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# SURFACE RUNOFF ESTIMATION BY SCS CURVE NUMBER METHOD USING GIS FOR RUPEN-KHAN WATERSHED, MEHSANA DISTRICT, GUJARAT

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## ABSTRACT

*For the effective management of water resources, an accurate understanding of hydrological behaviour of an area is very important. Per capita availability of land for cultivation has been decreasing over the years hence water and related land resources are to be developed, utilized and managed in an integrated and comprehensive manner. Runoff is the most basic and important parameter needed for planning water management strategies. In the present study Rupen-Khan watershed which is located in the Rupen basin of Mehsana district has been taken as case study for the estimation of runoff by SCS curve number method using Geo-spatial technology. Direct runoff depends on rainfall, soil type, soil moisture, drainage density, topography, size and shape of watershed, land cover etc. Various thematic layers such as Soil, land use, slope have been generated in GIS environment. The curve number (CN) polygon wise has been estimated using a combination of land use, soil, and antecedent soil moisture condition (AMC). The original soil map has been converted to a map of Hydrologic Soil Groups (HSG). Weighted area curve number has been determined in order to find a representative curve number by integrating attributes of various thematic layers in Arc GIS using the areas of different land cover and soil types as weighting factor. Study reveals that SCS-CN method coupled with Remote Sensing and GIS is capable of simulating runoff pattern and runoff volume successfully for Rupen-Khan watershed. It is also observed in this study that due to changing land use pattern, volume and runoff rate are changed significantly.*

***Keywords:*** *Antecedent Soil Moisture Condition (AMC), Curve Number (CN), GIS, Hydrologic Soil Groups(HSG).*

## INTRODUCTION

A watershed is the area covering all the land contributes runoff water to a common point. Each watershed has definite characteristics like size, shape, slope, drainage, vegetation, geology, soil, geomorphology, climate and land use. Watershed management implies the proper use of all land and water resources of a watershed for optimum production with minimum hazard to natural resources.

Runoff is very important hydrologic variable in the water resources applications. The occurrence and quantity of runoff are dependent on the characteristics of rainfall event like intensity, duration and distribution. There are number of methods available for finding out the runoff such as Rational method, Green-Ampt method, and SCS-CN method. Rational Method is mainly used for the estimation of the maximum discharge of catchment for small drainage areas of up to about 200 acres (80 ha) whereas SCS-CN and Green-Ampt methods for estimation of runoff are used for relatively large areas (K R ARORA). The SCS-CN Method was developed by US Department of Agriculture in which CN is estimated using a combination of land use, soil, and Antecedent Soil Moisture Condition (AMC). There are four Hydrologic Soil Groups: A, B, C and D. Soils having high infiltration rate were kept under group 'A', whereas soils having low infiltration rate come under group 'D'. The Study carried out in Rupen Khan watershed of Mehsana district indicates the result of Runoff by SCS CN Method. The SCS-CN Method has been used in present study considering size of catchment 162080 ha for calculation of runoff. Songara et al., (2015) showed that estimation of runoff by SCS-CN method integrated with GIS can be used in watershed management effectively. Jasrotia et al., (2002) used a mathematical model to estimate rainfall-runoff in conjunction with remote sensing data and GIS using SCS- CN method and runoff potential map. Dhawale (2013) used the SCS-CN model for the estimation of surface runoff depth when adequate hydrological information is not available. Sindhu et al., (2013) estimated the runoff from the SCS-CN model, which is used to know the variation of runoff potential with different land use/land cover and with different soil condition. GIS and Remote sensing techniques are being increasingly used for planning, development and management of natural resources. GIS in particular helps in integrating various data sets and perform spatial analysis for decision making. The objective of this study is to estimate the runoff using Remote Sensing (RS) and Geographic Information System (GIS) by SCS-CN method.

## STUDY AREA

The study area of Rupen-Khan watershed lies in Rupen basin in Mehsana District, Gujarat. The catchment area falls under the category of sub watershed as per size (162080 ha). The study area falls between latitude 23°33' and 24°0' N and longitude 72°0' and 72°42' E. The highest relief in the watershed is found to be 369 m and the lowest relief is 49 m above the mean sea level. The SOI toposheets of 1:50,000 (46A/5, 46A/9, and 46A/13) were obtained. Total area of watershed as computed using GIS is 162080 ha. Figure 1 shows location map of study area. Soils of watershed area are loamy skeletal, fine loamy and course loamy.

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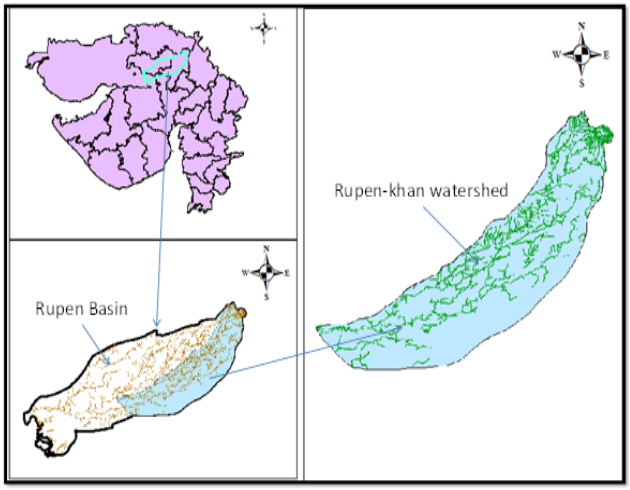


**Fig. 1: Location Map of study area**

## METHODOLOGY

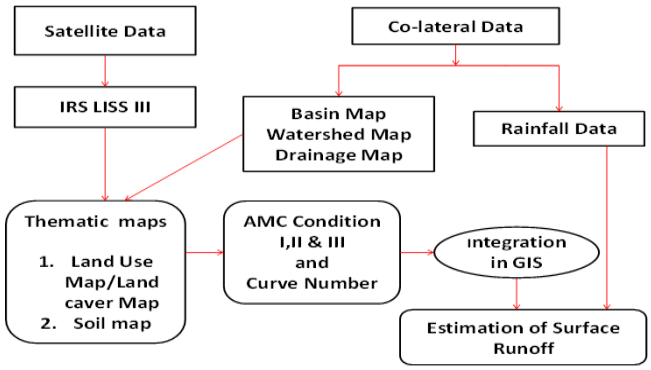


**Fig. 2: Flow chart of Methodology**

The methodology adopted is:

- Definition of map and the boundaries of watershed for the calculation of curve number as well as area of watershed.
- Mapping the soil type and land use for the watershed.
- Converting the soil types to Hydrologic Soil Groups.
- Overlaying the land use map and hydrologic soil group maps, identifying each unique land use soil group polygon and determination of the area of each polygon.
- Assigning a curve number to each unique polygon, based on standard SCS curve number table.
- Finding the weighted curve number and calculating potential maximum retention (S) using eq. (6) and Initial Abstraction ($I_a$) using eq. (4).
- Calculation of the daily, monthly and annually runoff using eq. (5).

## SCS CURVE NUMBER METHOD

In the early 1950s, the United States Department of Agriculture (USDA) and Natural Resources Conservation Service (NRCS) (then named the Soil Conservation Service (SCS) developed a method for estimating runoff from rainfall. This method is also referred as the CN method.

The SCS curve number method is based on the water balance equation & two fundamental hypotheses which are stated as, (1) ratio of the actual direct runoff to the potential runoff is equal to the ratio of the actual infiltration to the potential infiltration, and (2) the amount of initial abstraction is some fraction of the potential infiltration. (Handbook of Hydrology, 1972).

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

$$F = (P - I_a) - Q \quad (2)$$

Substituting eq. (2) in eq. (1) and by solving;

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

where, F=the cumulative infiltration excluding $I_a$, Q = actual runoff (mm), P = rainfall (mm), $I_a$ = initial abstraction, which represents all the losses before the runoff begins and is given by the empirical equation.

$$I_a = 0.2\ S \quad (4)$$

Substituting eq. (4) in eq. (3); the eq. (3) becomes

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \quad \text{For } P>I_a\,(0.2S) \quad (5)$$

S = the potential infiltration after the runoff begins given by following equation

$$S = \frac{25400}{CN} - 254 \quad (6)$$

The CN (dimensionless number ranging from 0 to 100) is determined from a table, based on land-cover, HSG and AMC. HSG is expressed in terms of four groups (A, B, C, D) according to the soil's infiltration rate. AMC is expressed in three levels (I, II and III), according to rainfall limits for dormant and growing seasons. CN value was adopted from Technical release (TR-55).Although, SCS method is originally designed for use in watersheds of 15 $km^2$, and it has been modified for application to larger watersheds by weighing curve numbers with respect to watershed/land cover area. Equation of Weighted CN is given below.

$$CNw = \frac{\Sigma(CNi*Ai)}{A} \quad (7)$$

Where,

*CNw* = weighted curve number.

*CNi* = curve number from 1 to any no.

*Ai* = area with curve number CNi

## ANTECEDENT SOIL MOISTURE CONDITION (AMC)

Antecedent Moisture Condition (AMC) refers to the water content present in the soil at a given time. It is very important factor for determining actual CN value. SCS developed three antecedent soil-moisture conditions and labelled them as I, II, III, according to soil Characteristics and rainfall limits for dormant and growing seasons. Classification of Antecedent

Moisture Condition is shown in Table 1. In present study, average condition (AMC-II) is taken for determinining CN value for Rupen-Khan watershed.

**Table 1: Classification of Antecedent Moisture Conditions (AMC)**

| AMC Class | Soil Characteristics | Total 5 day Antecedent rainfall(mm) | |
|---|---|---|---|
| | | Dormant Season | Growing Season |
| I | Soils are dry not to wilting point, Cultivation has taken place | < 13 mm | < 36 mm |
| II | Average Condition | 13-28mm | 36 - 53 mm |
| III | Heavy or light Rainfall and low temperatures have occurred within the last 5 days; saturated soils | > 28 mm | >53 mm |

*(Source: Engineering Hydrology, K. Subramanya, 2008)*

The conversion of $CN_{II}$ to other two AMC conditions can be made through the following correlation equation

**$CN_I$ for AMC-I:** $\frac{CN_{II}}{2.281-(0.01281*CN_{II})}$ (8)

**$CN_{III}$ for AMC-III:** $\frac{CN_{II}}{0.427+(0.00573*CN_{II})}$ (9)

## THEMATIC MAPS USED

***Land Use/Land Cover Classification Map***

Land use involves the management and modification of natural environment or wilderness into built environment such as settlements and semi-natural habitats such as arable fields, pastures, and managed woods. The land use/land cover classification map of the study area was prepared by using unsupervised classification, as very little ground truth data were available. The unsupervised classification was performed using Arc GIS software as shown in fig.3.

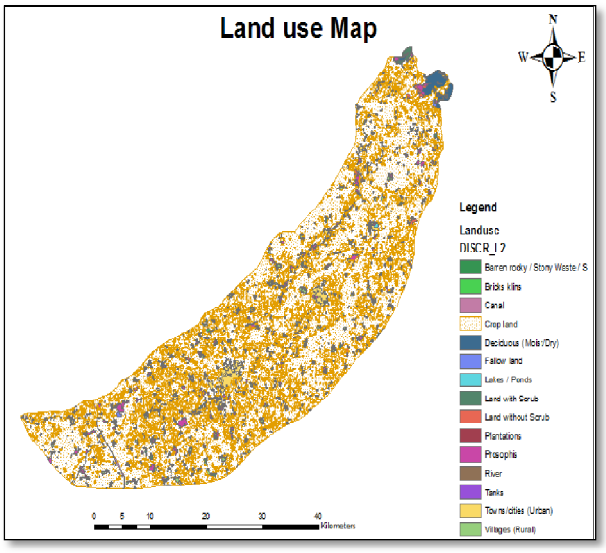


**Fig. 3: Land use Map of Study Area**

***Soil Map***

Three types of soil have been identified in the area which is Coarse Loamy, Fine Loamy and Loamy Skeletal. Most of area is covered by Fine Loamy soil. The soil map is shown in fig. 4 which is prepared from data given by BISAG, Gandhinagar.

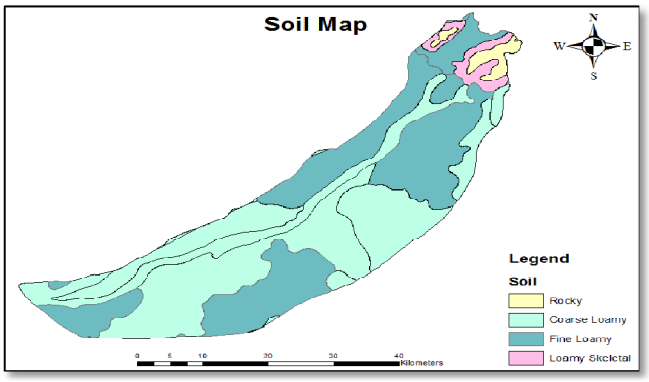


**Fig.4: Soil Map of Study Area**

## HYDROLOGIC SOIL GROUP CONDITION (HSG)

The hydrological soil group classification is shown in table- 2. CN values were determined from hydrological soil group and antecedent moisture conditions of the watershed. The Curve Number values for AMC-I and AMC-III were obtained from AMC-II. Runoff curve numbers (AMC II) for hydrologic soil cover complex are shown in Fig.5 (shows the HSG map ) & Fig. 6 (shows the CN map of Rupen-Khan watershed).

**Table 2: USDA-SCS Soil Classification**

| S. N. | HSG | Soil Textures | Runoff Potential | Minimum Rate of Infiltration (mm/hr) | Water Transmission |
|---|---|---|---|---|---|
| A | Deep, well drained Soils | Sand, Loamy sand or sandy loam | Low | 7.62- 11.43 | High rate (0.30 in/hr) |
| B | Moderately Deep, well drained with moderately fine to coarse textures | Silt loam or loam | Moderate | 3.81- 7.62 | Moderate rate (0.15-0.30 in/hr) |
| C | Moderately Fine to Fine textures | Sandy Clay loam | Moderate | 1.27- 3.81 | Low rate (0.05-0.15 in/hr) |
| D | Soil which swell significantly when wet, Heavy plastic and soil with a permanent high water table | Clay loam, Silty Clay loam, Sandy Clay, Silty Clay, Clay | High | 0 - 1.27 | Very Low rate (0-0.05 in/hr) |

*(Source: USDA-SCS Soil Classification)*

### *A. Preparation of Hydrologic Soil Group Map*

Soil classification system developed by SCS-CN has been followed while classifying soils into different hydrologic soil groups. In this classification system, soils are classified as A, B, C or D hydrologic soil group depending on their properties. Hydrologic soil group map of the study area has 3 classes of soil.

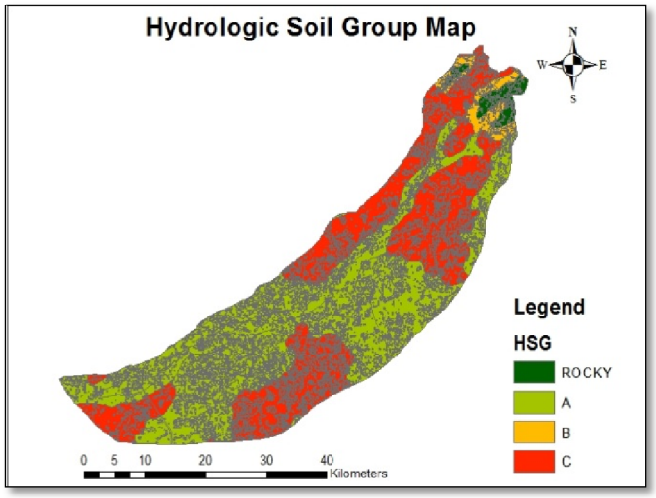


**Fig. 5: Hydrologic Soil Group Map of Study Area**

### *B. Weighted Area Curve Number*

Different layers of land use/land Cover, soil, HSG were added in Attribute table was using ArcGIS 9.3. by using Tool box Union of the above layers are prepared. The result obtained from union attribute was used to compute weighted area CN of the study area and is shown in Table 3.

**Table 3: Calculation of Weighted Curve Number**

| SR NO | DIFFERENT CLASSES | SOIL TYPE | HSG | CN | AREA (km^2) | %AREA | %AREA*CN | WEIGHTED CN |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| 1 | Crop land | Coarse loamy | A | 72 | 48.08 | 14.48 | 1042.67 | |
| | | Fine loamy | C | 88 | 194.08 | 58.46 | 5144.31 | |
| | | Loamy skeletal | B | 81 | 39.29 | 11.83 | 958.51 | |
| | | | | | 281.44 | | | |
| 2 | Deciduous forest | Coarse loamy | A | 70 | 1.03 | 0.31 | 21.61 | |
| | | | | | | | | |
| 3 | Fallow land | Coarse loamy | A | 77 | 0.27 | 0.08 | 6.16 | |
| | | Fine loamy | C | 91 | 0.44 | 0.13 | 12.02 | |
| | | Loamy skeletal | B | 86 | 0.03 | 0.01 | 0.68 | |
| | | | | | 0.73 | | | |
| 4 | Lakes/Ponds | Coarse loamy | A | 100 | 0.12 | 0.04 | 3.54 | |
| | | Fine loamy | C | 100 | 0.23 | 0.07 | 7.05 | |
| | | Loamy skeletal | B | 100 | 0.02 | 0.00 | 0.46 | |
| | | | | | 0.37 | | | |
| 5 | Land with scrub | Coarse loamy | A | 36 | 0.32 | 0.10 | 3.49 | |
| | | Fine loamy | C | 73 | 2.19 | 0.66 | 48.09 | |
| | | Loamy skeletal | B | 60 | 0.56 | 0.17 | 10.03 | |
| | | | | | 3.06 | | | |
| 6 | Land without scrub | Coarse loamy | A | 45 | 0.53 | 0.16 | 7.23 | |
| | | Fine loamy | C | 77 | 2.41 | 0.73 | 56.00 | |
| | | Loamy skeletal | B | 66 | 1.41 | 0.42 | 28.04 | |
| | | | | | 4.36 | | | |
| 7 | Plantations | Coarse loamy | A | 45 | 0.03 | 0.01 | 0.36 | |
| | | Fine loamy | C | 67 | 0.02 | 0.01 | 0.49 | |
| | | Loamy skeletal | B | 53 | 0.04 | 0.01 | 0.68 | |
| | | | | | 0.09 | | | |
| 8 | Prosophis | Coarse loamy | A | 61 | 1.91 | 0.57 | 35.04 | |
| | | Fine loamy | C | 74 | 4.47 | 1.34 | 99.53 | |
| | | Loamy skeletal | B | 70 | 0.44 | 0.13 | 9.25 | |
| | | | | | 6.81 | | | |
| 9 | River | Coarse loamy | A | 97 | 0.18 | 0.05 | 5.18 | |
| | | Fine loamy | C | 97 | 0.16 | 0.05 | 4.59 | |
| | | | | | 0.33 | | | |
| 10 | Towns/Cities | Coarse loamy | A | 89 | 0.04 | 0.01 | 0.97 | |
| | | Fine loamy | C | 94 | 0.57 | 0.17 | 16.08 | |
| | | Loamy skeletal | B | 92 | 0.02 | 0.01 | 0.55 | |
| | | | | | 0.62 | | | |
| 11 | Villages(rural) | Coarse loamy | A | 72 | 0.46 | 0.14 | 10.01 | |
| | | Fine loamy | C | 87 | 1.63 | 0.49 | 42.73 | |
| | | Loamy skeletal | B | 82 | 0.17 | 0.05 | 4.19 | |

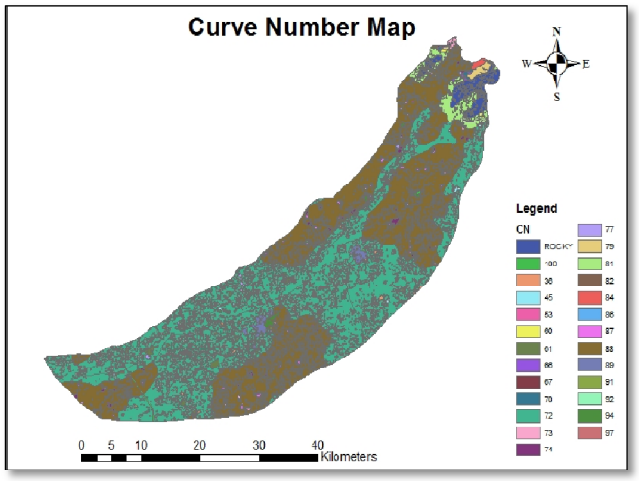


**Fig. 6: Curve Number Map of Study Area**

## CALCULATION RUNOFF USING SCS METHOD

Available daily rain fall data from the year 1991 to 2010 has been evaluated. Below Table shows the annual rainfall and runoff for Rupen Khan watershed for the period 1998 to 2014. From SCS Curve number, the maximum runoff for the watershed was estimated to be 501.78 mm in the year 2006 and minimum runoff of 4.57 mm in the year 2009 which is shown in Table 4.

**Table 4: Result of Rainfall-Runoff**

| YEAR | RAINFALL(mm) | RUNOFF(mm) |
|---|---|---|
| 2014 | 533 | 103.21 |
| 2012 | 327 | 22.27 |
| 2011 | 456 | 58.72 |
| 2010 | 518 | 68.00 |
| 2009 | 282 | 4.57 |
| 2008 | 531 | 95.25 |
| 2006 | 1489 | 501.78 |
| 2004 | 540 | 72.57 |
| 2003 | 868 | 137.26 |
| 1998 | 859 | 206.09 |

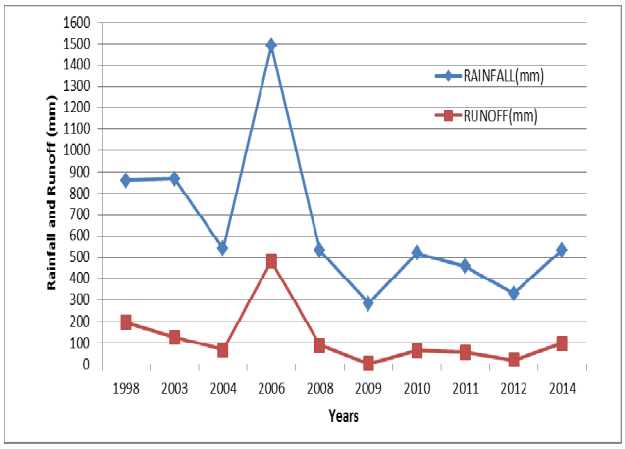


**Fig.7: Yearly variation of Rainfall-Runoff**

## CONCLUSION

Results obtained clearly show the variation in runoff potential with different land use/land cover and with different soil conditions. The weighted curve number computed for this study is 76. From SCS Curve number, the maximum runoff for the watershed was estimated to be 501.78 mm in the year 2006 and minimum runoff of 4.57 mm in the year 2009. Estimated runoff using SCS-CN method can be used for the effective watershed management in conjunction with GIS study. This method is also useful for un-gauged watersheds.

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