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Estimation of Runoff Using SCS-CN Method and Arcgis for Karjan Reservoir Basin

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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. Water resources of the world in general and in India are under heavy stress due to increased demand and limitation of available quantity. Proper water management is the only option that ensures a squeezed gap between the demand and supply. 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. Estimation of direct rainfall-runoff is always efficient but is not possible for un-sampled location the basin. Use of remote sensing and GIS technology can be useful to overcome the problem for estimating runoff. The method used in this study is SCS-CN Model. The Daily rainfall data of 5 Rain gauge stations is collected and used for the daily runoff calculation using SCS-CN model and GIS. The Linear Regression model is used for verification of runoff obtained from SCS-CN method. It is found that the results obtained from runoff obtained from SCS – CN model demonstrate deviations from the observed runoff. Linear regression model is closely agrees with the observed runoff from the basin in comparison to the SCS – CN model.

Keywords: ArcGIS, SCS-CN, Rainfall, Runoff

INTRODUCTION

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 [1]. Water resources structures need appropriate planning to ensure the fulfilment of the goals of water management [2]. 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 [3]. 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 [4][5][6]. As population density and development continue trending upward, storm water runoff from increased impervious surfaces presents challenges on local and global scales [Ref 7]. 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 [3]. 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 [4] [5] [6]. The SCS – CN model is used in this study to compute the runoff from the available daily rainfall data in Karajan reservoir basin. The observed inflows at Karajan reservoir have been also collected as a data. The results of runoff obtained from SCS – CN method is compared with the observed runoff/inflows at the reservoir site. Also, the Linear regress model is established for the rainfall – runoff correlation. The results obtained from runoff through regression model is closely agreeing with the observed runoff.

Study Area

The river Karjan originates from the Satpuda hills in Gujarat. Karjan dam is constructed on river Karjan. Concrete dam is constructed, through that a small watershed basin is form on upstream of Karjan dam which is located at73º 23’ to 73º 54’ East longitude and 21º 23’ to 21º 50’ North latitude. The catchment area of Karajn reservoir is 1358.8 Sq. km. Figure 1 shows the study area map.

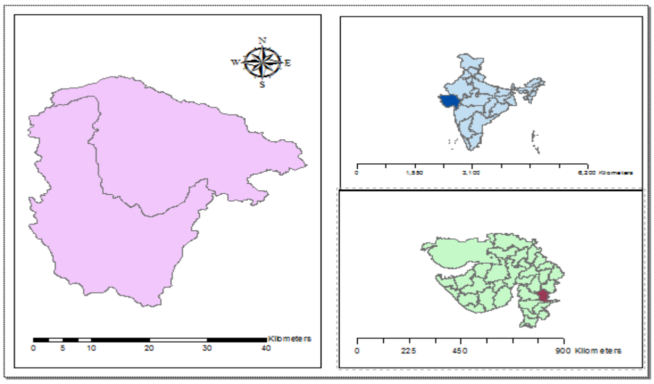

Figure 1: Map of Karajan reservoir basin, India

MATERIALS AND METHODS

The adopted methodology of the present study is shown in Figure 2. The land use and land cover map is obtained from Satellite image LISS III collected from Bhaskaracharya Space Application And Geo-Informatics (BISAG). The data for Soil types (clayey and fine) and texture have been collected from National Bureau of Soil Survey And Land Use Planning

(NBSS&LUP, India). Digital Elevation model (DEM) is made available from BISAG. The daily rainfall data is collected from 1991 upto 2015 from State 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 is widely used in determination of 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 linear regression model is also established for rainfall – runoff correlation. The results obtained from SCS - CN model and linear regression model are compared with observed runoff at the Karajan reservoir site.

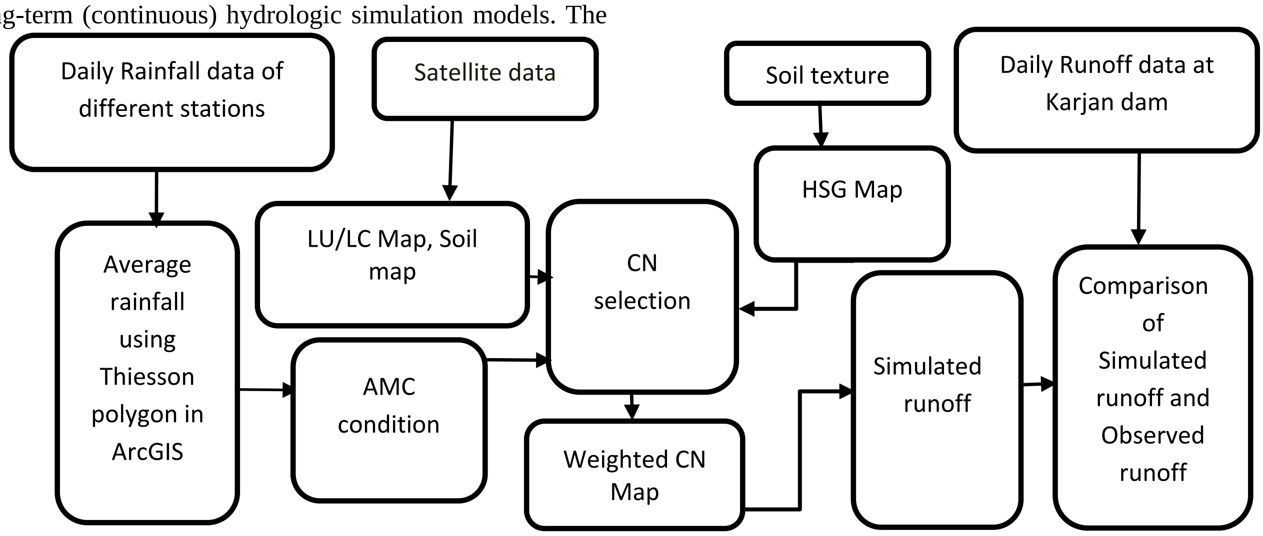

Figure 2: Flow chart showing methodology

Assessment of average rainfall by Thiesson Polygon tool

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 2 and Figure 3 shows Thiesson polygon for the study area for 5 raingauge station and 4 raingauge station respectively.

The average precipitation of the area is given by

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

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.

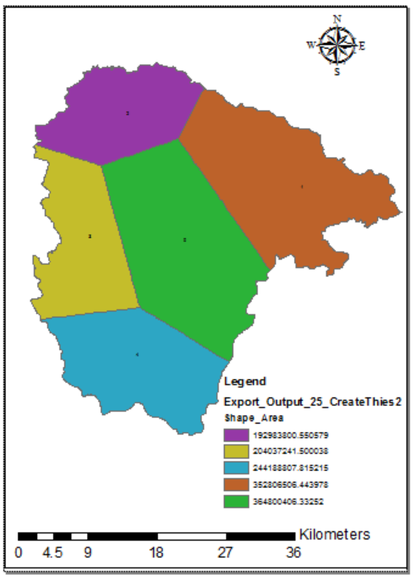

Fig 3 Thiesson polygon of study area for 5 rain gauge station

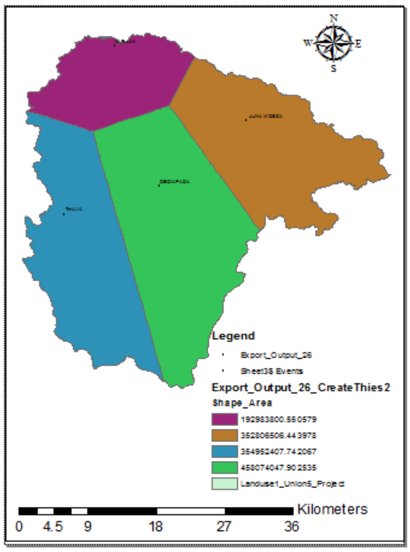

Fig 4 Thiesson polygon of study area for 4 rain gauge station

Surface runoff through SCS - CN model

Hydrological Soil Group is developed from the type of soil in the study area. Land use and land cover (LU/LC) map is integrated to Hydrological soil group map. The curve number map is developed in GIS based on HSG group and Land use Land cover [8][9]. The weighted curve number have been obtained by area-weighting calculated from the land use-soil group polygons within the drainage basin boundaries.

SCS-CN model

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 for estimating runoff from rainfall. This method also referred as the CN method [10]. The SCS curve number method is based on the water balance equation.

The SCS-CN method, expressed as equation (1) below.

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

$$Ia = 0.2S$$

where, Q = Accumulated storm runoff, m; P = Accumulated storm rainfall, mm, S = Potential maximum retention of water by the soil, Ia = Initial quantity of interception, depression and infiltration.

Substituting in equation (1), the equation becomes

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

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):

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

Where CN = function of watershed hydrologic land use/land cover units hydrologic soil groups antecedent moisture condition. CN values can be obtained for different land uses and hydrologic condition from the standard Table CN values for AMC-I and II can be obtained using the following equation (4) and equation (5).

The CN (dimensionless number ranging from 0 to 100) is determined from a Table 1 as shown below. Table 1 shows the Hydrologic Soil Group based on land-cover, AMC condition. HSG is expressed in terms of four groups (A, B, C, D) according to the soil's infiltration rate. AMC is expressed in three levels (I, II and III), according to rainfall limits for dormant and growing seasons. Table 2 shows the classification of the Antecedent moisture content.

Table 1: USDA-SCS Hydrologic Soil Group

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)

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	36-53mm
III	Heavy or light Rainfall and low temperatures have occurred within the last 5 days; saturated soils	> 28 mm	>53 mm

CN value is obtained from Technical release TR-55. [10].

Antecedent Soil Moisture condition (AMC)

Antecedent Moisture Condition (AMC) refers to the water content present in the soil at a given time. It is a factor important to determine 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. Classification of Antecedent Moisture Condition is shown in Table 4.2.

Since, standard table for CN values (ranges from 1 to 100), considering land use/cover and HSG are given for AMC-II [Ref.2], following conversion formulas are used to convert CN from AMC-II (average condition) to the AMC-I (dry condition) and AMC-III (wet condition) (SCS, 1972).

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

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

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

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.

$$CNw = \frac{\Sigma(CNi*Ai)}{A}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(6)$$

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

Hydrologic Soil Group (HSG) map

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 4.2 Category "C" has fine soils and Category "D" has clayey soils.

RESULTS

The Hydrological Soil Group map and Curve number map for the study area have been developed in GIS as shown in Figure 5 and Figure 6 respectively..

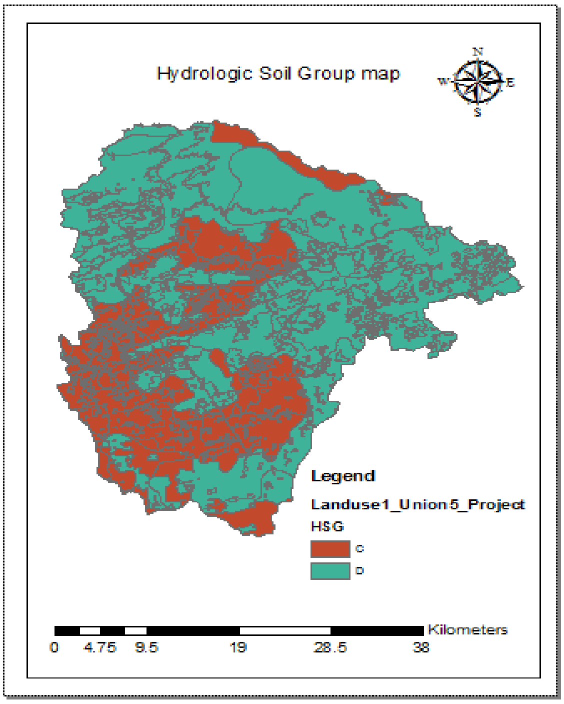

Fig 5: Hydrologic soil group map

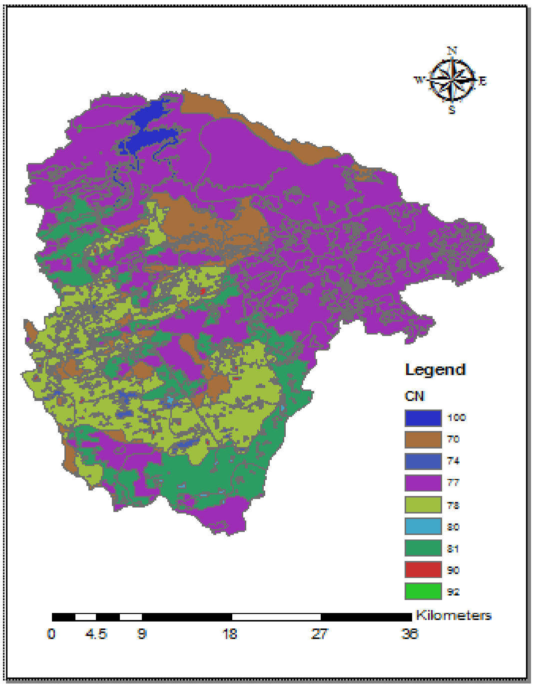

Fig 6: Curve Number (CN) map

Percentage area and Curve number can be used to find out area weighted curve number by using Equation (6). Estimated composite curve number for catchment area of Karjan is 88.95 for AMC-III. Details of curve number estimation for catchment area of Karjan are shown in Table 3.

Table 3: Details of weighted curve number of the study area

Land use type	Soil type	Area (km^2)	%Area	HSG	CN (AMC-II)	CN (AMC-III)	(%AREA*CN) /100	Area Weighted Curve Number
Agriculture	clayey	204.91	15.08	D	81	90.75	13.68	88.95
	fine	248.31	18.27	C	78	89.08	16.28	
built up	clayey	5.73	0.42	D	92	96.36	0.41	
	fine	9.87	0.73	C	90	95.39	0.69	
Forest	clayey	692.25	50.95	D	77	88.51	45.09	
	fine	133.66	9.84	C	70	84.29	8.29	
Others	clayey	0.67	0.05	D	80	90.20	0.04	
	fine	4.58	0.34	C	74	86.75	0.29	
Wastelands	clayey	4.57	0.34	D	80	90.20	0.30	
	fine	12.93	0.95	C	74	86.75	0.83	
Waterbodies	clayey	35.22	2.59	D	100	100.00	2.59	
	fine	6.10	0.45	C	100	100.00	0.45	

Table 4 and Figure 7 shows the annual rainfall and annual simulated runoff through SCS-CN model.

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
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

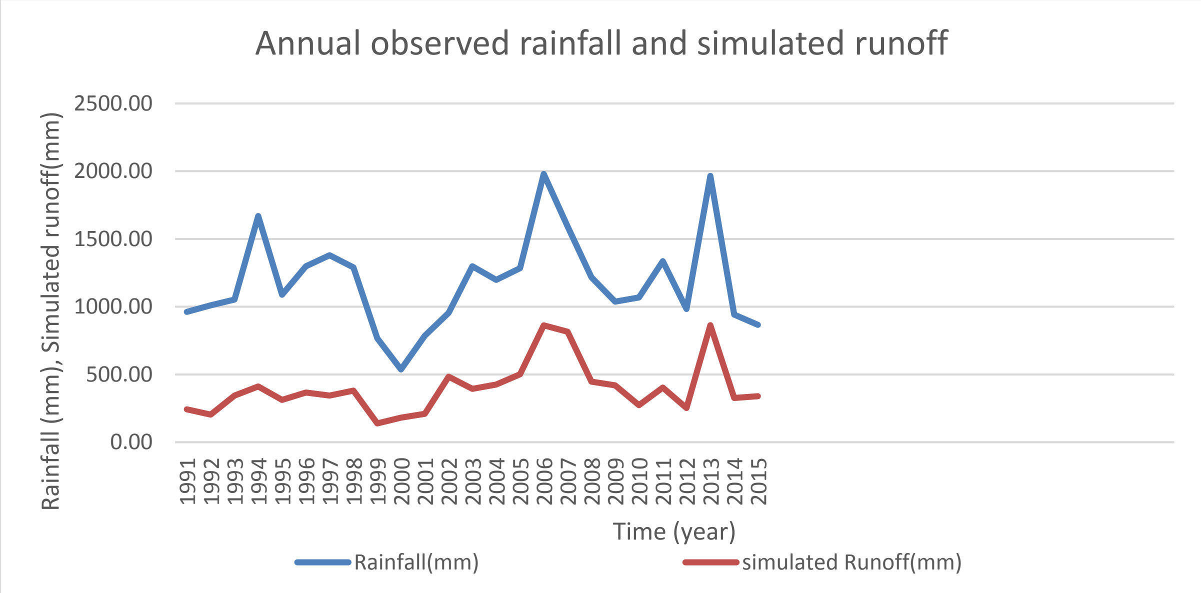

Fig 7: Annual Rainfall and Simulated runoff by SCS-CN method

Comparison of the result of SCS-CN model and regression model have been made and is as shown in Fig. 8.

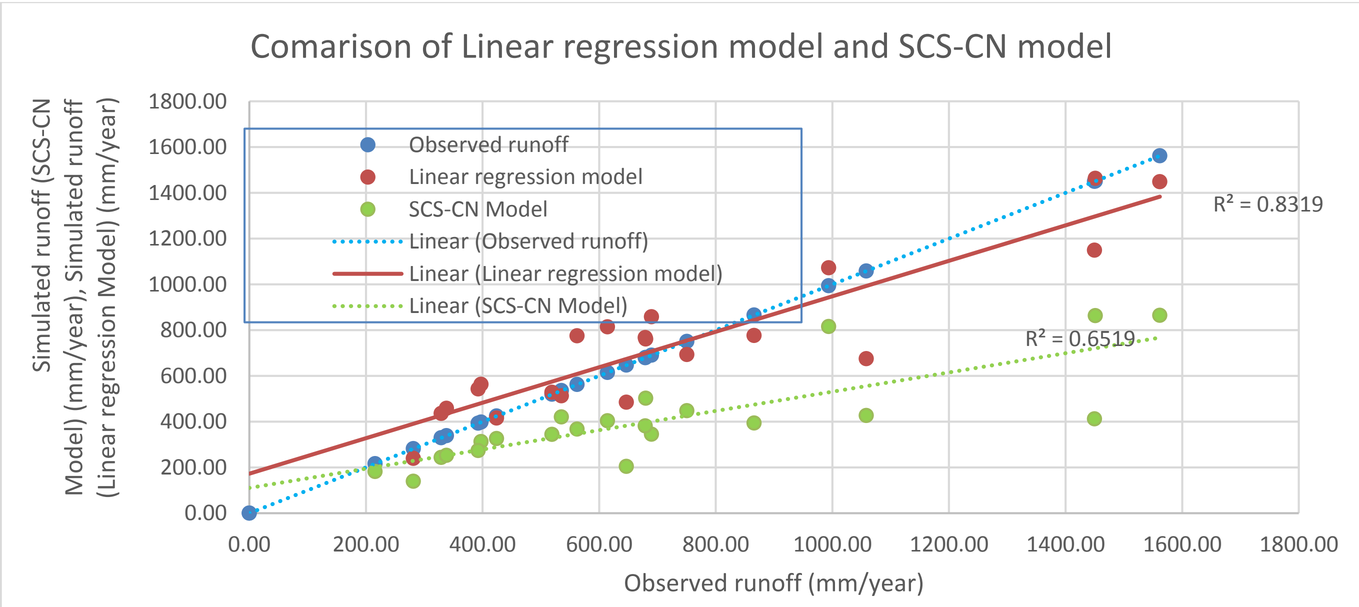

Fig 8: Annual observed runoff Vs. simulated runoff (SCS-CN model) and simulated runoff (Linear regression)

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 matching in comparison to SCS-CN model.

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.

ACKNOWLEDGEMENT

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