Integration of Remote Sensing, GIS, and SCS-CN Model for Runoff Volume Estimation in Al-Deir Valley Basin, Iraqi Jazira Desert

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Abstract
Iraq's Jazira Desert faces a severe water security challenge, a problem exacerbated by a significant lack of field-based hydrological data that critically hinders effective water resource management. This study addresses this gap by presenting the first quantitative assessment of water harvesting potential in the ungauged 114 km² Al-Deir Valley Basin, a representative arid catchment. The significance of this research lies in its potential to provide actionable data for mitigating water scarcity. The study integrates Remote Sensing (RS), Geographic Information Systems (GIS), and the Soil Conservation Service-Curve Number (SCS-CN) model. Land cover and hydrological soil groups (HSG) were derived from Landsat imagery and the Harmonized World Soil Database (HWSD), respectively, while rainfall data was spatially interpolated using the Inverse Distance Weighting (IDW) method. The derived Curve Number (CN) values ranged from 77 to 90, indicating high runoff potential. Based on these parameters, the model estimated a mean annual runoff depth of 81.40–115.28 mm, corresponding to a total harvestable volume of up to 4.96 million m³. Sensitivity analysis confirmed the model's robustness, showing that a ±5% variation in CN values resulted in an ~11% change in runoff depth. The findings highlight the basin's high suitability for water harvesting projects and provide a foundational geospatial baseline for developing strategic interventions to enhance water security and drought resilience in this data-scarce region.

Keywords: Arid Hydrology, Geographic Information Systems, Iraqi Jazira Desert, Remote Sensing, Runoff Estimation, SCS-CN Model, Water Harvesting

1. Introduction

Iraq, known as Mesopotamia is currently facing an increasingly severe water security challenge. This is particularly true of its vast arid and semi-arid areas of which Jazira forms a part, characterised by low precipitation and high evaporation [1] and [2]. This reality renders the shift towards non-conventional water resources, such as water harvesting, a strategic imperative rather than a secondary option [3]. The Al-Deir Valley basin is a representative and vital hydrological entity in this fragile situation, and the conditions and potentials of such an area are herein shown. Nevertheless, the utilization of water harvesting system in such basins is faced with a major barrier: the large lack of hydrological data in the field, which is essential for accurate estimation of surface runoff. This informational gap represents a fundamental impediment to the strategic planning and administration of water harvesting initiatives in the region [4][5][6] and [7]. The primary objective of this study is to develop the first detailed, quantitative estimation of surface runoff potential on the Al-Deir Valley. To achieve this, the study sets the following sub-objectives: (1) describe major features of the basin with GIS and remote sensing methods, (2) Use the SCS-CN methods to estimate necessary hydrological parameters and runoff volume, and (3) to evaluate the overall suitability of the basin for water harvesting. The results contribute toward providing a basic scientific datum for future water management measures in this poorly studied area.

2. Literature Review

The integration of Geographic Information Systems (GIS), Remote Sensing (RS), and the Soil Conservation Service-Curve Number (SCS-CN) model has become a standard and reliable methodology for estimating runoff in ungauged arid and semi- arid basins [8] and [9]. This approach is favored due to its cost-effectiveness and its ability to function with limited ground data. The methodology has been proven efficient in various research performed in Iraq. For example, these methods have recently been successfully used to quantify the runoff potential of the Al-Tahinat and Alrakhmah valley basins [3] and [10]. Similarly, research in the Al-Shagrah Basin confirmed that such integrated methodologies are essential for identifying optimal water harvesting sites [11]. While these studies confirm the validity of this approach in diverse Iraqi environments, they simultaneously highlight a distinct research gap, as the Al-Deir Valley Basin has not yet been subjected to a similar quantitative assessment despite its hydrological significance.

Recent advancements internationally have further refined this approach. For example, studies have increasingly focused on integrating high-resolution satellite precipitation products to overcome the limitations of sparse rain gauge networks in arid regions, as demonstrated [12] and [13] in their evaluation for basins in western Iraq. Research has also explored modifying the initial abstraction ratio (Ia) in the SCS-CN model to better suit the specific soil and storm characteristics of arid zones, with studies [14] proposing adjustments for catchments in the Arabian Peninsula. These developments underscore the continuous evolution of runoff estimation techniques, reinforcing the need to apply them to specific, understudied catchments like Wadi Al-Deir.

3. Materials and Methods

This section outlines the methodological framework designed to meet the study's objectives. The workflow encompassed several distinct phases, from data acquisition and processing to the final application of the SCS-CN model for runoff volume estimation.

3.1 Study Area Description

The Al-Deir Valley Basin, located in the northeastern Al-Jazeera Desert, Anbar Governorate, Iraq, lies between latitudes 34°38′42″N–34°23′54″N and longitudes 43°03′53″E–42°19′37″E, as shown in Figure 1. It is bordered by Wadi al-Shakik to the north, Wadi Sarsir to the east, and Wadi al-Shahban to the west, draining southward into the Euphrates River [15]. Covering 114 km², the basin comprises Tertiary and Quaternary formations (Euphrates, Fatha) and Quaternary residual soils, which influence infiltration capacity and runoff potential, see Figure 2 and Table 1.

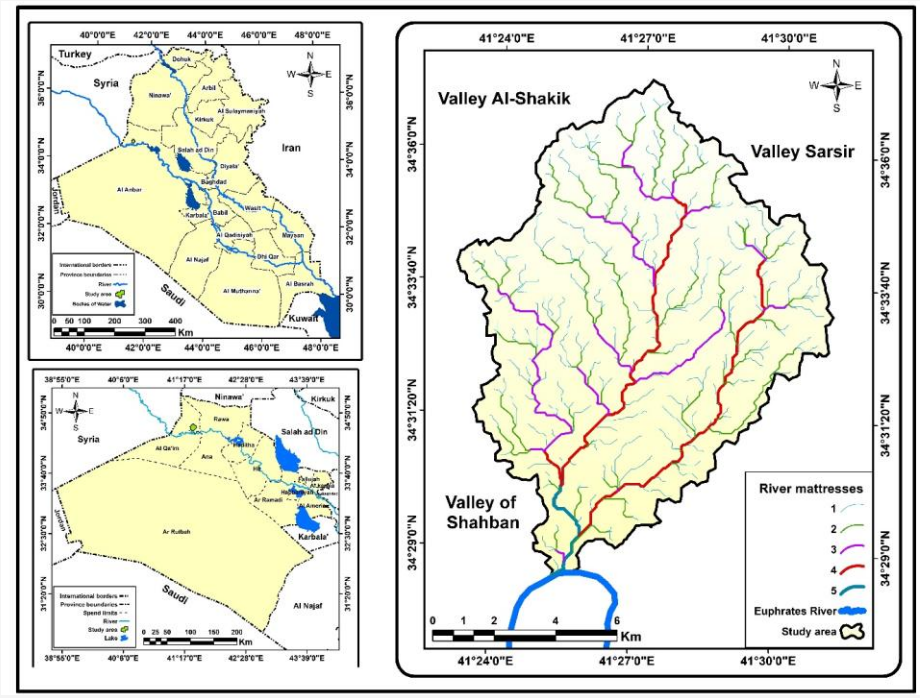

Figure 1: Location of the Al-Deir valley basin

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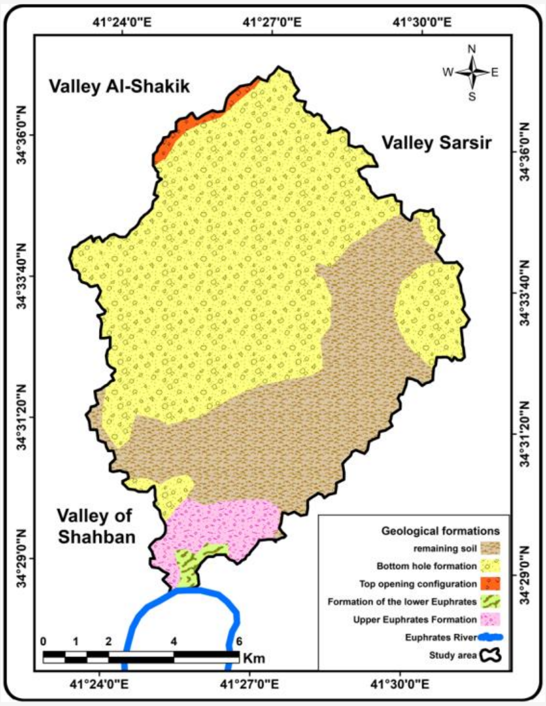

Figure 2: Geological formations of Al-Deir valley basin

Table 1: Areas and percentages of geological formations in wadi Al-Deir basin

Era	Period	Epoch	Formation	Thickness (m)	Area (m^2)	Ratio %
Cenozoic	Tertiary	Lower Miocene	Lower Euphrates	35.5-75	2	1.7
			Upper Euphrates	23.5-46.5	6	5.2
		Middle Miocene	Upper Euphrates	55.0-75.0	1	0.8
			Lower Euphrates	80.0-100.0	69	60.5
Modern	Quaternary	Pleistocene	Residual Soil	1.5-2.0	36	31.5
					114	100%

The workflow, as shown in Figure 3, involved several stages:

1. *Land use land cover (LULC) Classification*: The LULC map was generated from Landsat imagery using the Maximum Likelihood Classifier (MLC), a standard supervised classification method, within ArcMap 10.8. This process was informed by ground truth data collected via GPS during field visits, which were used to create unique spectral signatures for each of the four land cover categories: Residential lands, Valley sediments, Barren lands, and Poor natural vegetation cover. To validate the classification, an accuracy assessment was conducted, which achieved an overall accuracy of 85% and a Kappa coefficient of 0.80. These metrics signify a high degree of correspondence between the classified map and the ground reference data.
2. *Hydrological Soil Group (HSG) Classification*: Based on the HWSD data, the basin's soils were classified into two main hydrological groups, B and C, according to SCS standards.

3. *Curve Number (CN) Generation*: The LULC and HSG layers were combined in ArcMap to generate a spatial *CN* map. As a parameter that ranges from 0 to 100, the CN value quantifies an area's potential for runoff, which is a function of its combined land and soil attributes.

The assignment of CN values to each polygon was accomplished through the spatial intersection of the LULC and HSG map layers. The specific values were selected based on standard lookup tables from the USDA National Engineering Handbook (NEH-4), assuming Antecedent Moisture Condition II (AMC II), as detailed in Table 2.

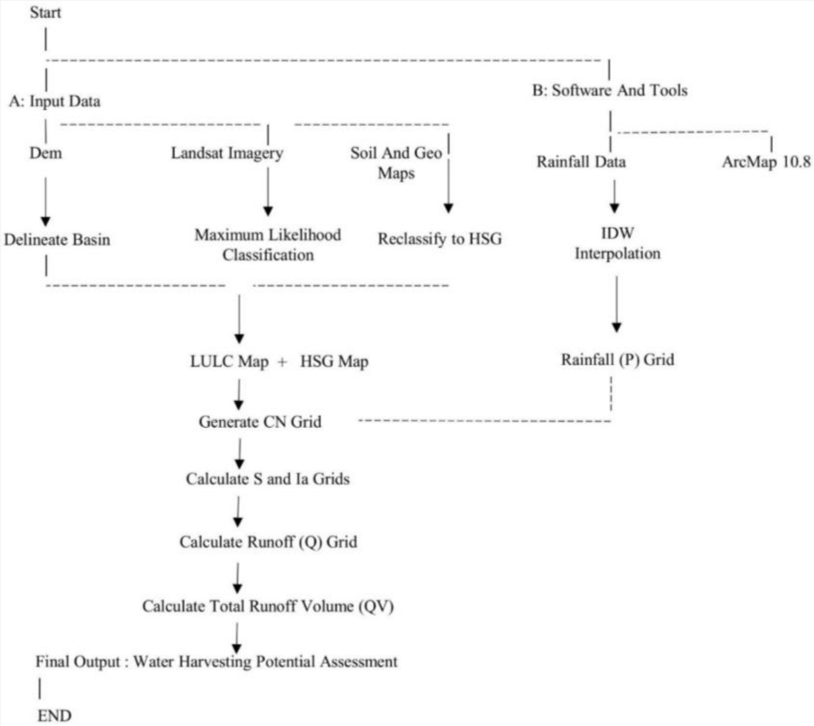

Figure 3: Methodological flowchart of the study

Table 2: SCS-CN values assigned for LULC and hydrological soil group (HSG) combinations [16]

Land Use/Land Cover (LULC)	Hydrological Soil Group (HSG) B	Hydrological Soil Group (HSG) C
Barren Lands	89	90
Poor Natural Vegetation Cover (Pasture/Range)	77	86
Residential Lands	85	90
Valley Sediments	77	86

4. *Parameter Calculation***:** Using the generated CN map and the relevant equations, spatial layers for S, I_a, Q, and finally QV were calculated sequentially within the GIS environment.
5. Landsat imagery was processed using ArcMap 10.8 with standard supervised classification techniques.

To illustrate the model's sensitivity to its key parameter, a calculation was performed to assess the impact of a ±5% variation in the dominant Curve Number value (CN=90) on the resultant runoff depth (Q).

3.2 Data Acquisition

The spatial data used in this study were acquired from several official sources. The basin's location and administrative boundaries (see Figure 1) were delineated using the Administrative Map of Iraq and Anbar Governorate (Scale 1:1,000,000), provided by the Iraqi Ministry of Water Resources (2021). The geological formations (see Figure 2) were identified from the Geological Map of Iraq, produced by the Ministry of Industry and Minerals, General Authority for Geological Survey and Mineral Exploration. Land cover was derived from a Landsat 8 OLI/TIRS satellite image, acquired on March 17, 2025. The imagery was obtained free of charge from the U.S. Geological Survey (USGS) EarthExplorer data portal (https://earthexplorer.usgs.gov/). Soil characteristics were derived from the Harmonized World Soil Database (HWSD). Climatic data (1990–2024) from Haditha and Salah al-Din stations, (see Figure 4**)**, were interpolated via Inverse Distance Weighting (IDW) to produce a continuous rainfall surface for model input.

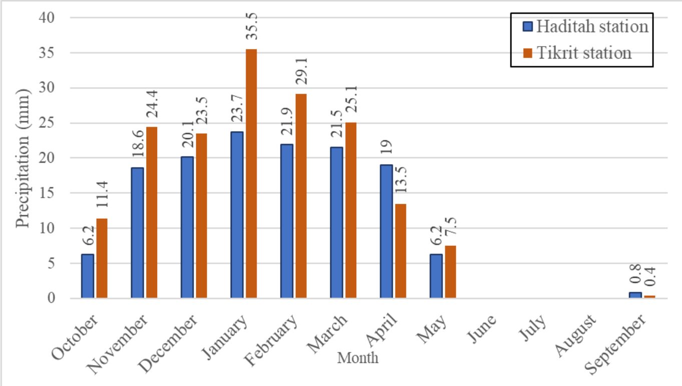

Figure 4: Mean monthly rainfall data from Haditha and Salah al-Din stations (1990–2024)

Table 3: Hydrological Soil Types According to the SCS Method [17][18][19] and [20]

Class	Runoff Potential	Soil Type	Infiltration Rate (mm/hr)
A	Low	A deep sand layer	> 7.6
B	Medium	A sand layer shallower than	3.8–7.6
C	Above average	A clay layer with a limited depth	1.3–3.8
D	High	A clay layer with a high swelling ratio	< 1.3

3.3 Runoff Estimation Methodology

The estimation of surface runoff volume was conducted using the Soil Conservation (SCS-CN) model, a method frequently utilized for unmonitored arid basins because of its minimal data needs and inherent flexibility [17]. This model calculates runoff based on precipitation and the basin's hydrologic characteristics, as in Table 3.

The runoff depth (Q) is calculated by the primary Equation 1:

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

Equation 1

Where:

Q = Runoff depth

P = Precipitation

I_a = Initial abstraction (losses before runoff)

S = Potential maximum retention after runoff begins

The potential maximum retention (S) is derived from the Curve Number (CN). Since the analysis uses metric units, the following formula was applied Equation 2:

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

Equation 2

Where:

S = Potential maximum retention after runoff begins

CN = Curve Number

The initial abstraction (I_a) is empirically estimated as 20% of S, by Equation 3:

$$I_a = 0.2S$$

Equation 3

Where:

I_a = Initial abstraction (losses before runoff)

S = Potential maximum retention after runoff begins

Finally, the total runoff volume (QV) in cubic meters is calculated by Equation 4:

$$QV = \frac{QA}{1000}$$

Equation 4

Where:

QV = Total runoff volume

Q = Runoff depth

A = Basin area in square kilometers

3.4 Sensitivity Analysis and Model Validation

In order to test the reliability of the model and to assess the uncertainty of the primary parameter, sensitivity analysis was performed. This study quantitatively evaluated the impacts of ±5% and ±10% changes in Curve Number (CN) parameters on the predicted runoff depth (Q). The choice of a ±5% change is based on conventions in hydrological sensitivity analysis literature, where such small perturbations are commonly used to reflect typical uncertainty in land cover and soil data assignment. Previous studies, have adopted a 5% change in CN

for model calibration and sensitivity analysis purposes. This procedure is necessary to understand the potential error range associated with the interpretation of land cover and soil data [21]. This analysis is used as an indirect measure of model stability under lack of direct measurements of the runoff from the gauging station for more accurate calibration. The results presented in Table 4 show that the model is highly sensitive to changes in the *CN* value. A ±5% change in *CN* resulted in a corresponding change in runoff depth ranging from ±11% to ±13%. When the variation was increased to ±10%, the change in runoff depth was more significant, ranging from ±22% to ±26%. This confirms that accurate determination of the Curve Number is the most critical factor for achieving reliable runoff estimates using this model.

4. Results and Discussion

4.1 Basin Characteristics and their Hydrological Implications

The classification of land cover in the Al-Deir Valley basin identified four primary types, as shown in Figure 5 and Table 5. Barren lands were the dominant category, covering 57.0% (65 km²) of the total area. Poor natural vegetation cover accounted for 40.3% (46 km²), while valley sediments and residential lands occupied smaller portions, at 1.7% (2 km²) and 0.8% (1 km²), respectively.

Table 4: Sensitivity analysis of runoff depth (Q) to variations in curve number (CN)

Original CN	New CN	Change in CN (%)	Original Q (mm)	New Q (mm)	Change in Q (%)
77	69.3	-10	81.4	63.31	-22.20
77	73.2	-5	81.4	71.95	-11.60
77	80.9	+5	81.4	90.99	+11.8
77	84.7	+10	81.4	100.12	+22.9
86	77.4	-10	104.39	81.08	-22.30
86	81.7	-5	104.39	92.51	-11.40
86	90.3	+5	104.39	116.14	+11.3
86	94.6	+10	104.39	127.53	+22.2
90	81.0	-10	115.28	89.24	-22.60
90	85.5	-5	115.28	102.32	-11.20
90	94.5	+5	115.28	128.01	+11.0
90	99.0	+10	115.28	139.02	+20.6

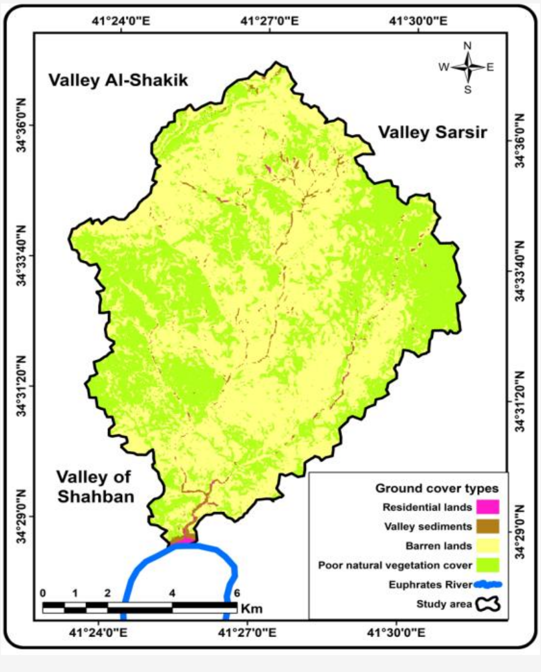

Figure 5: Land use land cover

Table 5: Vegetation cover types of Wadi Al-Deir basin

Types	Area (m^2)	Ratio (%)
Residential lands	1	0.8
Valley sediments	2	1.7
Barren Lands	65	57.0
Poor Vegetation cover	46	40.3
Average	114	100%

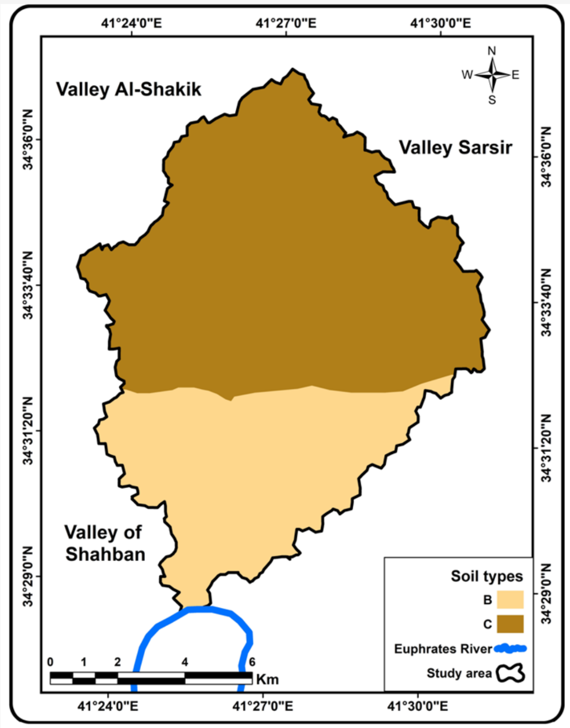

Figure 6: Soil type

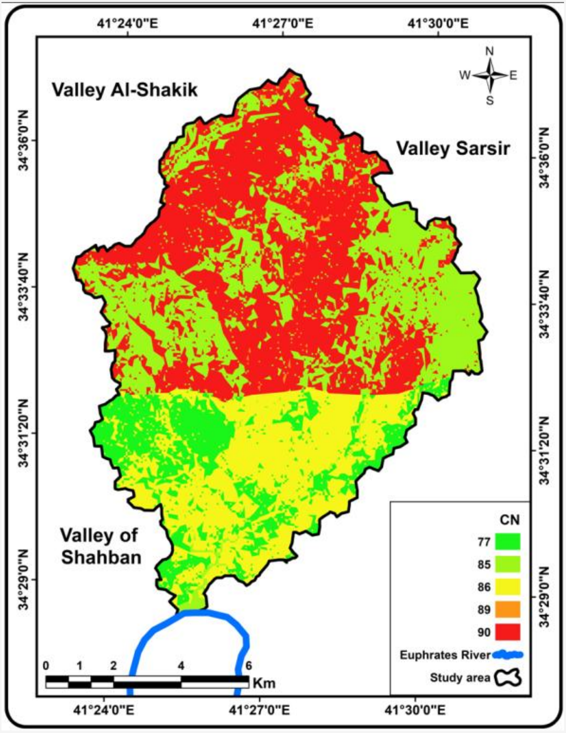

Figure 7: Hydrological soil groups (*HSG*)

The Group C soils, (see Figure 6) covering 66.6% of the basin, exhibit low permeability, while Group B soils (33.3%) have medium permeability, influencing runoff generation patterns. The hydrological significance of these characteristics is substantial. The basin's high potential for runoff is directly attributable to the combination of these two main factors: the prevalence of low-permeability soils (Hydrological Group C) and the extensive cover of barren lands. This combination yields high Curve Number (*CN*) values, which minimizes initial abstraction and soil water retention, thus maximizing the conversion of precipitation into surface runoff.

4.2 Hydrological Parameters and Runoff Estimation

By overlaying land cover and soil data within a GIS environment, essential hydrological parameters were generated. These parameters collectively provide a quantitative measure of the basin's significant potential for water harvesting. The findings indicate that the Al- Deir Valley Basin has high potential for water harvesting, with estimated annual runoff reaching 4.96 million m^3. By combining the land cover and hydrological soil group layers (Figure 7), a Curve Number (*CN*) map was generated (see Figure 8). The *CN* values for the basin ranged from 77 to 90, with a CN value of 90 being dominant, covering 37.7% (43 km^2) of the area, primarily concentrated in the northern portion corresponding to low-permeability Group C soils and barren land cover.

Consequently, the potential maximum retention (*S*) values, calculated from the *CN*, ranged from 28.22 to 75.87 mm (see Figure 9). Areas with the lowest retention value (S = 28.22), indicating the highest runoff potential, constituted 37.7% of the basin. These low S values correspond to zones of maximum runoff potential, critical for siting harvesting structures. This, in turn, resulted in low initial abstraction (I_a) values ranging from 5.64 to 15.17 mm (See Figure 10), signifying that minimal rainfall is lost to infiltration before runoff begins.

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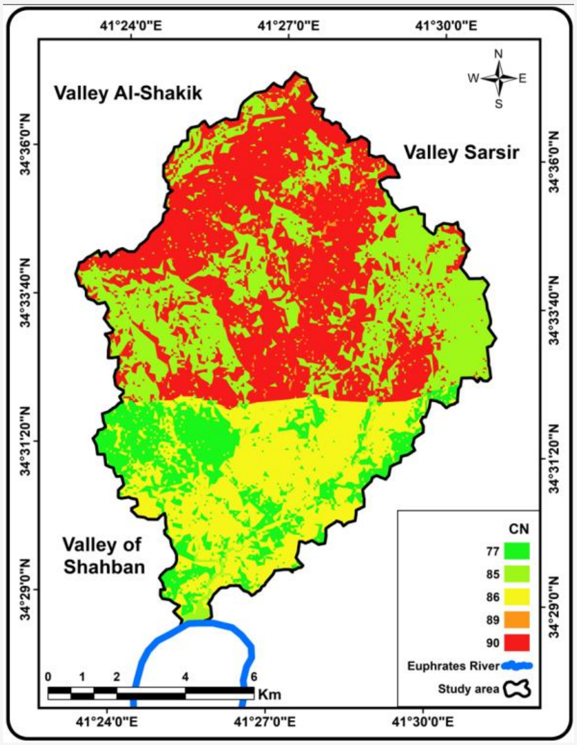

Figure 8: Curve number (*CN*)

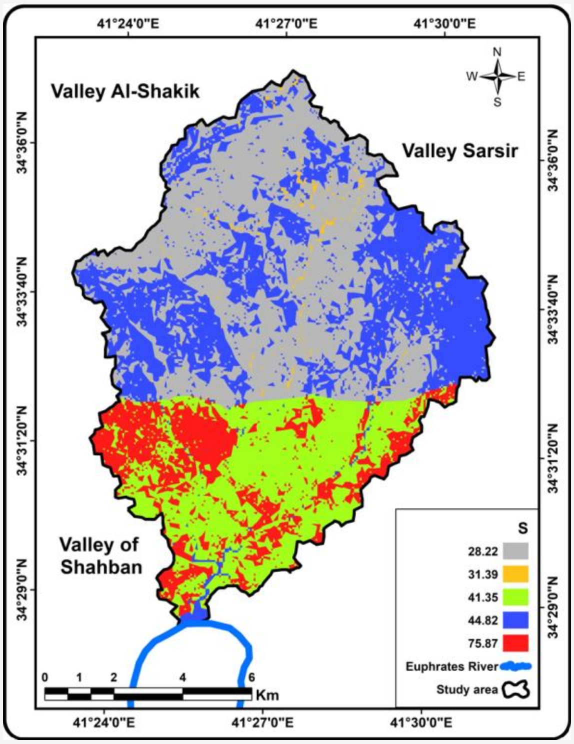

Figure 9: potential maximum retention (*S*)

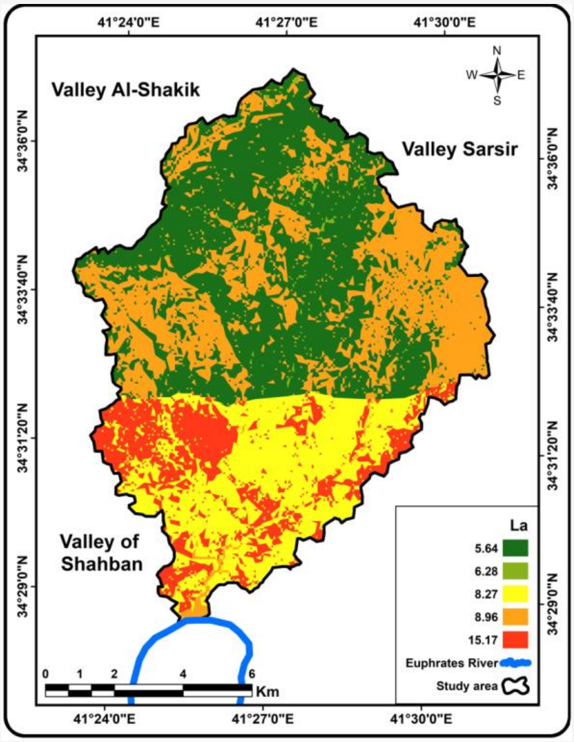

Figure 10: initial abstraction (I_a)

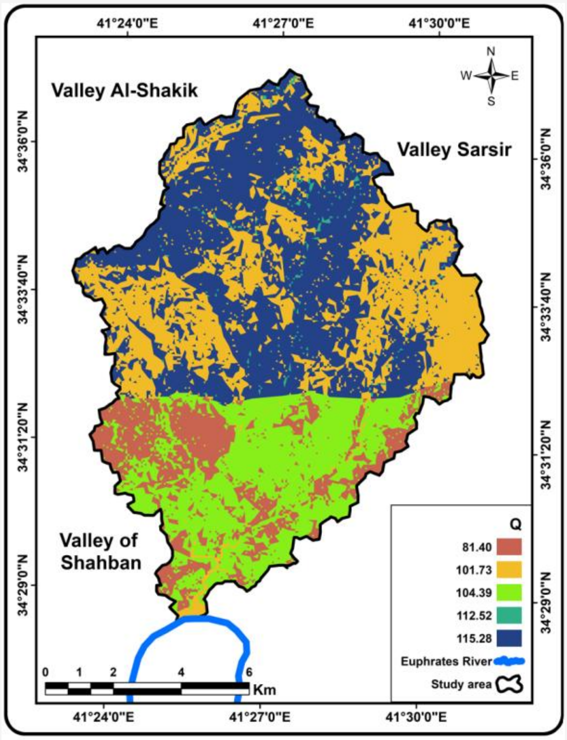

Figure 11: Runoff depth (*Q*)

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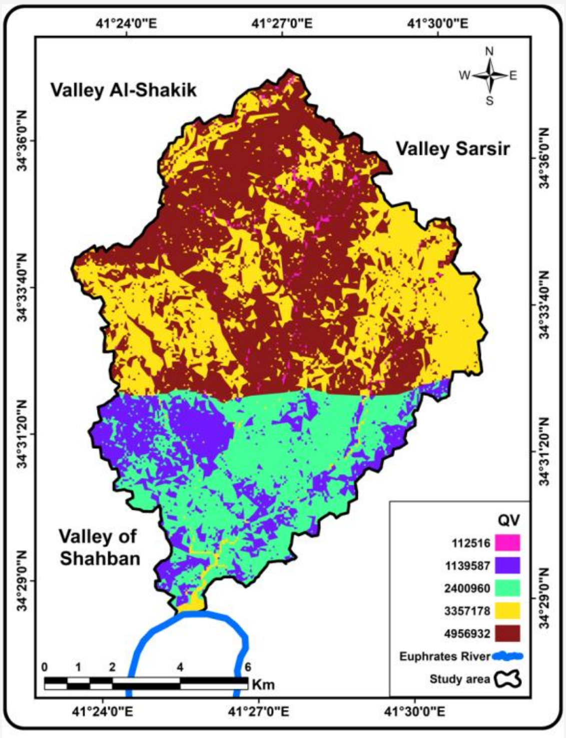

Figure 12: Estimated annual runoff volume (QV)

Based on these parameters, the annual surface runoff depth (*Q*) was estimated to range between 81.40 mm and 115.28 mm (see Figure 11). The highest runoff depth was found across the same 37.7% of the study area dominated by high *CN* values. Ultimately, this translates into a total annual surface runoff volume (*QV*) for the basin ranging from 1.14 to 4.96 million m³, as illustrated (see Figure 12), which highlights the spatial distribution of harvestable water potential.

A sensitivity analysis was performed to evaluate the model's reliability. The sensitivity analysis indicated a ±5% change in the dominant *CN* resulted in roughly ±11% change in runoff depth, thus emphasizing the necessity for accurate land cover/soil classification in determining model output. These results are consistent with findings from other arid basins in Iraq. For instance, recent studies [3] and [11] basins similarly demonstrated the efficiency of the integrated GIS and SCS-CN approach for runoff estimation in data-scarce environments. Furthermore, the high Curve Number values obtained in our study (ranging from 77 to 90) are comparable to those reported in other arid regions with similar geological and land cover characteristics, such as catchments in the Asir region of Arabia [9]. This consistency with regional literature strengthens the validity of our findings and confirms that the hydrological behavior of the Al-Deir Valley is representative of arid catchments with high potential for water harvesting schemes. This similarity verifies that the hydrologic behavior of the catchment is suitable for representing arid regions, with high potential for water harvesting schemes.

The practical implications of these findings are substantial. The harvestable water estimate is sufficient to irrigate approximately 1,000 hectares of strategic crops, an application that would significantly bolster regional food security and strengthen the area's resilience to drought. The spatial distribution maps generated in this study (Figures 6-10) serve as a foundational tool for prioritizing the placement of water harvesting infrastructure to maximize efficiency.

5. Conclusion

This study provides the first quantitative assessment of water harvesting potential in the Al-Deir Valley Basin using an integrated methodology of GIS, RS, and the SCS-CN model. Results indicate an annual runoff potential of up to 4.96 million m³, confirming the basin's high suitability for water harvesting initiatives. This significant potential is primarily driven by the predominance of low-permeability soils and extensive barren lands, which characterize the basin's landscape. By generating these spatially explicit runoff estimates, this study offers a foundational geospatial baseline to guide and improve strategic water resource planning in the arid western regions of Iraq. In light of these findings, the following recommendations are proposed to translate this research into practical action:

First: A critical first step is to conduct feasibility studies for the installation of hydrological monitoring stations at key sub-basin outlets. This network is essential for collecting real-time rainfall-runoff data, which will enable rigorous calibration of hydrological models and support the precise engineering design of future water harvesting structures.

Furthermore: regional authorities formulate a strategic and phased master plan for water harvesting. This plan should utilize the runoff potential maps from this study for the initial prioritization of sites for infrastructure such as check dams and cisterns, with final designs to be refined by data from the future monitoring stations.

Finally: the cost-effective GIS-RS-SCS-CN approach used in this study should be replicated in other ungauged basins across Anbar Governorate. Scaling this methodology would enable the creation of a comprehensive regional map of water harvesting potential, providing a powerful tool to guide larger-

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scale water security and agricultural support strategies to mitigate drought impacts.

6. Limitation and Future Work Recommendation

While the findings provide a robust first-order estimate of runoff potential, they should be interpreted in light of certain methodological limitations which pave the way for future research. Firstly, the reliance on rainfall data from a limited number of meteorological stations, interpolated using IDW, may not fully capture the spatial heterogeneity of precipitation, particularly the localized, intense storms common in arid zones. Future work could significantly refine these estimates by integrating high-resolution satellite-based rainfall products such as CHIRPS (0.05°) or GPM IMERG (0.1°). Furthermore, future modeling should consider the potential impacts of climate change, such as increased storm intensity, which could significantly alter runoff patterns in the region.

Secondly, as the SCS-CN model is empirical, direct model validation through field measurements was not feasible due to the absence of a gauging station in the basin. Therefore, a critical next step is the installation of a hydrometric station to obtain real-time runoff data. This would allow for rigorous model calibration and validation, substantially increasing confidence in its predictive accuracy for future engineering designs and water management scenarios, a crucial step that has been emphasized in similar studies on ungauged basins in other arid regions.

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