ESTIMATION OF RUNOFF USING SCS-CN METHOD AND ARCGIS FOR KARJAN RESERVOIR BASIN, INDIA

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Abstract: Water is one of the most important natural resources and a key element in the socio-economic development of a State and Country. Proper water management is the only option that ensures a squeezed gap between the demand and supply for the country like India. Rainfall is the major component of the hydrologic cycle and this is the primary source of runoff. Karjan reservoir basin, located between 21° 23' to 21° 50' North latitude and 73° 23' to 73° 54' East Longitude in Narmada districts, in Gujarat State, India has been used for the study. In this paper SCS- CN model is used to estimate the runoff. The Daily rainfall data of 5 Rain gauge stations was collected and used for the daily runoff calculation using SCS-CN model and GIS. The Linear Regression model is also used for verification of runoff obtained from SCS-CN method.

IndexTerms - SCS-CN Model, GIS, DEM, LULC, Linear Regression Model.

I. Introduction

Estimation of direct rainfall-runoff is always efficient but is not possible for most of the location in desired time. Use of remote sensing and GIS technology can be useful to overcome the problem in conventional methods for estimating runoff. Sustainable water management of a river basin is required to ensure a long-term stable and flexible water supply to meet crop water demands as well as growing municipal and industrial water demands. Water resources structures need appropriate planning to ensure the fulfilment of the goals of water management. Water resources management requires a systems approach that includes not only all the hydrological components, but also the links, relations, interactions, consequences, and implications among these components.

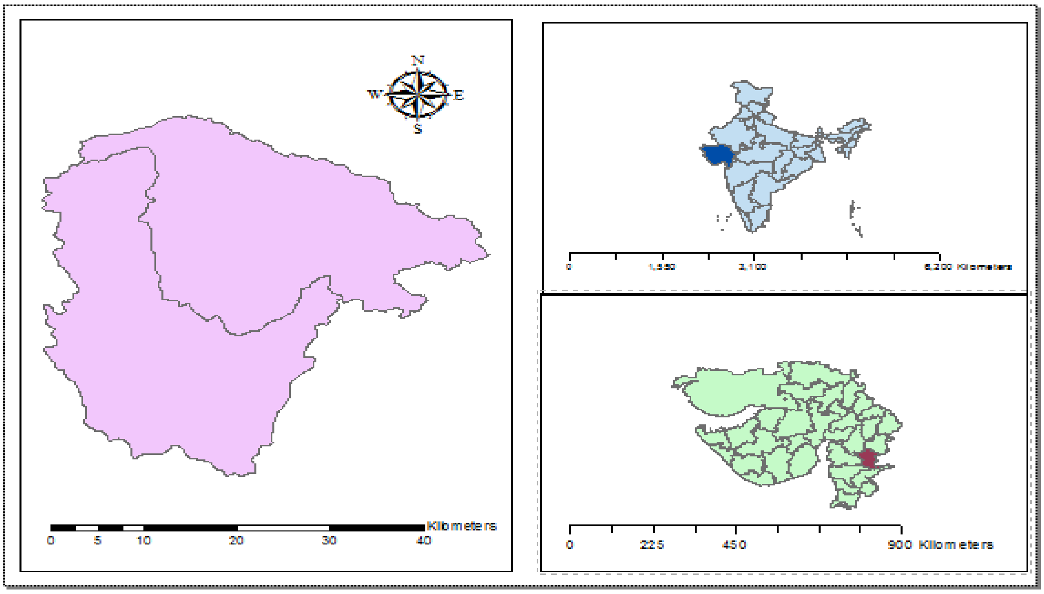

Figure 1. Location map of study area

Human modifications of the environment, including land cover change, irrigation, and flow regulation, now occur on scales that significantly affect seasonal and yearly hydrologic variations. As population density and development continue trending upward, storm water runoff from increased impervious surfaces presents challenges on local and global scales. Besides collecting contaminants from urban surfaces (nutrients, road salt, heavy metals, pesticides and bacteria), changes in storm water flow patterns can cause stream degradation, erosion, flooding and accompanying property damage (Sartor, Boyd et al. 1974). Hydrological watershed modelling has become a central tool for conceptualizing these flows of surface and subsurface water. Models can then be used to generating decision support tools for policy makers, regulators and resource managers (Daniel, Camp et al. 2011). Besides establishing water balances, models can also be used to predict the impact of different management practices on rainfall-runoff response, sediment and contaminant transport (Elliott and Trowsdale 2007). Available resources can be determined by knowing precipitation, runoff, groundwater, evaporation and transpiration. There is various computer based models developed to calculate water balance also many theoretical and experimental studies have been carried out in the past years. The SCS-CN method have been used in this study to estimate Runoff for the Karjan Reservoir Basin. The river Karjan originates from the Satpuda hills in Gujarat, India. Karjan dam is constructed on river Karjan. The location of the dam is shown in Figure 1.

II. RESEARCH METHODOLOGY

The flowchart indicating methodology for the present study is shown in this Figure 2. The land use and land cover map is obtained from Satellite image LISS III collected from Bhaskaracharya Institute for Space Applications and Geo- informatics (BISAG), Gujarat, India. Soil types (clayey and fine) have been obtained from National Bureau of Soil Survey and Land Use Planning (NBSS & LUP),Udaipur, India. Digital Elevation model (DEM) obtained from derived from USGS Website (https://lta.cr.usgs.gov/DEM), and daily rainfall Data is collected from 1991–2015 from Stata Water Data Centre SWDC, Gujarat, India. The integration of GIS and Soil Conservation Service - Curve Number Method is used to estimate the surface runoff. The Soil Conservation Service Curve Number (SCS-CN) method (USDA-SCS ,1986). is widely used in determination of direct surface run-off in long-term (continuous) hydrologic simulation models. The appropriate area-weighted curve number for the study area is computed using overlaying tool of ArcGIS. Then the daily rainfall database is incorporated in the analysis to estimate the direct runoff. The result obtained is useful for water management, flood management and irrigation scheduling of the study area.

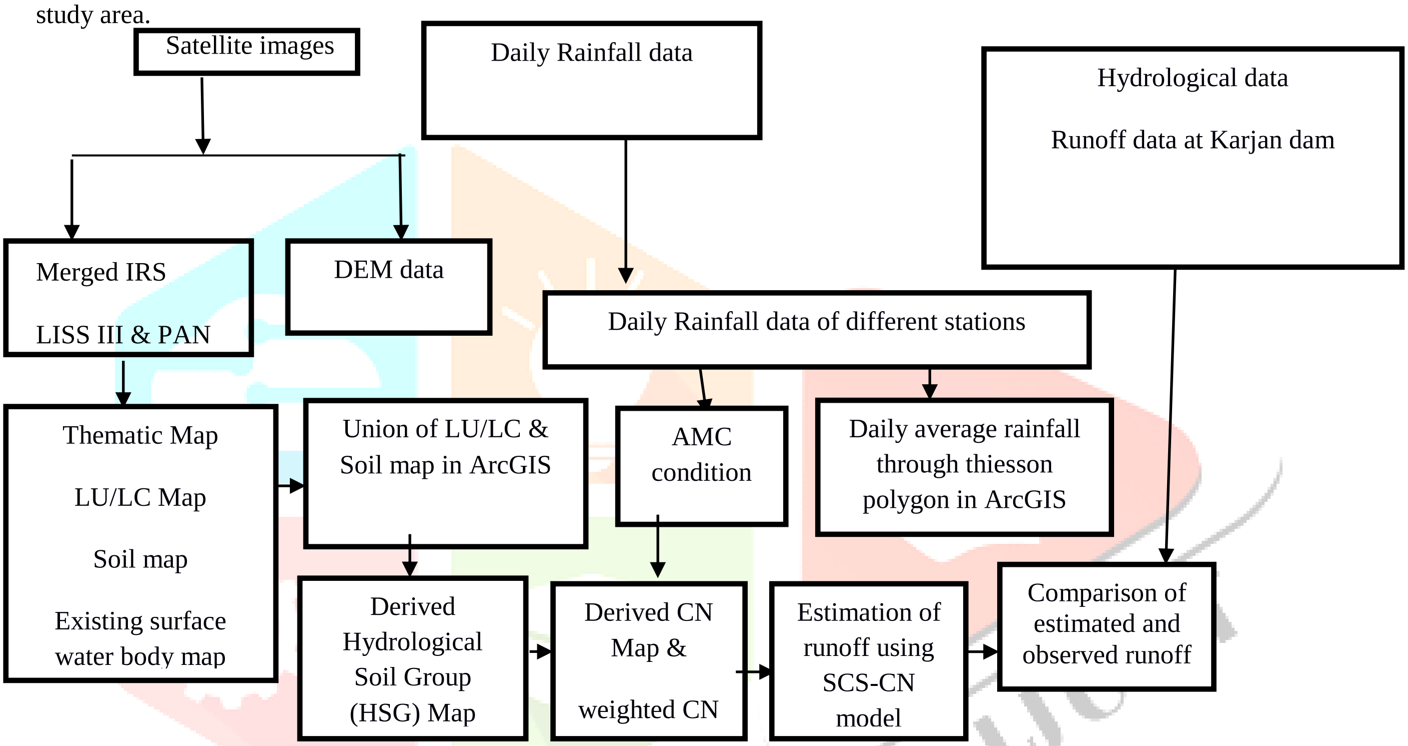

Figure 2. Flow chart showing methodology

2.1 SCS-CN method

In the early 1950s, the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) (then named the Soil Conservation Service (SCS)) developed a method (USDA-SCS, 1986) for estimating runoff from rainfall. The SCS-CN equations have been expressed as below.

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

$$Ia = 0.2S$$

Substituting in Eq.1, the equation becomes

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

Which is valid for P > 0.2S, otherwise Q = 0

S can be determined from the P- Q data. In practice, S is derived from a mapping equation expressed in terms of the curve number (CN).

$$S = \frac{25400}{CN} - 254 \qquad (3)$$

HSG is expressed in terms of four groups (A, B, C, D) according to the Soil Texture and Runoff potential as shown in Table 1. AMC is expressed in three levels (I, II and III), according to the rainfall limits for dormant and growing seasons as shown in Table 2 (Subramanya K., 2013). Classification of the Antecedent Moisture Condition is shown in Table 2.

Table 1. USDA-SCS Soil Classification

Sr no	HSG	Soil Textures	Runoff Potential	Minimum Rate of Infiltration (mm/hr.)	Water Transmission
A	Deep well drained soils	Sand, loamy sand, sandy loam	Low	7.62- 11.43	High rate (0.3 in/hr.)
B	Moderately deep, well drained with moderately fine to coarse texture	Silt loam or loam	Moderate	3.81- 7.62	Moderate rate (0.15-0.3in/hr.)
C	Moderately fine to fine texture	Sandy clay loam	Moderate	1.27- 3.81	Low rate (0.05-0.15in/hr.)
D	Soil which swell significantly when wet, heavy plastic and soil with a permanent high-water table	Clay loam, silty clay loam, sandy clay, silty clay, clay	High	0-1.27	Very low rate (0-0.05in/hr.)

Antecedent Moisture Condition (AMC) refers to the water content present in the soil at a given time. It is very important factor for determine final CN value. SCS developed three antecedent soil-moisture conditions and labelled them as I, II, III, according to soil conditions and rainfall limits for dormant and growing seasons. Since, standard table for CN values (ranges from 1 to 100), considering land use/cover and HSG are given for AMC-II (Satheeshkumar et al. 2017). Following conversion formulas were used to convert CN from AMC-II (average condition) to the AMC-I (dry condition) and AMC-III (wet condition) (SCS, 1972) gives recommended curve number values for a range of different land uses.

Table 2. Classification of Antecedent Moisture Conditions (AMC)

Sr No	Soil characteristics	Total 5-day antecedent rainfall(mm)	
		Dormant Season	Growing Season
I	Soils are dry not to wilting point, Cultivation has < 13 mm < 36 mm taken place	< 13 mm	< 36 mm
II	Average Condition	13-28mm	36-53 mm
III	Heavy or light Rainfall and low temperatures have occurred within the last 5 days; saturated soils	> 28 mm	> 53 mm

$$CN(AMC-I) = \frac{4.2 * CN(AMC-II)}{10 - 0.058 * CN(AMC-II)} \quad (4)$$

$$CN(AMC-III) = \frac{23 * CN(AMC-II)}{10 + 0.13 * CN(AMC-II)} \quad (5)$$

Where, *(II) CN* is the curve number for normal condition, (I) *CN* is the curve number. For dry condition, and (III) *CN* is the curve number for wet conditions.

The CN (dimensionless number ranging from 0 to 100) is determined from Table 1, based on land-cover, Hydrological Soil Group (HSG), and for the Antecedent Moisture Content (AMC). Although, SCS method is originally designed for use in watersheds of 15 km², and it has been modified for application to larger watersheds by weighing curve numbers with respect to Watershed/land cover area. The equation of weighted curve number is given Below.

$$CNw = \Sigma (CNi * Ai)/A \quad (6)$$

Where CNw is the weighted curve number; Cni is the curve number from 1 to any number N; Ai is the area with curve number Cni; and A the total area of the watershed.

The daily rainfall data was available from the period 1991 to 2000 for 4 rain gauge station and from the period 2001 to 2015 for 5 rain gauge station. The average rainfall over a reservoir basin is computed using Thession Polygon Tool in ArcGIS software.

A.M. Thiesson (1911) suggested this method in which weighing effect of area in the area in the form of polygon closet to the station has been considered. Thus, it tries to eliminate the error due to non-uniform distribution of rain gauges. Figure 4 and 5 shows, Thiesson polygon for the study area for 5 rain gauge station and 4 rain gauge stations respectively.

The average precipitation of the area is given by,

$$P = (P1A1 + P2A2 + \cdots + PnAn)/(A1 + A2 + \ldots + An) \quad (7)$$

Where, A1, A2…., An =Areas of the Thiesson polygon representing the stations 1, 2, …., n.

P1, P2, …., Pn = Precipitations of corresponding stations. A= Total area of the catchment.

The average daily rainfall value so obtained is incorporated in the Eq. 2 to get daily runoff over a basin. The observed runoff through this basin have been also obtained as a data to validate result of the SCS-CN model.

III. RESULTS AND DISCUSSION

Soil properties influence the generation of runoff from rainfall in the methods of runoff estimation. Soil map prepared by National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) and soil report of the study area have been used for classifying various soils into hydrologic soil groups. Soil classification system developed by SCS-CN has been followed while classifying soils into different hydrologic soil groups.

In this classification system, soils are classified as A, B, C or D hydrologic soil group depending on their properties. Category "A" has lowest runoff potential whereas category "D" has highest runoff potential. Hydrologic soil group map of the study area having mainly 2 classes of soil as fine and loamy clayey are shown in Figure 2. Category "C" has fine soils and Category "D" has clayey soils.

Curve Number map have been generated by integrating land use/ land cover map on hydrological soil group map. Each curve number is assigned using land use/ land cover for antecedent moisture condition (AMC II) and is shown in Figure 3. Considering AMC-III condition for the study area, Eq. 5 is used to obtain curve number for AMC-III condition. The generated CN map of study area is shown in Figure 4.

Table 3. Computations for Area weighted curve number

For AMC-III Condition									
Land use type	**Soil type**	**Area (m²)**	**Area (km²)**	**% Area**	**HSG**	**CN (AMC-II)**	**CN (AMC-III)**	**(%AREA*CN) /100**	**Area Weighted Curve Number**
Agriculture	clayey	204910919	204.91	15.08	D	81	90.75	13.68	88.95
	fine	248312578	248.31	18.27	C	78	89.08	16.28	
built up	clayey	5729335	5.73	0.42	D	92	96.36	0.41	
	fine	9872841	9.87	0.73	C	90	95.39	0.69	
Forest	clayey	692253355	692.25	50.95	D	77	88.51	45.09	
	fine	133656876	133.66	9.84	C	70	84.29	8.29	
Others	clayey	669033	0.67	0.05	D	80	90.20	0.04	
	fine	4575503	4.58	0.34	C	74	86.75	0.29	
Wastelands	clayey	4565878	4.57	0.34	D	80	90.20	0.30	
	fine	12933903	12.93	0.95	C	74	86.75	0.83	
Water bodies	clayey	35219652	35.22	2.59	D	100	100.00	2.59	
	fine	6103278	6.10	0.45	C	100	100.00	0.45	

As study area has more than one land use, a composite curve number have been obtained and used in the analysis. Percentage area and Curve number have been used to compute the area weighted curve number by using Eq. 6. Estimated composite curve number for catchment area of Karjan is computed as 88.95 for AMC-III. Details of curve number estimation for catchment area of Karjan are shown in Table 3.

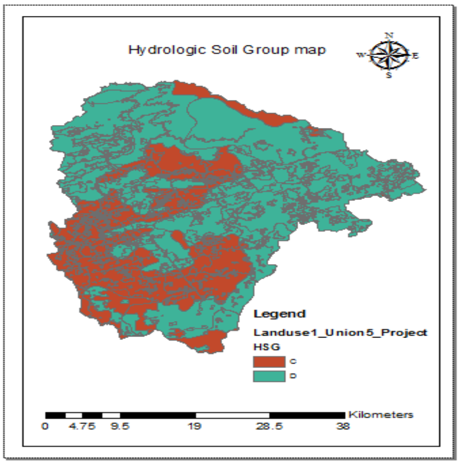

Figure 3. Hydrologic soil group map

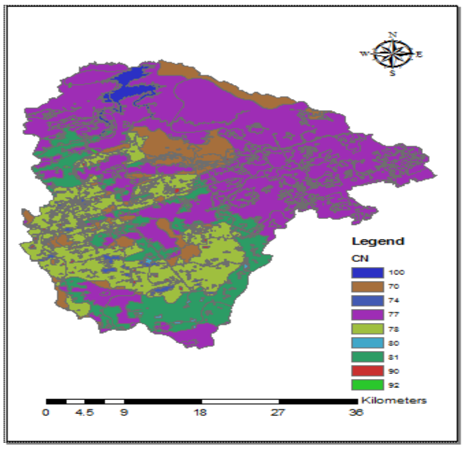

Figure 4. Curve Number (CN) map

Figure 5 and 6 shows Thiesson polygon for the study area for 5 raingauge station and 4 raingauge stations respectively.

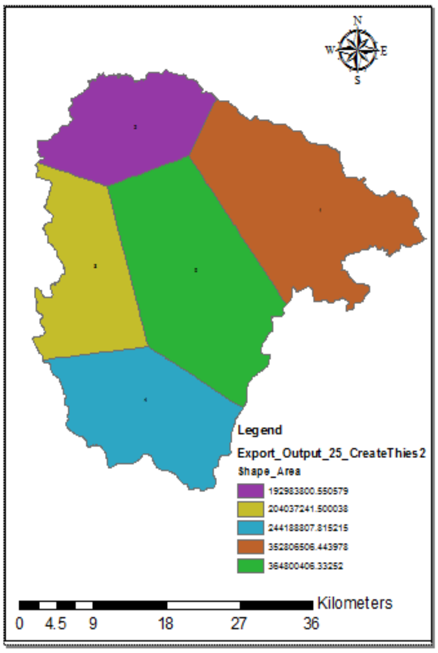

Figure 5. Thiesson polygon of study area for 5 rain gauge station

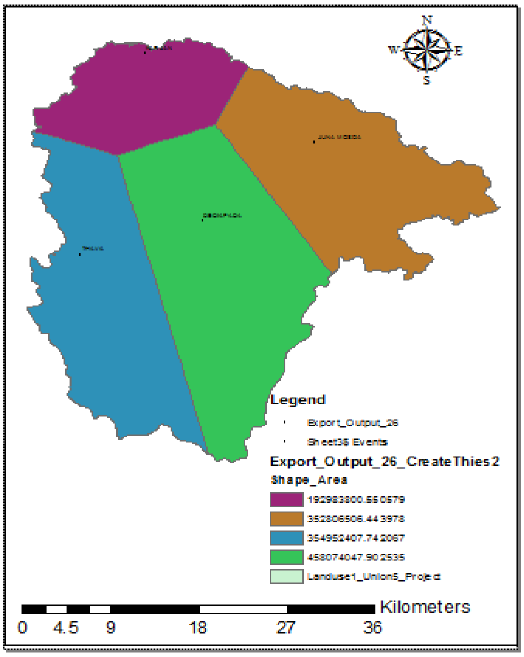

Figure 6. Thiesson polygon of study area for 4 rain gauge station

Table 4 shows the annual Rainfall and annual Simulated (SCS- CN model) runoff for the period 1991 to 2015.

Table 4. Annual Rainfall and SCS-CN model- simulated runoff

Year	**Rainfall (mm)**	**SCS-CN model - simulated Runoff (mm)**	**Year**	**Rainfall (mm)**	**SCS-CN model - simulated Runoff (mm)**
1991	961.87	243.01	2003	1298.96	393.31
1992	1010.16	204.15	2004	1198.37	426.23
1993	1052.79	344.04	2005	1283.62	501.63
1994	1668.65	411.99	2006	1979.88	862.61
1995	1088.00	312.36	2007	1592.36	815.23
1996	1297.95	367.05	2008	1216.45	447.07
1997	1380.42	344.26	2009	1037.60	420.08
Year	**Rainfall (mm)**	**SCS-CN model - simulated Runoff (mm)**	**Year**	**Rainfall (mm)**	**SCS-CN model - simulated Runoff (mm)**
1998	1290.37	380.89	2010	1067.67	273.51
1999	767.03	139.02	2011	1336.24	403.41
2000	536.47	181.74	2012	983.52	252.03
2001	785.81	209.30	2013	1965.17	864.09
2002	954.30	483.28	2014	941.61	325.94
2003	1298.96	393.31	2015	865.97	339.69

The results of annual rainfall and runoff have been represented in Figure 7.

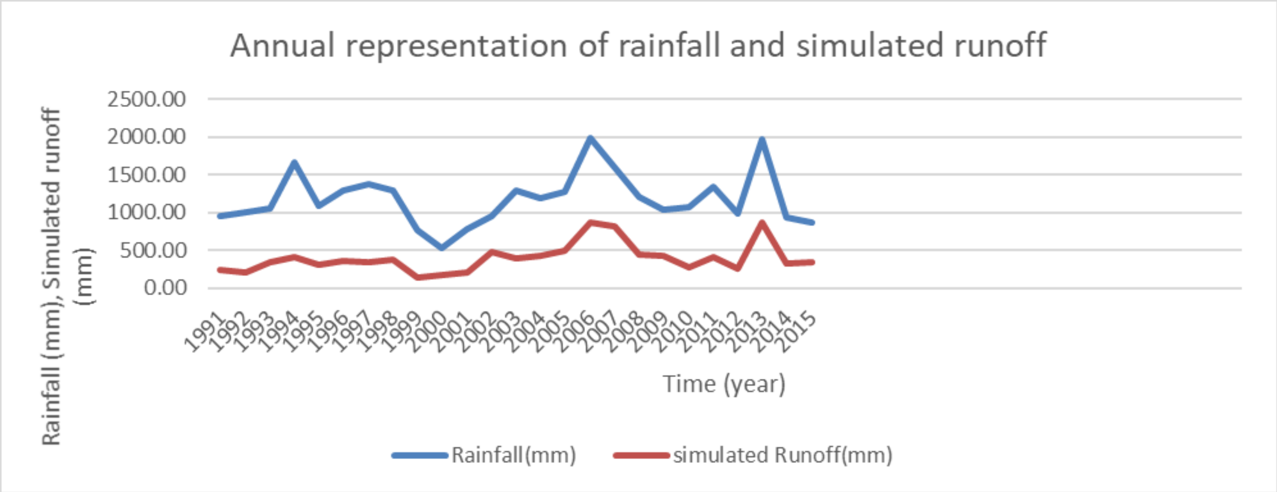

Figure 7. Annual Rainfall and SCS-CN model- simulated runoff

The comparison of the results of runoff obtained through SCS-CN model and Linear Regression model have been made with observed runoff and is shown in Figure 8.

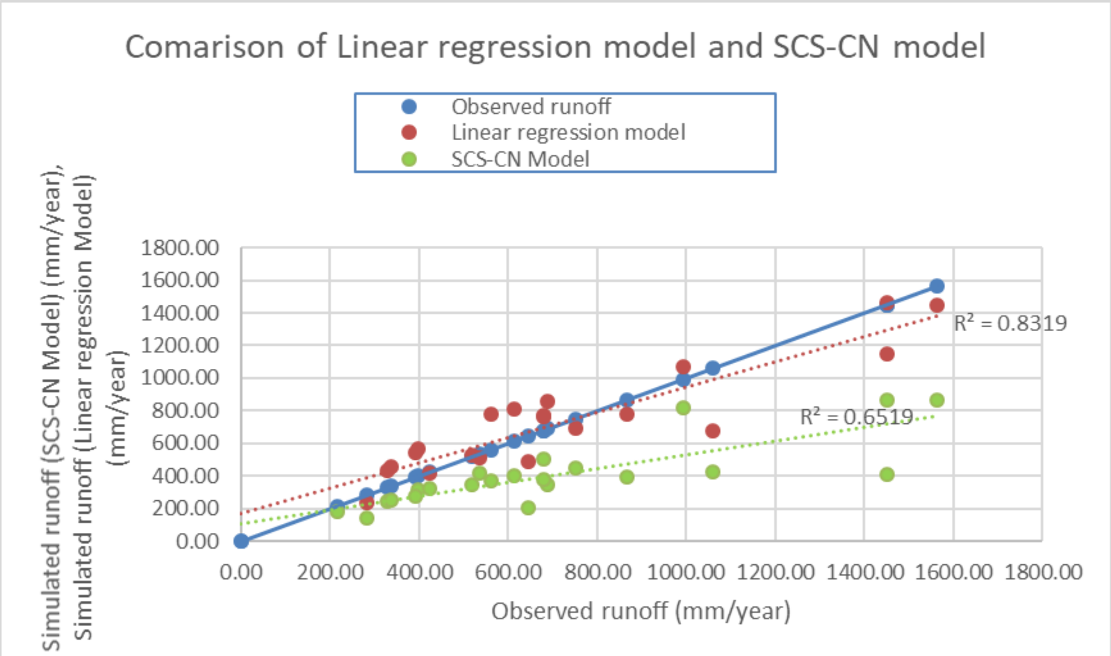

Figure 8. Annual observed runoff Vs. simulated runoff (SCS-CN model) and simulated runoff (Linear regression)

Fig 8 shows that the result of simulated annual runoff using Linear regression is more matching with the observed annual runoff in comparison to the simulated annual runoff using SCS-CN model.
As Linear regression model is found more accurate in comparison to SCS-CN model, the linear monthly rainfall-runoff correlation has been also established in the study.

IV. CONCLUSION

The result of simulated annual runoff using Linear regression is more matching with the observed annual runoff in comparison to the simulated annual runoff using SCS-CN model. It can be concluded that, Linear regression model is found more accurate in comparison to SCS-CN model. The value of coefficient of determination (R^2) for SCS-CN Model is 0.65 and the value of coefficient of determination (R^2) for Linear Regression Model is 0.83.

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