# Estimation of Surface Runoff Using Remote Sensing and GIS Techniques for Cheyyar Sub Basin

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***Abstract*- Water is one of the most important natural resources and a hydrological key element in the socio-economic development of a country. Due to urbanization, the land use and land cover pattern has changed over the years, which has resulted in the modification of relationship between rainfall and runoff. Rainfall runoff modeling, a basic tool in the implementation of water resource management system gives the estimated surface runoff from the given amount of rainfall. In the present study, the runoff was estimated for the Cheyyar sub basin which falls under the Palar basin using the Modified Soil Conservation Service (SCS- CN) Curve Number method with Remote Sensing and GIS techniques. Various thematic maps such as land use land cover map, soil map, Hydrological Soil Group (HSG) map and rainfall maps were generated using Arc GIS 10.3 and ERDAS Imagine environment and the curve number values were derived from the inherent characteristics of the sub basin and 5$^{th}$ day Antecedent Moisture condition (AMC). Using the SCS – CN equation, the calculated curve number values and the non spatial rainfall data values were used to calculate the runoff of the sub basin and the obtained results were compared with the actual measured runoff for validation. This model gives more acceptable results compared to the runoff calculated by the other methods. It also found that the model can predict runoff more accurately and reasonably.***

***Keywords*- Runoff, Modeling, SCS, Curve number, AMC**

## I. INTRODUCTION

A Hydrological model is a simple model which is used for understanding, predicting, and managing water resources problem [1]. The “Hydrological cycle” is a continuous process in which water gets evaporated from surfaces and oceans, moves as moist air masses and produces precipitation or rainfall. Rainfall is essentially required to fulfill various demands including agriculture, hydropower, industries, environment and ecological system and is the primary source of “Runoff”. During rainfall, the excess water above the surface flows due to the imperviousness of the strata. As depression storage begins to fill and overflow, it is termed as “Surface Runoff”. Urbanization and man-made activities are found to have an impact on the natural land use pattern, leading to runoff. Determining the relationship between rainfall and runoff is one of the most key aspects in management of hydrological resources and modeling in an area.

Soil Conservation Service (SCS) method plays a vital role in the rainfall runoff modeling. Developed by the United States Department of Agriculture (USDA), this method also known as Natural Resources Soil Conservation Service Curve Number method (NRSC- CN) [2]. This method, not only considers the climatic factors in the area, but also the basin characteristics like soil texture, soil group, land use land cover pattern and slope [3]. In this paper, the curve number values, complimented with the integration of Remote Sensing and GIS techniques, is employed to estimate the surface runoff from excess rainfall for the Cheyyar sub basin, located in the state of Tamil Nadu, India. The GIS techniques can handle the spatial and non – spatial data in effective manner and provides better results [2].

## II. MATERIAL AND METHODOLOGY

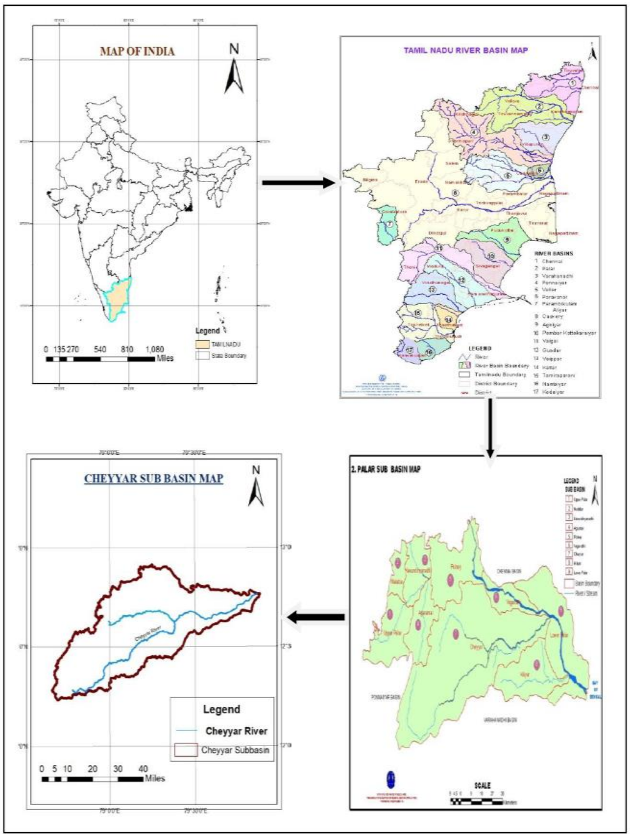


Figure 1. Location of Study Area

### A. *Study area description*

Cheyyar Sub basin is bounded by Kancheepuram, Thiruvannamalai and Vellore districts, covering an area of 4372.181km$^2$. The basin has a central coordinates of 79°50'59.99" E longitude and 12°45'59.99" N latitude. The average annual rainfall in the basin is 1074.70 mm. Nearly 45 per cent of the rainfall is received during the Northeast monsoon period (October to December). The average annual temperature is 28.2°C. Cheyyaru River is an important seasonal river that runs through Thiruvannamalai District. It is a tributary of Palar River, a river which originates in Jawadhu Hills and flows through Thiruvannamalai district before emptying into the Bay of Bengal. The river Palar receives two important tributaries namely, the Poini on the left bank and the Cheyyar on the right bank. It flows in the northeasterly direction before the joining with Palar near Tirumukkudal. Of all the total of seven tributaries, the chief tributary is Cheyyaru River. The river receives most of its water from the two monsoons and is the major source of irrigation for several villages such as Cheyyar and Vandavasi, located on its banks along its run of flow. The location of the study area is shown in Figure 1.

### B. *Data sources*

The land use land cover map was prepared using the Landsat ETM + satellite imagery ( 30 m Resolution) , downloaded from the United State Geological Survey (USGS) website (https://earthexplorer.usgs.gov/). The soil data for the study area was collected from Institute of Remote Sensing (IRS), Anna University Chennai. The rainfall data was collected from the State Ground and Surface water resources data center for a period of 25 years, 1991-2016 for the estimation of runoff in the sub basin

### C. *Methodology*

The aim of the study is attained in three steps. First, all the spatial and non spatial data were collected from different data sources and then, various thematic layers such as land use land cover map (LLULC), Hydrological Soil Group (HSG) map and soil map were prepared and overlaid. Finally, the runoff is estimated on the basis of the rainfall that occurred in the study area. The overall methodology is shown in Figure 2.

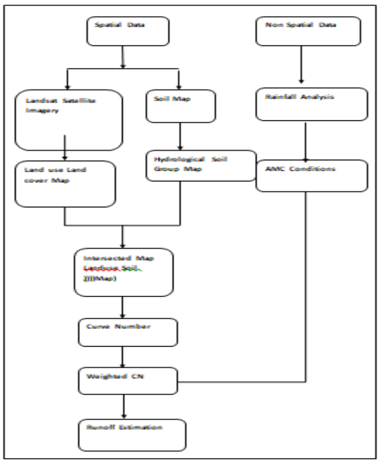


Figure 2. Methodology of the Study

### D. *Land use Land cover Map (LULC)*

The Landsat ETM+ satellite imagery is acquired from the USGS website (https://earthexplorer.usgs.gov/) which is used to prepare the land use/land cover map. Since the whole sub basin wasn't covered in a single scene of satellite imagery, scenes covering the whole basin, 2 imageries (scene1- path 142 and row 51, scene2 - path 142 and row 53) were mosaicked. The LULC map was prepared by running supervised classification of maximum likelihood classifier using ERDAS Imagine 14. The features indentified in the study area are agricultural land, barren land, water body, forest, and settlements. The accuracy assessment is done for the prepared LULC map using Kappa Statistics.

### E. *Soil and Hydrological Soil Group (HSG) Map*

The soil map of Cheyyar Sub basin was prepared using Arc GIS 10.3 software. The study area comprised of various kinds of soil textures- loamy, silty loam, fine loamy, clay, and sandy. The soil map is then classified into hydrological soil group map, which refers to the infiltration capacity of the soil and classified into 4 classes such as A, B, C, D. The table 1 shows their corresponding Hydrological Soil Group characteristics.

| Hydrological Soil Group ( HSG) | Description | Soil Texture |
|---|---|---|
| Group A | These soil having low runoff potential and high infiltration rates even when thoroughly wetted they consist of chiefly of deep, well to excessively drained sands or gravels and have a high rate of water transmission. | Sand, Loamy sand or Sandy loam. |
| Group B | These soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. | Silt Loam or Loam, Gravelly loam soils |
| Group C | These soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine textures. These soils have a low rate of water transmission. | Gravelly loam soils, Clayey soils. |
| Group D | These soils have high runoff potential. They have low infiltration rates when thoroughly wetted and consist chiefly of clay soil with a high swelling potential, soils with a high permanent high water table and soil with a clay layer. These soils have a very low rate of water transmission. | Rocky outcrops, Clay, Silty clayey. |

(Source : National Engineering Handbook - Part:650)

Estimation of Curve Number values (CN)

The LULC map and HSG maps were overlapped with each other through "INTERSECT" tool, available from Arc GIS 10.3 software. The attribute table of the output layer was found to contain the intersected attribute value of LULC and HSG. The CN value was assigned by referring the standard values, as shown in table 2. The weighted curve number value for the whole basin was considered on the basis of antecedent moisture condition, calculated using equation (1)

$$CN = \frac{(\sum CN_i \times A_i)}{\sum_{i=1}^{n} Ai} \qquad (1)$$

Where,

$CN_i$ - Curve number for particular land use unit

$A_i$ – Area of each land use.

The calculated CN value for average AMC II (Average) condition could be converted into CN values for AMC I (Dry) and AMC III (Wet) conditions using the equation (2) and (3) respectively.

$$CN\ (I) = \frac{CN\ (II)}{2.334 - 0.01334\ CN(\ II)} \qquad (2)$$

$$CN\ (III) = \frac{CN(II)}{0.427 + 0.00573\ CN\ (II)} \qquad (3)$$

Table 2
Curve Number Values

| Sl. No. | LANDUSE | RUNOFF CURVE NUMBERS FOR HYDROLOGICAL SOIL GROUPS | | | |
|---|---|---|---|---|---|
| | | A | B | C | D |
| 1 | Agricultural land | 59 | 69 | 76 | 79 |
| 2 | Barren land | 71 | 80 | 85 | 88 |
| 4 | Forest | 26 | 40 | 58 | 61 |
| 5 | Settlements | 77 | 86 | 91 | 93 |
| 7 | Water bodies | 100 | 100 | 100 | 100 |

(Source: Kumar et al, 1991)

After calculating the weighted curve number value, the maximum storage potential retention (S) and initial abstractions ($I_a$) were calculated by successively using equation (4) and (5) respectively.

$$S = \left(\frac{25400}{CN}\right) - 254 \qquad (4)$$

$$I_a = (\lambda\ x\ S) \qquad (5)$$

Where λ is the initial abstraction value and varies from 0.1 to 0.3. $I_a$ = 0.3 for Indian condition and 0.2 for general condition. If P > $I_a$ the runoff is calculated using the equation (6).

$$D = \frac{(P-I_a)^2}{((P-I_a)+S)} \qquad (6)$$

Where,

P – Total Rainfall in mm

S – Maximum Potential Retention in mm

$I_a$ – Initial Abstraction in mm

D – Total Runoff in mm. If P < 0 (D = 0)

## III. RESULTS AND DISCSSION

For the estimation of runoff for the Cheyyar sub basin, the LULC map, soil map, HSG map and CN maps were processed using Remote Sensing and GIS techniques. The overall accuracy of the LULC map was found to be 96.77% and the Kappa statistics was 0.9503. The major land use types in the study area are agricultural land (14.48%), barren land (16.87), forest (15.58%), water bodies (41.75%), and settlement (11.37%) shown in figure 3.

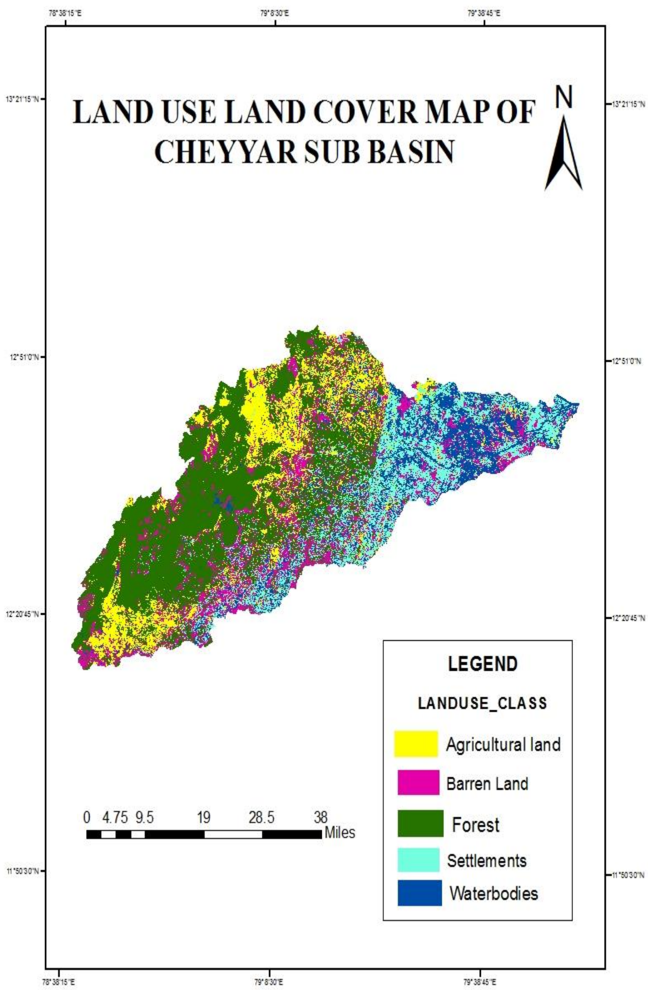


Figure 3. Land use Land cover Map

All four Hydrological Soil Groups (A, B, C, D) were found to be in the study area. Most part of the study area is covered by Group B soil which has moderate infiltration rate. The soil and HSG maps are shown in figure 4 and 5 respectively.

The CN values are one of the empirical measures which range from 0 to 100. A CN value of "0" represents low runoff while CN value of "100" represents higher runoff value. Table 2 represents the CN values for different LULC type. It can be noted that the water bodies have high runoff values because 100% of rainfall is converted into runoff. The agricultural land has lower CN values, ranging from 55 to 80, in comparison to the settlements presented in the study area, which range between 75 to 95. About 17% of area has CN value ranging from 70 to 90. Figure 6 shows the CN Value map

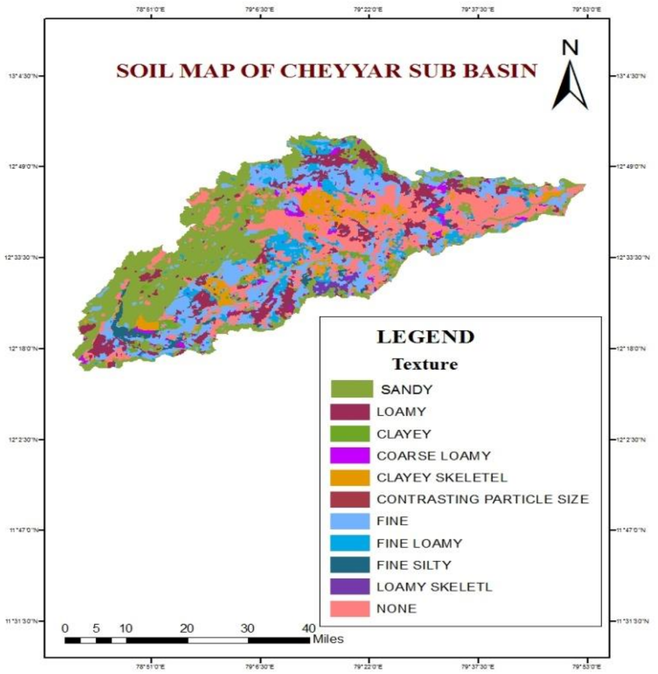


Figure 4. Soil Map

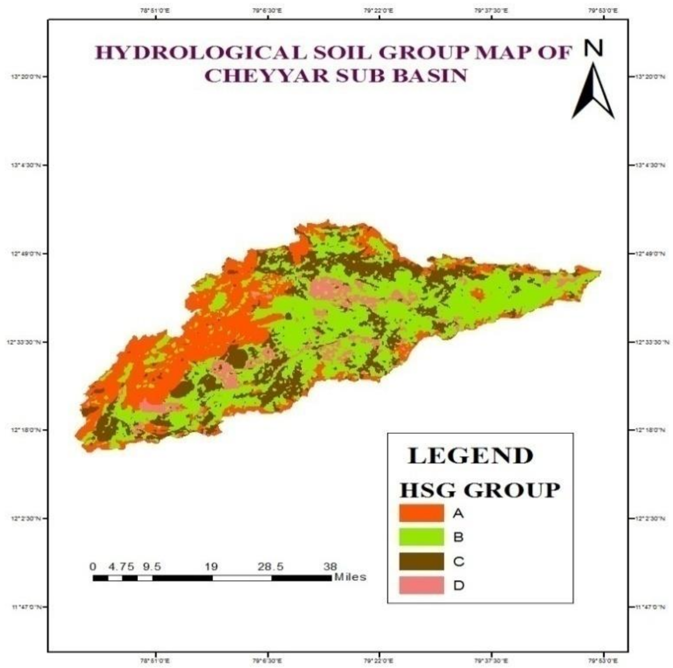


Figure 5. Hydrological Soil Group Map

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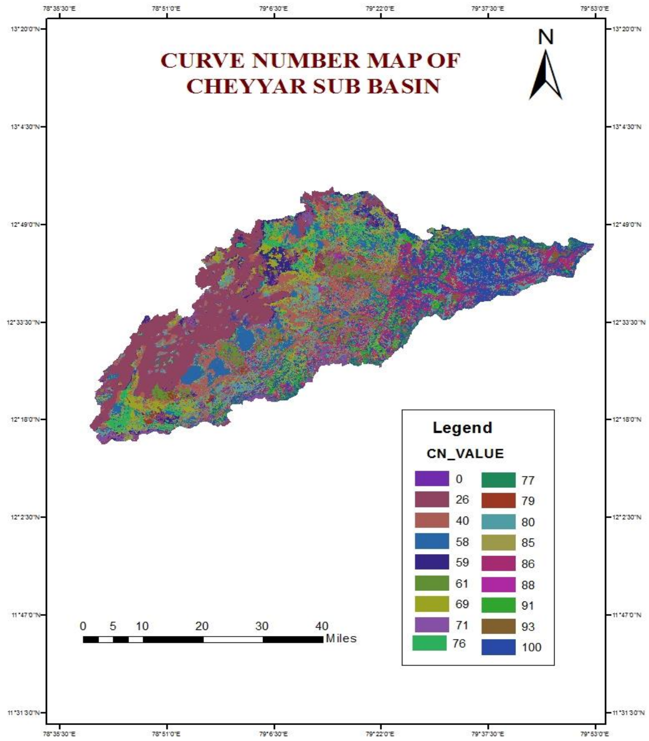


Figure 6. CN Value Map

The weighted CN values calculated for the study area under AMC (I), AMC (II) and AMC (III) conditions are 44.156, 64.35, and 80.67 respectively. For various initial abstraction ($I_a$) conditions, the runoff values are calculated using SCS – CN equation (6). The average runoff value for $I_a$ = 0.1, 0.2 and 0.3 are computed to be 989.675mm, 964.800mm and 961.084mm respectively. The estimated average runoff values using the SCS-CN method is summarized in table 3.

Table 3
Estimation of Runoff by SCS – CN Method

| SL NO | YEAR | Annual Rainfall (mm) | CN Value (AMC - II) | S (mm) | Ia = 0.1 S (mm) | Runoff (mm) | Ia = 0.2 S (mm) | Runoff (mm) | Ia = 0.3 S (mm) | Runoff (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1991 | 987.657 | 64.35 | 140.72 | 14.072 | 850.635 | 28.144 | 836.78 | 42.216 | 822.952 |
| 2 | 1992 | 777.714 | 64.35 | 140.72 | 14.072 | 644.818 | 28.144 | 631.092 | 42.216 | 617.377 |
| 3 | 1993 | 1040.114 | 64.35 | 140.72 | 14.072 | 902.294 | 28.144 | 880.429 | 42.216 | 874.569 |
| 4 | 1994 | 1101.457 | 64.35 | 140.72 | 14.072 | 985.37 | 28.144 | 940.904 | 42.216 | 935.023 |
| 5 | 1995 | 1186.7 | 64.35 | 140.72 | 14.072 | 1046.985 | 28.144 | 1033.077 | 42.216 | 1019.206 |
| 6 | 1996 | 1721.129 | 64.35 | 140.72 | 14.072 | 1577.0497 | 28.144 | 1563.064 | 42.216 | 1549.075 |
| 7 | 1997 | 1173.329 | 64.35 | 140.72 | 14.072 | 1033.77 | 28.144 | 1019.88 | 42.216 | 1005.973 |
| 8 | 1998 | 1344.643 | 64.35 | 140.72 | 14.072 | 1203.31 | 28.144 | 1109.368 | 42.216 | 1175.428 |
| 9 | 1999 | 1018.286 | 64.35 | 140.72 | 14.072 | 880.78 | 28.144 | 866.932 | 42.216 | 853.08 |
| 10 | 2000 | 1081.529 | 64.35 | 140.72 | 14.072 | 943.127 | 28.144 | 929.248 | 42.216 | 915.373 |
| 11 | 2001 | 1225.229 | 64.35 | 140.72 | 14.072 | 1085.085 | 28.144 | 1071.167 | 42.216 | 1057.252 |
| 12 | 2002 | 707.9 | 64.35 | 140.72 | 14.072 | 576.835 | 28.144 | 563.171 | 42.216 | 549.52 |
| 13 | 2003 | 1147.386 | 64.35 | 140.72 | 14.072 | 1008.136 | 28.144 | 994.238 | 42.216 | 980.343 |
| 14 | 2004 | 1048.429 | 64.35 | 140.72 | 14.072 | 910.488 | 28.144 | 896.76 | 42.216 | 882.758 |
| 15 | 2005 | 1641.071 | 64.35 | 140.72 | 14.072 | 1497.48 | 28.144 | 1403.498 | 42.216 | 1469.518 |
| 16 | 2006 | 816.2571 | 64.35 | 140.72 | 14.072 | 682.466 | 28.144 | 660.712 | 42.216 | 654.96 |
| 17 | 2007 | 1236.043 | 64.35 | 140.72 | 14.072 | 1095.781 | 28.144 | 1001.862 | 42.216 | 1067.945 |
| 18 | 2008 | 1186.657 | 64.35 | 140.72 | 14.072 | 1046.966 | 28.144 | 1033.03 | 42.216 | 1019.152 |
| 19 | 2009 | 895.943 | 64.35 | 140.72 | 14.072 | 760.516 | 28.144 | 746.714 | 42.216 | 732.919 |
| 20 | 2010 | 1322.71 | 64.35 | 140.72 | 14.072 | 1181.58 | 28.144 | 1167.643 | 42.216 | 1153.707 |
| 21 | 2011 | 1302.286 | 64.35 | 140.72 | 14.072 | 1161.352 | 28.144 | 1147.412 | 42.216 | 1133.486 |
| 22 | 2012 | 1087.157 | 64.35 | 140.72 | 14.072 | 948.679 | 28.144 | 934.798 | 42.216 | 920.922 |
| 23 | 2013 | 871.083 | 64.35 | 140.72 | 14.072 | 736.138 | 28.144 | 722.35 | 42.216 | 708.57 |
| 24 | 2014 | 989.5 | 64.35 | 140.72 | 14.072 | 852.449 | 28.144 | 838.604 | 42.216 | 824.764 |
| 25 | 2015 | 1622.893 | 64.35 | 140.72 | 14.072 | 1479.419 | 28.144 | 1465.439 | 42.216 | 1451.463 |
| 26 | 2016 | 773.129 | 64.35 | 140.72 | 14.072 | 640.034 | 28.144 | 626.622 | 42.216 | 612.868 |
| | | | | | | **989.675 (mm)** | | **964.800 (mm)** | | **961.085 (mm)** |

It could be inferred from equation (5) that, the increase in λ value shows decrease in runoff based on the potential retention parameter (S). If the initial abstractions like interceptions of plant, surface storage, infiltration rate and evaporation are high, runoff is possible only when rainfall is greater than 0.2 S. Else, resulting runoff is zero.

## IV. CONCLUSION

The base of any runoff estimation in a given area is to incorporate in the calculation, the hydrological parameters and the interaction between them- precipitation with topography, existing land use and soil. Usage of GIS, as a base for storing, interpretation and display of data is an efficient platform for the above process. The study mainly concentrated on the use of Remote Sensing and GIS in hydrological modeling. By SCS method, the runoff for the sub basin was estimated. The annual average runoff in AMC (II) condition was calculated to be 964.8mm. It was concluded that the runoff behavior of the study area varied with respect to the land use / land cover type, soil condition and rainfall amount. The higher the CN value, the runoff was found to be high while lower CN value accounted for lesser runoff.

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