

# Geospatial technique for runoff estimation based on scs-cn method in upper south koel river basin of Jharkhand (India)

## Abstract

The present research uses SCS-CN technique for run-off computation using geoinformatics. The major part of the south Koel river basin located in Jharkhand state is drought prone with recurrent drought conditions during monsoon season. The watershed is characterized by high run-off discharge volume with 59 percent of total water of rainfall moved as runoff (i.e 2880 mm of runoff from 4855 mm of rainfall) during the monsoon season (June-October) and high runoff volume is observed mainly in the month of August (881.34 mm of runoff from 1388.4 mm of rainfall) for entire basin using monthly rainfall data of 5 years (2009-2013). The entire basin is divided into six sub-watersheds as I,II,III,IV,V and VI in which sub-watersheds II and IV exhibits high runoff (59%). The study recommend the sub-watersheds having high runoff value needs hydrological harvesting structure construction such as farm ponds, check dams and nala bunds etc in future for proper ground water management. The study demonstrated the use of geoinformatics for watershed management to combat drought.

**Keywords:** runoff estimation, scs-cn, upper south koel river basin

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**Arvind Chandra Pandey, Stuti**

School of Natural Resource Management, Centre for Land Resource Management, Central University of Jharkhand, India

**Correspondence:** Arvind Chandra Pandey, School of Natural Resource Management, Centre for Land Resource Management, Central University of Jharkhand, India, Email arvindchandrap@yahoo.com

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## Introduction

Jharkhand state is characterized by plateau terrain and facing severe water scarcity largely on account of high runoff generated by adequate annual rainfall of about 1400mm per year. The run-off is one of the important hydrologic variables used for assessment of potential water yield of a watershed and appropriate measures for ground water recharging. The quantity and rate of runoff is influenced by rainfall parameters and conjointly by many alternative watershed factors viz., kind of construction of catchment, physical nature of the soil, distribution and type of vegetative cover, degree and length of slope, shape form and size of watershed. When the speed of precipitation exceeds the speed at that water infiltrates into the soil considered as runoff. Run-off volume and also the run-off rate will increase as watershed size will increase.<sup>1</sup> SCN based rainfall-runoff model are mostly used for computation of runoff<sup>2</sup> as compared to conventional techniques i.e expensive and need hydrological and meteorological data measurement. The rainfall-runoff studies by conventional techniques enhance to large extent because of remote sensing tools and technologies. Interpretation of satellite data help us to demarcate thematic information on land use, soil, vegetation, drainage, hydrogeomorphology etc that combined with rainfall parameter and topographic parameters (slope, contour and height) provide the crucial inputs data during rainfall-runoff models computation. Geo-referenced database is prepared in Geographical data system (GIS) based on information extracted from remote sensing and different sources. Therefore, the utilization of a GIS is most popular over the conventional techniques for deduce surface run-off and analyzing the factors accountable for run-off. The runoff information in Jharkhand is very scarce because of dominantly forest covered regions and only available at few limited sites. Also, the majority of the agricultural watersheds in India are ungauged, having nil historical records of the rainfall-run-off

processes.<sup>3</sup> In the Jharkhand with dominantly forest lined regions the correct info on run-off is scarce and present at very limited sites. There are various models used for runoff estimation some of them are SWAT model i.e soil and water assessment tools, autoregressive integrated moving average (ARIMA), Seasonal autoregressive integrated moving (SARIMA) model, artificial neural network, fuzzy model and SCS-CN model etc was used for long term runoff forecasting. Among the various methods used for rainfall-run-off estimation, the soil conservation service curve number<sup>4</sup> (renamed as natural resources conservation services curve number (NRCS-CN)) (USDA 1994) technique has been mostly applied to ungauged watershed systems to establish the rainfall-run-off relations<sup>5,6</sup> and proved to be accurate and fast for surface runoff estimation.<sup>7</sup> This approach is cheap, simple to use through minimum information and provides adequate results.<sup>4-10</sup> The NRCS-CN technique is largely accepted by scientists, forester's hydrologists, water resources planners and engineers meant for the estimation of surface run-off. Bhuyan et al.<sup>11</sup> used the modified curve number (CN) technique designed for predicting surface run-off by adjusting the CNs based on expected Antecedent moisture Condition (AMC) ratio. Daily storm events data was used to estimate run-off using NRCS-CN technique<sup>12</sup> in the Damodar Barakar catchment in Jharkhand, India. Many regions in Jharkhand are drought prone with unpredictable rainfall pattern, rendering kharif crops mostly susceptible to agricultural drought during the rainfall period.<sup>13</sup> Because of hard rock undulating terrain most of the rainfall water goes as runoff and therefore, rainwater move down slope and inadequately recharge the aquifers. It is necessary that the most water accessible as the run-off be utilized for maintaining crop development and recharge of groundwater. By considering these views, the present study was performed to estimate the run-off due to rainfall for select watershed of upper South Koel basin located in Ranchi and Lohardagga districts of Jharkhand state. Shallow unconfined aquifers are refilled by rainwater during monsoon

season which temporally fulfill the need of people in these areas for limited periods till February end. Thus quantification of run-off water that can be available from these watersheds can help in implementing water preservation through development of surface water harvesting structures.

### Study area

The study area is (a part of South Koel basin) with an area of 772 sq km is bounded by latitude 23°17'16" N -23°32'16"N and longitude 84°14'15"E - 85°46'51"E (Figure 1)( Figure 2). It lies in SOI toposheet no 73 A/14, 73 A/15, 73 E/2, 73 E/3 covering Ranchi as well as Lohardaga district of Jharkhand. South Koel is the main river in the area with Kandani river and Saphi rivers as its major tributaries. The drainage pattern is mostly dendritic. The climate of the region is subtropical with average annual rainfall of 1400mm, 82% of which generally received during the monsoon periods from June to September. Temperature is lowest in the months of December and January with mean minimum temperature of 9°C and highest in April and May with mean maximum temperature of 37.2°C.

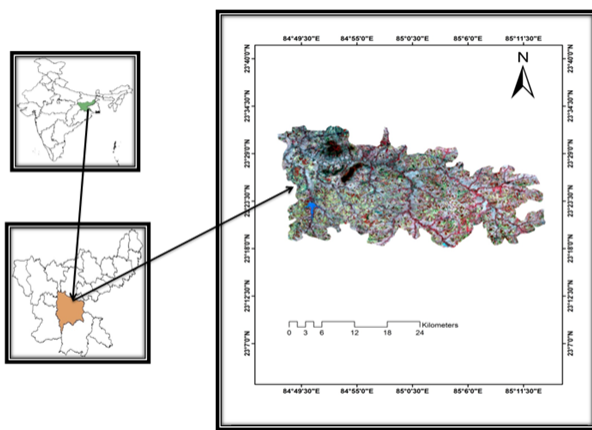


Figure 1 Satellite image of study area of LISS-III.

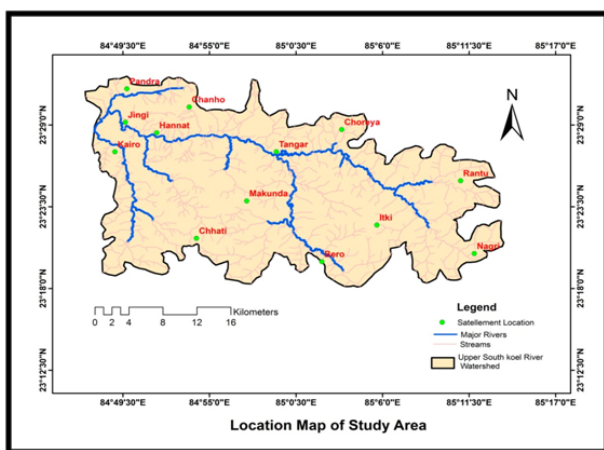


Figure 2 Location map of upper South Koel river basin.

### Data used and methodology

The study area comprising parts of upper South Koel river basin, delineated on the Survey of India topographical (SOI) map of scale 1:50000 were updated using LISS III satellite data having resolution

23.5meter (Table 1) IRS-P6 LISS-III satellite data interpreted to demarcate various land use/land cover map and geology map of study area and digitized using Arc-GIS 10.2 software to compute the area under each class. Soil map of the watershed obtained from the National Bureau of Soil Survey (NBSS) was used to create database on the hydrological soil group (HSG). Slope and relief map is prepared by using cartosat DEM data using Arc-GIS tool box option. Curve numbers (CN) for each soil type required to be assigned for the assessment of run-off. As CN depends on soil type, therefore, on the basis of drainage condition, water transmission capacity, infiltration rate, texture, depth and the soil was categorized into different HSGs: A, B, C and D. The criteria adopted for such classification of HSGs is based on the USDA-SCS<sup>4</sup> method. The SCS model computes run-off through an empirical equation and to require rainfall (antecedent soil moisture condition), land cover, soil and the curve number (CN), which represents the run-off prospective of the land cover soil complex.<sup>8</sup> To calculate the run-off available from the selected watershed using the NRCS soil conservation services (SCS) curve number method, the monthly rainfall data for five years (2009-2013) of monsoon season was acquired from the Indian Meteorological department. The model involves the relationship among land cover, hydrologic soil class and antecedent soil moisture to assign curve number.<sup>14</sup> Physical characteristics (LU/LC and soil) of the watershed AMC and recharge capacity of the watershed are basic requirement for determination of curve number method.<sup>15</sup> The indication of moisture used in run-off estimation is selected as AMC-I, AMC-II and AMC-III which represent dry, normal and wet conditions, respectively. In the present study, HSG and the thematic maps of land use/land cover were prepared in Arc-GIS software for different sub six watersheds and then spatially intersected to calculate the watershed area under the different hydrological similar units (HSU) for assigning CN values to compute total discharge for different sub watersheds. In upper South Koel river watersheds, mainly two hydrological soil group (HSGs) was classified i.e HSG‘B’, and HSG ‘C’, and the area under each HSG was calculated. The type of soil in HSG‘B’ was coarse loamy and the HSG‘C’ are fine and it covers the maximum portion of the watershed. Same process was applied for sub Watershed I, II, III, IV, V and VI to compute curve number values for individual sub watershed. Once the Curve Number was recognized for different land classes, the weighted curve number for watershed was calculated using equation (1).

$$\text{weighted curve number} = \frac{\sum CN_1 \times a_1 + CN_2 \times a_2 + \dots + CN_n \times a_n}{\sum a} \quad (1)$$

Where  $CN_1$  = curve number for particular land unit 1

$a_1$  = area for that particular land unit 1

$CN_n$  = curve number for nth land unit of watershed,  $a_n$  = area of nth land unit of watershed

$\sum a$  = sum of total area.

Potential maximum soil retention (S) was estimated for the watershed based on weighted curve number using Equation (2)

$$S = \frac{25,400}{CN} - 254 \quad (2)$$

The SCS curve number is based on basic statements i.e for a single storm event, maximum potential of soil retention is equivalent to the

ratio of direct run-off and available rainfall. Subsequent to calculation of potential highest soil retention, the initial abstractions ( $I_a$ ) were calculated. The initial abstractions ( $I_a$ ) were considered as water losses. Thus, equation (3) is obtained.

$$\frac{P - I_a - Q}{S} = \frac{Q}{P - I_a} \quad (3)$$

Thus, value of Q is calculated by using equation (2)

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)} \quad (4)$$

To simplify the equation (4), ( $I_a$ ) initial abstraction is related to potential maximum retention and  $P > I_a$ . It was considered that if the storm event is less than the initial abstraction value then there is no run-off available for that rainfall event, and only the storm events higher than the initial abstraction value are considered for the run-off estimation.<sup>16</sup> Hence, for storm events is considered for runoff estimation as compare to initial abstraction because of most advancement for the period of five years. The curve number is different for different antecedent field condition. The initial abstraction ( $I_a$ ) was taken as 0.2S (AMC-II) in the present study. The initial abstractions ( $I_a$ ) were calculated for 5 years (2009-2013) on monthly basis (June-October) using Equation (6) for the watershed. Weighted curve number and the potential maximum soil retention (S) were calculated by using  $I_a$  values shown in Table 6. The whole process was done for six sub-watersheds of upper South Koel basin along with the composite basin area.

$$\text{Thus, } I_a = 0.2S \quad (5)$$

The same weighted curve number (WCN) was used for run-off estimation accordingly given by Anbazhagan et al.<sup>16</sup> by using AMC-II condition as shown in Equation (6):

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (6)$$

Where Q, Actual direct run-off (mm); P, Total Rainfall (mm); S, Maximum soil retention potential mm, CN, Curve Number

By using Equation (6), run-off was calculated in the upper South koel river basin on a monthly (June to October) basis for the period of 5 years (2009-2013, and then observed run-off was estimated using linear regression equation (equation 7) and by computing all runoff value observed the specific month identify which having high runoff volume of discharge during these monsoon season. The correlation between rainfall and runoff can be estimated by obtaining a linear regression line between these two variables.<sup>17</sup> provided the equation (7) used for regression analysis between run-off (R) and rainfall (P).

$$R = aP + b \quad (7)$$

Where P, Rainfall (mm); R, Run-off (mm); N, No of sets of Rand P

$$r = \frac{N \sum PR - (\sum P)(\sum R)}{\sqrt{[N(\sum P^2 - \sqrt{P^2})] \times [N \sum R^2 - \sum R^2]}}$$

Where P, Rainfall (mm); R, Run-off (mm); N, No. of sets of R and P

**Table 1** Details of satellite data used in study

Data used (Satellite Image)						
Sensor name	Resolutions		Path /row	Detail of acquisition		Sources
LISS III	Spatial	Spectral	94/37	Year	Month	BHUVAN
	Band 2 to 4	band		2016	August	
	-23.5					

## Results

Based on visual interpretation elements viz. color, size, shape, texture and association with standard false color composite of multispectral satellite data of LISS-III nine LULC classes has been identified. The classes and their areal extent obtained as intense agriculture (143.65 km<sup>2</sup>), sparse agriculture (148.72 km<sup>2</sup>), Open forest (39.59 km<sup>2</sup>), degraded forest (46.54 km<sup>2</sup>), Reservoir/water bodies (9.24 km<sup>2</sup>), Fallow land (131.47 km<sup>2</sup>), Barren land (91 km<sup>2</sup>), Barren land rocky (80.37 km<sup>2</sup>) and Built up urban /rural areas (81.68 km<sup>2</sup>) as shown Figure 3 & Table 2. Soil map has been taken from NBSS mainly showing three types of soil for an area of 772 km<sup>2</sup> i.e Fine loamy, Coarse loamy and Fine soil these three classes further divided into nine classes i.e Fine loamy (Aeric Haplaquents 309.52 km<sup>2</sup>), Coarse loamy (Haplaquents 230.02 km<sup>2</sup>), Fine loamy (Typic Ustochrepts 91.01 km<sup>2</sup>), Fine (Ustochrepts 11.92 km<sup>2</sup>), Fine

loamy(Aeric 11.09 km<sup>2</sup> sq), Fine loamy (Haplaustalfs 45.83 km<sup>2</sup>), Fine (Vertic Ustochrepts 53.62 km<sup>2</sup>) shown in Table 3 & Figure 4. Geology map has been also prepared based on visual interpretation elements of LISS-III satellite data major six types of geological features has been identified in the area as Alluvium (414 km<sup>2</sup>), Granite Gneiss (303.4 km<sup>2</sup>), Hornblende Schist & Amphibolite (24 km<sup>2</sup>), Schist (26.70 km<sup>2</sup>), metabasic Dykes (1.23 km<sup>2</sup>) and Laterite (3.36 km<sup>2</sup>) (Figure 5). The entire watershed has been divided into six sub-watersheds based on drainage map prepared by using toposheet of scale 1:50,000 (SOI) (Figure 8) i.e sub-watersheds I, II, III, IV, V and VI each sub-watershed having nine LULC classes the different classes and their areal extent shown in Table 4 & Figure 8. As curve number values lies between 0-100, the highest curve number obtained 82 for intense agriculture and minimum curve number value is 0 for water bodies and 61 for fallow land 68 for built-up area as shown

(Table 5). Based on different hydrological soil group, hydrological condition and land treatment practice CN values for each class is determined. The weighted curve number is calculated for individual sub-watersheds using equation (1) i.e 65, 70, 67.60, 70.19, 67.70 and 67.50 for sub watershed I, II, III, IV, V and VI respectively (Table 7 & 8). Initial abstraction and soil retention is calculated for sub-watersheds based on different CN values obtained using equation (2 and 5) as shown Table 5 & Table 6. Rainfall data of five years from 2009 to 2013 for monsoon season (June-October) taken from Indian Metrological Department is used for computation of runoff using equation (6) which required precipitation data, maximum soil retention and Curve number. The quantity of water discharge from stream is considered as runoff. The average runoff volume estimated from watershed during 2009-2013 for monsoon season was found to be 2880.98 mm generated from 4855mm of rainfall i.e 59% and showing (53, 59, 55, 59, 56 and 57)% of runoff respectively. The relationship between rainfall and runoff volume for five years was examined and plotted (Figure 6) (Figure 7). The result shows high degree of positive co-relation i.e with an increase in rainfall the runoff volume increases. The coefficient of determination was found to be 0.9 for the month (June- October) for different years of observation. The runoff discharge volume has been observed high in the month of August i.e 881.34 mm of runoff in 1388.4 mm of rainfall data for monsoon period of five years from June-October (Table 9).

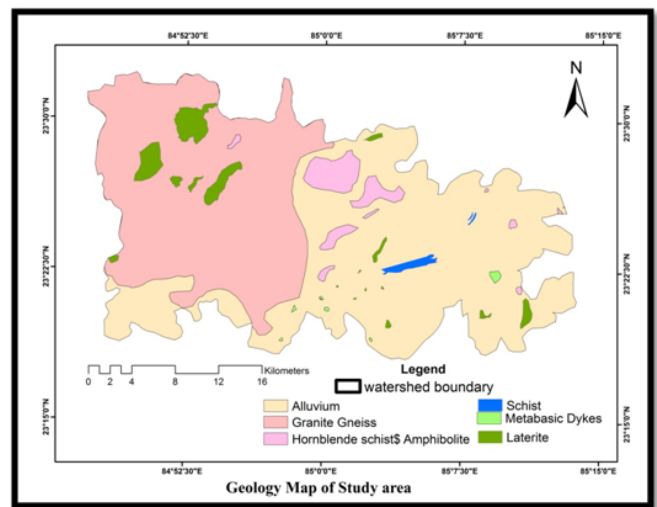


Figure 5 Geology map of study area.

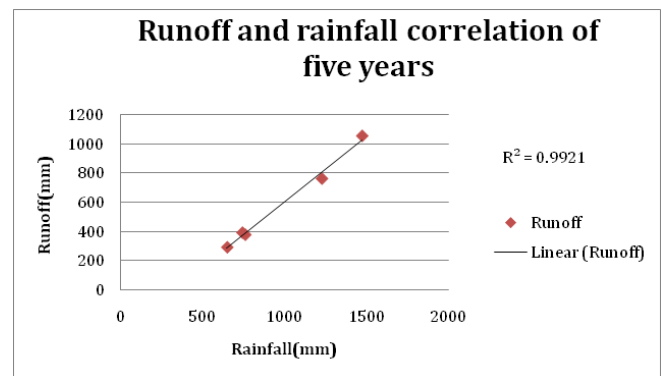


Figure 6 Correlation between rainfall and run-off.

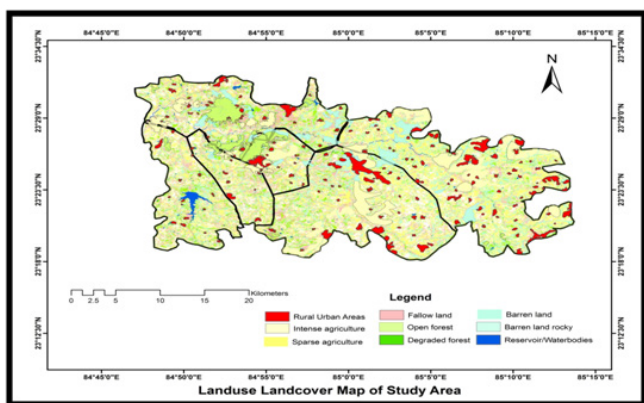


Figure 3 Land use land cover classes of upper South Koel river basin Jharkhand.

Table 2 Land use land cover classes and their respective areas

S.no	Lulc Classes	Lulc classes area(sq km)	% of area of lulc classes
1	Intense agriculture	143.65	18.6
2	Sparse agriculture	148.72	19.26
3	Open forest	39.59	5.12
4	Degraded forest	46.54	6.02
5	Reservoir/water bodies	9.24	1.19
6	Fallow land	131.47	17
7	Barren land rocky	80.37	10.41
8	Barren land	91	11.78
9	Rural/Urban areas	81.68	10.5

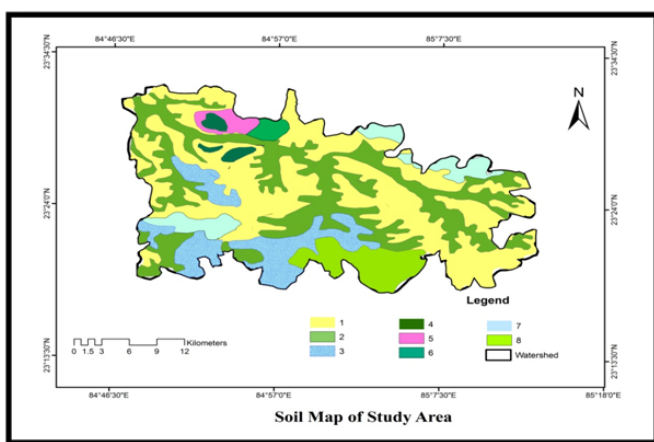
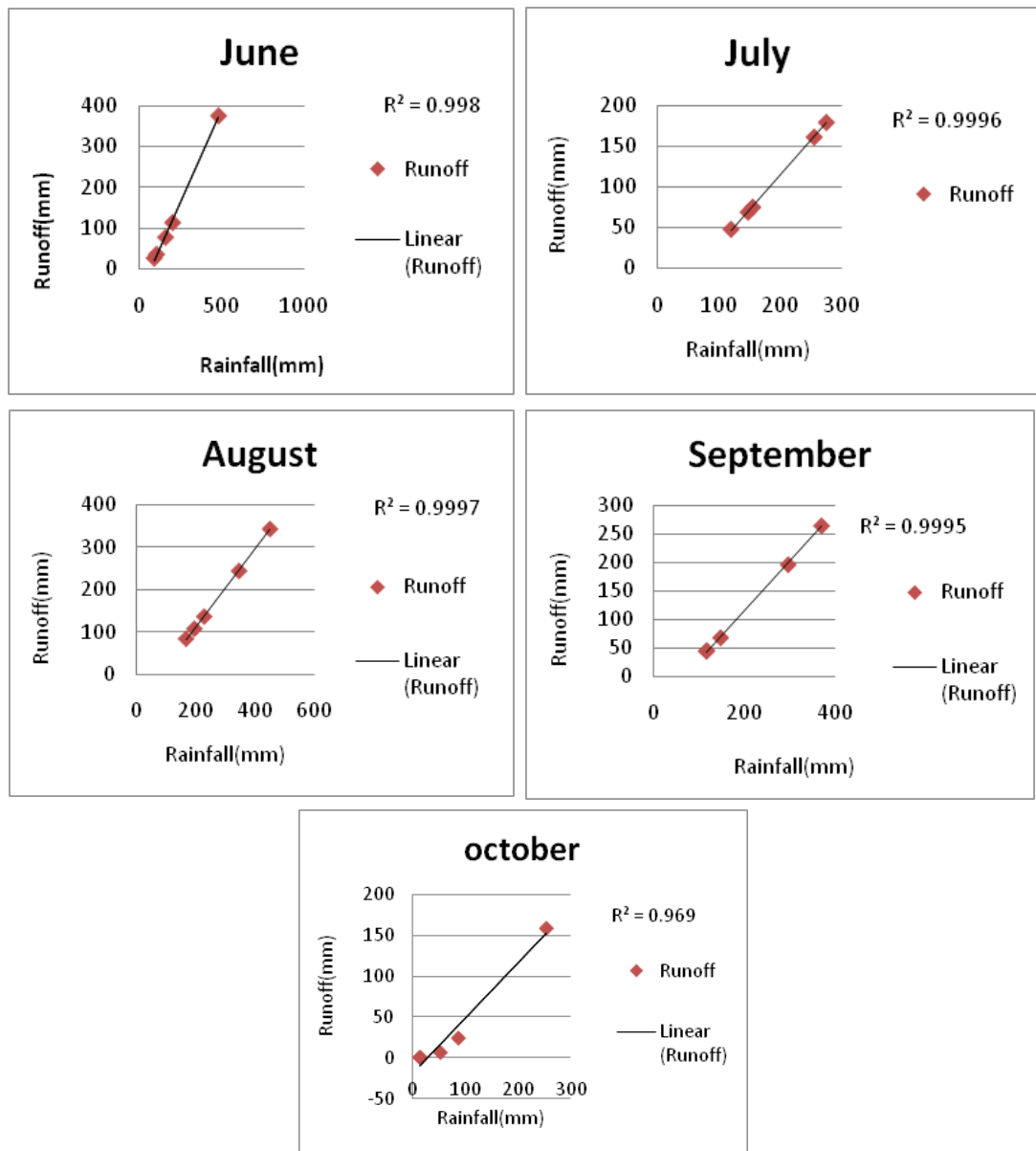
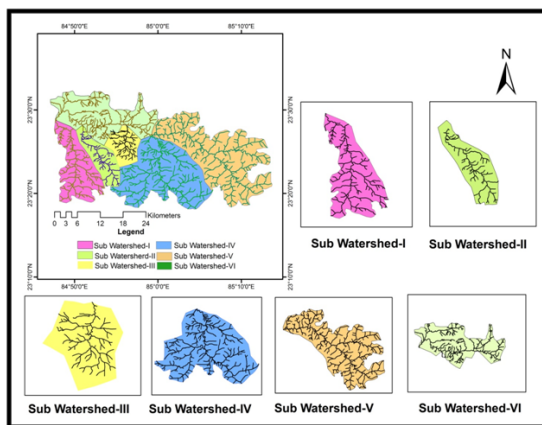


Figure 4 Soil map of study area (Source–NBSS).





**Figure 7** Graphs showing correlation between run-off and rainfall for the monsoon months (June, July, August, September and October) calculated for a period of 5 years (2009–2013).



**Figure 8** Sub watershed map of upper South Koel river basin.

**Table 3** Classes of fine loamy and coarser loamy soil and their respective areas

Soil map area statistics		
S. no	Classes of soil	Area(sq km)
1	Fine loamy(Aeric Haplaquents)	309.52
2	Coarse loamy(Haplaquents)	230.02
3	Fine loamy(Typic Ustochrepts)	91.01
4	Fine(Ustochrepts)	11.92
5	Fine loamy(Ustochrepts)	18.94
6	Fine loamy(Aeric)	11.09
7	Fine loamy(Haplaustalfs)	45.89
8	Fine(Vertic Ustochrepts)	53.62

**Table 4** Land use land cover classes and their respective areas of sub watersheds

Lulc	Sub-watershed I	Sub-watershed II	Sub-watershed III	Sub-watershed IV	Sub-watershed V	Sub-watershed VI
Intense agriculture	20.15	7.09	8.4	50.02	60.05	10.52
Sparse agriculture	6	9.28	2	17.04	27	19
Open forest	10.28	2	2.25	8.69	10.2	6
Degraded forest	2	4.06	5.5	7	4.02	23.4
Reservoir/Water bodies	3.26	0.23	0.54	1.04	1.22	2.9
Fallow land	19.36	10.29	7.79	39.6	23.57	29.96
Barren land rocky	3.05	3.59	2.04	12	15	20.04
Barren land	15.4	7	6.1	30.69	45.7	6
Built-up(Urban/Rural)	14.4	7.07	5.51	24.68	28.91	15.94
Weighted Curve number	65	70.4	67.6	70.19	67.7	67.5
Initial abstraction(la)	27.32	21.35	24.34	21.57	24.22	24.96
Soil retention parameter(S),mm	136.6	106.79	121.7	107.5	121.1	124.82

**Table 5** Showing land use land cover, hydrological soil group, hydrological condition, treatment practices and their estimated curve number

Land use land cover	Hydrological soil group	Hydrological condition	Treatment practices	Curve number
Intense agriculture	B	Good	Contoured	75
Sparse agriculture	C	Good	Contoured	82
Open forest	B	Good	Contoured	55
Degraded forest	C	Fair	Contoured	70
Reservoir/water bodies	B	Good	-	0
Fallow land	B	Poor	Straight row	61
Barren land rocky	C	Poor	Straight row	79
Barren land	B	Poor	-	69
Built-up (Urban/Rural)	B	Poor	-	68

**Table 6** Weighted curve number, retention parameter and initial abstraction of the upper South Koel watershed

Parameters	Computed values
Weighted curve number	70
Soil retention parameter (S), mm	108
Initial abstraction (la), mm	21.7

**Table 8** Cumulative annual rainfall and runoff of sub-watersheds

Upper south koel basin	Rainfall (mm)	Runoff (mm)	Runoff (%)
Sub watershed I	4855	2574.95	53
Sub watershed II	4855	2896.2	59
Sub watershed III	4855	2685.62	55
Sub watershed IV	4855	2887.32	59
Sub watershed V	4855	2731.39	56
Sub watershed VI	4855	2811.85	57

**Table 7** Cumulative annual rainfall and runoff of five years

Year	Cumulative annual rainfall (mm)	Cumulative annual runoff (mm)
2009	760	377.51
2010	650	291.08
2011	1474.1	1057.09
2012	742.5	391.81
2013	1228.3	763.19

**Table 9** Monthly rainfall and runoff values for the duration of five years of Monsoon season of entire Watershed

2009–2013	Rainfall (mm)	Runoff (mm)
June	948	598.43
July	956.3	496.12
August	1388.4	881.34
September	1141.7	725.53
October	420.6	178.97

## Discussion

The average run-off volume estimated from the watershed was found to be 2880.98 mm generated from 4855 mm of rainfall in the upper South Koel basin i.e 59 percent of water is goes as runoff and only 41percent is infiltrate and recharge ground water. The agriculture area covers most part of the watershed (143.65 km<sup>2</sup> intense agriculture and 148.72 km<sup>2</sup> sparse agriculture) having undulating slope and topography which results in the maximum portion of rainwater to escape as run-off and reduces water percolation and infiltration capacity which affect agricultural growth and cause drought condition. The less infiltration and more run-off is also because maximum portion of the watershed is underlain by fine (Aeric Haplaquents) soil (309.52 km<sup>2</sup>) which has a slow water transmission and infiltration rate. Slope distribution is essential parameter as it plays a significant role in determining infiltration vs. runoff relation. Infiltration is inversely related to slope i.e. gentler is the slope, higher is infiltration and less is run-off and *vice-versa*. Geologic structures have great control as they influence the nature of flow, erosion and sediment transportation. Hard granitic rocks in the basement under shallow soil cover and weathered zone in the study area allows less water to percolate down to the aquifers and therefore major component of rainwater escapes as run-off, thus a large amount of rainwater is vanished as run-off resultant into higher total run-off volume per year causing ground water level depletion in the region of the order of 2.5m per year (CGWB). The geology, extent and type of vegetation cover determines to a large extent the infiltration capacity of the soil and hence the run-off volume.<sup>1</sup> Watershed is divided into major six sub- watersheds i.e sub-watersheds (I,II,III,IV,V and VI) having runoff (53,59,55,59,56,57)% respectively in which sub-watersheds II and IV having high runoff i.e 59% covered with fallow land as the major class (10.29 and 29.96 respectively) and comprised of fine loamy (Typic Ustochrepts) soil and relief is in between 615-650 m because of high runoff in these areas agricultural land may be converted into fallow land. These sub-watersheds must required proper implementation plan to reduce runoff and increase ground water prospect as hydrological harvesting structure construction such as farm ponds, check dams and nala bunds etc in future to combat drought. Coefficient of determination was found to be 0.9 for the months (June-October) for different years of observation which shows high degree of positive correlation i.e with an increase in rainfall, the total runoff volume increases. The resulted observed run-off estimation using SCS-CN is validated with the observed run-off in different studies. Tejram et al.<sup>18</sup> estimated good correlation between rainfall and run-off of the Uri river watershed in the lower Narmada basin of Central India using SCS-CN model. The present study also shows similar type of result and exhibit a good correlation between observed rainfall and run-off.<sup>19</sup> Also estimated

total runoff of Jharkhand covering Ranchi and Lohardagga district having rainfall of 1400mm per year and remarked that 60% goes as runoff and only 40% infiltrate and recharge ground source of water. Our study also shows that in Lohardagga district comprising a part of watershed covering an area of about 772 sq km having 2880.98mm of runoff out of 4855 mm of monsoon rainfall i.e 59% of water goes as runoff and about 41% infiltrate and recharge ground water, validating present runoff computation for study area.<sup>20-23</sup>

## Conclusion

The present study accurately estimated the total run-off generated in the upper South Koel watershed. Estimation over six sub watersheds helped to quantify the total amount of run-off expected from the individual watershed annually so that runoff could be stored in the suitable recharge structures. The rainfall-run-off modeling using the SCS-CN method showed that the run-off generated in the basin is high over the past 5 years with 2880 mm of runoff generated from 4855 mm of rainfall recorded during the monsoon season (June-October) in which sub watershed II and IV showing high runoff. This entails setting up of various water harvesting structures as per prioritization based on high runoff area, ground water deficit zone considering various drainage morphometric parameters. Less availability of water for domestic and drinking purposes entails building recharge structures to store the run-off water and to provide life saving irrigation facility during agricultural drought as well recharging of aquifers in the watershed.

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## Conflict of interest

Authors declare there is no conflict of interest in publishing the article.

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