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Estimation of Surface Runoff by Soil Conservation Service Curve Number Model for Upper Cauvery Karnataka

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Abstract- Accurate estimation of runoff and sediment yield amount is not only an important task in physiographic but also important for proper watershed management. Watershed is an ideal unit for planning and management of land and water resources. Direct runoff in a catchment depends on soil type, land cover and rainfall. Of the many methods available for estimating runoff from rainfall, the curve number method (SCS-CN) is the most popular. The curve number depends upon soil and land use characteristics. This study was conducted in the Upper Cauvery Karnataka using remote sensing and GIS. SCS-CN method has been used for surface runoff estimation for Eight watersheds of Upper Cauvery. The soil map and land use were created in the GIS environment, because the curve number method is used here as a distributed model. The major advantage of employing GIS in rainfall -runoff modelling is that more accurate sizing and catchment characterization can be achieved. Furthermore, the analysis can be performed much faster, especially when there is a complex mix of land use classes and different soil types. The results showed that the surface runoff ranged from 170.12-599.84 mm in the study area, when rainfall rates were received from 1042.65-1912 mm. To find the relationship between rainfall and runoff rates, The straight line equation was used, That was found there a strong correlation between Runoff and precipitation rates, The value correlation coefficient between them was 86%. The Average depth of runoff is more in watershed A4, Average runoff coefficient is less in Watershed B2, the correlation coefficient is high in A4 to a value of almost 95%. Through of these results, the study recommends take advantage of runoff rates by reserving them at collection of Watershed and then using them for agricultural purposes in the vicinity. This would be better than reserving water from the total area which is 10874.65 square kilometers, and then will evaporate or infiltrate before reaching the dam lake.

***Key words**:* AMC Condition, Curve Number, Infiltration, Rainfall, Runoff, Theisson polygon.

I. PREAMBLE

Runoff means the drainage of flowing off of precipitation from a catchment area through a surface channel. Thus, it represents the output from the catchment in a given unit of time. To determine the quantity of surface runoff that takes place in any river basin, understanding of complex rainfall and runoff processes which depends upon many geomorphologic and climatic factors are necessary. Estimation of surface runoff is essential for the assessment of water yield potential of the watershed, planning of water conservation measures, recharging the ground water zones and reducing the sedimentation and flooding hazards downstream. Also it is an important and essential prerequisite of Integrated Watershed Management (IWM).
Runoff is one of the most important hydrologic variables used in most of the water resources applications. Reliable prediction of quantity and rate of runoff from land surface into streams and rivers is difficult and time consuming to obtain for ungauged watersheds, however, this information is needed in dealing with many watershed development and management problems. Conventional methods for prediction of river discharge require hydrological and metrological data. Experience has shown that SOI topomap data can be interpreted to derive thematic informations on land use/land cover, soil, vegetation, drainage, etc. which combined with conventionally measured climatic parameters (precipitation, temperature etc) and topographic parameters such as height, contour, slope provide the necessary inputs to the rainfall-runoff models.

II. MATERIALS AND METHODS

A. Study Area

The study area geographically lies between 75^0 29’ 19” E and 76^0 37’ 40” E longitude and 11^0 55’ 54” N and 13^0 23’ 12.8” N latitude, as shown in Fig 1, and has an area of 10874.65 Sq km [3]. The maximum length and width of the study area is approximately equal to 143.73 km and 96.75 km respectively. The maximum and minimum elevation of the basin is 1867 m and 714 m above MSL, respectively. The study area covers five district of Karnataka state i.e., Chikmangalur, Hassan, Kodagu, Mandya and Mysore as shown in Fig 2 [6]. It is divided in eight watersheds (A1, A2, A3, A4, B1, B2, B3 and B4) as shown in Fig 3 [4]. The total Area (A), Perimeter (P) of Eight Watersheds is calculated using Arc GIS and values are tabulated in Table 1.

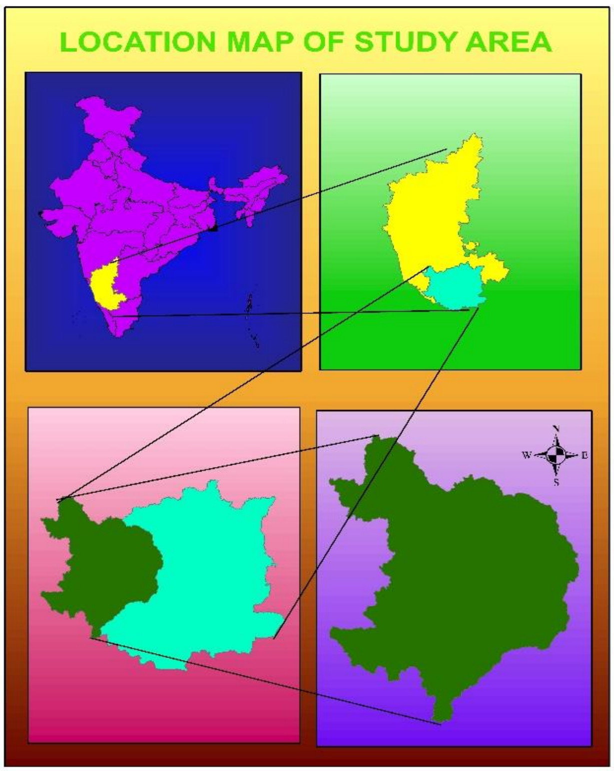


Fig 1 Location Map of Study Area

The study area which is of 10874.65 km^2 was divided into eight watersheds as (A1, A2, A3, A4, B1, B2, B3 and B4). Forty three raingauges were considered namely kushalnagar, malalur, mallipatna, nuggehalli, periyapatna, ponnampet, sakaleshpur, salagame, shantigrama, arehalli, arkalgud, basavapatna, bettadapura, bilur, channenahally, chikkamagalur, doddabemmatti, galibidu, gonibeedu, gorur, hagare,halllibailu, hallimysore, harangi, hassan, hosakere, hunsur, kechamanna hosakote, naladi, shantebachahalli, belur, belagodu, javali, talakavery, shravanabelagola, siddapura, srimangala, sukravarsanthe, krishnarajpet, virajpet and yelawala. Rainfall data was collected from 2001 to 2015.

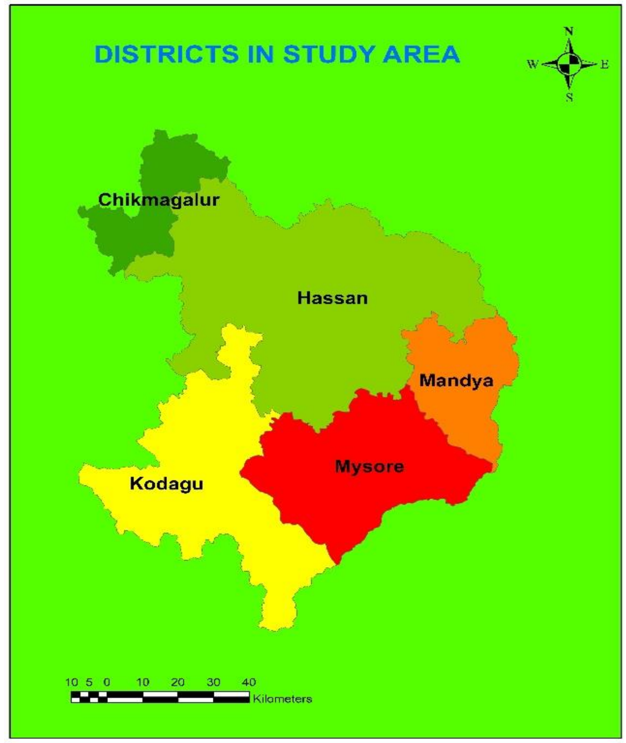


Fig 2 Districts in Study Area

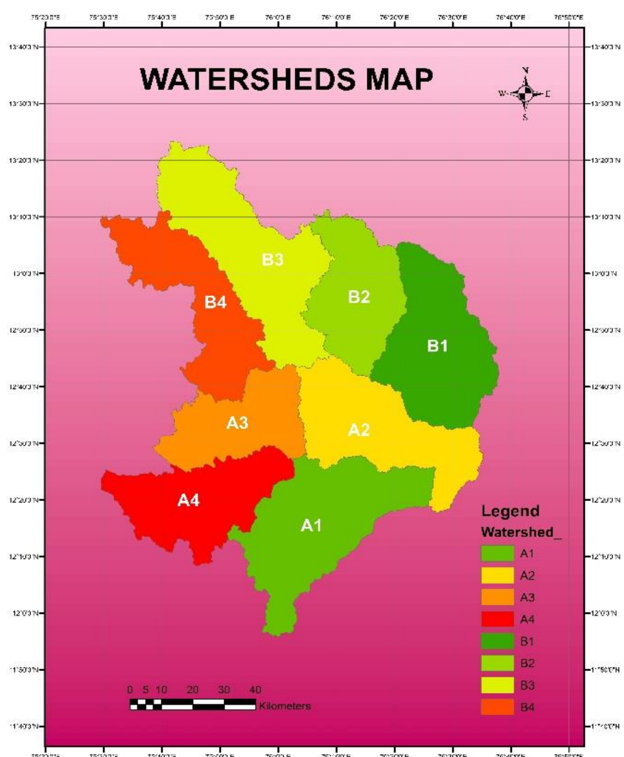


Fig 3 Watershed Map

Table 1 : Watersheds of Upper Cauvery Catchment				
Subwatersheds	Area (km^2)	Perimeter (km)	Length (km)	Width (km)
A1	1705.50	263.13	76.20	56.52
A2	1411.28	244.53	50.02	24.30
A3	973.81	201.52	38.50	22.84
A4	1205.17	222.98	52.17	22.21
B1	1463.36	202.94	38.75	24.87
B2	1097.97	193.21	31.85	30.40
B3	1759.84	315.76	86.83	21.3
B4	1257.72	297.45	65.26	15.22

B. Methodology

Soil Conservation Service (SCS) Curve Number Model

In this model, runoff will be determined as a function of current soil moisture content, static soil conditions, and management practices. Runoff is deduced from the water available to enter the soil prior to infiltration. Fig.4 shows the methodology adopted for runoff estimation using SCS curve number method. This method is also called hydrologic soil cover complex number method. It is based on the recharge capacity of a watershed. The recharge capacity can be determined by the antecedent moisture contents and by the physical characteristics of the watershed. Basically the curve number is an index that represents the combination of hydrologic soil group and antecedent moisture conditions. The SCS prepared an index, which is called as the runoff Curve Number to represent the combined hydrologic effect of soil, land use and land cover, agriculture class, hydrologic conditions and antecedent soil moisture conditions. These factors can be accessed from soil survey and the site investigations and land use maps, while using the hydrologic model for the design.

The specifications of antecedent moisture conditions is often a policy decision that suggest the average watershed conditions rather than recognitions of a hydrologic conditions at a particular time and places.

Expressed mathematically as given,

$$\frac{Q}{P-Ia} = \frac{F}{S} \quad (1)$$

Where Q is the runoff, P is the precipitation and F is the infiltrations and it is the difference between the potential and accumulated runoff. Ia is begining abstraction, which represents all the losses before the runoff begins. It include water retained in surface depressions, water intercepted by vegetations, and initial infiltrations. This is variable but generally is correlated with soil and land cover parameter; S is the potential infiltrations after the runoff begins.

Thus, a runoff curve numbers is defined to relate the unknown S as a spatially distributed variables are,

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

$$Q = \frac{(P-0.2S)2}{(P+0.8S)} \quad (3)$$

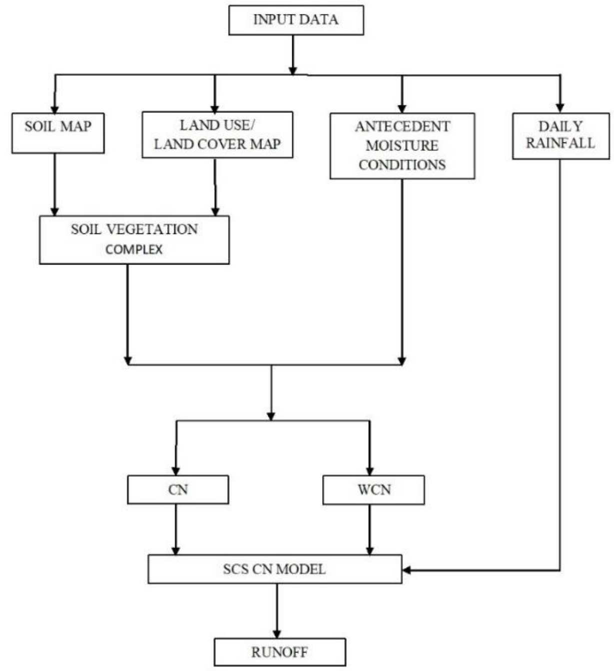


Fig 4: Methodology SCS Curve Number

Determination of Curve Number (CN)

The SCS cover complex classification consists of three factors: land use, treatment of practice and hydrologic condition. There are approximately eight different land use classes that are identified in the tables for estimating curve number. Cultivated land uses are often subdivided by treatment or practices such as contoured or straight row. This separation reflects the different hydrologic runoff potential that is associated with variation in land treatment. The hydrologic condition reflects the level of land management; it is separated with three classes as poor, fair and good. Not all of the land use classes are separated by treatment or condition.

CN values for different land uses, treatment and hydrologic conditions were assigned based on the curve number table. Runoff Curve Numbers for (AMC II) hydrologic soil cover complex is shown in Table 2.

Table 2 Runoff Curve Numbers for (AMC II) hydrologic soil cover complex

Sl No	Land use	Hydrologic Soil Group			
		A	B	C	D
1	Agricultural land without conservation (Kharif)	72	81	88	91
2	Double crop	62	71	88	91
3	Agriculture Plantation	45	53	67	72
4	Land with scrub	36	60	73	79
5	Land without scrub (Stony waste/rock outcrops)	45	66	77	83
6	Forest (degraded)	45	66	77	83
7	Forest Plantation	25	55	70	77
8	Grass land/pasture	39	61	74	80
9	Settlement	57	72	81	86
10	Road/railway line	98	98	98	98
11	River/Stream	97	97	97	97
12	Tanks without water	96	96	96	96
13	Tank with water	100	100	100	100

Hydrological Soil Group Classification

SCS developed a soil classification system that consists of four groups, which are identified as A, B, C, and D according their minimum infiltration rate. The identification of the particular SCS soil group at a site can be done by one of the following three ways (i).soil characteristics (ii).county soil surveys and (iii).minimum infiltration rates. Table 2 shows the minimum infiltration rates associated with each soil group.

Group A

Soils in this group have a low runoff potential (high-infiltration rates) even when thoroughly wetted. They consist of deep, well to excessively well-drained sands or gravels. These soils have a high rate of water transmission.

Group B

Soils in this group have moderate infiltration rates when thoroughly wetted and consists chiefly of moderately deep to deep, well-drained to moderately well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Group C

Soils have slow infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes the downward movement of water, or soils with moderately fine-to fine texture. These soils have a slow rate of water transmission.

Group D

Soils have a high runoff potential (very slow infiltration rates) when thoroughly wetted. These soils consist chiefly of clay soils with high swelling potential, soils with a permanent high-water table, soils with a clay layer near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission

Antecedent Moisture Condition (AMCs)

Antecedent Moisture Condition (AMC) refers to the water content present in the soil at a given time. The AMC value is intended to reflect the effect of infiltration on both the volume and rate of runoff according to the infiltration curve. The SCS developed three antecedent soil-moisture conditions and labeled them as I, II, III. These AMC's correspond to the following soil conditions. Table shows the AMC's classification.

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

AMC II: Average conditions.

AMC III: Heavy rainfall or light rainfall and low temperatures have occurred within last 5 days; Saturated soils. Table 4 shows the seasonal rainfall units for the AMC classification and for CN.

The value of CN is shown for AMC II and for a variety of land uses, soil treatment, or farming practices. The hydrologic condition refers to the state of the vegetation growth. The Curve Number values for AMC-I and AMC-III can be obtained from AMC-II by the method of conservation. The empirical CN_1 and CN_3 equations for conservation methods are as follows:

$$CN_1 = \frac{CN_2}{2.281 - 0.01281 CN_2} \quad (4)$$

$$CN_3 = \frac{CN_2}{0.427 + 0.00573 CN_2} \quad (5)$$

A weighted runoff was estimated for the watershed as

$$Weighted Q = \frac{(A_1 * q_1 + A_2 * q_2 + \ldots\ldots\ldots + A_n * q_n)}{(A_1 + A_2 + \ldots\ldots\ldots + A_n)}$$

where A_1, $A_2 \ldots A_n$ are the areas of the watersheds having respective runoff q_1, $q_2 \ldots . q_n$. The weighted runoff approach was again extended to quantify the total amount of runoff from the entire Area.

Table 3 Minimum infiltration rates associated with each soil group

Soil Group	Minimum Infiltration Rate (mm/hr)
A	7.62 - 11.43
B	3.81 - 7.62
C	1.27 - 3.81
D	0 - 1.27

Table 4 Antecedent Moisture Condition (AMCs)

AMC_S	FIVE DAYS ANTECEDENT RAINFALL (mm)	
	Dormant season	Growing season
I	< 12.7 mm	<35.56 mm
II	12.7-27.94 mm	35.56-53.34 mm
III	> 27.94 mm	53.34 mm

III. RESULTS AND DISCUSSIONS

Theisson polygon maps were generated for all the watersheds as shown in fig 6. Watershed B1 was influenced by less station and watershed B3 was influenced by more raingauge stations. Curve number map for whole area was generated as shown in fig 5. It was observed the in case of watershed A1 the average runoff coefficient was about 0.19 with correlation coefficient of 89%, In watershed A2 the average runoff coefficient was about 0.18 with correlation coefficient of 79%, In watershed A3 the average runoff coefficient was about 0.16 with correlation coefficient of 81%, In watershed A4 the average runoff coefficient was about 0.33 with correlation coefficient of 95%, In watershed B1 the average runoff coefficient was about 0.15 with correlation coefficient of 82%, In watershed B2 the average runoff coefficient was about 0.12 with correlation coefficient of 80%, In watershed B3 the average runoff coefficient was about 0.16 with correlation coefficient of 88% and in watershed B4 the average runoff coefficient was about 0.24 with correlation coefficient of 90%. The weighted of all these values gives the amount for the total area as rainfall varies from 1042.65 to 1912 mm from 2001 to 2015 with an average value of 1486.80mm the runoff of these area varies from 170.12 to 599.84 mm with the average value of 366.20mm. The correlation coefficient of the total area is as high as 86%.

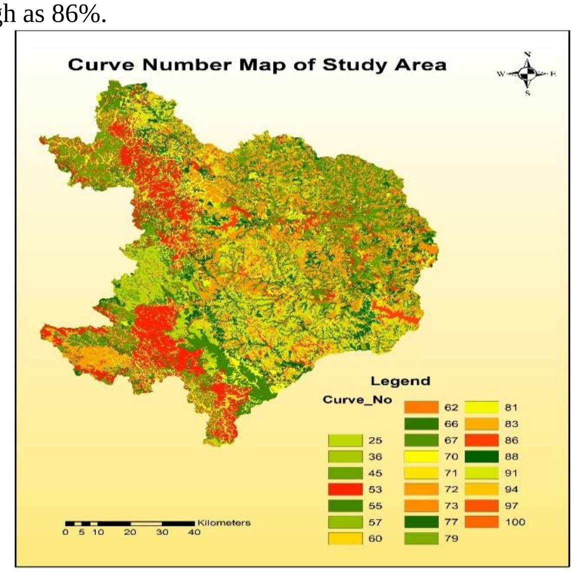
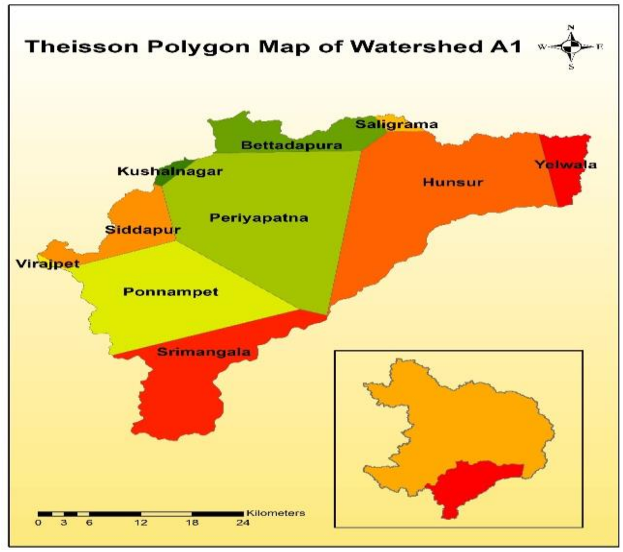
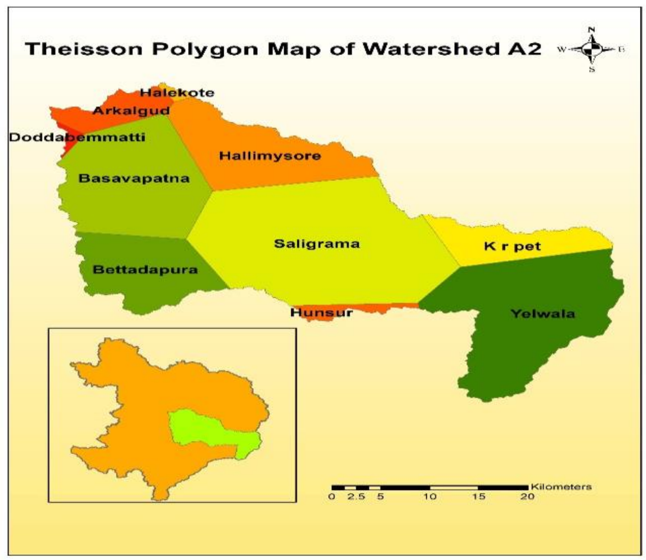
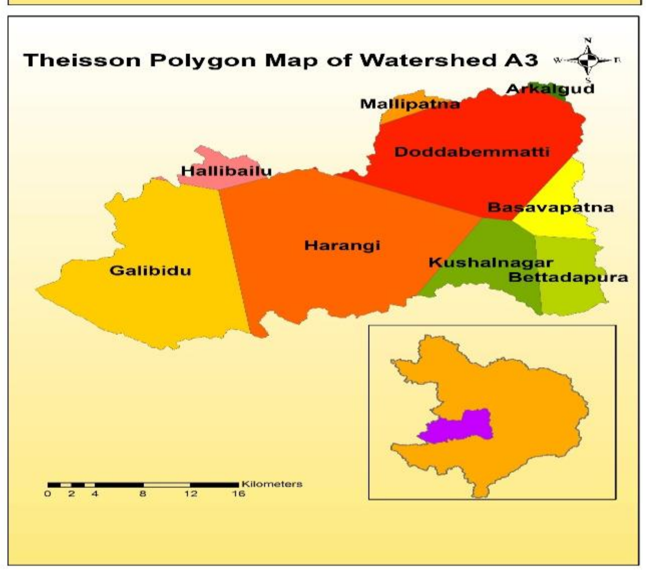
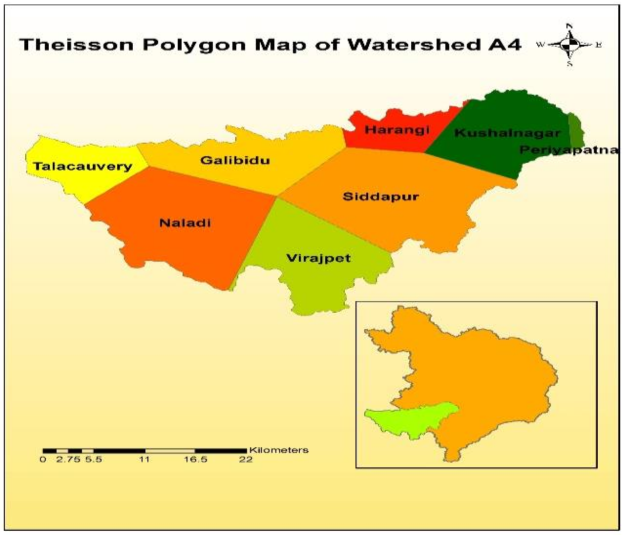


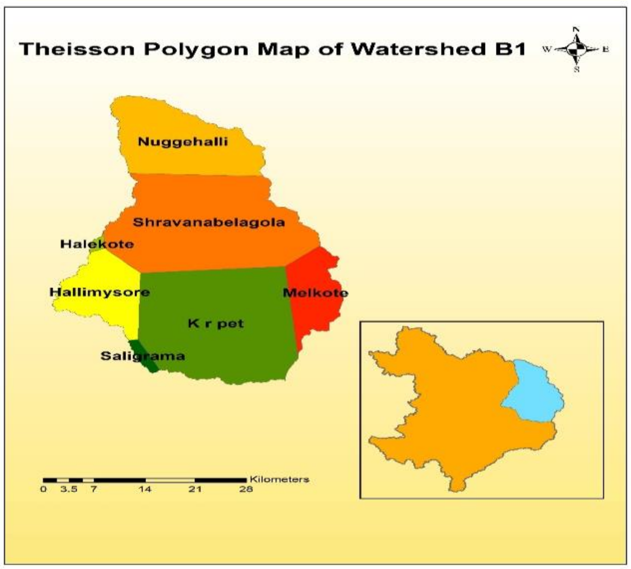
Fig 5: Curve Number Map

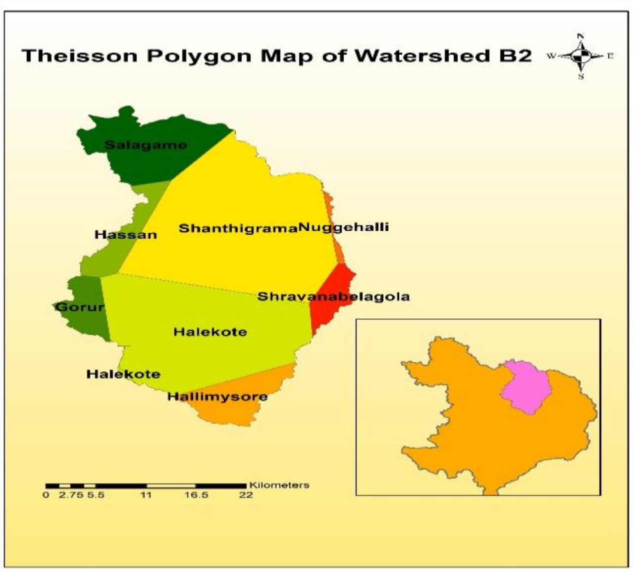


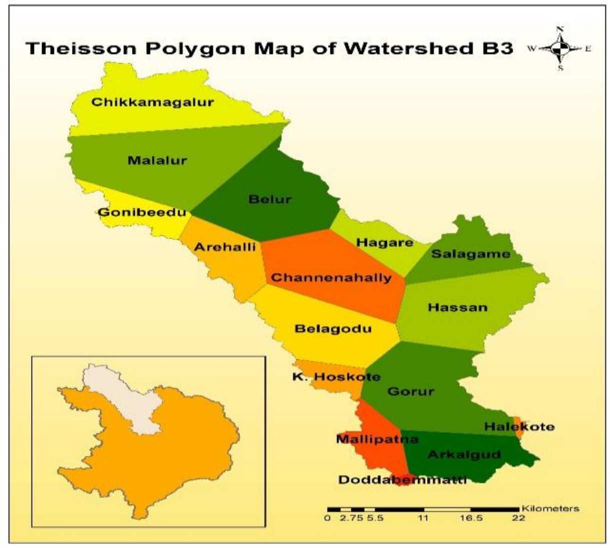












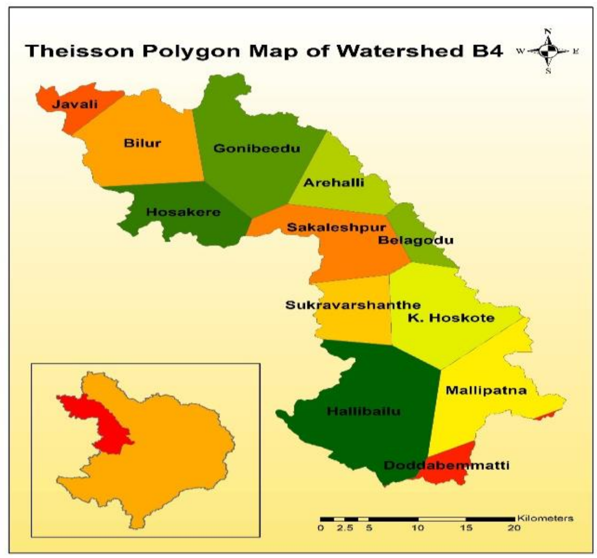


Fig 6: Theisson Polygon Map

Table 5: Runoff for Watershed A1

Year	RainFall in mm	Runoff in mm	Runoff Coefficient
2001	1191.59	258.86	0.22
2002	1011.32	159.14	0.16
2003	995.92	113.28	0.11
2004	1217.19	209.29	0.17
2005	1741.97	400.80	0.23
2006	1402.97	259.13	0.18
2007	1803.85	519.15	0.29
2008	1206.21	186.28	0.15
2009	1477.18	335.52	0.23
2010	1285.60	174.35	0.14
2011	1410.17	196.34	0.14
2012	1035.03	164.08	0.16

2013	1427.89	310.84	0.22
2014	1357.17	260.69	0.19
2015	1058.20	199.92	0.19

Table 6: Runoff for Watershed A2

Year	RainFall in mm	Runoff in mm	Runoff Coefficient
2001	753.37	172.01	0.23
2002	599.81	135.66	0.23
2003	558.72	83.78	0.15
2004	913.84	193.75	0.21
2005	1058.56	251.16	0.24
2006	573.64	75.21	0.13
2007	831.42	153.51	0.18
2008	838.18	127.55	0.15
2009	801.10	157.85	0.20
2010	907.81	152.77	0.17
2011	691.24	105.76	0.15
2012	466.92	64.56	0.14
2013	710.72	100.94	0.14
2014	873.56	190.04	0.22
2015	889.22	156.86	0.18

Table 7: Runoff for Watershed A3

Year	RainFall in mm	Runoff in mm	Runoff Coefficient
2001	1474.26	175.84	0.12
2002	1313.55	196.31	0.15
2003	1501.03	214.24	0.14
2004	1797.72	317.01	0.18
2005	2224.87	424.14	0.19
2006	1942.45	330.47	0.17
2007	2097.81	477.97	0.23
2008	1706.08	276.74	0.16
2009	1765.05	299.29	0.17
2010	1674.08	177.32	0.11
2011	1893.61	249.34	0.13
2012	1142.17	153.90	0.13
2013	2329.26	459.47	0.20
2014	1771.54	331.77	0.19
2015	1587.76	230.63	0.15

Table 8: Runoff for Watershed A4

Year	RainFall in mm	Runoff in mm	Runoff Coefficient
2001	2657.37	741.26	0.28
2002	2354.02	681.58	0.29
2003	2290.68	590.08	0.26
2004	2776.78	844.76	0.30
2005	3646.19	1377.92	0.38
2006	3770.65	1505.20	0.40
2007	4237.52	1917.65	0.45
2008	2796.72	865.95	0.31
2009	3243.68	1232.64	0.38
2010	2825.84	746.72	0.26
2011	3248.44	1051.83	0.32
2012	2401.43	731.98	0.30
2013	3458.81	1253.20	0.36
2014	3373.85	1338.19	0.40
2015	2714.05	826.72	0.30

Table 9: Runoff for Watershed B1

Year	RainFall in mm	Runoff in mm	Runoff Coefficient
2001	858.49	128.95	0.15
2002	757.85	108.34	0.14
2003	616.75	90.85	0.15
2004	1047.45	142.88	0.14
2005	1205.10	243.35	0.20
2006	740.20	95.30	0.13
2007	1049.23	217.63	0.21
2008	1073.23	176.97	0.16
2009	1132.55	234.99	0.21
2010	1122.84	166.31	0.15
2011	859.37	105.52	0.12
2012	548.42	61.77	0.11
2013	836.21	93.76	0.11
2014	927.69	146.59	0.16
2015	743.35	103.63	0.14

Table 10: Runoff for Watershed B2

Year	RainFall in mm	Runoff in mm	Runoff Coefficient
2001	687.47	90.98	0.13
2002	603.94	81.24	0.13
2003	432.16	14.09	0.03
2004	798.99	84.77	0.11
2005	999.43	154.88	0.15
2006	728.18	53.19	0.07
2007	800.51	92.90	0.12
2008	1011.24	152.63	0.15
2009	746.99	68.37	0.09
2010	1048.15	133.20	0.13
2011	711.87	47.62	0.07
2012	448.80	47.68	0.11
2013	1031.69	179.96	0.17
2014	955.81	127.89	0.13
2015	786.81	112.84	0.14

Table 11: Runoff for Watershed B3

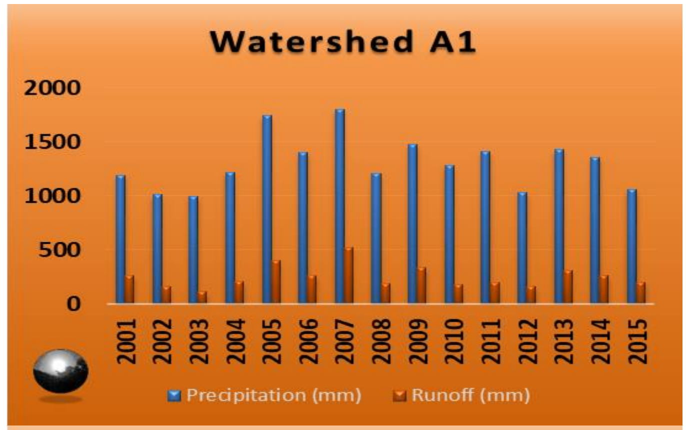
Year	RainFall in mm	Runoff in mm	Runoff Coefficient
2001	878.30	124.04	0.14
2002	792.30	112.14	0.14
2003	622.33	69.60	0.11
2004	1083.33	171.25	0.16
2005	1410.49	289.25	0.21
2006	1180.24	179.67	0.15
2007	1334.55	307.01	0.23
2008	1272.80	261.38	0.21
2009	1324.86	256.85	0.19
2010	1485.58	289.63	0.19
2011	1214.42	157.78	0.13
2012	769.31	84.81	0.11
2013	1243.42	217.57	0.17
2014	1238.21	198.29	0.16
2015	853.39	126.63	0.15

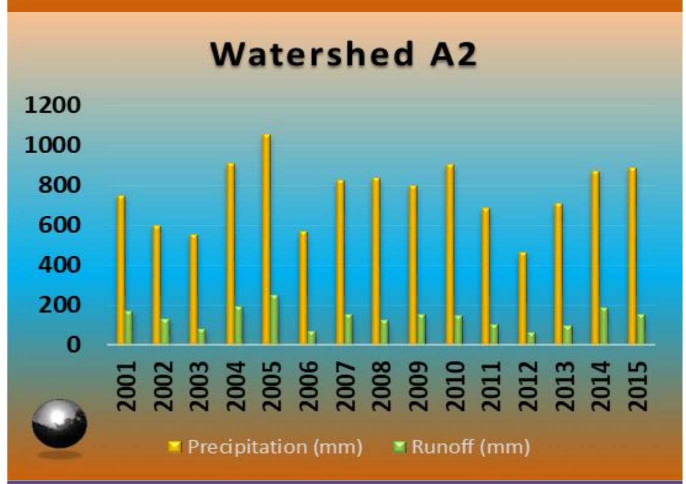
Table 12: Runoff for Watershed B4

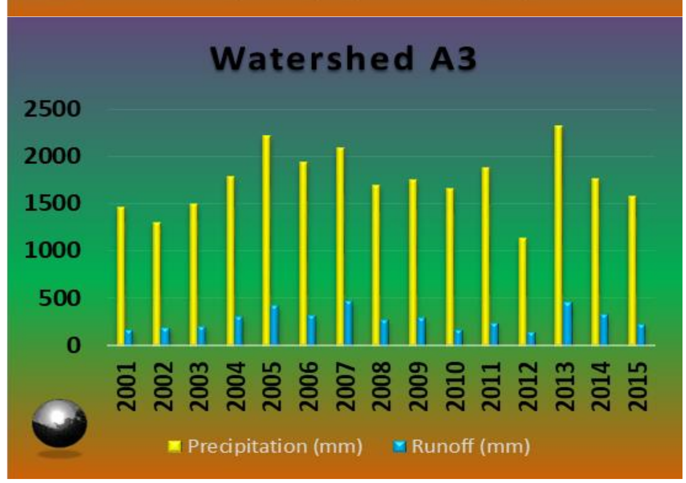
Year	RainFall in mm	Runoff in mm	Runoff Coefficient
2001	2330.01	486.10	0.21
2002	1937.11	368.79	0.19
2003	1714.81	276.59	0.16
2004	2670.35	698.01	0.26
2005	3119.02	882.24	0.28
2006	3115.20	843.68	0.27
2007	3687.36	1338.69	0.36
2008	2704.37	686.88	0.25
2009	3160.08	911.36	0.29
2010	2369.65	377.64	0.16
2011	2681.04	516.97	0.19
2012	2218.86	504.52	0.23
2013	3090.00	871.24	0.28
2014	2827.36	785.00	0.28
2015	2148.46	499.87	0.23

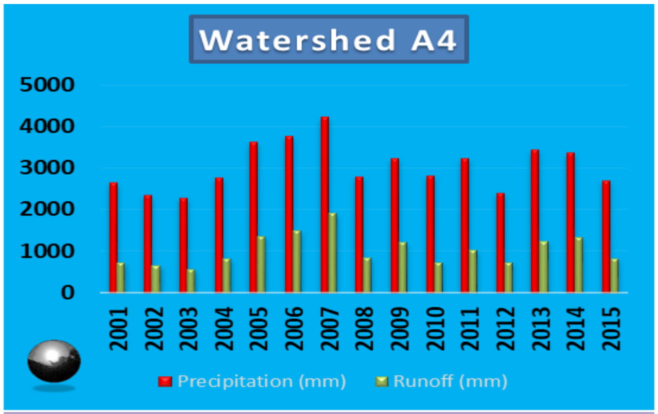
Table 13: Weighted runoff of area

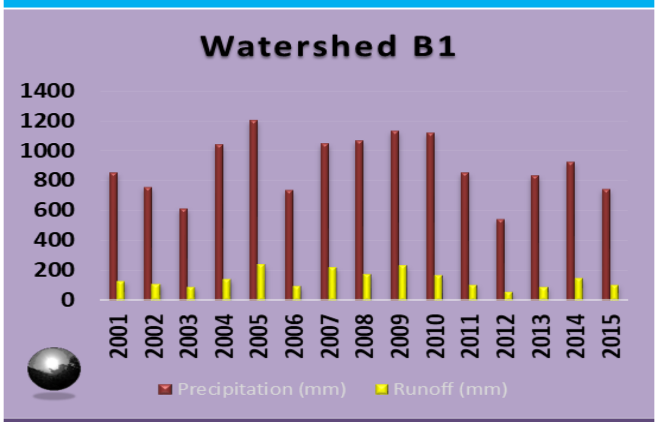
Year	RainFall in mm	Runoff in mm	Runoff Coefficient
2001	1307.72	263.65	0.20
2002	1130.17	219.26	0.19
2003	1042.65	170.12	0.16
2004	1483.99	316.20	0.21
2005	1865.96	483.37	0.26
2006	1610.72	391.65	0.24
2007	1912.73	599.84	0.31
2008	1525.94	327.48	0.21
2009	1660.88	422.01	0.25
2010	1553.92	272.18	0.18
2011	1534.57	287.75	0.19
2012	1091.57	214.22	0.20
2013	1683.37	408.64	0.24
2014	1607.48	399.08	0.25
2015	1290.38	267.63	0.21

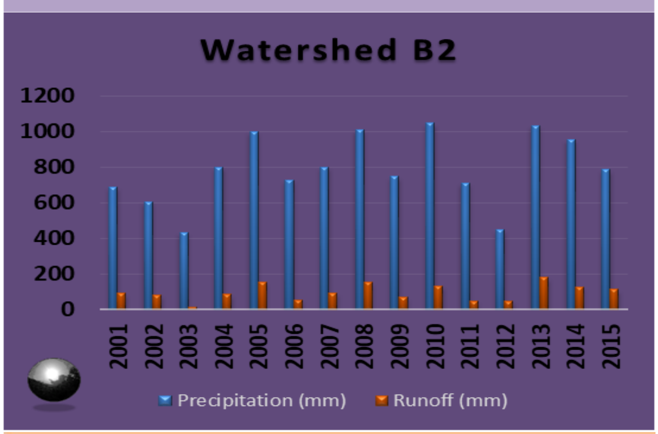


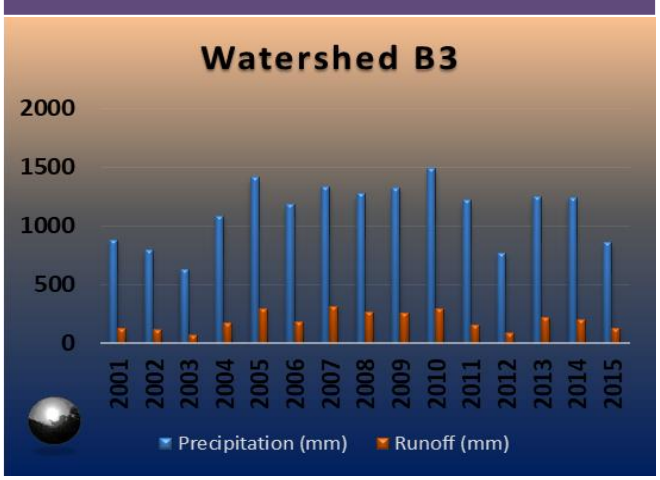












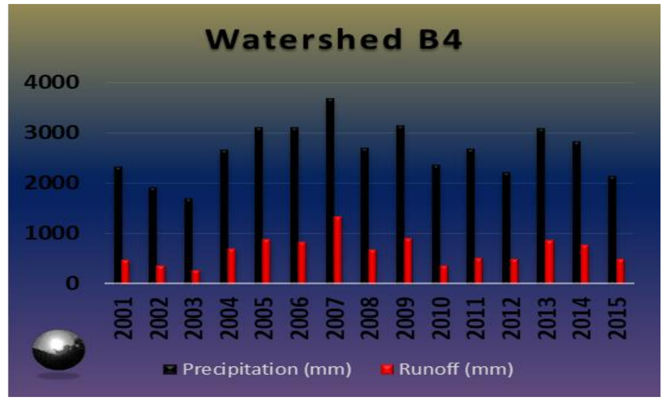
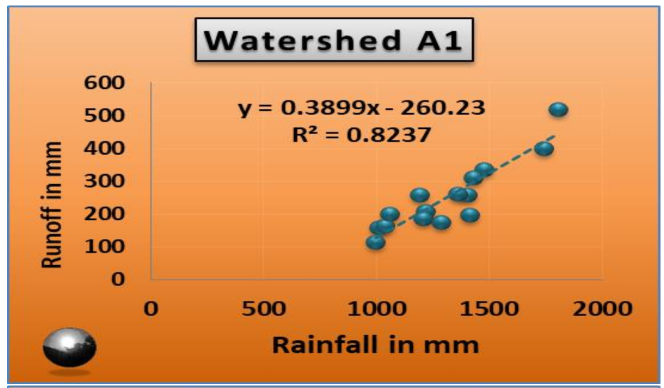
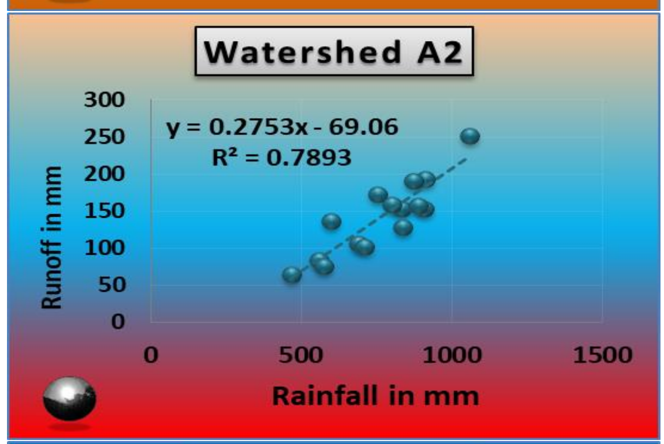
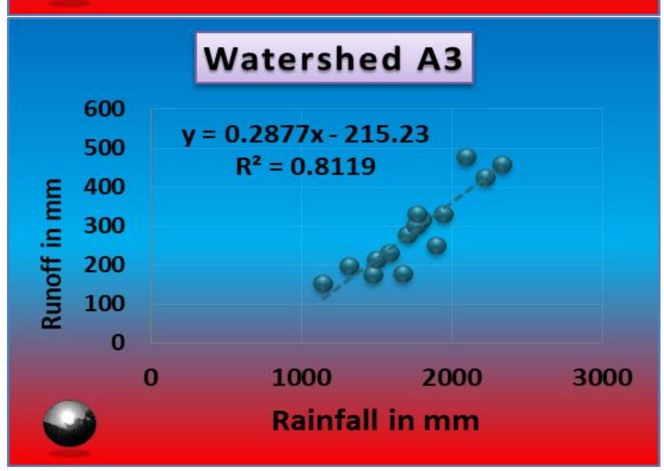
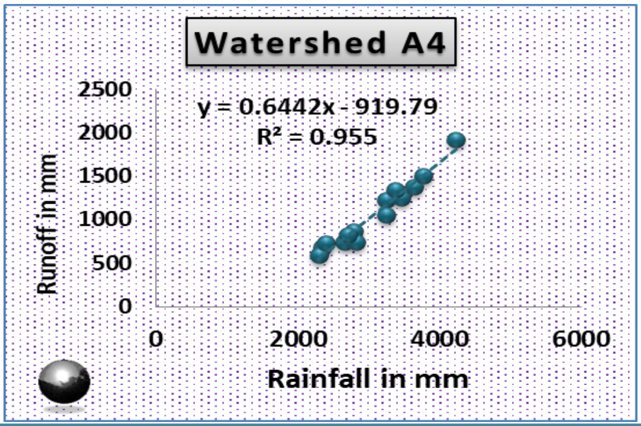


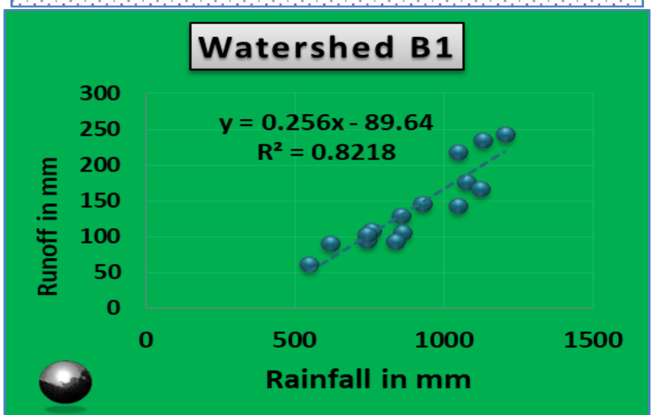
Fig 7: Rainfall – Runoff yearly depth

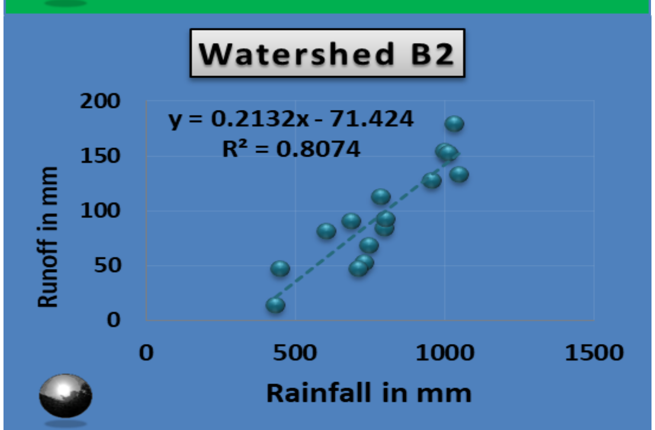


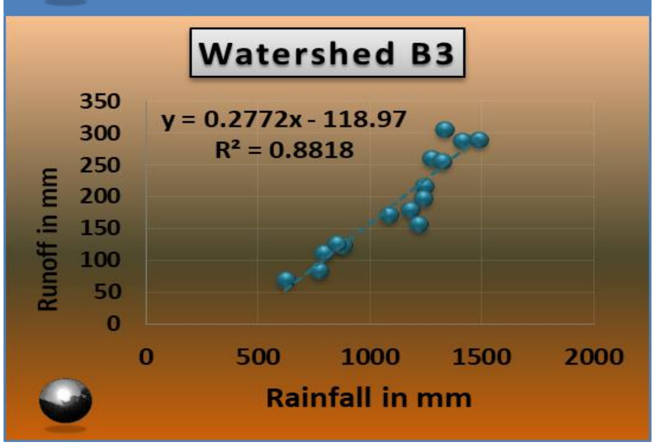












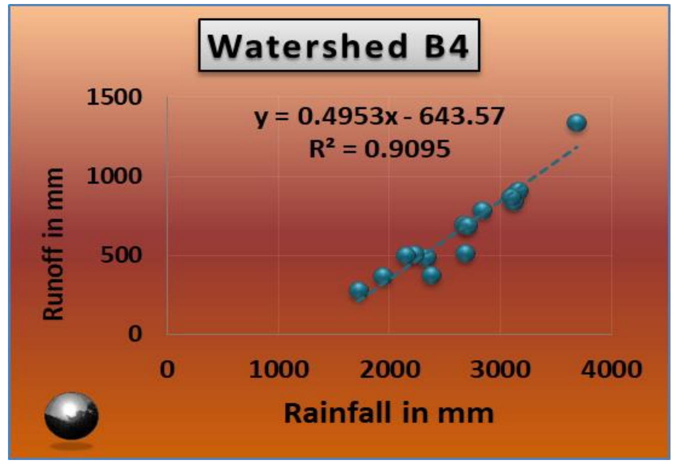


Fig 8: Rainfall – Runoff Correlation

IV. CONCLUSION

The SCS curve number method uses, minimum data as input, and gives reliable output by using remote sensing and GIS techniques in most efficient way. The purpose of this study was to evaluate the performance of the procedure using land cover database from remotely sensed data. From the Table 13 it is observed that during the year 2007 maximum runoff depth of 599.84 mm has occurred. It was also observed that the minimum runoff depth of 170.12mm has occurred in the year 2003. The values of correlation coefficients are very high as it ranges from 0.79 to 0.95 Watershed A4 has high value of it. The value of runoff coefficient varies from 0.16 to 0.31. Hence, it can be said that there is a strong positive linear dependence between the annual rainfall and annual runoff and it can be observed that in the regression equation as the values of slope increases the runoff generated also increases. The runoff estimation carried out by using SCS curve number method will help in proper planning and management of catchment yield for better planning of river basin.

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