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Estimation of Runoff Using NRCS-CN Method and SHETRAN Model

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Abstract: The most basic challenges of hydrology are the prediction and quantification of catchment surface runoff. Surface runoff information is required for watershed management purpose. It is a function of many variables including rainfall intensity and duration, soil type, soil moisture, land use, cover, and slope. In the study runoff was estimated using two models in Upper Krishna river basin, Maharashtra. NRCS-CN method and SHETRAN model was used to find runoff depth.

Monthly Runoff was calculated using NRCS-CN model and daily runoff computed for each catchment using SHETRAN for the year 2012. Landsat 7 (with resolution 30 m) satellite data for the year 2012 has been used for the preparation of land use land cover (LU/LC) map. The hydrologic soil group is mapped using GIS platform. SHETRAN, requires more number of parameters to run the model while NRCS-CN method involves the use of a simple empirical formula and readily available tables and curves. Both model used Land use map and soil data as main input. Validation was done using measured runoff recorded in discharge gauge stations. Results of the study show that land use changes determined from satellite images are useful in studying the runoff response of the un-gauged basins. Study reveals that there is no significant difference between measured and estimated runoff depths. Using NRCS-CN method for each sub-catchment, statistically positive correlations were detected between observed and estimated runoff depth ($0.6<R^2<1$).Using SHETRAN model a correlation coefficient (R^2) greater than 0.84 is obtained.

Keywords: Curve Number, GIS, Runoff, SHETRAN.

I. INTRODUCTION

A rainfall-runoff model is a mathematical model describing the rainfall - runoff relations of a catchment area, drainage basin or watershed. More precisely, it produces the surface runoff hydrograph as a response to a rainfall hydrograph as input. Hydrological models are important and necessary tools for water and environmental resources management. Demands from society on the predictive capabilities of such models are becoming higher and higher, leading to the need of enhancing existing models and even of developing new theories. The NRCS-CN method is one of the most popular methods for computing the volume of surface runoff in catchments for a given rainfall event. The SCS method (now called Natural Resources Conservation Service Curve Number method (NRCS-CN)) is widely used because of its flexibility and simplicity.

SHETRAN is a physically based spatially distributed (PBSD) system for modelling coupled surface and subsurface water flow in river basins. SHETRAN gives a detailed description in time and space of the flow and transport in the basin, which can be visualized using animated graphical computer displays. This makes it a powerful tool for use in studying the environmental impacts of land erosion, pollution, and the effects of changes in land-use and climate, and also in studying surface-water and ground-water resources and management. SHETRAN is currently being integrated into a decision-support system to maximize its usefulness in environmental impact management.

II. DATA PRODUCTS AND STUDY AREA

A. *Study Area*

For the present study, that part of Krishna basin which lies in Maharashtra is considered. It extends from $15^0 49'$ N to $19^0 26'$ N latitude and $73^0 20'$ E to $76^0 53'$ E longitude. The total study area is 69,425 Sq.km. The study area was divided into five sub catchments such that each contains one stream gauge station, as shown in Fig. 1.

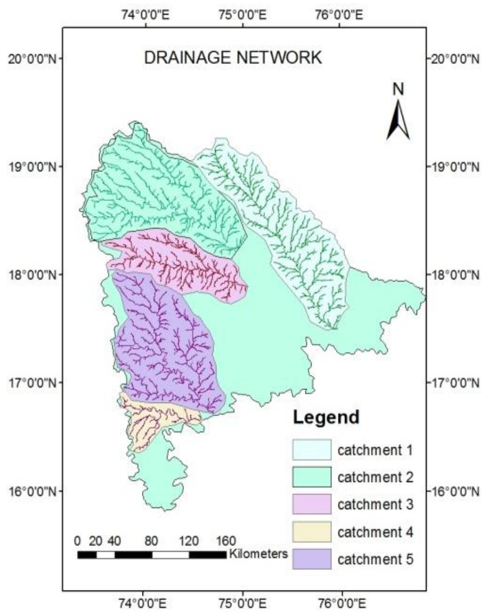

Fig. 1. Sub catchments present in the study area

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B. *Data Products*

- Satellite Imagery- Landsat 7 (with resolution 30 m) satellite data for the year 2012 is downloaded from USGS earth explorer.
- Soil Map-Soil map is obtained from the National Bureau of Soil Survey (NBSS) Nagpur.
- Rainfall Data- Rainfall data obtained from Indian Meteorological Department, Pune. This data was collected from 59 raingauge stations in the study area.
- DEM-The Digital Elevation Model (Cartosat-1:DEM - Version 1.1) for the study area was obtained from http://bhuvan.nrsc.gov.in/. The resolution of the obtained imagery was 32m.
- Discharge data- Discharge data for the year 2012 was obtained from official site of Central Water Commission- (http://www.kgbo.com/) available for 12 river gauge stations

C. *Objectives*

1) To classify the study area in to five classes using supervised classification method.
2) To estimate monthly runoff from the study area using NRCS-CN method
3) To estimate daily runoff using SHETRAN model.

III. NRCS-CN METHOD

In this method several important properties of the watershed namely soil type, land use and antecedent soil water conditions are taken into consideration. Their runoff producing capability is expressed by a numerical value varying between 0-100. The curve number is a function of land use and hydrologic soil group (HSG).

A high curve number means high runoff and low infiltration; whereas a low curve number means low runoff and high infiltration (dry soil). The NRCS-CN method provides a rapid way to estimate runoff change due to land use change. The main reason behind the selection of NRCS method is that in the past 30 years the NRCS method has been consistently usable results for runoff estimation. Once the data has been gathered, the typical process for estimating the curve number for drainage is as follows:

Once the data has been gathered, the typical process for estimating the curve number for drainage is as follows:

- Define and map the boundaries of the drainage basin for which curve number will be calculated.
- Determine the area of the drainage basin.
- Map the soil types and land use for the drainage basin of interest.
- Convert the soil types to hydrologic soil groups.
- Overlay the land use and hydrologic soil group maps, identify each unique land use soil group polygon, and determine the area of each polygon.
- Assign a curve number to each unique polygon, based on standard NRCS-CN table, as shown in Table I.
- Calculate the curve number for each drainage basin by area-weighting the land use soil group polygons within the drainage basin boundaries.

TABLE I: RUNOFF CN FOR THE INDIAN CONDITIONS (AMC-II).[5]

No	Land Use	Treatment /Practice	Hydrologic condition	Hydrologic soil group A	B	C	D
1	Cultivated	Straight row	_____	76	86	90	93
		Contoured	poor	70	79	84	88
			good	65	75	82	86
		Contoured and terraced	Poor	66	74	80	82
			good	62	71	77	81
		Bunded	Poor	67	75	81	83
			good	59	69	76	79
		Paddy(rice)	_____	95	95	95	95
2	Orchards	With under stony cover	_____	39	53	67	71
		Without under stony cover	_____	41	55	69	73
3	Forest	Dense	_____	26	40	58	61
		Open	_____	28	44	60	64
		Shrubs	_____	33	47	64	67
4	Pasture	_____	Poor	68	79	86	89
			Fair	49	69	79	84
			good	39	61	74	80
5	Waste Land	_____	_____	71	80	85	88
6	Hard Surface	_____	_____	77	86	91	93

IV. SHETRAN MODEL

The starting point for the development of SHETRAN was the System Hydrologic European (SHE) which was developed by a consortium of Danish Hydraulic Institute, the British Institute of Hydrology and SOGREAH, France. SHETRAN is a physically based spatially distributed (PBSD) system for modeling coupled surface and subsurface water flow in river basins. SHETRAN gives a detailed description in time and space of the flow and transport in the basin, which can be visualized using animated graphical computer displays. SHETRAN is currently being integrated into a decision-support system to maximize its usefulness in environmental impact management. It is designed to simulate water flow, sediment transport, and contaminant transport at the catchment scale. Within SHETRAN, the spatial distribution of catchment properties, rainfall input and hydrological response is achieved in the horizontal direction through the representation of the catchment and its channel system by an orthogonal grid network and in the vertical direction by a column of horizontal layers at each grid square. SHETRAN V2.101 has four components: FR frame, WAT water flow, Sediment yield, Solute transport.

FR frame - Frame module of SHETRAN provides the overall control of a simulation including its

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initialisation, simulation time steps, results output, and termination. The frame component consists of two modules: the frame module (FR), and the bank (BK). The major function of FR frame is to assign element numbers, sizes and areas to each discretization element (grid, bank or channel link), and the total catchment area is calculated and checked.

WAT frame - WAT water flow component consist of ET (evapotranspiration) module, OC (overland/channel) flow module, VSS (variably saturated subsurface flow) module and SM (snow melt) module. ET module calculates net rainfall which is transferred to OC and VSS module and evaporation by Penman- Montieth equation which is transferred to OC module. ET module calculates interception by modified Rutter formula. OC module gives flow rate and water level at each time step to be computed as a function of space and time by diffusive wave approximation of Saint Venant's equations. The equations are solved by finite difference approximations. Water level calculated from OC module is used by VSS module. VSS module finds soil moisture, ground water levels and flows using variably saturated flow equations (SHETRAN user manual).

Sediment transport - It deals with soil erosion and multifraction transport on ground surface and in stream channels.

Solute transport - Deals with multiple, reactive solute transport on ground surface and in stream channels and subsurface.

There are number of parameters to be defined by user such as thickness of stream bed, saturated hydraulic conductivity, relative hydraulic conductivity, porosity, specific storage etc. and initial and boundary conditions to be defined. Input data required are Precipitation, Potential evaporation, DEM, soil maps and vegetation details. All the input data used in the model are in Arc ascii grid format. A Graphical User Interface (GUI) has been developed which allows SHETRAN to be set up rapidly, even by non- expert users [13]. In the present study SHETRAN GUI version 2.101 is downloaded and installed. Digital elevation model in arc ascii grid format of different grid sizes obtained from ArcGIS is an input of slope in the model. Mask which gives the extent of the study area is also an input to the model. Runoff was estimated for maximum rainfall of 24hr duration using SHETRAN model. Peak runoff has been found for 24hr running total rainfall and hydrograph was also plotted for all 5subcatchments.

A. *Parameters*

i) Vegetation parameters - The vegetation library of SHETRAN has 7 types such as grass, deciduous forest, urban, bare ground etc. Study area includes forests mainly consist of acacia trees, areas covered with lawns which were categorized as grass, area comprising buildings and pavements which were categorized as urban and small plain area without trees as bare ground. Study area contains acacia forest and trees like mango, coconut etc. Canopy storage capacity, leaf area index, maximum rooting depth, AE/PE ratio at field capacity was the main vegetation parameters. From the literatures it is found that Acacia forest has a storage capacity in the range of 0.77 to 1.44mm [6] and leaf area index of 2.3 and mango, cashew trees has a canopy storage capacity of 0.8mm and leaf area index of 1-1.25 [3]. Coconut trees having a leaf area index of 1.15. Rooting depth varies according to the stage of growth and soil condition. Factors affecting depth of root are soil aeration, fertility moisture and mechanical resistance. Model takes maximum rooting depth up to 20m.Water table limits the growth of root depth. Most of the main trees maximum root depth was 2m [7].Water table in the study area was 2 to 4.3m and major type of soil was silt. Considering all these factors maximum rooting depth has been selected as given in the following table. Ratio of actual evaporation to potential evaporation at monsoon period varies from 0.9 to 1 [1]. Vegetation parameters used in SHETRAN are shown in table II.

ii) Soil parameters - SHETRAN has soil library having twelve types of soil (e.g. clay, loamy sand, peat etc.). In the study area major types of soil are silty sand, silt and sandy silt (according to ASTM classification). Since SHETRAN has soil library according to USDA classification, silt, silty sand and sandy silt was taken as silt loam, sandy loam, sandy silt loam respectively. Saturated moisture content(w), residual moisture content(R), saturated hydraulic conductivity(K), Van Genuchten alpha(α) and n are the main soil parameters used in SHETRAN. Values of these parameters were selected based on the type of soil and from the earlier studies [11] and shown in table III.

TABLE II: VEGETATION PARAMETERS IN SHETRAN

Vegetation types	Canopy storage capacity	Leaf area index	Maximum rooting depth	AE/PE ratio
Urban	0	0	0	1
Bare ground	0	0	0	1
Grass	1.5	6	1	1
Decidious forest	1.25	2.3	2	1
Arable	0.6	1.125	1	1

TABLE III : SOIL PARAMETERS IN SHETRAN MODEL

Soil type	w(m)	R	K	α	n
Silt loam	0.46	0.034	0.06	0.016	1.37
Sandy loam	0.41	0.065	1.0608	0.075	1.89
Sandy silt loam	0.43	0.078	0.2496	0.036	1.56

iii) Other Parameters -Strickler's overland flow coefficient is a parameter which is the inverse of Manning's roughness coefficient.Other parameters listed in table IV.

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TABLE IV: OTHER PARAMETERS IN SHETRAN MODEL

Strickler's overland flow coefficient	Grid size (m)	Initial Water Table Depth (m)
10	15	2 to 4
50	30	
90	60	

V. RESULT

A. *Land Use Land Cover Classification*

In the present study, the LU/LC is required for the estimation of total runoff volume using curve number method, shown in Fig. 2. For identifying LU/LC classes the satellite imagery (2012) has been used. Supervised classification technique is used for identification of land use/cover classes. The accuracy obtained for the classification is 88%. Percentage area of different LU/LC types in each sub-catchment is tabulated in table V.

TABLE V: PERCENTAGE AREAS OF DIFFERENT LU/LC TYPES IN THE STUDY AREA

Sub catchments	Water (%)	Vegetation (%)	Barren Land (%)	Cultivated Land (%)	Built-up (%)	Total Area (km^2)
1	3.3	0.02	2.6	47.3	46.7	12313
2	4.78	1	18.77	27.03	48.46	13153
3	2.72	0.45	19.19	26.57	51.07	6651.2
4	4.65	2.08	34.78	34.06	24.43	11850
5	3.5	9	36.27	30.28	21	2397

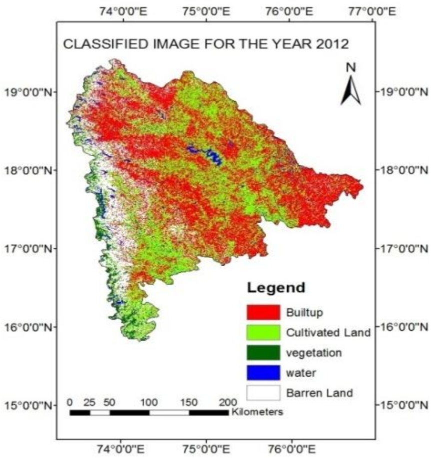

Fig. 2. Land use/land cover map for the year 2012

B. *Computation of surface runoff using NRCS-CN method*

After preparing the HSGs, the soil and land use were then overlaid to create polygons. A look-up table to contain SCS CN for all land use and soil groups was also created. The appropriate SCS CN values for each reclassified land use were assigned according to soil group. Then runoff was calculated. The graph is drawn against measured runoff and calculated runoff versus time in months which is shown in the fig. 3.

In sub-catchment 1 measured runoff and calculated runoff have similar plots. Looking at the plot for sub-catchment 2 it can be observed that the measured and calculated runoff values almost agree with each other till the month of June. A similar relationship between measured and calculated runoff values is found in sub-catchment 3& 4. In sub-catchment 3 measured runoff and calculated runoff have similar plots with an offset in the runoff values. In sub-catchment 5 variations seems to be different from the rest of the cases. Here the plot for measured runoff has two distinct peaks, whereas the calculated runoff shows a single peak hydrograph.

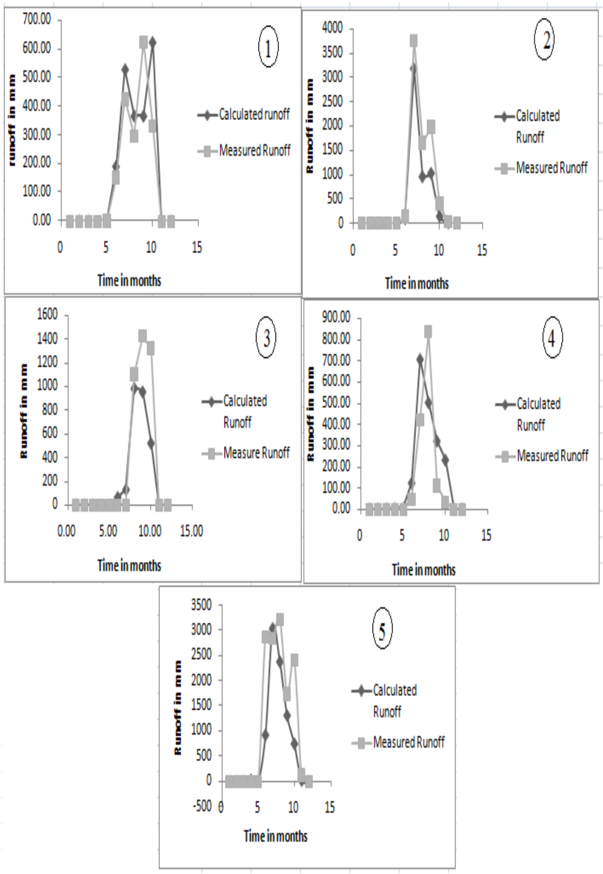

Fig. 3. Monthly runoff hydrograph for catchment 1, 2, 3, 4, 5

Correlation of observed runoff versus estimated runoff is shown in the fig. 4. The results showed that there is no significant difference between observed and estimated runoff depths.

For each sub-catchment, statistically positive correlations were detected between observed and estimated runoff depth ($0.6<R^2<1$).

C. *Computation runoff using SHETRAN*

Using SHETRAN model daily runoffs for the year 2012 for five catchments were calculated. In this model daily rainfall data is used.

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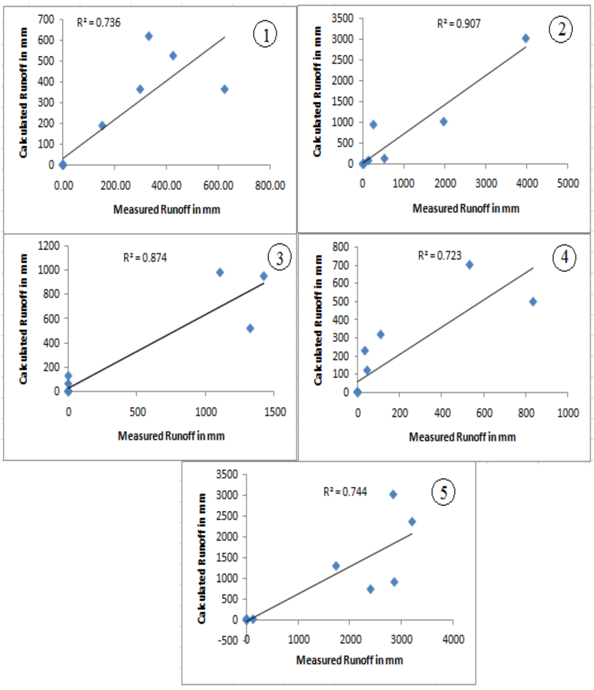

Fig. 4. Correlation graph for catchment 1, 2, 3, 4, 5

Linear regression analysis is done to find the correlation between the measured values from the discharge gauge station and the obtained value from the model. Correlation coefficients greater than 0.84 is obtained for the catchments, indicates that the model output was in agreement with the observed values. Runoff was estimated for rainfall of 24hr duration using SHETRAN model and tabulated. Peak runoff has been found for 24hr rainfall and hydrograph was also plotted for all 5subcatchments for the year 2012, as shown in fig. 5. In catchment 1 the maximum rainfall was distributed in 3 months August, September and October. During months of January, February and March the runoff is considerably low. It is due to low precipitation during these months. At the end of September there is a reduction in runoff in both the graphs. Considering sub-catchment 2 the maximum runoff was observed during months of July and August. During first five months the runoff in catchment 2 is considerably less. In sub-catchment 3 runoff is considerably increased during the month of June and August with a peak runoff 799.25 cumecs. In the beginning of July the runoff is decreases to 85.7 cumecs followed by a rapid increase in runoff during August. So Sub-catchment 3 shows clearly a double peak hydrograph. Runoff is very large in Sub-catchment 4. It is observed that peak runoff obtained is considerably large as compared to catchment 1, 2 and 3. Percentage Area of vegetation is very low compared to barren land. It is one of the major causes for higher runoff. Rapid increment and decrement of runoff is observed in Sub-catchment 5. Maximum runoff is observed at the month of July and August.

Correlation graph of measured runoff versus calculated runoff is shown in the Fig. 6. The results show that there is no significant difference between observed and estimated runoff depths.

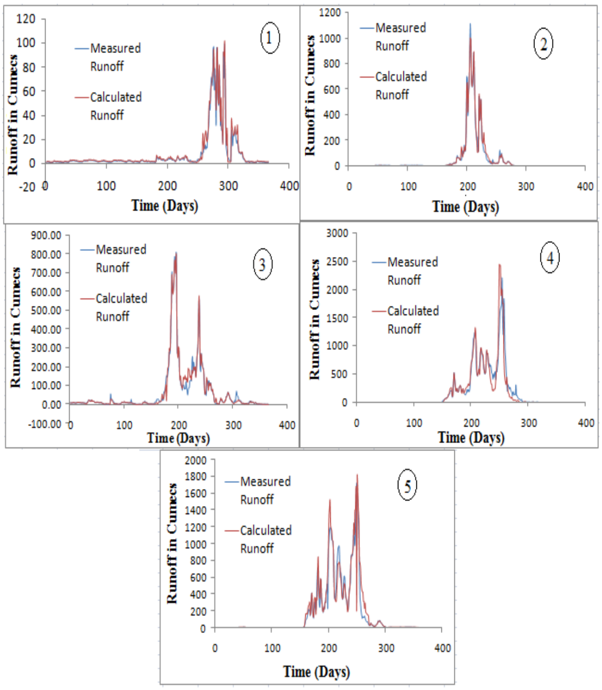

Fig. 5. Hydrograph for 24hr rainfall in sub-catchments 1, 2,3,4,5

For each sub-catchment, statistically positive correlations were detected between observed and estimated runoff depth. A correlation coefficient greater than 0.84 is obtained which indicating a good correlation between the measured and calculated runoff.

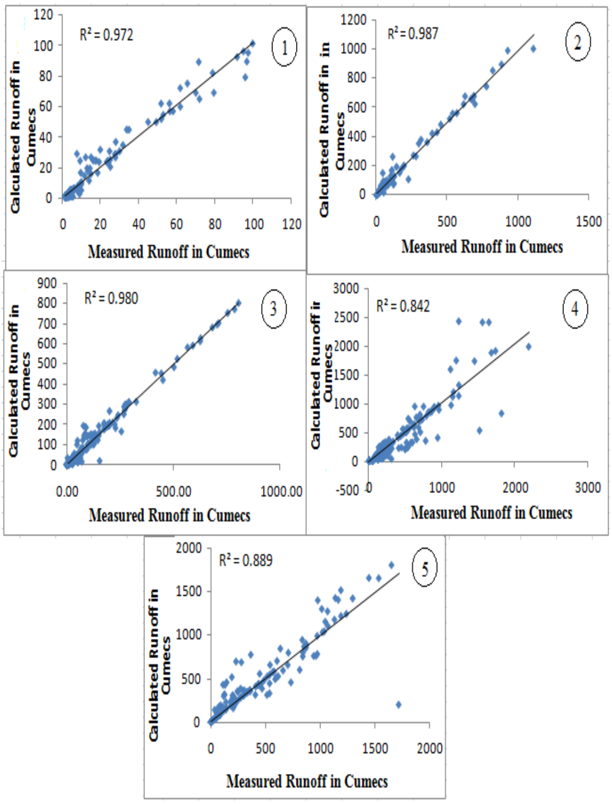

Fig. 6. Correlation graph for sub-catchments 1, 2, 3, 4, 5

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VI. CONCLUSION

Based on the analysis of results obtained in the study, following conclusions can be drawn

- The land use land cover map is generated for the year 2012.
- When comparing the rainfall-runoff results major portion of runoff is observed in the month of July.
- It has been observed from the results that if there is change in the land use then change in weighted curve number leads to increase in runoff.
- Runoff was estimated for maximum rainfall of 24hr duration using SHETRAN model.
- Peak runoff was found to be maximum in sub-catchment 4 and minimum in sub-catchment 1.
- Validation of result is done in both models. For NRCS-CN method a correlation coefficient greater than 0.720 was obtained, while SHETRAN gives a far better correlation with correlation coefficient greater than 0.85.
- From the study it can be concluded that NRCS-CN method can be adopted if only limited data is available and when high accuracy is not relevant.

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