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RUNOFF MODELING USING SCS METHOD

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NATIONAL INSTITUTE OF HYDROLOGY
JALVIGYAN BHAWAN
ROORKEE - 247 667 (INDIA)

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PREFACE

Estimation of volume of runoff is important in design and planning of water resources projects. The information on runoff volumes is useful in watershed management for erosion and flood control and other hydrological applications. SCS curve number technique is used in estimating direct runoff volumes from rain storms. The SCS curve number technique has been modified for application to Indian catchments in earlier studies. The technique uses physical variables such as landuse/ cover and soils. The variables can be derived from remote sensing technique. Visual interpretation technique is useful in preparing landuse/ cover and soil maps from visual form of remotely sensed data. The interpreted maps are digitized using tablet digitizer converting maps in digital form suitable for manipulation, storage and output in a Geographic Information System (GIS). A GIS is a tool for input, output, storage and manipulation of spatial data and is suitable for applications in hydrology requiring spatial data. The modified SCS method has not been validated in many catchments. Thus, the study is undertaken with the objective of validating the modified method in a catchment in Narmada basin.

In the present study, the runoff computation is done for a storm in Temur catchment. The area of the catchment is approximately 813 sq. km. Direct runoff is computed for many scenarios of crop types and management practices, hydrological conditions of forest and waste land. Error in direct runoff prediction varies from -8.6 to 26.5 % in modified method and 3.7 to 37.1 % in original method. The input data used are landuse/ cover map, soil map and hydrometeorological data. The landuse/ cover and soil for the catchment has been obtained using remote sensing technique.

The study is done by Mr. D.S.Rathore, Scientist 'C' of Remote Sensing Applications Division.

(S.M.SETH)
DIRECTOR

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ABSTRACT

SCS curve number technique is used to obtain runoff volume from landuse/ cover, soil and rainfall data. The technique is applied to Temur catchment of Narmada basin. The catchment lies between latitudes 22°35'N to 23°02'N and longitudes 79°40'E to 79°58'E. The area of catchment upto gauge discharge site is approximately 813 sq. km. The landuse/ cover and soil maps are derived from visual interpretation of IRS LISS II FCC paper prints. The landuse/ cover map is verified from Survey of India topographic maps. Land treatment, crop type in agricultural area and hydrological conditions of forest are assumed. From daily rainfall data, rainfall maps are obtained using moving average interpolation technique. Thrice daily Discharges are obtained from gauge discharge relationship. The base flow separation is done using technique for complex storms. The volume of base flow and total runoff are used to compute direct runoff volume. The curve numbers are derived from various hydrological conditions and crop types. landuse cover map and soil map. Error varies from -8.6 to 26.5 % in modified method and from 3.7 to 37.1 % in original method.

CHAPTER 1 INTRODUCTION

Water is a precious renewable resource available to mankind for utilization in many activities. Water resource is although renewable but is limited in its availability. In India, about 36% of total surface water resource is estimated to be available for its effective utilization. In addition to it around 0.24 multiple of total surface water resource is replenishable ground water resource in the country (Publication Department, Ministry of Information and Broadcasting,, Government of India, 1993). Thus, it is essential to utilize water through water resources projects. To prepare hydrology of water resources projects, the runoff modeling for the basins is needed. For water resources planning, modelling of runoff is done.

Processes acts upon hydrological variables and convert the variables to output e.g. stream flow. Variable and processes together constitute a hydrologic system. Complex hydrologic systems are simply represented in models. In nature, the hydrological processes are very complex. The runoff generated in a catchment reaches an outlet by flowing over land and in channels. The runoff occurs in the form of surface, sub surface and ground water runoff. Water from sub surface storage and ground water aquifers takes more time to reach an outlet in the channel in the catchment, Whereas the surface runoff reaches faster to the channel outlet. Sub surface water percolates to deep aquifers. This allows the separation of runoff components in the runoff hydrograph. Various models are used for runoff components. The models are one amongst physical, analog and mathematical. Mathematical models represent systems by set of equations (Varshney R.S., 1979). Hydrological models are classified as deterministic and stochastic. Deterministic models considers physical processes to determine runoff from watersheds. Conceptual models use mathematical equations to describe hydrological processes e.g. evaporation, runoff routing and consider water budget of various storages in the catchment (Shaw E.M., 1988).

There are many hydrological methods for computation of runoff. These methods are empirical methods using formulae and tables, rational methods, unit hydrograph methods and synthetic hydrograph methods (Varshney R.S.,1979). SCS curve number technique determines direct runoff of small catchments from storm events. The runoff depends on soil cover complex. A fallow land does not offer any protection to soil from rain drop impact and does not detain the flowing water allowing no time for infiltration. The processes of compaction of surface crust, clogging of surface soil pores and high velocity of flowing water influences runoff. The process is controlled by the surface cover, landuse and soil. The useful soil properties are hydraulic conductivity and profile depth. Based on runoff generating characteristics of soils, soils are classified in groups designated by alphabets 'A' to 'D'. Each landuse/ cover and soil complex is assigned curve numbers. The curve numbers are used to determine direct runoff volume.

CHAPTER 2 REVIEW OF LITERATURE

SCS curve number technique models surface runoff volumes for storms from small catchments using equations 2.1 and 2.2. The model has been modified for Indian conditions. In the modified model the initial abstraction has been take as 0.3 times storage term in the model (Kumar P. et. al, 1991, Dhruva Narayann V.V, 1993). The initial abstraction has been further modified for black soils in India and equated to 0.1 times storage for antecedent moisture conditions II and III (Dhruva Narayan V.V., 1993).

$$Q = \frac{(P-0.2S)^2}{(P+0.8s)} \quad P>0.2S \quad \text{In MM} \qquad 2.1$$

$$= 0 \quad P<=0.2S$$

$$S = \frac{25400}{CN} - 254 \quad \text{In MM} \qquad 2.2$$

Where Q is direct runoff in MM
P is rainfall in MM
S is potential storage in MM
and CN is a curve number, a dimensionless quantity.

Antecedent moisture condition (AMC) represents wetness of a catchment. Wetness of a catchment influences its runoff generating potential and hence AMC for catchments is computed. An AMC is defined based on 5-days rainfall prior to commencement of rain storm event. Values of 5 day antecedent precipitation are used to define different AMC. A curve number is modified based on AMC using formulae expressing curve numbers in terms of curve number for average conditions in the catchment (Chow V.T, et. al,1988). The curve number can also be changed using curve number table (Ogrosky, H.O., 1964), which results in same values as computed using formulae.

Storm runoff estimation techniques such as curve number technique estimate direct runoff. Thus, it is necessary to separate base flow from total runoff. For separating base flow, direct runoff and base flow recession characteristics are determined for the catchment. In computing base flow for complex storms Linsley and Ackermann's modified procedure is used. The initial discharge is computed treating recession as, truly, recession from direct runoff. From the computed initial direct runoff first approximation of initial ground water runoff is obtained, which is used to compute ground water recession. To correct direct runoff, recession is computed by subtracting ground water recession from total recession. The modified initial direct runoff is computed using modified direct runoff recession. The procedure necessitates identifying all recession limbs and all complex storms. Base flow curve is traced approximately below second storm. In other methods, approximate base flow curves are drawn. The techniques are termed as simple technique. The

techniques are described below :
1. The base flow curve is a horizontal line from the point of rise on the hydrograph.
2. The base flow curve is drawn as a straight line from point of rise to a point on the hydrograph at a fixed number of days from runoff peak or the end of runoff causing rainfall which ever occurs later.
3. The base flow curve is drawn by extending the recession curve of earlier storm beyond the point of rise of the storm upto a point below the runoff peak and then drawing straight line from this point to a second point as used in technique 2. For a basin of area less than 1000 sq. km., the direct runoff recession ends in 3 days from peak flow or end of runoff causing rainfall (Linsley R. K. et. al, 1975).

In conceptual models prototype behavior is simplified. example of conceptual model is Stanford Watershed Model IV (Shaw E.M., 1988; ASCE Task committee, 1982) In empirical models, representations of systems are based on experimental data rather than on general physical laws. Example of empirical models are rational formulae for peak flow estimation, monthly, annual or storm runoff estimation using runoff Coefficients (Varshney R.S., ASCE Task committee, 1982).

In the technique using curve numbers, direct storm runoff is estimated. In computation of storm runoff from a given storm, the runoff from areas with different curve numbers are computed and weighted over the catchment. Based on soil hydraulic conductivity and landuse/ cover, management practices areas are assigned curve numbers. The factors which influence runoff from an area are canopy cover, crop type and rotation, grazing, farming operations, litter, brush and small trees within forested areas (Ogrosky H.O. et. al, 1964).

A GIS is used in prioritization of watersheds based on runoff generating potential using SCS curve number technique by Das S.N. et. al (1992). The case study is done in catchment of Tilaiya reservoir, Bihar, India. The reservoir is located at latitudes of approximately 24 20 N and longitudes of 85 30 E. The results in the study are not validated as no discharge data were available. The storage term 'S' in the SCS curve number technique is modified using slope factor. The reduction is limited to a maximum of 25%. The values of priority ranking are computed. The ranking are changed when slope factor is used. Both digital and visual analysis techniques are used. All watersheds of order 2 are prioritized. Digital analysis technique of vegetation index and density slicing are used. Using density slicing technique different classes in vegetated areas are determined. The standard SCS curve number table is used to derive curve numbers. The study is done on a GIS ERIM on Vax 11/780 platform. Kumar P et. al, 1991 has found a good correlation between observed and computed values of storm direct runoff in Kaliaghai catchment of Ganga (Hughali) basin. In the model IRS LISS II digital data has been used to obtain landuse cover map for the catchment. The catchment has been divided in 25 sub catchments and computations have been done on the sub catchments. The treatment practices of the landuse/ cover classes could not be determined from the digital data. The field data have been used for this purpose.

CHAPTER 3 STATEMENT OF PROBLEM

SCS curve number method has been used in United States of America and in many countries. The technique has been modified in India. The modified as well as original method have been used for catchments in India. It is proposed to apply the technique in a catchment in Narmada basin as this technique has not been applied in the basin in past. In a GIS it is possible to overlay maps and to obtain soil cover complex and curve numbers for a catchment. It is also possible to make computations at raster points using a GIS map overlay operation. Thus, it is proposed to use a GIS, ILWIS (Integrated Land and Water Information System) in this study to model runoff using landuse/ cover and soil map.

CHAPTER 4 STUDY AREA

Temur catchment (Fig. 4.1), Narmada basin has been selected for runoff modelling using SCS technique. Temur river is a left bank tributary of Narmada river and it joins at a point at 381 Km distance from source of Narmada river. The length of the river is 61 Kms and catchment area is 892 Sq.Km. The catchment area lies between latitudes 22°35'N to 23°02'N and longitudes 79°40' Eto 79°58'E. The upper part of catchment lies in Seoni district of Madhya Pradesh and the lower part of the catchment lies in Jabalpur district of Madhya Pradesh. The river is a north flowing river. This catchment is gauged at Bargi Khapa gauge discharge site. The area of the catchment upto gauge discharge site is 814 sq.km. The site is maintained by Government of Madhya Pradesh, Water Resources Department, Sub division NO. 5, Jabalpur. The R.L. of the site is 372.6 m. The maximum elevation above MSL in the catchment is 637 m.

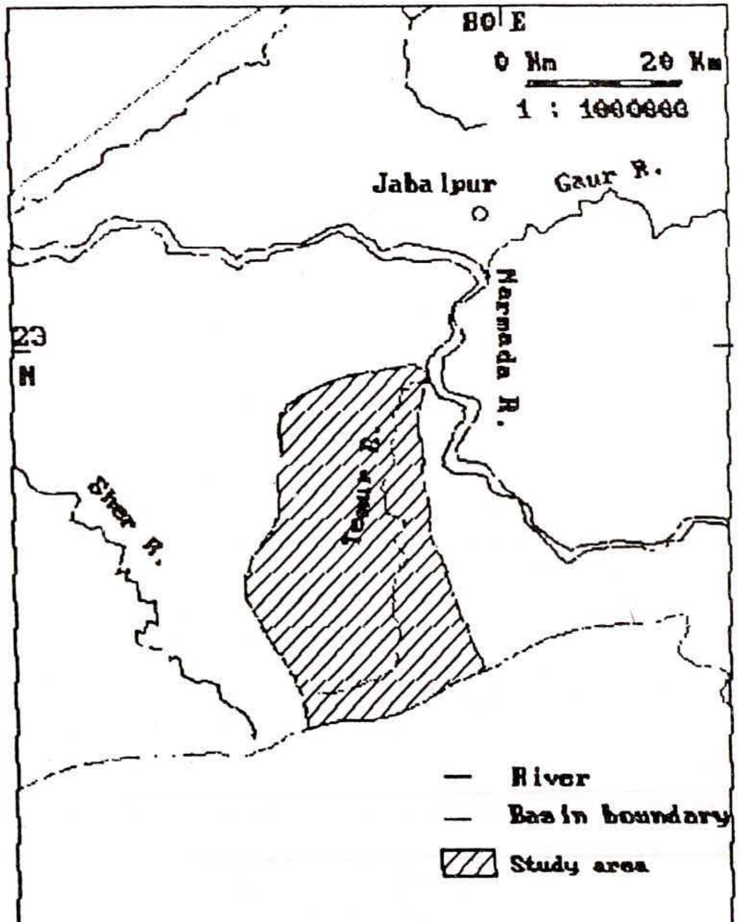

Fig 4.1 Study area map

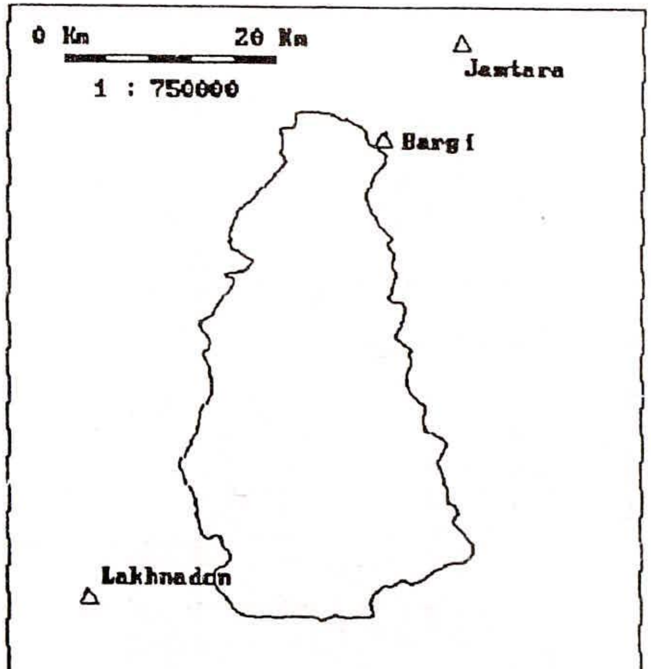

Fig 5.1 Raingauge stations location map

CHAPTER 5 AVAILABILITY OF DATA AND METHODOLOGY

5.1 Availability of data

The collateral data, satellite data and hydrometeorological data are required in this study. Topographic map 55N at a scale of 1:250000 is available. FCC of LISS II sensor of Indian Remote Sensing Satellite (IRS) are available. The path, row and quadrant for IRS (Indian Remote Sensing Satellite) LISS (Linear imaging self scanning) II FCC are 25-52 A1. The dates for the data are 12.04.89 and 18.11.89. Hydrometeorological data of gauge and discharge and daily rainfall are available for the catchment. Gauge data are available for morning, afternoon and evening from July 16, 1983 to 1994. The daily discharge at 8 Hrs. is available for August and September, 1983. There are three ordinary rain gauge sites close to the catchment (Fig 5.1). The daily rainfall data for the raingauge sites are available for years 1981 to 1990.

5.2 Methodology

The direct runoff volume is computed using SCS curve number technique. The runoff is computed using rainfall, landuse/ cover and soil data and maps. The main steps in the computation for direct runoff are as follows :

1. Preparing input data and maps
2. Making computations in a GIS

In the first step, data are obtained from various sources. The maps are prepared using remotely sensed data and input to a GIS, ILWIS (Integrated Land and Water Information System). Map crossing GIS operation is used to obtain curve number map from landuse/ cover and soil maps. Rainfall maps are obtained from daily rainfall data using interpolation operation in GIS. Discharge is computed in map calculation GIS operation. Intermediate maps calculated are as follows :

1. Antecedent precipitation
2. Antecedent moisture condition (AMC)
3. Curve number for AMC
4. Potential storage
5. Initial abstraction
6. Initial abstraction subtracted from unity
7. Discharge using various initial abstractions

To validate the results, the base flow separation is done. The base flow separation is done using method for complex storms. The volumes of total runoff and base flow are computed using trapezoidal rule. The direct runoff and base flow curves are extended upto 3 days from runoff peak. The direct runoff is obtained by subtracting base flow volumes from total runoff volume. direct runoff volume is used to verify the estimates obtained from the curve number technique.

CHAPTER 6 RESULTS

6.1 Landuse/ Cover and soil

IRS LISS II FCC paper prints at scale of 1:250000 are used to obtain landuse/ cover and soil map (Fig. 6.1 and Fig. 6.2 respectively). Major land cover is forest. The landuse/ cover map is verified from Survey of India Topographic maps. The upper part of the catchment and valley portion are under cultivation. The topographic map is from surveys carried out in years 1971 to 1975. Color of agricultural area is mixed red and yellow. The texture is coarse to smooth. Pattern is patchy and the area lies in command and in valley. Waste land- open has mixed yellow and black color and coarse to medium texture. Dense forest has red color and smooth texture. Open forest has mixed red and yellow color. The texture is coarse. Water has black tone and smooth texture. The areas of landuse cover categories, agriculture, waste land- open , dense forest, open forest and water are respectively 34291, 11234, 28220, 7543 and 104 Ha. The percent areas are respectively 42.1, 13.8, 34.7, 9.3, 0.1. Tone of sandy soil is bright in FCC. Tone of clay is dark. Skeletal soil has bright tone and coarse texture. The areas of skeletal, sand and clay are respectively 25320, 40800 and 15310 Ha. and percent areas are respectively 31.1, 50.1 and 18.8.

6.2 Curve numbers

The SCS curve numbers are assigned to soil cover complexes in the catchment. The curve numbers are adopted from standard curve number table. Skeletal soils, sand and clay are assigned hydrological soil categories A,B and D respectively. Curve numbers are obtained for various crop types, management practices, hydrological condition of forest and fallow land (Table 6.1).

6.3 Runoff computations

The gauge discharge rating curve is obtained from the available daily gauge at 8 hrs. and corresponding discharge data. The relationship derived, is given in equation 6.1. The gauge data ranges are 0.4 to 3.66 m and discharge data ranges are 11.38 to 253.15 cumecs. Runoff computation is done for the rain storms of August 11 to August 18, 1983 (Table 6.1). Daily rainfall hyetograph for rain gauge stations Jamtara, Bargi and Lakhnadon and average for the catchment are shown in Fig. 6.4. For computation of ground water runoff below recession limb in complex storms 8 hourly recession constants for direct and ground water runoff are taken equal to 0.67 and 0.97 respectively. The recession limbs in the storms are computed using 8 hourly recession constants 0.84, 0.86, 0.89, 0.9, 0.91, 0.928, 0.935, 0.94. The ground water runoff curve is extended using 8 hourly ground water recession constant equal to 0.97. Observed total runoff and base flow are shown in Fig. 6.3. In the figure, the runoff upto day 2 is difference of measured runoff of current storm and direct runoff from preceding storm. The runoff, both total and base flow after day 8, are computed runoff using recession constants specified above. Observed total and direct runoff are respectively 48.16 and 28.82 mm. Observed average rainfall over the catchment during the rain storm is 70.68 mm. The computed direct runoff and its % variation from observed direct runoff is given in Table 6.1.

$$Q = 82.714\ (H-0.3)^{0.827} \qquad 6.1$$

Where, Q is discharge in cumecs and H is gauge reading above gauge RL in m.

Table 6.1 Computed direct runoff and error of prediction

Landuse/ cover			Direct runoff	Per err	Direct runoff	Per err (original)
SMsr,g,	Fb,	Wf,Wg	31.23	8.4	34.33	19.1
Rsr,p,	Fb,	Wp,Wf	36.45	26.5	39.50	37.1
Rsr,p,	Fb,	Wp,Wg	35.42	22.9	38.19	32.5
Rc&t,cr,g,	Fcr,g,	Wf,Wg	27.80	-3.5	31.23	8.4
"	"	Wp,Wf	29.41	2.0	33.16	15.1
CLc&t,g,	Fcr,g,	Wf,Wg	26.35	-8.6	29.90	3.7
		Wp,Wf	27.97	-2.9	31.83	10.4
SMc&t,cr,g,	Fcr,g,	Wf,Wg	29.61	2.7	32.85	14.0
"	"	Wp,Wf	31.23	8.4	34.78	20.7
Rc&t,cr,g,	Fb,	Wf,Wg	28.25	-2.0	31.64	9.8
"	"	Wp,Wf	29.87	3.6	33.57	16.5
CLc&t,cr,g,	Fb,	Wf,Wg	26.81	-7.0	30.30	5.2
"	"	Wp,Wf	28.42	-1.4	32.23	11.8
SMc&t,cr,g,	Fb,	Wf,Wg	30.07	4.3	33.26	15.4
"	"	Wp,Wf	31.68	9.9	35.19	22.1
Rc&t,cr,g,	Fcr,p,	Wf,Wg	28.23	-2.0	31.62	9.7
"	"	Wp,Wf	29.84	3.5	33.55	16.4
Clc&t,cr,g,	Fcr,p,	Wf,Wg	26.79	-7.0	30.29	5.1
"	"	Wp,Wf	28.40	-1.5	32.22	11.8
SMc&t,cr,g	"	Wf,Wg	30.05	4.3	33.24	15.3
"	"	Wp,Wf	31.66	9.9	35.17	22.0
Rc,cr,p,	Fcr,p,	Wf,Wg	32.71	13.5	35.65	23.7
"	Fb	" "	32.74	13.6	35.67	23.8
"	Fcr,g	" "	32.28	12.0	35.26	22.3
"	Fb	Wp,Wf	33.62	16.7	36.92	28.1
"	Fcr,g	Wp,Wf	33.90	17.6	37.19	29.0
Rc,g,	Fcr,p,	Wf,Wg	30.96	7.4	34.07	18.2
"	Fb	" "	30.98	7.5	34.09	18.3
"	Fcr,g	" "	30.53	5.9	33.68	16.9
"	Fb,	Wp,Wf	31.87	10.6	35.34	22.6
"	Fcr,g	" "	32.15	11.6	35.61	23.6

SM,R,CL are respectively small grain, row and close seeded crops
sr,c,c&t are respectively straight row, contoured and contoured and terraced cropping system respectively
F and W are fallow land and wood respectively
cr is crop residue
p,f,g are poor,fair and good hydrological conditions of cover respectively

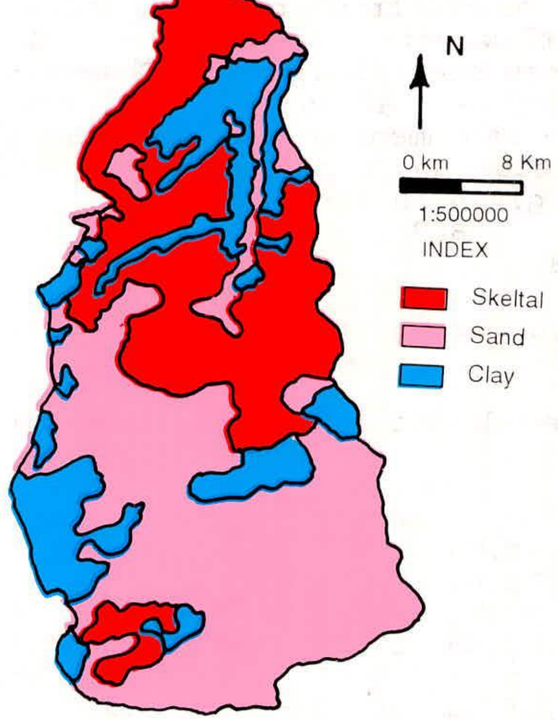

Fig. 6.1 Soil Map

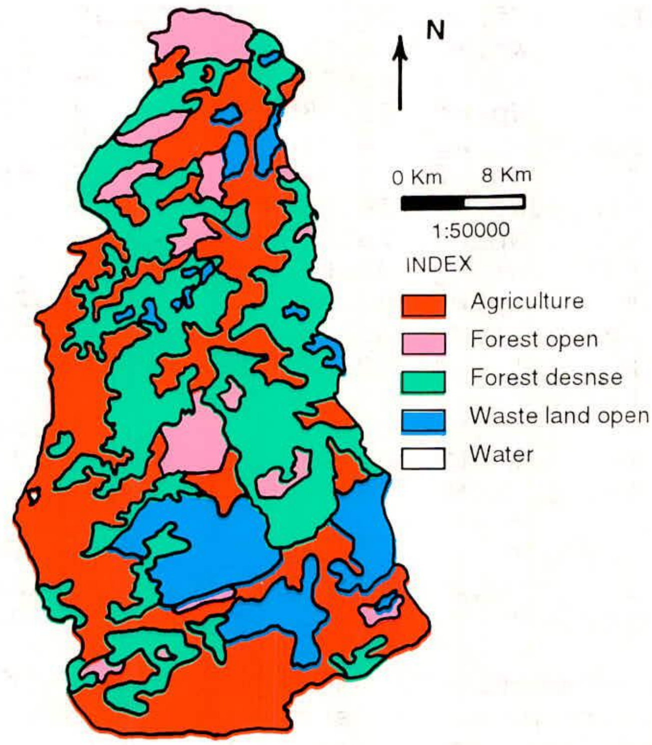

Fig. 6.2 Landuse / cover map

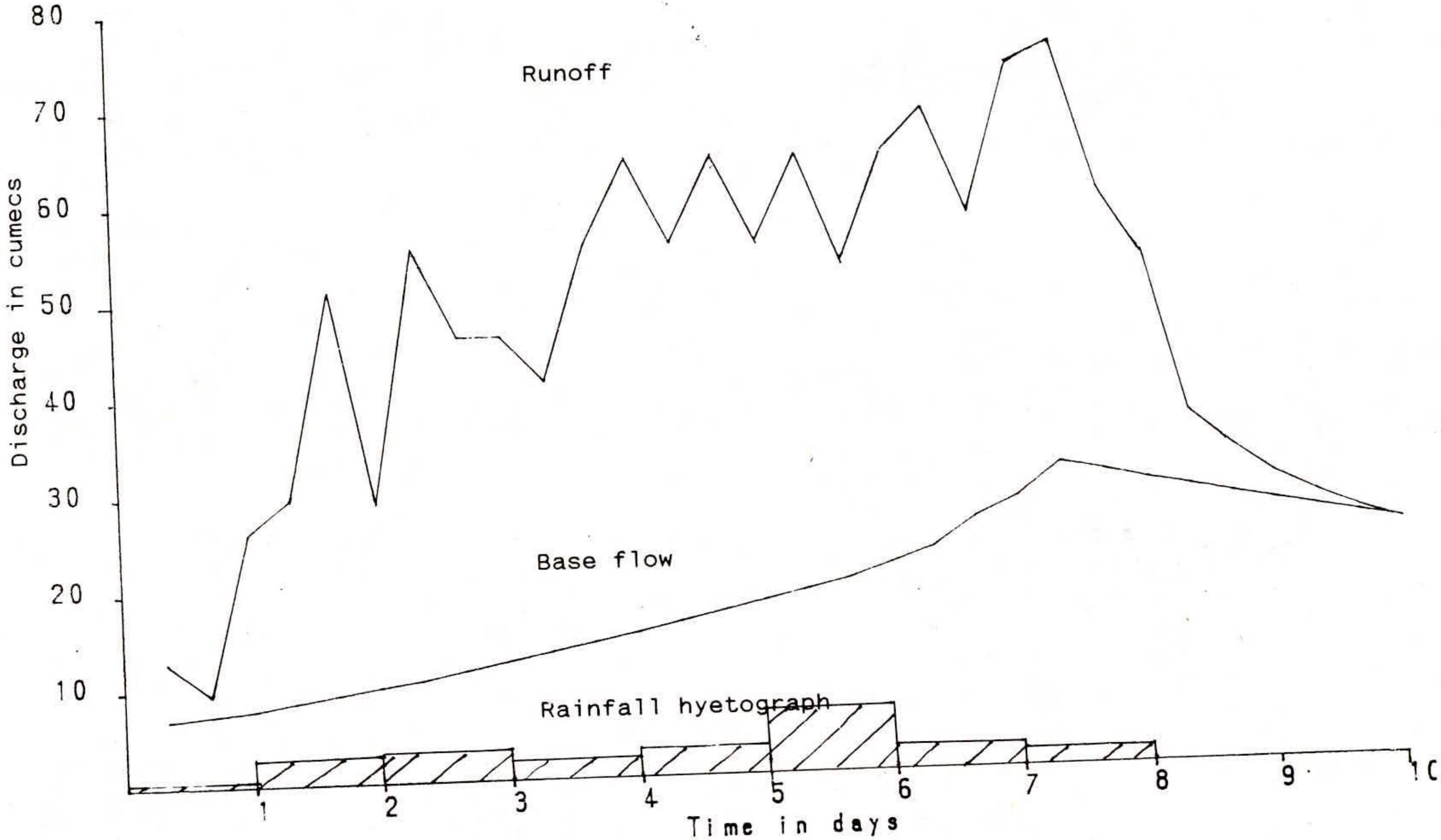

Fig 6.3 Runoff August 11 to 20, 1983

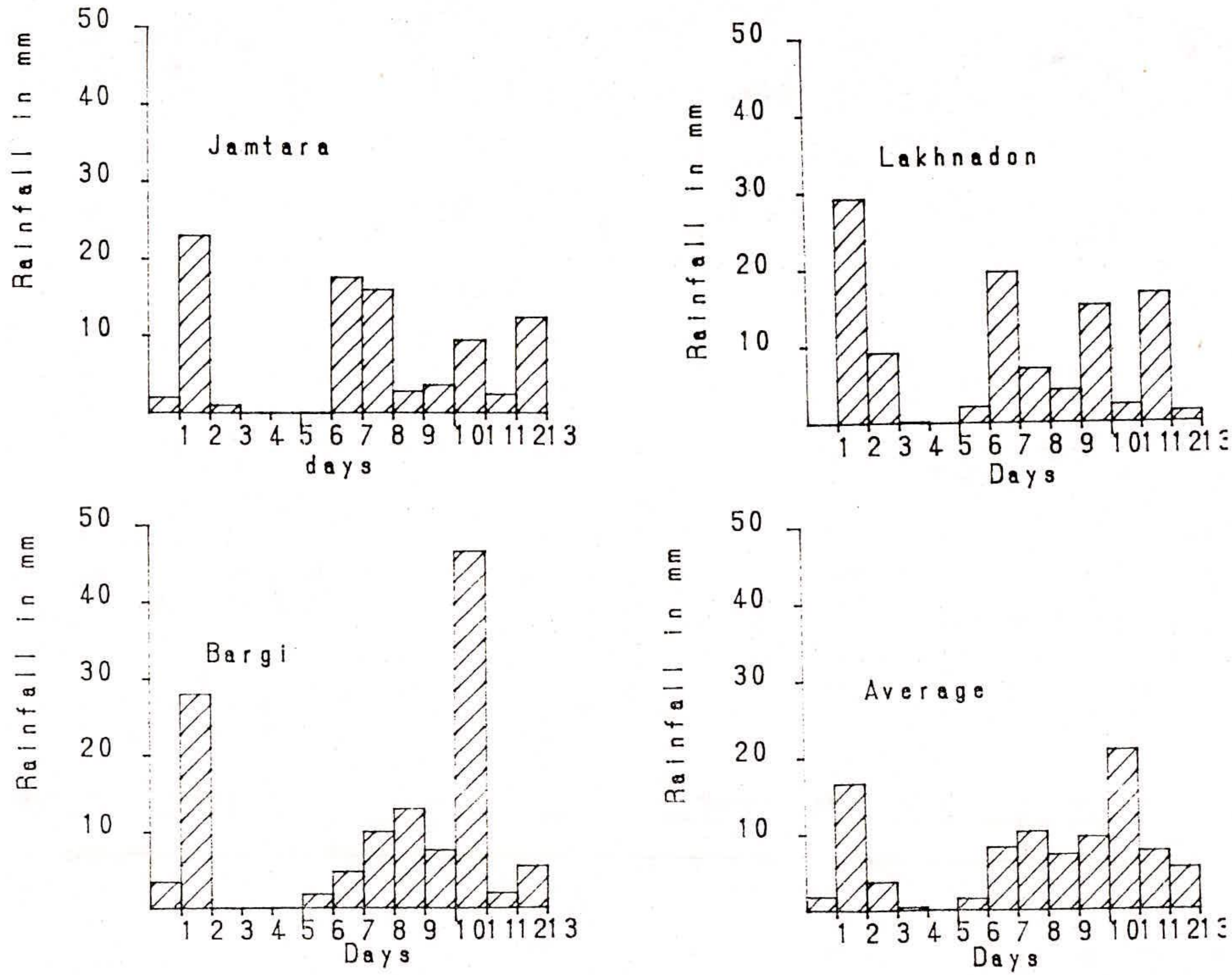

Fig. 6.4 Rainfall hyetograph for storm Aug. 11-18,83

CHAPTER 7 CONCLUSIONS

SCS method in this study is used for estimating direct runoff volume. The method has computed direct runoff with small percentage error. Remote sensing is a very effective tool for mapping landuse/ cover and soil in a catchment. Landuse/ cover is an important physical variable, since, it controls the yield from a catchment. This information can be used in hydrological models for runoff volume estimation from a storm events.

The point rainfall data is another useful input in hydrological models used in runoff computations. The spatial rainfall can be interpolated from point rainfall data in a GIS. The other maps can be digitized in a GIS. All the maps can, then, be overlaid in a GIS using mathematical equations and functions to obtain various hydrological quantities such as direct runoff volume from rain storm. Averages of hydrological quantities such as rainfall and runoff can also be determined in a GIS. The results can be compared with observed values.

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DIRECTOR : DR S.M.SETH

HEAD : DR. V.K.CHOUBEY

STUDY GROUP

Mr. D. S. RATHORE, Sc. 'C'