Research Article

# Spatial verification of SCS-CN and Φ-Index methods in correlation to land use/land cover and Soil characteristics

Varsha Mane[1*], Y B Katpatal[2], K R Aher[3]

[1]Senior Geologist, [3]Junior Geologist, Groundwater Survey and Development Agency, Maharashtra, INDIA.
2 Professor, Department of civil Engineering Visvesvaraya National Institute of Technology, Nagpur (MS) INDIA.
**Email:** vasumane@gmail.com

**Abstract**

Groundwater recharge planning in microwatersheds is based on realistic information on infiltration characteristics. The present paper focuses on identification of infiltration characteristics within Mini watersheds by estimating runoff parameters and Φ-index. For this, the landuse /land cover and hydrological soil groups of the study area have been generated in GIS environment. By using landuse and soil classes, curve number has been generated. In the process, the SCS- CN method has been used to estimate runoff depth, peak discharge, and potential maximum retention, time of concentration and time to peak discharge for individual ten micro-watershed of the study area. For computation of infiltration rate from rainfall runoff data, infiltration indices i.e. Φ -index has been used. The study reveals that the SCS-CN method can be significantly used to determine the runoff estimation with input of LU/LC from RS data in comparison to the rational method. The study also verifies the fact that the Φ-index is related to the landuse, especially vegetation intensity and soil type of the micro-watershed. Result shows that WGK-2, 1/10 micro-watershed having highest Φ–index (2.29 mm/day) value, lower runoff (711.3) and Curve number value (64.33), has 70% forest area and gravely sandy loam type of soil. WGK-2, 10/10 micro-watershed having lowest Φ–index (0.81 mm/day) has higher runoff (807.29 mm) and Curve number value (84.7).

**Keywords:** SCS Curve Number. Antecedent Moisture, Rainfall runoff. Φ–index.

***Address for Correspondence:**
Dr. Varsha Mane, Senior Geologist, Groundwater Survey and Development Agency, Maharashtra, INDIA
**Email:** vasumane@gmail.com

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## INTRODUCTION

For the effective watershed management program, a proper understanding of hydrologic behavior of a watershed including accurate estimation/ prediction of depth and rate of runoff are required. In India, where 70% irrigation still depends on groundwater, the availability of accurate information on runoff is scarcely available and that too in a few selected sites where recording and automatic hydrologic gauging stations are installed. Thus, there is an urgent need to generate information on basin runoff and silt yield for the acceleration of the watershed development and management programmes (Zade *et al.* 2005). In India, most of the agricultural watersheds are ungauged; having no past record whatsoever of rainfall-runoff processes (Sarangi *et al.* 2005a, b). Non-availability of continuous rainfall and runoff records in majority of Indian watersheds has led to the development of techniques for estimation of surface runoff from ungauged basins (Chattopadhyay and Choudhury 2006). Out of several methods for runoff estimation from ungauged watershed, the Natural Resources Conservation Services Curve Number (NRCS-CN) method along with its modifications have been widely applied to ungauged watershed systems and proved to be a quicker and accurate estimator of surface runoff than other empirical and lumped parameter models (Mishra *et al.* 2003). The Soil Conservation Service Curve Number (SCS-CN) method (SCS 1956) has been widely accepted by scientists, hydrologists, water resources planners, agriculturists, foresters, and engineers for estimation of

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surface runoff (Patil *et al*., 2008).Bhuyan *et al*. (2001) used the modified curve number technique for prediction of surface runoff by adjusting the curve numbers based on the estimated antecedent moisture content (AMC) ratios. It was revealed that the CN approach could be used for accurate prediction of runoff depths from storm events. Pandey and Sahu (2002) estimated the runoff from Karso watershed situated in Damodar Barakar catchment of Hazaribagh district, Jharkhand. The Soil Conservation Service (SCS) CN estimation techniques were applied to estimate the runoff from daily storm events and these were validated with the measured runoff of a few selected events during the monsoon period of 1993. The maximum and minimum deviations between the observed and predicted runoff depths were observed to be 28.33 and 3.27% respectively. Geetha *et al*. (2005) studied the applicability of modified NRCS-CN concept to identify the dominant runoff generation process in the study catchments. The SCS model was investigated for simulating the surface runoff for single rainstorm in Wangdonggou watershed, a typical small watershed based on the remote sensing geo-information in the Loess Plateau, located in Changwu County of Shaanxi Province of China. (LIU Xianzha, and LI Jiazhu, 2008). Patil *et al*. (2008), has made an attempt to develop an interface in ArcGIS for watershed runoff estimation using the CN based techniques and compare the performance of three modified CN methods using the recorded data of a gauged watershed to ascertain its applicability in ungauged watersheds. In this study runoff is estimated using the SCS-CN method which is accurate method compare to the any other available method. This runoff is compared with the runoff calculated from the Rational Method. Rational Method was first introduced in 1889 (Viessman *et al*., 1989), even though it has frequently come under criticism for its simplistic approach, no other drainage design method has received such widespread use. The rational method is recommended for estimating the design storm peak runoff for areas as large as 81 ha (Conn DOT Drainage Manual, 2001). Although the rational method was originally designed for use on watersheds of 8 $Km^2$, it has been modified by some users (Jackson *et al*., 1976) for application to larger watersheds, principally by land-cover based area weighting of coefficients. The precision of the runoff coefficient value depends on local topography, land-management, and storm pattern conditions (Yulin Zhan *et al*.,2005). Remote sensing and GIS technologies were integrated to estimate runoff for Binjiang basin, China where runoff coefficients were computed by the Rational method for each year of the study (Yulin Zhan *et al*.,2005). In this study the runoff calculated using rational method found the values nearly equal to the values obtained by SCS-CN method. Runoff coefficient is calculated by weighing the distinct zone area (according to the slope) with their runoff coefficient values. Infiltration is the most important hydrologic variables used in most of the water resource application. Infiltration is the processes where water enters in to the soil pores when applied to the soil surface through rainfall and irrigation. The rate of infiltration is largely controlled by the factors like slope, soil structure, surface roughness, soil texture, surface cover, hydraulic conductivity and surface water content (Leonard and Andrieux, 1998). Direct runoff from a watershed depends upon spatial and temporal distribution of rainfall as well as properties of soil and geomorphology (Lee, 1988). The time required to saturate the soil depends upon the average rate of infiltration, soil moisture and thickness (Overton and Meadows, 1976). Geomorphology reflects the topographic and geometric properties of the watershed and its drainage channel network. It also controls the hydrologic processes from rainfall to runoff, and the subsequent flow routing through the drainage network. The separation of total runoff into direct runoff plus interflow and groundwater, and total rainfall into effective rainfall plus abstractions (interception, evapotranspiration, depression and detention storage, and infiltration), is a common feature of most lumped rainfall-runoff models (Viessman *et al*. 1977). Several infiltration models have been proposed in the literature and verified using real data (Chow *et al*. 1988). Several studies to estimate the infiltration by using mathematical calculation (Dewang, *et al*., 1999; Milena Clislerova, *et al*., 1988; Sumathi, *et al*, 1999; Sumathi, *et al*., 2000; Coskun, M., *et al*., 2005; Ritesh Vijay, 2007) have been carried out. In this study the rate of infiltration is calculated as a Φ-index value neglecting the surface storage and interception losses. In the recent years, the Remote Sensing (RS) data and Geographical Information System (GIS) techniques are being effectively used in the field of hydrology and water resources development. The technique is used to generate the land use/land cover map and also to compute runoff of the watershed (Ragan and Jackson, 1980; Tiwari *et al*., 1997; Pandey and Sahu, 2002; Nagraj *et al*., 2002). Rao and Rao (1997) incorporated land use/land cover and related roughness parameters based on remote sensing data in their hydrologic model. Using GIS has been growing steadily throughout the past decade to develop event-based rainfall–runoff watershed models because of its capability to store and analyze the spatially distributed data (Saghafian *et al*. 2000, Shrestha, 2003, Anbazhagan *et al*. 2005) developed a distributed hydrological model using remote sensing, and GIS tools to assess the changes in runoff value due to land use change over the Kathmandu Valley basin, Nepal. In the study, a spatially distributed model with SCS curve number was developed to assess the surface runoff variability due to alternate land use scenarios. Schultz (1994) used remote sensing and GIS in the meso-scale modeling of runoff and water balances. Fortin *et al*. (2001a, b) described physically distributed watershed model, Hydrotel, which is compatible with remote sensing and GIS techniques.

## METHODOLOGY

In the present study for evolution of a realistic SCS-CN runoff model, spatially variable geomorphologic parameters such as rainfall, soil characteristics, and land use change etc. are considered. The values obtained from SCS-CN method is compared with then values obtained from rational model which are more or less equal. Spatial Runoff Performance Units ( SRPU) were also derived using spatial overlay technique to classify microwatersheds as per runoff characteristics based on geology, geomorphology, slope, soil texture and drainage density. Also, the infiltration rates, calculated as Φ-index have been calculated and represented spatially. It has been observed that the changes in the runoff values are observed due to the variation in the landuse/landcover. Study proves that the SCS-CN model serve as an efficient tool for land use management of typical watershed in the Loess Plateau for the 21st century.

### Land Use Land Cover and Soil Classes delineation from satellite Data

As input data for run off estimation through SCS CN, the satellite data was used for interpreting various land use/land cover patterns in the basin. For this, the topographical maps 55- O/3 of Survey of India on 1:50000 scale, IRS-IC LISS III digital data dated 10 Jan, 2006 and 15 May 2005, pan IRS-1C are used. In the process, the IRS-1C LISS III data and PAN data were geometrically rectified and registered with SOI topographical map on 1:50000 scale using ERDAS Imagine 8.4 image processing software. Several studies have been carried out to demonstrate the feasibility of interpreting the land-use categories from remotely sensed data and further used as input data in a hydrologic modeling for estimating the runoff (Ragan and Jackson 1980; Slack and Welch 1980; Kathryn *et al*. 1986; Jackson *et al*. 1996). Further, the LISS-III image was subsequently classified in ERDAS classifier module to obtain the land use/land cover map of study area. The knowledge of soil cover and subsoil conditions is essential for prediction of runoff or recharge condition in a basin. The classification of soils is based on effective depth, average clay content, infiltration and its probability. Based on infiltration rate, texture, depth, drainage condition and water transmission capacity, soils have been classified into different hydrological soil groups as per the standard classification given after Chow *et al*. (1988) and Viessman *et al*. (1989). The soil map for the area was prepared and digitized on the basis of published National Bureau of Soil Surveys and Land Use Planning (NBSS and LUP) Nagpur district atlas- 1994. The precipitation data for the year 2008 in centimeters is collected from Groundwater Surveys and Development Agency, Maharashtra. Parameters including drainage length, watershed areas were calculated in GIS environment. The antecedent moisture condition and physical characteristic of watershed are correlated to give hydrologic soil groups.

### Estimation of runoff using U.S. Soil Conservation Services (SCS) Method

The SCS-CN method of determination of peak rate of runoff for mini watersheds, given after Ogrosky and Mockus (1957) explains the methodology of response of the basin to the rainfall. For the present work, calculation of curve numbers for the individual watersheds area was done on the basis of soil groups, land use/ land cover classes by considering AMC-II conditions (USDA, 1986). A runoff curve number (CN) is developed through field studied by measuring runoff from different soils at various locations. For calculation part, the estimation of runoff curve numbers is done using several parameters like land use, soil and antecent moisture condition (AMC). A GIS based methodology is used to get the input parameter at pixel level. The volume and the rate of runoff depends on both meteorological and watershed characteristics and the estimation of runoff requires an index to represent these two factors. The precipitation volume is probably the single most important meteorological characteristics for the estimation of volume of runoff. The soil type, land use and hydrological condition of land cover are the watershed factors. The antecedent soil moisture is also an important determinant of runoff volume.

### Spatial intersection and derivation of curve number

In order to obtain a weighted CN for each watershed, land use/ land cover classes are intersected with the hydrological soil groups along with their relevant curve number values in the GIS environment. All the calculations are made by considering average antecedent soil moisture condition i.e. AMC II (USDA- NRCS, 1972). Since the study area consists of more than one classes of land use, the composite curve number (CN) for the watershed has been obtained by weighing them in proportion of area. The value of CN is taken lower for soils with high infiltration than for soils with low infiltration (Patra, 2002).

1) Calculation of potential maximum retention S in cm,

$$CN = \frac{2540}{(25.4 + S)} \quad (1)$$

2) Calculation of runoff depth for all soils in India except Black soil region of AMC II and III where Initial losses (considering interception depression storage and infiltration) i.e. Ia (initial abstraction) equals to 0.2S,

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

Where,

P- Mean rainfall in cm.

3) Calculation of time of concentration

$$Tc = \frac{L^{0.8} * ((1000/CN) - 9)^{0.7}}{190 * S^{0.5}} \quad (3)$$

Where,

Tc- Time of concentration in hr.

L- Drainage length

4) Calculation of time to peak discharge

$$Tp = 0.6Tc + Tc^{(1/2)} \quad (4)$$

Where, Tp- Time to peak discharge in hr.

5) Calculation of peak discharge i.e. Qp (cubic m/sec)

$$Qp = \frac{0.0208 * A * Qd}{Tp} \quad (5)$$

Where, A- Area in ha.

## Runoff estimation by using Rational Method

In this method peak discharge of the basin is calculated. Slope and soil type of the basin is considered to calculate the runoff coefficient.

The peak discharge is as given below

$$Qp = 0.278C * I * A \quad (6)$$

Where, Qp- peak discharge in cubic m /sec

C- Runoff coefficient representing a ratio of runoff to rainfall

A- Catchments area in square km.

I- Rainfall intensity in mm/hr whose duration should be equal to time of concentration of basin.

## Runoff Estimation by overlay analysis

The microwatersheds have been classified as Spatial Runoff Performance Units (SRPU) in terms of Very good or poor runoff zones. These performance units have been derived on the basis of the natural resource parameters viz. geology, geomorphology, slope, LU/LC, soil texture and drainage density by assigning reverse weights to polygons through GIS overlay analysis (Krishnamurthy, 2000). The runoff index map showing SRPU is given as Fig.

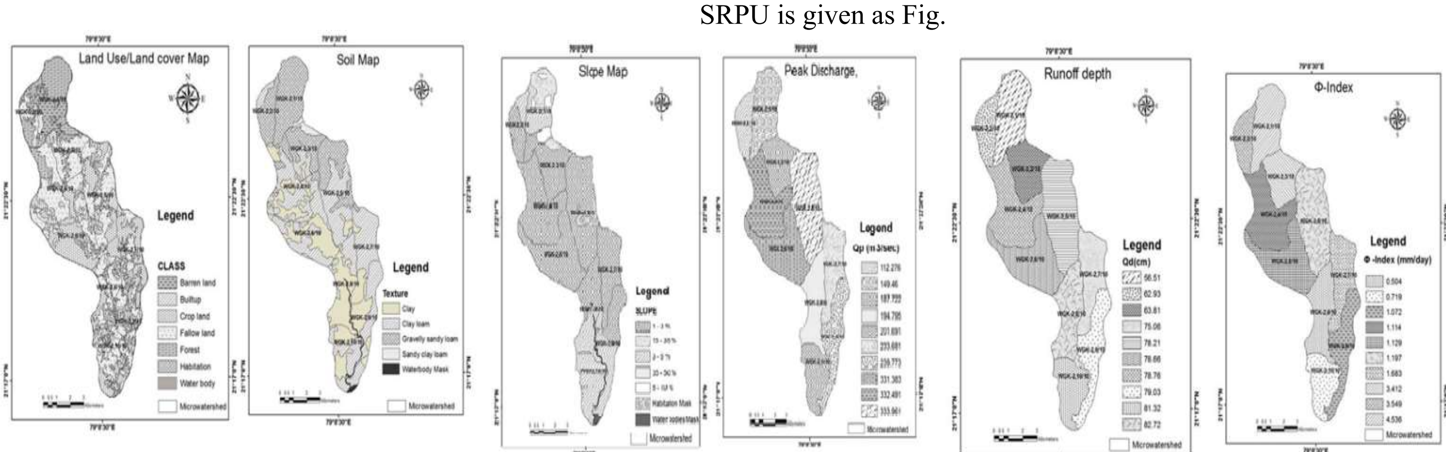


Fig-1 Fig-2 Fig-3 Fig-4 Fig-5 Fig-6

## Infiltration calculation for determination of Φ-index

Infiltration capacity is the maximum rate at which a given soil can absorb water under given set of conditions at a given time. At any instant the actual infiltration can be equal to infiltration capacity only when the rainfall intensity is greater than the infiltration capacity otherwise the actual infiltration will be equal to rate of rainfall. For computation of infiltration rate from rainfall runoff data, mostly infiltration indices i.e. Φ–index and W-index were used. The average rate of rainfall volume above which the rainfall volume equals to runoff volume is called Φ–index. Center Water Commission (1988) suggests relation as fallows,

$$F = \frac{(P - R)}{te} \quad (7)$$

Where, $R = a * I^{1.2}$

**Table 1:** Runoff calculation by using SCS-CN method

| Watershed Name | Soil Type | Land use/ Land cover | Area, A (hector) | Drainage Length (m) | Precipitation (cm) | CN |
|---|---|---|---|---|---|---|
| WGK-2 1/10 | Gravelly sandy loam, Clay loam | Open land, Forest, Agriculture | 860 | 6993 | 86 | 43.96 |
| WGK-2 2/10 | Gravelly sandy loam, Clay loam | Agriculture | 424.3 | 4516 | 86 | 51.76 |
| WGK-2 3/10 | Clay loam, sandy loam | Agriculture | 617 | 3719 | 86 | 52.96 |
| WGK-2 4/10 | Clay loam and clay | Agriculture | 1061 | 5581 | 86 | 79.852 |
| WGK-2 5/10 | Clay loam, sandy loam | Agriculture | 1211 | 6752 | 86 | 78.591 |
| WGK-2 6/10 | Clay loam | Agriculture | 1117 | 6075 | 86 | 79.62 |
| WGK-2 7/10 | Clay and Clay loam | Agriculture | 785.4 | 5519 | 86 | 71.746 |
| WGK-2 8/10 | Clay and Clay loam | Agriculture | 709 | 6949 | 86 | 90.05 |
| WGK-2 9/10 | Clay and Clay loam | Agriculture | 737.4 | 5291 | 86 | 80.5 |
| WGK-2 10/10 | Clay and Clay loam | Agriculture | 623.3 | 5475 | 86 | 86.26 |

## RESULT AND DISCUSION

The infiltration characteristics (Φ-index) and runoff are estimated here for 10 micro-watersheds of the study area (table- 2). The study area possesses mainly four types of soil viz. clay, clay loam, sandy clay and gravely sandy loam (fig. 2). The land use / land cover map shows mainly six classes for the watershed area (fig.3). Precipitation of 860 mm recorded in rain gauge station for the year 2008 in all the ten watersheds because all these micro -watershed fall in Parshivani taluka of Nagpur district, which is having only one rain gauge station. Weighted CN values falls in between 43.96 to 84.7 for the ten watersheds calculated individually. On the basis of this weighted CN, Potential Maximum Retention, S (cm) is calculated (table-2).

**Table 2:** Φ –Index calculation

| Watershed | Potential Maximum Retention, S (cm) | Runoff depth, Qd (cm) | Time of concentration, tc (sec) | Time to peak discharge, tp (sec) | Peak Discharge, Qp ($m^3$/sec) | R (mm) | P (mm) | Storm Duration (day) | Φ -Index (mm/day) |
|---|---|---|---|---|---|---|---|---|---|
| WGK-2 1/10 | 32.380 | 56.513 | 6.896 | 6.764 | 149.461 | 565.135 | 860 | 65.00 | 4.536 |
| WGK-2 2/10 | 23.673 | 62.933 | 4.651 | 4.947 | 112.277 | 629.331 | 860 | 65.00 | 3.549 |
| WGK-2 3/10 | 22.561 | 63.819 | 3.956 | 4.363 | 187.722 | 638.189 | 860 | 65.00 | 3.412 |
| WGK-2 4/10 | 6.409 | 78.760 | 4.990 | 5.228 | 332.491 | 787.601 | 860 | 65.00 | 1.114 |
| WGK-2 5/10 | 6.919 | 78.220 | 5.814 | 5.900 | 333.962 | 782.198 | 860 | 65.00 | 1.197 |
| WGK-2 6/10 | 6.502 | 78.662 | 5.340 | 5.515 | 331.383 | 786.616 | 860 | 65.00 | 1.129 |
| WGK-2 7/10 | 10.003 | 75.061 | 5.014 | 5.247 | 233.681 | 750.612 | 860 | 65.00 | 1.683 |
| WGK-2 8/10 | 2.807 | 82.721 | 6.266 | 6.263 | 194.795 | 827.214 | 860 | 65.00 | 0.504 |
| WGK-2 9/10 | 6.153 | 79.033 | 4.782 | 5.056 | 239.774 | 790.330 | 860 | 65.00 | 1.072 |
| WGK-2 10/10 | 4.046 | 81.328 | 4.990 | 5.228 | 201.691 | 813.284 | 860 | 65.00 | 0.719 |

Runoff depth calculation for all ten mini-watersheds has been done which ranges from 56.51 to 82.72, where WGK-2, 1/10 shows minimum value and WGK-2, 8/10 shows maximum runoff depth. In this study the soil conservation service equation is used to determine time of concentration (Eq.3), this equation requires mainly channel length, average and curve number of the micro-watershed, which is evaluated by the GIS tools. In table -2 shows that Tc ranges from 3.95 to 6.89. Calculation of time to peak discharge is also done by using Eq.4, where Tc is main parameter of this equation. The time of concentration is directly related with time to peak discharge (Fig-10), which is maximum for WGK-2 1/10 and minimum for WGK-2 3/10 (table-2). Peak Discharge, Qp (cubic m /sec) which is main output from SCS-CN method has been calculated by using Eq.5, this equation requires area of the micro-watershed, runoff depth and time to peak discharge. Peak discharge has also been calculated by rational method which is less as compared to discharge calculated by SCS CN method. Fig 7 and table 2 shows that Qp ranges between 149.46 to 333.98 in WGK-2, 1/10 and WGK-2, 5/10 miniwatershed respectively. The values of peak discharge calculated by above two methods may be spatially compared with the runoff units qualitatively derived through overlay analysis (Fig. 7). Result shows that WGK-2, 1/10 and WGK-2, 7/10 mini-watershed have very good runoff zone, whereas WGK-2, 10/10 shows poor to moderate runoff zone.

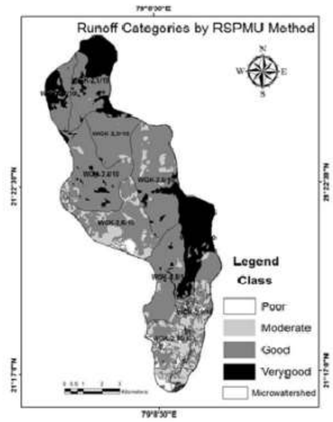


Fig-7

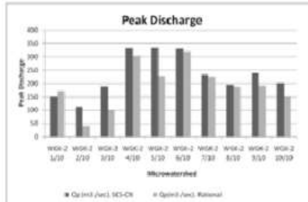


Fig-8 Peak Discharge from SCS and Rational Method

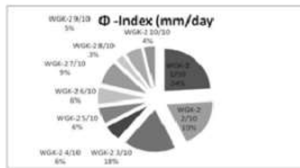


Fig-9 Shows micro-watershed wise Φ-index

Determination of Φ-index which is a generally used infiltration index has been carried out on the basis of runoff in mm, and precipitation (Eq-6) (Table 2). Φ-index values ranges from 0.504 to 4-53 wherein WGK-2, 1/10 has maximum and WGK-2, 8/10 minimum value (Fig 7). Mini-watershed having dense forest and Gravelly sandy loam, soil type, therefore this watershed having low CN number (43.96) and high infiltration rate. The value of CN is lower for soils with high infiltration than for soils with low infiltration (Patra, 2002). This relation is found verified as shown in Fig- 12. Fig-10 shows relation between **Φ** -index and runoff depth of mini watershed. The correlation between runoff and **Φ** -index clearly shows inverse relationship between them. This suggests that increase in runoff leads to decrease in the **Φ** -index and vice-a-versa. The trend line shows a direct relationship between the two parameters. This clearly indicates that the peak discharge increases with the time of concentration (Fig.11). When runoff and **Φ** – index values of micro watersheds are compared with slope of the area, it is found that WGK-2, 1/10 micro-watershed has slope range between 15%-35%, and 3-5 %( Fig-3), but has high **Φ**–index value and low runoff. This result is observed because this micro-watershed is mostly covered with dense forest and gravelly sandy loam soil type resulting in high **Φ**–index value.

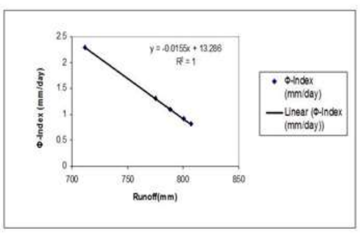


Fig 10. Relation between **Φ** -index and runoff depth of mini watersheds

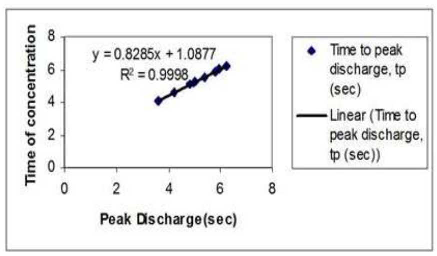


Fig-11. Relation between Time of concentration and peak discharge of mini watersheds

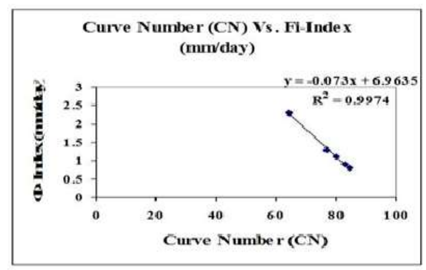


Fig-12. Relation between **Φ** -index and Curve number of mini watersheds

## CONCLUSION

From the above studies it is clear that the land-use and land cover information interpreted from satellite data can be used as one of the main input parameters for estimating runoff through the SCS curve method. The areas with higher slopes where higher runoff is expected shows high infiltration index due to presence of coarse soil texture and dense vegetation. The remote sensing based integrated terrain analysis is useful for identifying and prioritizing the suitable sites for groundwater recharge. The GIS technique is useful in spatial intersection of different land use and land cover with various hydrological soil groups in the watershed areas. The results of spatial intersection were used for calculating the weighted curve number (CN) in each watershed. On the basis of these CN number runoff depth and volume of runoff has been calculated. Φ Index for all 10 mini watersheds wears also estimation, which shows infiltration characteristics of particular watershed.

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