SCS-Curve Number Based Runoff Estimation for Dharta Watershed, Udaipur, Rajasthan

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Abstract: ***This study focuses on surface runoff estimation by using the SCS and Curve Number method (SCS-CN) in a catchment of Dharta watershed Udaipur district, Rajasthan. The daily and annual surface runoff was computed for the Sixteen-year period (2001-2016) by using the SCS-CN model. Land use/Land cover (LULC) map of the study catchment was prepared with the help of ArcGIS10.1. The study area consists of a total number of eleven distinct land use/Land cover types, namely Road, Railways, Drainage, Settlements, Kharif crop, Rabi crop, Rabi & Kharif crop, Fallow land, Land with shrubs, and Land without shrubs. It is apparent from the LULC map that agriculture land covers an area of 42.67 km2 encompasses the highest proportion (i.e. 67.68 %) in the study area. The hydrological soil group (HSG) of the catchment was assigned based on soil type. The weighted curve number under antecedent moisture condition (AMC) I, II, and III was computed as 57.56, 76.14, 88.00, respectively. The annual runoff ranged from 63.19 mm (17.40 % of rainfall) in the year 2002 to 445.20 mm (45.23% of rainfall) in the year 2006. Relatively high R2 0.86 values indicated a significant linear relationship between rainfall and runoff.***

Keywords: SCS-CN model, Surface Runoff, Dharta Watershed, Land use/Land cover map, AMC condition

1. Introduction

The correlation between amount of rainfall and the resultant amount of runoff is generally dependent on soil penetration characteristics. The type of land use and land cover, agricultural supervision, hydrologic conditions, type of soil distribution and soil wetness, these all things are essential for rainfall runoff analysis. Method used to estimate rainfall runoff is USDA – SCS, as runoff Curve Number (CN) method (USDA, 1972). This method has been used by many researchers to establish the rainfall runoff relationship (Stuebe & Johnston, 1990; Sharma *et al.*, 2001; Sharma & Kumar, 2002; Mishra *et al.* 2004; Pandey & Dabral, 2004; Pandey & Sahu, 2004; Pandey *et al.* 2005; Mishra *et al.* 2005; Jain *et al*. 2006). Curve number method depends on land use, management type, hydrologic conditions and hydrologic soil group. In this paper soil conservation service is used for the curve number (SCS-CN) approach for rainfall-runoff estimation with Antecedent moisture condition (AMC). SCS-CN approach is widely used as a simple method for predicting direct runoff volume for a given rainfall event. The CN parameter values corresponding to various soil, land cover, and land management conditions can be selected from tables, but it is preferable to estimate the CN value from measured rainfall-runoff data if available. However, previous researchers indicated that the CN values calculated from measured rainfall-runoff data vary systematically with the rainfall depth. Hence, they suggested the determination of a single CN value observed for very high rainfall depths to characterize the watersheds' runoff response. The Dharta watershed considered for study situated $74^0$08' to $74^0$15'E longitudes & $24^0$30' to $24^0$36'N latitudes, at Bhinder block of Udaipur district of Rajasthan (Fig. 1), the total watershed covered an area is 63.04 km^2. The catchment area is mainly occupied by agricultural lands.

2. Index Map of Study Area

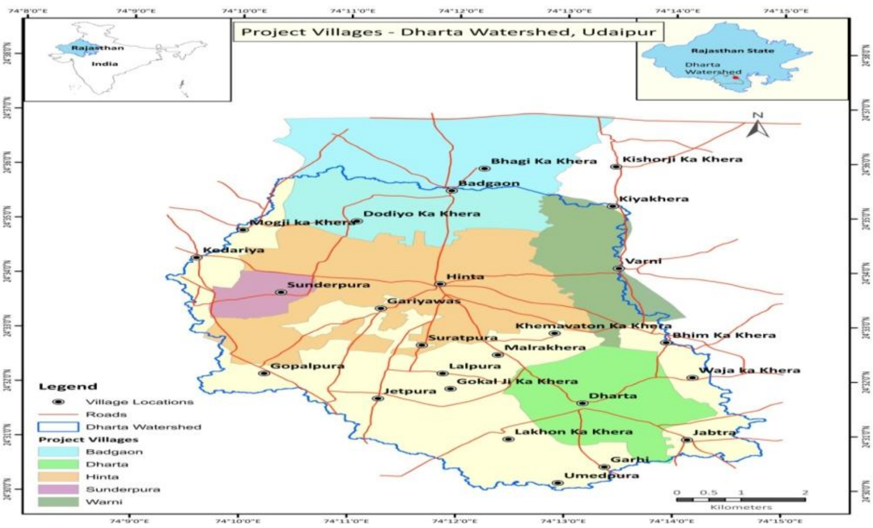

Figure 1: Location map of Study Area

3. Material and Method

3.1 SCS-CN Model

In this study, the Soil Conservation Service Curve Number (SCS-CN) model was used to estimate surface runoff for the study area. A stepwise methodology is given in flow chart (Fig. 2). Firstly, the surface runoff was computed on daily basis, which was later on converted to annual surface runoff value for Sixteen years (2001-2016).

The Soil Conservation Service Curve Number (SCS-CN) model developed by Soil Conservation Services (SCS) of USA in 1969 is a simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth (USDA SCS, 1969). It relies on only one parameter, *i.e.* curve number (CN). Currently, it is a well-established method, having been widely accepted for use in USA and many other countries (Sahu. *et al.*, 2007; Amutha and Porchelvan 2009; Pradhan *et al.*, 2010; Kumar *et al.*, 2012). The details of the SCS-CN model are described ahead.

The SCS-CN model is based on the water balance equation and two fundamental hypotheses. The first hypothesis equates the ratio of the amount of direct surface runoff (Q) to the total rainfall P (or maximum potential surface to the runoff) with the ratio of the amount of infiltration (F_c) to the amount of the potential maximum retention (S). The second potential equality hypothesis relates the initial abstraction (I_a) to maximum retention (S). Thus, the SCS-CN method consisted of the following equations (Subramanya, 2008).

Water balance equation:

$$P = I_a + F_c + Q \qquad \text{...... (i)}$$

First hypothesis:

$$\frac{Q}{P - I_a} = \frac{F_c}{S} \qquad \text{...... (ii)}$$

Second hypothesis:

$$I_a = \lambda S \qquad \text{...... (iii)}$$

Where, P = Total rainfall, I_a = Initial abstraction, F_c = Cumulative infiltration excluding I_a, Q = Surface runoff, S = Potential maximum retention or infiltration and λ = Regional parameter dependent on geologic and climatic factors ($0.1<\lambda<0.3$).

Solving equation i and ii;

$$Q = \frac{P - I_a}{P - I_a - S} \qquad \text{...... (iv)}$$

Or,

$$Q = \frac{(P - I_a)^2}{p - (\lambda - 1)S} \qquad \text{...... (v)}$$

The relation between I_a and S is developed by analyzing the rainfall and runoff data from experimental small watershed and is expressed as I_a = 0.2S. Combining the water balance equation and proportional equality hypothesis, the SCS-CN method is represented as:

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

The potential maximum retention storage 'S' of watershed is related to a CN, which is a function of land use, land treatments, soil type and antecedent moisture condition of watershed. The CN is dimensionless and its value varies from 0 to 100. The S-value in mm can be obtained from CN by using the relationship:

$$S = \frac{25400}{CN} - 254 \qquad \text{...... (vii)}$$

A CN of 100 represents a limiting condition of a perfectly impermeable catchment with zero retention, in which all rainfall becomes runoff. A CN of zero conceptualy represents the other extreme, with the catchment abstracting all rainfall and with no runoff regardless of the rainfall amount.

3.2 Curve Number

In determining the curve number, the hydrological classification of the soils is adopted. Here soils are classified into four classes A, B, C and D based on the infiltration and other characteristics (Singh *et al.*, 1981). The important soil characteristics that influence the hydrological classification of soils are effective depth of soil, average clay content, infiltration characteristics and the permeability. Following is a brief description of four hydrologic soil groups:

- Group A (Low Runoff Potential): Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sand or gravels. These soils have high rate of water transmission.
- Group B (Moderately Low Runoff Potential): Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soil with moderately fine to moderately coarse textures. These soils have moderate rate of water transmission.
- Group C (Moderately High Runoff Potential): Soils having low infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well-drained soil with moderately fine to moderately coarse textures. These soils have moderate rate of water transmission.
- Group D (High Runoff Potential): Soils having low infiltration rates when thoroughly wetted and consisting chiefly of clay soils with high swelling potential, soil with permanent high water table, soils with clay pan or clay layer at or near the surface and shallow soils over nearly impervious material.

3.3 Antecedent Moisture Condition

The antecedent moisture condition (AMC), depending upon accumulated rainfall amount occurred in previous five days, is an important criterion in deciding curve number. The AMC refers to the moisture content present in the soil at the beginning of the rainfall-runoff event under consideration. It is well known that initial abstraction and infiltration and are governed by the AMC. For purposes of practical applications, three levels of the AMC are recognized by the SCS-CN model as follows:

AMC I: Soils are dry but not to wilting point. Satisfactory cultivation has taken place.

AMC II: Average conditions.

AMC III: Sufficient rainfall has occurred within the immediate past five days and saturated soil conditions prevail. The criteria of three different AMC conditions depending on cumulative rainfall amount of five days are given in Table 1.

Table 1: Antecedent Moisture Conditions (AMC) for determining the values of CN

AMC Type	Total Rainfall in Previous 5 Days	
	Dormant Season	Growing Season
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

(*Source:* Soil Conservation Service 1972; Hawkins et al., 1985)

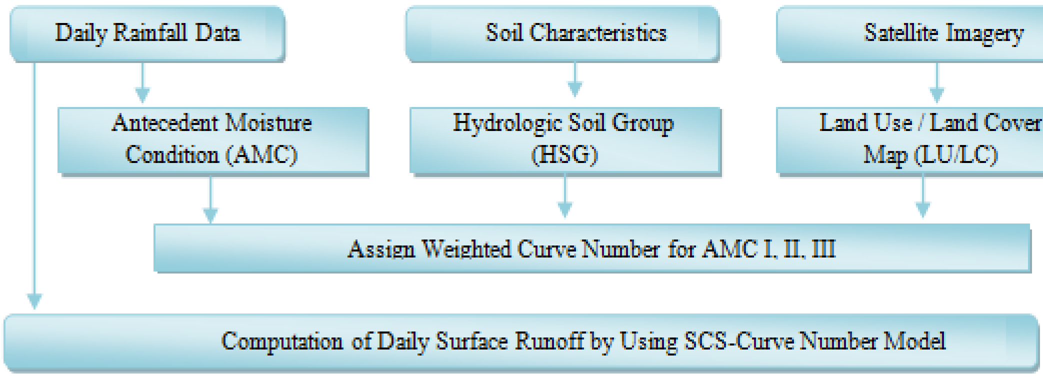

Figure 2: Flowchart illustrating methodology for SCS-CN based estimation of surface runoff

4. Results

4.1 Analysis of Rainfall Data

Analysis of rainfall is essential for estimating the groundwater recharge potential as it is the major source of recharge. Total rainfall for monsoon months, number of rainy days, and number of dry days of different intervals play an important role in groundwater recharge. Daily rainfall data of the period 2001 to 2016 were analyzed and results are presented in the following sections.

4.2 Rainfall Distribution

The yearly distribution of monsoon rainfall during the period of 2001-2016 is shown in Figure 3. Long term average monsoon rainfall is 606 mm and average annual rainfall is 688mm.

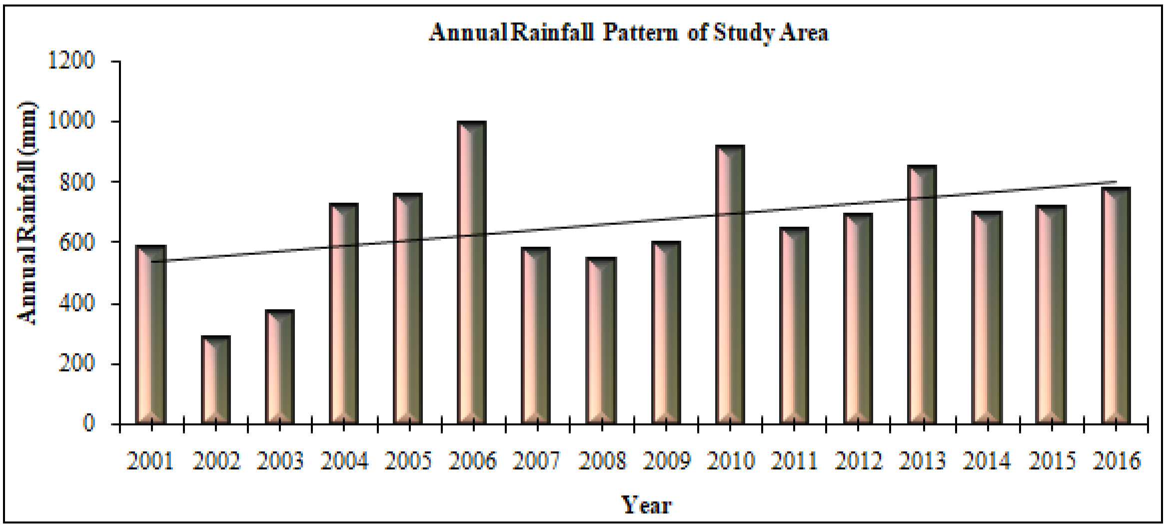

Figure 3: Yearly distribution of monsoon rainfall during 2001-2016

4.3 Rainy Days and Dry Days

The rainy days in the monsoon months having rainfall of 2.5 mm or more. The numbers of normal rainy days (average a number of rainy days duration of 2001-2016) were 27. The years 2006 and 2011 recorded the highest number of rainy days 37 and 34 days respectively. It was also observed that a number of rainy days in monsoon months had an increasing trend (Fig. 4). This indicates that year 2016 received good rainfall during monsoon months.

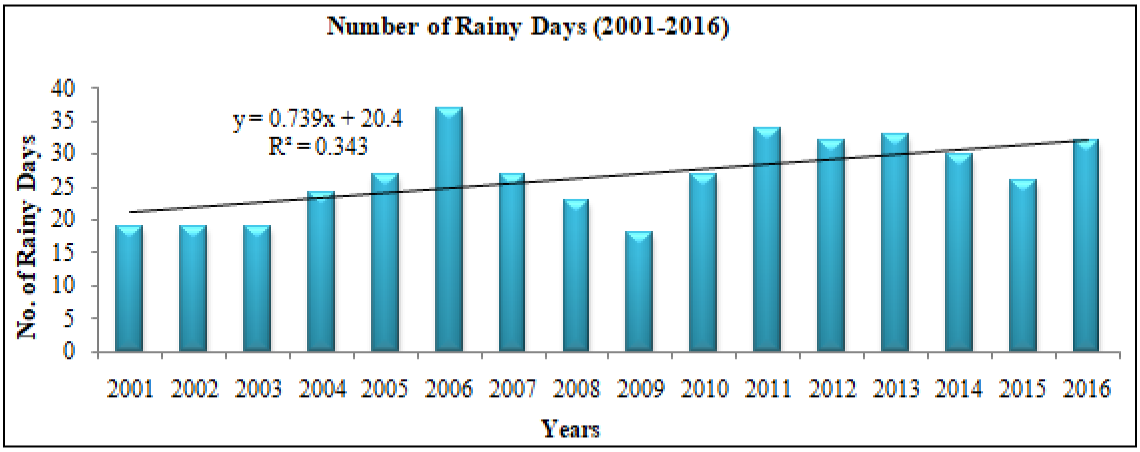

Figure 4: Yearly distribution of rainy days monsoon rainfall during 2001-2016

Consecutive dry days of 7 and 14 days were determined for monsoon months of each year from 2001 to 2016. This was done to establish the trend of consecutive dry days cover the years (Table 2). A number of consecutive dry days of 7 days varied from 0 to 3 duration from 2001 to 2016. A maximum number of consecutive 7 dry days were observed in 2005, 2009, and 2011 (each year has 3 events). Consecutive dry days of 14 days varied from 0 to 4. Years 2008 recorded 4 spells. In the year 2001, 2003, 2009 & 2015 there was 1 event of consecutive equal to or more than 30 days dry spell. One event of a dry spell of consecutive 20 days was in almost year of duration 2001-2016.

Table 2: Number of rainy days and dry days

Year	Number of Rainy days	Consecutive 7 dry days	Consecutive 14 dry days	Consecutive 20 dry days	Consecutive =<30 dry days
2001	19	2	1	0	1
2002	19	2	2	1	0
2003	19	2	3	0	1
2004	24	1	2	1	0
2005	27	3	2	1	0
2006	37	2	2	0	0
2007	27	2	1	1	0
2008	23	2	4	0	0
2009	18	3	2	0	1
2010	27	0	3	0	0
2011	34	3	0	1	0
2012	32	2	1	1	0
2013	33	2	0	1	0
2014	30	1	1	1	0
2015	26	1	1	1	1
2016	32	2	0	1	0

The results revealed that rainfall during monsoon is erratic and dry spells of longer duration exhibit an increasing trend. This would decrease the natural groundwater recharge at Dharta watershed. The declining trend of the total number of rainy days and increasing trend of consecutive dry days of longer intervals in monsoon months are major concerns from groundwater recharge, development, and management point of view.

Estimation of Surface Runoff

Land Use/Land Cover Type of the Study Area

The study area consists of a total number of eleven distinct land use/land cover types, namely Road, Railways, Drainage, Settlements, Kharif crop, Rabi crop, Rabi & Kharif crop, Fallow land, Land with shrubs, and Land without shrubs. Areas under distinct land cover types are given in Table 4.4. It is apparent that agriculture land covers an area of 42.67 km 2 encompasses the highest proportion (i.e. 67.68 %) in the study area. Whereas, water body with 0.53 km2 area has the least extent (i.e. 0.84 %) in the study area. It is discernible that forests are located near the boundaries of the study area. Cultivation in the study area mainly takes place nearby watercourses. This is most likely due to the low-cost availability of nearby river water for irrigation water supply. Settlement lands are concentrated in the central part of the study area. Curve number values for antecedent moisture condition (AMC) type II assigned to HSG classes C and eleven categories of the LULC features are mentioned in Table 3.

The weighted curve number for the entire study area was worked out to be 76.14 under AMC II conditions for computing runoff from the catchment. The curve number for the AMC I and AMC III was computed to be 57.26 and 88.0, respectively.

Table 3: Curve numbers for different land use/land cover classes under hydrologic soil groups

S. No.	Land Use	Area, Ha	Curve Number	HSG	CN*Area, (Ha)
1	Road	95	82	B	7790
2	Railway	6	82	B	492
3	Drainage	57	100	B	5700
4	Waterbody	53	100	B	5300
5	Settelement	147	82	B	12054
6	Kharif Crop	2718	81	B	220158
7	Rabi Crop	1193	78	B	93054
8	Rabi And Kharif Crop	356	78	B	27768
9	Fallow Land	251	86	B	21586
10	Land With Scrubs/Shrubs	236	77	B	18172
11	Land Without Scrubs/Shrubs	1192	57	B	67944
	TOTAL	6304		B	480018
Weighted Curve Number for AMC II				76.14	

Runoff amounts were also computed as the proportion of the rainfall for sixteen years and annual runoff as a percentage of annual rainfall is shown in Table 5. It is observed that the proportion of rainfall to runoff varies from 17.40 % to 45.23 % over the sixteen-year period. The small proportion of the rainfall to runoff is most likely due to the semi-arid climate of the study area, and the occurrence of short-intensity and long-duration rainfall events with long-dry spells between two consecutive rainfall events. Due to dry spells, soil moisture deficiency occurs in the topsoil and a portion of next rainfall event contributes to raising soil moisture to its field capacity. The mean annual rainfall for the study area (688 mm) produces a mean annual runoff of 222mm, which is 28.93% of the mean rainfall.

The computed weighted curve numbers for AMC I, II, and III were used to estimate surface runoff on daily basis for sixteen years (2001-2016) in the study area by using the SCS-CN method through the developed spreadsheet programs in MS-Excel. The daily runoff values were converted to annual runoff values, which are shown in Table 5 along with the corresponding annual rainfall values (Fig.5). It is seen from Table 5 that the highest (445.20 mm) and the lowest (63.19 mm) amounts of the runoff could be generated in the years 2006 and 2002, respectively. The highest and the lowest amounts of annual runoff are due to the corresponding maximum and minimum annual rainfall amounts (985 and 363 mm, respectively) in the same years.

Table 5: Observed rainfall and estimated runoff amounts for sixteen-year (2001-2016) period

S. No.	Annual Rainfall	Annual Runoff(Q)	% Runoff
2001	531.20	157.93	29.73
2002	363.30	63.198	17.40
2003	497.40	118.30	23.78
2004	601.00	213.60	35.54
2005	885.20	398.61	45.03
2006	984.30	445.20	45.23
2007	494.30	90.59	18.33
2008	572.20	130.84	22.87
2009	489.60	100.15	20.46
2010	790.40	199.60	25.25
2011	1100.40	387.73	35.24
2012	666.90	195.18	29.27
2013	848.30	249.55	29.42
2014	692.20	185.33	26.77
2015	711.50	203.27	28.57
2016	774.70	232.23	29.98
Average	687.68	210.71	28.93

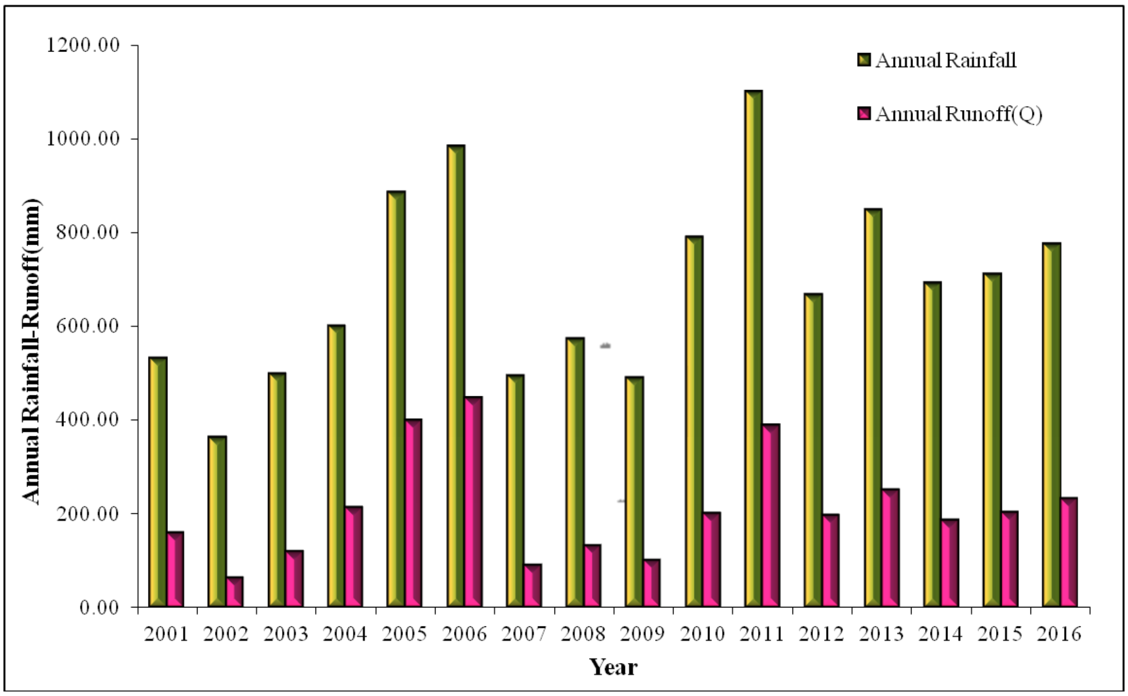

Figure 5: Graphical representation of rainfall- runoff of study area

Rainfall-Runoff Relationship

The estimations of the observed yearly precipitation and the assessed yearly runoff were plotted on x-y dissipate plot and a direct model was fitted to the plot to locate a straight connection between two information. The observed rainfall-runoff information and the fitted straight model is appeared in Fig. 6 alongside the created numerical model and the estimation of the coefficient of determination (R^2). The R^2 is used as a performance indicator to measure the significance of the developed linear relationship. The R^2 value is 0.86, which indicates a strong relationship between the annual rainfall and runoff for the study area.

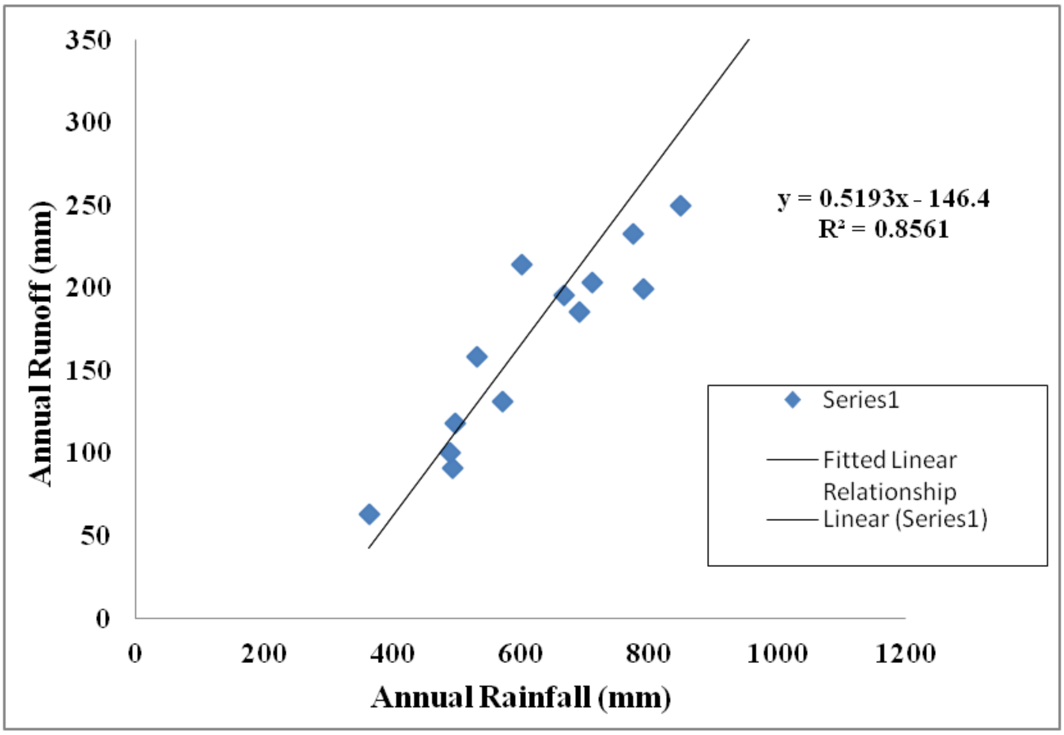

Figure 6: Linear rainfall-runoff relationship for 16-year period (2001-2016) data

Relation between Rainfall and Water Level

Rainfall pattern in the last 16 years (2001-2016) shows a wide variation e.g. annual rainfall in 2006, 2010, 2013 were higher than the rest of the years. A rainfall pattern, post-monsoon water level during the study periods that is 2014, 2015 years does not show much variation but in 2016 rainfall show high variation . The high variation is due to the variation (increase or decrease) in rainfall in particular years. It means recovery in water level takes place when the rainfall is more & vice-versa. An attempt was made to correlate the trend of water level in Pre & Post monsoon season with the annual & monsoonal rainfall of the wells located in the five Study villages viz. Hinta, Dharta, Badgaon, Sunderpura, & Varni.

5. Conclusion

The SCS-CN method facilitates runoff estimation and improves the accuracy of estimated data. Fairly comparable values are found between observed and computed values indicating a fair correlation. It is highly essential to assign Curve Number based on hydrologic soil group, land cover and A.M.C conditions judiciously, because chances of errors are very high. Higher the value of curve number, lower is the maximum potential retention and higher are the values of runoff depth and runoff depth percent. This is because higher values of curve number correspond to higher runoff and low infiltration. Results obtained clearly show the variation in runoff potential with different land use/land cover and with different soil conditions. The weighted curve number computed for this study is 76.14 for AMC II. From SCS Curve number, the maximum runoff for the watershed was estimated to be 445.23 mm in the year 2006 and minimum runoff of 63.19 mm in the year 2002.

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