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# QUANTITATIVE ANALYSIS OF SURFACE RUNOFF VOLUME AND FLOOD RISKS IN THE RUKRAM VALLEY BASIN USING THE SCS-CN METHOD: A STUDY IN APPLIED GEOMORPHOLOGY

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## ABSTRACT

The study of hydrological basins is crucial for identifying and estimating surface runoff and associated risks. Various software tools, including Arc GIS, WMS V11.0, and ENVI, were employed to analyze data specific to the Rukram Valley basin and determine its hydrological characteristics. This basin covers an area of 298.7 km², located in the northwest of Dohuk District and west of Dohuk Governorate.

The natural data of the basin's soil were analyzed based on laboratory tests. Land use and land cover were classified using satellite imagery through supervised classification. The Soil Conservation Service Curve Number (SCS-CN) method was utilized to estimate the volume of surface runoff using WMS V11.0. The region exhibits four types of hydrological soils (A, B, C, D), and land cover was classified into four categories using data from the American Landsat satellite to derive Curve Number (CN) values, which ranged from 36 to 100, with a weighted average of 61.9. In this study, the SCS-CN model was applied five times using rainfall events ranging from 20 to 100 mm, with increments of 20 mm. Additionally, an actual rainfall event of 86.3 mm on March 17, 2024, was used. The results indicated that a significant portion of the rainfall runs off the surface when rainfall exceeds 60 mm, with the surface runoff depth reaching 21.12 mm for 100 mm of rainfall. The maximum discharge was 400.32 m³/s over 1710 minutes during a 100 mm rainfall event. Surface runoff volumes ranged from 313,215.0 m³ for 20 mm of rainfall to 2,135,283.5 m³ for 100 mm of rainfall.

**Keywords:Rukram Basin, Duhok District, runoff volume, Curve Number (CN), hydrological soils, land cover.**

## INTRODUCTION

Surface runoff is one of the most important water resources in arid and semi-arid environments. Decision-makers must adopt appropriate methods and solutions to measure the volume of surface runoff. In this context, the Soil Conservation Service (SCS) method, abbreviated as CN (Curve Number), is a suitable approach for measuring surface runoff volume and identifying associated risks by determining hydrological characteristics, soil properties, and land use [(1).]

Recent climate changes, especially intense rainfall events over short periods, must be considered. These events generate significant surface runoff, increasing water density in main streams and valleys, posing

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a threat to adjacent lands, flat areas around rivers, and the structures and human activities they contain. To understand these risks, modern technologies such as WMS, Arc GIS, and ENVI programs are used to accurately determine watershed characteristics according to the models applied [(2)].

The research aims to estimate surface runoff volume, utilize watershed water for various purposes, and identify resulting hydrological risks. It also aims to determine the role of modern technologies in analyzing the hydrological characteristics of watersheds and their accuracy in estimating surface runoff volume.

The study problem lies in the scarcity of surface water resources in summer, with a significant increase during the rainy season, leading to soil threats from heavy rain showers or surface runoff. These events often pose risks in steep environments, threatening structures and villages adjacent to these areas.

The study hypothesizes that the effectiveness of flood risks varies according to natural determinants, primarily topography and slope gradients. Therefore, areas with changing slopes and hillsides are more exposed to recurring risks, particularly flooding.

The nature of the study necessitated the use of the inductive method and quantitative analysis through the application of models and mathematical equations, as well as modern technologies to achieve the study's objectives.

Study Area:
Geographically, the study area (Map 1) is located in the northwestern part of Dohuk District. It is bordered by Zakho District to the northwest, Semel District to the southwest, Amadiya District to the north and east, and Sheikhan District to the southeast. The study area covers an area of 298.7 km², accounting for 29.4% of the total area of Dohuk District, which is 1,015 km². The geographical coordinates of the study area are between latitudes 36° 47' 30" and 37° 07' 10" N, and longitudes 42° 48' 02" and 43° 17' 30" E.

Map 1:Location of the Nirdush Basin in Sheikhan District and Dohuk Governorate

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Created by the researcher using Arc GIS 10.6 based on the source: Administrative Map of Dohuk, 2020, at a scale of 1:191,000.

From a geological perspective, the surface formations of the study area vary between Mesozoic formations and Quaternary deposits. The rocks exhibit different responses to geomorphological factors and processes (3). This variability is due to the diverse environments of their formation. The Bakhtiari and Mukdadiya formations are the most extensive, covering an area of 94.2 km², followed by the Pilaspi formations with an area of 56.1 km². The least widespread outcrops are the Fatha and Injana formations, representing 8.9% and 11.6% of the area, respectively (Map 2 and Table 1).

Map 2:Geology of the Study Area

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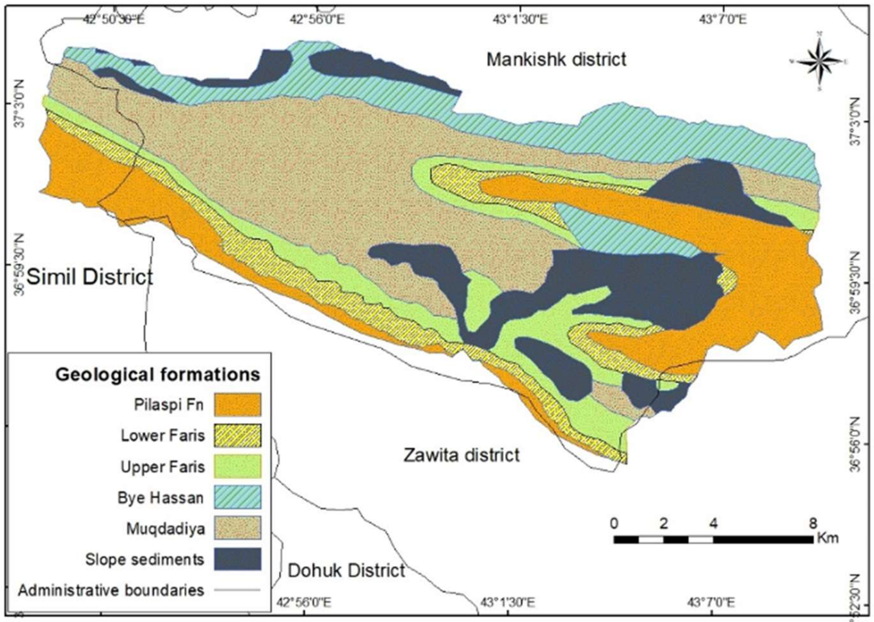


Created by the researcher using Arc GIS 10.6 based on the source:
- GEOLOGICAL MAP OF AL-MOSUL QUADRANGLE, SHEET NJ-38-13, Baghdad, Iraq, 2007.

Table 1: Areas of Geological Formations

| No. | Geological Formation | Area (km²) | % |
|---|---|---|---|
| **1** | Pilaspi | 56.1 | 18.8 |
| **2** | Fatha | 26.5 | 8.9 |
| **3** | Injana | 34.6 | 11.6 |
| **4** | Bakhtiari Bai Hassan | 40.6 | 13.6 |
| **5** | Bakhtiari Mukdadiya | 94.2 | 31.5 |
| **6** | Slope Deposits | 46.7 | 15.6 |
| **Total** | | 298.7 | 100 |

Created by the researcher using Arc GIS 10.6 based on the data from Map 2.

The surface of the study area varies, with the highest elevation reaching 1,419 meters within the high mountainous environment, located in the northern and northeastern parts of the basin. The lowest elevation is 521 meters, representing the point where the Rukram Valley meets the Khabur River (Map 3 and Table 2).

Map 3:Topography of the Study Area

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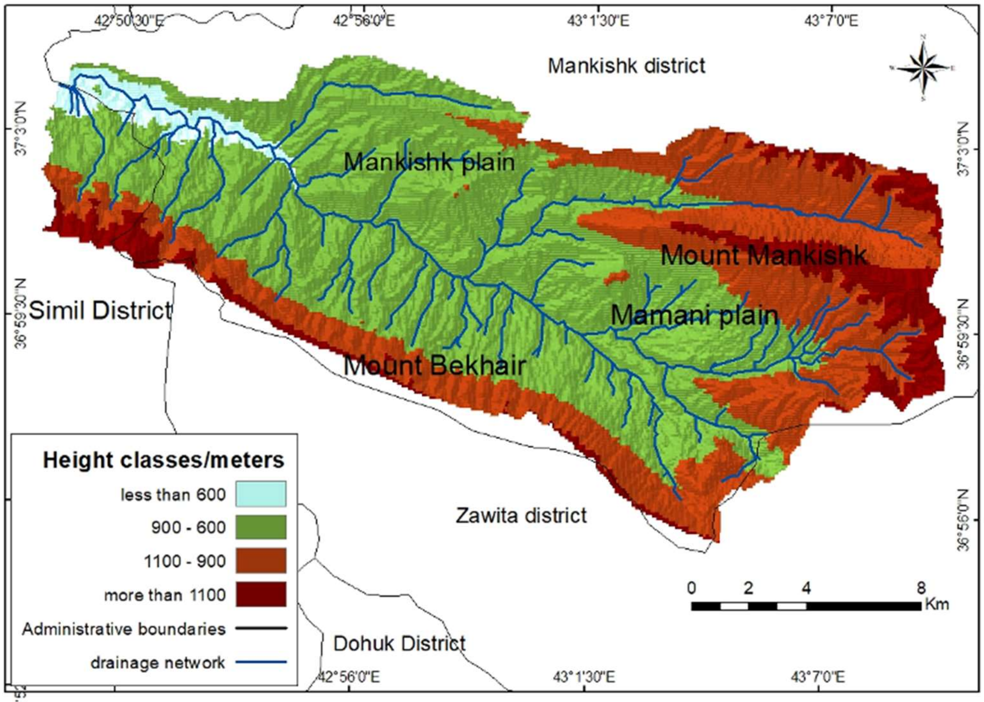


Created by the researcher using Arc GIS 10.6 based on the DEM of Dohuk Governorate.

Table 2: Areas of Elevation Categories

| No. | Elevation Categories (m) | Area (km²) | % |
|---|---|---|---|
| 1 | Less than 600 | 9.6 | 3.2 |
| 2 | 600 - 900 | 173.2 | 58 |
| 3 | 900 - 1100 | 88.5 | 29.6 |
| 4 | More than 1100 | 27.4 | 9.2 |
| Total | | 298.7 | 100 |

Created by the researcher using Arc GIS 10.6 based on the data from Map 3.

This topographic variation affects the slope gradient of the area's surface, which generally slopes from southeast to northwest. According to Zink's classification, the slope gradient of the area varies from 41.3 degrees in the mountainous slopes (source areas of the basin) to 1.2 degrees at the confluence of the valley with the Khabur River (Map 4 and Table 3).

Map 4:Slope Gradient in the Study Area According to Zink's Classification

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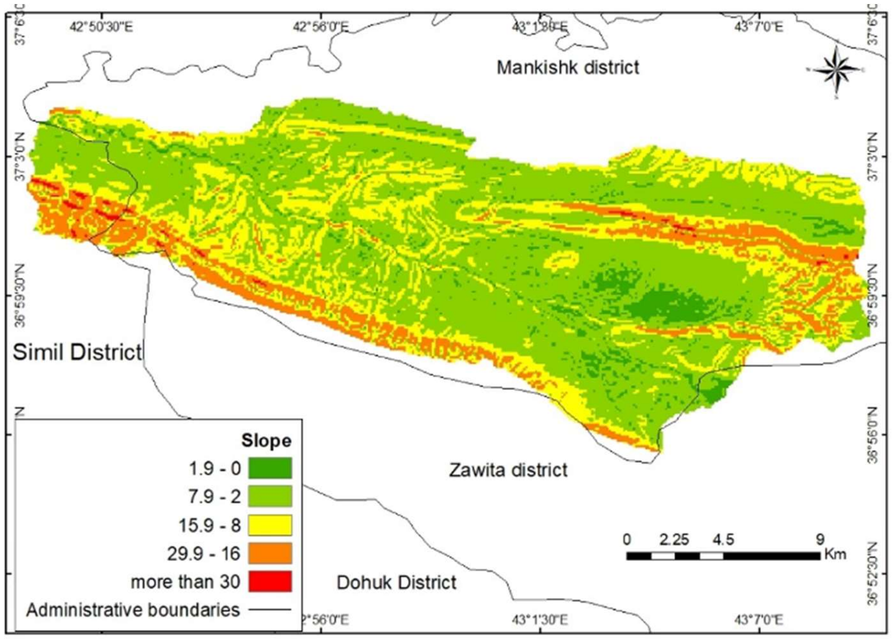


Created by the researcher using Arc GIS 10.6 based on the DEM of Dohuk Governorate.

**Table 3: Areas of Slope Gradient Categories (Zink)**

| No. | Slope Gradient Categories (°) | Area (km²) | % |
|---|---|---|---|
| **1** | 0 - 1.9 | 48.7 | 16.3 |
| **2** | 2 - 7.9 | 150.2 | 50.3 |
| **3** | 8 - 15.9 | 51.2 | 17.1 |
| **4** | 16 - 29.9 | 25.6 | 8.6 |
| **5** | More than 30 | 23.0 | 7.7 |
| **Total** | | 298.7 | 100 |

Created by the researcher using Arc GIS 10.6 based on the data from Map 4.

The soils of the study area can be classified into four types as shown in Map 5 and Table 4:

1. Sandy Loam Soil: Covers an area of 11.4 km², located in the extreme southern part of the area.
2. Silty Sandy Loam Soil: Covers 41.2 km² and is distributed throughout most of the northern parts of the basin, reflecting the effectiveness of the alluvial channels.
3. Clayey Loam Soil: Covers an area of 225.6 km² and is the most common soil type in the region. It has a clayey property, which increases surface runoff.
4. Clay Soil: Covers 20.5 km², found in the extreme southeast of the area.

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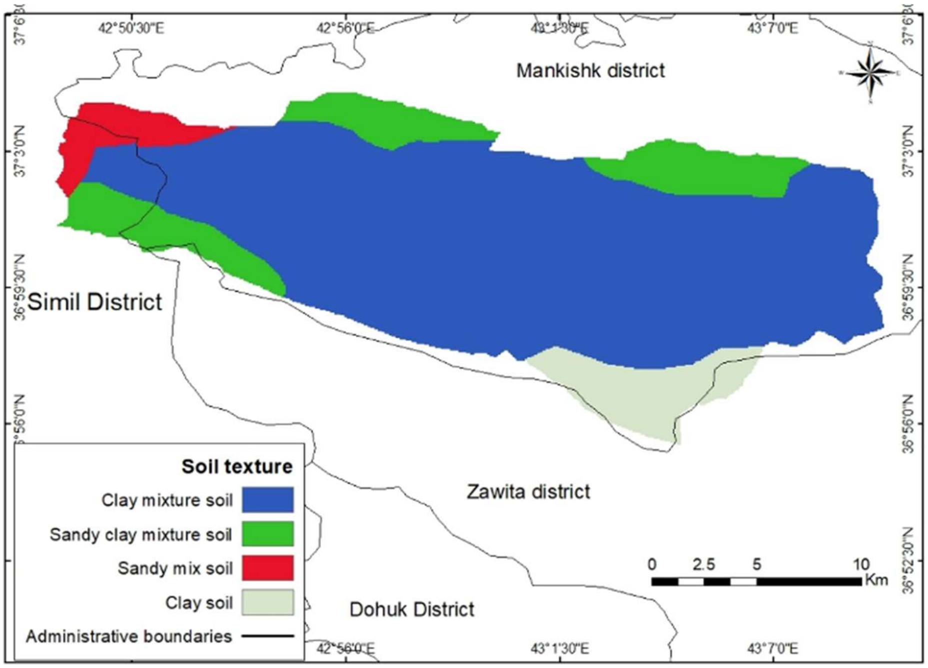
Map 5: Soil Types in the Study Area




Created by the researcher using Arc GIS 10.6 based on:

Shamal Ahmed Amin, N. (2016). Soil Erosion Risks in Dohuk District: Measurement, Risks, and Conservation. Master's thesis, Faculty of Humanities, University of Dohuk, p. 98.

**Table 4: Soil Areas in the Study Area**

| No. | Soil Texture | Soil Type | Area (km²) |
|---|---|---|---|
| 1 | Sandy Loam | A | 11.4 |
| 2 | Silty Sandy Loam | B | 41.2 |
| 3 | Clayey Loam | C | 225.6 |
| 4 | Clay Soil | D | 20.5 |
| Total | | | 298.7 |

Created by the researcher using Arc GIS 10.6 based on the data from Map 5.

The region predominantly experiences a semi-arid climate with significant seasonal variation in temperature. The average summer temperature reaches 32.4°C, while it drops to 3.7°C in winter, according to data from the Mankeshk station, with an annual average of 20.5°C. Precipitation levels vary year by year, with annual totals at Mankeshk station recorded as 675.8 mm for 2011 and 981.3 mm for 2024. This significant variation increases the risk of surface runoff.

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## 2.Data and Methodology:

2.1 Digital Elevation Model (DEM): Obtained from the U.S. Geological Survey (USGS) for the study area with a spatial resolution of 30 meters.

2.2 Satellite Imagery: Captured on August 16, 2023, from the U.S. Geological Survey (USGS) website.

2.3 Use of Virtual Rainfall Events: Five virtual rainfall events ranging from 20 to 100 mm, with increments of 20 mm, along with an actual rainfall event of 86.3 mm that occurred on March 17, 2024, in the study area.

2.4 Software Used:

Arc GIS 10.6
WMS V11
ENVI
The purpose of using these software programs was to extract spatial characteristics of the study area, build the necessary database for estimating surface runoff, including the development of soil maps, land cover maps, and derivation of Curve Number (CN) and other variables for surface runoff estimation.

## 3. Hydrological Characteristics of the Rukram Valley Basin

The relationship between precipitation and surface runoff intensity is a fundamental aspect of surface water hydrology, as surface runoff is the product or final stage of rainfall. Understanding these parameters is essential for water harvesting and flood risk management [4].

Thus, extracting the hydrological characteristics of the study area aims to provide information on surface runoff volume, depth, and peak runoff. Several mathematical methods can be employed to utilize this data, including the Curve Number (CN) method, which is specifically used for surface runoff calculations in hydrological studies (Number Runoff Curve, abbreviated as RCN). This model was developed by the Soil Conservation Service (SCS) of the United States Department of Agriculture in 1970, with its famous formula established in 1986 [5].

3.1 Surface Runoff According to the SCS-CN Method

The primary challenge in hydrology for estimating surface runoff is determining the runoff coefficient resulting from a rainfall event in basins lacking measurement stations. The Curve Number (CN) is a key factor in determining surface runoff in the SCS hypothesis, considering land use, soil type, geological structure, vegetation cover, and precipitation [6].

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First: Hydrological Soils

To determine and estimate surface runoff, it is crucial to consider soil types based on their texture in the region, as they are significant factors influencing runoff [7]. The SCS method identifies four hydrological soil groups based on the rate of water infiltration [8]. The soil hydrological groups were determined using the soil map (5), as shown in Table 5.

Table 5: Hydrological Soil Groups [9]

| No. | Hydrological Soil Class | Runoff Depth | Soil Type |
|---|---|---|---|
| **1** | A | Low | Deep sandy layer with very low amounts of clay and silt. |
| **2** | B | Medium | Sandy layer less deep than Class A with moderate runoff potential. |
| **3** | C | Above Average | Clayey layer with limited depth and below-average infiltration rate or rocky layer covered by soil. |
| **4** | D | High | Thick clayey layer covered by a shallow layer of fine silt or bare rocky layer. |

USDA – SCS, Urban Hydrology for Small Watersheds, Department of Agriculture, USA, 1986, p. 3.

According to Map 6 and Table 6, the study area contains four types of hydrological soils as follows:

1. Soil Class A: These soils have high permeability, generally consisting of a high percentage of sand, which enhances permeability and reduces surface runoff. This class covers an area of 11.4 km², accounting for 3.8% of the total area.

2. Soil Class B: With moderate drainage due to the presence of both sand and clay, this soil type covers 41.2 km², making up 13.8% of the total area.

3. Soil Class C: These soils have higher surface runoff compared to other hydrological soils due to their high clay and silt content. They cover an area of 225.6 km², representing 75.5% of the total area.

4. Soil Class D: Due to its deep clayey layer, this soil type exhibits high surface runoff and covers 20.5 km², which is 6.9% of the total area.

Map 6: Hydrological Soils in the Nirdosh Basin

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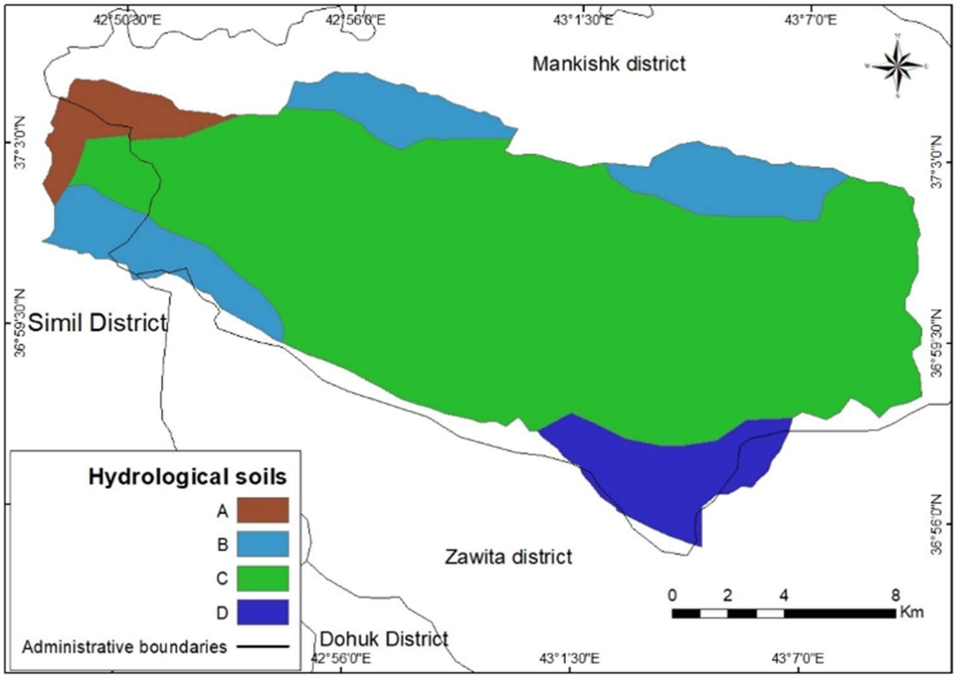


Created by the researcher based on Map 5 and Table 5.

Table 6: Areas and Percentages of Hydrological Soils in the Region

| No. | Soil Texture | Soil Class | Area (km²) | % |
|---|---|---|---|---|
| 1 | Sandy Loam | A | 11.4 | 3.8 |
| 2 | Silty Sandy Loam | B | 41.2 | 13.8 |
| 3 | Clayey Loam | C | 225.6 | 75.5 |
| 4 | Clay Soil | D | 20.5 | 6.9 |
| Total | | | 298.7 | 100 |

Created by the researcher based on Map 6.

Second: Land Cover (Land Use)

Based on the Landsat OLI8 satellite imagery from the U.S. Geological Survey (USGS) with a spatial resolution of 30 meters, captured on August 16, 2023, and analyzed using supervised classification in ENVI software, the land cover and land use in the study area are detailed in Map 7 and Table 7.

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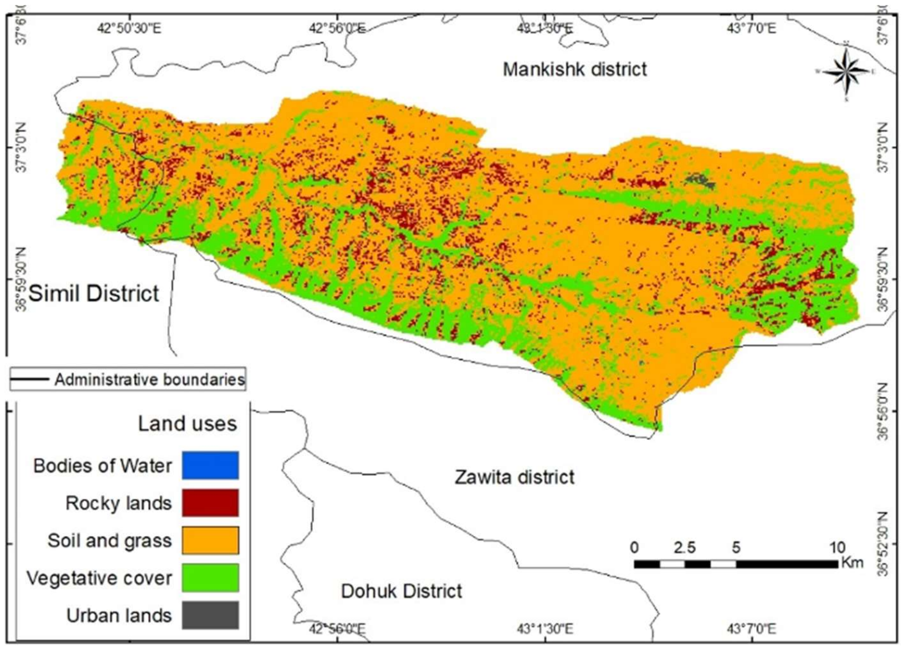
**Map 7: Land Cover and Land Use**




Created by the researcher using ENVI software based on Landsat OLI8 imagery.

1. Water bodies cover approximately 0.4% of the region's total area.
2. Rocky terrains account for an area of up to 26.6 km², characterized by impervious surfaces which increase surface runoff, thereby heightening the risk of flooding in areas where these terrains are present.
3. Natural pastures and soils cover an area of 197.7 km², representing 66.2% of the region's area. These areas are inherently natural, resulting in lower surface runoff and higher water permeability.
4. Vegetative cover impedes the flow of water, which increases infiltration due to the enhanced number of soil pores created by root systems and surface obstruction, leading to increased infiltration compared to surface runoff. This cover extends over an area of 70.8 km², constituting 23.7% of the watershed area.
5. Urban areas are among the most impervious surfaces with minimal water infiltration due to the prevalence of concrete or other materials with low permeability, such as rocks and roads. These areas cover 2.3 km², making up 0.8% of the study area.

**Table 7: Areas and Percentages of Land Uses in the Rokram Basin**

| No. | Land Cover and Use | Area (km²) | Percentage (%) |
|---|---|---|---|
| **1** | Water Bodies | 1.3 | 0.4 |
| **2** | Rocky Terrains | 26.6 | 8.9 |
| **3** | Natural Pastures and Short Grass | 197.7 | 66.2 |
| **4** | Vegetative Cover | 70.8 | 23.7 |
| **5** | Urban Areas | 2.3 | 0.8 |

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| **Total** | 298.7 | 100 | |
|---|---|---|---|

Source: Data adapted from Map 7

3-2. Mathematical Formula for Measuring Surface Runoff Volume

To calculate surface runoff volume using the SCS method, refer to the following equation [(10)].

Feel free to let me know if you need any additional adjustments!

$$Q = (P - Ia)^2 / (P - Ia + S)$$

where:
- Q= Direct surface runoff (mm)
- Ia = Initial abstraction (losses before runoff begins)
- S = Maximum retention capacity

Initial abstraction (Ia)is typically represented as 20% of the maximum retention capacity (S), thus:

$$Ia = 0.2S$$

Substituting this into the original equation:

$$Q = (P - 0.2S)^2 / (P + 0.8S)$$

**3-3 Calculation of the Curve Number (CN) and Weighted Curve Number (CNw)**

To determine the Curve Number (CN), three primary factors were considered: hydrological soil groups, land use (land cover), and the antecedent moisture condition of the soil. The study relied on a moderate moisture condition, as the region is classified as having relatively reliable rainfall and its soil is neither excessively dry nor extremely wet.

The CN values represent surface permeability and hydrological response, expressed as dimensionless values ranging from 0 to 100. Values approaching 100 indicate low permeability and impervious surfaces, while values closer to 0 denote higher permeability and reduced surface runoff generation.[(11)]

According to Map 8 and Table 8, CN values range from 36 in areas with increased infiltration and reduced surface runoff, to values approaching 100 in impervious areas where water infiltration is minimal and surface runoff is elevated.

Map 8: CN Values for the Rokram Valley Basin.

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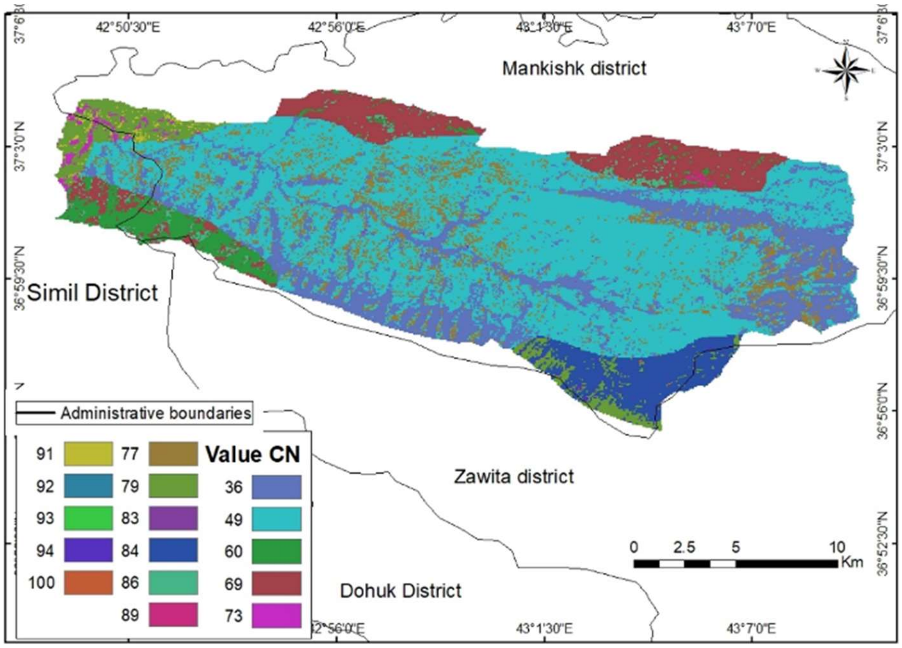


The data were generated by the researcher using ArcGIS 10.7, based on Maps 6 and 7.

Table 8: Curve Number (CN) Based on Land Use and Hydrological Soil Group

| Anderson LULC Code | Land Use and Cover | Curve Number (CN) by Hydrological Soil Group | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| **16** | Urban Areas | 83 | 89 | 92 | 93 |
| **52** | Water Bodies | 100 | 100 | 100 | 100 |
| **41** | Forests and Trees | 36 | 60 | 73 | 79 |
| **3** | Soil and Natural Pastures | 49 | 69 | 79 | 84 |
| **77** | Rocky Areas | 77 | 86 | 91 | 94 |

The data were generated by the researcher using ArcGIS 10.7, based on Maps 6 and 7.

Table 8: Curve Number (CN) Based on Land Use and Hydrological Soil Group

The data were derived by the researcher using Anderson's (1976) classification and ArcGIS 10.6 software.

The weighted average Curve Number (CNw), calculated using the following equation [(12),] is 61.9.

$$CNc = (CN1A1 + ... + CNnAn) / (\sum Ai)$$

where:

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CNi = Curve Number for the sub-area
Ai = Area of the sub-basin
N = Total number of sub-basins
CNc = Curve Number value
3-4 Calculation of Surface Runoff Volume ($m^3$) Using the Following Equation ([13]):

QV = (Q × A) / 1000

where:

QV = Surface runoff volume ($m^3$)
Q = Depth of surface runoff (mm)
A = Basin area ($m^2$)
3-5 Calculation of Peak Time (TP), Lag Time (TL), and Time of Concentration (TC)

These are calculated using the following equations [(14):]

Tp = tr / 2 + t1,
Tp = (tc + 0.133 tc) / 1.7

where:

t1 = 0.6 tc
The time of concentration (tc) is calculated using:

tc = 0.0195 (L^0.77 / S^0.385)^m

where:

L = Length of the river channel (mm)
S = Channel slope
These hydrological equations and calculations were performed using WMS V:11.0 software.

3-6 Maximum Retention Capacity (S)

This represents the soil's ability to retain water before surface runoff begins, indicating the saturation of the soil. Values close to zero suggest low water retention and high runoff potential, while values approaching or exceeding 254 indicate the soil’s high water retention capacity and increased infiltration, leading to reduced surface runoff [(15).]

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3-7 Initial Abstraction (Ia)

This refers to the amount of water lost from precipitation through evaporation or vegetation interception before runoff occurs. Higher values indicate lower surface runoff and increased water loss [16].

**4- Hydrological Parameters for the Rokram Valley Basin Using WMS V11.0**

4-1 Lag Time (TL)

This refers to the time for surface runoff to occur and is related to the basin's hydrological components. There is an inverse relationship between lag time and surface runoff; shorter durations with reduced water losses or impediments due to land cover lead to faster runoff and increased water volume. In the study area,([17] the lag time is 3.9 hours from the onset of precipitation to the occurrence of runoff (Table 9).

4-2 Time of Concentration (TC)

This is the time required for water to travel from the farthest point of runoff to the river mouth. A longer TC indicates a more elongated basin shape, suggesting a reduced flood risk due to increased TC values [18]. In this basin, TC is 8.1 hours (Table 9), reflecting its elongated shape and lower flood risk due to gradual water arrival at the river mouth.

4-3 Depth of Surface Runoff (mm)

This represents the amount of precipitation falling within the basin, accounting for the difference between total precipitation and losses. Hypothetical rainfall values ranging from 20 mm to 100 mm (at 20 mm intervals) and an actual rainfall of 86.4 mm were used. Increased soil infiltration capacity results in reduced surface runoff depth, with dense vegetation being a significant factor in enhancing groundwater infiltration [19].

From Table 9, it is evident that the depth of surface runoff increases with higher precipitation. At 40 mm of rainfall, only 11.32 mm of runoff occurs due to increased losses. However, higher precipitation over a short period leads to soil saturation and increased runoff. For 60 mm of rainfall, runoff depth reaches 21.12 mm. At 100 mm of rainfall, over half of the precipitation contributes to surface runoff, reaching a depth of 51.02 mm, indicating a higher risk of flooding in the area.

Table 9: Hydrological Characteristics of the Rokram Valley Basin 2024

| Rainfall (mm) | Lag Time (hours) | Time of Concentration (hours) | Peak Discharge ($m^3/s$) | Time to Peak | Depth of Runoff (mm) | Runoff Volume ($m^3$) |
|---|---|---|---|---|---|---|

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| | | | | Discharge (minutes) | | |
|---|---|---|---|---|---|---|
| **20** | 3.9 | 8.1 | 6.82 | 1815 | 1.69 | 313,215.0 |
| **40** | 3.9 | 8.1 | 6.98 | 1745 | 11.32 | 472,107.2 |
| **60** | 3.9 | 8.1 | 165.32 | 1736 | 21.12 | 545,681.5 |
| **80** | 3.9 | 8.1 | 268.91 | 1725 | 38.93 | 1,013,244.1 |
| **86.4** | 3.9 | 8.1 | 348.82 | 1725 | 46.13 | 1,522,410.3 |
| **100** | 3.9 | 8.1 | 400.32 | 1710 | 51.02 | 2,135,283.5 |

Based on the WMS 11.0 software and the U.S. Soil Conservation Service (SCS) Curve Number (CN) Method.

**4-4 Surface Runoff Volume ($m^3$)**

The surface runoff volume represents the amount of water accumulated across the entire basin, reflecting the basin's hydrological characteristics related to soil and land cover. Table 9 illustrates the surface runoff volume based on precipitation events. The runoff volume reaches 472,107.2 $m^3$ for a rainfall of 40 mm. The risk of floods and torrents in the basin begins to increase when the precipitation amount reaches 60 mm, with the runoff volume rising to 545,681.5 $m^3$. This risk intensifies with increasing precipitation, reaching 1,013,244.1 $m^3$ at 80 mm of rainfall over a short period, and further increasing to 2,135,283.5 $m^3$ for a 100 mm rainfall event.

4-5 Time to Peak Discharge (minutes) and Peak Discharge ($m^3/s$)

These are important hydrological characteristics for assessing the flood risk of the basin and reflect the basin's hydrological attributes as indicated by the Curve Number (CN) values. The weighted CN (CNw) is 61.9, indicating that the basin has high discharge and low infiltration. As shown in Table 9, with increasing rainfall, the discharge volume also increases, while the time to reach peak discharge decreases. For 20 mm of rainfall, the peak discharge is 6.82 $m^3/s$ with a time to peak of 1815 minutes. This discharge increases to 268.91 $m^3/s$ with a time to peak of 1725 minutes at 60 mm of rainfall. For a 100 mm rainfall event, the peak discharge reaches 400.32 $m^3/s$ with a time to peak of 1710 minutes, indicating a higher risk of flooding.

**Conclusions:**

1. Soil Types: Four types of soil are identified in the area based on texture analysis. However, clayey loam soils cover the majority of the basin, with an area of 225.6 $km^2$, representing 75.5% of the basin area. These soils fall under Hydrological Soil Group (C), characterized by higher runoff compared to infiltration due to their high clay content.

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2. Curve Number (CN) Values: The CN values for the study area generally exceed the average of 50, indicating increased surface runoff and higher potential for floods and torrents, particularly in the outlet areas.

3. Runoff Depth: The depth of surface runoff increases with precipitation. For 80 mm of rainfall, the runoff depth reaches 38.93 mm, and for 100 mm of rainfall, it reaches 51.02 mm. This indicates that more than half of the precipitation flows over the surface, increasing the risk of flooding.

4. Maximum Runoff Volume: The maximum runoff volume reaches 2,135,283.5 $m^3$ for a 100 mm rainfall event, which is significant for a basin of the study area's size (298.7 $km^2$). To mitigate flood risks, it is recommended to install early warning systems for high rainfall events. Additionally, constructing small and earthen dams can help in water storage during rainy seasons, thus reducing flood risks and benefiting various human uses of the water.

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