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Water Harvesting for Wadi Al-Qasab, in Nineveh Governorate by Constructing a Virtual Dam

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ABSTRACT

Wadi Al-Qasab basin is considered one of the seasonal largest basins located in the eastern part of Nineveh Governorate. However, the region suffers from water scarcity in summer and abundance in winter. This study aims to determine the storage capacity resulting from the construction of a hypothetical dam at the bottom of the basin after analyzing the morphological and hydrological characteristics of the basin during 2018 using a GIS program. The Watershed Modeling System WMS program is used to calculate the curve number CN and annual surface runoff by introducing data for three parameters (soil moisture, ground cover, and hydrogeological characteristics). The surface runoff volume is estimated using a GIS program based on the runoff depth and basin surface area. Based on these findings, there are several possible scenarios for constructing a hypothetical dam at the bottom of the basin. The first proposed dam, with a length of 60 m, can hold water for 183 500 m^3, whereas the second proposed dam, with a length of 285 m, will hold water for 144 2258 m^3. In the last one, a dam spanning 530 m can store 5492700 m^3 of water. After studying the morphological characteristics of the basin, it is found that it has a high CN, giving preference of water storage over infiltration. The largest third proposed dam can be chosen due to its high storage capacity, which gives the longest storage period for rainwater.

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حصاد المياه لوادي القصب في محافظة نينوى من خلال إنشاء سد افتراضي

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الملخص

يعتبر حوض وادي القصب من أكبر الأحواض الموسمية الواقعة في الجزء الشرقي من محافظة نينوى. ومع ذلك، فان المنطقة تعاني من شح المياه في الصيف ووفرتها في الشتاء. تهدف هذه الدراسة إلى تحديد الطاقة التخزينية الناتجة عن إنشاء سد افتراضي عند اسفل الحوض بعد تحليل الخصائص المورفولوجية والهيدرولوجية للحوض خلال عام 2018 باستخدام برنامج نظم المعلومات الجغرافية. تم استخدام برنامج نظام نمذجة مستجمعات المياه **WMS** لحساب كل من قيمة رقم المنحنى **CN** والجريان السطحي السنوي من خلال إدخال بيانات لثلاثة عوامل هي (رطوبة التربة، والغطاء الأرضي، والخصائص الهيدروجيولوجية). تم تقدير حجم الجريان السطحي على أساس عمق الجريان السطحي ومساحة سطح الحوض باستخدام برنامج نظم المعلومات الجغرافية. بناءً على هذه النتائج، هناك عدة سيناريوهات محتملة لبناء سدود افتراضية في قاع الحوض، صغير، متوسط ، وكبير. يستطيع السد الأول بطول 60 مترًا أن يحتفظ بالمياه بمقدار 183,500 مترًا مكعبًا، في حين أن السد الثاني بطول 285 مترًا سيحتفظ بالمياه بكمية 144,2258 مترًا مكعبًا، وفي الأخير يمكن لسد يبلغ طوله 530 مترًا تخزين 5,492,700 مترًا مكعبًا من المياه. بعد دراسة الخصائص المورفولوجية للحوض تبين أنه يحتوي على قيمة عالية من رقم المنحنى **CN** مما يعطيه الأفضلية على تخزين المياه على الترشيح. يمكن اختيار السد الثالث الأكبر نظرا لسعته التخزينية العالية، مما يعطي أطول فترة تخزين لمياه الأمطار. تلعب برامج نظم المعلومات الجغرافية وبرامج إدارة المستودعات أدوارًا مهمة في تحديد مدى ملاءمة المواقع لتجميع مياه الأمطار.

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Introduction

Water plays a key role in agriculture, industry and energy production, making it a cornerstone of economic development (Abdaki *et al.*, 2023). In addition, water provides recreational opportunities and supports ecosystems by feeding a variety of plants and animals (Alwan *et al.*, 2020). Ecosystems depend highly on water to maintain environmental balance, as it facilitates nutrient cycling, influences climate, and sustains myriad ecosystems (Liu *et al.*, 2017) Water is a pure natural resource that helps to sustain planetary ecosystems. It is important to understand, conserve and protect this precious resource for present and future generations (Adham *et al.*, 2023; Al-Salim and Al-Ozeer, 2020).

Gray and Sadoff (2007) defined water security as "acceptable water quantity and quality for health, livelihood and production, including acceptance of water-related risks". The demand for water exceeds the supply (Dastourani, 2022); therefore, the water scarcity has severe consequences for individuals, communities and the environment. In addition, water scarcity affects agricultural activities and the economy significantly. This in turn stresses biodiversity leading to its loss and habitat degradation (Sarkar and Biswas, 2022). Moreover, water scarcity exacerbates the socioeconomic inequalities. However, if water scarcity is not addressed immediately, it can have catastrophic consequences for the well-being of the planet and its inhabitants (Faisal and Abdaki, 2021).

Water availability and quality is an issue of great concern in Iraq, as several factors exacerbate water scarcity in Iraq (Al-Ozeer *et al.,* 2020). Generally, Iraq has an arid to semi-arid climate, so water scarcity is an ongoing issue. The country is highly dependent on the Tigris and Euphrates rivers, which are the main sources of water for agriculture, drinking and industrial purposes (Ammar *et al.,* 2016). Factors such as drought, construction of surface water bodies, climate change and poor water management will all contribute to the reduction of water availability (Abdaki *et al.,* 2021; in Rahi *et al.,* 2019). This has resulted in poor access to safe drinking water, increased river salinity and reduced agricultural productivity (Al-Ozeer and Al-Abadi, 2022). Water scarcity in Iraq has significant social and economic impacts including food shortages, displacement. There are also public health concerns (Sayl *et al.,* 2017).

Water harvesting (WH) was introduced by Mekdaschi and Liniger (2013) as "the collection and management of rainwater runoff to increase water availability for domestic and agricultural use, as well as ecosystem sustenance.". This concept involves the collection and storage of rainwater or runoff for later use (Sadeq and Mohammad, 2022). The WH has become increasingly accepted as an effective strategy for managing water scarcity and developing sustainable water resources (Aziz *et al.,* 2023). WH approach demonstrates many benefits. First, increasing surface and groundwater availability, particularly in regions with lower rates of precipitation, or water sources are unreliable. It offers a cost-effective solution to meet water requirements for different purposes (Qi *et al.,* 2019). Second, the WH technique recharges groundwater in the aquifers decreases soil erosion and prevents flooding by managing storm water runoff (Al-Abadi *et al.,* 2017). Furthermore, it enhances ecological function and biodiversity conservation by creating small water bodies (Roy *et al.,* 2022). Third, WH promotes various ecosystem services including diminishing dependence on external water sources, improving water quality, and strengthening resilience to climate change (Nabit *et al.,* 2023). Overall, WH approach provides a sustainable framework to efficiently management of water resources, mitigates water scarcity, and fosters ecological balance and ecosystem functions (Alwan *et al.,* 2020; Aziz *et al.,* 2023; Qi *et al.,* 2019)

In recent decades, the integration of geographical information systems (GIS) and remote sensing (RS) technologies have shown significant value in the context of WH applications (Al-Hussein and Yahyaa, 2019; Al-Kubaisi and Al-Kubaisi, 2023). These tools allow researchers and policymakers to effectively and precisely analyze and set reliable plans for water resource management for harvesting purposes (Al-Siaede, 2019; Alsalmany *et al.,* 2023; Rana and Suryanarayana, 2020). GIS facilitates the collection, storage, and analysis of biophysical variables and spatial data elements such as topography, land use, and hydrological features (Fatah *et al.,* 2020; Hamrawi and Ibrahim, 2021). This information, when combined with RS data, provides a comprehensive understanding of the distribution and availability of water resources (Ali and Al-Abadi, 2021; Rahman, 2017). The RS enables the detection of suitable potential locations for water storage and assessment over large areas (Adham *et al.,* 2023; Hashim and Sayl, 2021). However, integrating GIS and RS technologies offers valuable insights and tools for effective water harvesting (Al-Khuzaie *et al.,* 2020).

There are no studies investigating the harvesting methods and water potential in the Wadi al-Qasab basin. Despite the importance of water in the area, there is a lack of research and understanding of the ecological, social and economic benefits, challenges and feasibility of using water harvesting methods. This study, therefore, seeks to answer the following question: “What are the potential benefits, challenges and feasibility of water harvesting will be used in Wadi Al-Qasab?”. The objective of this study is to assess the suitability of the designated area for surface rainfall water storage and to estimate the potential volume of the stored water resulting from three different scenarios involving exposed dams of varying sizes (small, medium, and large).

Materials and Methods

The study area:

Wadi Al-Qasab basin is about 1306.5 km^2 and is located in the eastern part of Nineveh Governorate, Iraq. The basin is located between the longitudes (42° 40' 36" to 43° 19' 26" E) and latitudes (35° 49' 19" to 36° 18' 22" N) as shown in Figure (1). The topography of the study area shows that the northern part represents the high area with an elevation about 544 m above sea level, and the southern part represents the low area with an elevation about 177 m above sea level. According to Al-Youzbakey (2022), Wadi Al-Qasab discharges its seasonal water contains sediment loads into the Tigris River north of Qayyarah town. The sediments are dominated by sandy clayey loam with some amount of gypsum. The soil profile made of sandy to silty loam, and the soil texture changed laterally to silty clayey loam, according to the prior floodplain sediment distribution.

Data Collection and Analysis:

Data pertaining to the study area are obtained through a comprehensive collection process using various reliable sources. First, RS images tht obtained from Landsat 8, which enabled the acquisition of detailed and up-to-date information at 16 days intervals. Additionally, an exploratory map depicting the territory of Iraq at a scale of 1:1000,000, officially released by the Ministry of Agriculture, Directorate of Agricultural Research and Projects, served as a valuable resource. This map provided essential contextual information for the study area. Finally, local rainfall data specifically from the Mosul rain station, covering the years 2018-2019, are utilized to analyze the precipitation patterns within the region. Collectively, these diverse data sources facilitated a comprehensive understanding of the environmental dynamics and instrumental use in conducting subsequent analyses. These different data types are analyzed using various softwares including ArcGIS 10.8, Global Mapper 18, and Watershed Modeling System (WMS) 11.2.

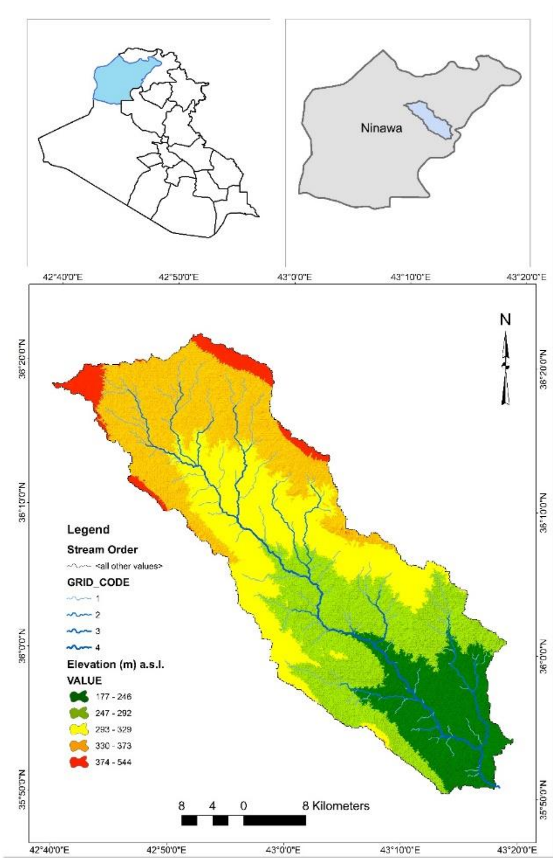

Fig. 1. Location map of the study area.

Volume of water stored determination:

Several steps are followed to determine the volume of water stored in the proposed lakes as a flow chart shown in Figure (2).

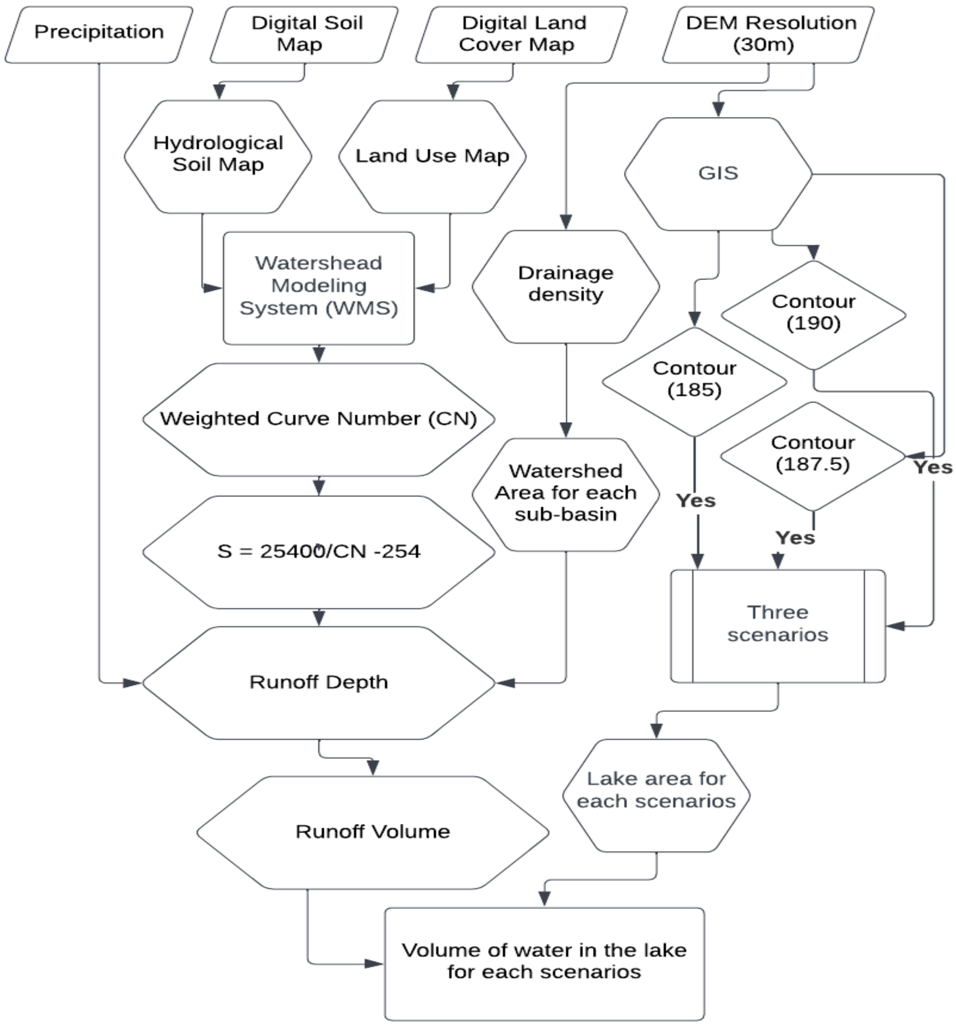

Fig. 2. Flow chart for determination of water volume in the proposed lake.

Hydrological characteristics:

Hydrological characteristics include many parameters: basin slope (BS), soil texture, hydrological soil group (HSG), Landuse/Landcover, and Rainfall. According to Strahler (1957) classification, the amount of stored surface water is controlled by the order of streams and the extent of their effect in the basin. To retain rainwater for an extended period, the basin must have a slope of less than 2%. Figure (3) depicts the basin drainage net map, which shows that the basin slope is 0.015.

The soil type is classified following the classification of soil conservation system (SCS) (USDA, 1986), which consists of four types as shown in Table (2). The soil at the study site is classified as class B as shown in Figure (3). According to satellite images, the land cover of the study site is classified as follows: bare area, sparse vegetation (less than 15%), cropland (20–50%), and grassland or shrub land (50–70%) of the total basin area (Table 1).

The curve number (CN) is calculated by introducing data from three factors: the hydrogeological soil group (HSG), Land cover, and hydrological properties of the studied area (Gilewski and Wglarz, 2018). The CN value is calculated using WMS V.11 software. The value of CN is unitless ranging from zero to 100. When the value of CN is close to zero, it indicates an increase in infiltration in the soil, and vice versa; if the value approaches 100, it indicates a decrease in the value of infiltration and an increase in surface runoff (Caletka *et al.*, 2020; Mishra *et al.*, 2003)

Table 1: Classification of soils according to USDA (1986),

Soil Group Hydrological	Soils Characteristics	Range of Minimum Infiltration (mm/hr)
A (Low runoff Potential)	High infiltration percentage with thoroughly wet conditions. Deep sands or gravels with a well-drained and high rate of water transmission. Mostly sand, loamy sand, or sandy loam.	8 – 12
B	Moderate infiltration rates during thoroughly wet conditions. Moderately deep to deep, moderately to well-drained, textures are moderately fine to moderately coarse. Silt loam or loam.	4 – 8
C	Infiltration rates is slow even thoroughly wetted. Usually has a layer that impedes downward movement of water or has moderately fine to fine textured soils. Sand clay loam.	1 – 4
D (High runoff Potential)	Infiltration rate is very sow when thoroughly wetted. Mostly clay soils with a high swelling potential; soils with a high permanent water table; clay layer near the surface of this soil profile; shallow soils over near-impervious materials. Mostly clay loam, silty clay loam, sandy clay, silty clay, or clay.	0 - 1

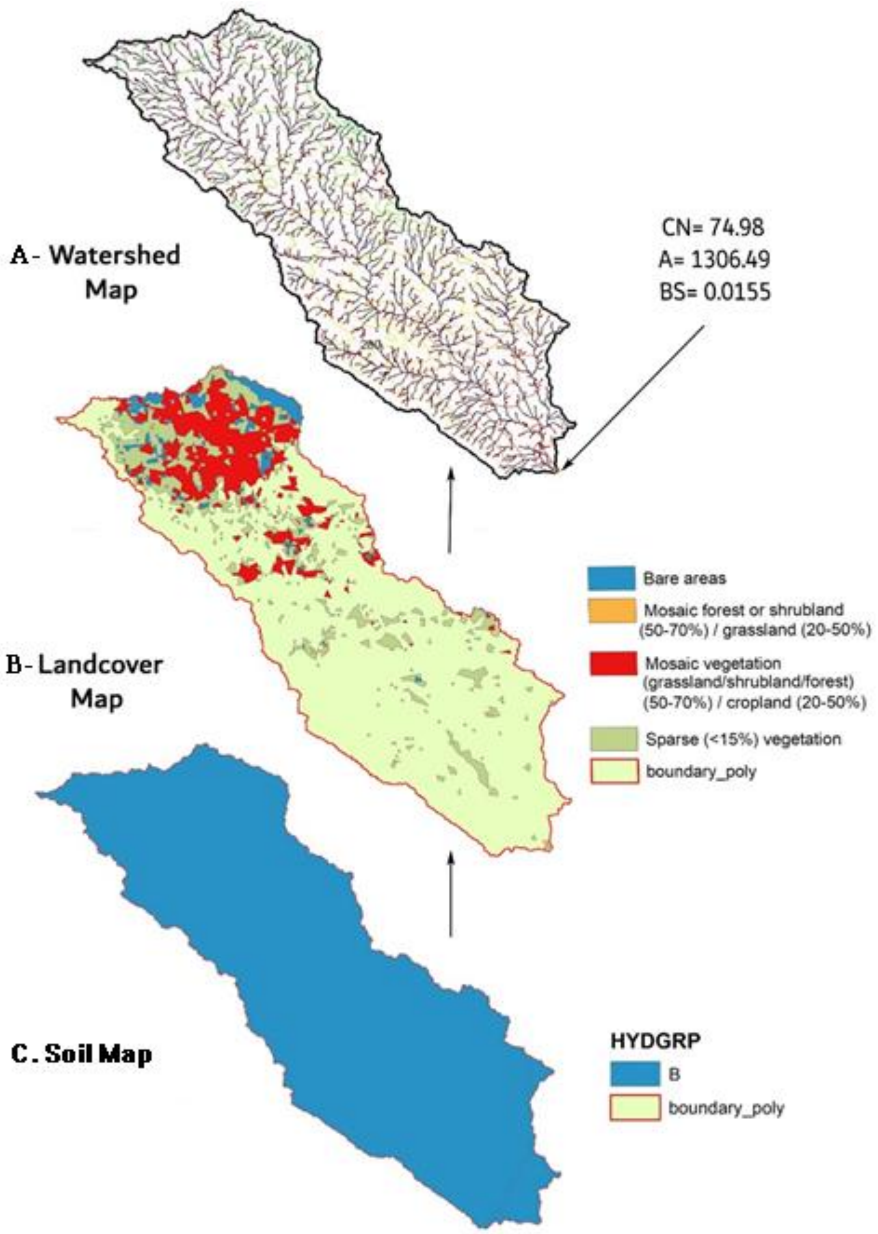

Fig. 3. Map of the study area showing: A. Watershed Map; B. Land Cover Map; C. Soil Map.

Results and Discussion

Runoff results:

The corresponding CN value is 75. This score indicates that the hydrological properties in the study area collect more water than can infiltrate, which indicates that the site is ideal for the construction of a dam to collect surface water (Table 2).

Table 2: Runoff CN Report Generated by WMS

Sun May 10 17:40:09 2020				
Runoff Curve Number Report for Basin 1B				
HSG	Land Use Description	CN	Area	Product
			km^2	CN x A
B	Sparse (<15) vegetation	86	566.597	48727.356
B	Mosaic vegetation (grassland/scrubland/forest)	60	605.543	36332.572
B	Bare areas	98	128.144	12558.105
B	Mosaic Forest or shrub land (50-70) / grassland	56	6.282	351.768
CN (Weighted) = Total Product \ Total Area= 74. 98				

The value of the retention constant (*S*) is proportional to the value of CN; that is, the greater the CN, the lower the value of the retention constant is, and vice versa (Equation 1) below:

$$\boldsymbol{S = \frac{25400}{CN} - 254} \ldots\ldots\ldots\ldots\ldots\ldots.(\mathbf{1})$$

Runoff is calculated according to equation (2):

$$\boldsymbol{Runoff\ Depth = \frac{(p - 0.2\,S)^2}{p + 0.2\,S}} \ldots\ldots\ldots\ldots..(\mathbf{2})$$

Where; $\boldsymbol{p}$: represents annual rainfall during (2018-2019).

Runoff volume is estimated using equation (3):

$$\boldsymbol{Runoff\ volume = \frac{Runoff\ depth * A}{1000}} \ldots\ldots\ldots\ldots\ldots..(\mathbf{3})$$

A: represents the study area, and the number 1000 is used to convert mm to meters.

The summation of the resulting Volume of Runoff values equals to 32,740,203 m^3 as shown in Table (3).

Table 3: Volume of estimated surface Runoff (V).

Month	Amount of Rainfall (mm)	Depth Runoff (mm)	Volume of Runoff (m^3)
Jan	80.0	5.0574	6607580
Feb	62.2	0	0
Mar	138.3	0.1039	135842
Oct	28.8	0	0
Nov	146.6	3.2058	4188432
Dec	171.5	16.692	21808348
SUM	627.6	25.059	32740203

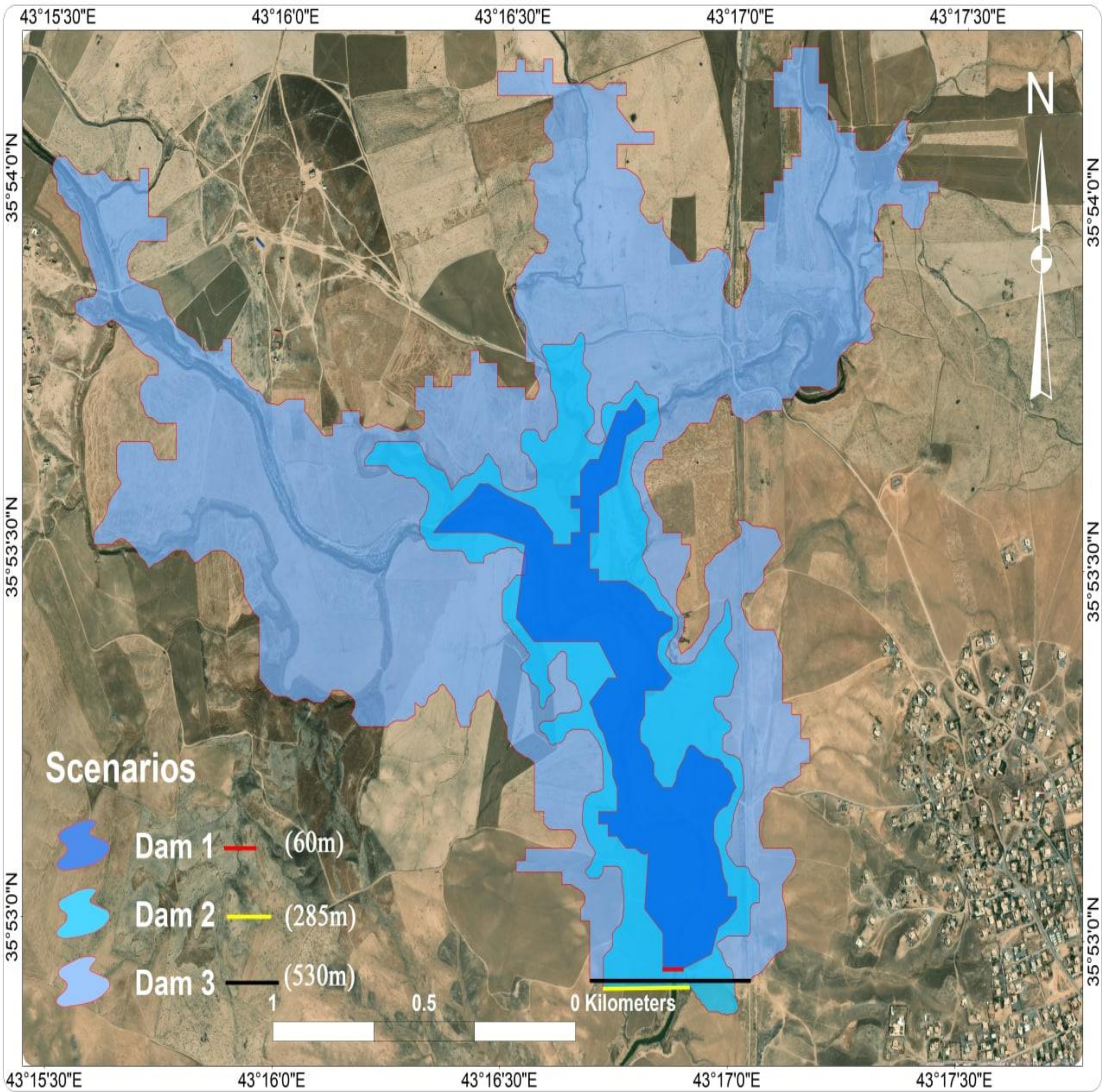

Fig.4. The locations of hypothetical dams and the resulting lake surface areas

Storage capacity of hypothesized dams:

Morphological and hydrogeological parameters, as well as the volume of surface runoff, must be calculated prior to the construction of any dam. The site of the proposed dam was calculated using remote sensing data and GIS software. The storage capacity of the proposed dam was determined using three scenarios based on the size of the dam body and a contour map of the water levels in the proposed dam's lake. The first estimated dam measured 60 m in length, and 185 m in elevation and held 183,600 cubic meters of water. The estimated length of the second dam was 285 m, with a water level elevation of 187.5 m and a capacity to collect 1,442,258 m3 of water. The last estimated length of the dam was 530 m, with a water level elevation of 190 m and a capacity of 5492700 m3 Table 4, and Fig. 4. A cross-section of the lakes generated by the three proposed dams is shown in Fig. (5).

Table 4: Volume of water stored in the three proposed scenarios.

Seniors	Length of dam (m)	Elevation water level in Lake (m) a. s. l	Height of the dam (m)	Area lake (m^2)	Water volume (m^3)
Dam1	60	185	3.3	344,308	183,600
Dam2	285	187.5	4.1	774,800	1,442,258
Dam3	530	190	6.2	2,709,975	5,492,700

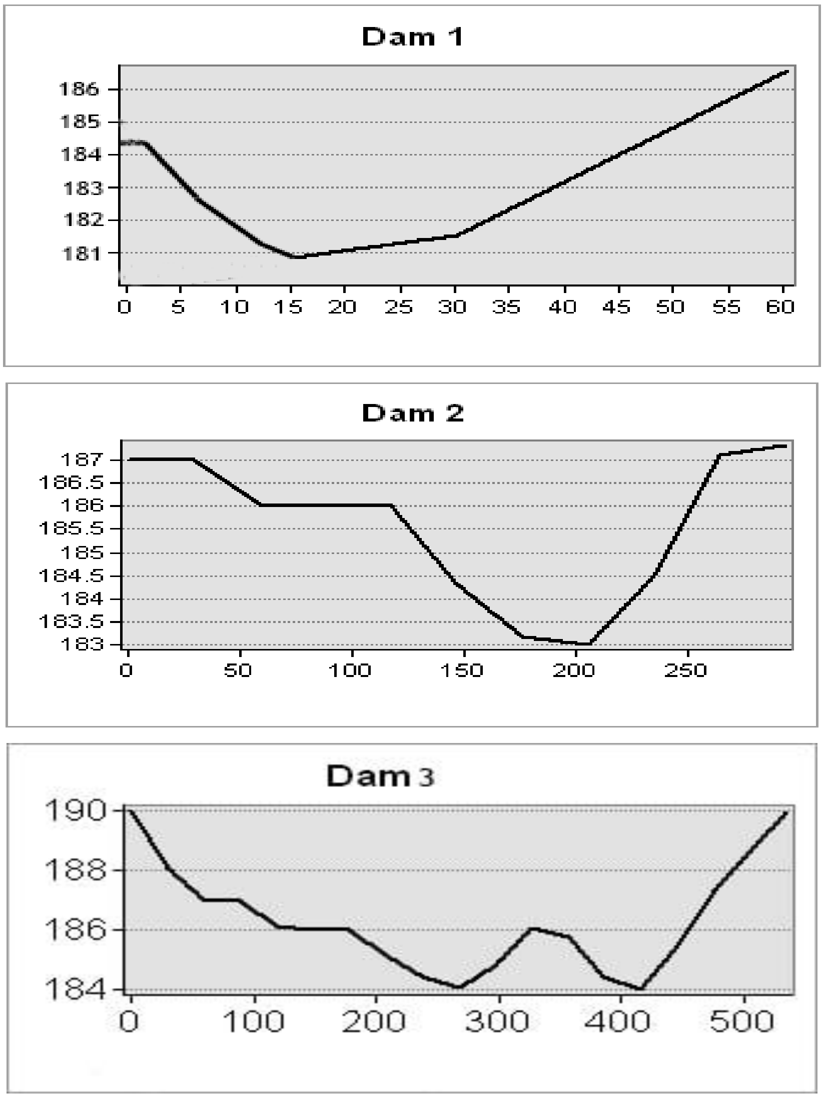

Fig. 5. lake cross section.

Estimating the net storage volume of each scenario:

To determine the amount of evaporation from each lake generated by the proposed dams, the (Iraqi Climatic Center Data, 2023) is used, which stated that the expected evaporation rate is 6 mm per month in this region. The net storage volume is then calculated by subtracting the evaporation rate from storage volume (Table 5). It is noticed that the third dam can collect water about 33 times more than than the first and about 3.8 times more than the second dam. This implies that the third dam, despite its high evaporation, is more appropriate.

Table 5: Estimating the net Volume of the storage lakes for each scenario

	Lake storage Area, A (m^2)	Storage volume, V (m^3per year)	Evaporation (m^3 per year)	Net volume (m^3 per year)
Dam1	344,308	183,600	24,790	158,810
Dam2	774,800	1,442,258	55,776	1,386,482
Dam3	2,709,975	5,492,700	195,118	5,297,582

Conclusions

According to the hydrogeological and morphological characteristics of the study area, the curve number (CN) value is high, which indicates that the basin has a high ability to collect water. Based on these findings, several possible scenarios exist for constructing of a hypothetical dam at the bottom of the basin. The third scenario has a higher storage capacity because it is expected that the water stored in it will be irrigated for a sufficient period during the summer.

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Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript

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