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Relationship between Rainfall-Runoff using SCS-CN and Remote Sensing Technique in Upper-Helmand River Basin, Afghanistan

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Abstract: ***For the design of hydraulics structures, rainfall-runoff relationship is one of the most important aspects. The present study revealed the runoff estimation using SCS-CN method with Arc-GIS and remote sensing for Upper-Helmand river basin, Afghanistan. SCS-CN method can be effectively used for the runoff estimation which is now being used worldwide. It depends upon only few number of parameters, such as Curve Number (CN) and precipitation. The LULC map and HSG map are prepared using Arc-GIS for Upper-Helmand river basin to Generate CN.***

Keywords: SCS (Soil Conservation Service), CN (Curve Number), Arc-GIS, Upper-Helmand, LULC (Land Use Land Cover), HSG maps

1. Introduction

Runoff occurred when the rainfall intensity (I) is more than the rate of infiltration (f) at the surface soil. After saturation of soil excess water flows over the land surface to nearby channels [8]. Such a process of runoff is referred as Hortonian runoff who has firstly described it. Two conditions must be satisfied to generate Hortonian flow, first one the rainfall intensity should be more than the rate of losses on the land surface (I>f) and secondly, the time required for saturation of the surface soil must be lesser then the duration of rainfall [5]. Manmade activities and urbanization may modify the nature of land surface and accordingly the runoff processes. Curve number (CN) is the method which combines the climatic factor and watershed parameters in one entity [10]. Using SCS-CN method, it is observed that in general, good correlation has been found between observed and computed runoff [11]. If conventional hydrological data are insufficient for the purpose of design of water resources system, then remote sensing data are of great use [13]. The runoff Curve Number (CN) can be effectively used in the practical models to calculate surface runoff [16]. When rainfall data of only five rain gauge stations are available the ANN model is best option for run off estimation in comparison SCS-CN model [2]. The results of SCS-CN model could have been improved if more rain gauges are available in a large catchment. For runoff processing following steps can be summarized:

- Extraction of satellite image for the studied area.
- Digital Image Processing (DIP) for satellite images.
- Surface soil map preparation for studied area.
- LULC map preparation for the study area.
- Curve Number map generation for the studied area.
- Runoff estimation using appropriate equation.

2. Brief Literature Review of the Study

Shadeed et al. (2010) [15], Sekhar et al.(2014) [14], Ahmad et al. (2015) [1], Bhuktar et al. (2015) [3] used GIS based SCS-CN model for runoff estimation. They have used daily rainfall and CN values as inputs to the model to calculate daily runoff. Various thematic layers such as hydrologic soil, land use, and watershed boundary have been created in GIS environment and used to derive curve number by Jasima et al. (2015) [7], Vinithra et al. (2013) [17], Kudoli et al. (2015) [9]. As per knowledge of the investigators, so far nobody has used the SCS-CN model and GIS technique for assess of surface runoff for the Upper-Helmand river basin. Therefore, the present study was carried to investigate the relationship between Runoff – Rainfall using SCS-CN curves and Remote Sensing technique for Upper-Helmand river basin.

3. Study Area

The study area is located between latitudes 32.254 to34.653 N and longtitude 65.092 to 68.687 E with an area of 46,793 Km^2 (Fig. 1).Hight of the area is varring from 968 m to 5036 m w.r.t mean sea level. The Upper-Helmand river basin area is embodied by large hills, burried pediments, vallies and alluvial plains. The soil textures is silty clay, sandy, loamy and alluvium. The upper-Helmand river basin originated in a westerly extension of the Hindu Kush mountain range near Paghman about 40 kilometers west of Kabul and runs southwesterly for about 590 kilometers to the reservoir of Kajaki dam. The river water runoff comes mostly from rainfall at the average elevations of the basin in winter and spring season and from snow melting of from the glaciers of at the high altitude of mountains which escalate to elevations of 5036 meters. Range of Annual precipitations varies between 100mm to 670mm and precipitate mostly at higher altitudes during winter and spring [4]. The Mountains cause many local variations,though the upper-Helmand river basin is categorized by a dry continental climate. The temperatures of this rigions is varing from minus (-)10 °C in winter to plus (+) 34 °C in summer. The fluctuations in temperature are not uniform in character all over the whole basin.

The catchment is very important in the context of serving inter-sectorial demands including drinking, irrigation and hydropower generation. There is one major reservoir exist in the drainage basin with storage capacity of 1,844 Mm^3 at the current spillway elevation [12].

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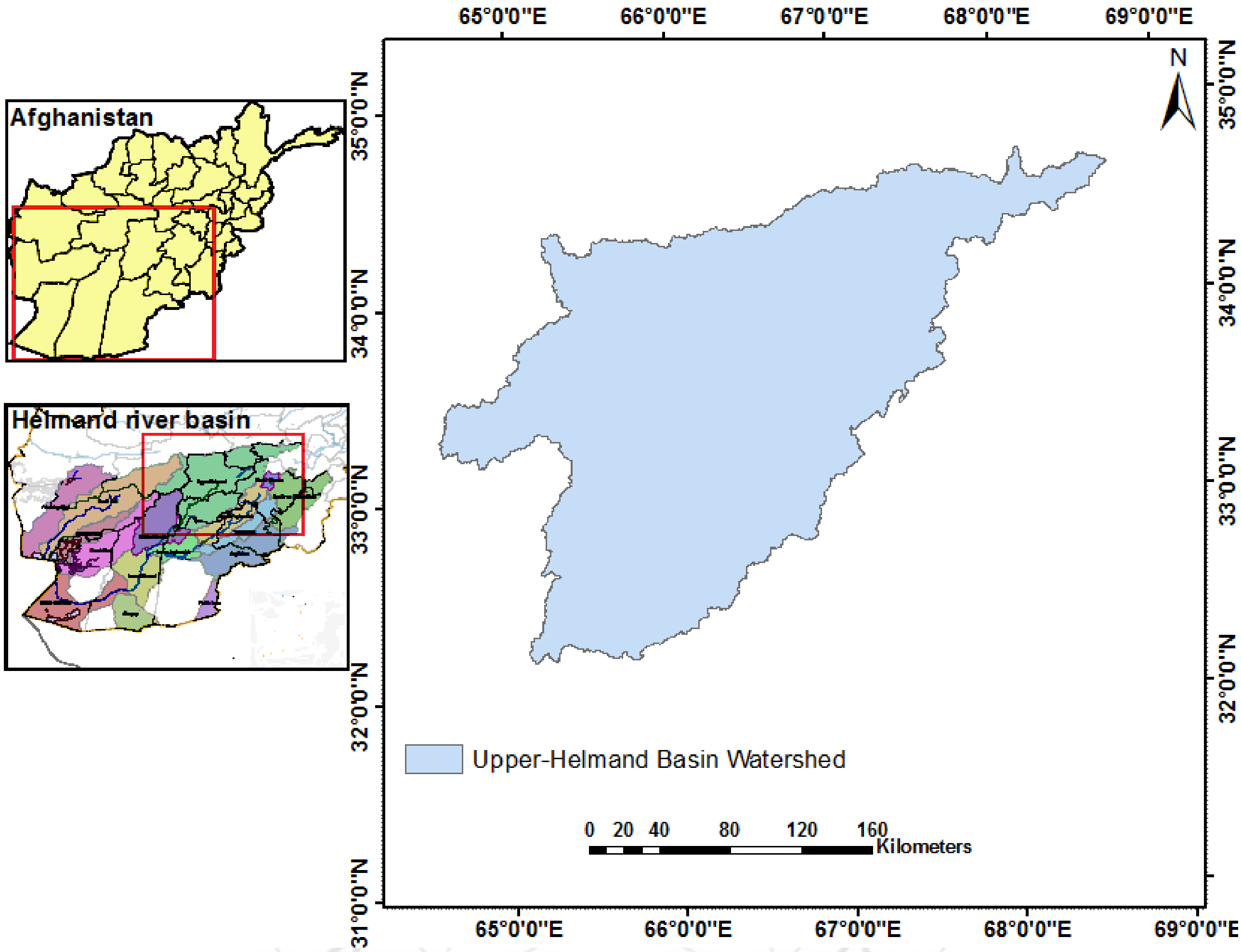

Figure 1: Upper-Helmand River Basin Location Map

4. Methodology

The study is complemented in three stages; Stage-1, all data (spatial and non-spatial) are collected from different sources, Stage-2, the articles with related layers of hydrologic soil group and land use maps prepared along with overlaid with one another. The overlaid endings are allocated by curve numbers, and finally Stage-3, the runoff is estimated based on rainfall occurred in study area.

4.1 Data Acquisition

Land use land cover map is downloaded from the United State Geological Survey (USGS) Land Cover Institute (LCI). Soil map, Soil properties such as soil types, structure and texture are obtained from Food and Agriculture Organization (FAO) soil map. DEM (Digital Elevation model) is derived from ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) and 35 years rainfall data is downloaded from global weather.

4.2 Land Use and Land Cover (LULC) Map:

In hydrologic modeling, Land Use Land Cover (LULC) information is used to know detection values or surface roughness. For the prediction of water holding capacity and percolation, land-use information is combined with the hydrologic characteristics of soils on the land surface. From vegetated land- use types, such as forest, the amount of expected runoff is not only affected by the surface, soil and physical properties, but also by the intercept capacity of the vegetation present, (Lynn; 2009). As a result, for the runoff process land use and land cover are important characteristics which also affects evapo-transpiration, erosion and infiltration. Land use labels that shows how a land is used (such as for residence, agriculture, or industry) the land cover labels also shows the materials (such as rocks, vegetation, water…etc.) that present on the surface. For an area the land cover may be evergreen forest, but the land use may be various combination of activity such as recreation, oil extraction…etc. (Jalil, 2002). (Fig.2). the area corresponding to each land cover and land use is given in Table 1

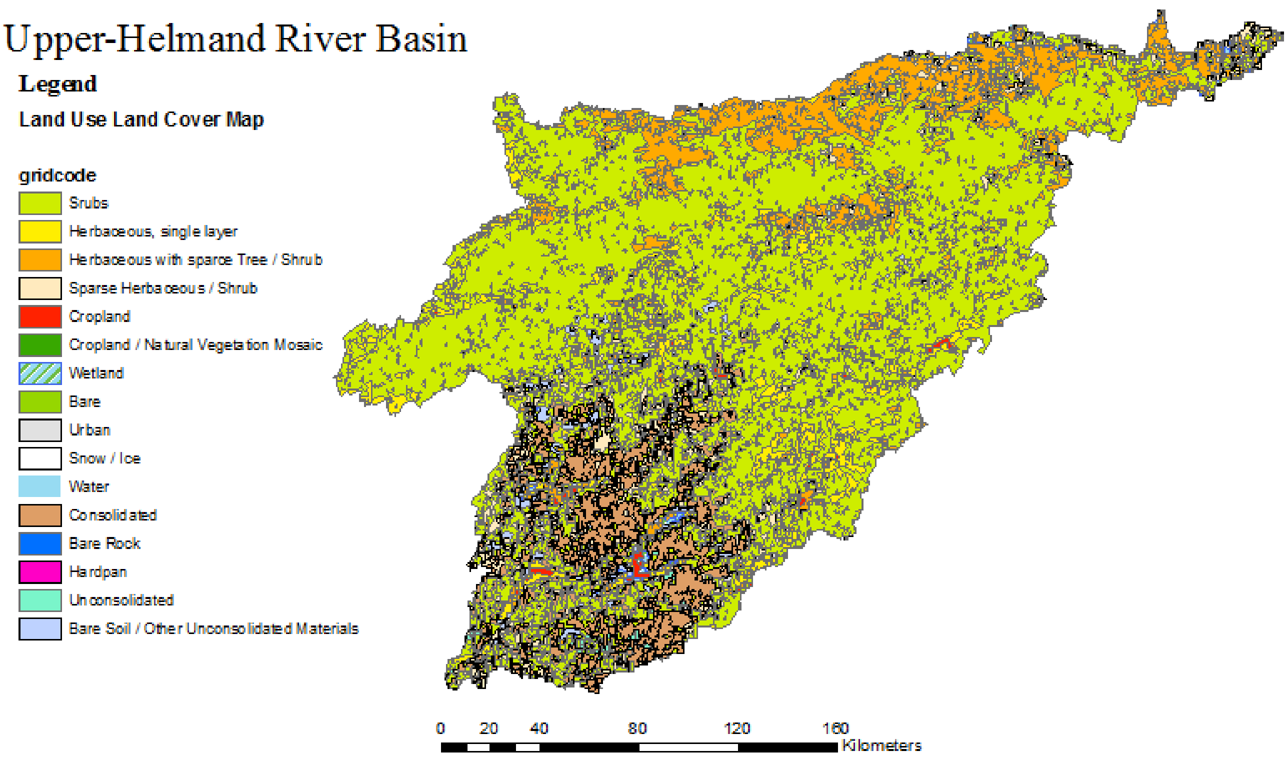

Figure 2: Upper-Helmand river basin - land use land covers Map

Table 1: Land Cover Classification

SN	Land Cover	Colour Comb	Area (Km^2)
1	Srubs		29420.63
2	Herbaceous, sinle layer		3270.00
3	Herbaceous with sparce Tree		5826.69
4	Sparse Herbaceous/Shrub		3001.97
5	Cropland		213.98
6	Cropland/Natural Vegetation		0.56
7	Wetland		114.29
8	Bare		17.78
9	Urban		67.60
10	Snow/Ice		0.82
11	Water		13.47
12	Consolidated		3850.79
13	Bare Rock		7.41
14	Hardpan		0.82
15	Unconsolidated		178.59
16	Other Materials		807.58

4.3 Soil

The soil map obtained from Food and Agriculture Organization (FAO) has been classified into two hydrologic groups, such as Group C (92%) and Group D as (8 %) as shown in Fig. 3. Accordingly, area wise the soil classification is given Table 2.

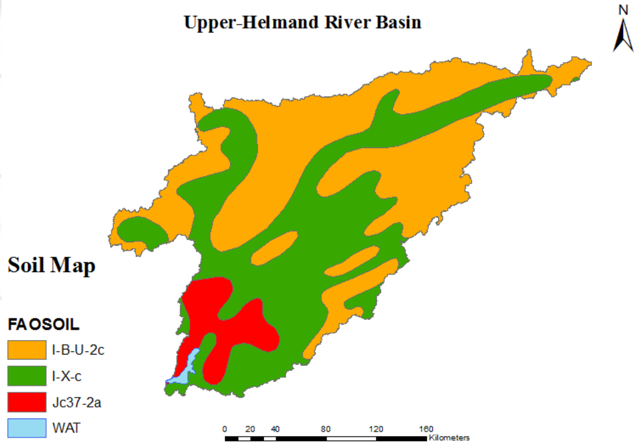

Figure 3: Upper-Helmand river basin soil map

Table 2: Soil classification as per Soil Map of Food and Agriculture Organization (FAO)

Record Number	Colour Comb	Mapping Unit Name	Dominant soil type	Associated soil type	Texture	Slope Class	HSG	Area (Km^2)
3503		I-B-U-2c	lithosols	Cambisols Rankers	Medium	Steeply dissected to mountainous	C	22,348
3512		I-X-c	lithosols	Xerosols	Medium	Steeply dissected	C	20,767
3525		Jc37-2a	Calcaric Fluvisols	Calcaric Fluvisols	Medium	Level to rolling	D	3,473
6997		WAT	Water				D	204

4.4 Curve Number Values

In Arc-GIS to create a curve number, extra tools are necessary. For creation of curve number values and its calculation, original version of Arc-GIS does not provide any tool. However, these tools namely, Arc Hydro, Hec-GeoHMS and HEC-HMS used with Arc-GIS program are available in ESRI website for updating Arc-GIS [6]. The required data are Land Cover Land Use (LULC) and Hydrologic Soil Group (HSG) maps. Arc-GIS and Arc Hydro tools are used to obtain the preliminary analysis such as calculation of Agreedem, Fill Sink, and Fill Direction from Data Management Tool (DMT). These data were collected and uploaded to Arc-GIS for further calculations. Accordingly, the curve numbers based on land cover land use and soil maps are generated and shown in Fig.4 and also given in Table. 3.

4.5 SCS - CN Method

SCS-CN method is carried out based on two parameters rainfall data and Curve Number (CN) ranges from 0 to 100. The most important parameter in CN is Antecedent Soil Moisture Condition (AMC). However, antecedent soil moisture condition is classified into the antecedent moisture classes AMC I, AMC II and AMC III, that illustrate dry, average and wet conditions respectively. All classes (AMC I, AMC II, AMC III) are based on five-day antecedent rainfall amount and season category and are given in Table.4

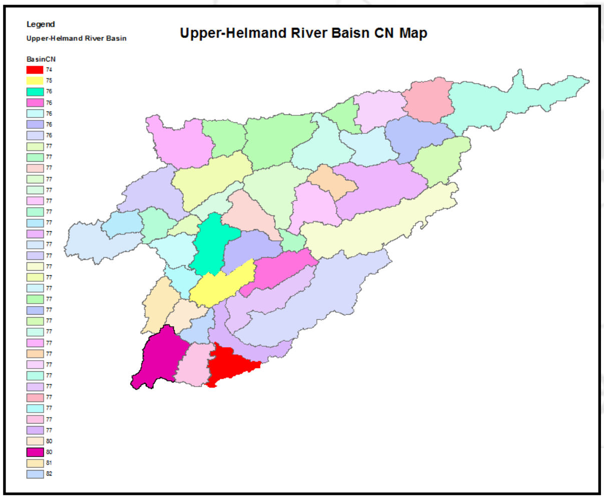

Figure 4: Upper-Helmand river basin curve number map

Table 3: CN Classification

No	Area (Km^2)	CN	No	Area (Km^2)	CN
1	795	74	20	1604	77
2	1043	75	21	942	77
3	1171	76	22	3129	77
4	1072	76	23	1231	77
5	746	76	24	1147	77
6	992	76	25	1286	77
7	3763	76	26	1526	77
8	291	77	27	587	77
9	279	77	28	1029	77
10	1002	77	29	2727	77
11	1605	77	30	1421	77
12	520	77	31	1110	77
13	1091	77	32	469	77
14	569	77	33	768	77
15	517	77	34	1028	77
16	2247	77	35	529	80
17	1269	77	36	1326	80
18	1395	77	37	827	81
19	3264	77	38	467	82

Table 4: AMC determination for CN

AMC	Total Rain Classification of AMC in Previous 5 days	
	Dormant Season	Growing Season
I	Less than 13 mm	Less than 35 mm
II	13 to 28 mm	35 to 52.5 mm
III	More than 28 mm	More than 52.5 mm

4.6 Direct Runoff Depth Estimation

Direct runoff depth (D) is calculated by The SCS-CN method using following expression:

$$D = \frac{(P - 0.2\,S)^2}{P + 0.8S} \quad (1)$$

In Eq. (1), P is the total rainfall in mm in antecedent 5 days and S is dimensionless parameter known as potential maximum retention, which can be obtained using Eq. (2). The parameter depends on the soil vegetation and land use of the catchment and the AMC in the catchment is just prior to the commencement of the rainfall event. The Soil Conservation Service (SCS) of USA expresses the potential maximum retention (S) as dimensionless parameter for easiness in practical application. The SCS conducted number of empirical studies and specified that S can be calculated using equation (2) as follow:

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

The constant 254 is used to define (S) in mm. Curve number CN depends on soil type, LULC, and AMC which ranges from 0 to 100. A 100 CN value represents a condition of zero potential retention and CN = 0 represent an infinitely abstracting catchment.

A composite curve number of a catchment with catchment which have different soil types and LCLU is determined by weighting the curve number values for the different sub-catchment in proportion to the land area associated with each and is given by Eq. (3) as follows:

$$CN_c = \frac{CN_1A_1 + CN_2A_2 + \cdots + CN_iA_i + \cdots + CN_nA_n}{\sum_{i=1}^{n} A_i} \quad (3)$$

For the average condition (AMC II), runoff curve numbers is taken from land use and soil type. However, for other two condition, dry (AMC I) and wet (AMC III) following equations are used for obtaining equivalent curve numbers.

$$CN\,(I) = \frac{CN\,(II)}{2.334 - 0.01334CN\,(II)} \quad (4)$$

And

$$CN\ (III) = \frac{CN\ (II)}{0.427+0.00573\ CN\ (II)} \qquad (5)$$

5. Result and Discussion

The estimated AMC I, AMC II and AMC III, the corresponding curve numbers are 59.8, 77.67 and 89.1. As per the growing five - day's rainfall, curve number falls in Antecedent Soil Moisture Condition III (AMC III). Hence the runoff is estimated and the mean runoff of the 35 years is 354.81 mm per year. Runoff estimation is given in Table.5 for 35 years.

The rainfall and correspondingly runoff is also shown (blue colour) (red colour)

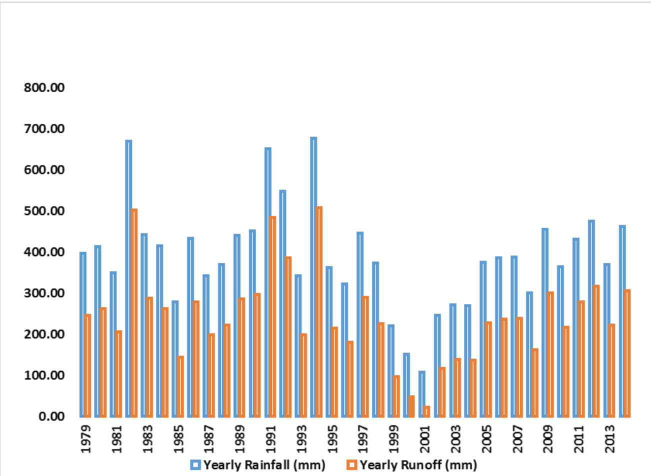

Figure 5: Graph of Rainfall and Runoff of Upper-Helmand River basin

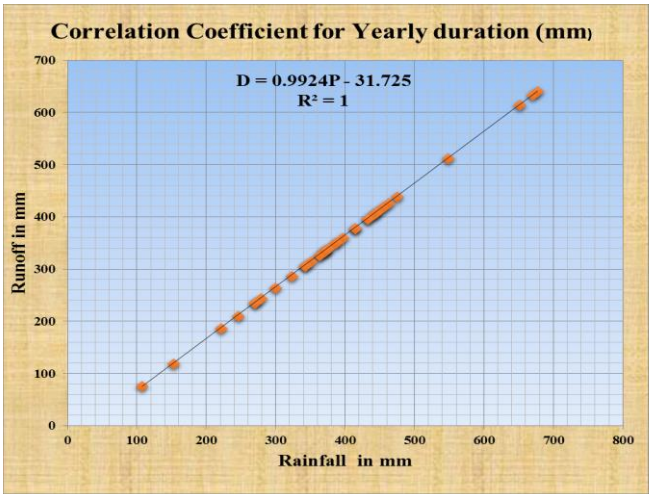

Figure 6: Correlation Graph of Rainfall and Runoff

Table 5: 35 years runoff estimation by SCS-CN method.

Year	Annul Precipitation (mm)	CN (AMC- III)	PMR S	Runoff (mm)	Area (Km^2)	Runoff (Mm^3)	Runoff (Mhm)
1979	396.72	89.1	31.037	361.727	46793	16,926.30	1.693
1980	414.57	89.1	31.073	379.483	46793	17,757.15	1.776
1981	350.94	89.1	31.073	316.224	46793	14,797.09	1.480
1982	670.82	89.1	31.073	634.924	46793	29,709.98	2.971
1983	442.79	89.1	31.073	407.569	46793	19,071.36	1.907
1984	415.06	89.1	31.073	379.964	46793	17,779.64	1.778
1985	279.36	89.1	31.073	245.248	46793	11,475.91	1.148
1986	433.77	89.1	31.073	398.586	46793	18,651.03	1.865
1987	343.68	89.1	31.073	309.010	46793	14,459.52	1.446
1988	370.71	89.1	31.073	335.865	46793	15,716.15	1.572
1989	441.61	89.1	31.073	406.389	46793	19,016.15	1.902
1990	451.83	89.1	31.073	416.569	46793	19,492.52	1.949
1991	651.98	89.1	31.073	616.122	46793	28,830.19	2.883
1992	548.90	89.1	31.073	513.295	46793	24,018.60	2.402
1993	342.68	89.1	31.073	308.024	46793	14,413.37	1.441
1994	677.51	89.1	31.073	641.600	46793	30,022.39	3.002
1995	362.93	89.1	31.073	328.130	46793	15,354.17	1.535
1996	323.16	89.1	31.073	288.649	46793	13,506.75	1.351
1997	445.79	89.1	31.073	410.551	46793	19,210.92	1.921
1998	373.50	89.1	31.073	338.636	46793	15,845.79	1.585
1999	221.55	89.1	31.073	188.182	46793	8,805.62	0.881
2000	152.71	89.1	31.073	120.855	46793	5,655.18	0.566
2001	107.80	89.1	31.073	77.790	46793	3,640.02	0.364
2002	245.82	89.1	31.073	212.100	46793	9,924.80	0.992
2003	272.38	89.1	31.073	238.338	46793	11,152.54	1.115
2004	270.45	89.1	31.073	236.431	46793	11,063.33	1.106

2005	376.03	89.1	31.073	341.155	46793	15,963.67	1.596
2006	386.15	89.1	31.073	351.216	46793	16,434.47	1.643
2007	387.91	89.1	31.073	352.964	46793	16,516.26	1.652
2008	300.11	89.1	31.073	265.796	46793	12,437.38	1.244
2009	456.31	89.1	31.073	421.031	46793	19,701.29	1.970
2010	363.78	89.1	31.073	328.980	46793	15,393.96	1.539
2011	432.69	89.1	31.073	397.516	46793	18,600.98	1.860
2012	475.44	89.1	31.073	440.079	46793	20,592.61	2.059
2013	370.79	89.1	31.073	335.941	46793	15,719.69	1.572
2014	463.52	89.1	31.073	428.209	46793	20,037.18	2.004

6. Conclusion

The SCS-CN method is widely used method for the estimation of surface runoff for a given rainfall event in a catchment. The advantage of the Remote Sensing and GIS bass application of SCS-CN model is that, most powerful, faster and reliable method for the determination of the amount of runoff from rainfall event for complex mix LUL watershed with different type of soil.

Originally SCS-CN method was developed for the humid region which has quit characteristics deferent with arid to semiarid region. Therefore, the *Ia* value in SCS-CN method formula had been investigated, and verified for dry condition.

For the calculation of composite CN in the present study, Remote Sensing and GIS approach was used. Therefore the input data which has a significant role in the processing of generate complex CN are easily carried out in Arc-GIS such as Soil map, Land use/Land cover map, HSG map and Curve Number map for Upper-Helmand region.

As per the growing five days' rainfall a composite curve number for whole catchment is fall under AMC III and its value is as 89.1.

The mean runoff of the 35 years is 354.81mm per year.

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