Heliyon 10 (2024) e27273

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

An integrated new approach for optimizing rainwater harvesting system with dams site selection in the Dewana Watershed, Kurdistan Region, Iraq

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ARTICLE INFO

Keywords:
Rainwater harvesting
Remote sensing
Geographic information system
Multi-criteria decision analysis
Suitability index maps
Dam sites selection maps

ABSTRACT

Water scarcity in Kurdistan-Iraq has become a crucial problem, particularly in semi-arid regions, as a result of severe droughts over the last decades. One potential solution to this water shortage is using rainwater harvesting (RWH) techniques. In this study, optimal sites of RWH in the Dewana watershed were identified using a combination of remote sensing (RS) and geographic information system (GIS), with multi-criteria decision analysis (MCDA) models, including analytical hierarchy process (AHP) and weighted sum method (WSM). Sixteen thematic layers are used. As a result of the AHP and WSM models, 236.89 km^2 and 267.15 km^2 were identified as highly suitable areas for RWH techniques in the suitability index map. They identified 13.06 km^2 (5.55%) and 58 km^2 (21.81%) as highly suitable for constructing dams in the dam site selection maps. The present study found that 11 proposed dam sites are suitable for dam construction. The weighted product model (WPM) was used to rank the proposed dam sites, with Dams #10 and #2 being the top-ranked sites. Accuracy assessment results indicated that the WSM model outperformed the AHP model with an overall accuracy rate of 50.5% and 52.78%, respectively. However, the AHP model demonstrated a higher receiver operating characteristic (ROC) and an area under the curve (AUC) score of 1.00, while the WSM model had an AUC of 0.78.

1. Introduction

Water is widely recognized as a highly valuable natural resource due to its essential role in sustaining human, animal, and plant life, as well as facilitating the growth and enhancement of economic systems [1,2]. Water scarcity is a pressing global issue, and its impact is particularly felt in semi-arid regions like the Iraqi Kurdistan Region (IKR). This study delves into a crucial aspect of water resource management, specifically, RWH system optimization coupled with dam site selection in the Dewana Watershed, situated in the IKR. As water demands continue to rise and climatic conditions pose new challenges, an integrated new approach, utilizing technologies such as RS, GIS, and MCDA, becomes essential to ensure a sustainable and efficient water supply for the region. Iraq, a semi-arid nation in the Middle East, has suffered serious scarcity for the last two decades due to various causes, including population growth, high demand for water, urbanization, water pollution, and unsustainable water resources in many areas due to climate change [3,4]. Several studies demonstrate that Iraq will encounter extra challenges as the country's water deficit problem worsens over time [5–8]. The Dewana

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https://doi.org/10.1016/j.heliyon.2024.e27273
Received 12 November 2023; Received in revised form 6 February 2024; Accepted 27 February 2024
Available online 7 March 2024
2405-8440/

watershed area, which is one of the agricultural and tourism hotspots, is confronting a water shortage. It obtains its water primarily from springs, ephemeral streams, and groundwater, such as wells, for irrigation and household needs [9]. The authorities in the IKR are focused on enhancing the management of precipitation, recognized as the primary source of surface and groundwater replenishment in the region. The persistent water scarcity issues in the Dewana Watershed underscore the need for a comprehensive strategy that not only optimizes RWH systems but also strategically selects dam sites. Previous studies in the region have made strides in understanding rainwater harvesting. However, there is a critical research gap concerning the integration of RWH and dam site selection. The GIS-based multi-environmental, socio-economic criteria and MCDA method for evaluating and selecting sites for RWH have grown in popularity worldwide [10–15]. To date, limited studies have been conducted on the implementation of ArcGIS and RS with MCDA methods for RWH in the IKR. Previous research, including studies [16,17], and [18] focused on determining suitable site selection for RWH in the Erbil, Dohuk, and Sulaymaniyah governorates. Additional research, denoted by Refs. [19,20] concentrated on identifying optimal dam sites in the Greater Zab and Khabour River basin. However, only [9] has been conducted to develop a comprehensive and integrated GIS-MCDA approach for selecting suitable dam sites in the area. The existing literature lacks a holistic approach that considers the synergy between RWH and dams to maximize water availability and sustainability in the Dewana Watershed. This study hypothesizes that the integration of advanced geospatial techniques, such as GIS and RS, with MCDA models, will lead to an enhanced optimization of RWH systems and a more strategic selection of dam sites in the Dewana Watershed. The application of the AHP, WSM, and WPM will contribute significantly to the identification and prioritization of suitable sites for constructing dams, ultimately resulting in a more sustainable and efficient water supply for the IKR. The specific objectives include identifying and prioritizing suitable sites for constructing dams by utilizing advanced geospatial techniques and MCDA models. This study presents a novel approach by integrating three distinct stages with different criteria for each stage. The inclusion of suitability index maps and dam site selection maps, achieved through the application of AHP and WSM, marks a significant advancement. Additionally, the ranking of proposed dam sites is introduced using the WPM, a method not previously employed in similar studies. Furthermore, this research contributes to the field by not only adopting innovative methods in dam site selection but also by applying unique parameters within the WPM model for the first time in ranking proposed sites, thereby enhancing the comprehensiveness and novelty of the study.

2. Materials and methods

2.1. Study area

The Dewana watershed lies in the southern part of the Sulaymaniyah governorate within the IKR, with a total area of 605 Km^2, as shown in Fig. 1. The study area has mountain ranges stretching from southeast to northwest with altitude ranges of 369–1853 m above sea level, through which the Dewana perennial river flows and drains into the Sirwan River. The study area includes two districts

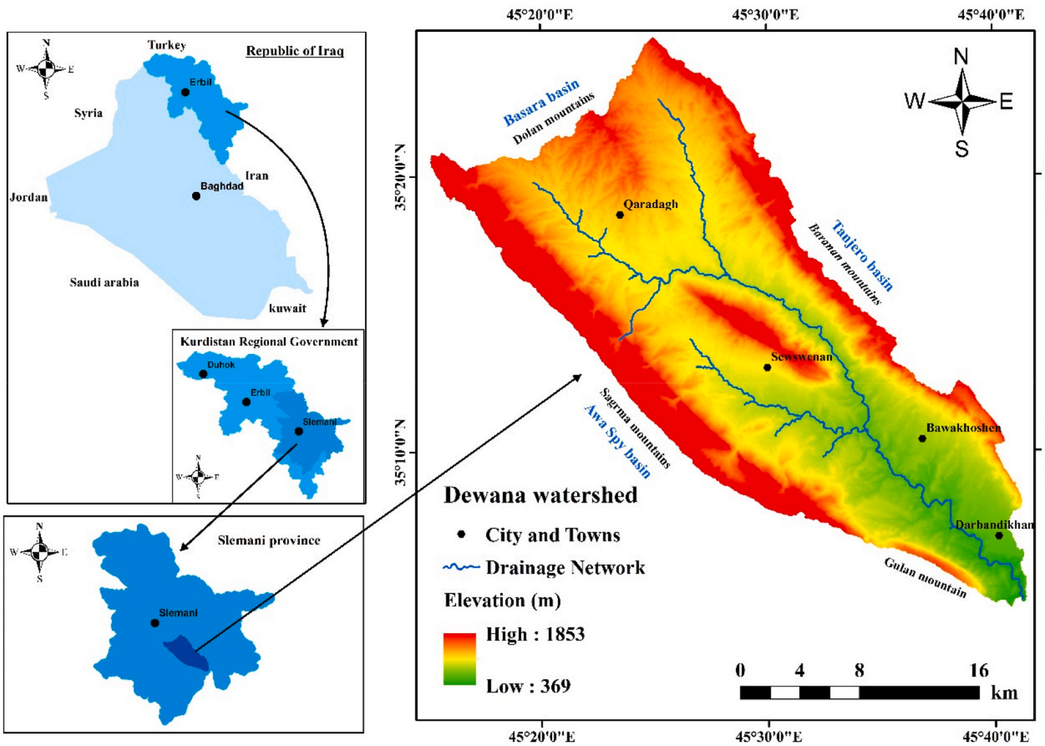

Fig. 1. Location map of the Dewana watershed.

(Darbandikhan and Qaradagh), two subdistricts (Sewssenan and Bawakhoshen), and 67 villages. According to the Ministry of Planning in the IKR [21] the total population in the Dewana watershed is ~105,000. The Dewana watershed has a semi-arid environment [22, 23]. The average annual rainfall ranged between 610 and 687 mm over the years 2010–2020, with an average annual evaporation of (5.02) mm.

2.2. Input data

2.2.1. Predictive criteria selection

Criteria selection and the preparation of thematic layers are crucial parts of any model [24]. In the present study, we selected thirteen predictive criteria as thematic maps, after reviewing 100 high-quality papers. These papers dealt with RWH techniques and were published between 2012 and 2022, as shown in Table S1, which was added as supplementary material. As a result, more than 50% of these criteria used slope, soil texture, land use/cover, rainfall, runoff, and drainage density as significant predictive criteria for all RWH techniques. The criteria that affect the dam site selection include geological formations, lineament density, and stream order, which are each 26%, 23%, and 39%, respectively, as well as socioeconomic factors, such as the distance to (roads, residential areas, and farmland) are used. Finally, the ranking of dam sites was determined based on several criteria, including population density, archaeological map, and distance to construction materials, as well as geometric characteristics of the dam [19,20].

2.2.2. Preparation of thematic maps

The creation of the spatial database is a crucial phase in the GIS projects [25]. The study made use of maps created from various sources, as illustrated in Table 1. ArcGIS is used to process, analyze, and interpret spatial datasets [12,25]. The GIS spatial analysis tools e.g., geo-reference, clip, extract, resample, Euclidean, convert, buffer, reclassification, and overlay were employed to evaluate each criterion's rating value. The pixel sizes of the thematic maps were resampled to precisely align with the 30 m spatial resolution of the digital elevation model (DEM) from the United States Geological Survey (USGS). The geo-referencing of certain layers, such as geology formations and archaeology, was done using the Universal Transverse Mercator (UTM) system, WGS 84, and zone 38 N. According to literature reviews, scientific specialists recommend reclassifying each input factor into five main classes: very high suitable, high suitable, moderately suitable, low suitable, and very low suitable [18–20]. The scores of the five major classes are 1, 3, 5, 7, and 9, where the very low suitable is 1 and the very high suitable is 9, as shown in Table S2. The geometrical characteristics of the proposed dams were determined and then used for ranking the proposed dams with other factors, such as population density map, archaeology map, and distance to construction materials map. This study involves four main steps: Firstly, a suitability index map is created by identifying areas that are potentially suitable for water harvesting techniques based on physical factors such as slope, soil texture, rainfall, land use/cover, drainage density, and runoff. However, further analysis is required to determine the most suitable sites for specific water harvesting techniques, such as dam construction.

Secondly, the creation of the dam site selection map involved incorporating a highly suitable score from the suitability index map, along with various factors, such as geological formations, lineament density, stream width, distance to roads, residential areas, stream orders, and farmland. Third, the identification of proposed dam sites involved integrating a highly suitable score from the dam site selection map, along with geometric characteristics factors. Finally, the proposed dam sites were ranked using the WPM, considering

Table 1
Source of the criteria map.

S. No	Criteria	Source
1	Slope	Digital Elevation Models (DEM) with 30 m resolution obtained from the USGS, https://www.usgs.gov/.
2	Stream orders	
3	Drainage density	
4	Soil texture	The Pipette Method (PM)
5	Land use/cover	Satellite Imagery Sentinel-2A was registered in June 2021 with a 10 m resolution.
6	Rainfall	The Global Precipitation Measurement (GPM -v06) mm/month from Google Earth Engine (GEE) with a resolution $0.1^\circ \times 0.1^\circ$, (Converge 2010 to 2020).
7	Runoff	Land cover, Soil map, and rainfall data were adopted to produce the runoff depth
8	Roads	World Imagery-GIS base map
9	Residential area	
10	Stream width	
11	Geological Formations	Iraqi Geological Survey (Scale 1: 250,000) GEOSURV-IRAQ World Imagery-GIS base map
12	Construction Materials	
13	Lineament density	Satellite Imagery Sentinel-2A was acquired on July 2, 2020 with a 10 m resolution.
14	Population density	Ministry of Planning, Kurdistan Region Statistics Office. Erbil, Iraq, 2019. Available online: www.krso.gov.krd (accessed on May 27, 2022). Population Statistics of Iraq: http://www.citypopulation.de/Iraq-Cities.html (accessed on May 16, 2023).
15	Archaeology	The survey map of the Iraqi Department of Antiquities from the 1940s (scale: 1:200,000) and The Archaeological Project (QDRAP) in 2015.
16	Farmland	The field survey from https://www.sentinel-hub.com/explore/sentinel-playground/[Accessed: on January 2022].

their geometric characteristics and other factors, as illustrated in Fig. 2.

2.2.3. Criteria restriction

Criteria restriction is an important aspect to consider when creating water harvesting techniques [9,19,20]. GIS spatial analysis tools create special geographical features by using buffer zones around criteria [26]. Each criterion for selecting a dam site should be described by the distance recommended by experts, taking into account environmental concerns and extra costs, and complying with relevant government rules [9,19], as shown in Table S2.

2.3. Predictive factors

The predictive factors are divided into two categories: biophysical and socio-economic.

2.3.1. Biophysical factors

Biophysical criteria for RWH refer to the physical and biological factors that are considered when assessing the suitability and effectiveness of RWH systems [27].

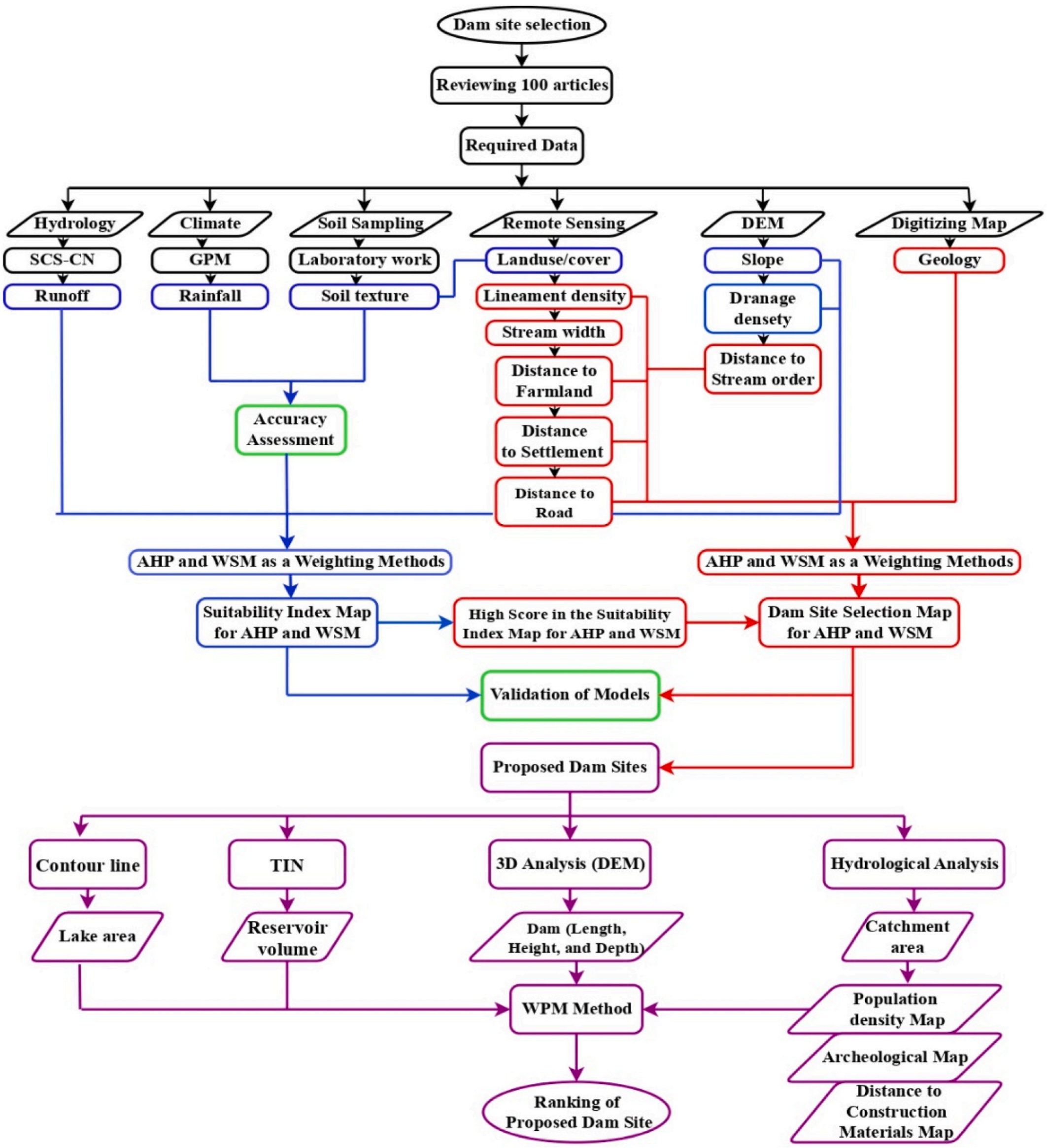

Fig. 2. Flowchart of the rainwater harvesting system with dam site selection in the Dewana Watershed.

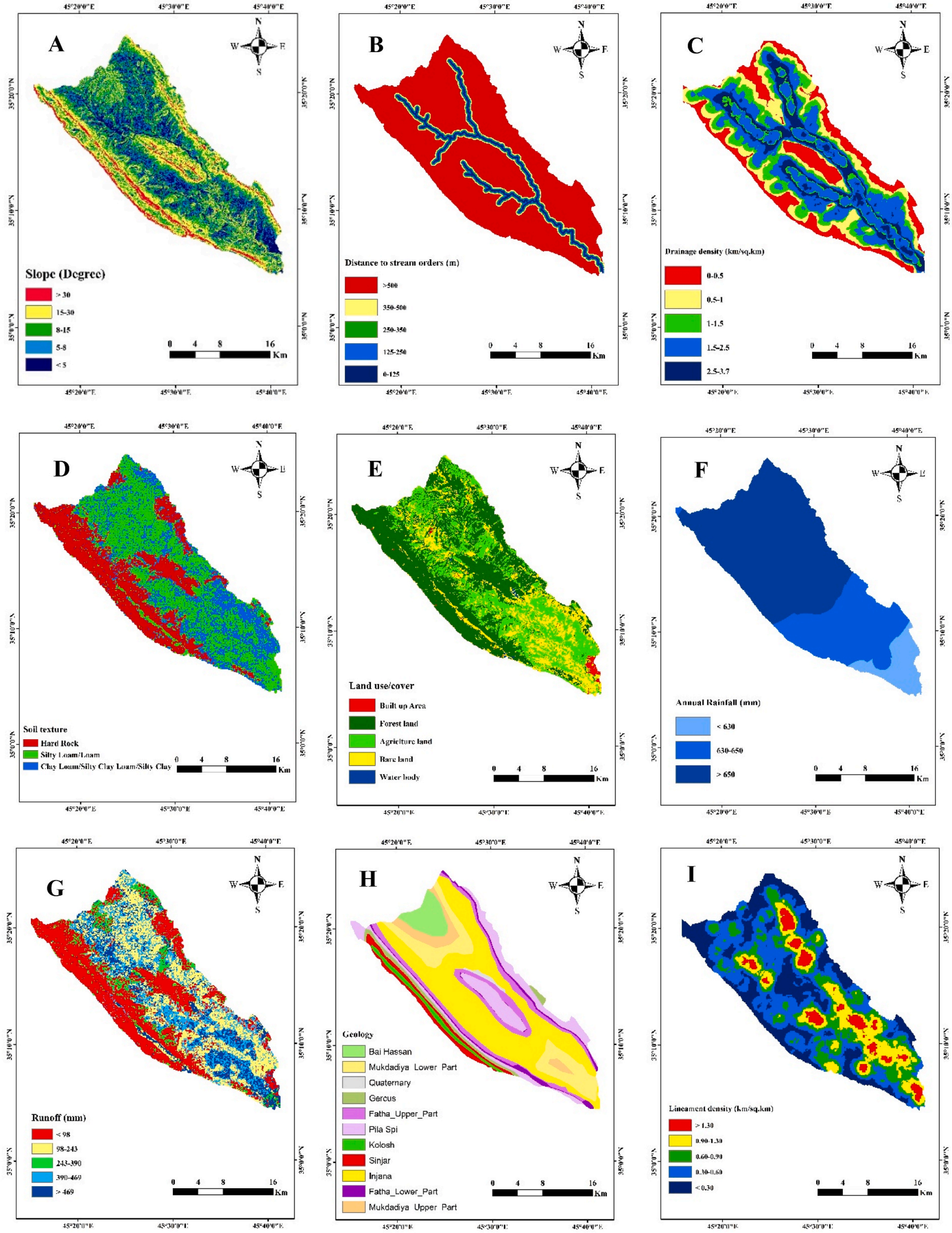

Fig. 3. Input thematic layers; (A) slope; (B) distance to stream orders; (C) drainage density; (D) soil texture; (E) land use/cover; (F) rainfall; (G) runoff; (H) geological formation; (I) lineament density; (J) stream width; (K) distance to roads; (L) distance to residential areas; (M) distance to farmlands; (N) population density; (O) archaeological sites; and (P) distance to construction materials.

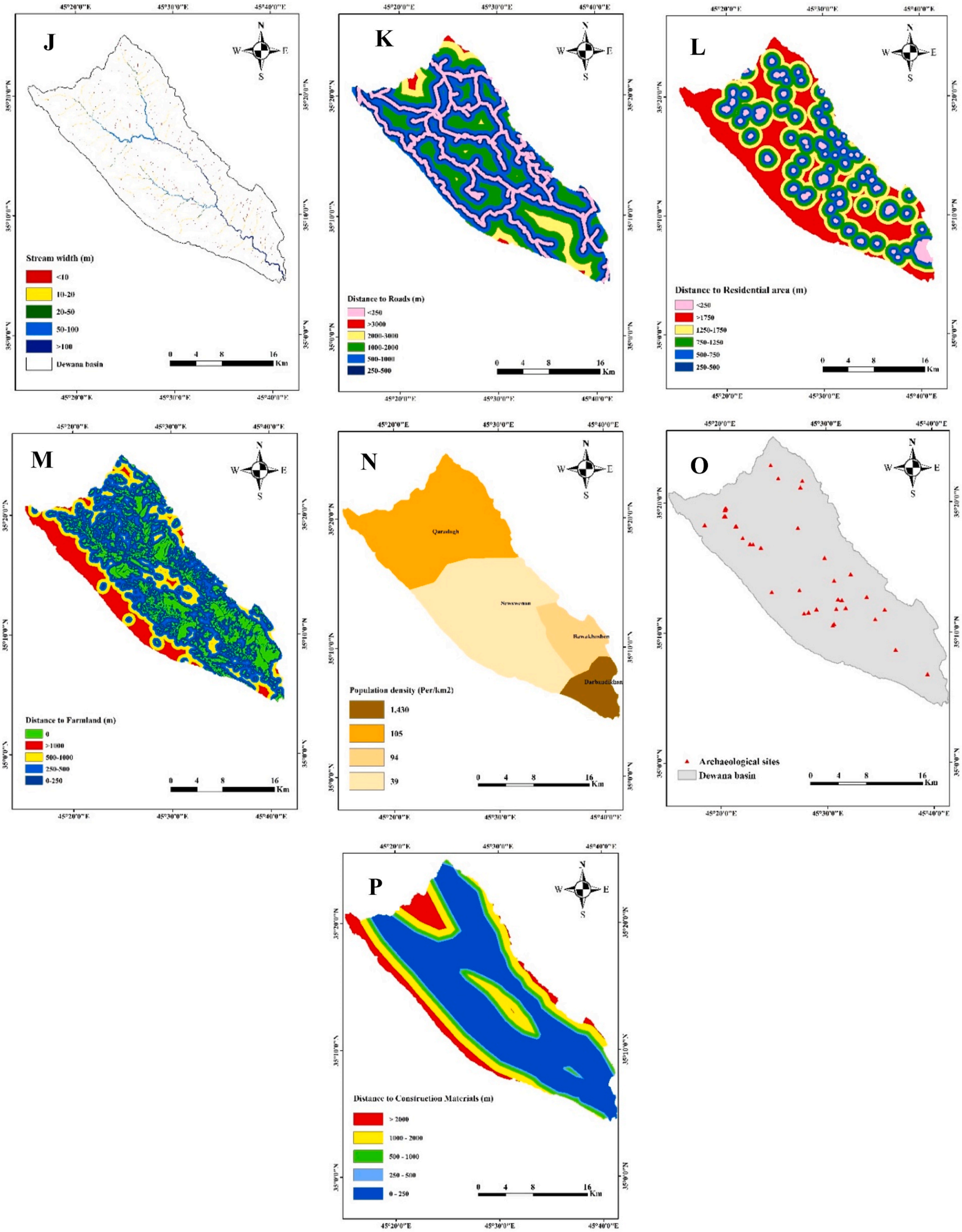

Fig. 3. (*continued*).

2.3.1.1. Slope. The slope is an important key factor to assess the method of the RWH technique. The slope is determined through the application of a topographic ratio, which involves computing the elevation variation between two points and dividing it by the horizontal distance separating these two points [28,29]. The Food and Agriculture Organization (FAO) standard guidelines have classified the evaluation of slope into 5 classes based on percentage and lower steep slopes which are more suitable than higher steep slopes [30–32], as shown in Fig. 3A.

2.3.1.2. Stream orders. Stream order implies the hierarchical arrangement of flow sections, permitting the classification of drainage basins according to their size [17,33,34]. To determine the flow direction, the DEM sink has been filled, and the D8 algorithm has been used to define the slope direction for each pixel [1,25], creating the flow accumulation by using the threshold 700 value, which directly affects the structure and density of extracted river networks [35] and finally derive 5th stream order. According to Refs. [14,17,25,36], and [37], the stream orders need to be higher and equal to the third order for selecting the dam sites. Being closer to the stream orders is more beneficial and economical than those further away because they require less construction work and do not lose water via evaporation and seepage [38,39], as shown as Fig. 3B.

2.3.1.3. Drainage density. Drainage density has been identified as a valuable indication for assessing the suitability of an RWH site [40, 41]. It is determined by dividing the total length of stream channels within a drainage basin by the sum of the basin's area [42,43] as shown in Equation (1).

$$D_{\mathrm{d}} = \frac{\sum_{i=1}^{\mathrm{n}} L}{A_{\mathrm{basin}}} \tag{1}$$

where D_d is the drainage density, n is the number of streams, L is the stream length (km), and A is the drainage basin (km). Drainage density is inversely related to infiltration but directly related to RWH sites [1,44,45], and is classified into five groups, as shown in Fig. 3C.

2.3.1.4. Soil texture. Soil texture greatly impacts the selection of a suitable RWH site by influencing infiltration rates and runoff volume [33,46,47]. To identify soil texture in the study area, 21 soil samples were collected from different locations except for mountain areas, which are classified as thin or absent soil cover and have high infiltration rates [9]. The samples were analyzed using the pipette method, and soil texture classes were created based on the United States Department of Agriculture (USDA) triangle classification, as shown in Fig. S1 was added as supplementary material. Soil texture was mapped using Sentinel 2 satellite images with a resolution of 10 m and a supervised classification method. Silty clay loam, clay loam, and silty clay textures with high runoff rates are suitable for RWH sites. However, high elevation and gradient areas are not suitable due to the presence of joints and fractures, providing perfect pathways for rainwater to percolate [9,30,47–51] as shown in Fig. 3D. The overall accuracy assessment between the pipette method and spectral reflectance is 88%, as shown in Table S3.

2.3.1.5. Land use/Land cover (LULC). Land use and land cover are significant factors in selecting suitable sites for the RWH. They have a significant impact on runoff velocity, infiltration, and evapotranspiration, which are vital factors in identifying suitable sites for the RWH [52–54]. The research area was divided into five categories using a supervised classification with a maximum likelihood log-arithm, and accuracy was assessed using 100 ground control points (GCPs) for the five major land cover classes, the overall accuracy was obtained at 90%, as shown in Table S4. The agricultural land and bare land are considered to be of high suitability for constructing RWH sites [55,56] whereas the urban areas and water bodies are considered restricted to all RWH sites [57,58], as shown in Fig. 3E.

2.3.1.6. Rainfall. Rainfall is essential in determining suitable locations for RWH. The GPM dataset was used to estimate precipitation data because of the limited number of weather stations in the study area and kriging was used to interpolate values at unmeasured locations [59,60]. The average annual precipitation in the study area was found to be between 610 and 687 mm, which exceeds the minimum required precipitation for RWH [61]. The correlation coefficient between the GPM data and the Darbandikhan station is 0.96, as shown in Fig. 5. The study classified the rainfall into three categories using the natural breaks (Jenks) classification method, as shown in Fig. 3F.

2.3.1.7. Runoff. Runoff is an important factor in determining suitable RWH sites [14]. The soil conservation service curve number (SCS–CN) method is the most frequently employed for estimating runoff events in small to medium-sized drainage basins [17,62,63]. This method takes into consideration the relationship between rainfall, soil texture, and land cover/use in the generation of runoff. According to the USDA, soil texture has been classified into three hydrologic soil groups (HSGs): B, C, and D [42,64]. The CN was obtained by combining the LULC and HSG layers in an index file created with the ArcGIS tool. As a result, the curve number ranges from 55 to 98. The SCS-CN model was applied to estimate the spatial variability in runoff depth for each pixel, as shown in Equation (2).

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

where Q is the runoff depth (mm), P is the total rainfall (mm), S is the potential maximum retention after a runoff (mm), and Ia is an initial abstraction in (mm).

The CN can be utilized to estimate the maximum potential retention (S), as shown in Equation (3).

$$S = \frac{25400}{CN} - 254 \tag{3}$$

I_a represents the initial abstraction, which accounts for all losses occurring before runoff initiation, including infiltration, evaporation, and water interception by vegetation [65,66]. A standard value of 0.2 is commonly used by the SCS for the parameter la [67]. The la can be calculated using equation (4).

$$Ia = 0.2 * S \text{ For } P > 0.2 \tag{4}$$

Finally, the Jenks were selected as the classification method, which is divided into five categories, as shown in Fig. 3G.

2.3.1.8. Geological formation. The geological factor is more important than any other natural factor influencing dam site selection [19,20,40] because it protects the study area from geological hazards by comprehending the engineering characteristics of the geological formations [9,68]. Geological formations were categorized based on the understanding of lithology and sediment permeability, which impacts the infiltration rate and capacity of the dams [9,34,69]. To create the geology map, various sources of data, including maps from Ref. [70], and [71], were utilized. Additionally, field surveys conducted with experts and RS were employed to extract information about the lithological units in the area. In addition to Quaternary sediments, the main eight geological formations, including Bai Hassan, Mukdadiya, Injana, Fat'ha, Pila Spi, Sinjar, Kolosh, and Gercus formations have been identified and classified into five categories to determine suitable sites for dam construction. The formations of Injana and Mukdadiya (lower part), which include claystone, siltstone, clayey sandstone, and pebbly sandstone lithology units, were assigned a high suitability score for dam site selection, whereas, gypsum and conglomerate lithology units, such as Fatha Formation (lower part), Bai Hassan Formation, Mukdadiya Formation (Upper part), and Quaternary (unconsolidated material), were given a low suitability score for dam site selection, as shown in Fig. 3H.

2.3.1.9. Lineament density. Lineaments are a big obstacle when determining a site for the RWH techniques because they are geologically or tectonically weaker zones for any construction due to the presence of fractures and joints that increase infiltration [9,19,72,73]. According to Ref. [74], the spectral band 8, visible and near-infrared (VNIR) of Sentinel-2A, is considered one of the most suitable bands for lineament extraction. The lineaments were automatically extracted using the PCI Geomantic software's dedicated tool [20,74–76]. The lineament density was created by line density, a spatial analyst tool, ArcGIS. The relationship between lineament density and dam sites is inverse: the higher the lineament density, the lower the RWH site [37,40,72,77]. The lineament density map was categorized into five classes, as shown in Fig. 3I.

2.3.1.10. Stream width. River discharge plays a crucial role in selecting dam sites and estimating reservoir capacity [20]. However, the Dewana watershed faces challenges in obtaining hydrological data due to the absence of river gauges. To overcome this limitation, the basin storage capability was calculated using stream order, as suggested by Refs. [28,78]. Another alternative proposed by Ref. [19] involves measuring the stream width, serving as a substitute approach for obtaining river discharge data. The researchers used the base map imagery from ArcGIS, acquired in January 2019, to measure the width of each stream since that year had the highest rainfall. To measure correctly, we split streams into multiple segments of less than 5 km. As a result, the stream width map has a range of 7 m–148 m. The construction of a dam is considered unacceptable in areas where there are no streams or where the streams are less than 20 m wide. The width of streams was found to be directly related to dam site selection, as shown in Fig. 3J.

2.4. Socioeconomics factors

Socio-economic criteria help ensure that RWH systems are socially acceptable, economically viable, and aligned with the needs and priorities of the communities and stakeholders involved [79].

2.4.1. Distance to roads

Roads have a significant socio-economic role in the region by providing access to water for livestock and domestic use. Therefore, locating proposed dam sites near roads can be advantageous by reducing transportation costs [14,20,80]. The maximum distance between roads and pixels in the study area is 3.88 km. To avoid potential conflicts between the proposed dams and future road development, or for safety reasons, it is recommended to maintain a distance of at least 250 m from roads [30,81,82], as shown in Fig. 3K.

2.4.2. Distance to residential areas

The potential sites for water harvesting should be located reasonably close to residential areas to reduce transportation costs and provide access to water for livestock and domestic use [14,19,20]. The greatest distances between each pixel in the study region and the residential areas were calculated to be about 7.52 km. To prohibit any potential conflicts between the constructed dams and the future development of residential areas, it is recommended that a minimum distance of 250 m from residential areas be maintained

[80,81,83,84], as shown in Fig. 3L.

2.4.3. Distance to farmlands

Agricultural land is the primary source of income for the majority of people in the Dewana watershed. The potential dam sites should be located reasonably close to farmlands to minimize transportation costs and ensure access to water for agriculture [14,19,47,80]. The research revealed that the farthest distances between pixels in the study area and the farmlands are 3.99 km. To preserve the environmental and safety significance of farmlands, it is recommended to maintain zero-meter intervals [30,47,83,85], as shown in Fig. 3M.

2.4.4. Population density

According to FAO guidelines, population density plays a significant role in selecting suitable water harvesting sites [46,86,87]. The official Iraqi government documents and local authority indicate a total population of 105,000 people in the Dewana watershed [21,88]. RWH sites are typically located near areas with high population density, as it reduces pumping and diversion costs [14,39,46,89,90]. The population density was classified into four classes based on administrative units, as shown in Fig. 3N.

2.4.5. Archaeological sites map

The Dewana watershed in the IKR is home to a variety of significant archaeological sites that span from the Paleolithic era to the middle Islamic period [91]. One of these remarkable monuments is the Naram-Sin relief [92]. The archaeology map was created by merging data from two surveys: the first conducted by the Iraqi Department of Antiquities in the 1940s and the more recent survey by the Qara Dagh Regional Archaeological Project (QDRAP) [91,92]. These surveys have identified 40 archaeological sites within the area, as shown in Fig. 3O.

2.4.6. Distance to construction materials

The distance to the materials map is an important factor in constructing dams. It provides valuable information for identifying potential sources of construction materials, reducing transportation costs, thus improving project efficiency [19,93]. Required materials such as loose gravel, clay compounds, and rock are acquired from the geological map [19,94,95]. Shells are constructed using a combination of loose gravel and clay materials sourced from alluvial deposits in the river bed and floodplain of the Dewana River [19,94]. Limestone rocks from the Pila Spi and Sinjar formations are commonly selected for rip-rap layers due to their erosion resistance and ability to protect water-harvesting structures [59]. The lower part of Mukdadiya Formation contains a mixture of claystone and conglomerate that has compacted to create materials that are ideal for producing large-scale concrete aggregates. The clay substances were extracted from claystone layers within the Injana Formation and old alluvial deposits in the study area [19]. The largest distances between each pixel in the study area and the materials range up to 4.3 km. The distance of materials is directly related to dam site selection [19,20], as shown in Fig. 3P.

2.5. Accuracy assessment

To assess the effectiveness and accuracy of a classified image or change detection map, it is essential to compare it with reference data, which is considered to be reliable and true [61,96,97]. The accuracy assessment for the LULC and soil texture map should include reporting on overall accuracy, user accuracy, and producer accuracy. These metrics are evaluated using the Kappa coefficient (KC) [61] as shown in equations (5)–(8) and illustrated in Tables S3 and S4. For accuracy assessment, 100 ground control points (GCPs) were collected randomly during the fieldwork survey for the five major land cover classes. As a result, the LULC map showed 90% overall accuracy (with a Kappa coefficient: 0.88), while the soil texture map achieved 88% overall accuracy (with a Kappa coefficient: 0.85).

On the other hand, the accuracy of the rainfall map was assessed by determining the correlation coefficient (R^2) between Darbandikhan station and the cloud station of the GPM near Darbandikhan station. The correlation coefficient was found to be 0.96, indicating a very strong positive relationship, as shown in Fig. S2.

$$\text{Overall accuracy} = \frac{\text{Total number of correctly classified pixels (Diagonal)}}{\text{Total number of Reference Pixels}} \times 100 \tag{5}$$

$$\text{User accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{number of classified pixels in the category (The Row total)}} \times 100 \tag{6}$$

$$\text{Producer accuracy} = \frac{\text{Number of correctly class number of correctly classified pixels in each categorified pixels in each category}}{\text{Total Number of Reference Pixels in the Category (The column total)}} \times 100 \tag{7}$$

$$\text{Kappa coefficient} = \frac{N\left(\sum_{i}^{r} = 1xii\right) - \sum_{i}^{r} = 1(xi + .x + i)}{N^{2-} \sum_{i}^{r} = 1(xi + .x + i)} \tag{8}$$

r = Number of rows in the error matrix, xii = Number of observations in row (i) and column (i), Xi+ = Total of observations in row (i), X + i = Total of observations in Column (i), N = Total number of observations included in the matrix.

2.6. Apply models: multi-criteria decision analysis methods

2.6.1. Analytical hierarchy process (AHP)

AHP is the most common MCDA method for determining the weight of criteria [19,42,98]. Enrique [99] recommends a range of 5–9 criteria for the AHP and suggests combining criteria into a main criterion with sub-criteria if there are more than 9. The suitability index map and dam site selection map consider different factors with varying levels of importance. The significance of each parameter was determined through a literature review, field observation, and expert judgment. The AHP comprises two main steps [100,101];

Step 1: Determination of weights:

The relative significance of various criteria is crucial information for decision-makers. The pairwise comparison matrix is employed to assess the relative importance of different criteria by comparing all possible pairs, determining which criterion holds higher priority, as shown in Equation (9) and Table S5.

$$a_{ij} = \frac{1}{a_{ji}}, a_{ij} \neq 0 \tag{9}$$

The pairwise comparison matrix was normalized using Equation (10), and then the weights of the criteria were calculated using Equation (11), as shown in Table 2.

$$X_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{10}$$

$$W_i = \frac{\sum_{j=1}^{m} X_{ij}}{N} \tag{11}$$

Wi is the weight; X is the normalized pairwise comparison matrix and N is the number of criteria.

Step 2: Evaluation of pairwise comparison matrix consistency:

The Consistency Ratio (CR) is used to evaluate the precision of pairwise comparisons. The CR proposed by Saaty [102], was calculated using the following equations (12) and (13):

$$CR = \frac{CI}{RI} \tag{12}$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{13}$$

Where Lambda max (max) is the major eigenvalue determined using the eigenvector technique, and the number of criteria is n.

The Random Index (RI) value was found on the specific table based on the number of criteria, as shown in Table S6. The next step in ArcGIS involves using the raster overlay algorithm to compute the map of suitable sites for water harvesting techniques. This process utilizes Equation (14).

$$AHP = \sum_{i=1}^{n} x_i w_i \tag{14}$$

where xi is the value of predictive factor i (where i = (predictive factors)), wi is the weight for predictive factor i, and n is the number of predictive factors.

Table 2
The computed values of weights (priority vector), CI, RI, and CR for reviewing literature and local expert opinions.

Filed	Criteria	Weight priority vector	Max	CI	RI	CR
Suitability index map	Slope	0.33				
	Soil texture	0.251				
	Land use/cover	0.179				
	Rainfall	0.112	6.296	0.059	1.24	0.048
	Runoff	0.074				
	Drainage density	0.054				
Dam site selection map	Distance to stream orders	0.293				
	Distance to road	0.226				
	Distance to settlement	0.163				
	Geological formations	0.123	7.314	0.051	1.32	0.040
	Stream width	0.090				
	Liniment density	0.067				
	Distance to farmland	0.038				

2.6.2. Weighted sum method (WSM)

The WSM is the most widely used and simple MCDA method for evaluating multiple alternatives in terms of various decision criteria [20,103,104]. The equal weight of each factor is one of the weighted sum method deficiencies [20,105,106]. The classification and ranking of the thematic layers were based on previous literature and the expert's judgment in the domain. Each factor was categorized into five classes, as shown in Table S2. The next step is the summation of all factors in the GIS raster environment by using Equation (15).

$$\text{WSM} = \sum_{i=1}^{n} w_j a_{ij} \tag{15}$$

where n is the number of factors, a_{ij} is the actual value of the $_i$ of the j criteria, and w_j is the weight of the $_j$ criterion.

2.6.3. Weighted product model (WPM)

The process of ranking dams is crucial for helping decision-makers identify the most promising sites for dam construction and operation. This determination is based on various geometric characteristics of the dams, including lake surface area, storage capacity, height, length, and depth [107]. The WPM, as a subset of the MCDA model, allows decision-makers to evaluate and compare alternatives based on a set of criteria and their relative importance. To normalize the decision matrix based on the nature of the criteria. Positive criteria with larger desired values are normalized using Equation (16), while negative or cost criteria with smaller desired values are normalized using Equation (17). The normalized values for each alternative are exponentiation to the power of their corresponding weights. Then, the weighted values for each alternative are multiplied together to get the final score for that alternative. The alternative (dams) with the highest score is considered the best option, as shown in Equation (18) and Table S7.

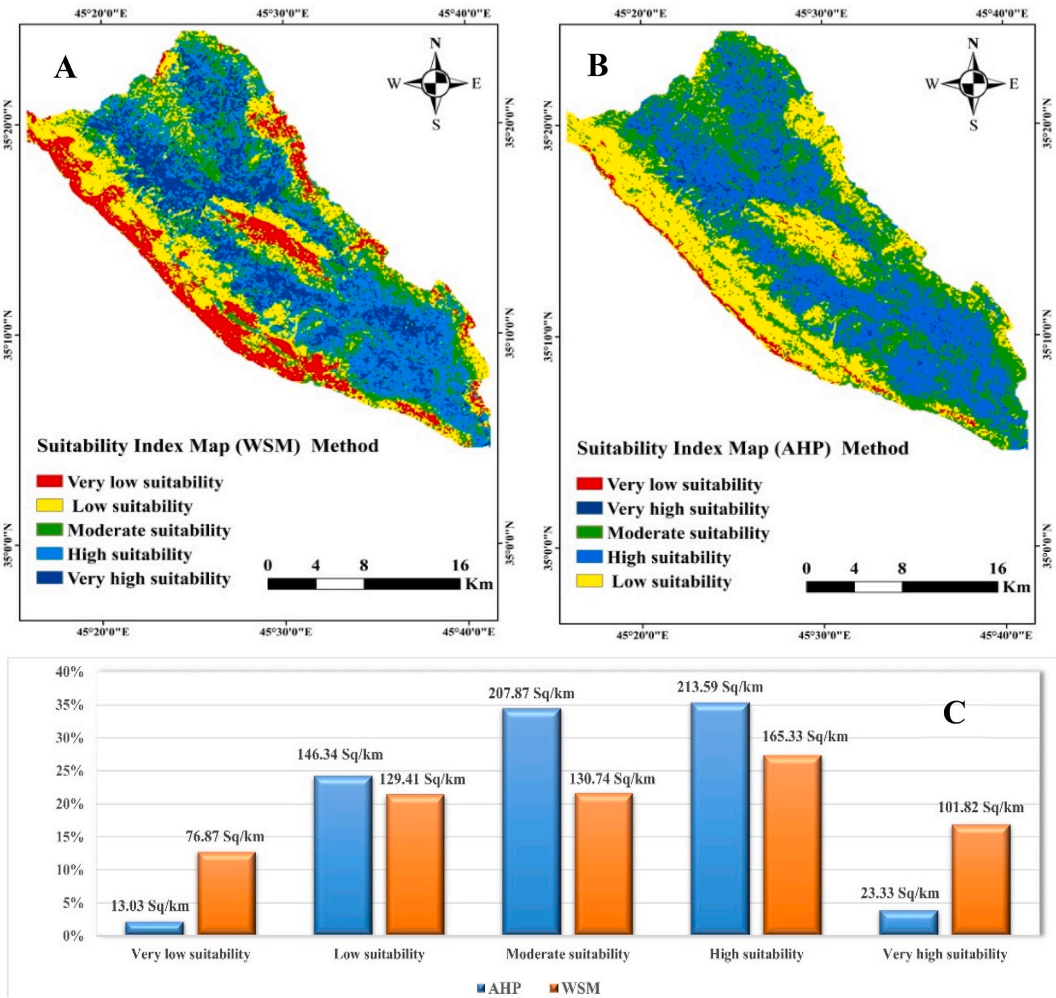

Fig. 4. The suitability index maps (A and B) for RWH, created using the WSM and AHP methods, and Figure (C) compares suitability index maps.

$$n_{ij} = \frac{r_{ij}}{r_j^{max}} \tag{16}$$

$$n_{ij} = \frac{r_j^{min}}{r_{ij}} \tag{17}$$

$$v(A_i) = \prod_{1}^{n} \left(r_{ij}\right)^{w_j} \tag{18}$$

Where ν(Ai) represents the score of alternative Ai r_{ij} represents the normalized value of alternative Ai for criterion j, wj represents the weight of criterion j, and n represents the total number of criteria.

2.7. Characteristics of the proposed dams

2.7.1. Proposed dam sites

The selection of sites for the proposed dams was guided by the highly suitable pixels identified in the dam site selection map

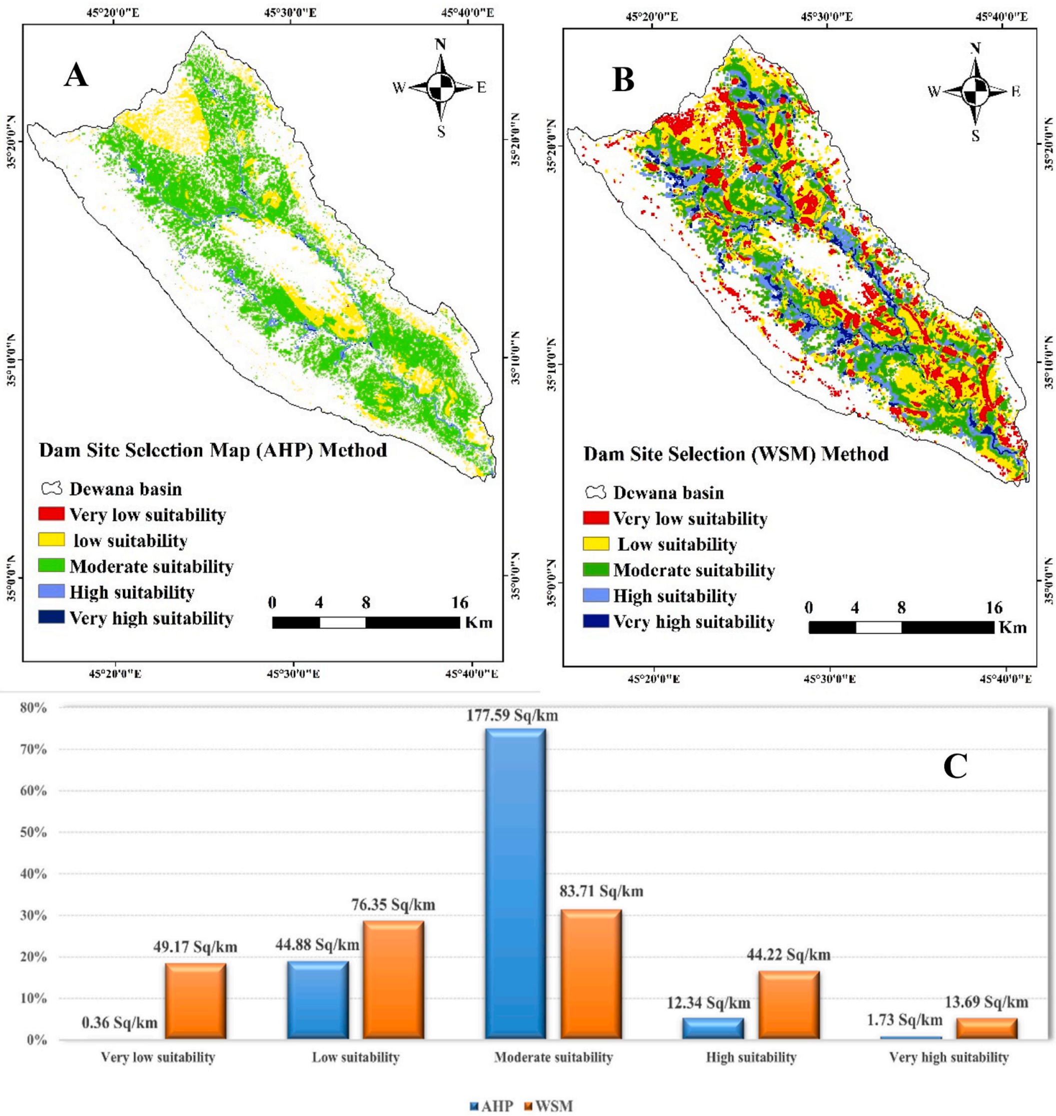

Fig. 5. Suitability maps (A and B) for dam site selection, created using the WSM and AHP methods, and Figure (C) compares suitability maps for dam site selection.

generated through the AHP method. Additionally, an integrated dataset was utilized, comprising contour lines at 5-m intervals, stream orders (3rd to 5th Orders), and a triangulated irregular network (TIN) extracted from the DEM using 3D spatial analyst tools in ArcGIS. The application of cross-section techniques played a key role in the selection process for the proposed dam sites.

2.7.2. Proposed dams profile

The dam profile includes various characteristics, such as the elevation of the dam's sea level, dam height, dam length, storage capacity, and lake area [16,19,52,53,108]. To find out the surface area and volume of the dams, the DEM is used to create a contour map with 5 m intervals and the TIN. Then, the surface volume sub-tool inside the 3D analyst tool of the ArcMap platform is utilized to compute the surface area and volume of the dams. The length and height of the dams are determined by extracting the dam's profile from the cross-section using the DEM in ArcGIS 3D Analyst spatial tools.

3. Results

3.1. Suitability index maps

The suitability index map for RWH was created with the integration of RS and GIS based on the AHP and WSM models, taking into account six layers. The most significant subfactors are slope (degree) < 5, soil texture of clay loam, silty clay loam and silty clay, bare land, rainfall >650 (mm), runoff >469 (mm), and drainage density between 2.5 and 3.7 km/sq.km, as shown in Table S2. The surface area of the highly suitable area, the WSM model identified 267.15 km^2 as highly suitable for water harvesting sites, compared to the AHP model's 236.89 km^2 as highly suitable, as shown in Fig. 4 A and B. To determine the most reliable method, compare the suitability

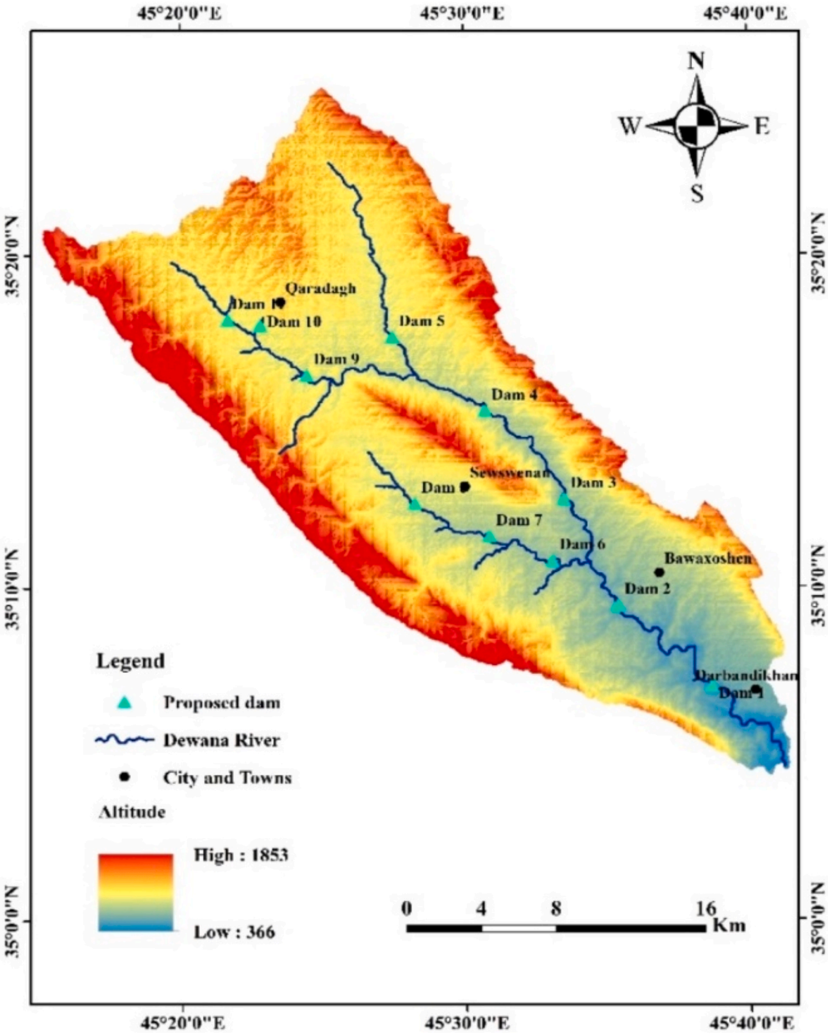

Fig. 6. Location of the proposed dams in the study area.

in AHP and WSM method areas in a percentage calculated for all classes, as shown in Fig. 4C.

3.2. Dam site selection maps

To select dam sites, high scores on the suitability index maps from the AHP and WSM methods were used, covering an area of 236.89 km^2 and 267.15 km^2, respectively. Additionally, biophysical and socio-economic criteria were taken into consideration during the selection process. The most significant subfactors, both biophysical and socio-economic, are distance to stream orders 250 m, distance to roads and residential area between 250 m and 500 m, geology formations of Injana and Mukdadiya (lower-part), lineament density <0.30 km/sq.km, distance to farmland <250 m, and stream width >20 m, as shown in Table S2. The outcomes of the AHP model show that 13.06 km^2 (5.55%) is an area that is highly suitable for constructing dams, whereas 44.88 km^2 (19.05%) and 177.58 km^2 (75.40%) are areas with low suitability and moderate suitability, respectively, as shown in Fig. 5A

The WSM model outcome demonstrates that suitable sites are scattered throughout the study area rather than being concentrated in one place. The WSM model proposed constructing dams over a 58 km^2 (21.81%) area. However, only a 13.69 km^2 (5.14%) area was considered to have a very high level of suitability, whereas 124 km^2 (46.62%) and 84 km^2 (31.57%) are areas with low suitability and moderate suitability, respectively. As shown in Fig. 5B. To determine the most reliable method for selecting dam sites, it is essential to analyze and compare the maps produced by the AHP and WSM techniques, as shown in Fig. 5C.

3.3. Characteristics of the proposed dams

3.3.1. Proposed dam sites

Selected dam sites were chosen considering highly suitable pixels, terrain characteristics, and proximity to drainage networks. Fig. 6 illustrates the locations of the 11 proposed dam sites, spanning an elevation range from 480 m to 815 m. The cross-section method played a crucial role in the selection process, focusing on river sections passing through mountainous areas [19,20,34], It is advised that the dams be strategically positioned along the drainage network [16,19,20,53,109]. Regarding stream orders, only one proposed dam was situated in the third-stream order, while six dams were in the fourth stream order, and four dams were in the fifth stream order. Consequently, four dams are positioned in the north, five in the middle, and two in the south.

3.3.2. Proposed dams profile

According to Refs. [16,19,20,52,53], and [110], dams are categorized into three types: small, intermediate, and large dams. This classification is based on dam size, including storage capacity and dam height, as indicated in Table S8. Consequently, our proposed dams were further classified into three categories: small dams (Dams 10 and 11), medium dams (Dams 3, 4, 5, 6, 7, 8, and 9), and large dams (Dams 1 and 2). The cross sections of proposed dam sites are shown in Fig. S3 A to K, whereas the profile of proposed dams is shown in Table S7. The study revealed that the 11 proposed dams exhibited varying heights, ranging from 10 m to 55 m, and lengths ranging from 72 m to 650 m. The storage capacity of the lakes aligned with the topographic conditions of the surrounding areas, ranging from 88,200 m^3 to 76,822,200 m^3. The surface area of the lakes varied from 36,771 m^2 to 3,613,060 m^2. The proposed dams in the study area have a combined storage capacity of 250,966,800 m^3, with the largest volume situated in the southern region.

3.4. Ranking of the proposed dams

In addition to the geometric characteristics of the dams (stated in subsection 2.7.3), this study utilized additional factors, such as the archaeological map, distance to population density map, and distance to construction materials map are taken into consideration [17,19,20,52,107,111] to rank 11 proposed dam sites. The ranking of the dam sites was determined, with Dam #10 being ranked as the first choice. Then, the second, third, fourth, and fifth choices were Dam #2, Dam #1, Dam #11, and Dam #3, as shown in Table S7. The Dam #10 site has the lowest height, reducing construction costs. Furthermore, the construction of this dam will not sink any villages or archaeological sites. However, it should be noted that this dam has a relatively smaller water storage capacity of 352,800 m^3. The second and third-ranked dam sites, corresponding to proposed Dams #2 and #1, are situated in the southern part of the study area. These dams have the largest reservoirs, with areas of 3,362,104 m^2 and 3,613,060 m^2, respectively, and the capacity to hold 76,815, 900 m^3 and 76,822,200 m^3 of water. Additionally, the average depth at these sites is ~23 m, resulting in lower evaporation rates. However, the downside of these dam sites is that they have a length of 405 m and 547 me, which would add to the construction costs. Moreover, each of these dams would cause the submersion of one village and one archaeological site. The fourth-ranked dam site corresponds to Dam #11, which is located in the northern part of the study area. The fifth, sixth, seventh, eighth, ninth, tenth, and eleventh-ranked dam sites (dam #3, 7, 9, 4, 6, 5, and 8) are situated in the middle section of the study area. Additionally, Dam #4 and Dam #5 would result in the submersion of one village and one archaeological site, while Dam #8 would result in the submersion of one village. Finally, the ranking of dams can help ensure that the development of water resources is sustainable and contributes to the long-term well-being of communities and ecosystems. After conducting thorough assessments, Dam #10 and Dam #2 have been ranked as the first and second choices, respectively. These rankings are based on their strategic locations within the Dewana watershed. Dam #10 is situated near the Qaradagh district in the north, while Dam #2 is positioned between the Darbandikhan and Bawakhoshen communities in the southern part of the watershed.

4. Validation of the models

One of the key approaches used in the current study is a validation of the models, which is based on comparing predictions with field reality and evaluating the model's ability to correctly identify suitable and unsuitable areas [112–114]. This study uses two different methods for validation: Segmentation accuracy assessment for the suitability maps and ROC for the dam site selection maps. Both methods are used to evaluate image classification or segmentation algorithms, but they differ in their approach. Segmentation accuracy assessment evaluates the agreement between a segmentation algorithm and a ground truth at a pixel level, while ROC analysis evaluates the overall performance of a binary classifier in terms of true and false positive rates at different classification thresholds [9,19,115].

4.1. Validation for suitability index maps from the AHP and WSM methods

To examine the outcomes derived from the AHP and WSM models, a segmentation accuracy assessment was conducted to identify suitable water harvesting sites [19,20]. This assessment involved determining the location of the reference point (three dams) on the map of suitable water harvesting sites. Subsequently, three buffers were generated around the reference point at distances of 250, 500, and 1000 m for the dams [19,20]. The spatial analyst tools in ArcGIS 10.7.1 were utilized to calculate the statistics, including the total number of pixels, the number of suitable pixels, and distance between suitable pixels, and the reference point within these buffers. The accuracy of suitable pixels, accuracy of distance from the reference, and overall accuracy were then computed using Equations (19)–(21):

$$\text{Accuracy of suitable pixels} = \frac{n}{\sum n}\% \tag{19}$$

n: Number of highly suitable pixels

$$\text{Accuracy of distance from reference} = \frac{\text{max} - \text{distance from the reference}}{\text{max} - \text{min}} \tag{20}$$

$$\text{Overall accuracy} = \frac{(\text{accuracy of suitable pixels} + \text{accuracy of distance from reference})}{2} \tag{21}$$

The average accuracy of suitability pixels for the WSM model (69.22%) is higher than the average accuracy of suitability pixels for AHP (62.22%). The reason is that the AHP needs explicit judgments, where the decision-makers may feel more confused when filling out the pairwise comparison matrix because real-world decision problems are complicated and unclear [19,116]. The average accuracy distance of suitability pixels from reference points for the WSM model is lower than the average accuracy distance of suitability pixels for AHP, which were 36.33 %, and 38.78 %, respectively. It is demonstrated that the number of suitability pixels in the WSM method is scattered and spread around the reference points. While the suitability pixels in the AHP model are mostly clustered, because of the WSM's lack of consideration for the serious shortcomings that may arise as input factors when all other aspects are given equal weight [20]. Finally, the average overall accuracy of the WSM model is higher than the average overall accuracy of the AHP model, at 50.50% and 52.78%, respectively, as shown in Table S9.

4.2. Validation for dam site selection maps from the AHP and WSM methods

The AHP and WSM models' results for dam site selection maps were evaluated using the ROC and the AUC techniques [9,112,117]. The ROC technique represents the balance between the "False Positive Rate" and the "True Positive Rate" graphically for each value of the probability [23,118]. Each pixel value in the dam site selection maps was classified based on the suitability classes' validity by comparing the classified map with the existing dams [19,119]. The AUC value was computed using the ArcSDTM software package within ArcGIS [9,120]. The AUC scale ranges from 0 to 1, where a value of 1 indicates a perfect model and a value below 0.5 indicates a random or incorrectly selected model [9]. The AUC-ROC results revealed that both models performed well for dam site selection maps. The AHP model showed the highest AUC (AUC = 1.00), followed by the WSM model (AUC = 0.78), as shown in Fig. S4 A and B. This suggests that both models displayed close agreement between predicted and actual values, with the AHP model performing better than the WSM model for dam site selection maps.

5. Discussion

Suitability index maps are created using GIS techniques and MCDA models, which is a difficult task due to the impact of various factors. For example, the slope was found to have the greatest impact on the suitability of water harvesting sites when compared to other factors. Moreover, built-up areas and water bodies were designated as restricted areas due to environmental and safety concerns [47,52,121]. The suitability index maps indicate that suitability for water harvesting sites increases when moving from the border of the watershed toward the center. This is attributed to a reduction in slope and an increase in drainage density. However, it should be noted that the central area of the watershed, which is covered by forest land and hard rocks, deviates from this trend. The results reveal that the northern and southern regions are more favorable for water harvesting compared to the middle and edges of the watershed border. In terms of dam site selection, the geological formation was the primary factor for selecting the dam sites [19,23,122]. The areas within 250 m of residential areas and roads were designated as restricted areas due to economic and safety considerations [83,123]. Then, the farmlands are considered valuable resources for both economic and environmental reasons and, therefore, must be excluded from water harvesting techniques, if proper safety measures are maintained, the proximity to RWH systems can be an advantage [30,81,83,124,125]. The dam site selection map generated by the AHP model in GIS shows that suitable sites are clustered along the river's path. The northern part of Dewana is not a suitable site for constructing dams due to several reasons. Firstly, there is a high density of lineaments in the area which can cause instability and difficulty in constructing the dams [71]. Secondly, the geological formations in the area, such as the Bai Hassan and Fatha formations, are weak and not able to support a dam [22]. Finally, the low drainage density in the area, particularly in streams of the third order or higher, leads to low stream width. Most of the middle part of the study area is considered suitable for dam construction due to the low lineament density and high drainage density, especially in streams of the third order or higher, which leads to high stream width [20,71]. The southern region of Dewana was identified to have moderate suitability for dam construction, mainly due to high lineament density and weak geological formations, such as Fatha Formation [19,22]. Additionally, there are more farmlands and settlements in this region compared to other areas. Eleven possible dam sites were proposed, only one proposed dam was located in the third-stream order, while six dams were located in the fourth-stream order and four dams were located in the fifth-stream order. The largest dam volume is situated in the southern region. This is because the narrow valleys in the middle and northern parts of the area do not retain as much water, and the steep slopes in those areas would require more extensive construction work compared to the southern part. The ranking of dams can help ensure that the development of water resources is sustainable and contributes to the long-term well-being of communities and ecosystems. Dam #10, being ranked as the first choice, is situated in the northwest part of the study area, with a distance of 1.68 km from the Qaradagh district. This district has the second-highest population density and relies on four artisan wells in the Swerraw village [21]. Dam #2, the second-ranked dam, is located in the southern Dewana watershed. This site is highly suitable for addressing the water scarcity issues faced by the communities of Darbandikhan and Bawakhoshen. Currently, these communities are experiencing a lack of clean drinking water primarily due to the discharge of sewage and municipal wastes from cities surrounding Darbandikhan Lake into the lake itself, as well as the release of 34 % of sewage from the Darbandikhan into Dewana Lake [126,127]. Moreover, the southern region has a larger area of cultivable land than the other parts, providing an opportunity to expand grain cultivation and increase agricultural productivity. Furthermore, the first and second-ranked dams are located near the lower part of the Mukdadiya Formation, which is characterized by a mixture of claystone and conglomerate. This geological composition makes it an ideal source for producing large-scale concrete [19]. To the best of our knowledge, this research is the first one to employ an archaeology map and distance to materials, along with the geometric characteristics of the dams, within the WPM model to rank proposed dams. The proposed dam sites are not only intended to control water flow during a flood season but can also serve multiple purposes, such as supplying water for households, irrigation surrounding lands, and providing enough water for livestock [16,52,53]. The location of the dams can be designed to be near residential areas to make it easier to supply water to households [14,19,20]. Additionally, the water from the dams can be transferred to other parts of the study area to provide supplemental irrigation during dry spells.

6. Conclusion

As a response to water resource shortages in the IKR, constructing a dam has been a possible solution considered by both the central government of Iraq and the Kurdistan Regional Government. The research provides a valuable example of the combination of RS images, GIS, and geotechnics in the development of water resources. Based on relevant literature reviews, field observations, and expert opinions, this study identified several important criteria for creating suitability index maps, including slope, soil texture, land use/cover, rainfall, runoff, and drainage density. For dam site selection maps, important criteria included geology formations, lineament density, stream width, stream order (3rd and 5th order), and distance to roads, residential areas, and farmland. Furthermore, the ranking of dams considered population density, archaeology, distance to materials, and geometric characteristics of the structures. The accuracy assessment was conducted for the LULC, soil texture, and rainfall maps, achieving accuracies of 90%, 88%, and 0.96, respectively. The weights obtained from the decision-making models were used in GIS to generate suitability index maps. The AHP model identified an area of 236.89 km^2 as highly suitable for water harvesting techniques, while the WSM model identified a larger area of 267.15 km^2 as highly suitable. The WSM model indicated that the results were distributed and scattered throughout the study area, while the AHP model identified the suitable areas as clustered areas. To evaluate and compare the models, a segmentation accuracy assessment was conducted on the suitability index maps using three buffers created around the reference point at distances of 250, 500, and 1000 m for dams. The average overall accuracy of the WSM model was 60%, 57%, and 54% for the three buffers (i.e., 250, 500, and 1000 m), respectively. While that of the AHP model was 59%, 55%, and 52% for the buffers 250, 500, and 1000 m, respectively. These results indicate a decrease in accuracy as the area expands. Therefore, the researchers recommend focusing on the construction of small and medium-sized dams. The average overall accuracy of the WSM model is (53%), which is higher than that of the AHP model (51%). To create dam site selection maps, high scores in the suitability index maps from both the AHP and WSM models, along with socio-economic criteria were used. The weights obtained from the decision-making models were implemented in GIS to create dam site selection maps. Among the criteria for creating the dam site selection map, the geological factor was given the highest weight. According to the AHP model, only 13.06 km^2 (5.55%) of the study area is highly suitable for dam construction, whereas the WSM model identified over 58 km^2 (21.81%) as highly suitable. However, the WSM model only considered 13.69 km^2 (5.14%) as having a very high level of suitability. The results of the WSM model indicate that suitable sites are dispersed throughout the study area rather than concentrated in one location, while the AHP model shows that suitable sites are clustered along the path of the river. The AUC-ROC was utilized to evaluate and compare the models used for dam site selection maps. The results indicate that both models have good prediction capabilities. In terms of dam site selection, the AHP model demonstrated the highest AUC with a perfect score of

1.00, followed by the WSM model with an AUC of 0.78. Proposed dam sites were selected based on the highly suitable pixels identified by the AHP model for the dam site selection map, using contour lines with 5-m intervals, stream orders, and a TIN. A total of 11 dam sites were proposed using these models. The ranking of proposed dam sites was conducted using the WPM and geometric characteristics, as well as the archaeological map, distance to a population density map, and distance to materials map. The results of the ranking indicate that Dam #10 is the highest-ranked site, followed by Dam #2 in second place and Dam #3 in third place. The highest-ranked dam site is located in the north of the study area, while the second and third-ranked dams are situated in the south and middle of the study area, respectively. The outcomes of this study will prove advantageous to relevant authorities by diminishing dependence on groundwater and ensuring a sustainable, long-term water supply for domestic, animal, and irrigation purposes in the study area. Additionally, we recommend that future research harness enhanced geospatial techniques, integrate considerations for climate change, and explore additional criteria. Exploring these aspects in future studies has the potential to significantly refine existing models, improve accuracy, and contribute to a more comprehensive and effective approach to water resource management.

CRediT authorship contribution statement

Bakhtyar Ali Ahmad: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Sarkawt Ghazi:** Supervision. **Azad Jalal Shareef:** Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e27273.

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