by multiplying the variable weight obtained through AHP by its rank in Table 4 as in equation 1. The final output was collected to obtain the pixel validity of the map in percentage by using the Algebra expression (Raster Calculator). The highest pixel values are isolated, which represents the highest degree of validity through using the same tool. Figure 4 expresses model steps.

$$D.S=\sum \qquad Wi\,XiD.S=\frac{(Xx*Wx)*100}{900} \qquad \text{……..}\ 1$$

Table 3: AHP matrix and criteria weight

AHP Matrix Consistency Ratio= 0.0123			1	2	3	4	5	6	7	8	9	10	11	12	13	14	Criteria Weight
			Stream of Seventh Order	**Run off**	**Land Cover**	**Stream of Sixth Order**	**Slope**	**Soil Group**	**Rainfall**	**Agriculture Density**	**Pop Density**	**Stream of Fifth Order**	**Elevation**	**Livestock Density**	**Settlement Centers**	**Roads**	
Items:	**1**	Stream of seventh order		1	2	2	2	2	4	5	5	4	5	6	6	7	**16.61%**
	2	Runoff	1		2	1	1	1	3	4	4	3	4	5	4	6	**12.78%**
	3	Landcover	1/2	1/2		1	1	1	2	3	3	3	4	4	4	6	**10.86%**
	4	Stream of sixth order	1/2	1	1		1	1	2	3	3	3	3	4	4	5	**10.38%**
	5	Slope	1/2	1	1	1		1	2	3	3	3	3	3	4	5	**10.06%**
	6	Soil group	1/2	1	1	1	1		2	3	3	2	3	3	4	5	**9.74%**
	7	Rainfall	1/4	1/3	1/2	1/2	1/2	1/2		2	2	2	2	3	3	4	**6.89%**
	8	Agriculture density	1/5	1/4	1/3	1/3	1/3	1/3	1/2		1	1	1	2	2	3	**4.24%**
	9	Pop density	1/5	1/4	1/3	1/3	1/3	1/3	1/2	1		1	1	2	2	3	**4.24%**
	10	Stream of fifth order	1/4	1/3	1/3	1/3	1/3	1/2	1/2	1	1		1	1	2	2	**3.70%**
	11	Elevation	1/5	1/4	1/4	1/3	1/3	1/3	1/2	1	1	1		1	2	2	**3.58%**
	12	Livestock density	1/6	1/5	1/4	1/4	1/3	1/3	1/3	1/2	1/2	1	1		1	2	**2.83%**
	13	Settlement centers	1/6	1/4	1/4	1/4	1/4	1/4	1/3	1/2	1/2	1/2	1/2	1		2	**2.48%**
	14	Roads	1/7	1/6	1/6	1/5	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1/2		**1.59%**



D.S = Degree of Suitability, Wi = Criterion weight (AHP outcome), Xi = criteria rank in Table 4.

Figure 4: Flow chart of potential WH sites selection model

Table 4: Biophysical and socio-economic criteria, rank, sub-class and AHP weight

Biophysical Criteria				
No.	**Variable**	**Classes**	**Rank**	**AHP**
1	Stream of seventh order	0-1000m	9	**16.61%**
		1000-2000m	6	
		2000-3000m	3	
		>3000m	1	
2	Stream of sixth order	0-1000m	9	**10.38%**
		1000-2000m	6	
		2000-3000m	3	
		>3000m	1	
3	Stream of fifth order	0-1000m	9	**3.70%**
		1000-2000m	6	
		2000-3000m	3	
		>3000m	1	
4	Runoff	96.2-125 (mm)	1	**12.78%**
		125-150 (mm)	2	
		150-175 (mm)	3	
		175-200 (mm)	4	
		200-225 (mm)	5	
		225-250 (mm)	6	
		250-275 (mm)	7	
		275-300 (mm)	8	
		>300 (mm)	9	
5	Land cover/land use	Urban & settlement Rural land	0	**10.86%**
		Gypsum land	2	
		Mountain or hills	3	
		Bare exposed rocks	3	
		Exposed land	6	
		Grassland	8	
		Agriculture land	8	
		Water or wet land	8	
		Crops land	9	
6	Soil group	A	3	**9.74%**
		B	6	
		C	9	
7	Rainfall	172.4-200 (mm)	2	**6.89%**
		200-225 (mm)	3	
		225-250 (mm)	5	
		250-275 (mm)	7	
		275-300 (mm)	8	
		>300 (mm)	9	

Biophysical Criteria

No.	Variable	Classes	Rank	AHP
8	Slope	0% - 2% Flat	7	**10.06%**
		2% - 7% Gently sloping	9	
		7% - 12% Sloping	7	
		12% - 18% Mod. steep	5	
		18% - 24% Steep	3	
		>24% Very steep	1	
9	Elevation	122-200 m	9	**3.58%**
		200-350 m	8	
		350-500 m	6	
		500-650 m	4	
		650-800 m	2	
		800-1000 m	1	
		1000-1387 m	0	

Socio-economic Criteria

No.	Variable	Classes	Rank	AHP
1	Settlement centers	0-1000 m	0	**2.48%**
		1000-2000 m	9	
		2000-3000 m	7	
		3000-4000 m	5	
		>4000 m	3	
2	Agriculture density	0-17.5	2	**4.24%**
		17.5-35	4	
		35-52.5	6	
		52.5-70	8	
		>70	9	
3	Population density	0-5	2	**4.24%**
		5-10	2	
		10-15	4	
		15-20	4	
		20-30	6	
		30-40	8	
		>40	9	
4	Livestock water demand (mm^3/year)	264-500	3	**2.83%**
		500-750	5	
		750-1000	7	
		>1000	9	
5	Roads	0-150 m	0	**1.59%**
		150-1000 m	9	
		1000-2000 m	7	
		>2000 m	5	

Results and Discussion

Potential Water-Harvesting Sites

The map in Figure 5 shows the results of the suitability degree for water harvesting and location of potential dams. It was developed by integrating multi-criteria evaluation by GIS based on an AHP statistical method, taking into account 14 layers, in order to yield the final map of optimal water harvesting suitability. Five comparable classes are used to indicate the degree of suitability for potential water-harvesting sites: very high suitability, high suitability, medium suitability, low suitability and very low suitability. Figure 5 indicates that the north and middle of the study area are much more suitable for water harvesting compared to the south. The outcomes show that medium suitability has the largest percentage at 37.77% (2315.72 km^2) followed by low suitability at 29.10% (1784 km^2) and then high suitability at 24.895% (1525.9 km2). However, very low suitability and very high suitability covers 6.881% (421.80 km2) and 1.339% (82.06 km2) respectively. As illustrated in Figure 6, around 63% of the study area is suitable for water harvesting. In addition, the three dams were located in high suitability areas. Table 5 shows the coordinates for them.

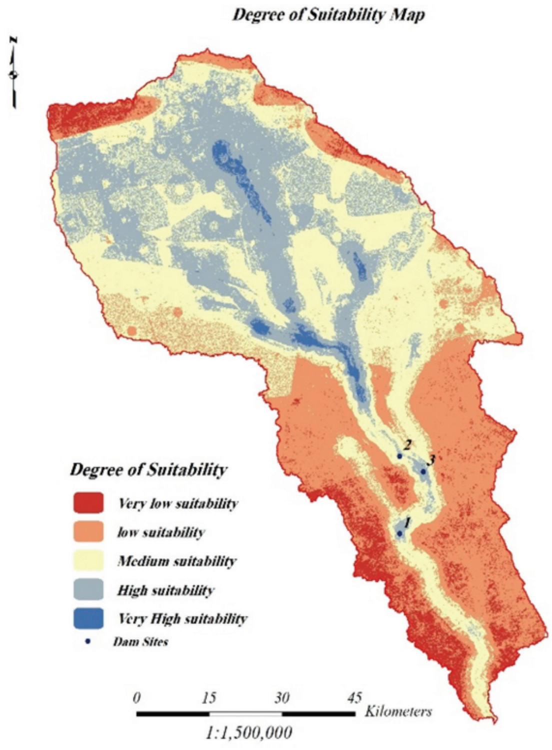


Figure 5: Degree of suitability and potential suitable sites for water harvesting

Table 5: Storage capacity and coordinates of proposed dams

Dam	Storage Capacity (m^3)	Latitude	Longitude
1	37,359,680.5	35° 39’ 5.8196” N	42° 42’ 26.8565” E
2	76,273,409.9	35° 47’ 20.5545” N	42° 42’ 13.8538” E
3	9,690,685.6	35° 45’ 45.4550” N	42° 45’ 31.4739” E

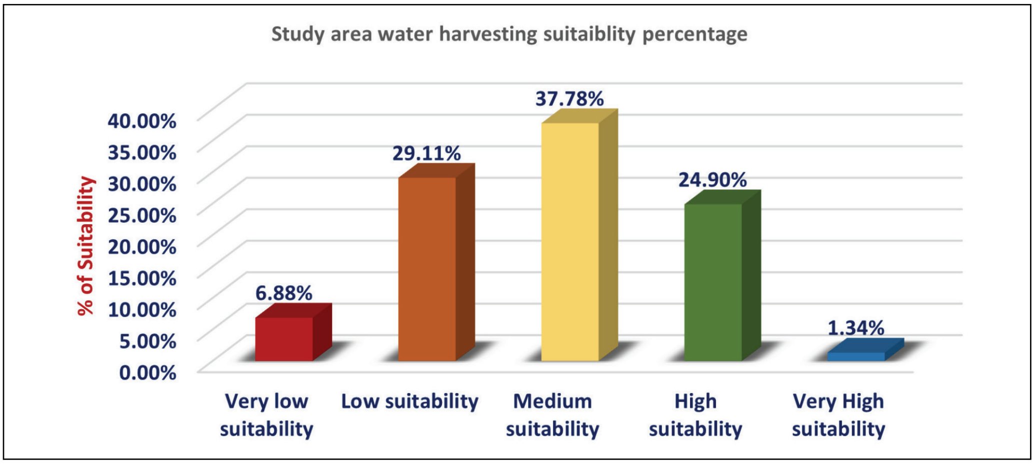
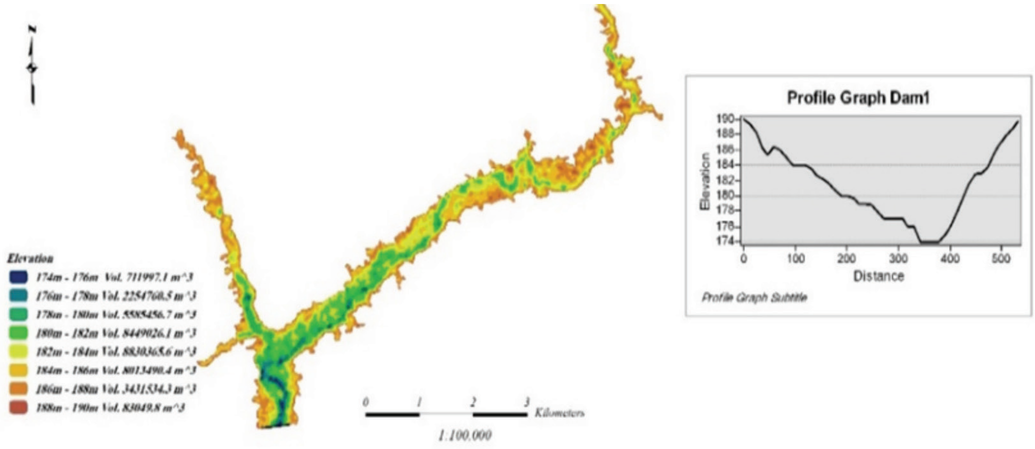


Figure 6: Percentage of water harvesting suitability in the research area

Proposed Sites for Dams

Dams are the most common and appropriate structure for water harvesting (Adham *et al.,* 2018). The Triangulated Irregular Network (TIN), drainage layer and contour lines functions of the ArcScene program are used to get a cross-section profile of the proposed dam sites in the study area. The TIN and polygon volume tools are used to calculate volume and height of dams with contour interval 2m. The storage capacity and profile of the three potential dams are shown in Figure 7.



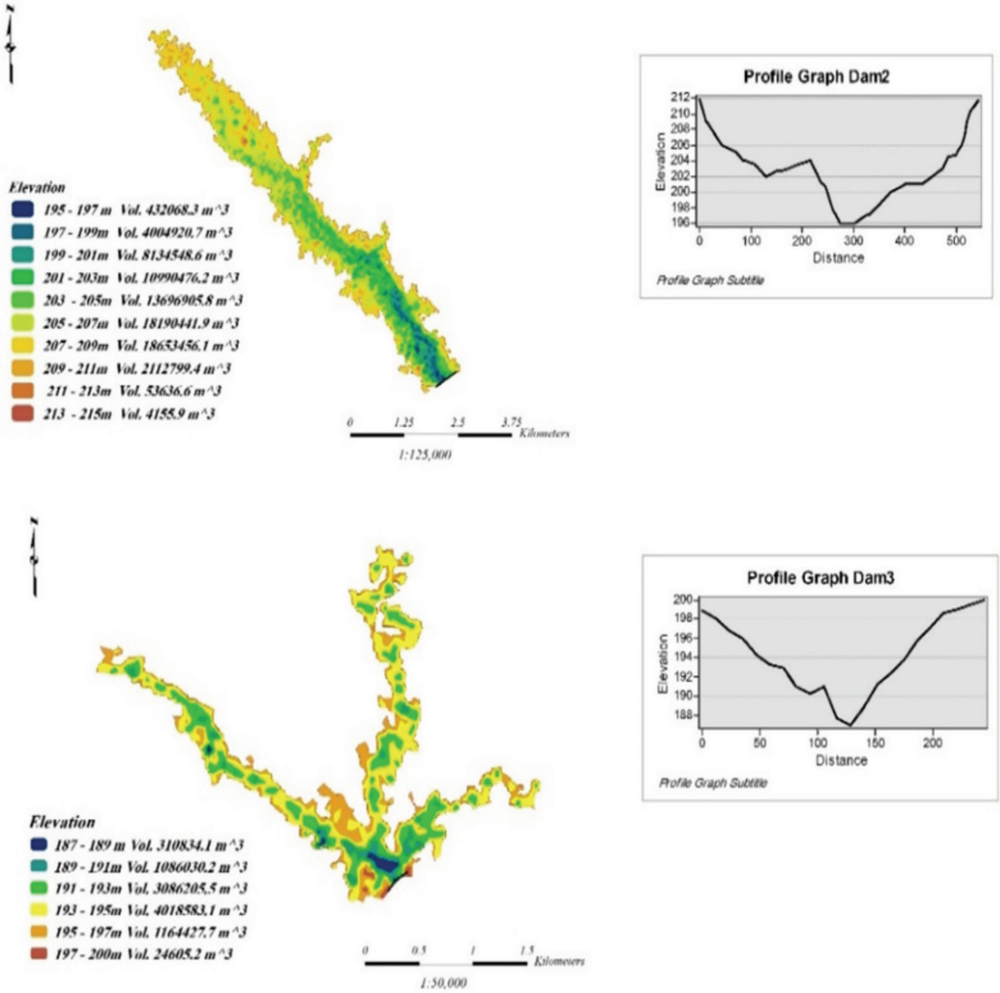


Figure 7: Proposed dams' details, elevation, cross section and storage capacity in the study area

The results of the model and AHP analysis indicate that the study area is suitable for building water harvesting structures. From the central to northern region, a medium degree of suitability is found. The suggested sites have gentle slopes, which are crucial elements in water-harvesting structures as they enhance collection of runoffs. Ibrahim *et al*. (2019) suggested that slopes steeper than 7% are unsuitable due to irregular and rough runoff flow. They also require more earthworks. The potential sites are in zones receiving enough annual rainfall to trigger reasonable amounts of runoff. Stream order is a key element in the selection of harvesting sites. It reflects the permeability and infiltration of water. However, higher stream order is directly proportional to the high runoff supply of potential storage sites. The three dams are located on 7th order streams, so they have continuous water flow.

All proposed sites are very close to intense agriculture activities, and will serve agricultural demand for water, including livestock. The sites are near, but not too close to main and secondary roads, as the distance (0-150m) is restricted (Wu *et al.,* 2018). They are also near the villages, so that not many earthworks are needed. These structures in inhabited croplands are more practical than relocating them to potential harvesting sites. The results of this study agree with previous studies on water harvesting site selection (Adham *et al.,* 2018; Alwan *et al.,* 2020; H. Al-Ardeeni, 2018; Ibrahim *et al.,* 2019; Salman *et al.,* 2017; Walega & Salata, 2019). These locations for water harvesting can fulfil the water demand for livestock, agriculture as well as human populations (Krois & Schulte, 2014). Water harvesting could raise agriculture production and can be an alternative source of water (Perez-Uresti *et al.,* 2019). The proposed locations are in an area facing high risk of drought.

This research has valuable outcomes as it suggests a sustainable solution for water shortage in arid regions. However, it emphasizes that the model does not take into consideration the economic feasibility of implementing a water harvesting system and the quality of stored water. Therefore, future research on such aspects should be done.

Conclusion

Water harvesting is a potential technique to effectively cope with water scarcity. The study is conducted on a large watershed in Iraq that is facing water scarcity. The study was based on the suitability model derived from ArcGIS 10.5, GIS-based multi criteria and AHP tool to determine the potential site for water harvesting. This study also tries to incorporate biophysical and socio-economic criteria in the selection for suitable water harvesting sites. The study indicates that GIS-based multi-criteria can produce an integrated model, which is very effective in achieving the objectives of the study. The results concluded that the northern and central sections of the study area have higher degree of suitability for water harvesting. These areas have higher elevation, rainfall, runoff rate and complex drainage networks compared to the southern part. The three proposed sites for dams are in a high suitability area with reasonable storage capacity. For further validation, field work investigation will provide more insight into socio-economics parameters.

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