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A Comparison Between SCS-CN and Rational Methods to Runoff Estimation for Duhok Dam Watershed, Northern Iraq

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ABSTRACT

Estimating the surface runoff that reaches the dam's reservoir is an urgent demand in the design of dams construction projects and managing water resources. There are many techniques used to estimate the runoff generated from rainfall. This research aims to compare the peak and volume of runoff that enter to the Duhok Dam reservoir in Duhok City in Northern Iraq by two widely used techniques, Soil Conservation Service Curve Number (SCS- CN) and Rational Method. Integrated GIS with remote sensing data are used to apply both techniques over the dam catchment. The Digital Elevation Model (DEM) of 30 m resolution and Sentinel (2A) image of 10 m resolution of 17th February 2016, incorporated with FAO soil group as well as interpolation of rainfall data of four stations have been used to produce the objectives maps for these methods. The result of surface runoff depth shows that the values range from 568 mm to 777 mm by the SCS-CN method and 142 mm to 646 mm by the rational method. According to this study, the SCS-CN method provides proper results of runoff estimation by considering different characteristics of the runoff and according to the size of the watershed.

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دراسة مقارنة لتقدير الجريان السطحي بين طريقة صيانة التربة (SCS-CN) وطريقة العقلانية(Rational) لحوض تصريف سد دهوك، شمالي العراق

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الملخص

تقدير معدلات الجريان السطحي الواصلة الى خزانات السدود واحدة من المتطلبات المهمة في تصميم السدود وادارة الموارد المائية. هنالك العديد من الطرق التي يتم استخدامها في تقدير معدلات هذا الجريان الناتج من الساقط المطري. يهدف هذا البحث الى اجراء مقارنة لحجم وقمة الجريان السطحي المتوقع الداخل الى خزان سد دهوك في مدينة دهوك شمالي العراق بطريقتي صيانة التربة (SCS-CN) وطريقة ال (Rational) واسعتي التطبيق. تم تطبيق الطريقتين على منطقة الدراسة عن طريق تكامل بيانات التحسس النائي مع نظم المعلومات الجغرافية. تضمنت البيانات المستخدمة نموذج الارتفاع الرقمية بدقة تميزية 30 متر، وصورة القمر الاصطناعي سينتنل بدقة تميزية 10 أمتار ملتقطة بتاريخ 17 شباط لعام 2016، وبيانات الترب الصادرة عن منظمة الفاو بالاضافة الى معطيات الساقط المطري لاربع محطات قريبة للمنطقة.

استخدم برنامج ال (ArcGIS) في تطبيق الخوارزميات الرياضية المتعلقة بكلتا الطريقتين في تقدير معدل السيح السطحي. اظهرت نتائج عمق الجريان السطحي بطريقة صيانة التربة قيمة تراوحت بين 568 ملم و 777 ملم، في حين تراوحت قيمة معدل الجريان بين 142 ملم الى 646 ملم بالطريقة العقلانية. وفقا لهذه الدراسة، فان طريقة صيانة التربة تقدم نتائج مناسبة اكثر في تقدير حجم الجريان من خلال الاخذ بنظر الاعتبار الخصائص المختلفة للسيح السطحي فضلا عن حجم جابية الجريان.

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Introduction

The water shortage issue in arid and semi-arid regions in the last years caused by climate change and growing population requires the proper management of the watershed as a sequence of water necessary in the domestic, agricultural, economic, and industrial sectors. A watershed is a unit area that drains surface runoff generated from precipitation into a water body. Understanding the hydrological activity of a watershed that has an influence on the surface runoff is significant for water resource management, flooding control, agriculture, drainage network, recharge, …..etc (Sissakian et al., 2014; Gajbhiye, 2015). Construction of hydrological projects such as earth-fill dams in semi-arid regions, where rainwater is the main source of water, is important. The characteristics of earth fill dam require extensive knowledge of the watershed and expected runoff volume. The surface runoff volume or overland flow is different via storm events and various climate conditions as well as the type of land cover (USDA-SCS, 2004), and it mainly relies on the amount of precipitation, slope, soil properties, watershed area, and LU-LC (Rajbanshi, 2016; Gupta and Dixit, 2022). Many methods have been developed to be used in estimating the surface runoff depth and volume of different-sized catchments. The Rational Method and Soil Conversations Service-Curve

Number (SCS-CN) also called Natural Resources Conservation Service-Curve Number (NRCS-CN) are the two most commonly used methods allover the world (Mazahreh et al., 2018; Cheah et al., 2019; Pathan and Joshi, 2019). Both methods are applied easily with no time-consuming, and they are appropriate for ungagged watersheds (Chandramohan and Vijaya, 2017). Recently, integration of two methods with GIS and remote sensing has provided a quick technique to estimate the runoff spatially and temporally. Runoff parameters, such as land cover and soil maps, can be generated and analyzed more effectively using geospatial techniques (Gajbhiye, 2015; Muttaqin et al., 2021; Sudaryatno et al., 2021). The current study includes an examination of the efficiency of each of the rational and SCS-CN methods for the estimation of the surface runoff of Duhuk Dam catchment. The results of this comparison will give researchers the possibility to choose the appropriate method and a range of credibility of the results.

Study Area

The study is conducted in Duhok Dam Watershed, which is a small watershed located at the north of Duhok City in northern Iraq. The area is bounded by latitudes 36° 51′ 30″ N and 37° 0′ 30″ N, and longitudes 42° 49 ′ 30″ E and 43°5′ 30″ E (Fig. 1). The watershed covers an area of 134 Km^2 with a perimeter of 63.61 Km, extending from NW to SE, its elevation varies from 593 m to 1375 m above sea level. Duhok dam is an earth fill dam constructed in 1988 at the Rubari Duhok River located in Galli Duhok valley at the outlet of the catchment. Firstly, a dam was built for irrigation purposes to service the agricultural area in the city. However, nowadays the dam lake is used as a source of water supply and tourism. Most of the rainwater that falls over this catchment after infiltration and initial abstraction enters the dam reservoir as surface runoff. The study area has a semi-arid climate characterized by dry, warm summer and cold winter with a moderate precipitation rate. Geologically, the region is situated within high folded zone of the northern Arabian platform (Jassim and Goff, 2006). Stratigraphically, the outcropped formations in the area of interest are of Cretaceous to the Pliocene ages (Bamerni et al., 2020). The surface cover in the location mostly consists of barre soil and rock with few oak trees and vegetation, and the majority of soil type in place is loam soil.

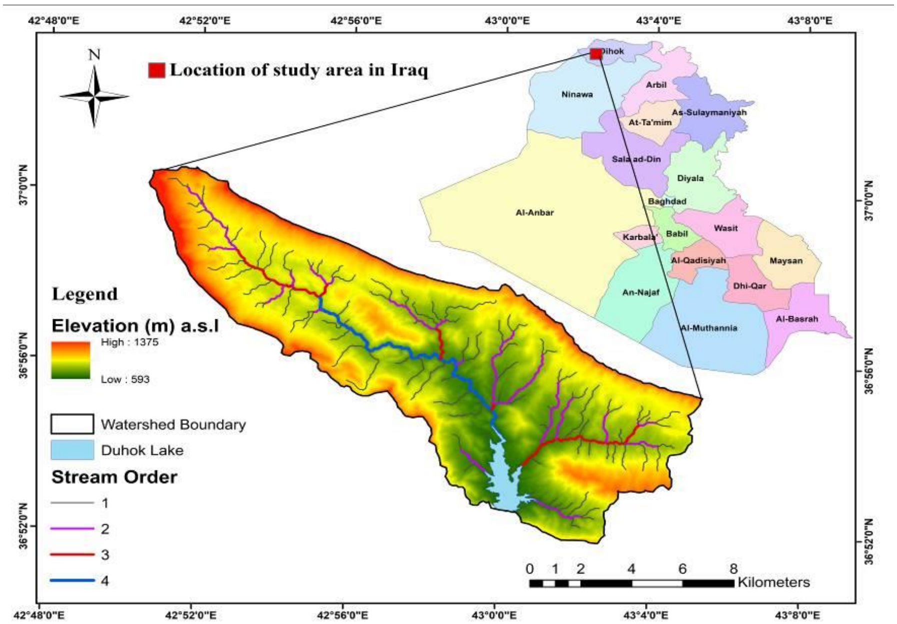

Fig.1. Location map of the Duhok Dam Watershed with stream orders using digital elevation

model

Data used

The current study requires the use of a variety of data concerned with runoff estimation to generate the surface runoff by SCS-CN and Rational methods. Wherefor this project, a Digital Elevation Model (DEM) is applied depending on a Shuttle Radar Topographic Mission (SRTM) of 30 m resolution and a Sentinel 2A image of (17th February 2016) with 10-meter spatial resolution, both are derived from the USGS website https://earthexplorer.usgs.gov/. The annual rainfall data of the four nearest stations (Mangesh, Zawita, Duhok, Duhok dam) are obtained, the first three stations data are from Duhok Directorate of Meteorology and Seismology, while the data of the Duhok dam station are obtained from monitoring station of Duhok Dam Directorate. The watershed soil data are downloaded from the global soil dataset website https://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/en/ of the Food and Agriculture Organization (FAO). The ArcGIS 10.4 software is used to process and prepare thematic maps of the data used in this research.

1. Rainfall Data

Rainfall is an important variable in the hydrological studies. The collected rainfall data are interpolated in ArcGIS by IDW (Inverse Distance Weighted) method. IDW method mostly relies on value assumptions. In order to collect new values, they can be constructed using the collection of available values from adjacent rain gauge stations (Chen and Liu, 2012; Samhitha and Srikanth, 2017). IDW method is preferred over the other interpolation methods as Kriging and Spline method because IDW has the benefit of being simple and easy to apply, also to comprehend the results (Babak and Deutsch, 2008; Liu et al., 2021). Morevere, the IDW method is more suitable for current rainfall data. Figure (2) shows the spatial distribution of the annual rainfall range of years 2015-2016 over the study area. The result of applying the IDW method for rainfall data shows that the annual rainfall varied from 639 mm to 817 mm, and the highest expected precipitation rate appears in the NE trend of the catchment near the Zawita area.

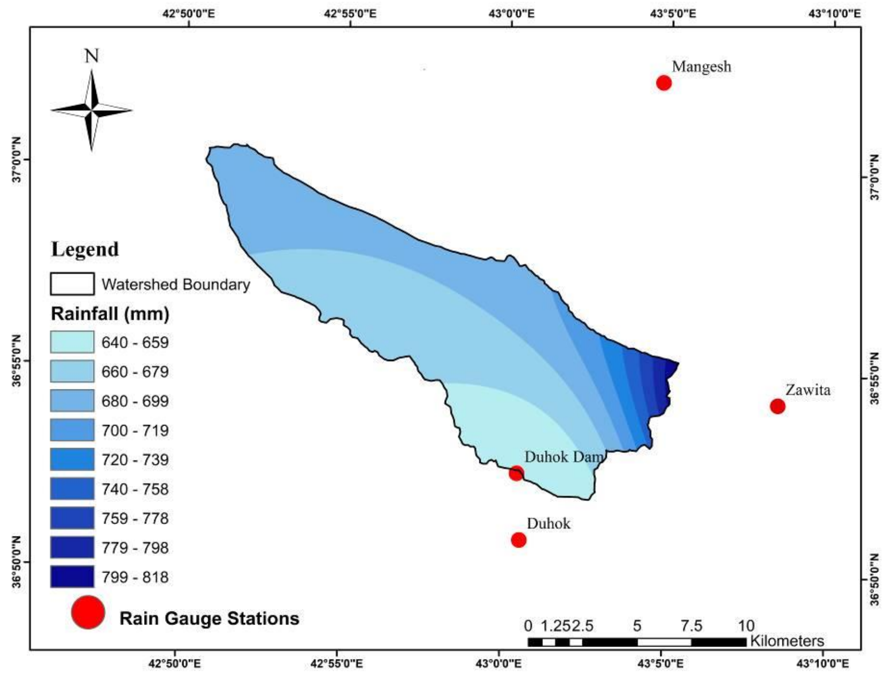

Fig. 2. Annual Rainfall map of the year 2015-2016

2. Soil map

The soil characteristic has a high influence on the runoff estimation methods, where a soil type affects the generated runoff from rainfall. There are four soil groups (A, B, C, and D) belonging to the SCS-CN method. According to FAO data, the majority of catchment soil (about 98.27%) is loamy soil; so, only (1.73%) is clay soil, therefore, the catchment soil belongs to the hydrologic soil group (D). . Moreover, the soil within this group is characterized by high runoff and low infiltration (Abraham et al., 2020). Figure (3) shows the soil map of the study area.

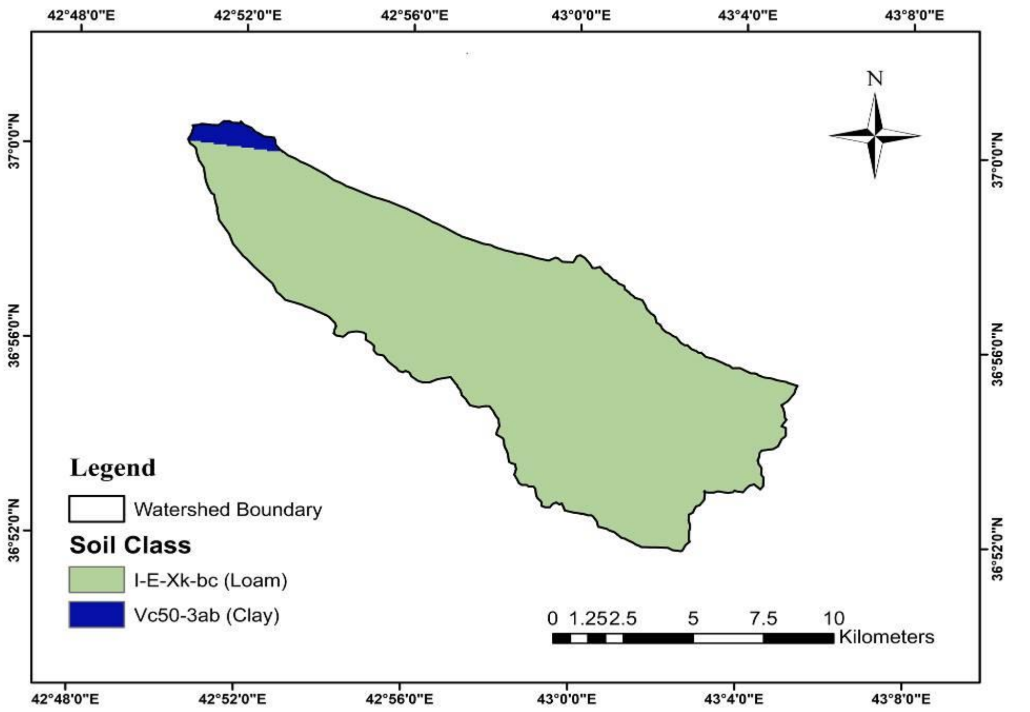

Fig. 3. Soil map of the study area

3. Land Use Land Cover (LU-LC)

LU-LC map of Duhok Dam watershed has been generated using the supervised classification in ArcGIS from the satellite image. A supervised classification works on employing appropriate algorithms to detect specific ground cover or classes in an image pixel. Three bands (4, 3, 2) were combined to create a band composite image to easily detect the different land surfaces.

The LU-LC map of the region shows that the surface cover in the study location could be classified into five different classes of land covers (barren land, waterbody, forest, farmland, and build-up area) (Fig.5). Although (Fig. 4) shows the sentinel image used for this purpose.

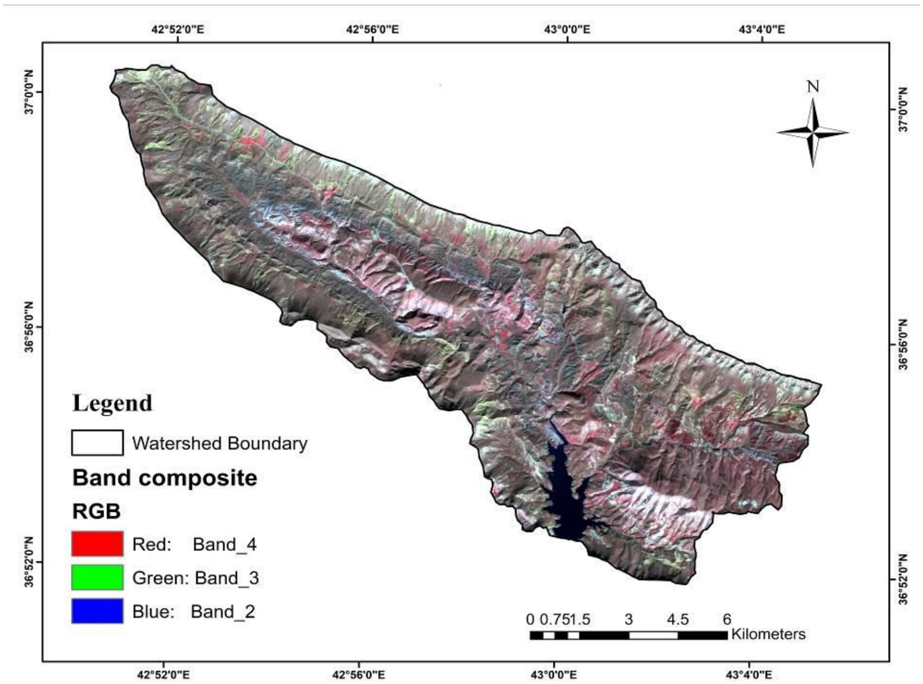

Fig. 4. Sentinel image of the study basin

While depending on LU-LC map, the majority of the surface cover is barren land recognized by bare open soil and rock with few oak trees, which has a high impact on increasing runoff. The dam lake is considered a water body in the area. Table (1) shows the area, percentage, and runoff coefficient of each class.

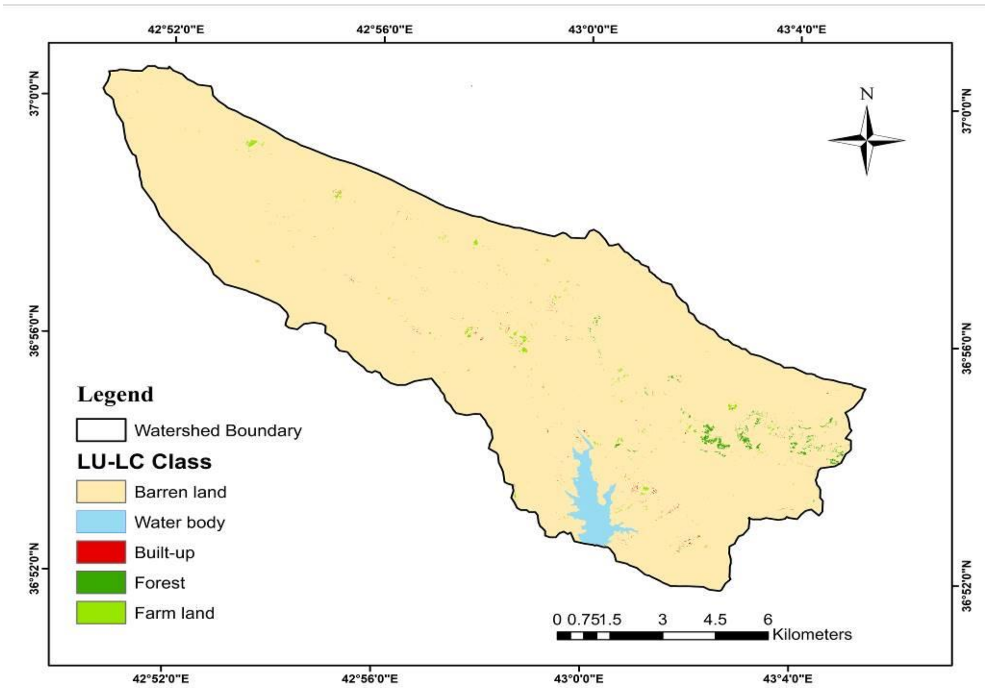

Fig. 5. LU-LC map of the study location

Rational Method

Since its introduction in the USA by Kuichling (1889), the Rational formula for estimating peak runoff rate has been extensively utilized as a tool for drainage design, especially for sizing water-conveyance structures. It is an empirical model with simplifying assumptions that indicates the runoff rate that would be equal to the product of rainfall intensity and area of catchment if the product of rainfall intensity and the area remained stable over the time period needed to entirely drain a watershed (Cleveland et al., 2011). The formula is expressed by the following equation:

$$Q=0.287C\ I\ A \qquad (1)$$

Where (Q) is the peak runoff (m^3/s), (C) is the runoff coefficient varying from 0 to 1, (I) is the rainfall intensity (mm/hr), and (A) is the watershed area (km^2). (0.287) is a correction factor used to convert units into metric (Chin and Asce, 2019).

The average annual runoff volume of the catchment can be calculated by multiplying the average runoff depth by the area of catchment.

SCS-CN Method

The Soil Conservation Service Curve Number (SCS-CN) method was sophisticated in 1956 by the United State Department of Agriculture (USDA). It is a method uses a simple empirical equation depending on precipitations and curve numbers (CN) to estimate the runoff volume for watersheds with various sizes (Bansode and Patil, 2014; Rajbanshi, 2016; Gupta and Dixit, 2022). The basic idea of the equation is that the direct runoff ratio of a rainfall event is equal to the proportion of maximum possible retention to exact retention as given by equation (2):

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

$$Q = 0 \qquad \text{when } P < 0.2S \qquad (3)$$

Where (Q) is the runoff depth (mm), (P) is the rainfall (mm), and (S) is the potential maximum retention which is given by equation (4):

$$S = \frac{25400}{CN} - 254 \qquad (4)$$

Where (CN) is the basic parameter in the equation. It is based on LU-LC soil and antecedent moisture conditions in the place. Figure (6) shows the standard curve numbers graph. CN values range from 0 to 100. Where the highest number influence in high runoff rate, which means the quantity of water that becomes surface runoff is greater than infiltration (Alagha et al., 2016).

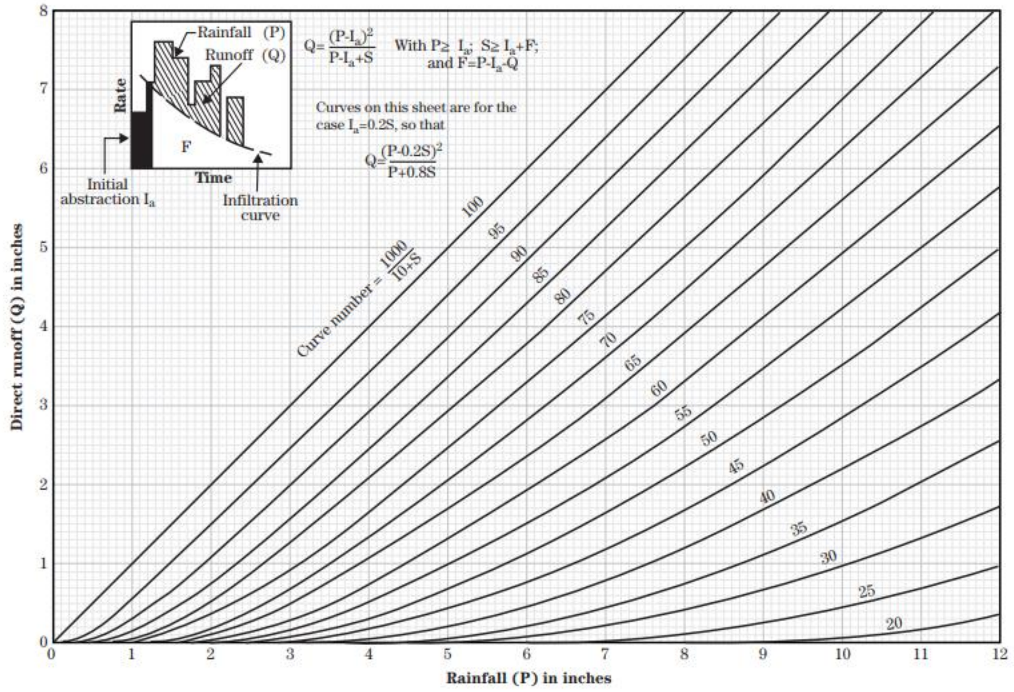

Fig. 6. Standard SCS-Curve Numbers graph showing the relation between rainfall, direct runoff, and curve numbers (USDA-SCS, 2004)

Results and Discussion

Runoff Estimation by Rational Method

The runoff depth by the Rational method is simply estimated using equation (1). The land cover variation performs a significant role in defining the runoff coefficients (C) for each LU-LC class. Table (1) shows the (C) values that are used for each class. The results of annual runoff are shown as a map in figure (7), where the runoff depth ranges from 142 mm to 646 mm.

The average annual runoff volume of the catchment can be calculated by multiplying the average runoff depth which is 394 mm by the area of catchment which is 134.07 km^2. The calculated average annual runoff volume of the study area by this method is about 52 823 580 m^3/year in 2015-2016.

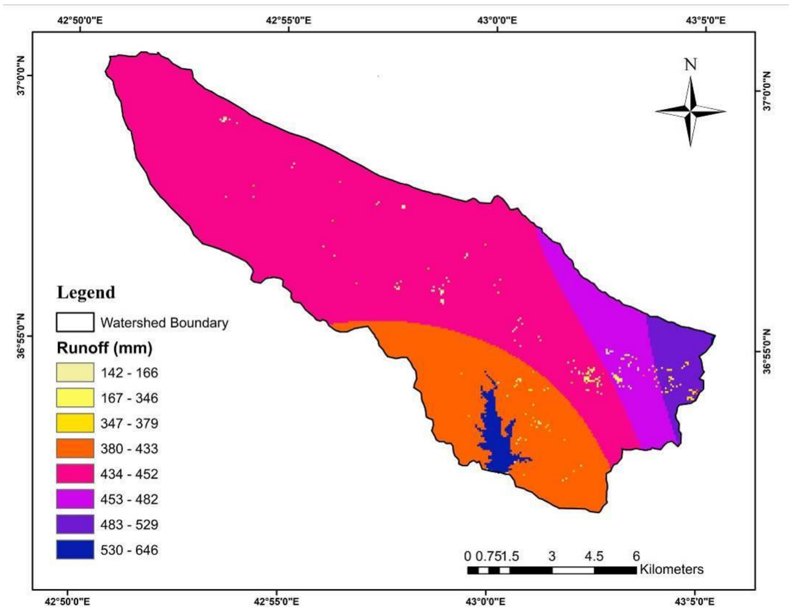

Fig. 7. Runoff map of study area by Rational method

Table 1: Different land use land cover class with the area and percentage of each class and CN and C numbers

	LU-LC class	Percentage %	Area Km^2	CN	C
1	Barren land	97.60	130.86	88	0.65
2	Water body	1.68	2.25	99	0.98
3	Build-Up	0.09	0.12	93	0.55
4	Forest	0.33	0.44	79	0.48
5	Farm land	0.30	0.40	78	0.22
6	Total	100	134.07	-	-

Runoff estimation by SCS-CN

The application of this method requires setting a value for the curve number according to the type of land cover, soil, and hydrological condition. According to the SCS-CN model, three types of Antecedent Moisture Conditions (AMC) are available, dry AMC I, moderate AMC II, and wet AMC III. In the current study, moderate AMC II as an average condition is used. CN values for each class are taken from Table (1). These numbers are used in equation (4) to calculate the potential maximum retention (S) to be applied in equation (2). The values of (S) and (I) with rainfall layer are calculated and processed in map algebra raster. The results are shown as a map of runoff depth in mm (Fig. 8). The runoff estimation depth of the year 2016 ranges from 568 mm to 777 mm.

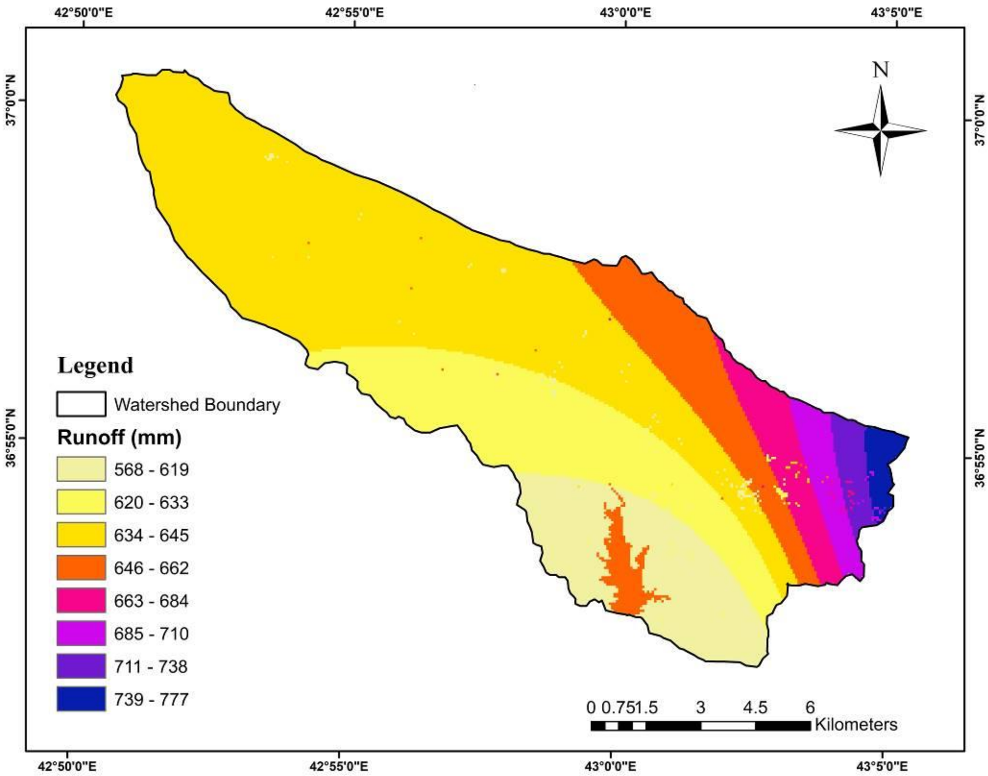

Fig. 8. Runoff mapof study area by SCS-CN method

The measured average annual runoff depth of catchment by SCS-CN method was 673 mm. The average annual runoff volume of the catchment can be calculated by multiplying the average runoff depth by the area of catchment which is 134.07 km^2. The calculated average annual runoff volume of the study area by this method is about 90 229 110 m^3 /year in 2015-2016.

In addition , the data of the Directorate of Duhok Dam about the amount of inflow to the lake and the discharge of the Duhok dam during the studied year wwas closer to the estimated results from the SCS-CN method.The rainfall rate in the studied year was really high, which results in high runoff and discharge.

Conclusion

This study successfully integrates the remote sensing and GIS techniques for comparison to estimate Duhok Dam Watershed surface runoff between SCS-CN and Rational methods. The thematic layer of the LU-LC map shows that the barren land class is dominant over the study area (97.60%), which greatly influences the surface runoff and groundwater recharge rate. Also, the soil cover of the area of interest is characterized by loamy soil, which has a corresponding effect on the runoff with the surface cover class, leading to a high runoff ratio. This indicates that Duhok Dam reservoir located at the outlet point in the catchment area is suitable for storing the preferred quantity of surface runoff that comes from upstream. It is concluded in this study that the Rational method gives a lower value for surface runoff in comparison with SCS-CN method. Rational method gives more suitablility to small catchment specially in impervious surface condition as urban area, and depends essentially on the rainfall intensity more than the hydrogeological condition. Also through this work, the SCS-CN technique is performed better in convenient way for the runoff estimation of Duhok Dam watershed by taking into consideration more details than Rational method for land cover type, soil, and hydrological condition. To differentiate exactly between these two methods, field measurements of surface runoff are required to reach more accuracy in determining the appropriateness of applying these methods to similar watersheds.

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