GIS for Rainfall-Runoff Modeling

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Abstract—*The highly complex nature of human and natural systems, the ability to understand them and project future conditions using a watershed approach has increasing taken a geographic dimension. Geographic Informatics System (GIS) technology has played critical roles in all aspects of watershed management. The NRSC-CN method is a widely used method for estimating the surface runoff volume for a given rainfall event. The major advantage of employing GIS in rainfall-runoff modeling is that remote sensing data are of great use for the estimation of relevant hydrological parameters, such as land use land cover, soils, geomorphology, drainage etc. In this context, it is important to note that, originally, the NRSC-CN method was developed for humid catchments. In the present study the Maniyar watershed, which receives an annual average rainfall of 124.6 cm making the method applicable for this region. In this study NRSC-CN modified for Indian condition has been used for generation of runoff from this watershed. For un-gauged watersheds accurate prediction of the quantity of runoff from land surface into rivers and streams requires much effort and time. But this information is essential in dealing with watershed development and management problems. Remote sensing technology can augment the conventional method to a great extent in rainfall-runoff studies.*

Keywords*: Remote Sensing, GIS, NRCS Curve Number, DEM*

1. INTRODUCTION

Rainfall-Runoff model play an important role to understand hydrological condition of basin areas and predict their behavior over time. Accurate process for prediction runoff volumes is used to flood warning, navigation, water quality management and many water resource applications. Land surface characteristics are important to generate rainfall-runoffmodel, distributed model need remote sensing and GIStechnologies to produce more accurate spatial data which play an important role to derive input data such as land use/cover, soil type.

Conventional hydrological model, to estimate runoff model input parameters have to be determined through ground truth measurement which still need huge economic and time–labor consuming. Therefore, remote sensing can also provide information about runoff input data most cost-effective and large-land coverage. Remote sensing can be used to obtain extremely valuable input data for distributed hydrological model. Remote sensing can provide measurements of many of the hydrological variables used in hydrologic and environmental model applications, either as direct measurements comparable to traditional forms, as surrogates of traditional forms, or as entirely new data set.

GIS is a computer based system used capture, store, analyze, update and display data. GIS handle mainly two classes of data which are spatial data, identifying the location and topography of map and attribute data, identifying the characteristics of these feature. GIS technology provides a flexible environment for entering, analyzing, and displaying digital data from various sources necessary for urban feature identification, change detection, and database development. With the aid of a GIS, distributed parameter of hydrological model, digital elevation model (DEM) processing have become popular_ analysis watersheds topographic.

In this study Soil conservation curve number method was used to determine runoff depth with the aid of remote sensing and GIS technologies.

2. DESCRIPTION OF STUDY AREA

2.1 Location

The Maniyar Watershed is a constituent of the Bhagirathi river basin and is located near Tehri Dam in Tehri Garhwal district of Uttarakhand. The watershed is bounded within 78^0 22’ to $78^0$28’ E longitude and 30^0 20’ to 30^0 25’ N latitude covering an area of 4394.06 hectares. TehriGarhwal is one of the mountainous districts of Uttarakhand state. The elevation of this area varies from 742m to 2393m above mean sea level. The area is covered by the Survey of India topographical maps no. 53 j/7 on 1:50,000 scale. The Tehri district is bounded by Uttarkashi district in the North, Rudraprayag district in the East, PauriGarhwal district in the South and Dehradun in the West.

2.2 Rainfall and Climate

Based on long-term climatological data of the area, it is summarized that January is the coldest month with mean maximum temperature of 19.6°C and the mean minimum temperature of 4.6°C. Temperature becomes highest usually during June, having mean minimum and mean maximum temperatures of 32.6°C and 36.5°C respectively.

Relative Humidity in the area increases rapidly with the onset of monsoon and reaches maximum (85% in the morning and

84% in the evening) during August, when peak monsoon period sets in. Relative Humidity is minimum during the summer months (from April to June) with May being the driest month (47% in morning and 25% in evening). Maximum rainfall is recorded during the monsoon period i.e. from July to September. During the non-monsoon season, rainfall is quite low in November and increases from December onward till March. The annual rainfall at Tehri Observatory is 1246.36 mm whereas the average number of rainy days (having daily rainfall ≥2.5) is 61.5 days.

2.3 Physiography

Physiographically, area is subdivided into three major units based on similarity in relief, slope, texture, geology, and arrangement of landform features moderate sloping hill, steep sloping hill and very steep sloping hill. These are sub classified as agriculture, mixed forest, pine forest, oak forest and scrub.

2.4 Drainage

The runoff water from river and streams sub watershed flow into main Maniyar River which flows towards Tehri Dam.

2.5 Soil Group

As per All India Soil And Land Use Survey Organisation, the study area, Dabka watershed falls under the hyrdrologic soil group 'B'. The soil group B has moderate rate of water infiltration.

3. MATERIALS USED

Collection of data

The various data required to meet out the objectives of this study included procurement of topographic map, obtaining remotely sensed data from satellite, soil map of the area, meteorological data of the watershed as well as the hydrological data.

3.1 Topographical sheet

The Survey of India topographical maps no. 53 j/7 on 1:50,000 scale were used.

3.2 Remote sensing data DEM (Digital Elevation Model)

A CARTOSAT1 Digital Elevation Model (DEM) was downloaded from NRSC Bhuvan website for the study area. The satellite imagery of the area is downloaded from NRCS website, Bhuvan of LISS III data of 2011.

3.3 Meteorological Data

Daily rainfall data of the year 2008 for all four meteorological stations was collected from IMD Dehradun and the average values of daily rainfall for the Dabka watershed was also obtained.

3.4 Hydrological data

The monthly discharge data for the year 2008 was also collected from Department of Geology, HNB Garhwal university in order to validate and compare the estimated value with observed values.

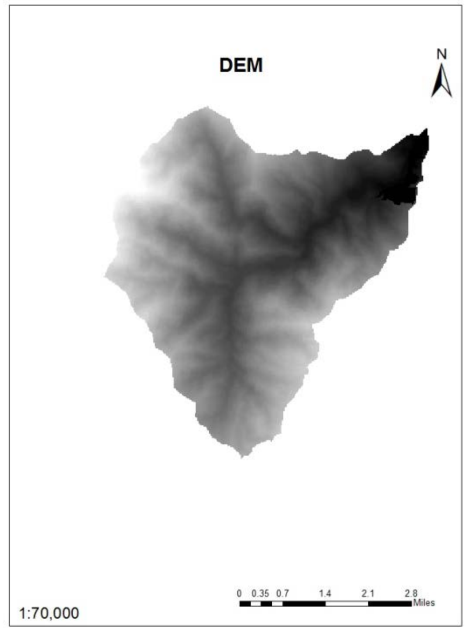

Fig. 1

4. METHODOLOGY

NRCS curve number method was as earlier known as SCS-Curve Number method. The NRCS-CN method is an event-based model which was conceptualised way back in 1954 and was successfully developed by the USDA Soil Conservation Service (SCS) in 1972. The Curve Number (CN) is a land-cover index for a given land use equation and soil type to determine the amount of rainfall that infiltrates into the ground and the amount that becomes runoff for a specific storm event. The hydrological response of watershed is usually altered due to revolution in the watershed development. Thus it is necessary to quantify the likely changes in the surface runnoff in a watershed as an impact of the planned or unplanned changes made in the land use. This method exploits the observed correlation between the calculated CN values and the rainfall depths alongside the watershed taking into account the specific characteristics of the watershed.

This method assumes it proportionality between retention and runoff,

$$\frac{F}{S} = \frac{Q}{P}$$

Where F = (P – Q)actual retention (mm)

S = potential retention (mm)

Q = total depth of direct runoff (mm)

P = total depth of rainfall (mm

Initial abstraction(I_a) is subtracted from rainfall P

$$\frac{P - Q - I_a}{S} = \frac{F}{P - I_a}$$

The amount on initial abstraction is a fraction of the potential maximum retention

I_a = ƛ S

For Indian conditions taking ƛ = 0.3 rainfall runoff equation is formed by substituting in eq

$$Q=\frac{(P-0.3S)^2}{P-0.7s}$$

Further, S values are transformed into curve numbers (CN) by the following equation

$$S=\frac{25400}{CN}- 254$$

4.1 Curve Number

The Curve Number (CN) values corresponding to different land use classes corresponding to AMC-I and AMC-II is calculated by Knowing the antecedent moisture condition for AMC-II, In the original NRCS-Cn method the effect of slope has not been considered , while calculating curve number. Moreover, land slope paremeter has been considered as an important factor in determining water movement. To overcome the problem of slope, Sharpley and Williams (1990), carried out some slope adjustment to CN_{II} calculation as follows:

$$CN_{II\alpha}= \frac{(CN_{III}-CN_{II})(1-2e^{-13.86\alpha}}{3} + CN_{II}$$

The values of CN depends upon

- Soil type
- Slope
- Antecedent moisture condition
- Land use cover

4.1.1 Soil type

Hydrologic soil groups of soil series established by all India soil and Land Use Survey Organization. Soil properties influence the process of generation of runoff from rainfall and they must be considered, even if only indirectly, in method of runoff estimation. The properties are depth of seasonally high water table, intake rate and permeability after long prolonged wetting, and depth to very slowly permeable layer. There are four types of soil groups, which are following:

Group- A (Low runoff potential)

Group —B (Moderately low runoff potential)

Group —C (Moderately high runoff potential)

Group —D (High runoff potential)

4.1.2 Antecedent moisture condition (AMC)

Rainfall in antecedent periods of 5 days before to a storm is commonly used as indexes of watershed wetness. An increase in an index means an increase in the runoff potential. Such indexes are only rough approximation because they do not include the effect of evapotranspiration and infiltration on watershed wetness. Three levels of AMC are used:

Table 1: Antecedent Moisture conditions (AMC) for determining the values of CN

AMC Group	Total 5 days antecedent rainfall	
	Dormant season(mm)	Growing season(mm)
I	Less than 12.7	Less than 35.6
II	12.7 to 27.9	36.6to 53.3
III	Over 27.9	Over 53.3

5. RESULTS AND DISCUSSIONS

As per the objectives of the project, the Maniyar watershed was delineated from the DEM (Digital Elevation Model) and various thematic maps were generated as per the requirement. The database related to precipitation was also prepared as per the input requirement of the model. Various hydrological components like surface runoff, stream order and other morphological parameters were also evaluated. The evaluated surface runoff was compared with the observed surface runoff.

5.1 Extraction of Watershed Characteristics

The Dabka watershed was delineated from DEM. The total area and perimeter was found to be 55.09 sq. km . Drainage map was also prepared from DEM up to the first order level. The GIS analysis showing the stream order map of the watershed is shown Based on the above statistics, morphological parameters were calculated for the Dabka watershed. The relief of Dabka watershed was found to in between 743 m to 2393 m.

5.2 Land use and land cover classification

Indian Remote Sensing Satellite (IRS-1C) LISS III data has been used for the analysis and mapping of land cover and land use. The classification of satellite data mainly follows two approaches i.e. supervised and unsupervised classification. In order to prepare the Land use/ Land cover map for Dabka watershed, supervised classification method using Maximum Likelihood classification algorithm was used. The maximum likelihood decision rule assigns each pixel having pattern measurements.

Table 2: Area of different classes

Sl. No.	Name of the Class	Area(km2)
1	Agricultural land	15.05
2	Dense Forest	25.83
3	Barren Land	2.67
4	Pasture Land	10.17
5	Streams/ Rivers	.826
	total	**55.09**

5.3 Soil classification of Dabka watershed

The soil map of Dabka watershed is generated from FAO (Food and Agricultural Organization) world soil map. The region is being clipped and used in order to obtain the LULC Soil Map. The Hydrologic Soil Group of this region is found to be Soil Group B (All India Soil and Land Use Survey Organisation).

5.4 Estimation of surface runoff

The surface runoff of the Dabka watershed is estimated using the NRSC-Curve Number Method. Curve Number Map is generated for different areas in the watershed and according to different AMC conditions, surface runoff is estimated for Maniyar watershed

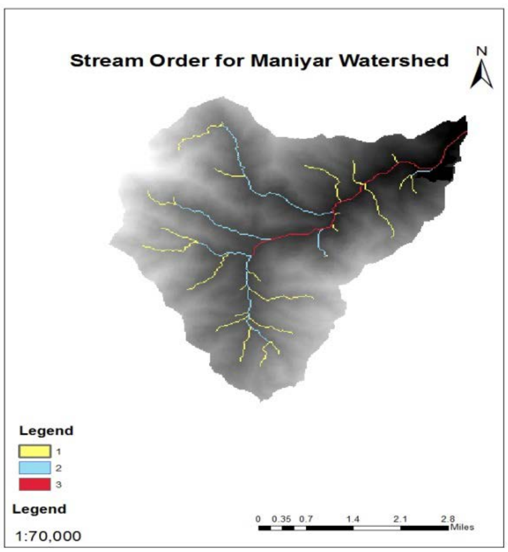

Fig. 2

5.5 Curve number map

Soil and LULC map is assigned curve numbers based on different land use classes and soil groups. Curve Number ranges from 0 to 100 and therefore each area constitutes different runoff for different areas. The Slope is taken into account in order to calculate the corrected slope curve number map. Fig. 4.5 and 4.6 shows the Curve Number map and slope

Table 3: Curve number for different classes

Sl. No.	Classes	Curve Number (CN_{II})
1	Dense Forest	44
2	Pasture Land	79
3	Barren Land	80
4	Agricultural Land	69
5	Stream/Rivers	100

5.4.1 Computation of average curve number

Area weighted average curve number for Maniyar watershed has been calculated. Appropriate CN values correspond to AMC-II have been assigned to each polygon obtained from cross map between land use and soil maps in ARC GIS Software. Finally, sum of the products of area and CN value of total polygons has been divided by the catchment area to get area weighted average CN value for the Dabka watershed.

5.6 Antecedent moisture conditions

Sohabani's (1975) and Hawkins et al., (1985) formulae are used for determination of CNI and CNIII values for AMC' and AMCHI conditions conversion is best. The conversion of CNII to other two AMC conditions can be made as follows as shown

For AMC-I:

$$CN_I = \frac{CN_{II}}{2.234 - 0.1334\ CN_{II}}$$

For AMC-III:

$$CN_{III} = \frac{CN_{II}}{0.427 - 0.00573\ CN_{II}}$$

Table 4: SCS CN model paremeters for different conditions

Parameters	Antecedent Moisture Condition		
	AMC-I	AMC-II	AMV-III
CN	46.58	67.06	82.66
S	291.33	124.76	53.28
I_a	87.39	37.428	15.98

Table 5: Computation of surface runoff month wise for rainy season

Month	Observed(Mm3)	Estimated(Mm3)	Percent absolute deviation
JUNE	0.169	0.152	10.06
JULY	0.236	0.231	2.12
AUGUST	0.266	0.243	8.64
SEPTEMBER	0.152	0.157	3.29

6. SUMMARY AND CONCLUSIONS

The NRSC-CN method is a widely used method for estimating the surface runoff volume for a given rainfall event. The major advantage of employing GIS in rainfall-runoff modeling is that remote sensing data are of great use for the estimation of relevant hydrological parameters, such as land use/ land cover, soils, geomorphology, drainage etc. In this context, it is important to note that, originally, the NRSC-CN method was developed for humid catchments. In the present study the Maniyar watershed receives an annual average rainfall of 124.6 cm making the method applicable for this region. In this study NRSC- CN modified for Indian condition has been used for generation of runoff from this watershed. The following results were drawn from the study:

1. The weighted average curve number for AMC-II of the area after applying slope correction factor was found out to be 67.07.
2. The highest variation between estimated runoff volume and observed runoff volume was found to be 10.06% for the month of June. This may be because of the value of used by the NRCS-CN method, which is not properly investigated in dry conditions and since June receives the lowest precipitation (during the monsoon season), there lies a scope for the variance in value between the estimated and observed runoff volume.
3. The lowest variation between estimated runoff volume and observed runoff volume was found to be 2.12% for the month of July. This could be because July receives the maximum amount of precipitation during the season and since NRCS- CN method is mainly an event based method, this holds true for prolonged periods of high rainfall, hence applicable for this month of July.

Remote sensing technology can augment the conventional method to a great extent in rainfall-runoff studies. In this study NRSC CN modified for Indian condition has been used for generation of runoff of the watershed.

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