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Estimation of Runoff by applying SCS Curve Number Method, in a complex arid area; Wadi Al-Mujib watershed; Study case

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ABSTRACT

Geographic information system (GIS), and the advance application of Remote Sensing (RS) techniques were used to estimate surface runoff in combination with the SCS-CN method in a complex arid area; Wadi Al-Mujib watershed. The runoff curve number (CN) is a key factor in determining runoff in the SCS (Soil Conservation Service) based hydrologic modeling method. This paper assesses the modeling of flow in a complex canyon arid area of Wadi Al-Mujib watershed; with historical annual rainfall ranging between <50 mm in most of the study area to 500 mm in the western mountain part. The SCS-CN is a quantitative description mainly controlled by the main factors; soil hydrologic groups (SHGs), rainfall data (P), land use /Land cover patterns (LULC), antecedent moisture condition (AMC) and Potential Maximum Retention (S). SCS–CN method based on remote sensing and GIS data as inputs and median of ordering data for all the three antecedent moisture conditions (AMC I, AMC II and AMC III) is used. For estimation the runoff, four storm events within sixteen days were selected in the years of 2010/2011,witen 20 days, 2015/2016 and 2016/2017,witen 25 day which represents the three moisture conditions, drought, wet, and normal conditions (AMC-I, AMC-II and AMC-III). The analysis indicated that there is a strong correlation between the CN values obtained from measured runoff and the rainfall depth. The result showed that 89.3% from the total area of Wadi Al-Mujib watershed under high CN value, which interprets in high runoff to the Wadi Al-Mujib watershed, as the most prominent of LULC were barren area 98.67% from the total area of Wadi Al-Mujib watershed. The total calculated runoff volume were 0.23, 1.97, and 19.09mm³ for the three moisture conditions, drought, normal and wet conditions, respectively. The present study reveals that SCS-CN method with integration of GIS and remote sensing technology can effectively be used to estimate the runoff in many an ungauged desert watershed in Jordan.

Keywords: SCS-CN, Hydrological Soil Group, Land Cover/Land Use, Runoff, Antecedent Moisture Condition.

1. Introduction

The arid and semi-arid catchments in general require a special effective management of water scarcity (Al-husband and Zghoul, 2017; Al-Weshah, and El-khoury, 1999). Hydrology is one of the most important elements in the management of resources (Woodward, et al, 2002; Amutha, and Porchelvan, 2009). In hydrology, a curve number (CN) is used to determine how much rainfall infiltrates into soil and how much rainfall becomes surface runoff. Ahigh curve number means high runoff and low infiltration means low runoff and high infiltration. The curve number is a function of LULC and HSG_S (McCuen, 1982; Ishtiyaq, et al, 2015). In the present study (SCS-CN), method was applied for estimating the runoff depth in Wadi Al-Mujib watershed; as it is classify semi-arid to hyper-arid land; where rainfall patterns are unpredictable and characterized by flash floods (Noy-Meir, 1973), with large heterogeneity of the landscape, short duration and high intensity patterns of rainfall, so runoff is the most important hydrologic elements required for water resources management. Therefore, the ability to efficiently harvest and control the rainfall runoff is of critical importance in Jordan; as it is suffered from water security, to maintain for agricultural production (Al-husban, 2018).

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The Soil Conservation Service- Curve Number (SCS-CN) method has been widely used to compute direct surface runoff (Rallison, 1980; USDA-SCS, 1986). The conceptual rainfall runoff models are simple, widely used and powerful methods for runoff predictions in large catchments (Anubha, et al, 2015; Ashish anf Patil, 2014; Victor Mockus, 1965, Handbook, Sect. 4; Satheeshkumar, et al, 2017; Anubha, et al, 2015; Amutha and Porchelvan, 2009; Ashish Bansode, and Patil, 2014). Geographic information systems (GIS) and Remote sensing (RS) were used in combination with the SCS-CN method applied in many studied for easy spatial analysis (Shaheed and Almasri, 2010; Woodward,et al,2002;Abdo, et al, 2009 Bansode and Patil, 2014; Nagarajan and Poongothai, 2012 Khaddor, et al,2017). The SCS-CN is mainly controlled by the major four parameters; soil hydrologic group (SHGs), rainfall data (P), land use /Land cover patterns (LULC), and antecedent moisture condition (AMC), (Haith, and Andre, 2000;Arwa , 2001; Bo X,et al,2011). Besides digital elevation models (DEM) was used in hydrology to parametrize elevation, slope, the catchment and Sub-catchment boundaries and drainage networks. All required parameter were fed into the SCS model in GIS environment and the catchment surface runoff was computed. In the study, the values of the curve numbers (CNs) were determined in three different conditions; drought, wet conditions, and normal. Four storm events 234.75, 321.62 and 521.98 mm were used for the SCS CN model. The SCS-CN method (SCS 1985) is one of the most popular methods for computing the volume of surface runoff in catchments for a given rainfall event. This approach involves the use of a simple empirical formula and readily available tables and curves. In this study, a GIS was employed as a tool to calculate the composite curve number for Wadi Al-Mujib watershed, and to estimate the runoff depth and volume based on spatially varying SHGs and LULC patterns.

2. Wadi Al-Mujib watershed

Wadi Al-Mujib watershed occupies ca.6584km², located in the central part of the Jordan Rift valley (JRV). Extends between latitudes 30˚39' and 36˚33' N and longitudes 35˚30' and 30˚39' E. (Figure 1). According to the location of study area and it is altitudes there are three distinct climatic patterns; the Jordan valley, Mountain Heights Plateau and the Desert or badia region. Nevertheless, most of it is area is typically semi-arid to hyper-arid, and it is rainfall commonly characterized by extreme highly spatial and temporal variation (Ghanem, 2013). The Mean annual rainfall for historical data (1980-2018) from the fourteen station ranges from <50mm to 500mm. The hydrological regime in these areas is extreme and highly variable mainly due to rainfall patterns characterized by events of short duration and high intensities. Wadi Al Mujib is a deep canyon watershed, which enters the Dead Sea at elevation of -430 meters (b.m.s.l), and up to 1273m. About 3014 km ² (42%) from the total area is deep Canyons, incised streams (Odeh, and Salameh, **2**005; Abed, 1985; Al-husban, and Almanasyeh, 2017; Al-husban, 2014). Wadi Al-Mujib watershed had been exposed to frequent flood hazards, which were responsible for many damages in several parts of the watershed (Abbas, et al, 2012; Atallah, 1981; Beheiry, 1969; Ch. de Jaeger and de Dapper, 2002; Al-Weshah, and El-Khoury, 1999). Based on the DEM of the study area terrain elevation and slope showed in figure 1. The elevation classified into four classes; elevation varies from −430 m (b.m.s.l) to 1273 m, the low area represents (3.1%) while (52.3%) is high hilly plateau (780-909m), and the high land >910m covers 15.6% from the total area. According to the historical rainfall data; about (76.6 %) from the total area of the watershed with average rainfall below 50mm, and only (6.9%) with average rainfall >80mm, it is classified as dry Mediterranean (Ghanem, 2013). The spatial distribution of slope it can be observed that the very gentle and gentle slope covers (52.7%) from the total area of Wadi Al-Mujib watershed, where low surface runoff. Whereas, steeply sloping to Cliffs covers 13.2%, with high surface runoff. Large rainfall variations also occur from year to year. Consecutive years of relatively high or low annual rainfall have an enormous effect on the region and, in the case of dry years, present the greatest challenge to managing the region's precious water resources. The rainy season usually begins in November and ends at the end of March. Rainfall is concentrated over a short period, with more than 60% of the annual rainfall commonly occurring mainly within two months Jan and Feb. Rain tends to fall in intense storms. This results in tremendous runoff during the four months; October, November, December, January and February, while the study area remains dry for most of the rest of the year. In Wadi Al-Mujib watershed, total rainfall of 234.75mm, 321.62mm and 521.98 mm have been recorded in the hydrologic years of 2010 and 2011, 2015 and 2016, and 2017 and 2018, respectively.Rainfall decreases from north to south and from high to low elevation. The study area divided to four main sub-basins numbered (1-4), varied in area from 2027.9km^2, 1230.44km^2, and 1734.72km^2 and 1567.71km^2, respectively.

Table 1.Avarege annual rainfall from all stations during the study period.

Average Rainfall (mm) during (1990-2018)	Area percentage (%)
0.04-22	34.3
23-44	42.3
45-79	16.5
80-155	5.7
156->305	1.2

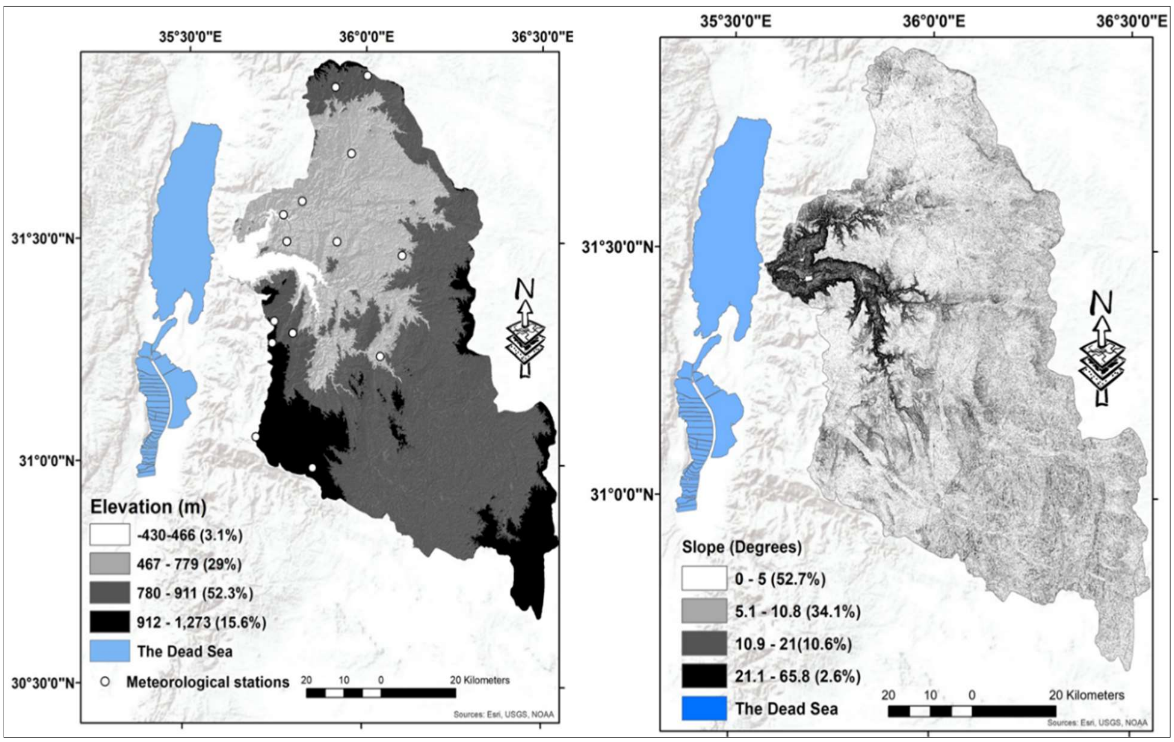

Figure.1. the location of Wadi Al-Mujib watershed, with elevation (m) and Slope, by area percentage; extracted from DEM with 30*30-meter ground resolution

3. Data and methodology:

3.1. Data

The SCS CN method dependent mainly on the main parameters; LULC, SHGs and rainfall data for estimating runoff volume, besides the digital elevation models (DEM). Spatial data; soil map, (LULC) elevation, and slope maps of the Wadi Al-Mujib watershed have been prepared, in addition the nun spatial data rainfall data from the (JMD) Jordanian Meteorological department. The study area covered by three different (HGS$_s$): **A**, **C** and **D**. Group **A** have high in-filtration rates, and groups **C** and **D** have low infiltration rates. The thematic layers of (SHGs) and (LULC) maps were prepared and overlaid to generate anew-thematic layer represent both the (LULC) and the (SHGs), then return to the Curve Numbers values tables whose values are given according to each LULC type.

3.1.1. Topographic analysis**:** Digital elevation model (DEM) downloaded from the NASA, which is available in Tiff format at the URL: ttp://glcf.umd.edu/data/landsat/. Topographic, drainage networks and areal, attributes (Elevation and Slope maps) computed from DEM; (Figure. 1), using Arc GIS.V10.5.1 (Spatial Analyst-Surface tools), Stream order computed according to Strahler's system 7-stream order, and the total length of all stream 5754.823km. The total area of wadi Al-Mujib watershed is 6584km², and divided into four main sub-basins, Figure 2. The area of the sub-basins are ranges between around 2028km² and 1230km².

3.1.2. Rainfall data; dally and annually rainfall data collected from Jordan Meteorological Department from the URL-http://jmd.gov.jo. The hydrological data from fourteen meteorological stations for Wadi Al-Mujib watershed which are concentrated in the western and southern parts (Figure.2).

3.1.3. Land use/cover; remote sensing Landsat 8 Operational Land Imager (OLI)/Terra for the year 2018 at a resolution of 30*30 m was used for LULC classification. The satellite data covering Wadi Al-Mujib watershed was acquired from United State Geological Survey (USGS) website https://glovis.usgs.gov (USGS, 2019). Supervised classification method with maximum likelihood algorithm was applied in Arc GIS.10.5.1. **LULC** is one of the most essential variables for runoff estimation. The eight classes have been reclassified into six **LULC** types; water bodies, Irrigated area, forest, built-up area, rocky land and the valley's Sedimentation. The detail statistics of **LULC** for the study area is shown in table 2.and figure.2.

Table 2. Statistical data of LULC classes and their corresponding areas and percentages.

LULC classes	Area KM²	Area %
Water bodies	2.00	0.03
Irrigated area	82.00	1.25
Forest	4.00	0.06
Built-up area	300.00	4.56
Rocky area	5878.00	89.28
valley's Sedimentation area	318.00	4.83
Total	6584	100

3.1.4. Soil map obtained from Ministry of Agriculture, Jordan (Ministry of Agriculture, 1995) at URL-/http://moa.gov.jo/ar-jo. Converted to digital soil map having 21 units. The soil map was reclassified and grouped into the three hydrologic soil groupings (HSGs) according to (USDA, 2007). Soil texture is very important for hydrologic soil group determination. Soil textures were classified by the fractions of each soil separate (sand, silt, and clay) present in a soil. The hydrologic soil refers to the infiltration potential of the soil after the wetting. There are mainly three hydrologic soil groups, covered the study area based on their minimum infiltration rate (SCS, 1972) covers 2.2 %, 32.3 %, and 65 % for the groups **A**, **C** and **D**, respectively Figure. 2. **Group A:** Soils in this group have low runoff potential and high infiltration rate. **Group C:** Soils in this group have moderately high runoff potential and low infiltration rate 6mm/h when thoroughly wet. Water transmission is somewhat restricted through the soil soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes down ward movement of water and soils with moderately fine-to-fine texture. **Group D:** soils have high runoff potential and slow infiltration, (Schulze, 1992; Mc. Cuen**,** 1982). For a catchment with sub-basins that have different HSGs types and LULC, a composite curve number is determined by weighting the curve number values for the different sub-areas.

3.1.5. Thiessen polygons

The Thiessen Polygon approach is one the most common methods used in hydrometeorology for determining average precipitation over an area when there is many measurement points. The basic concept is to divide the watershed into several polygons, each one around a measurement point (Siddi Raju R. et al, 2018 ;).In this study the areal rainfall distribution was calculated based on Thiessen polygon method for each identified meteorological station. For each Thiessen cell, area weighted CN (AMC II) and CN (AMC I) and CN (AMC III) were determined, and The CN for AMC

II is given in **Table 2**.Thiessen polygons with meteorological station presented in figures 2 and 3. Rainfall distribution by the thiessen polygon method in order to estimate the areal rainfall that the estimated values taken on the observed values of the nearby station (Ishtiyaq, et al, 2015). The spatial and temporal distribution of rainfall at sub-basin scale, in the study area in Figure 3.

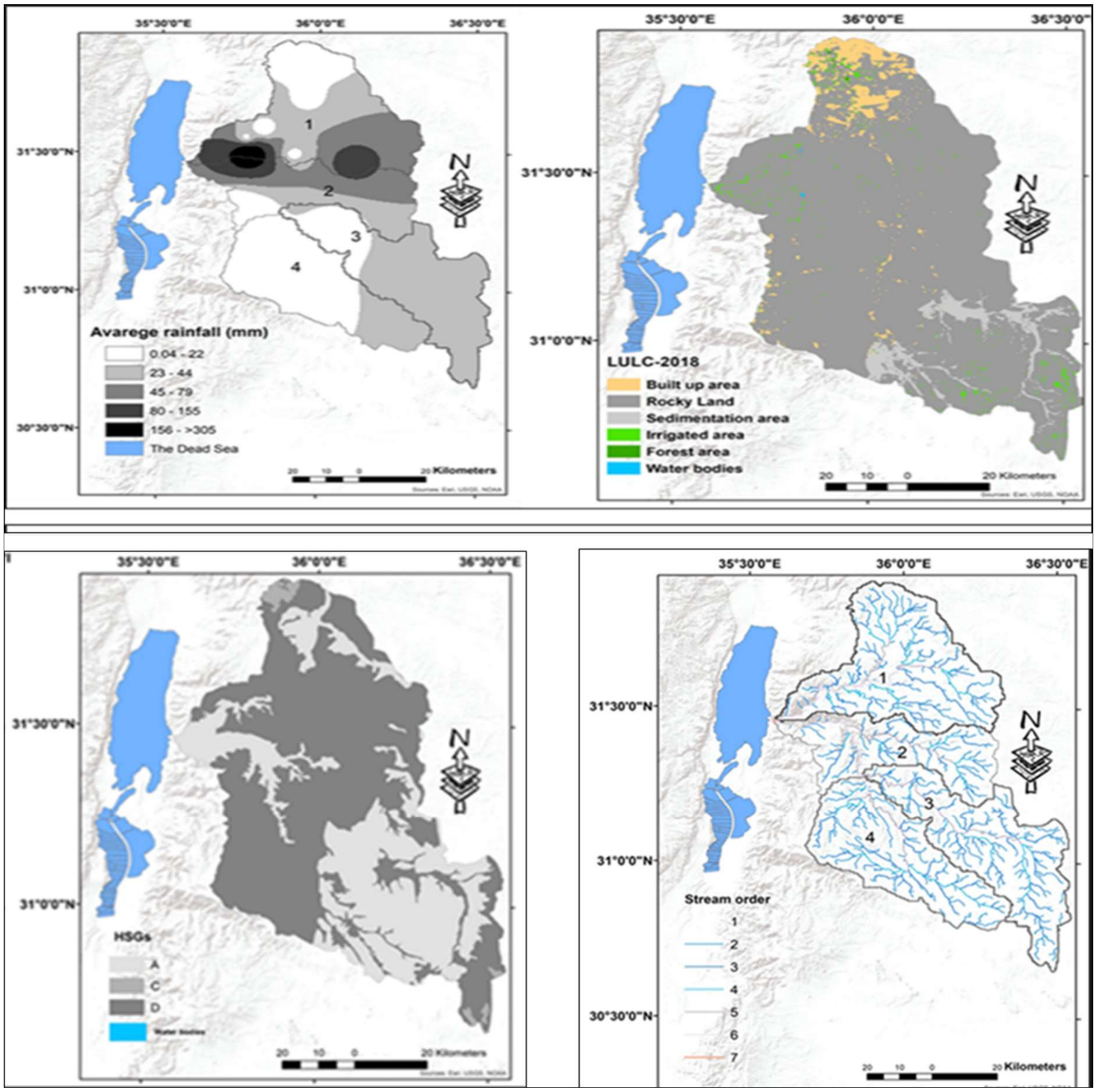

Figure. 2. Spatial distribution of the average annual rainfall, LULC, based on Landsat-8, ETM+ satellite image, October, 2018, SHGs, and the stream order.

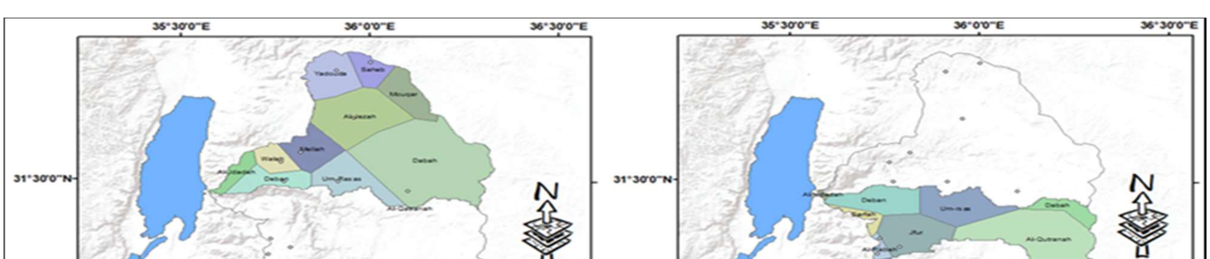

Figure 3. Thiessen polygons based on the meteorological stations for estimation the areal rainfall, on the level of the sub-basins.

3.2. Methodology

The adopted methodology of the present study is shown in figure. 4 .The various steps are involved as follows. The LULC map are obtained from Landsat 8-OLI for the year 2018. Soil types and Texture, structure was prepared. Rainfall Data collected 194–2018 from Jordanian Meteorological Department at URL-http://jmd.gov.jo. For 14 stations distributed within the study area. Digital Elevation model (DEM) downloaded from the NASA, which is available in Tiff format with 30-meter ground resolution. The various steps involved in the following manner as defined the boundary of the watershed, which used to find out curve number. After determine the LULC and convert the soil types into hydrological soil groups A, C and D according to their infiltration capacity. Then the LULC and the HSGs overlaid to obtain each LULC soil group with polygon and finally, find out the area of each polygon then assigned a curve number to each unique polygon, based on standard SCS curve number. The curve number for each drainage basin of area weighting calculated from the LULC-HSG_S polygons within the drainage basin boundaries (Ishtiyaq, et al, 2015).

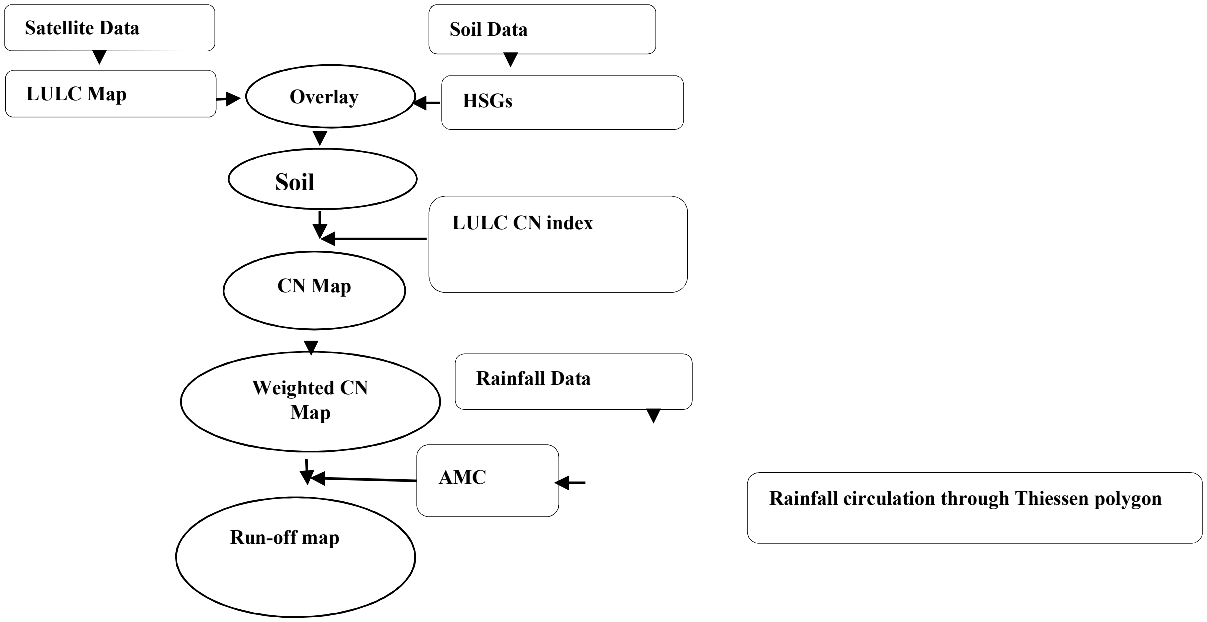

Figure. 4 Flow chart of Methodology for Rainfall-Runoff

4. SCS Curve Number

4.1. SCS Curve estimation

The main parameters required to estimated surface runoff depth for the CN method are rainfall events; hydrological soil groups (HSGs), LULC and the antecedent soil moisture condition (AMC). The study area classified in to Four sub-basins based on the DEM _with the Conditional (con) value in this study is >3000_. The overlay operation is performed using the LULC and HSGs maps to identify LULC- HSGs maps for each sub-basin and determine area by (km²) and area by percentage (%) of each LULC under the soil group (CN_s) of each pattern of LULC-HSG_S are assigned within the boundaries based on standard SCS curve number index, Table 3. In addition, Figure 5. The weighted curve number for each sub basin is calculated, for the three AMC conditions are 82 68 and 92 respectively; applying the (**E.q. 1and 2**)

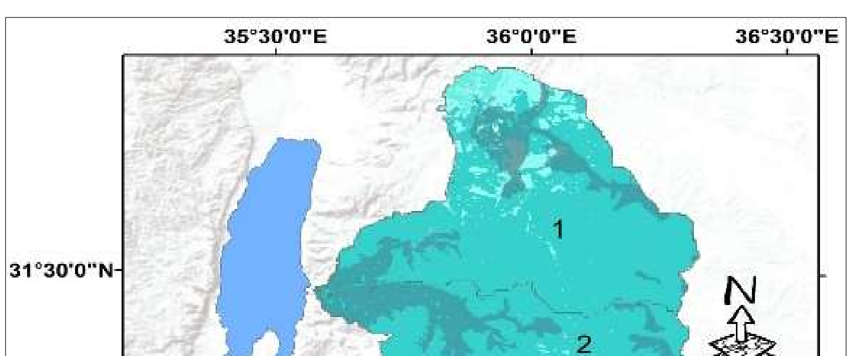

Figure 5. Curve Number distribution map of the study area, based on SCS model, HSGs and LULC, and the numbers 1-4 the sub-basins.

4.2. Surface runoff estimation

The standard SCS-CN method is based on the following relationship between rainfall, P (mm), and runoff, Q (mm) (SCS-USDA 1986; Schulze et al. 1992): by applying the following equations. The weighted curve number for each sub basin is calculated by using the (**E.q. 1**)

$$\textbf{Weighted CN} = \frac{\boldsymbol{CN1 * A1 + CN2 * A2 + \cdots + CNn * A4}}{\boldsymbol{A1 + A2 + \cdots An}}$$

Where,

CN1, CN2, ----------- CN_n are the curve numbers for different LULC and HSGs present in the sub-basin of the total watershed, A1, A2, -----------An. are its respective sub-basin areas.

The weighted CN for the whole basin is calculated by using the (**E.q.2**).

$$\boldsymbol{Weighted\ CN} = \frac{\textbf{CN of sub} - \textbf{basin} * \textbf{A}}{\textbf{Total area of watershed}}$$

Where,

CN is curve number of hydrologic soil cover complex, which is a function of soil type, land cover and antecedent moisture condition (AMC).

CN values were determined from hydrological soil group and antecedent moisture conditions of the watershed. The Curve Number values for AMC-AMCII, and AMC-III, were obtained using (**E.q.3-6**), respectively:

$$\textbf{RCN (I)} = \frac{\textbf{(4.2RCN(II)}}{\textbf{(10}-\textbf{0.058RCN(II)}}$$

$$\boldsymbol{R}\mathbf{CN}\ (\mathbf{II}) = \frac{(\mathbf{CNI} * \mathbf{AI}) + (\mathbf{CN2} * \mathbf{A2}) + (\mathbf{CNN} * \mathbf{AN}))}{((\mathbf{N} * \mathbf{AN})}$$

$$\mathbf{RNC(III)} = \frac{\mathbf{23RCN(II)}}{\mathbf{10 + 0.13RCN(II)}}$$

The SCS model (SCS, 1972) invo

lves relationships between LULC, HSGs and curve number. The (**E.q.7**) is used to calculate the surface runoff of the Wadi Al-Mujib watershed, (USDA, 1986).

$$\mathbf{Q} = \frac{(\boldsymbol{P} - \boldsymbol{Ia})^2}{(\boldsymbol{P} - \boldsymbol{Ia} + \boldsymbol{S})}$$

Where, **Q**: is actual surface runoff in mm, **P**: is rainfall in mm, **S**: is the potential maximum retention in mm, and **Ia**: is 0.2*S **(**is all loss before runoff begins; initial abstraction (mm) or losses of water by soil and vegetation.

Therefore, the modified form of the equation 3 can be express in (**E.q.8**) (USDA, 1986)

$$\boldsymbol{Q} = \frac{(\boldsymbol{P} - \mathbf{0.2} * \boldsymbol{S})^2}{(\boldsymbol{P} + \mathbf{0.7}\boldsymbol{S})}$$

To calculate the value of potential maximum retention (S) (**E.q.9**) is used.

$$\mathbf{S} = \frac{(\mathbf{1000})}{\boldsymbol{CN}} - \mathbf{10}\ \ldots$$

5. Results

Based on the hydrological soil group, the maximum area of Wadi Al-Mujib watershed is covered by D HSG 63.857%, for the group **D**, it has very low infiltration rate, and C HSG covered about 32.3 % from the total area, this soil have slow infiltration rate, while only 2.2 %covered by **A** soil group; this soil group have low runoff potential and high infiltration rate. The runoff curve number for LULC delineation definable from the given in table 3 is used for determination of curve number for each sub-basin. The curve numbers of the study area ranges between 0-88;ahigh curve number means high runoff and low infiltration, about 64.4% from the total area has CN above 80,whereas a low curve number means low runoff and high infiltration, and only 0.03% from the total area has zero CN which represents the water bodies. The calculated dry, normal, and wet conditions, curve number at the level of the study area are 63, 74 and 84 respectively. According to the sub-basins level (1-4) the curve number ranges from 72, 74, 75, and 75 respectively.

Table 3. Curve numbers for different kind of LULC and HSHs (AMC II & Ia =0.2*S)

LULC classes	HSGs	CN	Area (km²)	Area percentage (%)
Built up area	A	54	61	0.93
	C	80	39	0.6
	D	85	200	3
Forest	A	39	2	0.03
	C	70	1	0.013
	D	77	1	0.013
Rocky Land	A	77	2062	31.3
	C	85	39	0.6
	D	88	3777	57.4
Sedimentation area	A	67	132	2
	D	85	186	2.8
Irrigated area	A	62	38	0.58

LULC classes	HSGs	CN	Area (km²)	Area percentage (%)
	C	65	4	0.06
	D	78	40	0.6
Water bodies	A	0	2	0.03
Total		72	6584	100

The values of CN range from 0 for water bodies the to 88 for the rocky areas .Antecedent moisture condition (AMC) is considered when little prior rainfall and high when there has been considerable preceding rainfall to the modeled rainfall event. For modeling purpose, AMC II in watershed is essentially an average moisture condition. Runoff curve numbers from LU/LC and soil type taken for the average condition (AMC-II) and dry condition (AMC-I) or wet condition (AMC-III), equivalent curve number (CN) can be computed by using the following equation (**E.q.3-6**),The calculated dry, normal, and wet conditions, curve number at the level of the sub-basins as showed in Table 4. Value of potential maximum retention varies according to the sub-basins, ranges from 37.95mm to 169.3mm, and Ia varies 7.59 to 33.9. As the study goal of using the SCS-CN method for Wadi Al-Mujib watershed is to determine the runoff amounts that result from selected rainfall events in order to manage these amounts to save water for expansion the irrigated area, and to achieve our goal four rainfall events were chosen for AMI conditions; (11-13/12/2010), (29/12-1/1/2011), (28/1-1/2/2011), and (3-7/2011), AMII, 25-27/10/2015, 1/1//2015, 29/12/2016,2016 1/8 -1/7 and2016/1/26/-1/23 and AMIII 25-26/12/2017,6-7/1/2018,23-27/1/2018 and 13-22/2/2018. Direct runoff depths of these events were estimated. The computed values of average CN, S and Ia for the three conditions of the years 2010/2011, 2015/2016 and 2017/2018 Characteristics of these events have been given in Table 4. These values have been used in SCS model to get the direct runoff volume for given rainfall for different AMC conditions.

Table 4: SCS-CN model parameters for the year 2010-2018, based on the four sub-basins.

2010/2011 for dry year runoff depth						
ID Sub-Basin	**Variables Q**		**Storm events (11-13/12/2010)**	**Storm events 29/12-1/1/2011)**	**Storm events (28/1-1/2/2011)**	**Storm events (3-7/2/2011)**
Sub-basin- (1)	P<0.2S	Rainfall	14.41	16.99	30.01	17.74
	S=130.8	Runoff Q	#	#	0.09	#
	Ia=26					
	CNI=66					
Sub-basin- (2)	P<0.2S	Rainfall	9.07	18.13	31.5	6.45
	S=149	Runoff Q	#	#	0.04	#
	Ia=29.8					
	CNI=63.					
Sub-basin- (3)	P<0.2S	Rainfall	4.36	22.17	2.4	1.78
	S=169	Runoff Q	#	#	#	#
	Ia=33					
	CNI= 60					
Sub-basin- (4)	P<0.2S	Rainfall	8.33	13.96	30	6.39
	S=169	Runoff Q	#	#	0.09	#
	Ia=33					
	CNI=60					

2010/2011 for dry year runoff depth						
Total	Total runoff depth (Q)		#	#	0.22	#
2016/2015for normal year runoff depth						
ID Sub-Basin	Variables Q	Variables Q	2015 10/27- 10/25	2015/12/29 2016/1/1	2016 1/8 1/7	- 1/26 - 1/23 2016
Sub-basin- (1)	P<0.2S	Rainfall	15.15	29.88	10.48	19.07
	S=98.7	Runoff Q	#	0.27	#	#
	Ia=19.7					
	CNII=72					
Sub-basin- (2)	P<0.2S	Rainfall	20.11	25.2	10.39	20
	S=89.2	Runoff Q	0.08	0.22	#	0.81
	Ia=17.8					
	CNII=74					
Sub-basin- (3)	P<0.2S	Rainfall	9.51	11.88	2.82	8.52
	S=84.6	Runoff Q	#	#	#	#
	Ia=16.9					
	CNIII=75					
Sub-basin- (4)	P<0.2S	Rainfall	17.65	13.66	10.87	11.87
	S=84	Runoff Q	0.03	#	#	#
	Ia=16.9					
	CNII=75					
Total		Total runoff depth (Q)	0.11	0.22	#	0.81
2017/2018for wet year runoff depth						
ID Sub-Basin	Variables Q		2017 12/26 - 12/25	2018 1/7 - 1/6	- 1/27 1/-23 2018	-2/22 2/13 2018
Sub-basin- (1)	P<0.2S	Rainfall	13.84	40.33	32.26	37.28
	S=63	Runoff Q	0.06	0.61	0.52	0.58
	Ia=12.7					
	CNIII=80					
Sub-basin- (2)	P<0.2S	Rainfall	22.77	47.1	34.44	42.09
	S=41	Runoff Q	0.55	0.77	0.69	0.74
	Ia=8					
	CNII=86					
Sub-basin- (3)	P<0.2S	Rainfall	11.87	29.22	12.69	20.85
	S=38	Runoff Q	0.28	0.67	0.33	0.55
	Ia=7.5					
	CNIII=87					
Sub-basin- (4)	P<0.2S	Rainfall	16.19	38.3	31.95	29.3
	S=38	Runoff Q	0.44	0.74	0.69	0.67
	Ia=7.5					
	CNIII=87					
Total		Total runoff depth (Q)	1.33	2.79	2.23	2.54
Note: # The value divided by zero. Hence, R cannot be calculated						

Table 5.Estimation of Potential Maximum Retention (S) in mm, and rainfall loss before runoff begins (Ia) according to each sub-basin for the three conditions.

ID Sub-Basin	AMC	CN	Potential Maximum Retention (S) in mm	Ia
	Dry AMC- I	66	130.9	26.2
	Normal AMC II	72	98.78	19.8
1	Wet -AMC III	80	63.5	12.7
	I	63	149.2	29.8
	II	74	89.24	17.9
2	III	86	41.35	8.27
	I	60	169.3	33.9
	II	75	84.67	16.9
3	III	87	37.95	7.59
	I	60	169.3	33.9
	II	75	84.67	16.9
4	III	87	37.95	7.59

From Table 5. It is indicated that high variation between the sub-basins in terms of Potential Maximum Retention (**S**) in mm and **Ia** which represents all forms of rainfall loss before runoff begins due to the variation of the sub-basin area, soil group, and LULC.

Table 6. Estimation of S (mm) and La for the sub-basins

_ID Sub-Basin	Area km²	CN	S (mm)	La
1	2028	72	127	25.4
2	1230	74	147	29.4
3	1735	75	83.8	16.76
4	1568	75	83.8	16.76
Total	6584			

The values of **S** ranges from 83.8mm for both the sub-basins 3 and 4 to 127 mm, and 147mm for the sub-basins of 2 and 1, respectively, these results indicated that the generated runoff depth from the sub-basins **2** and **1** are lower compared to the sub-basins of **3** and **4**; this is due to the fact that 99.9% from the area of the sub-basins 3 and 4 are barren, rocky, and 85% from the total area have elevation ranges from 780-1273m.As runoff is affected by antecedent moisture condition (AMC) which is the soil moisture before rainfall occurs and for the model purpose (AMC) are grouped into three conditions: AMC-1: low moisture (dry), AMC-II: average moisture condition and AMCIII: high moisture, heavily rainfall over proceeding few days (wet). For estimation the runoff, four storm events were selected in the years of 2010/2011,withen 20 days, 2015/2016 and 2017/2018,witen 25 days which represents the three moisture conditions, drought, wet, and normal conditions, these storms rainfall events recorded of 234.75, 321.62 and 521.98 mm for the three moisture conditions, drought, normal and wet conditions, respectively, table 7 and the total calculated runoff volume (mm^3) were 0.23, 1.97, and 19.09mm^3 for the three moisture conditions, drought, normal and wet conditions, respectively, Table 8.

Table 7. Rainfall-Runoff for the three moisture conditions, on the level of the sub-basins

ID-Basins	Rainfall/(mm)	Runoff/(mm)	Runoff Coefficient (k)	Rainfall/(mm)	Runoff/(mm)	Runoff Coefficient (k)	Rainfall/(mm)	Runoff/(mm)	Runoff Coefficient (k)
	2010/2011	2010/2011	2010/2011	2015/2016	2015/2016	2015/2016	2017/2018	2017/2018	2017/2018
Sub-basin- (1)	79.14	0.09	0.0011	96.75	0.27	0.0028	139.21	1.91	0.0137
Sub-basin- (2)	65.78	0.04	0.0006	85.3	1.11	0.013	166.6	3.24	0.0194
Sub-basin- (3)	31.18	0	0	73.91	0	0	85.77	2.1	0.0245
Sub-basin- (4)	58.65	0.09	0.0015	65.66	0.03	0.0005	130.4	2.93	0.0225
	234.75	0.22	0.0032	321.62	1.41	0.0163	521.98	10.18	0.0801

In the three of AMC the storm, rainfall is concentrated in the January and February; these two months form together about 72% from the total of rainfall.Runoff depths of 3.6, 15.7 and 29.7 mm were estimated for the three different Antecedent Moisture Conditions (AMC-I, AMC-II and AMC-III). A sub-catchment of Wadi Al-Mujib watershed was investigated and assessed to evaluate runoff and water harvest potential. For various curve numbers, the runoff estimated for different AMC conditions. The individual composite curve number was computed for all study area divided by sub-basins for the three AMC conditions. The runoff depths are computed for each rainfall event for the years 2010/2011, 2015/2016, and 2017/2018. At the level of the watershed, the yielded surface runoff (mm) values varied as illustrated in Table 7. From within 20 days rainfall storm in the dry condition 2010/2011of 79.14, 65.78, 65.78, 31.18mm these runoff value will make about 0.09, 0.04, 0, and 0.09 million cubic meters of water volume for the sub-basins numbered from 1-4, respectively, with total rainfall and water volume 234.75m, 0.22mm³, which is considered a positive indicator of harvesting water in such arid area. While in the normal condition, the yielded surface runoff (mm) within 25 days rainfall storm in the normal 2016/2015 were 96.75, 85.3, 73.91 and 65.66mm and this runoff value will make about 0.27, 1.11, 0 and 0.03 million cubic meters of water volume for the sub-basins numbered from 1-4, respectively, with total rainfall and water volume 321.62mm, 1.41mm³.in addition in case of the wet condition,2017/2018, the yielded surface runoff (mm) values From a 25 days rainfall storm, were 139.21, 166.6, 85.77 and 130.4mm, these runoff value will make about million cubic meters of water volume for the sub-basins numbered from 1-4, respectively 1.91, 3.24, 2.1and 2.93mm³, with total rainfall and water volume 521.98mm and 10.18mm³.

Table 8. Estimation of runoff depth and volume for the three conditions 2010/2011_2015/2016 and 2017/2018 respectively.

Sub-Basin_ID	Area km²	Rainfall depth Q (mm) 2010/2011	Runoff-m/m³ 2010/2011	Rainfall depth Q (mm) 2015/2016	Runoff-m/m³ 2015/2016	Rainfall depth Q (mm) 2017/2018	Runoff-m/m³ 2017/2018
1	2027.9	0.09	0.18	0.27	0.55	1.91	3.87
2	1230.44	0.04	0.05	1.11	1.37	3.24	3.99
3	1734.72	0	0	0	0	2.1	3.64
4	1567.71	0.09	0	0.03	0.05	2.93	4.59
Total	6560.77	0.22	0.23	1.41	1.97	10.18	16.09

6. Discussion

In this study, SCS-CN method was applied based on rainfall data. Rainfall values were collected from fourteen meteorological stations, which are representing the large watershed area. As the SCS-CN is mainly controlled by the soil hydrologic groups (SHGs), rainfall data (P), land use /Land cover patterns (LULC), antecedent moisture condition (AMC) and Potential Maximum Retention (S).The results of LULC were illustrated in figure 2.and table 2. Showed the spatial distributional pattern of the six LULC and their statistics in the study area; Water bodies, Irrigated area, Forest , Built-up area, Rocky area, and valley's Sedimentation area, about 98.67% among all of the six LULC are represents barren area, and the rest represents the Water bodies, irrigated area, forest. In other words, the LULC results one of the main reason for the relationship between rainfall, runoff and Rainfall depth**.** As the study area dominated by barren area, it is runoff yields were about 86% of total runoff volume. The high density of drainage network of the barren area due to the high slope, which is the most important factor that accelerates runoff making it suitable for constructing dams. Forest and irrigated areas cover about 1.31% of the study area and 14% of total runoff volume.

7. Conclusion

The SCS-CN method is widely used as a method for estimating the surface runoff volume for a given rainfall event.

Most of the sub-basins are indicating high curve number value, which is more than 80, that indicates high runoff in the study area. The maximum run off are indicated the low infiltration rate. Total surface runoff volume of Wadi Al-Mujib watershed in three different Antecedent Moisture Conditions were ranges from CNI=66,63,60 and 60, CNII=72,74,75 and 75, while CNIII 80,86,87,and 87 for the four sub-basins (1-4) respectively.

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تقدير الجريان السَّطحي باستخدام رقم منحنى معامل الجريان السطحي في منطقة معقدة وجافة: (حوض وادي الموجب دراسَة حالة)

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ملخص

تم استخدام نُظم المعلومات الجغرافيَّة، والتِّقنيات المتُقدمة للاستشعار عن بُعد لتقدير الجريَان السَّطحي بالتكامل مع منحنى معامل الجريان السَّطحي في منطقة جافة، ومعقدة تتمثل في حوض وادي الموجب. ويُعد رقم مُنحنى معامل الجريَّان السَّطحي العامل الأسَّاس في تحديد الجريَّان السَّطحي، اعتماداً على المنهج الهيدرولوجي. وقد تم تقدير الجريان السَّطحي في منطقة خانقَّية وهي حوض وادي الموجب الجاف؛ إذْ تراوح المعدل التاريخي للأمطار السَّنوية ما بين 50ملم في معظم منطقة الدراسة إلى 500ملم في الجزء الجبلي الغربي. يعتمد تقدير الجريان السَّطحي وفقاً لهذه المنهجية على مجموعة من العوامل الأساسية وهي: مجموعات التربة، وبيانات الأمطار، واستعمالات الأرض والغطاءات الأرضية، وحالات رطوبة التربة، إضافة لحالات الفيضانات الثلاثة التي تم اختيارها لتمثل رطوبة التربة. وأوضح التحليل قوة العلاقة ما بين قيمة منحى معامل الجريان وعمق الجريان. وبينت النتائج أن 83.3% من المسَّاحة الكُلية للحوض ذات قيمة عالية لمنحى الجريان وهذا يؤدي بدورة إلى زيادة كمية الجريان، خصوصاً وأن ما نسبته 98.67% من مسَّاحة منطَّقة الدراسة جرداء. وتُعد منهجيَّة البحث فعالة لمثل هذه المنطقة الصحراوية ذات المحطَّات المطريَّة غير الكافية.

الكلمات الدالـة: معامل منحى الجريان، مجموعات التربة الهيدرولوجية، استعمالات الأرض والغطاءات الأرضية، الجريان السَّطحي، حالة الرطوبة السابقة.

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