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Remote Sensing and GIS based Methodology for Curve Number Estimation in Rainfall - Runoff Modelling

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ABSTRACT. This study was conducted using satellite data, image processing techniques and GIS functionality to estimate the flow regime of a catchment using USDA Soil Conservation Service (SCS) Runoff Curve Number (CN) method. The selected catchment for the study was the Bainkhala watershed, Doon valley, Uttaranchal state, India. An IRS 1C LISS-III image was used to generate all the thematic layers of spatial data. The CN under different land use scenarios were adjusted by trial and error in the hydrological modeling process. Subsequently, these estimated curve numbers were used for the estimation of flow statistics. It was found that the different land use classes and the corresponding curve numbers were less sensitive to changes in the calculated runoff and the interactions between land use and soil basically determine the conversion efficiency of runoff generation from storm rainfall. Remotely sensed data, image processing techniques and basic GIS functionality are an efficient collection to estimate runoff curve numbers in the runoff estimation process.

INTRODUCTION

A catchment or watershed is defined as the spatial extent which contributes water to a selected location of the stream network. A watershed could encompass a few hectares as in the case of a small pond or an intermittent stream to thousands of hectares in the case of perennial rivers. Within each watershed, sub basins could be identified based on the elevation of each point on the stream network. Each watershed or sub watershed is an independent hydrological unit and hence it is easily manageable.

Runoff is the output of a watershed in terms of water yield of the hydrological unity. The measurement of runoff is a very tedious process and therefore, estimation methods are commonly employed. The most common runoff estimation methods include rational formula, Cooks method, Hydrograph method, Empirical formula method and USDA SCS Runoff Curve Number method. The SCS CN method is a simple, widely used and efficient method for determining the approximate amount of runoff resulting from a single storm event over a small watershed. Although this method has been designed for a single storm event, it can also be scaled to find average annual flow generations. The data and information requirements for this method are very low and require rainfall depths and curve numbers. The curve number can be estimated from the hydrologic soil group of the area, land use, treatments used on the land and hydrologic condition. The empirical equation requires rainfall depth and a coefficient for the watershed (curve number) as inputs (Juracek, 2002). Accurately

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estimated runoff rates and runoff volumes can be used for water supply forecasting, flood prediction and warning, hydropower production estimation, navigation management and many other water resources applications.

The main objective of the study is to explore the possibilities of employing remote sensing methodologies and GIS functionality to estimate runoff using USDA SCS runoff curve number method. The specific objectives include (a) creation of spatial database for hydrological modeling (b) establishment of rainfall- runoff relationship based on observed runoff data and (c) creation of curve numbers for the different hydrological unit and its sensitivity analysis.

DATA AND METHODOLOGY

Description of the study area

The study area covers Bainkhala watershed located in the western Doon valley, Uttaranchal state, India. It includes an area of approximately 16 km^2 and extends from 30^0 21' 04.71'' N to 30^0 24' 53.79'' N latitude and 77^0 52' 05.14'' E to 77^0 57' 05.16 E longitude. The watershed is bounded in the north by lesser Himalayan mountains, in the south by watershed of Asan river, in west by watershed of Suarna river and east by watershed of Barawala river. The Bainkhala River is basically a dry riverbed and flow is only found seasonally and hence could be categorized as non-perennial. The drainage pattern is sub-dendritic in upper part of watershed and braided in the lower part. The outlet of watershed joins the Asan River in the south. Rainy season is from mid June to September and annual rainfall is in the range of 1750 – 2000 mm (Bomjan, 1999).

The dominant land uses in the study area are forest and agriculture. Forest areas are homogeneous Sal forest. which are spread in the eastern side of the watershed. The major agricultural crops are rice, wheat and sugarcane. The agricultural fields are spread throughout the western side. The other prominent land use classes include Open forest, Scrubland, Orchard (Mango), Built-up lands and Riverbed. Open forest also mainly consists of Sal trees but the density is low and hence cannot be categorized into regular forest category. The prominent plant species of Scrubland is Lantana. There are three major soil texture classes identified as loamy skeletal, coarse loamy, fine loamy in the study area. Mostly A, B and C type of hydrological soil groups have been formed (Bomjan, 1999).

Data used

The data used in this study can be categorized into three (3) groups. Satellite data which include PAN and LISS-III merged data hard copy (path - 96, raw - 50) acquired on December 27, 2001 and LISS-III image (path - 96, raw - 50) acquired on February 11, 1999. The topographic data were obtained from Survey of India Toposheet No., 53F/15 on 1:50,000 scale (First edition, 1970) and from soil texture map prepared by Central Soil and Water Conservation Research and Training Institute, Dehradun. Further, 45 GPS points of the study area with ground truth were also collected. The meteorological data include daily Rainfall data at the Bainkhala meteorological station from July to September 1990 and runoff discharge data of the Bainkhala watershed at the gauging site from July to September, 1990.

In the processing of these satellite data, ERDAS Imagine 8.3 was used for geo referencing images and topographic map, and ILWIS 3.0 was used for some image processing and GIS analysis. The generic structure of the methodology adopted for this study is indicated in Figure 1. Satellite data were used to derive the land use status of the watershed through the unsupervised classification process. The accuracy of the classification was verified with GPS ground data. The derived land use map is shown in Figure 2. Contour information available on the toposheets and the demarcated boundary were transferred to obtain the Digital Elevation Model (DEM) and Slope aspect information. Attributes obtained from soil texture map were used along with the land use and slope data to determine the spatial distribution of hydrologic soil groups.

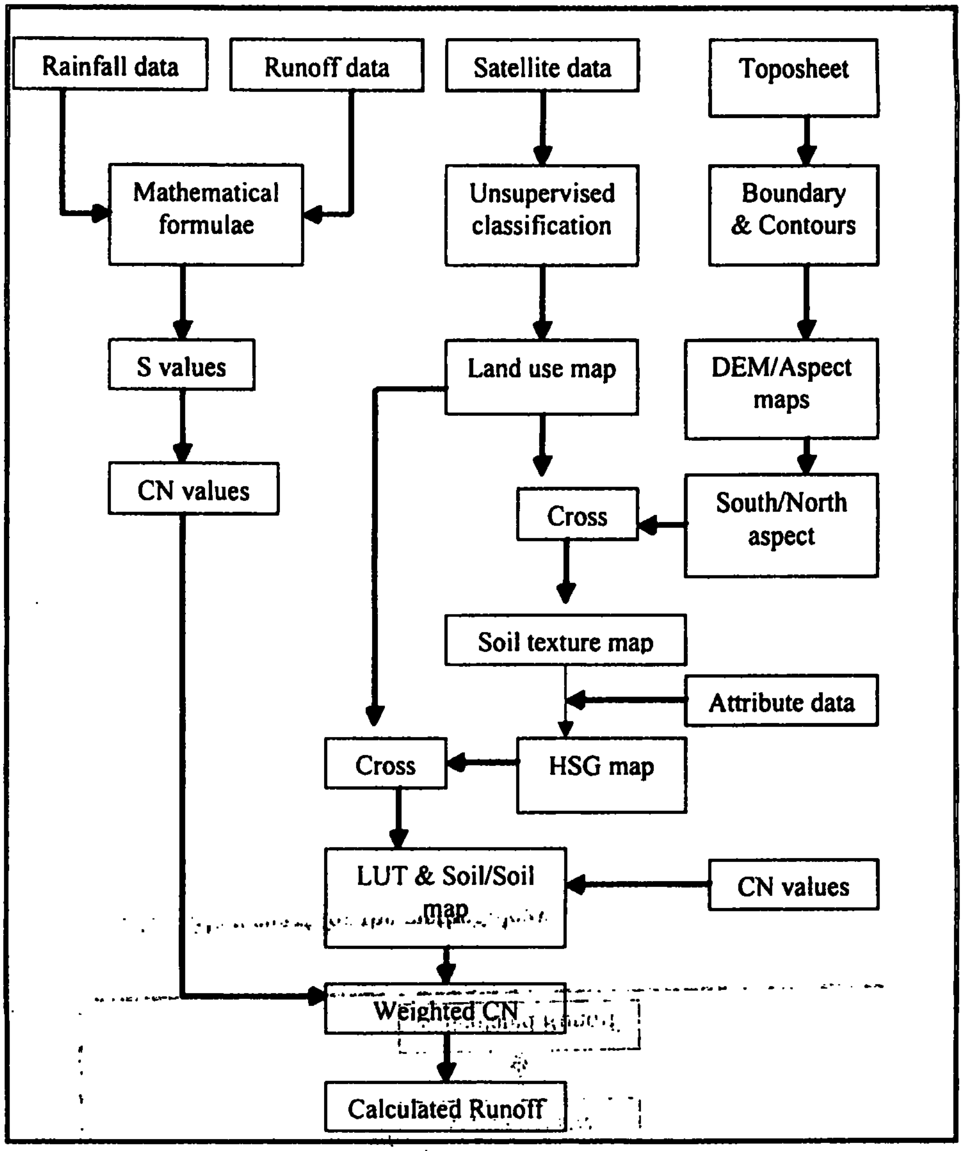

Fig. 1. Flow chart for the methodology.

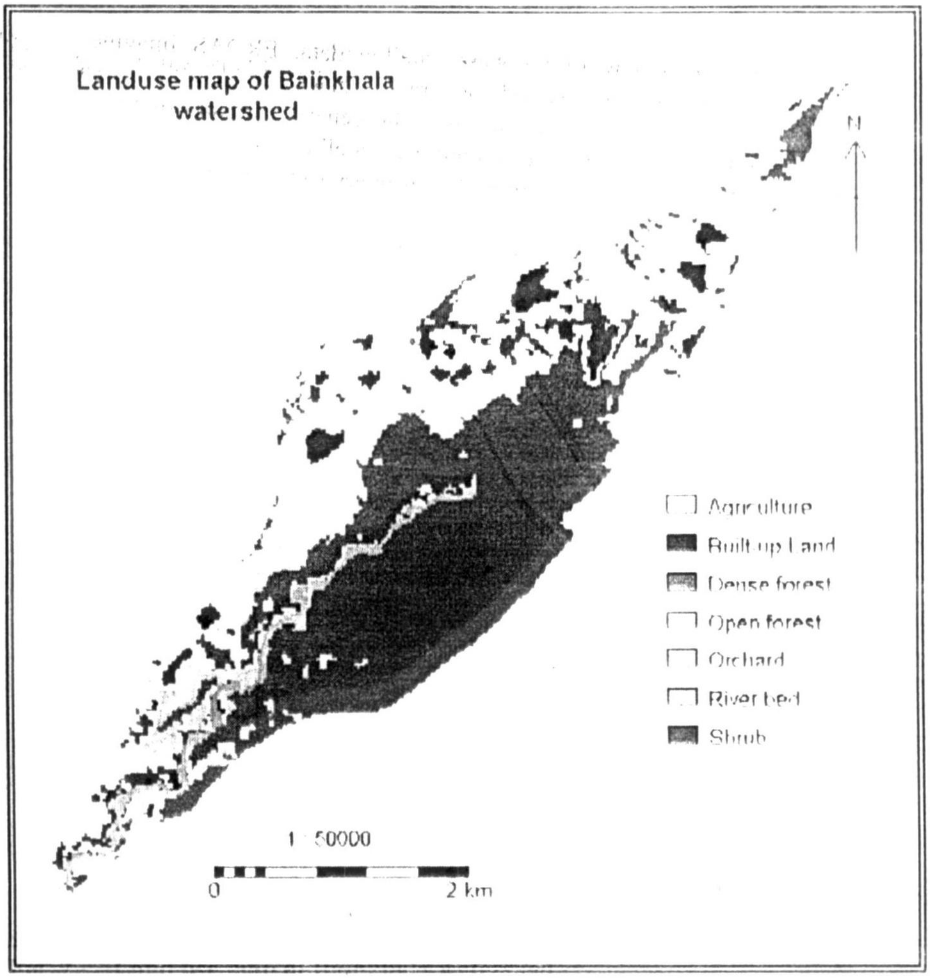

Fig. 2. Land use map of Bainkhala watershed.

The Storage capacity (S) values for the watershed were calculated using measured rainfall and runoff data. The Curve Number values for each rainfall and runoff event were calculated using these S values and the average value of the curve numbers was taken as the Weighted Curve Number as show in the following formulae.

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

hence,

$$S = \frac{(P - Ia)^2 - Q(P - Ia)}{Q} \qquad (Ia = 0.3S)$$

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

where, Q = Accumulated storm runoff (mm)
P = Accumulated storm rainfall (mm)
S = Potential maximum retention of water by the soil
Ia = Initial abstraction before ponding

RESULTS AND DISCUSSION

The curve number was taken as CNII and then CNI & CNIII were calculated using the CNII value. The Antecedent Moisture Conditions classes were determined by considering the status. The details are given in Table 1.

Table 1. Antecedent Moisture Classes Classification for Bainkhala watershed.

AMC class	Moisture (mm)	Condition
I	< 35.6	Dry soil but not the wilting point
II	35.6 – 53.3	Average conditions
III	> 53.3	Saturated soils; heavy rainfall or light rain

Based on the methodology of the USDA SCS CN method, the weighted curve numbers were calculated and are presented in Table 2.

Table 2. Calculated weighted CN values.

RF (mm)	RO (mm)-Observed	S1	S2	CN(S1)	CN(S2)
217.8	53.83	1627	244	14	51
16.6	12.37	203	4	56	99
53	12.13	385	62	40	80
60	11.06	406	80	39	76
25.2	11.8	244	15	51	94
34.2	9.65	268	35	49	88
7.2	9.45	123	-1	67	101
11.2	13.74	183	-2	58	101
20.8	14.37	244	6	51	98
2.6	10.76	103	-2	71	101
46.8	18.45	420	35	38	88
9	4.69	92	5	73	98
10.9	13.4	179	-2	59	101
105.6	52.99	1058	58	19	81
3.6	7.45	84	-2	75	101
81	18.41	587	96	30	73
21.2	22.49	317	-1	44	100
			CNII =	49	
			CNI =	29	
			CNIII =	69	

For each rainfall data two values for S (S1 and S2) were obtained. S cannot be a minus value and CN cannot be above 100. Therefore, only S1 values were taken for calculation. Further, in order to get the calculated weighted curve number (CNII), the curve numbers for different land use classes were adjusted. This was a trial & error method and the results are given in Table 3. Accordingly, the estimated CN map was generated as shown in Figure 3.

Table 3. Adjusted CN values for different areas.

Land use	Soil types	HSG	CN	NPix	Area (m^2)	S	Area*CN
Dense forest	Coarse loamy	B	54	11	7436	216.37	401544
Dense forest	Loamy skeletal	A	29	10054	6796504	621.86	197098616
Open forest	Fine loamy	C	64	6	4056	142.88	259584
Open forest	Coarse loamy	B	59	8	5408	176.51	319072
Open forest	Loamy skeletal	A	49	2533	1712308	264.37	83903092
Agriculture	Fine loamy	C	84	87	58812	48.38	4940208
Agriculture	Coarse loamy	B	80	127	85852	63.50	6868160
Agriculture	Loamy skeletal	A	71	7628	5156528	103.75	366113488
Scrubland	Fine loamy	C	54	4	2704	216.37	146016
Scrubland	Coarse loamy	B	46	894	604344	298.17	27799824
Scrubland	Loamy skeletal	A	32	353	238628	539.75	7636096
Riverbed	Coarse loamy	B	96	454	306904	10.58	29462784
Riverbed	Loamy skeletal	A	89	173	116948	31.39	10408372
Built-up Land	Coarse loamy	B	71	682	461032	103.75	32733272
Built-up Land	Loamy skeletal	A	56	80	54080	199.57	3028480
Orchard	Coarse loamy	B	59	1	676	176.51	39884
Orchard	Loamy skeletal	A	54	331	223756	216.37	12082824
	Total				15835976		783241316
					W. CN(CNII)	49	
					CNI =	29	
					CNIII =	69	

The study was extended to find the relationship between observed runoff values and calculated runoff values. The results are shown in Figure 4. Based on the composite CN values determined for the watershed, rainfall-runoff modeling was attempted as shown in Figure 5.

According to the modeling results as shown in Figure 5, there is no perfect agreement with the measured and predicted runoff. It indicates that further revisions of composite runoff curve number values are necessary to obtain better modeling results. The study needs to be extended to several more seasons to obtain more realistic composite curve numbers.

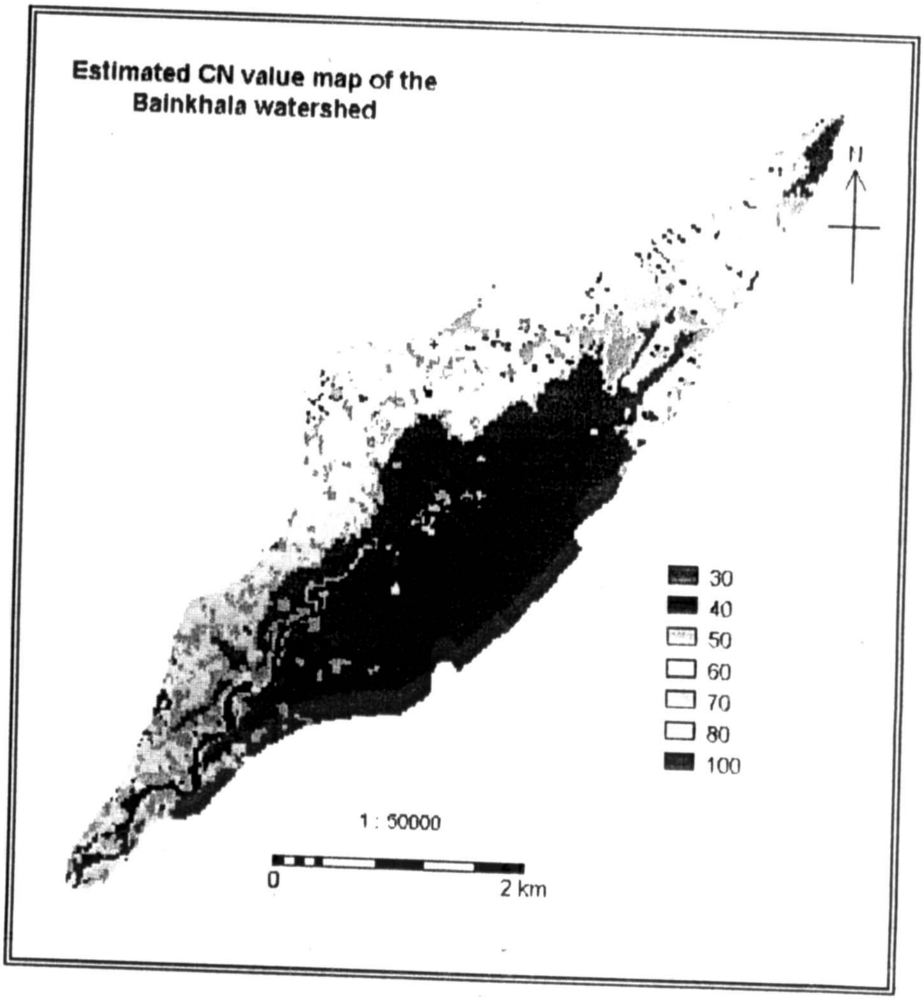

Figure 3. Estimated CN value map of Bainkhala watershed.

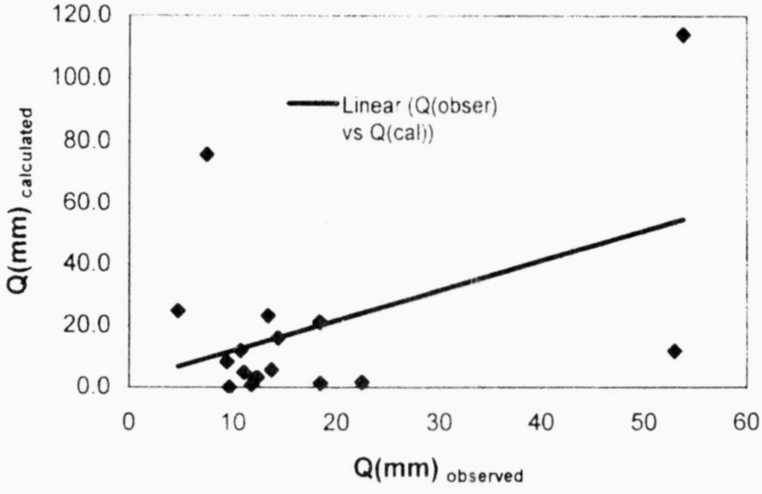

Fig. 4. Relationship between observed runoff and calculated runoff.

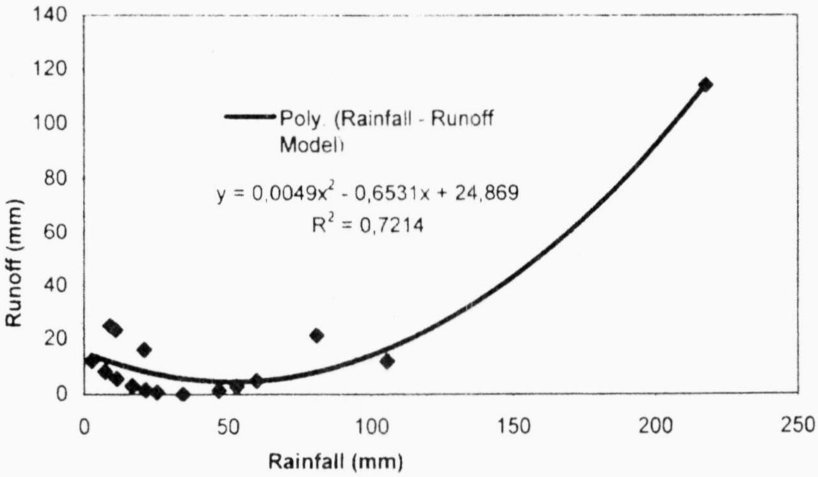

Fig. 5. Rainfall – Runoff model of the Bainkhala watershed.

CONCLUSIONS

The combination of land use categories such as dense forest and scrubland with soil types of loamy skeletal and HSG A group contributes for comparatively low CN values of the watershed thus indicating that these areas have low runoff potential. Similarly, Agriculture and Riverbed land use categories along with fine loamy, coarse loamy or loamy skeletal soils and HSG groups A, B or C generate higher curve numbers indicating high runoff potential areas.

For this study, a limited number of available runoff event data (17 observations) was used. It is useful to extend the runoff records to cover a large number of events to improve the results. Soil texture map used for this study was at a small scale. It is required to study Soil texture in detail on a large scale to improve the results.

From the results of the study, it can be concluded that remote sensing and GIS techniques are efficient and are comparatively easy methods to estimate runoff curve numbers when compared with the conventional methods. However, it is noted that different land use classes and curve numbers are less sensitive to changes in the calculated runoff. In estimation of curve numbers, the spatial distribution of dynamic variables need to be taken into consideration and hence, a combination of remote sensing data sources and GIS analytical capabilities could provide the required temporal and spatial resolution for the data and their analysis.

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