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Feasibility and Storage Capacity of Water Harvesting Dams in Al-Ghadaf Valley / Western Iraq

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ABSTRACT

Finding alternatives to water sources has become an important and strategic issue. The impact of the quantities of water revenues due to climate change, as well as the establishment of multiple projects on the rivers that feed Iraq, becomes clear. This study focused on locating suitable sites for water harvesting dams in the valley of Al-Ghadaf, which is located in the western desert of Anbar Governorate. The entire area is 8772.5 km^2, and water enters the valley of Al-Ghadaf through three sub-basins. The objective of this work is to carry out a hydrological examination and analyze data for the three basins utilizing the software HEC-HMS, which is among the most reliable and effective ways to determine the connection between precipitation and surface runoff. It was selected for several reasons that will be detailed later, to identify the optimal locations for water harvesting dams and their storage capacity. The maps were analyzed, and geographic data were to study the hydrology of the basins in valley Al-Ghadaf using ArcGIS Software Version 10.8 with HEC_HMS Version 4.11. Actual rainfall data were obtained from the Meteorology and Seismic Monitoring Authority for 2008-2022. Simulations using real rainfall data revealed that the greatest storage capacity inside Valley Al-Ghadaf was 114.72192M m^3. The basins of valley Al-Ghadaf were worked on as water harvesting dams Maximum storage capacity of the three sub-basins were (65.32704M m^3, 79.29792M m^3, and 115.49952M m^3) respectively. The study shows that the harvested water in Valley Al-Ghadaf might be used with the lowest loss rate to keep aquatic ecosystems in equilibrium, collect and manage flood waters from valley basins, retain water storage for future seasons, and improve and sustain water quality.

1. INTRODUCTION

One potential solution that was proposed to address the current water crisis is water harvesting dams Rainwater collection initiatives have been performed in locations with unequal water distribution, as well as in dry and semi-arid climates since ancient times. The primary goals are to keep people safe from flooding and to provide them with water during droughts conditions in recent years have made life difficult for locals since there isn't enough water for farming, drinking, and other uses. To address this issue and meet regional water management goals, it was studied to construct water harvesting dams in each basin valley Al-Ghadaf. These dams will collect rainwater and be utilized during times of water scarcity. Rainwater harvesting is a strategy to store, collect, and conserve local surface runoff for agricultural use in semi-arid and arid regions. Water harvesting structures vary depending on the type of water to be captured. Due to the climate changes that the planet Earth is witnessing, in addition to the lack of water imports from the Euphrates and Tigris rivers in recent years, whether due to drought or dams built by Turkey and Syria on these rivers. Therefore, locating reliable water sources and utilizing them efficiently has become critical [1, 2] found that the Al-Ghadaf Valley is the most promising area for water harvesting in Iraq by assessing the potential for rainwater collecting in Iraq's western desert and determining that the Horan and Ghadaf Wades have significant potential due to low water loss rates and high rainfall levels. Besides, the perfect prediction of the surface area and storage volume of dam reservoirs is very necessary for planning the collection projects of water bodies. This verifies the crucial role of reliable area-volume-elevation curves in identifying the ideal designs and optimizing locations for suitable water collection attempts [3]. In Iraq, the Tigris River suffers from a significant dry environment, which is linked to shortages in rainfall and a decrease in water resources, exhibiting a serious risk in the near future [4]. Mohy and Abed [5] introduced modern strategies in the planning, management, and implementation of rainwater projects to address these problems related to storing an adequate amount of water for dry periods, controlling the water flow rates, and preventing flooding. In this regard, outstanding technologies and criteria were employed to evaluate the perfect sites for water storage systems. Therefore, favorable management of water resources could be achieved in Iraq by evaluating the magnitude of surface runoff from rainfall in target water bodies [6]. For instance, an impactful study was conducted by Farhan and Al Thamiry [7] to estimate surface runoff in the

Al-Mohammedi Valley by using the soil and water assessment tool (SWAT) model integrated with GIS. This could introduce effective data for planning and infrastructure by simulating 79.2 million m^3 of water runoff from (1981 to 2019). Unfortunately, the water flow in Iraq has been significantly hampered by climate change, less rainfall, and irrigation and dam projects. Thus, flood control is considered a top priority to address these problems [8]. For example, an important investigation was conducted by Sayl et al. [9] using GIS and remote sensing, which found that 28% of the selected basins were suitable in Iraq's Haqlan Valley. In another work, the SWAT model integrated with ArcGIS software was successfully utilized by Farhan and Abed [10] to simulate the flow conditions and runoff modeling of selected sites (e.g., Kharr (A and B), Shoaib Al-Rahimawi, and Maleh). Besides, Farhan and Abed [11] declared that the collection of rainwater is crucial for climate adaptation and facing drought and scarcity. Faraj and Hamaamin [12] used ArcGIS tools to model and optimize bioswale placement, finding land use and soil types are important factors for effective bioswale systems. Drought is a natural occurrence in many arid, semi-arid, and wet areas. This demonstrated that drought affects every part of the planet. Global warming and climate change have generated extreme droughts [13]. The intensity-duration-frequency (IDF) relationship is the most helpful key in water resources engineering, which can be applied to plan, design, and operate water projects to minimize the impact of water [14]. The findings of the basin model's precipitation-runoff response simulation were used to evaluate water budget and flow estimations. The models employed control parameters using local meteorologic data, Kazezyılmaz-Alha et al. [15] indicated no significant fluctuations in the Baghdad and Sammara locations, while the precipitation findings increased at the Tikrit and Mosul locations. Moreover, an effective simulation for volume and flow characteristics was reported by Al-Zubaidi and Abed [16], which evaluated the surface water consumption in the Al-Shuwaija marsh by applying Watershed Modeling System (WMS) software. Significantly, the simulation tools, as well as advanced hydrologic modeling, assist in supporting the planning efforts for water resources and climate adaptation in target regions. Thus, our work tries to assess the feasibility and suitability of dam construction in Valley Al-Ghadaf and also aims to optimize the storage capacity and locations for these dams.

2. METHODOLOGY

In this work, the HEC-HMS software was employed to develop a hydrological model for Al-Ghadaf Valley. The online repository data of the United States Geological Survey (USGS) was gathered and employed as Digital Elevation Model (DEM) data for the study region. Moreover, the important elements of the input file, like sub-basin delineations, the stream network, and numerous hydrological parameters, were generated by HEC-HMS the main reason it was chosen was that it works well in semi-arid and dry areas and can calculate a lot of different hydrological parameters at set return intervals that the researcher specifies using rain data gathered over many years. These parameters include the hydrograph, the time of arrival at the drainage peak, the drainage curves, floods, the maximum discharge of water harvesting dams, etc., and the reliability of the findings is contingent upon the precision and high standard of the data used. The ArcGIS software was utilized to generate maps, analyze geographical data, and perform hydrological analyses of the valley basins. The digital elevation model, which determines the flow direction, was also used to determine the lowest points, which were then used to choose the locations of water harvesting dams. All data is integrated within an ArcGIS environment through a multi-step process. This comprehensive HEC-HMS model was subsequently utilized for the Al-Ghadaf Valley catchment to perform simulations based on daily precipitation records.

2.1 The selected study area

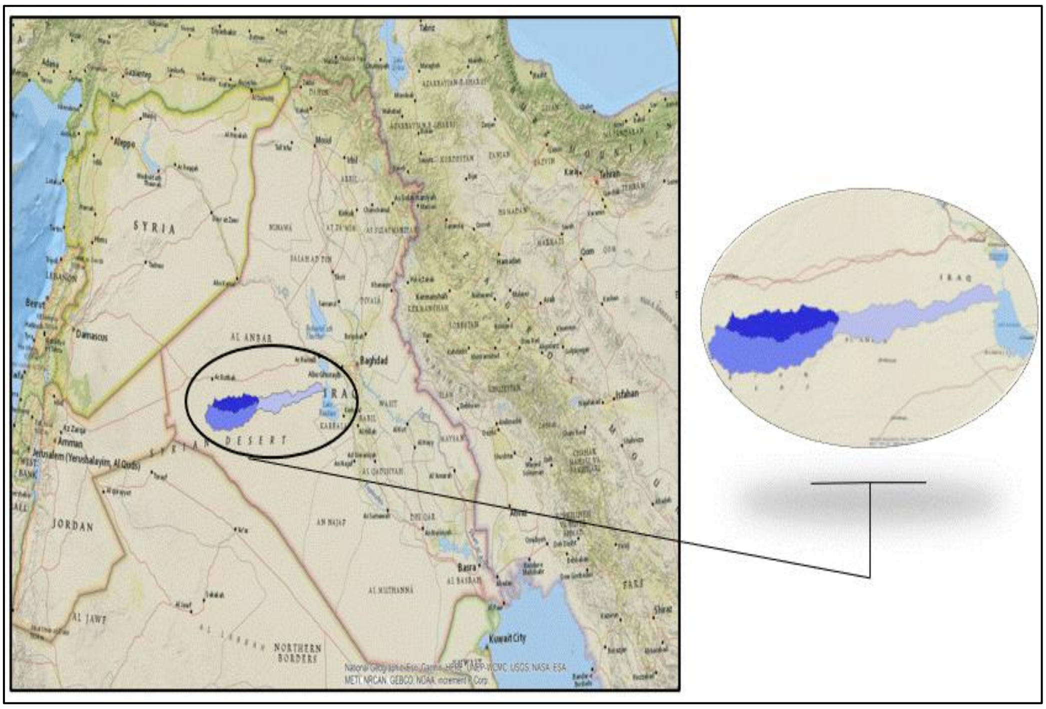

Figure 1. System (ArcGIS) applied to Al-Ghadaf Valley

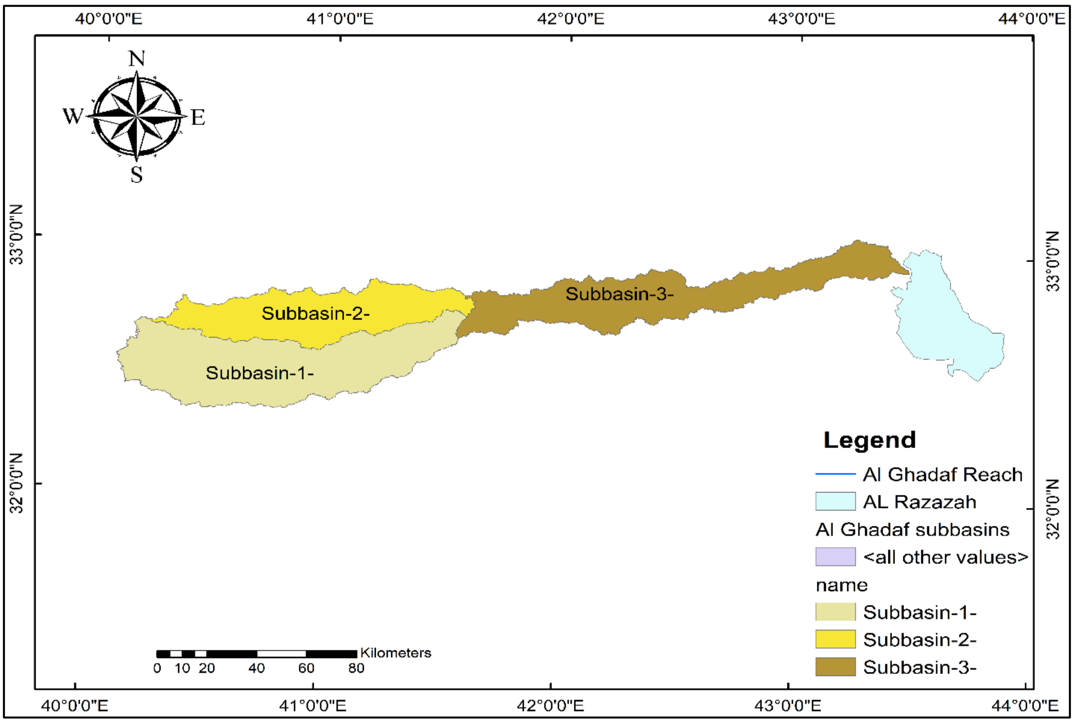

Figure 2. The three sub-basins of Al-Ghadaf Valley in the study area

The selected studying area, the Valley of Al-Ghadaf, is a seasonal valley in the Western Desert in the Al-Rutba District, south of the Western Province of Iraq (Figure 1). It extends about 50 kilometers from the Syrian-Jordanian and Saudi borders. The target watershed is situated within the geographic coordinates spanning from 32° 20′ 14″ to 33° 08′ 00″ N, and 40° 01′ 00″ to 43° 30′ 00″ E, with a total surface area of 8772.5 km^2 and its length is 260 km. The target watershed exhibits a desert climatic regime characterized by seasonal fluctuations in water availability. During the winter months, increased precipitation leads to rising water levels across the region. Conversely, the summer season is marked by elevated evaporative losses. The groundwater table within this domain is situated at a considerable depth, precluding any substantial recharge to the surface runoff. This hydrological setting has resulted in an artesian condition, as evidenced by the presence of several constructed wells in the area [17]. This valley originates from small springs that increase in width. To do this, many small valleys in the region drain the valley, which consists of three sub-basins that drain into Lake Al-Razzaza at its northwestern edge, as shown in Figure 2.

The Catchment area: Following the formation of the basins, Figure 2 revealed that the third basin (which had been misled) shares Valley Al-Ghadaf and empties into the Razzaza Lake, as per the boundary. The inflow for Razzaza Lake is the total of the three basins.

2.2 Hydrologic modeling system

The U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC) developed the Hydrologic Modeling System (HMS), which was used to model the hydrology of the Al-Ghadaf Valley in Iraq. HEC-HMS is a comprehensive software tool that simulates the key components of the hydrologic cycle, including runoff, infiltration, precipitation, evapotranspiration, and baseflow. It also incorporates advanced reservoir modeling capabilities. This widely adopted software has been utilized in various water resources applications, such as flood management, reservoir operation, and water supply planning. The dataset used in the current study is considered to provide a detailed characterization of the study region and its hydrological processes, enabling the application of the HEC-HMS model to effectively simulate the hydrology of the Al-Ghadaf Valley [18]. Table 1 shows input parameters for the run processing of the Hydrologic Engineering Center Hydrologic Modeling (HEC-HMS).

Table 1. Input parameters of the (HEC-HMS) model

No.	Model	Parameters of Method	Requisite (Unit)
1	Loss Rate Parameters	SCS Curve Numbers	Curve Numbers, Impervious area (%), and Initial abstraction (mm)
2	Runoff Transformation	SCS Unit Hydrograph	Lag time (min)
3	Constants of Routing Method	Muskingum	Dimensionless weight (X) and Travel time (K)

2.3 The input data

The data of land use information, observed rainfall data, curve number values, soil map, and digital elevation model were selected to deliver feedback for model simulation of the HEC-HMS hydrologic.

2.3.1 Digital elevation map of the study area

The earth's topography is a significant input to the HMS model. It is a valuable key for assessing watersheds, land surface features, and drainage patterns. Also used for catchment delineation, topography pre-processing, and basin processing [19]. A 30-meter resolution DEM was obtained from the global Shuttle Radar Topography Mission (SRTM) dataset provided by the U.S. Geological Survey (USGS). This DEM dataset was used to characterize the studying area's spatial features and elevation ranges, including identifying borders, elevations, and depressions within the research region. Those DEMs were consolidated and re-projected to the UTM zone in preparation for the HEC-HMS operations, which delineated the flow directions and watersheds, as shown in Figure 3.

2.3.2 Land use map

The land use information was obtained from the European Space Agency's GlobCover land cover dataset, which has a spatial resolution of 300 meters. The data corresponding to the year 2009 was utilized for this study. The study area was found to contain three main land use classes: bare areas, Mosaic of Forest/Shrubland (50-70%) and Grassland (20-50%) Sparse (>15%) vegetation, including woody vegetation, shrubs, and grassland. This land use information is illustrated in Figure 4.

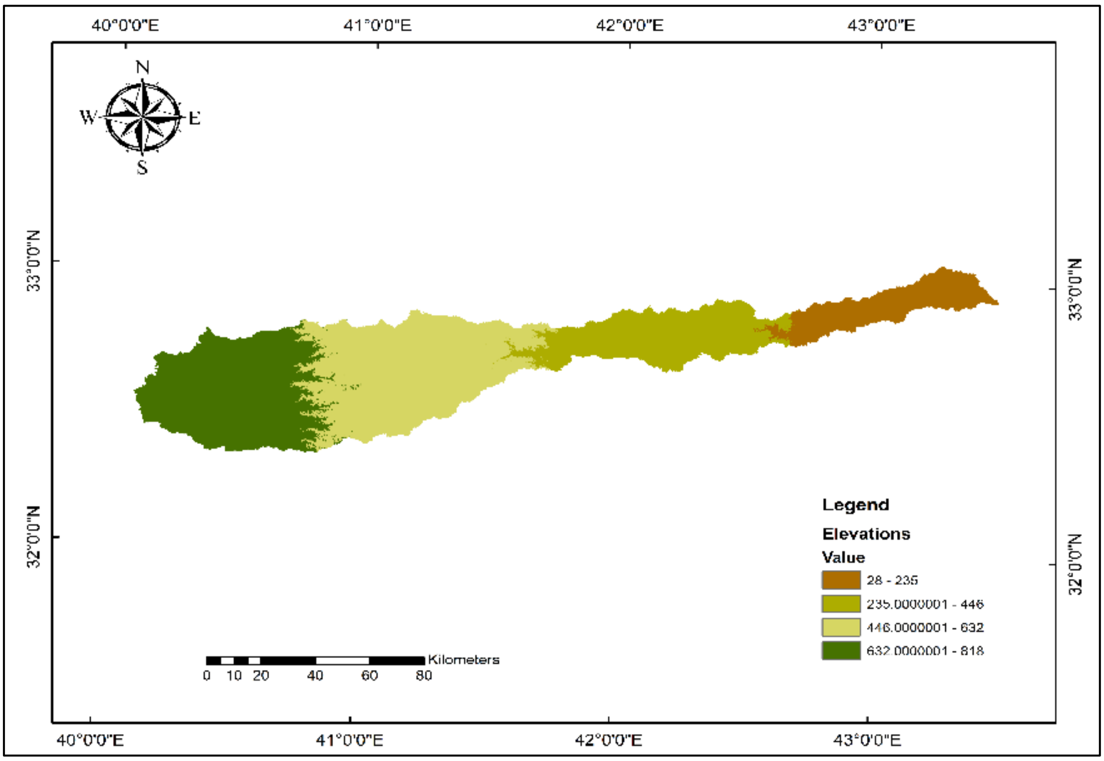

Figure 3. Digital elevation map of the Al-Ghadaf Valley in the study area

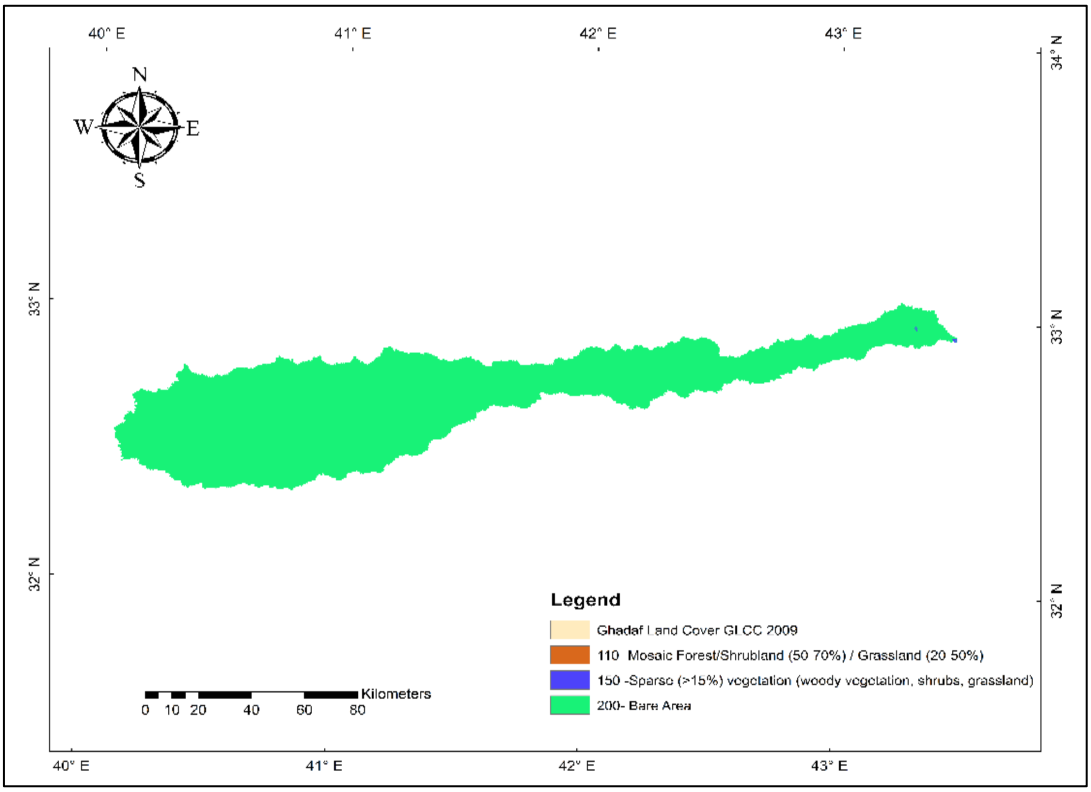

Figure 4. The land use map of Al-Ghadaf Valley

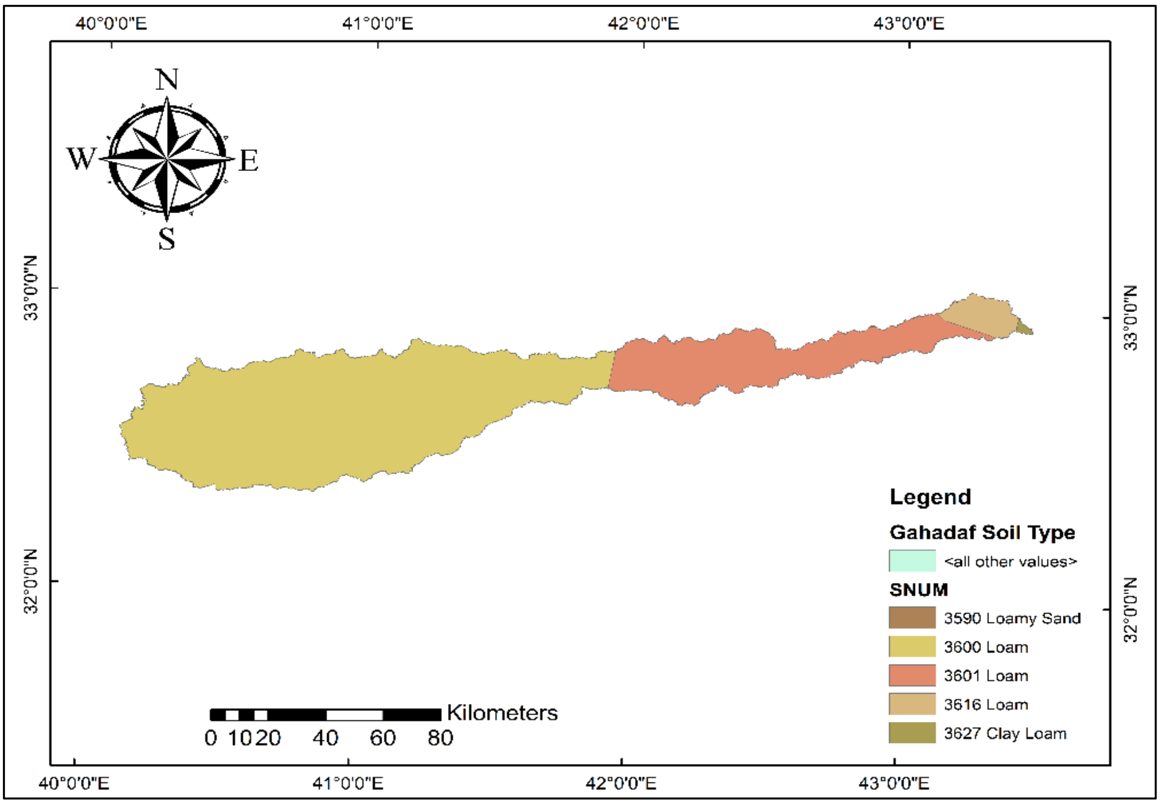

Figure 5. The soil map of Al-Ghadaf Valley

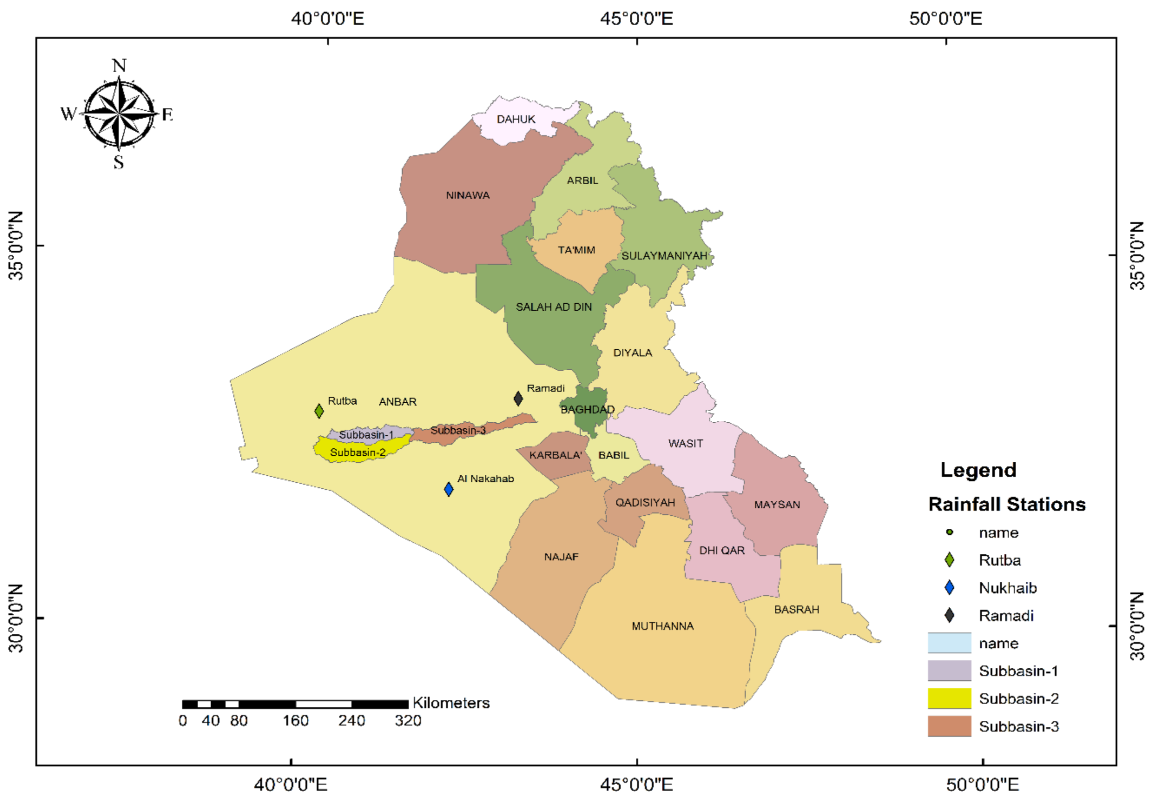

Figure 6. Rainfall stations of the study area

2.3.3 Soil map

The Food and Agriculture Organization provided the soil map utilized in the study, which was scaled at 1:5000. The map is broken into many polygons. Each polygon comprises several attributes of the soils of the research area, such as hydraulic conductivity, hydrological soil groups, chemical and physical qualities, and soil texture corresponding to the FAO soil catalog. These polygons were trimmed to designate the watershed region and then classed with ArcMap software to establish the kind of soil in the research area (Figure 5). The basins in the research region are categorized as loam, loamy sand, and clay loam.

2.3.4 Weather data

HEC_HMS software requires meteorological data such as relative humidity, wind speed, solar radiation, precipitation, and temperature. Daily rainfall data were acquired from the Iraqi Metrological Organization and Seismology (IMOS) for stations that have an impact on the study area within Iraq, including Rutba, Ramadi, and Nukhab, and for the period (2008-2022), as shown in Figure 6.

2.3.5 Curve number

The Curve Number (CN) values, required input for the HEC-HMS hydrologic model, were derived by combining the land use datasets and soil map for the study area. These CN values were then used to characterize the sub-basin properties and estimate the hydrological parameters needed to build and run the HEC-HMS model simulation.

3. PARAMETERS ESTIMATION

A detailed loss model and transform model for soil provided initial estimates of model parameters to evaluate the water harvesting processes.

3.1 Sub-basins model

Following the formation of the study basin, the area of each basin, the longest flow path, and the inclination of each basin were extracted to explain the operation of the sub-basin mechanism with the value and date needed to understand the downstream process of the entire catchment.

3.2 Loss model-curve number service for soil conservation

The curve number method was used to determine leaching losses in the basins based on the type of soil and plant cover. For each sub-basin, the CN values can be calculated by applying the equation [20]:

$$\mathrm{CN} = \frac{\sum \mathrm{AiNi}}{\sum \mathrm{Ai}} \tag{1}$$

where, the sub-basin area is represented as Ai (km^2), with the equivalent curve number as CNi, initial abstraction (Ia) includes losses before runoff begins, such as infiltration, evaporation, surface depression storage, and vegetation interception. Ia (mm) is calculated by multiplying the loss coefficient by the potential abstraction S (mm), which is a function of the curve number as per Eqs. (2) and (3) [21, 22].

$$\mathrm{S} = \frac{25400}{\mathrm{CN}} - 254 \tag{2}$$

$$\mathrm{Ia} = 0.2\ \mathrm{S} \tag{3}$$

3.3 Transform model-soil conservation service unit hydrograph method

The SCS Unit Hydrograph method was used to calculate the transformation method, which is the conversion of rainfall into surface runoff by calculating the period of concentration. It depends on the ground inclination of the basins, their areas, and the vegetation cover. The Eq. (4) from NRCS 1997 was used to calculate and estimate these data points.

$$\mathrm{TC} = \frac{\mathrm{L}^{0.8}(\mathrm{S}+1)^{0.7}}{1900\mathrm{Y}^{0.5}} \tag{4}$$

where,

Tc: Time of concentration (hours).

S: Maximum potential retention (in).

S =(1000/CN)-10.

Y: Average watershed land slope%.

Lag time =0.6 Tc.

4. RESULTS AND DISCUSSION

4.1 Subbasins analysis

The subbasin delineation process involved using the DEM data to map flow pathways and routes, which were then used to define the subbasin boundaries. The HEC-HMS software has defined Sub-basins using the DEM-based technique, and the flow rate for each sub-basin is determined.

4.1.1 Curve number

The curve number rate for the basins in the study area is presented below. The type of vegetation influences the watershed, and the quality or density of this cover substantially impacts soil infiltration, which is proportional to the inverse connection with the curve number. The majority of the soils in the valley Al-Ghadaf type B as shown in Table 2.

4.1.2 Time of concentration (Tc) and lag time

The basin characteristics were converted to the units provided in the equation, and the delay time equation was applied, yielding the findings in Table 2. It was discovered that the time to attain maximum discharge is recorded at the same time for each scenario. However, the concentration time and delay time varied between basins due to the longest path for each basin.

Table 2. The sub-basins characteristics of the study area

Sub-Basins	1	2	3
Station	**Rutba**	**Nukahib**	**Ramadi**
Latitude	33.02	32.02	33.27
Longitude	40.17	42.17	43.19
Catchment Area (km^2)	3446.17	2164.34	2787.79
Longest Flow path (km)	179.4	201.6	249.12
Basin Slope %	5.458	5.921	3.501
Curve Number (CN)	86	86	79
Potential Retention (in)	1.63	1.63	2.7
Time of Concentration (hr)	29.95	31.57	61.77
Ia (mm)	8.27	8.27	13.71
Lag Time (hr)	17.97	18.94	37.06

4.1.3 Subbasins delineation

HEC-HMS identifies basin flow points based on flow accumulation direction. Table 2 shows the sub-basins characteristics.

4.1.4 Generated Thiessen polygons

The uses actual rainfall data from Rutba, Nukhab, and Ramadi stations obtained from the Meteorology and Seismic Monitoring Authority of the Ministry of Transport for the period (2008-2022), with the Thiessen polygon method applied to know the effect of the rain stations on the used basins. The method, according to Figure 7, proved that the Rutba rain station in white color affects a part of the area of the first basin, estimated at 2161.3 km^2 out of 8772.5 km^2. The Nukhab indigo rain station in lead color affects a part of the area of the second basin, estimated at 3489 km^2 out of 8772.5 km^2, al-Ramadi station, which impacts the third basin with black color and has an estimated area of 3122.2 km^2 out of 8772.5 km^2. The results of utilizing actual rainfall data in the HEC-HMS model are as follows: 114.72192M m^3.

4.1.5 Average and peak discharges

Table 3 shows the maximum discharge values of the basins in the study area's Al-Gahdaf valley, the rivers belonging to each basin, and the period of this drainage.

Table 3. Maximum discharge values (m^3/sec) through the study period (2010) of the HEC-HMS model

Maximum Discharge Values (m^3/sec) Through 2010		Value	Date
Sub-Basin, Reach	Reach1	1296.0	26 Mar2010,00:00
	Sink-1	1327.8	26 Mar2010,00:00
	Subbasin 1	774.0	09Nov2020,00:00
	Subbasin 2	922.9	27Mar 2016,00:00
	Subbasin 3	800.3	24Dec2010,00:00

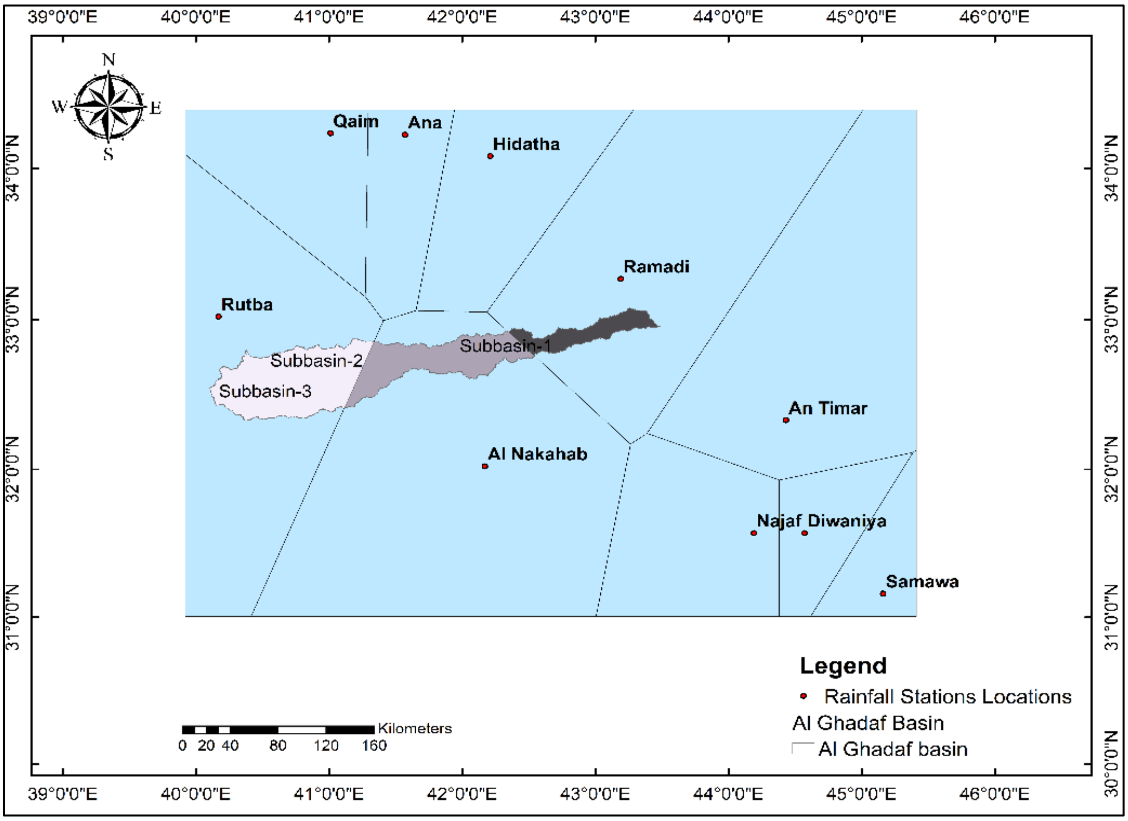

Figure 7. Thiessen polygon method

4.2 Choosing suitable sites for constructing water harvesting dams

Studying the region's geology and hydrology, the surface morphology of Al-Ghadaf Valley, and the three basins in the valley, the output maps found that the most appropriate sites for constructing water-collecting dams are presented in Figures 8-10. Three water harvesting dams are possible.

4.3 Storage capacity

The maximum storage capacity for harvesting water dams for the three sub-basins dams of Al-Ghadaf Valley is shown in Table 4.

In general, it is shown in Table 4 that the third basin has the highest storage capacity of the other basins, it is recommended that the water harvest be gathered in the third basin rather than in Lake Razzaza [23]. This is because the third basin has the biggest storage capacity. There are many factors the most important to the very high salinity of the water in this lake. the geological characteristics of the area, the high evaporation processes, the low rainfall rates in the area, and the low surface water sources in the area under study. This, in turn, will result in a decline in the quality of the water that is being drained into this lake from the three basins.

Table 4. Maximum storage capacity (million m^3) for Al-Ghadaf Valley of HEC-HMS model

Subbasins	Storage Capacity (Million m^3)
1	65.34
2	79.3
3	115.5

It may not be suitable water for any purpose, such as irrigation and local uses, among other reasons. For this reason, it is better to collect water inside the boundaries of the third basin to minimize the amount of water lost due to evaporation, filtering, and surface runoff and to prevent the water from becoming more contaminated, as mentioned above.

By comparing with the previous study by Kamel and Sulaiman [2] found that the Al Ghadaf valley has a storage capacity of water higher than other valleys in the study area.

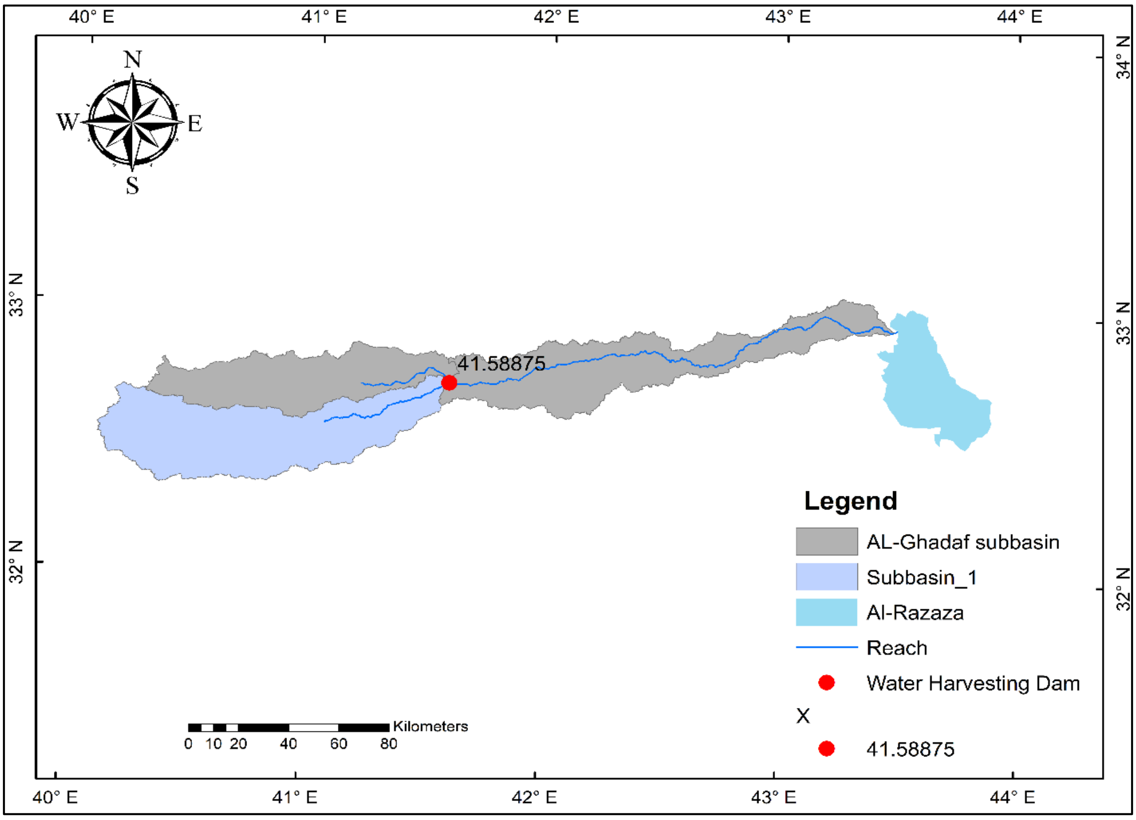

Figure 8. Water harvesting dam for subbasin 1

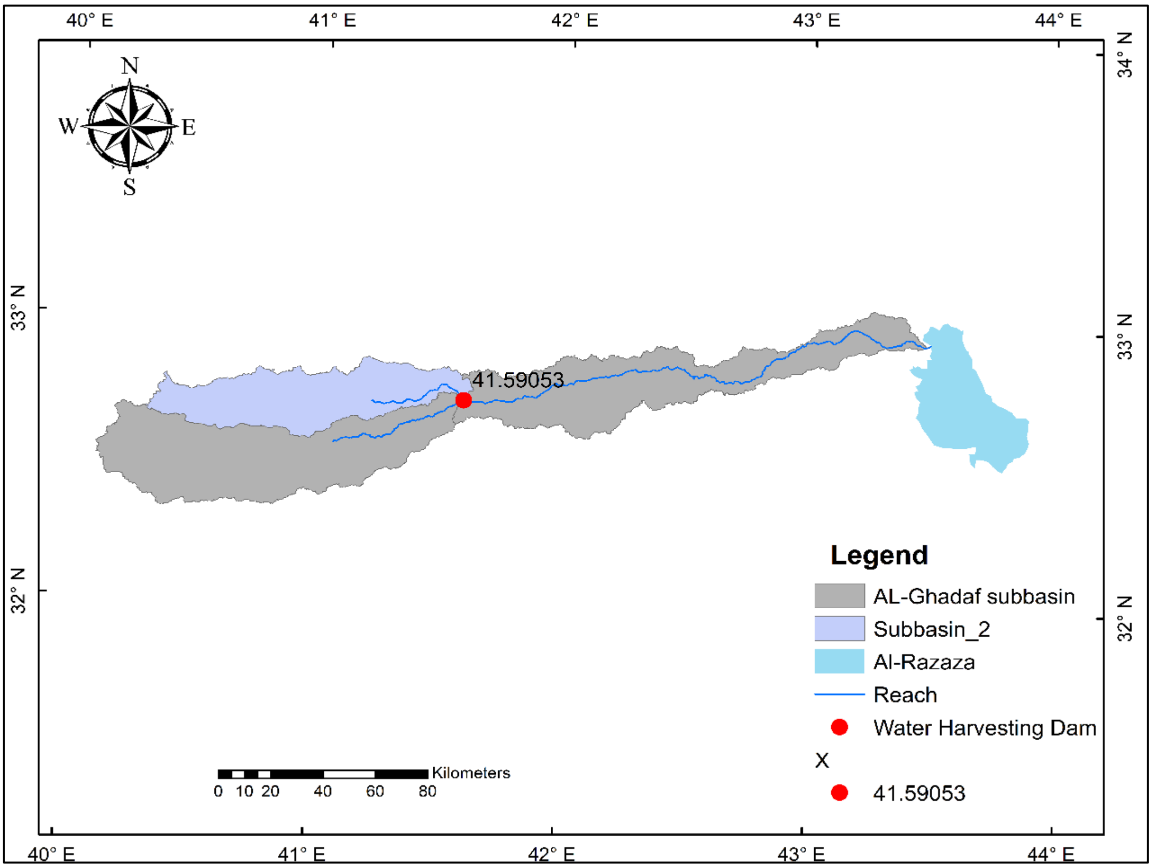

Figure 9. Water harvesting dam for subbasin 2

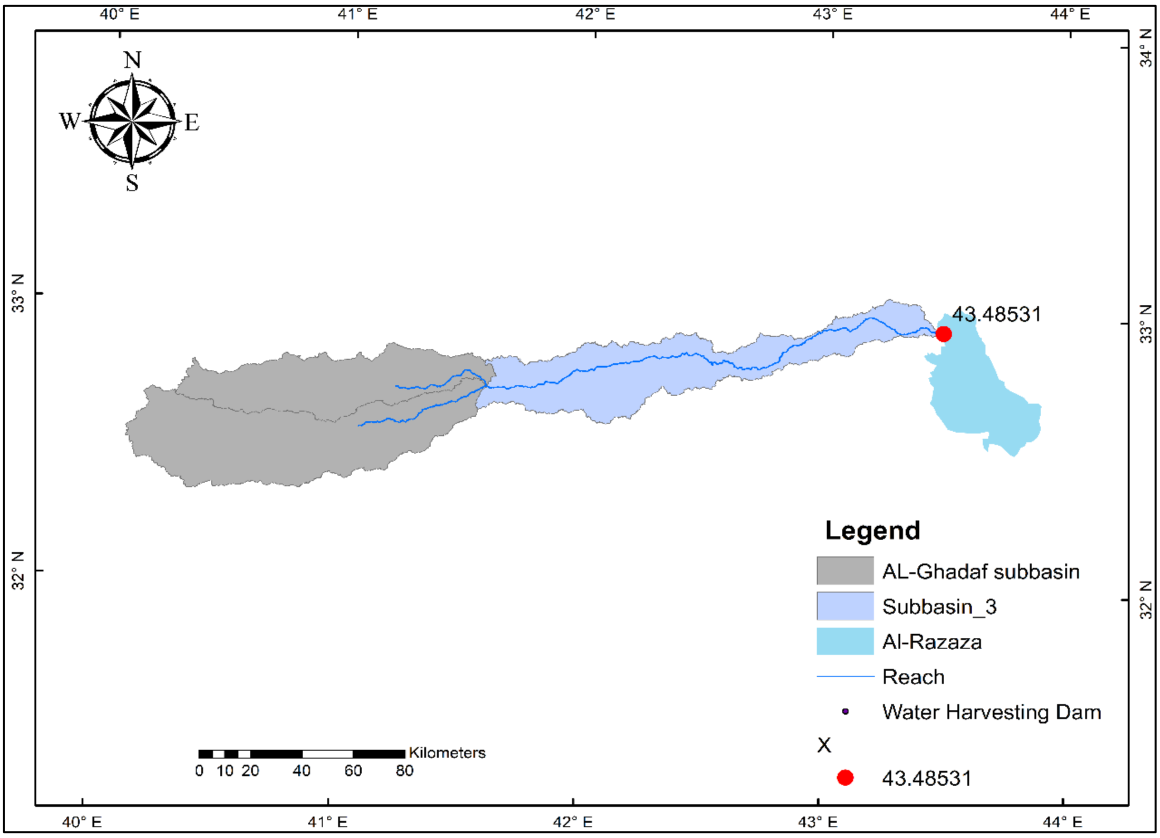

Figure 10. Water harvesting dam for subbasin 3

5. CONCLUSIONS

The HEC-HMS hydrologic model was integrated with GIS tools to simulate the rainfall-runoff processes and estimate the flow discharges for the Al-Ghadaf Valley. The key findings from this analysis are summarized as follows:

(1). Valley Al-Ghadaf is divided into three sub-basins with different areas and storage capacities.

(2). The possibility of constructing water harvesting dams due to remunerative water drainage.

(3). It is possible to construct three dams to harvest water in three locations suitable for their construction.

(4). The storage capacities were appropriate and evaluated for the first dam, 65.32704M m^3, the second dam, 79.29792M m^3, and the third dam, 115.49952M m^3.

(5). Recommendation for future studies that create small dams in the sub-basins that have a storage of water and to reduce the cost of the dam and for saving water for human, irrigation, and industrial demands.

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