*Desalination and Water Treatment*
www.deswater.com
doi: 10.5004/dwt.2020.25511

جمعية علوم وتقنية المياه
Water Sciences and Technology Association

# Rainfall-runoff estimation and comparative analysis using SCS method based on GIS

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**ABSTRACT**

Accurate estimation of runoff and sediment yield amount is not only an important task in physiography but also important for proper watershed management. Watershed is an ideal unit for planning and management of land and water resources. Direct runoff in a catchment depends on soil type, land cover and rainfall. Of the many methods available for estimating runoff from rainfall, the curve number method (SCS-CN) is the most popular. The curve number depends upon soil and land use characteristics. This study was conducted in the Kaam watershed in north western Libya using remote sensing and GIS. SCS-CN method has been used for surface runoff estimation for five sub-watersheds of Kaam. The soil map, land use and slope map were created in the GIS environment, because the curve number method is used here as a distributed model, it is necessary to obtain information on a large number of sub-catchments in the basin. Therefore, remote sensing and GIS techniques were used. The major advantage of employing GIS in rainfall -runoff modelling is that more accurate sizing and catchment characterization can be achieved. Furthermore, the analysis can be performed much faster, especially when there is a complex mix of land use classes and different soil types, Landsat satellite image was used to obtain ground cover information. The thematic layers such as the soil map, elevation map, rainfall map and ground cover map were created in Arc GIS 10.3. Then was set the values of Curve numbers in the study area, and by applying the SCS-CN method, the results showed that the surface runoff ranged from 94 to 165 mm in the study area, when rainfall rates were received from 204.07 to 284.6 mm. To find the relationship between rainfall and runoff rates, the straight line equation was used, That was found there a strong correlation between runoff and precipitation rates. The value of the determination coefficient was 73% and the correlation coefficient between them 85%. Through these results, the study recommends taking advantage of runoff rates by reserving them at collection of sub basins and then using them for agricultural purposes in the vicinity. This would be better than reserving water from the total area of the basin, which is 2,283 square kilometres, and then will evaporate or infiltrate before reaching the dam lake.

*Keywords:* GIS; SCS method; Rainfall-Runoff; Watershed; Land use

## 1. Introduction

The determination of the runoff value is necessary for designing dams, reservoir management, and prediction of risks and potential losses caused by flooding. Also, determining amount of the runoff is very important in projects related to sediment and erosion processes. Surface runoff and sediment losses are the two important hydrologic responses from the rainfall events occurring over the watershed systems (Gajbhiye et al. 2014c). Rainfall generated runoff is very important in various activity of water resources development and management such as a flood control and its management, irrigation scheduling, design of irrigation and drainage network, hydro power generation, etc. (Mishra et al. 2013). A watershed is an area covering all the land that contributes water after rainfall occurs to a common point. Watershed management programme is mainly for conservation and development of natural resources, where most

Presented at the 13th Gulf Water Conference – Water in the GCC: Challenges and Innovative Solutions. 12–14 March 2019, Kuwait

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of the watersheds in Libya are ungauged, having no past records of the rainfall-runoff process. There are several flow estimation methods for ungauged catchments such as rational method, SCS-curve number method, cook's method and unit hydrograph method. The Soil Conservation Service developed curve number method for predicting direct runoff or infiltration from rainfall excess of ungauged watershed. Soil and land use parameters which control surface runoff can be evaluated and mapped significantly through Landsat Thematic Mapper (Sharma et al. 1992). Curve Number method (SCS-CN) is one of the most widely used approaches for fast and accurate calculation of the basin surface runoff. This approach involves the use of a simple empirical formula and readily available tables and curves. Also, this method has been used more and provides accurately automatic runoff prediction by connected with the geographical information system (GIS). In recent decades, most researchers have considered the use of GIS (Patil. 2008). Remote sensing and GIS techniques are widely used in the determination of spatial distribution of the catchments ecosystem characteristics and their impact on catchments hydrology (Takeli et al. 2006, Sharma et al. 2001). GIS, which has been designed to restore, manipulate, retrieve and display spatial and non-spatial data, is an important tool in analysis of parameters such as land use/land cover, soils, topographical and hydrological conditions. To carry out resource monitoring and assessment of area of interest, information derived through remote sensing data has to be merged or integrated with database in GIS, Thus the remote sensing along with GIS application aid to collect, analyse and interpret the data rapidly on large-scale intermittently and is very much helpful for watershed planning (Sharma et al. 2014c; Gajbhiye 2014). Conventional methods of runoff estimation using SCS model are time consuming and error prone. Thus, remote sensing and geographical information (GIS) techniques are being increasingly used, as all the factors of SCS model are geographic in character. Due to geographic nature of these factors of SCS runoff model can easily be modelled into GIS data.

## 2. Materials and methods

### 2.1. Study area

Kaam Basin located within the coastal areas to the west of Libya, which is one of the large basins where rainwater accumulates, where the storage capacity has about 111 $m^3$. The catchment area has about 2,283 square kilometres, as well as the average height above sea level of about 283.5 m, the basic purpose of its establishment is a reservation rainwater and floods which amounts to an average of about 15 million $m^3$ a year, which was to go to the Mediterranean without the benefit of them. Fig. 1 shows the location map of study area.

### 2.2. Data source

Digital map of the soils Libyan study covers the area from previous studies (agricultural mapping project, the Ministry of Agriculture, 2006) at a scale of 1:1,000,000. Digital map land cover of the study area from previous study (agricultural mapping project, the Ministry of Agriculture, 2006) at a scale of 1:250,000. Digital Elevation Model at a resolution of 30 m was used to extract the sub-watershed, Arc Map 10.1 software was used for creating, managing,

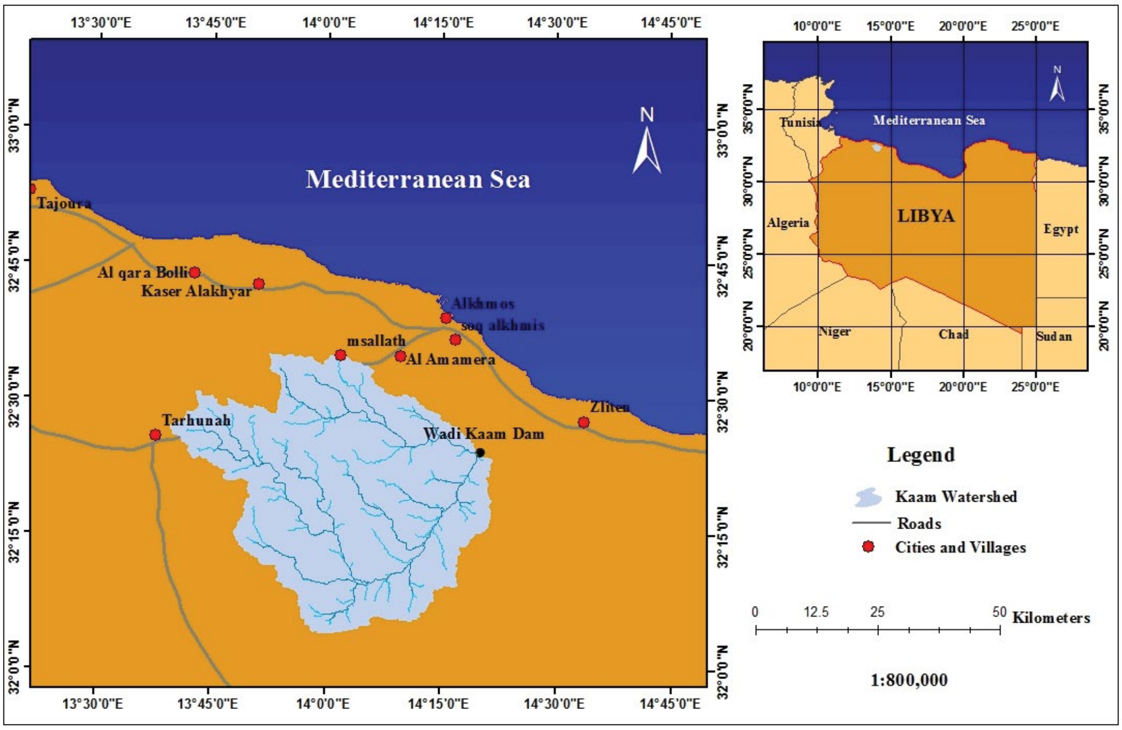


Fig. 1. Location of the study area.

and generating different layer and maps. The Microsoft Excel was used for mathematical calculation.

### 2.3. Methodology

Preparation of various thematic maps by ArcMap10.1 soil map of the study area, drainage map, slope map and land use/land cover map.

#### 2.3.1. Soil map

Soils were classified according to the sub-watershed hydrological soil groups (HSG) of the US Department of soil conservation, as in Table 1, There are main two types of soil in the present study area which comes under the hydrologic soil group A, B.

#### 2.3.2. Elevation map

The use of geographic information systems software Arc map 10.1 for the analysis of Digital Elevation Model and to obtain a topographic characteristic of the sub-watershed and drainage network extraction and slope. Fig. 2: shows the Hydrology Model.

Table 1
Hydrological soil groups

| Texture | HSG |
|---|---|
| Sandy, loamy, sandy loam | A |
| Silt loam or loam | B |
| Sand clay loam | C |
| Clay loam, silt clay loam, sandy clay, silt clay, or clay | D |

#### 2.3.3. Curve number map

To create the CN map, the soil map and land use map were uploaded to the Arc GIS. The soil map and land use map were selected for intersection, after intersection a map with new polygon representing the merged soil-land map. The appropriate CN value for each polygon of the soil-land map was assigned.

$$\mathrm{CN} = \left( \sum \frac{\left(\mathrm{CN}_i \times A_i\right)}{A} \right) \quad (1)$$

where,

CN = weighted curve number.
$\mathrm{CN}_i$ = curve number from 1 to 100.
$A_i$ = area with curve number $\mathrm{CN}_i$.
$A$ = the total area of the watershed.

#### 2.3.4. Determination of rain distribution by Thiessen method

The average precipitation over the study area was calculated from rainfall data from period by Theissen polygon method using the following equations:

$$P_{\text{Average}} = \frac{P_1 \times A_1 + P_2 \times A_2 + P_3 \times A_3 + \cdots}{A} \quad (2)$$

where:

$P_A$ = precipitation in polygon A.
$A_1$ = Area of polygon 1.
$A$ = the total area of the watershed.

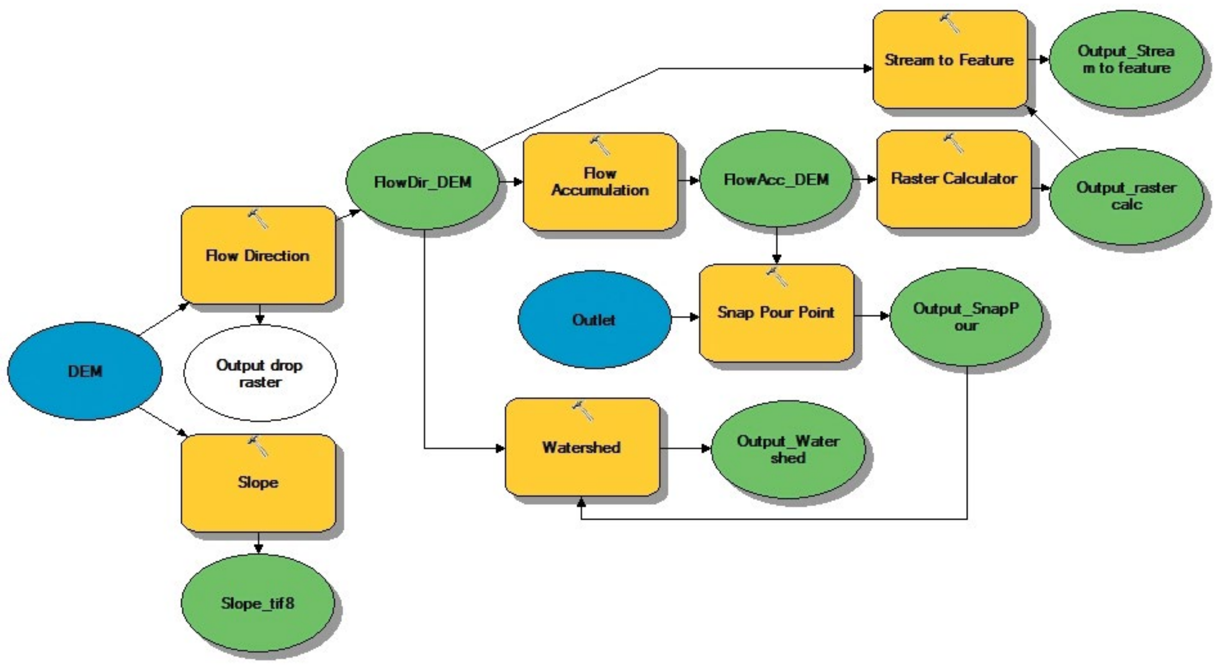


Fig. 2. Hydrology model.

*2.3.5. Estimation of runoff depth using SCS model*

SCS method estimates the runoff according to rainfall and characteristics of basins. So it is appropriate for estimating runoff where there is no station for the flow measurement in the basin. The SCS empirical method proposed by the US Soil Conservation Service is widely used for estimating direct runoff. The SCS method that is also well known as curve number method is based on water balance. The following equation is used for estimating runoff:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad (3)$$

Eq. (1) is true for $P$ > Ia, otherwise the estimated runoff to be zero. Initial retention (Ia) is in fact part of the precipitation that does not participate in the runoff and is considered equal to Ia = 0.2 S in SCS:

$$S = \frac{25,400}{\text{CN}} - 254 \quad (4)$$

where,

$Q$ = runoff depth (mm).
$S$ = maximum recharge capacity.
CN = curve number.
$P$ = rainfall depth (mm).

**3. Results and discussion**

To apply this method to Kaam catchments, the available land use and soil type maps were processed using GIS techniques. To determine the HSG, the USDA soil texture must be known. This can be determined according to the percentage of sand, silt, and clay. Table 2 Classifies the HSG by its USDA soil texture. In the GIS-based SCS-CN method, the CN and average rainfall values were used as inputs to compute yearly runoff for various curve numbers, the

Table 2
Calculation of Weighted Curve Number for AMC II

| Area% | Area/km$^2$ | CN | HSG | Land use |
|---|---|---|---|---|
| 0.33 | 7.71 | 67 | A | Irrigated plants |
| 0.15 | 3.51 | 78 | B | |
| 18.35 | 419 | 49 | A | Plants pain fed |
| 3.88 | 88.71 | 69 | B | |
| 1.42 | 32.53 | 63 | A | Barren rocks |
| 1.83 | 41.91 | 77 | B | |
| 1.06 | 24.28 | 77 | A | Barren soils |
| 1.62 | 37.05 | 85 | B | |
| 0.41 | 9.45 | 77 | A | Urban area |
| 0.13 | 3 | 85 | B | |
| 64.16 | 1465 | 68 | A | Herb plants |
| 6.28 | 143.40 | 79 | B | |

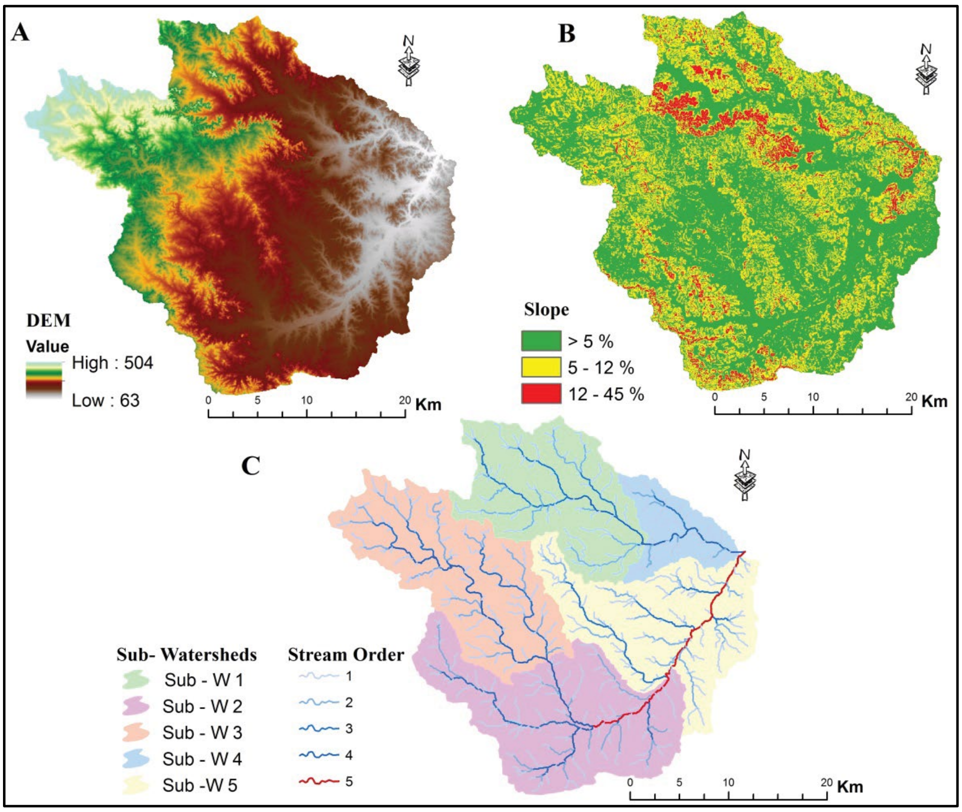


Fig. 3. A (DEM map), B (slope map) and C (sub-watershed map).

individual composite curve number was computed for all study area for AMC II condition using Eq. (1). Fig. 4 shows hydrological soil group, land use/land cover, CN map of Kaam sub-watershed.

SCS developed soil classification system that consists of four groups, which are identified as A, B, C and D according to their minimum infiltration rate. CN values were determined from HSG and AMC of the watershed. For the present study, average condition (AMC II) is selected foe study area. Runoff curve numbers for AMC II. Different layers of land use/land cover, soil, HSG were added in attribute table using union tool in ArcGIS 10.1. The result obtained from union attribute was used to compute weighted area curve number of the study area. Calculated value of CN is 88.14 (taking CN = 65) in Table 2.

Runoff mapping: runoff potential has been estimated using Soil Conservation Service (SCS) model. Maps for various parameters have been generated and finally a map showing variation in annual runoff potential has been prepared. Fig. 5 shows rainfall map, runoff map, runoff coefficient map, of Kaam sub-watershed.

SCS-CN method has been used for surface runoff estimation for five sub-watersheds of Kaam and the parameters of all sub-watersheds shown in Table 3.

The weighted CN value of sub-watershed 1, 2, 3, 4, and 5 comes to be 64,58, 63, 68, and 70, respectively. The runoff value for sub-watershed 1, 2, 3, 4, and 5 to be 165.07, 129.78, 94.57, 163.75, and 122.63, respectively. It can be inferred from Table 3. There is no provision for runoff monitoring in Kaam watershed; therefore this method could be used to find out the runoff. Thus the generated curve numbers may be used for prediction of runoff from an ungauged watershed. To using 20 years rainfall data from 1980 to 2000 runoff has been calculated for five sub-watersheds and graphs was drawn.

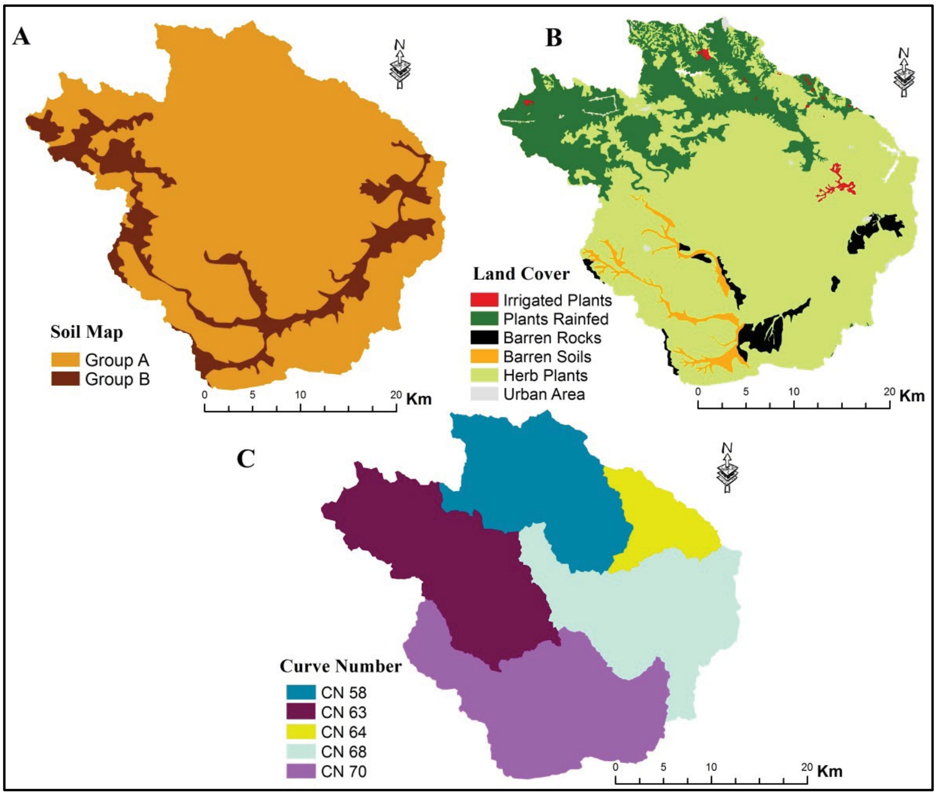


Fig. 4. A (hydrological soil group), B (land use/land cover map) and C (CN map).

Table 3
Average rainfall - runoff depth of kaam sub-watershed for season (1980–2000)

| Sr.no | Sub-watershed | Area ($km^2$) | Storage coefficient ($S$) mm | CN | Rainfall (mm) | Runoff (mm) |
|---|---|---|---|---|---|---|
| 1 | Sub1 | 153 | 141.6 | 64 | 284.60 | 165.07 |
| 2 | Sub2 | 460 | 182.4 | 58 | 268.35 | 129.78 |
| 3 | Sub3 | 547 | 147.6 | 63 | 204.07 | 94.57 |
| 4 | Sub4 | 516 | 114.6 | 68 | 264.39 | 163.75 |
| 5 | Sub5 | 602 | 106.2 | 70 | 212.10 | 122.63 |

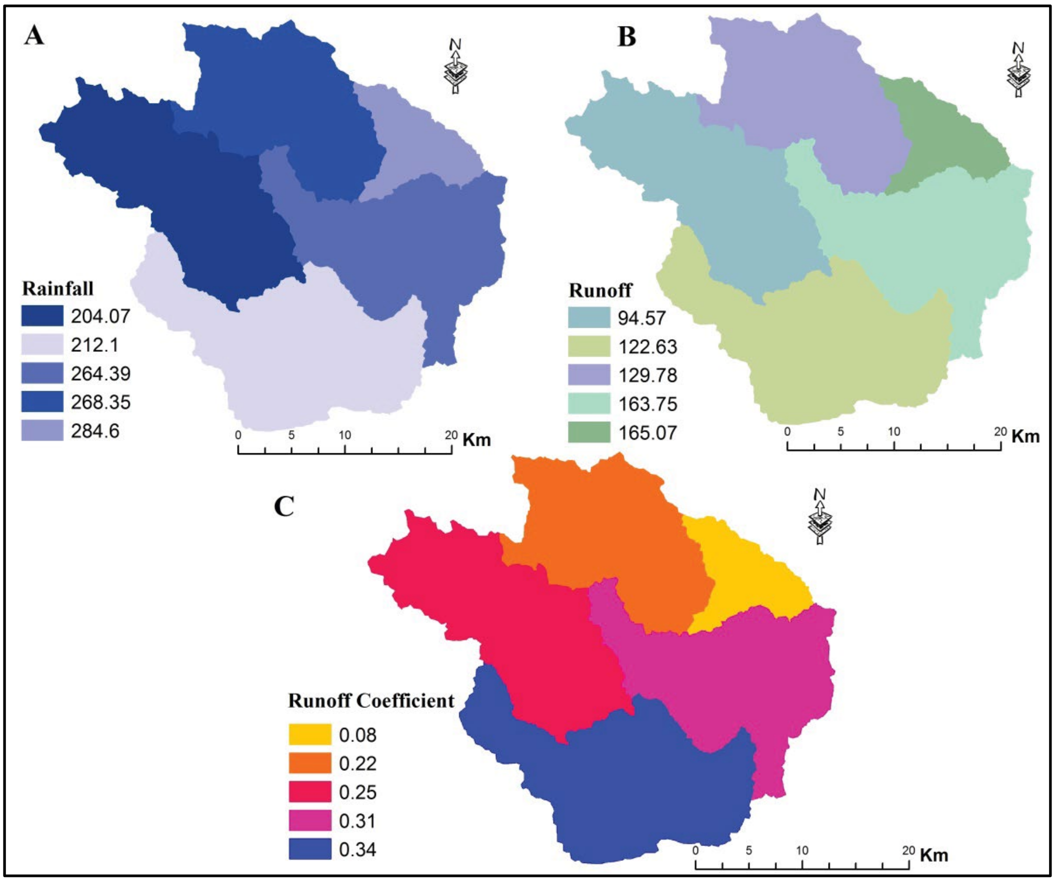


Fig. 5. A (rainfall map mm), B (runoff map mm) and C (runoff coefficient map).

Fig. 6 showing bar chart yearly variation of rainfall-runoff rate for five sub-watersheds in Wadi Kaam for 20 years 1980 to 2000.

To check the performance of curve number method, the calculated yearly runoff and the daily rainfall data were plotted using MS Excel to develop the relationship between them used to find the correlation coefficient of the data, the relationship between rainfall-runoff is shown in Fig. 7. The figure indicates that rainfall and runoff are strongly correlated with correlation coefficient (*r*) value being 0.855.

## 4. Conclusions

The estimation of runoff using GIS-based SCS curve number method can be used in watershed management

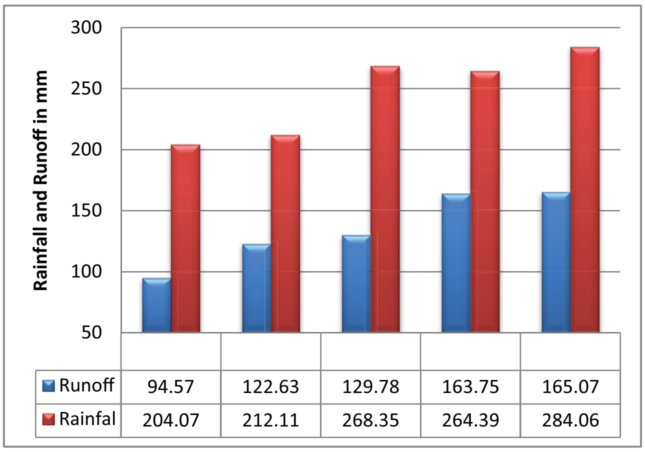


Fig. 6. Graph of rainfall-runoff rate for five sub-watersheds of period 1980–2000.

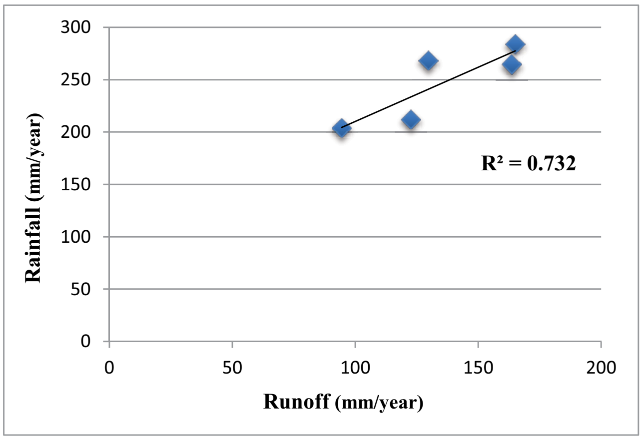


Fig. 7. Relationship between Average Rainfall and Runoff from (1980–2000).

effectively. All the factors in SCS model are geographic in character. Due to the geographic nature of these factors, SCS runoff model can be easily modelled into GIS. The study demonstrates the importance of remotely sensed data in conjunction with GIS to derive the model parameter to estimate surface runoff from the ungauged watershed. Results obtained clearly shows the variation in runoff potential with different land use/land cover and with different soil conditions. Based on the digital database creation, conservation techniques such as percolation pond, check dam, etc., can be recommended for better management of land and water resources for sustainable development of the watershed. In the present study, the process of runoff computation using SCS-CN model in GIS environment has been presented. Remote sensing and GIS with application of SCS-CN model proves to be a powerful tool for runoff estimation. Land use planning and watershed management can be done effectively and efficiently using SCS-CN number method with GIS. The SCS-CN method is a widely used method for estimating the surface runoff volume for a given rainfall event. The major advantage of employing GIS in rainfall-runoff modelling is that more accurate sizing and catchment characterization can be achieved. Furthermore, the analysis can be performed much faster, especially when there is a complex mix of land use classes and different soil types.

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