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GIS Based Surface Runoff Estimation for Sulaimani City, KRG, Iraq

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Abstract— Surface runoff estimation is the significant disputable process of hydrology. In the current study Soil Conservation Service - Curve Number (SCS – CN) method was employed to make assessment of surface runoff. Remote sensing and GIS integration were used to generate geospatial database of soil map, Hydrologic soil group (HSG), land use/land cover (LU/LC), and CN grid for Sulaimani city. The main goals of this study are to generate CN grid map using Geospatial Hydrologic Modeling (HEC-GeoHMS) extension and to estimate runoff for the study region using rainfall data of Sulaimani metrological station for 25 years from 1995 to 2020. The resulted weighted curve number from generated CN map for dry, average, and wet conditions were 63.7, 79.87, and 89.83 respectively. The study showed that the minimum runoff was 115.19mm for the water year 1998-1999 and the maximum runoff was 794.98mm for the water year 2018-2019. The average annual runoff for the selected 25 years was 338.27mm and the coefficient of determination (R^2) between rainfall and runoff was 0.8976. In addition the results revealed that most of the maximum runoff occurred in the three consecutive months of January, February, and March. The estimated runoff signify the chance of setting up artificial lakes or stores that may supply water for indoor and outdoor uses.

Keywords— Runoff, GIS, SCS-CN, Hydrologic soil group, HEC-Geo-HMS.

1. Introduction

Runoff is one of the foremost noteworthy hydrologic factors utilized in most of the water assets applications. Precise estimation of surface runoff and its quantity is useful for flood prediction, water supply forecasting, water management (quantity and quality), groundwater recharge, and to produce hydropower. Moreover it is used for establishing various hydraulic structures such as check dams and to monitor soil erosion [5]. The occurrence and quantity of runoff depend on the concentration, period and distribution of rainfall. Beside rainfall there are many factors affecting the occurrence and the quantity of runoff such as: soil texture, green vegetation cover, catchment type, slope and antecedent moisture condition (AMC) [1].

The soil conservation service curve number (SCS-CN) method is a strategy presented by Natural Resources Conservation Services (NRCS) for surface runoff estimation. The curve number CN is a significant factor used to predict surface runoff [8]. The higher CN values denotes high runoff with low infiltration and vice versa [6, 27]. The SCS-CN method is mainly influenced by LU/LC, HSG, slope, and climate conditions. There are four main HSGs: A, B, C and D. Group A have high infiltration rates with low runoff and group D have low infiltration rates with high runoff [1, 12].

The Geospatial Hydrologic Modeling (HEC-GEO HMS) Extension provide a valuable approach for CN-grid generation which is an integration of Hydrologic Modeling System (HEC-HMS), and ArcGIS. This integration simplify the entry of the data for the modelling in HEC-HMS. HEC-HMS is designed to model the rainfall- runoff for different watersheds and different conditions. This model is one of the products of the US Army Corps of Engineers generated by the Hydrologic Engineering Center [7, 9, 11, 16, 23, and 24].
Numerous previous studies has mentioned utilize of GIS as a successful alternative of ordinary method for surface runoff estimation [2, 5, 12, 13, 15, 20, and 29]. In a research studied by Zakaria, S. et al. in 2013 the annual harvested runoff was estimated for part of Sulaimani city

of total area of 176.79 km^2. The results of the watershed modeling system (WMS) revealed that the annual harvested water was 10.76 million cubic meters. Additionally the results indicated that the quantity of the harvested runoff was mainly affected by rainfall depth, area of the basin, curve number values, and (AMC) [22]. Sherwani, A. et al. in 2014 studied the runoff assessment using integration of Remote Sensing and GIS Approach in Aralamallige Watershed and as a result the runoff for the years 2000 to 2005 were 323.54mm, 188.64mm, 78.43mm, 22.27mm, 158.79mm and 42.16mm respectively [5]. Meshram, S. G. et al. in 2017 conducted a study in Kanhaiya Nala watershed to produced curve number with consideration of slope on curve number values using remote sensing and (GIS). Accordingly the result revealed that the values of CN adjusted with slope are lower in compare to CN unadjusted values [20]. In a study employed by Ara, Z. and Zakwan, M., 2018 in eastern Sone, India. The total estimated runoff in the study area during the year 2007 was17.98 mm. The maximum runoff which contributed 39.85% of the total was observed in the month of July [29]. In another study performed by Al-Ghobari et al., 2020, the results showed that the daily runoff of the study region increased from 15 to 74mm with the linear relation between rainfall and runoff with coefficient of determination of 0.98. The peak runoff hydrograph were 828, 1353, and 1603 m3/s for return periods 10, 50, 100 years, respectively [12].

Current study aims to explore the effect of LU/LC, HSG on the CN and to generate CN grid map using Geospatial Hydrologic Modeling (HEC-GeoHMS) extension which is has not been studied previously for the study region.

2. STUDY REGION

The chosen study region is in Sulaimani city, Sulaimani Governorate, Kurdistan Region-Iraq as shown in Figure (1). Based on to the digital elevation model (DEM) map, the minimum elevation is 526m and the maximum elevation is 2083 m. The study region bounded between the latitudes (35° 05' 15" N and 35° 45' 00" N); and the longitudes (44° 54' 00" E and 45° 40' 30" E) with the total area estimated as 2,413 km^2. Land use/ Land cover for the study area was classified into different classes such as: Water, Forest, Crop, Build up, and Bare soil as shown in Figure (2) [14].The average annual rainfall of Sulaimani metrological station for 25 years from 1995-2020 is 681 mm, taken from the Directorate of Meteorology and Seismology of Sulaimani (DOMSOS). The minimum rainfall value is 270mm and the maximum is 1317mm for the water years 1998-1999 and 2018-2019 respectively as shown in the Figure (3). The reason behind using 25 year span of rainfall data is that during the period numerous drought and wet years were occurred [18]. Normally most of the rainfall started from the months October to May with almost no rainfall in the months June to September. The city has semi-arid climate with cool wet winter and hot dry summer [4, 18].

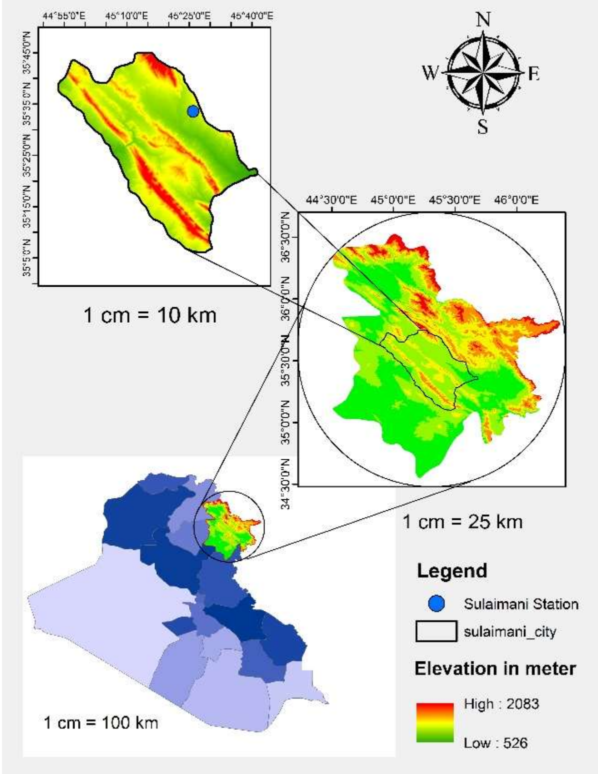

Figure 1: Proposed Study region

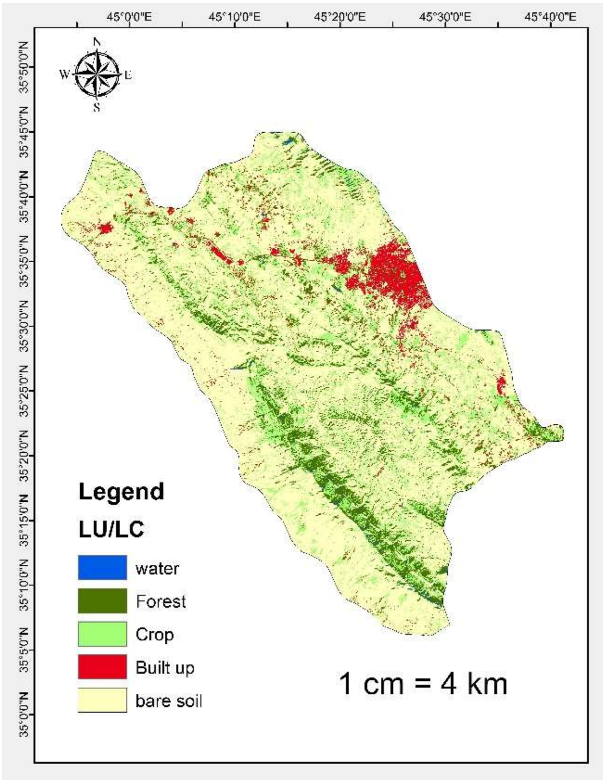

Figure 2: LU/LC map of Study region

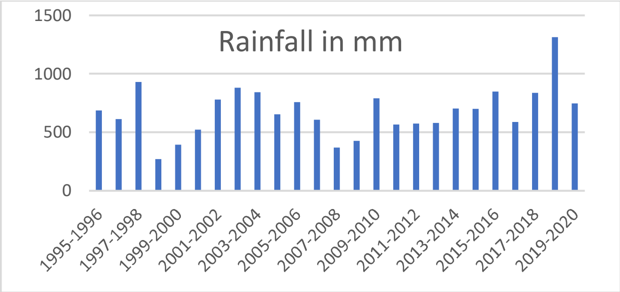

Figure 3: Rainfall histogram for Sulaimani metrological station (DOMSOS).

3. MATERIALS AND METHODS

The strategy performed in current study consider comprises three fundamental steps: (a) Geospatial database generation such as LU/LC, soil texture, and HSG, (b) Generation of CN using Hec-Geo HMS, and (c) Surface runoff calculation. The complete process of the surface runoff calculation is shown as flowchart in Figure (4).

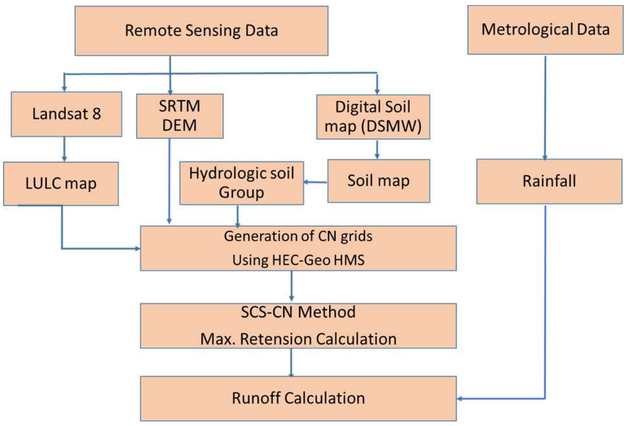

Figure 4: Flowchart process for surface runoff calculation

3.1 *Materials*

Generation of CN-grid map is mainly influenced by DEM, LU/LC, and HSG. From the DEM for Sulaimani city the elevations ranged from (526 to 2083 m) as shown in Fig. 1. The DEM raster data with cell size (30x30m) were acquired from USGS earth explorer using the topographic data generation of Shuttle Radar Topography Mission (SRTM). The LU/LC map was created using Arc GIS software using Landsat8 images (downloaded on October 2019) [14] as shown in Figure (2). The map representing soil texture was constructed based on the percentage of fine and course materials as shown in Figure (5) [14]. The distribution of soil texture in the study region was: 64% loam, 30% clay, and 6% sandy clay loam. The digitized Soil Map of the World were used to construct soil texture map. Accordingly the hydrological soil groups such as B, C & D were assigned for the study area based on the soil texture [3, 10, 19, 25, and 28] as shown in Table (1) and the dominant classes of HSG for the study region are Class B, C, and D as shown in Figure (6).

Table 1: HSG classification based on soil texture [3, 10, 19, 25, and 28]

HSG	USDA Soil ID	Soil Texture
A	S	Sand
	LS	Loamy Sand
	SL	Sandy Loam
B	SIL	Silt Loam
	SI	Silt
	L	Loam
C	SCL	Sandy Clay Loam
D	SICL	Silt Clay Loam
	CL	Clay Loam
	SC	Sandy clay
	SIC	Silty Clay
	C	Clay

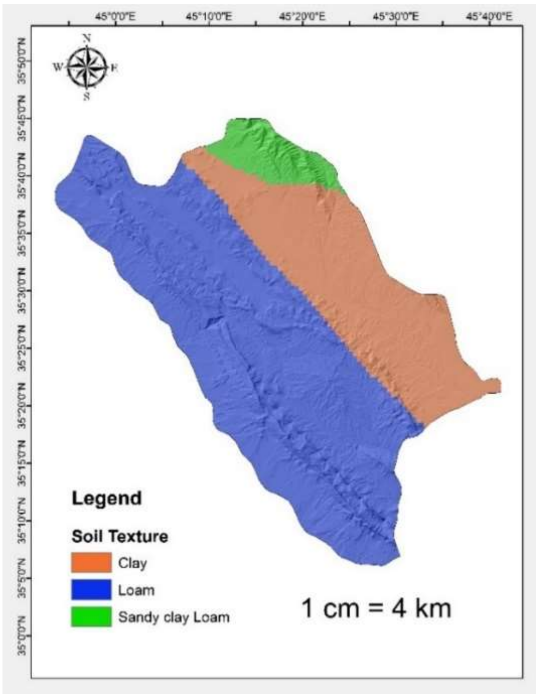

Figure 5: Soil texture map of study region

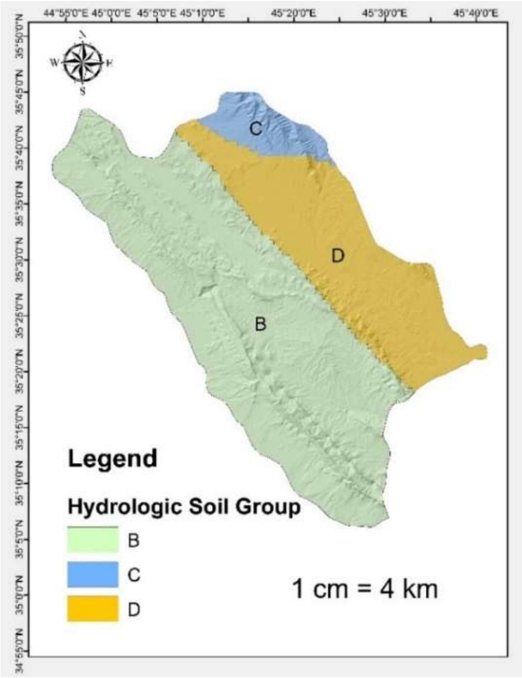

Figure 6: Hydrologic soil group of study region

3.2 *SCS Method*

The (SCS-CN) model is one of the foremost broadly utilized surface rainfall-runoff models because of its simplicity, predictability, stability and the constrained number of required parameters. It was produced based on a water balance relationship by the United States Department of Agriculture, in 1972 [30].
The SCS-CN method can be expressed based on rainfall depth using equation below:

$$Q = \frac{(P-I_a)^2}{\{(P-I_a)+S\}} \qquad (1)$$

I which, Q is surface runoff in (mm); P is total rainfall in (mm), S is potential maximum retention, $\boldsymbol{I_a}$ is initial abstraction (mm) which symbolize the entire losses prior the runoff initiates.
S value is obtained from curve number (CN) using following formula:

$$S = \frac{25400}{CN} - 254 \qquad (2)$$

I_a= 0.2S for an average condition [28]; then the runoff expresses as:

$$Q = \frac{(P-0.2S)^2}{\{P+0.8S\}} \quad \{\text{For P>0.2S and Q=0 for P≤0.2S}\} \qquad (3)$$

3.3 *Antecedent moisture conditions (AMC)*

The (AMC) is an index indicates the wetness of watershed, that can be calculated from the summation of rainfall in 5-day prior a storm. High index value indicates high runoff potential. Such indices are not representing the actual estimation of watershed wetness because the effects of evapotranspiration is not considered. There are three main type of AMC [1]:

1) AMC I for dry condition when the soils are dry.
2) AMC II for average conditions.
3) AMC III for wet condition (saturated soil or heavy rainfall).

3.4 *Curve Number (CN)*

CN values for dry AMC, average AMC, and wet AMC can be calculated from the empirical equations below:

$$CN(I) = \frac{4.2*\mathrm{CN_{II}}}{10- \ .058*\mathrm{CN_{II}}} \qquad (4)$$

$$CNII = \frac{25400}{S} - 254 \qquad (5)$$

$$N(III) = \frac{23*\mathrm{CN_{II}}}{10+ \ .13*\mathrm{CN_{II}}} \qquad (6)$$

Where, *CN (I)* represent dry condition curve number, *CN (II)* average condition curve number, and *CN (III)* wet condition curve number.

3.5 *Hydrological Soil Group (HSG)*

There are four main hydrological soil groups, known as A, B, C, D classified based to their minimum infiltration rate, which is calculated after extended wettings of bare soil. The SCS soil scientists classified the hydrologic soil groups into four groups according to the soil texture as shown in Table (1); and four classes based on minimum infiltration rate such as [1, 5-9, 11, 12, 16, and 27]

Group-A has high infiltration rate with very low runoff (consists >90% sand and <10% clay).
Group -B has moderate infiltration rate with moderately low runoff (consists of 50 to 90% sand and 10 to 20% clay).
Group -C has low infiltration rate with moderately high runoff (consists of 20 to 40% clay and <50% sand).
Group -D has very low infiltration rate with very high runoff (consists >40% clay and <50% sand).

4. RESULTS

4.1 *Calculation of Curve Number*

The Curve number is calculated in ArcGIS Desktop 10.4.1 through the union processing that combined the LU/LC and HSG layers, subsequently using HEC-GeoHMS extension in ArcGIS, the CN grid was created from the combined LU/LC and HSG layer with DEM after defining areas with different curve numbers [30]. The CN lookup table has created based on the TR55 report [26], the table represent the curve numbers values for various combinations of HSG and LU/LC as shown in the Table (2). The resulted CN maps for average, dry, and wet condition were shown in Figures (7, 9, and 11) respectively. Accordingly the potential maximum retention has been calculated for average, dry, and wet conditions using eqn.2 as shown in Figures (8, 10, and 12) respectively.

The weighted curve number for dry, average, and wet conditions have been used for calculation of surface runoff as shown in Table (3) using equation 7[17, 20].

$$CN = (\Sigma \frac{CNi}{Ai})/A \qquad (7)$$

CN=weighted curve number, CNi= curve number for each combined LU/LC and HSG, Ai=area associated with CNi, and A=summation of overall area.

Table 2: CN Lookup table used in HEC-Geo-HMS

LU/LC Description/ HSG	B	C	D
Forest	58	77	83
Built-Up	75	90	95
Crop	69	86	89
soil	79	87	89
Water	100	100	100

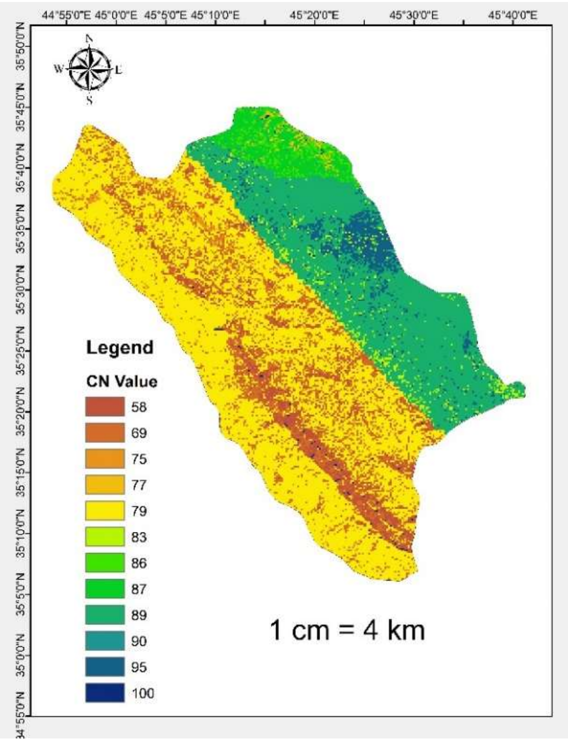

Figure 7: CN value for average condition

Table 3: Weighted curve number and Max. Retention used for runoff calculation

AMC	Weighted CN	Weighted Max. Retention
I	63.7	144.74
II	79.87	64.02
III	89.83	28.76

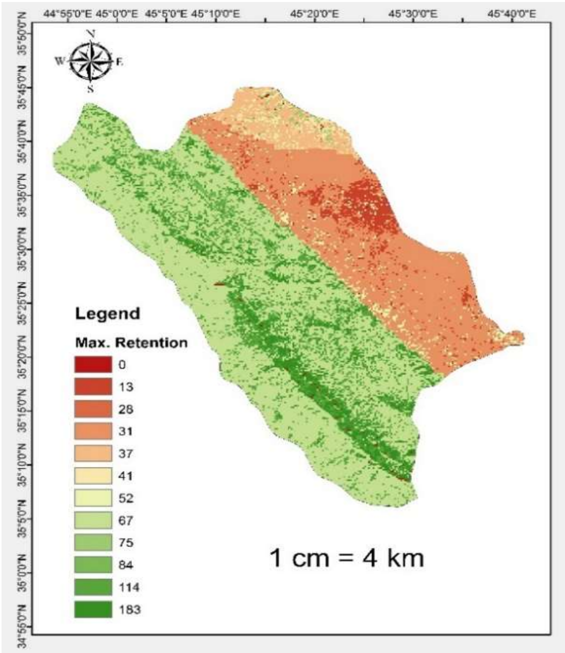

Figure 8: Max. Retention for average condition

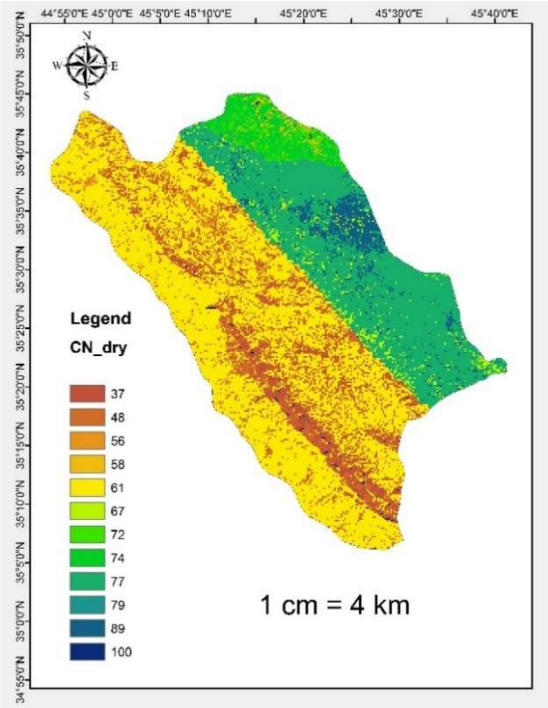

Figure 9: CN value for dry condition

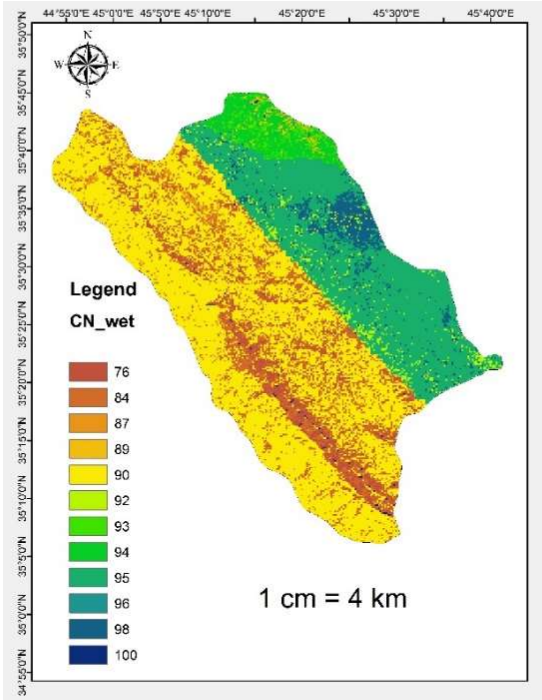

Figure 11: CN value for wet condition

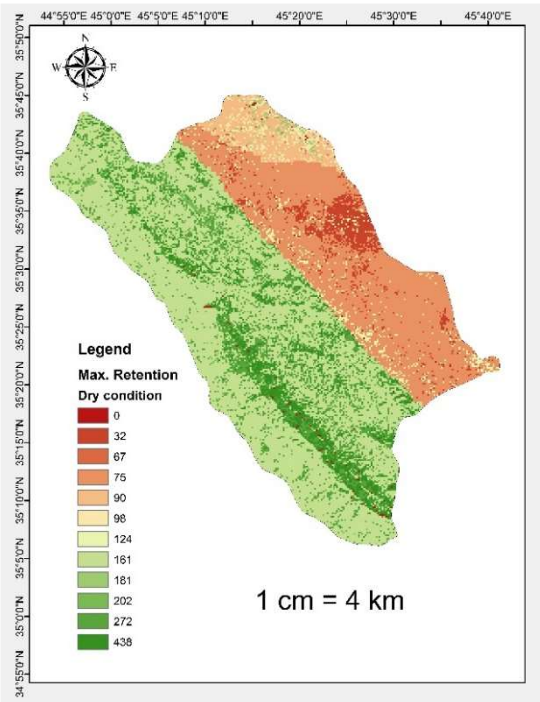

Figure 10: Max. Retention for dry condition

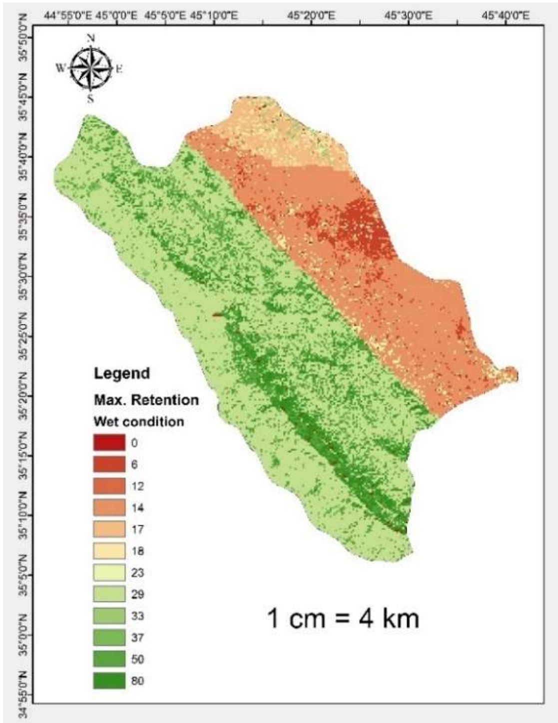

Figure 12: Max. Retention for wet condition

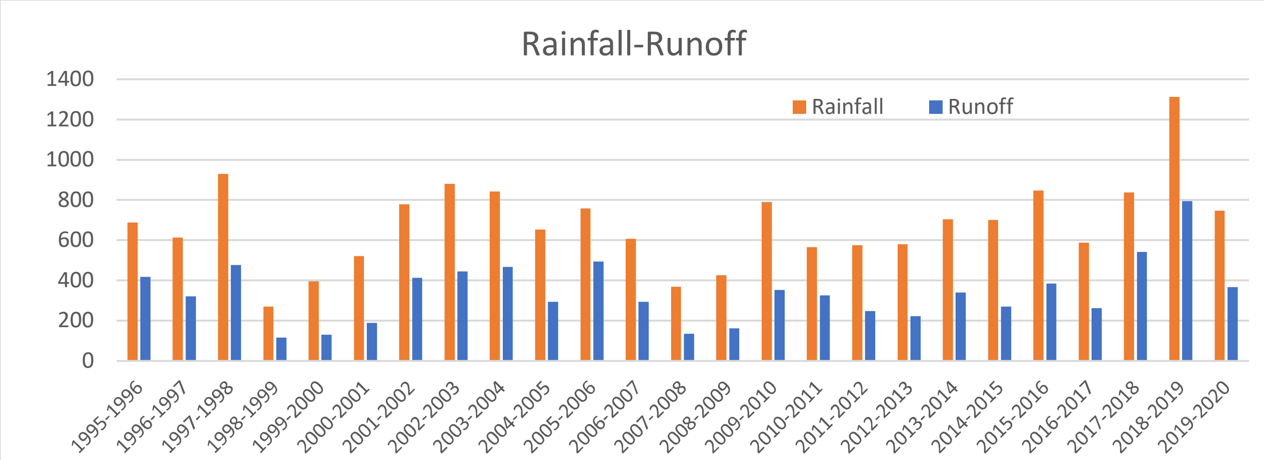

Figure 13: Rainfall-Runoff histogram for water years from 1995 to 2020

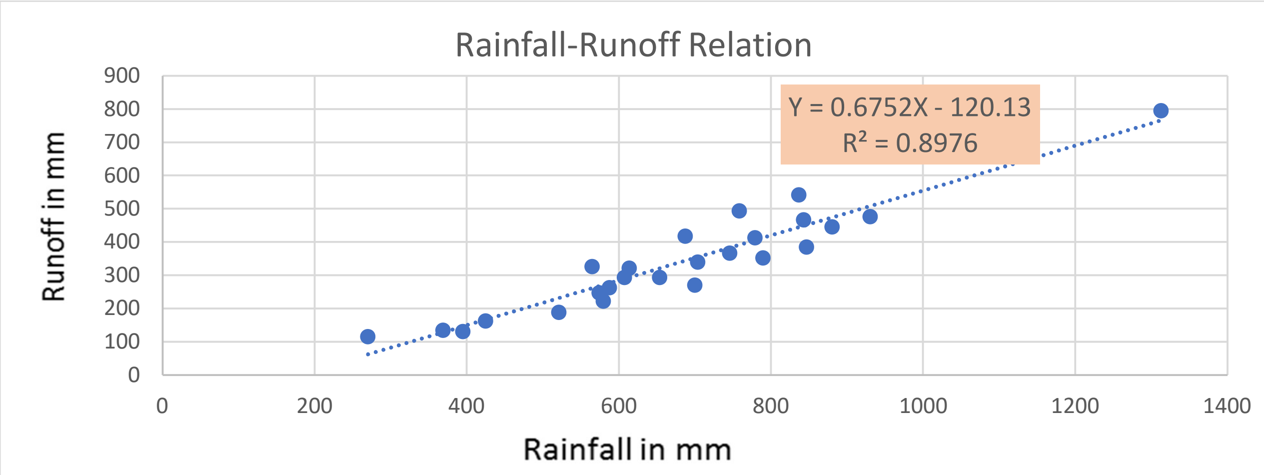

Figure 14: Rainfall-Runoff relation for water years from 1995 to 2020

4.2 *Runoff Calculation*

The runoff calculation has conducted in excel spreadsheet using Eqn (3) and the monthly rainfall data from years 1995 to 2020 has been utilized, the resulted rainfall-runoff histogram is shown in Figure (13). The weighted curve number used for runoff calculation assigned as CNI= 63.7 for the months October, November, and December; CNII=79.87 for the months January, February, and March; CNIII=89.83 for the months April, May, and June. An example of runoff calcualtion for the water year 1995-1996 is shown in Table (4). From the results, the minimum, and maximum runoff were: 115.19, and 794.98mm for the water year 1998-1999, and 2018-2019 respectively. The average annual runoff for the 25 years from 1995 to 2020 was 338.27mm. In addition the results reveal that most of the maximum runoff occurred in the months January, February, and March. The relation between rainfall and runoff has a linear relation with coefficient of determination (R^2) of 0.8976 as shown in Figure (14).

Table 4: Calculation example of runoff for the water year 1995-1996

Month	P	CN	S	0.2S	Q
October	0	63.7	144.74	28.948	0
November	10.7	63.7	144.74	28.948	0
December	43.3	63.7	144.74	28.948	0.71669
January	229.5	79.87	64.02	12.804	167.2764
February	113.8	79.87	64.02	12.804	61.81335
March	176.7	79.87	64.02	12.804	117.8588
April	90.8	89.83	28.76	5.752	63.55583
May	22.6	89.83	28.76	5.752	6.223801
June	0	89.83	28.76	5.752	0
July	0	-	0	0	0
August	0	-	0	0	0
September	0	-	0	0	0
Total(mm)	687.4				417.4448

5. Conclusions

GIS and remote sensing was performed to generate CN grid for Sulaimani city. Furthermore the runoff for the city was calculated for the rainfall data from the years 1995 to 2020. The results showed that the weighted CNI, CNII, and CNIII were 63.7, 79.87, and 89.83 respectively. From the results, the minimum, and maximum runoff were: 115.19, and 794.98mm for the water year 1998-1999, and 2018-2019 respectively. In addition the resulted average annual runoff for the 25 years from 1995 to 2020 was 338.27mm and the good relation between rainfall and runoff has observed with a correlation coefficient (R^2) value of 0.8976. From the rainfall data and runoff results it is concluded that the study area has faced numerous drought years such as in 1998-1999, 1999-2000, 2007-2008, and 2008-2009 and wet years in 2017-2018, and 2018-2019. One of the limitation of the current research is the LU/LC map used for the calculation of CN which was created from satellite images taken for the year 2019. Undoubtedly during the 25 years span chosen in the study, LU/LC will change due to the interaction between human and environment. Therefore, the additional researches are recommended using different LU/LC for each subsequent 5 years span started from 1995 to show the result of LU/LC changes in the calculation of CN. This applications of the CN grid map has the advantage to make assessment of flood and to estimate runoff from rainfall data which might indicate the chance to construct ponds or reservoirs that could provide water for indoor and limited outdoor uses.

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تقدير الجريان السطحي لمدينة السليمانية باستخدام نظم المعلومات الجغرافية

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الخلاصة – تقدير الجريان السطحي هو من اهم عمليات المتنازع عليها في علم الهيدرولوجيا. في الدراسة الحالية ، تم استخدام طريقة خدمة حفظ التربة - رقم المنحنى (SCS-CN) لإجراء تقييم للجريان السطحي. تم دمج تقنية الاستشعار عن بعد ونظم المعلومات الجغرافية لتوليد قاعدة بيانات جغرافية لخريطة التربة ، ومجموعة التربة الهيدرولوجية (HSG)، استخدام الأراضي / الغطاء الأرضي(LU/LC) و خريطة شبكة (CN) لمدينة السليمانية. تتمثل الأهداف الرئيسية لهذه الدراسة إنشاء شبكة (CN) باستخدام امتداد النمذجة الجيومكانية الهيدرولوجية (HEC-GEO HMS)، وتقدير الجريان السطحي لمنطقة الدراسة باستخدام بيانات هطول الأمطار لمحطة القياس السليمانية لمدة 25 عامًا من 1995 إلى 2020. رقم المنحني الموزون المتولدة للظروف الجافة والمتوسطة والرطبة كانت 63.7 و 79.87 و 89.83 على التوالي. كشفت الدراسة أن الحد الأدنى للجريان السطحي كان 115.19 ملم للسنة المائية 1998-1999 وكان الحد الأقصى للجريان 794.98 ملم للسنة المائية 2018-2019. بلغ متوسط الجريان السطحي السنوي للسنوات الخمس والعشرين المختارة 338.27 ملم وكان معامل التحديد (R^2) بين هطول الأمطار والجريان السطحي 0.8976. بالإضافة إلى ذلك ، كشفت النتائج أن معظم الجريان الأقصى حدث في الأشهر الثلاثة المتتالية في يناير وفبراير ومارس. يشير الجريان السطحي المقدر إلى فرصة إنشاء بحيرات أو مخازن مصنعة قد توفر المياه للاستخدامات المنزلية والخارجية .

الكلمات الرئيسية: الجريان، GIS ، SCS-CN ، مجموعة التربة الهيدرولوجية، HEC-Geo-HMS