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Insights of dam site selection for rainwater harvesting using GIS: A case study in the Al- Qalamoun Basin, Syria

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A R T I C L E I N F O

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A B S T R A C T

Today's world is plagued with water shortages, especially in developing countries. The problem is made worse by increasing water demands and decreasing rainfall occurrences in arid and semi-arid areas. Rainwater harvesting (RWH) has the potential to be a viable solution for this issue, as it can augment existing water supplies in the long term. This study aimed to identify suitable areas for RWH using a multi-criteria decision analysis (MCDA) based on the analytic hierarchy process (AHP) method, combined with geographic information system (GIS) and remote sensing (RS) techniques. This study has been carried out in the Al-Qalamoun Basin, the western part of Syria, which has not been studied for rainwater harvesting before. To fill this gap, a potential RWH map was created in the Al-Qalamoun Basin using nine factors, which are land use and land cover (LULC), soil texture, slope, rainfall, curve number (CN), stream order, distance to faults, distance to roads, and distance to residential areas. All thematic layers were allocated appropriate weights and combined using the weighted Overlay process (WOP) in ArcGIS 10.8 to produce a RWH map of the study area. The findings indicated that about 18.1% of the total study area was classified as most suitable and suitable for RWH. Validation of the RWH map with the existing dams indicated that the methodology adopted in this study had a high capacity to identify sites suitable for RWH. The study presents a useful and inexpensive tool for decision-makers to avoid unsuitable sites and focus on the most suitable sites for constructing dams.

1. Introduction

The world population and economic development are increasing day by day; consequently, the water demand will be more to meet the people's needs over the earth, whereas the rate of consumption of water is double increasing with the population. Furthermore, water availability is decreasing according to many factors, such as agriculture, industry, and climate change. In the last 100 years, the global water demand has increased by 600% [1]. According to the United Nations (2015), the population growth of people will

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increase in 2030 to become ~8.5 billion. That will be double the people population, which was in 1980 [2]. It will increase the water demand and lead to a water crisis that will break into the world [3]. Food and Agriculture Organization (FAO) maintained that the water availability for a person will decrease to half by 2025 [4]. In Syria, there is an expectation of water resources reducing at the beginning of 2050 due to climate change creating more water scarcity [5]. Therefore, enough water for future generations must be ensured.

Rainwater is considered an essential water resource in Syria, where the average annual precipitation is estimated at 46 billion m^3. However, in the drought years, this number decreases significantly [6]. Due to the irregular precipitation, spatial and temporal unequal water distribution occurs in the arid years. Therefore, applying rainwater harvesting (RWH) is a practical and effective storage method during water scarcity periods [7]. Water resources are widely affected by several factors, such as climate change, as one of the most significant factors. Less rain in the drought time and non-harvesting rainwater lead to water shortage [8]. Thus, RWH was one of the most necessary measures listed in the assessment report of the Intergovernmental Panel on Climate Change (IPCC) 2007 to deal with climate change and evaluate water resource management in the future [9].

RWH is defined as an approach to preserve the rainfall that runoff on the surfaces and is trapped to use later [10]. Thus, the rainwater is collected from the roof of the houses' surfaces, catchment areas, and streams and then harvested in storage tanks. Usually, the harvested water is used for irrigation and watering the crops as well for domestic issues [11]. RWH plays a vital role in several economic, social, and ecological aspects and is widely applied, especially in arid areas which are suffering from water shortage. It helps to reduce groundwater depletion and enhance the water table as a result reducing the pressure on the ecosystems [12], whereas many studies showed that RWH techniques extensively contribute to enhancing the groundwater recharge and increasing agricultural productivity, which deeply depends on sustainable water resources, especially in the dry areas [13]. RWH methods are very old and have been extensively used in many countries in the past, such as China, India, and some African and Arabic countries. These techniques were used in commercial, agriculture, and human utilization by applying simple ways that developed gradually later [14]. In these days, there are many problems that are deeply linked to the water supply in urban areas, such as the increasing water demand, fewer water resources and population growth, the high depletion of groundwater, and increasing surface runoff due to the wide road constructions. According to the above-maintained problems, the awareness of the RWH system is increasing in developing countries [11,15].

Generally, two sufficient factors influencing the RWH approaches would be applied in the study area. The first one is biophysical, and the other one is socio-economic factors. As well, the optimum understanding of these factors depends on the nature of the study regions, for instance, in terms of biophysical criteria, such as soil erosion and type, weather, land use and land cover (LULC), drainage network, distance to the stream and roads, and topography, which help more in valuable choices in RWH adoption and identify the most suitable areas for harvest the rainwater [14,16]. The first one who mention the link between the RWH system and socioeconomic factors for site selection was Oweis and Prinz (1998), and the most influential factor related was the cost.

Many methods are widely used in determining the suitable sites for water harvesting, such as RS and GIS applications, hydrological

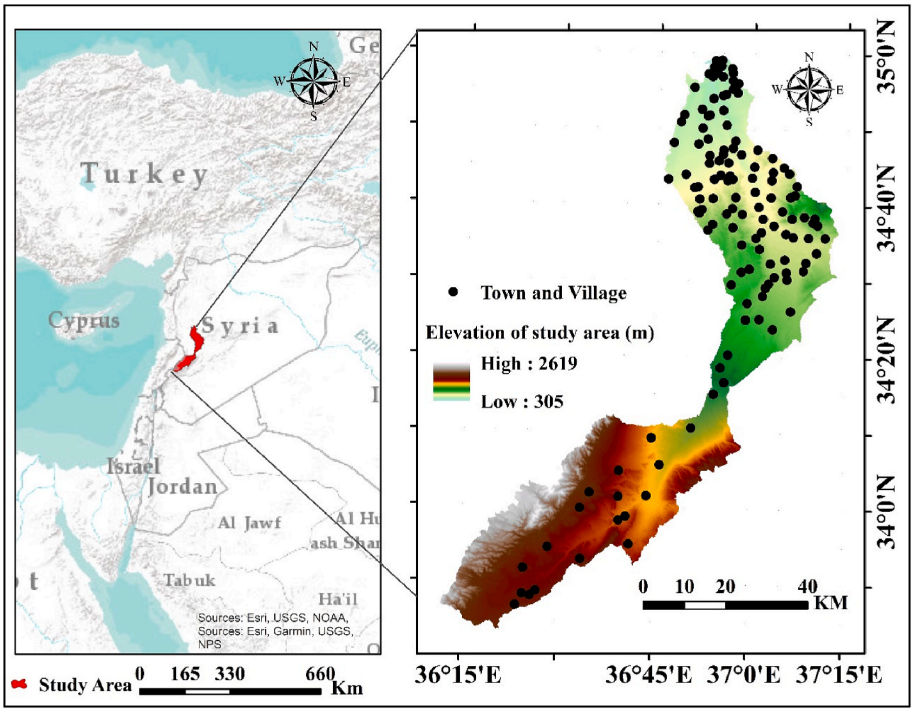

Fig. 1. Location map of the study area.

modeling (HM) with RS and GIS, and multi-criteria decision analysis (MCDA) depending on the HM approach [11,17–19]. RS and GIS methods are the most effective methods, whence the cost and time consumption also provide an accurate spatial and temporal resolution for RWH site selection. Even with the lack of information problems in the study areas that can face the researchers in developing countries, GIS and RS can easily determine the runoff estimation factors such as curve numbers (CN) and LULC information. By using GIS software and applying the spatial analysis, it is possible to generate various thematic layers for the most suitable RWH sites [14,20–22].

This research aims to develop a MCDA technique based on Remote Sensing (RS) and Geographic Information Systems (GIS) to assess the potential zones for RWH in the Al-Qalamoun Basin, which has not been studied before. The proposed technique will consider various factors, such as LULC, soil texture, slope, rainfall, CN, stream order, distance to faults, distance to roads, and distance to residential areas, to identify the most suitable areas for the RWH. The results of this research will be useful in providing information about the potential zones for RWH and will help decision-makers in making informed decisions about water resource management.

2. Study area

The study area is the main basin in the Al-Qalamoun region located between latitude 33°43′41″N and 34°59′30″N and longitude 36°11′45″E and 37°13′57″E in the western part of Syria (Fig. 1). The basin covers an area of ~3366 km^2; it includes ~133 residential communities (cities and villages). The region is characterized by a variety of topography, as it is plain in the northern part and mountainous plain in the southern part.

The weather condition of the study area is described by a humid and cold winter and hot and dry summer. The average annual rainfall is about 192 mm, according to the data recorded at Al-Nabek meteorological station in the period 2017 to 2020 (Fig. 2). The rainy period extends from October to May, with the highest rainfall recorded in March at 32 mm. The lowest average monthly temperature was recorded in February (6 °C with a humidity of 66%), while July is the hottest month (average monthly temperature 30 °C, humidity of 30%). Due to its semi-arid climate, the Al-Qalamoun area is currently experiencing a scarcity of water resources and a high population density, with agriculture serving as the primary source of livelihood for many inhabitants. Furthermore, the absence of stagnant surface water bodies or rivers in this area has resulted in a gradual depletion of available resources, necessitating the exploration of alternative water sources for irrigation purposes, such as RWH and capitalizing on flood seasons.

3. Methods and material

3.1. Preparation of criteria used

The main factors that the World Food Organization (FAO) has identified to determine the RWH zone are hydrology, climate, topography, agronomy, soil, and socioeconomic [18,23,24]. The factors used in this study were chosen not only based on the FAO list but also according to previous studies, where twenty scientific papers published during the last five years were reviewed, as shown in Table 1. According to these scientific papers published, the common factors used to determine RWH are LULC, soil texture, slope, rainfall, CN, stream order, distance to faults, distance to roads, and distance to residential areas. These factors have been used to estimate the RWH in this study area. The Digital Elevation Model (DEM) of the Shuttle Radar Topographic Mission (SRTM) with 30 m spatial resolution data was acquired from the EarthExplorer website (https://earthexplorer.usgs.gov/) has been used to create the stream order and the slope gradient of the study area. Rainfall data was prepared from the Tropical Rainfall Measuring Mission

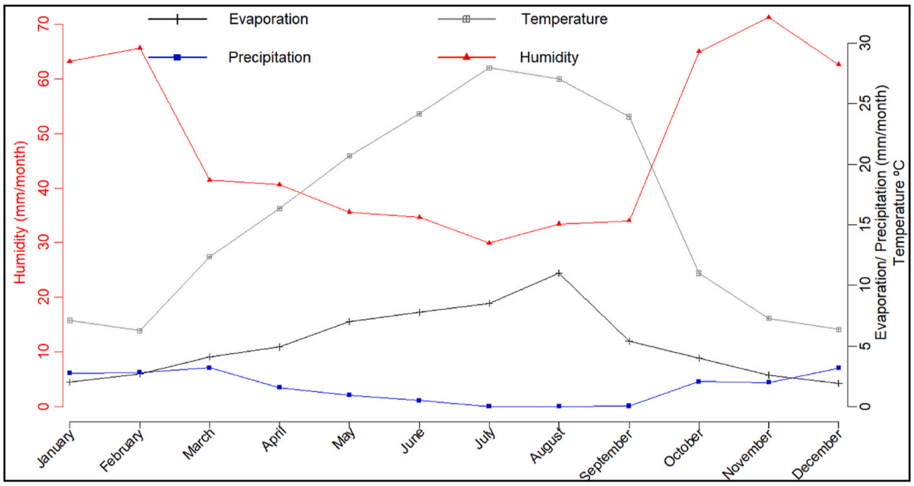

Fig. 2. Monthly precipitation, average monthly temperature, average monthly humidity, and monthly evaporation at Al-Nabek meteorological station were recorded between 2017 and 2020.

Table 1
Rate of the factors used in the literature review to map the potential of the RWH zones.

Reference	Landuselandcover	Soiltexture	Slope	CurvenumberorRunoff	Rainfall	Drainagedensity	Streamorder	Stakeholderspriority	Lithology	Tectoniczones	DistancetothelineamentsorFaults	Distancetotheroad(m)	Distancetoresidentialareas	Elevation(m)	Alluvialmap
[11]	*	*	*	*	*										
[26]	*	*	*	*	*	*									
[12]	*	*	*	*			*	*							
[19]	*	*	*	*	*		*		*	*	*	*	*	*	
[27]	*	*	*	*	*		*		*		*		*	*	
[28]	*	*	*	*	*						*	*	*		
[29]	*	*	*	*	*										
[30]	*	*	*		*				*	*	*	*	*		
[31]	*	*	*		*		*							*	
[32]	*	*		*			*								
[33]	*	*	*	*	*										
[34]	*	*		*										*	
[18]	*		*		*	*									
[35]		*	*	*	*	*	*								*
[36]	*	*	*	*	*		*				*		*		*
[37]	*		*	*			*				*	*	*		
[38]	*	*	*		*	*					*	*	*		
[39]	*	*	*		*		*					*			
[40]			*	*			*					*	*		
[41]	*		*	*	*		*							*	
frequency of factors used %	90	80	90	75	75	20	55	5	15	10	35	35	40	25	10

(TRMM) downloaded from the Earthdata website (https://disc.gsfc.nasa.gov/). TRMM's goal is to gauge global rainfall in tropical and sub-tropical areas; data used type was (3B43–V7) with temporal resolution (mm/month) and spatial resolution (0.25° by 0.25°) [25]. The average annual rainfall was figured out using the monthly TRMM (3B43–V7) data gained from January 1998–December 2019. To create a distribution of the precipitation factor, forty-eight pixels were chosen to encompass the research area and the areas nearby. The pixels were transformed into points to provide continuous coverage, and then, used the inverse distance weighting (IDW) approach to interpolate point-by-point precipitation data.

MODIS MCD12Q1 V6 was used to obtain the LULC map, which was downloaded from both NASA Erathdata and USGS ErathExplorer websites, acquisition date on January 1, 2020. In accordance with six distinct LULC legends, the MODIS LULC Type Product (MCD12Q1) offers a collection of scientific data sets (SDSs) that map the world's LULC at a spatial resolution of 500 m annually [42]. Soil data was acquired from Harmonized World Soil Database (HWSD) [43], available online: http://daac.ornl.gov/cgi-bin/dsviewer.pl?ds_id=1247 (accessed on December 27, 2022). The faults map of the study area was created by digitizing the tectonic map of Syria, with a scale of 1:1000000, published by the Department of Geological Survey and Mineral Research of Syria. DEM, LULC map and hydrological soil group were jointed in ArcGIS 10.8 to generate CN map of study area using HEC-GeoHMS model [44]. Socioeconomics data (residential areas and road shapfiles) obtianed from General Organization of Remote Sensing of Syria (GORS).

All thematic layers were given the same pixel size (30 m) using resample (Data management) tool in ArcGIS and coordinate system (UTM, WGS84; zone 37 N); additionally, a value was assigned to each layer in this study based on literature review and expert opinion using the AHP approach. The several weighted layers were then combined using a process based on MCDA to produce the final layer.

3.2. Processing and creation of the thematic layers

3.2.1. Land use and land cover (LULC)

LULC is a significant determinant of acceptable RWH sites [12,18]. The types of LULC play a major role in the amount of rainwater infiltration and surface runoff. For instance, in lands with bare soil or low vegetation dense, the infiltration is low, and the surface runoff is high, while in areas with high vegetation and agricultural lands dense, the infiltration is high, and the surface runoff is low [24,35]. Thus, barren lands and low vegetation cover provide better conditions for RWH than areas with an abundance of vegetation.

3.2.2. Soil

Soil is considered a crucial factor for determining the RWH sites because of its impact on water infiltration and surface runoff [18,32]. The quantity of water, which can be retained in the soil layer depends on the size of the soil particles since various soil textures have varied capacities for storing water [35]. The higher the percentage of sand in the soil, the greater the size of the pores, and thus, the higher permeability and the lower surface runoff. Conversely, the large proportions of clay in the soil decrease permeability. Therefore, areas with clay soil are considered suitable for RWH [19,45–47]. The natural resource conservation service (NRCS) has divided soil data into four hydrologic soil groups (HSGs) based on soil textures and their infiltration capability (Table 2). This classification allows soil data to be used in the SCS-CN model to create a CN grid [48].

3.2.3. Curve number (CN)

CN is a parameter that characterizes the stormwater runoff potential for drainage areas [49,50]. It is considered a function of the HSGs and LULC [11]. One of the crucial factors for determining CNs is the HSG, which is produced by reclassifying the soil textural map while considering the runoff potential [41,51]. The CN grid is a raster that includes the CN value allocated to each pixel of a hydrological soil group, and LULC to show the runoff potential for each pixel. There is a linear relationship between the CN and surface runoff (Equations (1)–(3)); [19,36].

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

*w*hen $I_a = 0.2$ S;

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

$$S = \frac{25400}{CN} - 245 \tag{3}$$

Table 2
NRCS classification of soil.

HSGs	Soil Taxonomy	Runoff Potential	Infiltration (mm/h)
A	Sand, loamy sand or sandy loam	Low	>7.62
B	Silt loam or loam	Moderate	3.81–7.62
C	Sandy clay loam	Moderate	1.27–3.81
D	Clay loam, silty clay loam, sandy clay, silty clay, clay	High	<1.27

where Q is runoff (mm), P is precipitation (mm), Ia is the initial abstraction, which has mostly been presumed that Ia = 0.2 S, and S (mm) is the maximum potential soil moisture retention after runoff starts. The S is calculated by applying Equation (2) and is inversely associated with the CN value [52,53]. When the value of the CN is equal to 100, the catchment gets a maximum surface runoff (S = 0 and Q = P). A CN value of 0 represents a high S (i.e., S = ∞), which implies an endlessly abstracting catchment with no capacity for runoff [54]. Thus, sites with high CN values are preferred locations for the RWH.

3.2.4. Rainfall

Rainfall is the main factor in deciding how much water can be collected and stored [55]. Rainfall determines the amount of water that can be harvested, as well as its quality. Without enough rainfall, even the most efficient RWH techniques may yield little to no benefit. The capacity to access precipitation data gathered over a long time is essential for determining the rainfall-runoff potential of a certain location. This is true, especially, in the areas that are semi-arid and arid, where the amount of precipitation fluctuates greatly from year to year [39]. However, regions with limited rainfall data can still utilize average rainfall [56].

3.2.5. Slope

The slope is a critical consideration when choosing and implementing RWH structures since it has an impact on runoff, recharge, and surface water flow [39,57–59]. Due to the significant amount of earthwork needed, building RWH structures in regions with high slope percentages is seldom ever seen as being economically feasible [38,60]. Areas with a medium or low slope are more practical since a considerable storage capacity may be easily accommodated in smaller constructing RWH structures [61]. For a high RWH potential, a catchment's slope should ideally be as moderate as feasible. Consider erosion management methods in locations where the watershed has a steeper slope since regions with slopes higher than 5% are often more susceptible to erosion [62].

3.2.6. Stream order

The stream orders provide a crucial piece of knowledge regarding the hydrological and geomorphological characteristics of the basin. Thus, the analysis of stream orders is considered significant for the determination of RWH sites [37,63]. A greater stream order signifies a higher flow of tributaries downstream, increasing the potential for water harvesting [63,64]. Higher infiltration and lower runoff occur in the small number of stream orders, and vice versa [37,39,63]. Stream orders ≥3 are the more suitable area for RWH sites [19,39,65].

3.2.7. Distance to faults

Faults are a major determinant of water harvesting sites as fault areas are associated with high infiltration. Therefore, faults are a significant obstacle when selecting an RWH system [37,38]. Thus, in the selection of RWH sites, it is vital to keep the fault area out of the chosen site [37,66]. The Euclidean distance tool in ArcGIS10.8 was used to prepare the distance to faults map.

3.2.8. Socioeconomics factors

Although socioeconomic factors do not directly affect the determination of water harvesting sites, not taking them into account while determining water harvesting sites does not serve the primary objective of establishing water harvesting sites. In this study, two socioeconomic factors were used: distance to residential areas and roads. The distance to roads is an important factor that should be considered when selecting RWH sites. The planned site's proximity to the existing roads helps keep transportation costs down [19,30, 37,66]. Distance to residential areas: this is concentrated on the local community, which serves as the study's aim, and the distance between the finest RWH sites and residential areas is thought to be a key determining factor [37,55]. Also, this considers the safety considerations of selecting an RWH site that should be more than 500 m away from residential areas [36].

3.3. RWH potential map

The artificial neural network (ANN) and fuzzy rule-based (FR) models require a substantial amount of input prediction data [67], such as the location of dam sites and ponds, in order to accurately predict rainwater harvesting (RWH). Conversely, multi-criteria

Table 3
Pairwise comparison matrix between parameters associated with rainwater harvesting.

parameters	CN	SP	LULC	SO	SR	R	DF	DA	DR	Weight
CN	1	2	3	4	5	6	7	8	9	0.31
SP	0.5	1	2	3	4	5	6	7	8	0.22
LULC	0.33	0.5	1	3	4	5	6	7	8	0.18
SO	0.25	0.33	0.33	1	2	3	4	5	6	0.10
SR	0.2	0.25	0.25	0.5	1	2	3	4	5	0.07
R	0.17	0.2	0.2	0.33	0.5	1	2	3	4	0.05
DF	0.14	0.17	0.17	0.25	0.33	0.5	1	2	3	0.03
DA	0.13	0.14	0.14	0.2	0.25	0.33	0.5	1	3	0.02
DR	0.11	0.13	0.13	0.17	0.2	0.25	0.33	0.33	1	0.02
λ_{max} = 9.53	n = 9		CI = 0.066		RI = 1.45		CR = 0.046 < 0.1 acceptable			

decision analysis (MCDA) models, including the analytic hierarchy process (AHP), do not rely on input data as they utilize logical classification of factors to assign weights and ratings to input parameters for the purpose of delineating the RWH map [68–70]. In this study, the Analytic Hierarchy Process (AHP)-based MCDA [71] and GIS-based Soil Conservation Service Curve Number (SCS–CN) were employed to generate a potential RWH map of the study area. To identify the zones suitable for RWH in the study area, thematic layers, such as LULC, soil texture, slope, rainfall, CN, stream order, distance to faults, distance to roads, and distance to residential areas, were taken into consideration. The weights of each thematic layer and its associated features were assigned on Saaty's scale [72], ranging from 1 to 9. All thematic layers and their features were evaluated based on their capacity to collect rainwater. Subsequently, pairwise comparison matrices of the allocated weights were generated using Saaty's AHP method Table 3. Afterward, the given weights were normalized using the eigenvector technique [73]. The weights of factors and scores of their sub-classes were calculated based on a combination of existing research and the expert opinion of the authors (Radwan and Alazba 2022; Alkaradaghi et al., 2022; Hashim and Sayl 2021; Balkhair and Ur Rahman 2021; Harka et al., 2020; Rana and Suryanarayana 2020; Ejegu and Yegizaw 2020; Matomela, Li, and Ikhumhen 2020; Noori, Pradhan, and Ajaj 2019). To assess the consistency of weights assigned to each thematic layer and its characteristics, the consistency ratio (CR) was calculated using Equations (4) and (5) proposed by Saaty [71]. It is permissible to compare criteria when CR < 0.1; otherwise, the CR necessitates a re-evaluation of the comparison.

$$CR = \frac{CI}{RI} \tag{4}$$

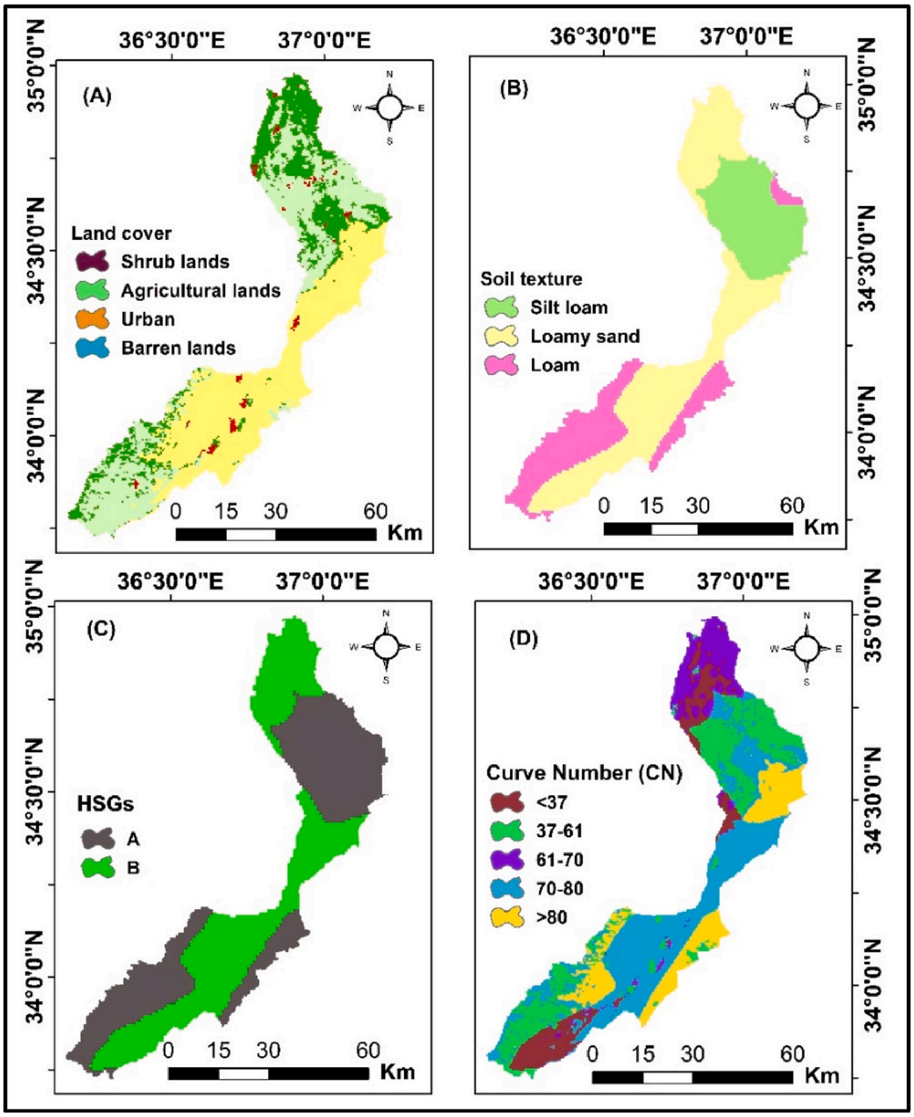

Fig. 3. A) LULC map, B) Soil texture map, C) HSGs map, and D) Curve number map.

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{5}$$

where CI is the consistency index, RI is the random consistency index, λ_{max} is the principal eigenvalue computed by the eigenvector technique, and n is the number of used factors.

Following the calculation of weights for each criterion, the Weighted Overlay Process (WOP)-based MCDA was employed to generate a suitable RWH map within a GIS environment. Each criteria raster layer was given its computed weight in the appropriateness analysis using ArcGIS for the WOP. The sub-classes in each thematic layer were then categorized in Table (4) using a standard appropriateness scale with values ranging from 1 (least suited) to 9 (highly suitable). Each thematic layer was multiplied by its weight and the results were added together using Equation (6) [41,74].

$$A = \sum W_i * R_i \tag{6}$$

where A denotes the suitability of the RWH sites, W denotes the weight of factor i, and R denotes the rank of sub-classes for factor i.

The DEM was used to estimate the location of the ponds in the study area. The fill DEM layer was created by subtracting the DEM to detect the ponds areas.

Table 4
Weight and scores of specific characteristics that were assigned to factors that influence RWH.

Factors	Parameters	Weight	rank
Curve Number (CN)	<37	31	1
Slope (degree)	37–61	22	2
	61–70		3
	70–80		7
	>80		9
	>20		1
	10–20		3
	2–10		7
	<2		9
Stream order	3	7	5
	4		7
	5		9
Soil texture	Loamy sand	10	3
	Silt loam		5
	Loam		7
LULC	Built-Up Land	18	1
	Shrub lands		3
	Barren Land		9
	Agriculture Land		5
Distance to faults (m)	<1000		1
	1000–2000	3	3
	2000–5000		5
	5000–10000		7
	>10000		9
Rainfall (mm)	>400	5	9
	350–400		7
	300–350		5
	250–300		4
	<250		3
Distance to residential areas (m)	<1000	2	1
	1000–3000		5
	3000–5000		9
	5000–10000		3
	>10000		1
Distance to road (m)	<1000		1
	1000–2000		9
	2000–5000	2	7
	5000–1000		3
	>10000		1

4. Results and discussion

4.1. Evaluation of predictive factors

Nine predictive criteria including LULC, soil texture, slope, rainfall, CN, stream order, distance to faults, distance to roads, and distance to residential areas —were used to determine the RWH sites in the study area.

The LULC map of the study area demonstrated the presence of four categories: built-up land, shrub lands, barren lands, and agricultural lands (Fig. 3A). It was determined that barren and agricultural lands are the most appropriate sites for the RWH [18,29], comprising approximately 65% of the total study area, thus were given a high rank of consideration (Table 4).

The soil texture in the study area can be classified into three distinct categories: silt loam, loam, and loamy sand (Fig. 3B), comprising 25%, 25%, and 50% of the overall research area, respectively. Based on the infiltration rates and soil classification data, the study area can be classified into two Hydrologic Soil Groups (HSGs): A (loamy sand) and B (silt loam and loam; Fig. 3C). The suitability of silt loam and loam for RWH was accorded a high level of significance as illustrated in Table 4. The CN was quantitatively mapped on a cell-by-cell basis through the integration of LULC and hydrological soil groups (HSGs) Fig. 3D. The CN map has been classified into five categories based on its suitability for RWH: Unsuitable (<37), Low (37–61), Medium (61–70), Suitable (70–80), and Very Suitable (>80). An increased CN value is indicative of an increased rate of surface runoff, thus suggesting a greater potential for the RWH [19,29].

Within the study area, the gradient of the slope varied from 0° to 53.5°. Fig. 4A shows the slope map, which was divided into four

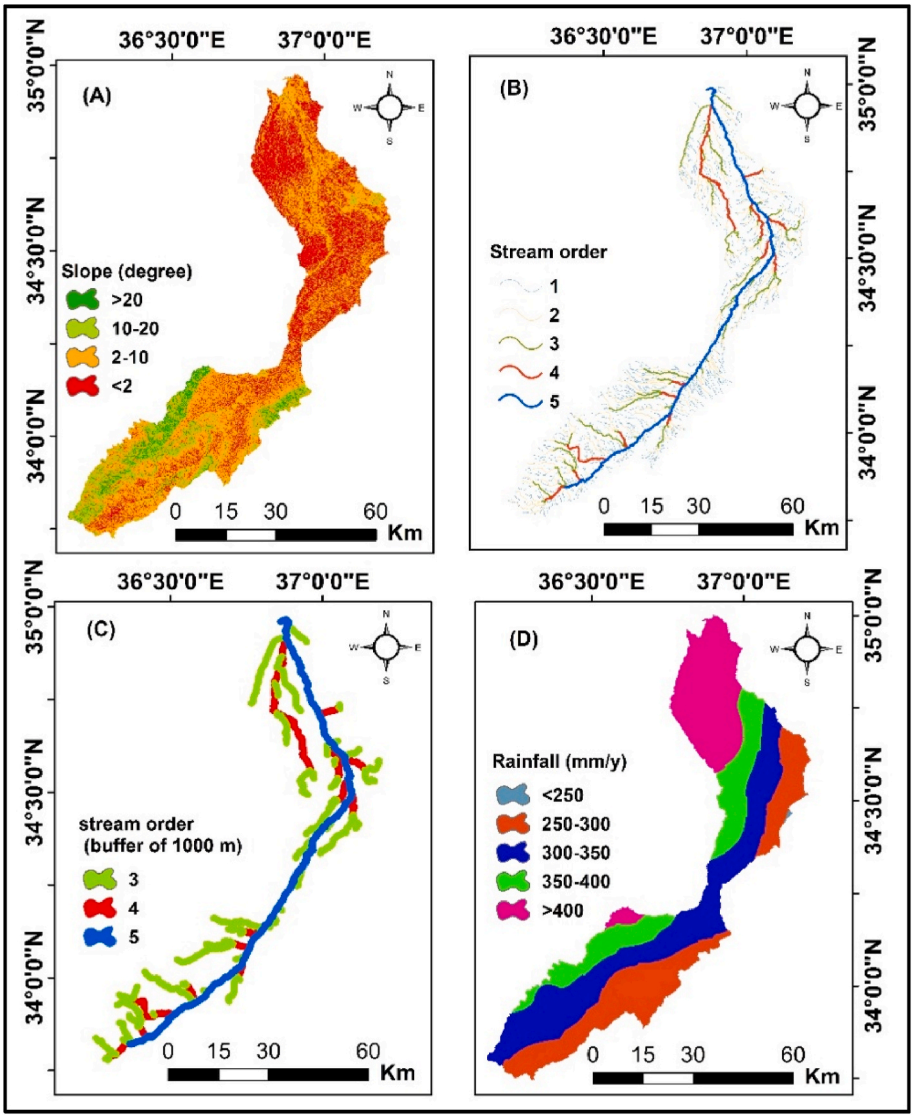

Fig. 4. A) Slope map, B) Streams order, C) Streams order with a buffer of 1000 m, and D) Average annual rainfall map of the study area.

groups according to its steepness: nearly level (0°–2°), gentle (2° −10°), moderate (10° −20°), and very severe (>20°). The nearly level and gentle slope groups, occupying 15% of the total study area, were found to be particularly suitable for the RWH sites [46,75]. The moderate slope category was distributed in large patches across the study area, covering 55% of the total study area, which was considered less suitable for RWH. Very severe slope categories, occupying 30%, were deemed unsuitable for the RWH due to their high slopes (Table 4).

The annual average value of rainfall ranges from 242 mm to 486.69 mm. According to Ref. [19], the rainfall map of the study area was categorized into five levels of suitability for RWH: not suitable (<250 mm), less suitable (250–300 mm), moderately Suitable (350-300 mm), suitable (350–400 mm) and most suitable (>400 mm), accounting 0.1%, 26.12%, 33.52%, 18.56%, and 21.7%, respectively (Table 4 and Fig. 4D). The hierarchical order of streams within the study area ranged from first to fifth order (Fig. 4B). Only higher orders were taken into account when selecting suitable RWH sites, as higher stream orders are associated with lower absorptivity and infiltration [19,39]. Streams belonging to order 3 or higher, with a buffer of 1000 m, were selected for the determination of RWH sites as illustrated in Table 4 and Fig. 4C.

The total length of the faults in the study area is estimated to be 303.4 km, with the majority of them exceeding 2 km in length. The primary orientation of the thrust faults is NW–SE, while the remaining faults are NE–SW (Fig. 5A). The distance between these faults and their respective cells ranges from 0 to 17 km (Fig. 5B). A shapefile of the faults was used to create a raster of fault factors, and the Euclidean distance to the closest fault was calculated for each cell. This distance was then classified into five categories based on suitability for RWH sites: not suitable (<1 km), less suitable (1–2 km), moderately suitable (2–5 km), suitable (5–10 km), and most suitable (>10 km; Table 4).

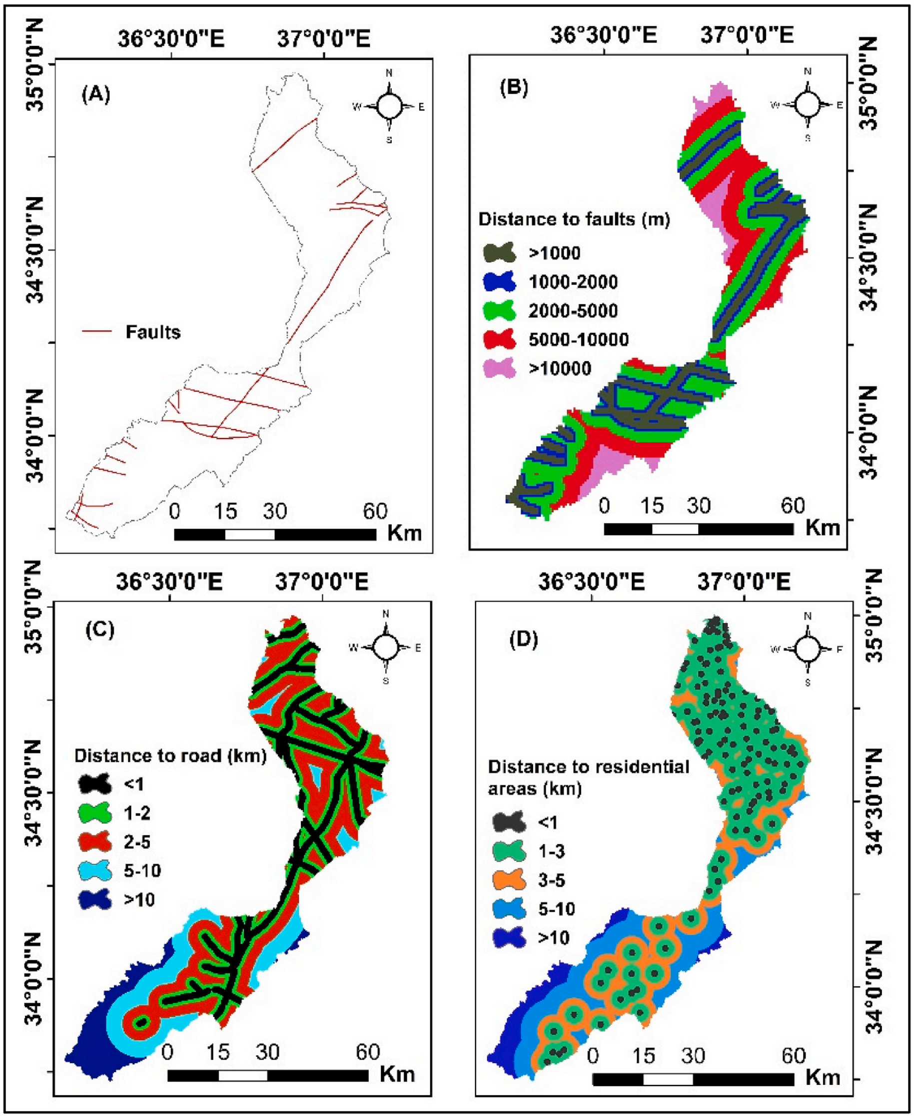

Fig. 5. A) Faults, B) Distance to faults, C) Distance to the road, and D) Distance to residential area maps of the study area.

The map of distances to roads in the study area was divided into five categories to determine the optimal location for the RWH sites. These categories were: not suitable (>10 km, <1 km), less suitable (5–10 km), suitable (2–5 km), and most suitable (1–2 km) as shown in Table 4 and Fig. 5C. This was done to ensure that the sites were not too far away from roads, thus avoiding high transportation costs, but also not too close to roads. Distance to residential areas map was classified into five categories of RWH site suitability: not suitable (>10, <1 km), less suitable (5–10 km), moderately suitable (1–3 km), most suitable (3–5 km) as illustrated in Table 4 and Fig. 5D.

4.2. RWH potential map

The RWH potential map of the study area was created by combining the various thematic layer using the WOP technique. The RWH potential map was classified into five potential categories: unsuitable, less suitable, moderately suitable, suitable, and most suitable (Fig. 7). The majority of the study area (66%) was classified as unsuitable for RWH, covering an area of 2224 km^2. The less and moderate suitable potential areas constituted 7.8% (262 km^2) and 7.4% (248 km^2) of the study area, respectively. Consequently, 18.8% (632 km^2) of the study area was deemed to be suitable and most suitable for the RWH sites.

The study area comprised two small earth dams, which were constructed to collect rainwater during the rainy season [76] (Fig. 6). The issue with these dams pertains to their construction on diminutive drainage basins, resulting in frequent desiccation and inadequate water retention. The RWH potential map was assessed by superimposing it with the position of existing dams with a buffer of 1000 m, which revealed that the dams were situated in the optimal zone identified by the study, The model's accuracy, as determined by the first and second dams, was 85.27% and 86.88%, respectively.

In addition, these pixels (i.e., buffer of 1000 m arround the dams) have been used to validate the RWH map using the area under the curve receiver operating characteristic (AUC-ROC). The resulted AHP of the RWH map shows high accuracy, where the AUC is 70.18% (Fig. 7).

Fig. 7 indicates that the methodology adopted in this study had a high capacity to identify sites suitable for the RWH. To select the most suitable locations for constructing dams in the research area, cost minimization was considered. So, the length of the dam structure is minimized and the depth and capacity of the reservoir are increased to mitigate evaporation [19,37]. Four sites were chosen in the study area, characterized by a decrease in the valley's cross-section, for the construction of dams. The most appropriate site for the dam is Dam #1, situated in the south part of the study area, which has the largest reservoir with an area of 7.5 km^2 and a capacity to store 100.7 million m^3 of water (Table 5 and Fig. 8). Furthermore, the mean depth at the lake of Dam #1 is approximately 13.5 m, which implies a lower rate of evaporation due to its greater reservoir depth. The construction of this dam will not cause any villages to be submerged. The cross-sectional length of the dam is 381 m, which minimizes the expenditure associated with its construction. As a result of the elevated location of this dam site (1381 m), it has the capacity to provide water for agricultural and

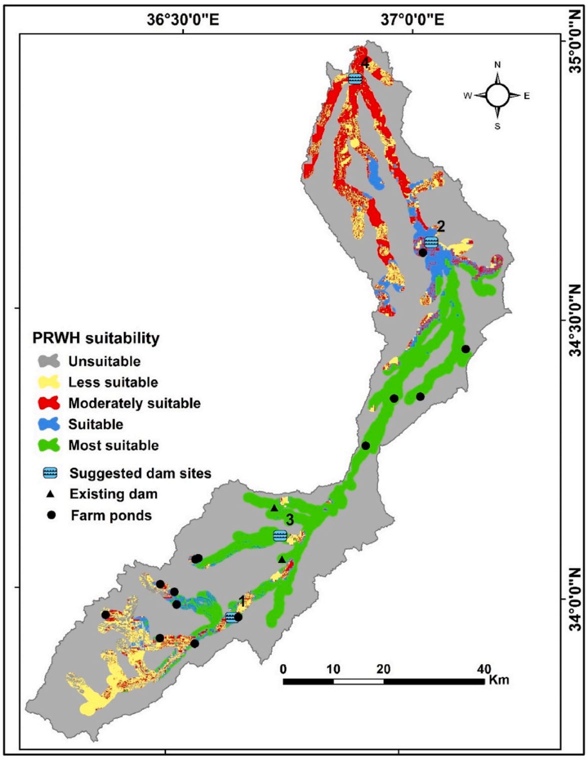

Fig. 6. RWH zones map of the study area.

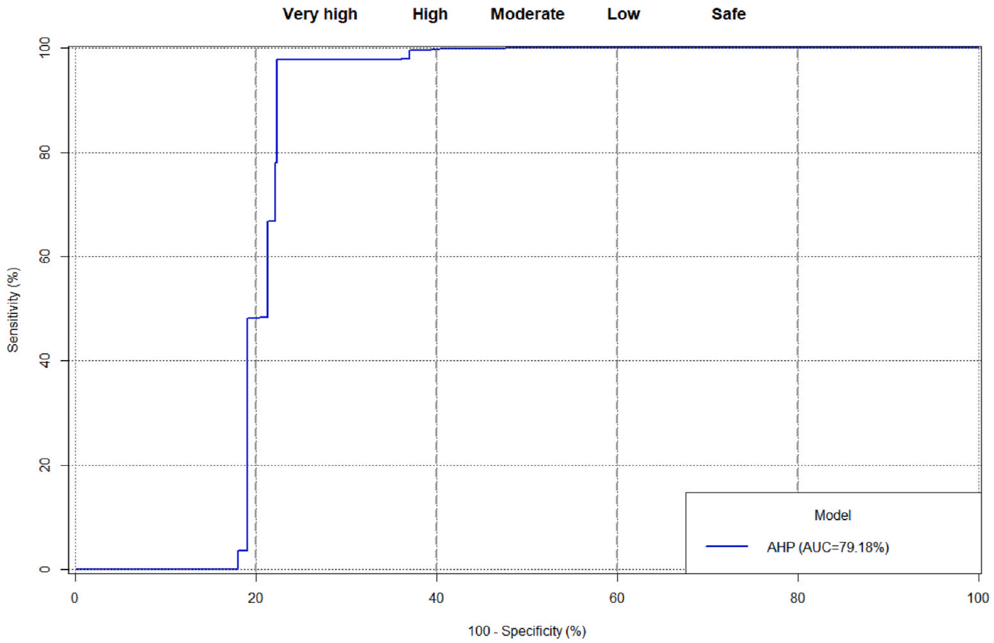

Fig. 7. Results of the ROC for validation of RWH maps using the AHP method.

Table 5
Characteristics of the proposed dam sites.

Property	Dam1	Dam2	Dam3	Dam4
Maximum elevation (m)	1425	650	1300	410
Mean elevation (m)	1411.5	641	1294	405
Mean depth (m)	13.5	9	6	5
Area of the lake (m^2)	7456155	2641339	399700	279342
Storage (million m^3)	100.658	23.77	2.4	1.4
X-UTM	282230	321306	291174	306160
Y-UTM	3760129	3834347	3776012	3866855

domestic purposes to over 13 villages, encompassing four major towns within the study area, namely Deir Attiay, Al-Nabek, Yabroud, and Qara. Dam #2, located in the northeast region of the study area, is a suitable site for the dam due to its reservoir with an area of 2.64 km^2 and a capacity to store 23.8 million m^3 of water (Table 5 and Fig. 8). Additionally, the mean depth at the lake of Dam #2 is approximately 9 m, which suggests a reduced rate of evaporation due to its greater reservoir depth. The construction of this dam will not result in any villages being submerged. The only disadvantage associated with this dam site is its cross-sectional length of 628 m, which would increase construction costs. Dam Site #4 has the shortest cross-sectional length (219 m), however, its reservoir capacity is the smallest, whereas the lake of Dam Site #3 has a mean depth (6 m) as well as a small reservoir capacity with a cross-sectional length of 521 m (Fig. 8). The suggested dams' coordinates and characteristics are shown in Table 5. The four dams that have been suggested are strategically located to provide irrigation and household water to each of the designated research zones. Furthermore, in order to effectively manage and conserve water resources while mitigating water loss through evaporation, the implementation of strategies, such as the utilization of small-scale farm ponds to enhance infiltration or RWH for agricultural irrigation purposes has proven to be highly beneficial. As a result, a total of 14 farm ponds have been identified and distributed throughout the basin as shown in Table 6 and Fig. 6.

5. Conclusions

Rainwater harvesting (RWH) has the potential to be a viable solution for mitigating water scarcity issues, as it can augment existing water supplies in the long term and reduce groundwater abstraction, especially in arid and semi-arid regions. The purpose of this study was to identify appropriate sites for potential RWH using a multi-criteria decision analysis (MCDA) based on the AHP method in combination with GIS and remote sensing techniques (RS). Nine factors layers, including LULC, soil texture, slope, rainfall, CN, stream order, distance to faults, distance to roads, and distance to residential areas, were used to create a potential RWH map in the Al-Qlamoun basin western part of Syria. The research findings indicated that the central region of the study area was the most suitable for RWH, thus leading to the suggestion of four sites for dam construction. This decision was based on factors such as storage

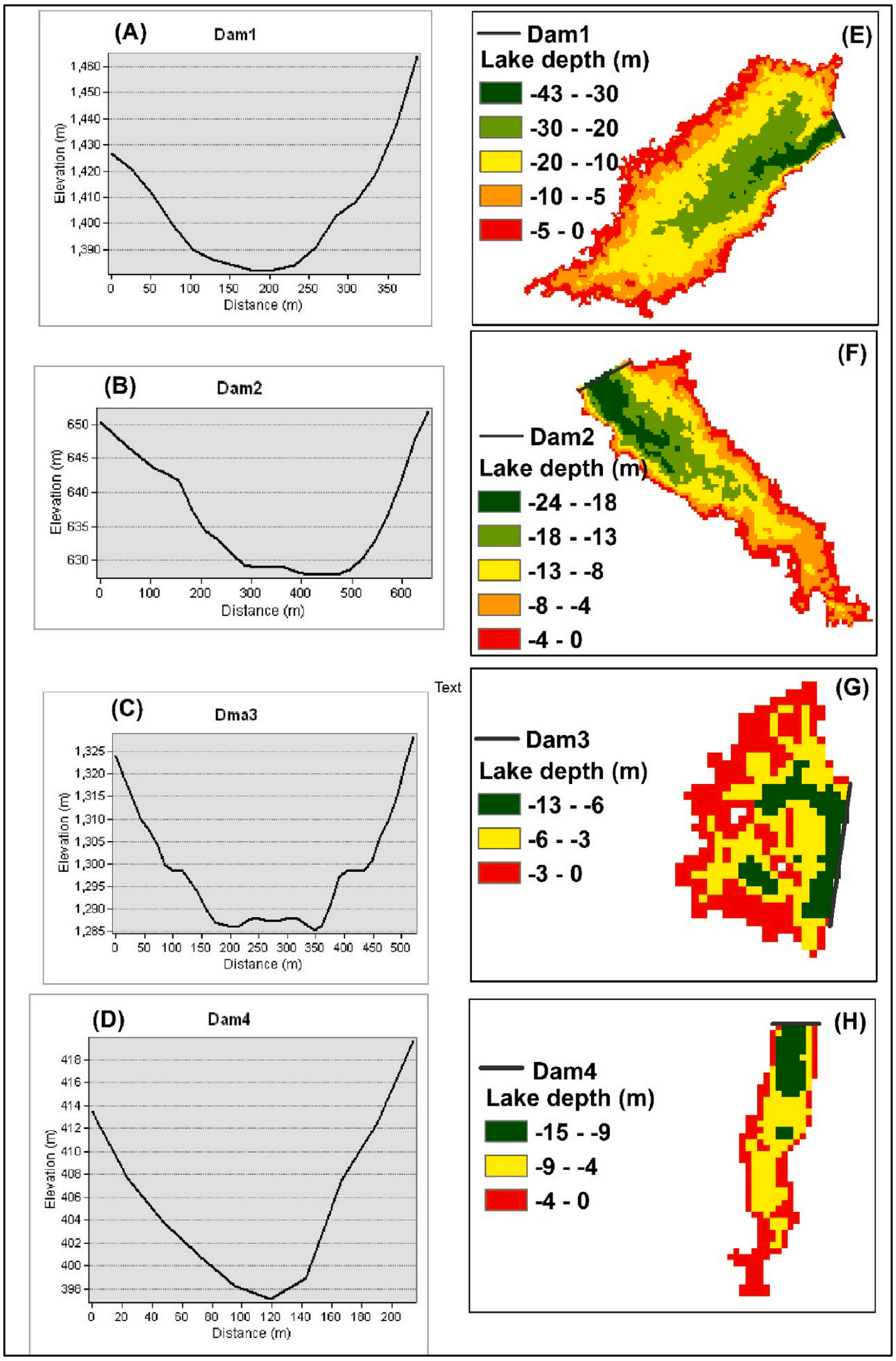

Fig. 8. A, B, C, and D are the cross sections for the proposed dams 1, 2, 3, 4 in the study area. E, F, G, and H are the suggested lakes of the dams 1, 2, 3, 4.

capacity, surface area to volume ratio, runoff availability, and cost minimization. Syria is in dire need of scientific tools that can assist policy-makers at various levels of government to address water scarcity, thus saving both the money and time required to identify the most suitable sites for RWH. The resultant map could be beneficial to decision-makers to optimize water resource management by selecting appropriate locations for RWH and conserving water spatially in arid and semi-arid regions.

The proposed subsequent phases of research entail conducting a more comprehensive examination of evapotranspiration to appraise the authentic harvestable water at designated locations and scrutinizing the ramifications of global change on rainwater harvesting (RWH). Additionally, it is suggested that forthcoming investigations should focus on evaluating the effects of RWH

Table 6
Characteristics of the farm ponds.

ponds	Area (m^2)	Mean of depth (m)	Volume (m^3)	X-UTM	Y-UTM
1	8220.678	13	106868.8	274,287.07	3,771,288.13
2	7398.61	12.5	92482.63	282,980.72	3,759,751.34
3	6576.543	11.6	76287.89	313,863.36	3,803,271.96
4	4110.339	15	61655.09	274,918.23	3,771,567.15
5	4110.339	11.5	47268.9	319,076.58	3,803,644.01
6	4110.339	13.8	56722.68	270,165.79	3,764,876.35
7	4110.339	10	41103.39	319,590.36	3,832,294.22
9	3288.271	13.5	44391.66	274,211.07	3,754,559.53
10	3288.271	14.5	47679.93	267,355.08	3,766,379.84
11	3288.271	13	42747.53	267,297.49	3,755,659.87
12	2466.203	10.5	25895.14	328,105.18	3,813,100.54
13	2466.203	13	32060.65	270,601.84	3,762,337.05
14	2466.203	11.4	28114.72	308,198.75	3,793,869.65

structures on both upstream and downstream ecosystems.

Author contribution statement

Imad Alrawi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper. Jianping Chen: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data. Arsalan Ahmed Othman: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data. Salahalddin S. Ali: Analyzed and interpreted the data. Fayez Harash: Contributed reagents, materials, analysis tools or data.

Data availability statement

Data included in article/supp. Material/referenced in article.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:This research was funded by No. 2017YFC0601502 from the National Key Research and Development Program of China.

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