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DETERMINATION OF SCS RUNOFF CURVE NUMBER AND LANDUSE CHANGES FOR HAMIDNAGAR SUB-BASIN OF PUNPUN BASIN

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LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Design of any hydraulic structure necessitates the estimation of runoff. The soil conservation service (SCS) model, developed by USDA, computes direct runoff through an empirical equation that requires the rainfall and watershed coefficient as inputs. The watershed coefficient is called the curve number (CN), which represents the runoff potential of the land cover-soil complex. The approach of estimating CN using remote sensing technique saves time and is less expensive as compared to conventional techniques.

The study of landuse changes is a prerequisite for making developmental plans. Landuse changes can be studied through satellite data, however, where rainfall-runoff data are available over a longer period of time, a general trend of landuse changes can also be assessed through establishment of runoff curve numbers.

A project is proposed for the construction of a diversion barrage on river Punpun at Hamidnagar at longitude 84° 38'E and latitude 25^{0} 4'N in the district of Aurangabad near Goh. For design of the barrage, estimation of water availability and runoff due to precipitation in the upper catchment is essential. In the present study, the runoff curve number for Hamidnagar sub-basin of Punpun basin is established using IRS 1A, LISS II data and soil information of Hamidnagar sub-basin. The rainfall-runoff data over a period of nine years are also used to develop the runoff curve numbers. Further, an attempt is made to study the landuse changes of Hamidnagar sub-basin by comparing the developed curve numbers.

1.0 INTRODUCTION

The output of hydrologic design is the input to hydraulic design and runoff is one of the basic output of hydrologic design. Runoff measurements usually require an elaborate stream gauging procedure. However, rainfall can be measured in a relatively simple way. This difference has led to rainfall data being more widely available than runoff data. The typical catchment has many more rain gauges than stream gauging stations, with the rainfall records likely to be longer than the streamflow records. The fact that rainfall data is more voluminous than runoff data has led to the calculation of runoff by relying on rainfall data. Although this is an indirect procedure, it has proven its practicality in a variety of applications.

One of the basic rainfall-runoff models is the linear model correlating runoff with rainfall. For developing this linear model, it is necessary to collect several sets of rainfall-runoff data and to perform a linear regression to determine the constants. The simplicity of this linear model precludes it from taking into consideration other important runoff-producing mechanisms such as rainfall intensity, infiltration rates, or antecedent moisture. In practice, the correlation usually shows a wide range of variation, limiting its predictive ability.

The effect of infiltration rate and antecedent moisture on runoff is widely recognized. Several models have been developed in an attempt to simulate these and other related processes. Typical of such models is the soil conservation service (SCS) runoff curve number model, which has had wide acceptance in engineering practice. The SCS model is based on a non-linear rainfall-runoff relation that includes a third variable (curve parameter) called the runoff curve number or the CN. The curve number is a function of the hydrologic soil type, land use and treatment, ground surface condition and antecedent moisture condition. Of these, the determination of land use and land cover is one of the most important tasks for the estimation of runoff curve number. Earlier, the information on land use and land cover were gathered mainly by ground surveys or low altitude photography. However, these survey methods are very expensive and time consuming. A potential method for collecting the requisite information on land use and soil type of broad areas is through the utilisation of satellite data. Further, where rainfall-runoff data are available, estimations of runoff curve numbers can be obtained directly from data.

The information on land use changes and its effect on basin wide runoff is useful in water resources management and development programs. The satellite capability to provide real time information makes it possible to have meaningful repetitive surveys, which can show how the changes have taken place in a particular period. However, where rainfall-runoff data are available over a longer period of time, a general assessment of land use changes can also be made through the determination of runoff curve numbers.

A project is proposed for the construction of a diversion barrage on river Punpun at Hamidnagar at longitude 84^0 38'E and latitude 25^0 4'N in the district of Aurangabad near Goh. The barrage will have irrigation systems to irrigate a gross command area (GCA) of 58,870 hectare during kharif season. For the design of the barrage, estimation of water availability and runoff due to precipitation in the upper catchment is essential.

In the present study, the runoff curve number for Hamidnagar sub-basin of Punpun basin is established using IRS 1A, LISS II data and the soil information of Hamidnagar sub-basin. Further, the rainfall-runoff data of previous years are also used to develop the runoff curve number of Hamidnagar sub-basin. These runoff curve numbers are then compared to have a preliminary assessment of the land use changes in Hamidnagar sub-basin.

2.0 STUDY AREA

The Punpun river originates from Chottanagpur hills of Palamau district in Bihar at an elevation of 300 m and at north latitude of 24°11' and east longitude of 84°9'. It is one of the important right bank tributaries of river Ganga. The Punpun river system lies approximately between longitude 84°10'E to 85°20'E and latitude 24°11'N to 25°25'N (Fig. 2.1). After flowing for most of its portion in north east direction it joins the river Ganga at Fatwa, about 25 km downstream of Patna, covering a total distance of 232 km. The river is rainfed and carries little discharge during non-monsoon period. It receives most of the discharge from the right bank tributaries. The length and the catchment area of all the important tributaries are shown in a line diagram (Fig. 2.2). The ground elevation varies from 300 m near the origin of the river to about 50 m near outfall into the river Ganga. The general direction of the drainage is from south-west to north-west.

The Punpun river basin is roughly trapezoidal in shape. The length of the basin is about 180 km and the average width in upper and lower reaches of the basin is 60 km and 25 km respectively. The total area of Punpun basin is about 8530 sq. km. which is one percent of the total area of Ganga basin in the country. The entire catchment lies within the state of Bihar and is spread over the districts of Patna, Gaya, Aurangabad, Hazaribagh and Palamau.

In the present study, Hamidnagar sub-basin of the Punpun basin is selected for the establishment of SCS curve number. The outlet of the Hamidnagar sub-basin is located at 84°38'E

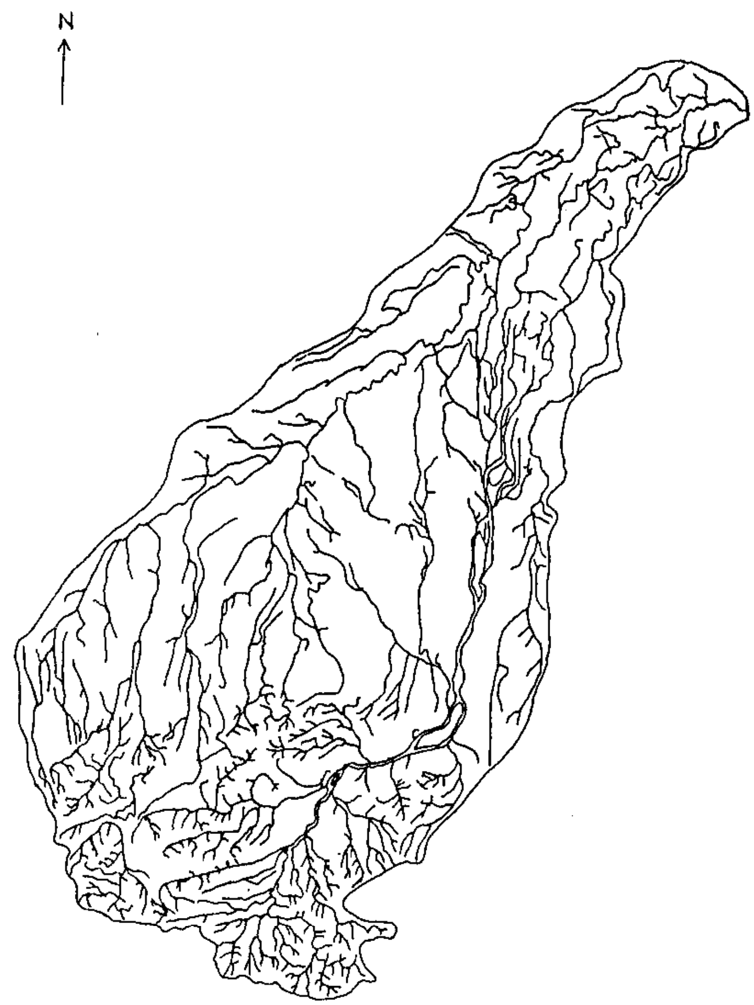

Fig. 2.1 Punpun river system

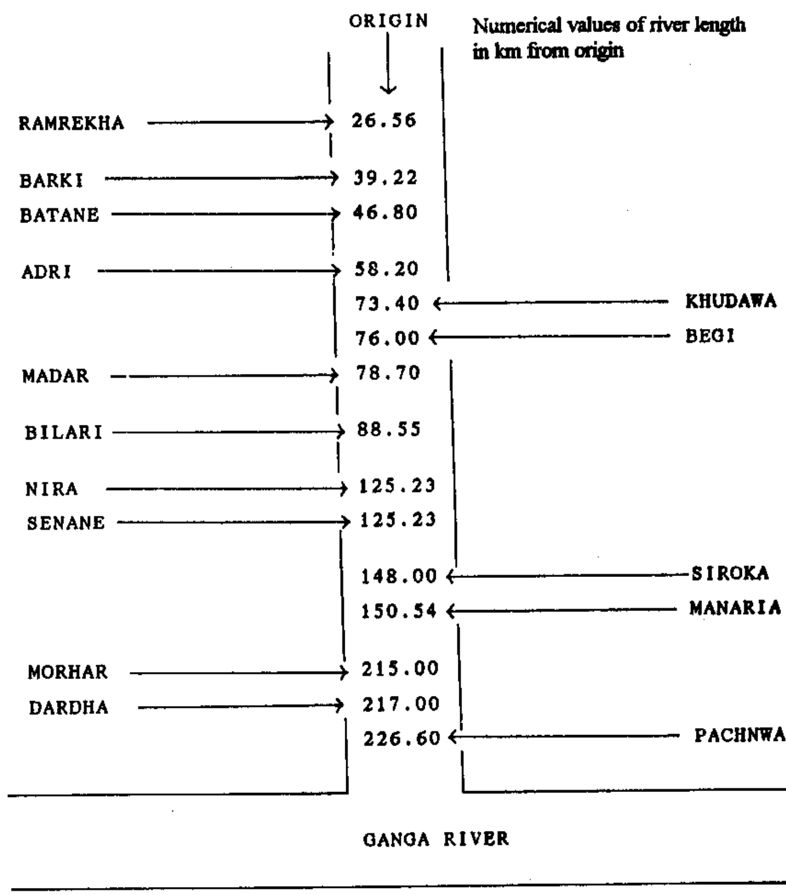

Fig. 2.2 Line diagram of Punpun river system

longitude and 25°4' N latitude in the district of Aurangabad near Goh, which is 112 km below the origin of the river Punpun (Fig. 2.3). The total area of Hamidnagar sub-basin is about 3314 sq. km. It has steep slopes with forests at the upper part and mild slopes at the lower part (Fig. 2.4). In the upper part of the catchment, precipation occurs more frequently and sometimes with high intensities for longer duration. Interception losses are significant due to the presence of forests. Infiltration losses vary from place to place due to change in soil and slope characteristics. In the lower part of the catchment, precipitation is uniform and does not vary frequently.

The geology of the area varies from granite, gneiss, charnokites in the hills to the recent alluvium in the plains (Fig. 2.5). The broad soil groups are calcium and non-calcium, recent and old alluvium and brown forest soils, red soil podzowe, lateritic soil with cover being very deep in plains and deep to shallow in hills.

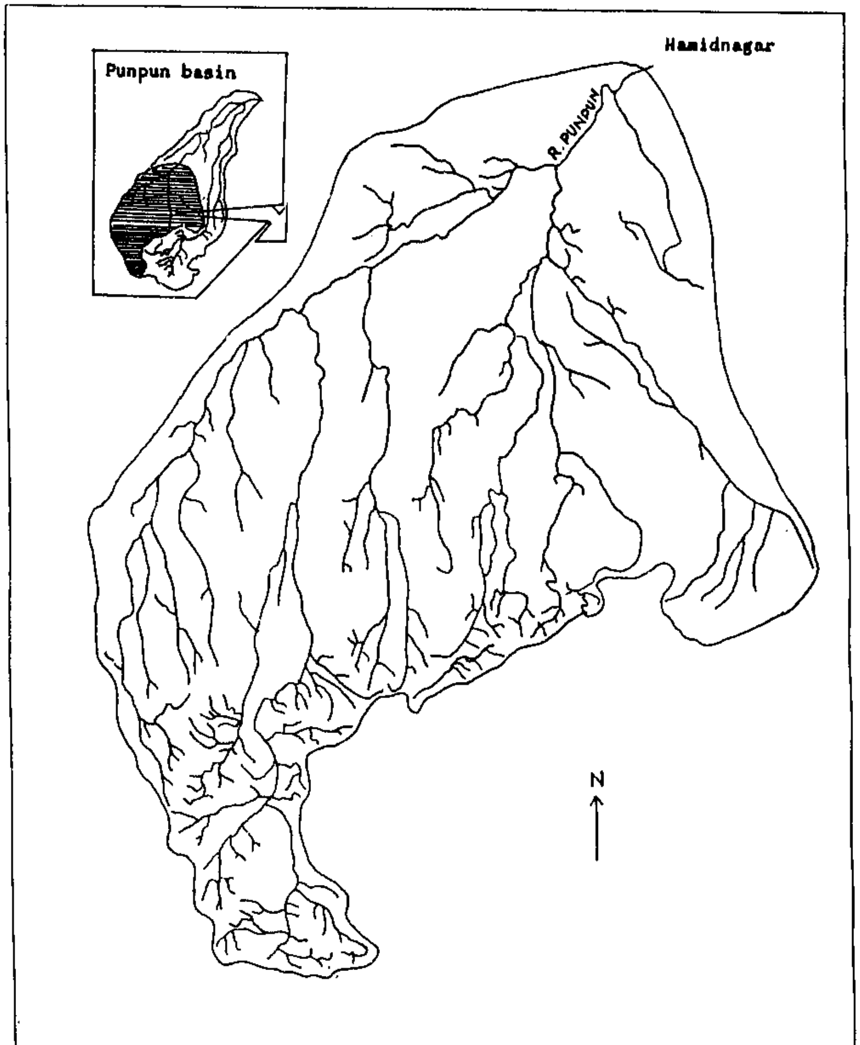

Fig. 2.3 The study area upto Hamidnagar

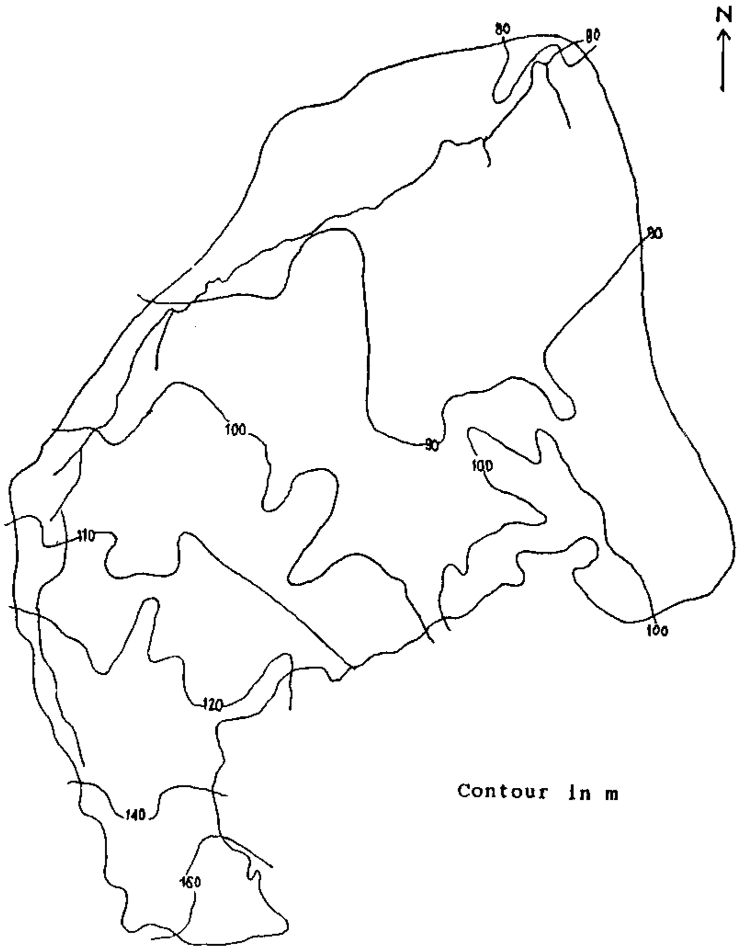

Fig. 2.4 Topographical map of Hamidnagar basin

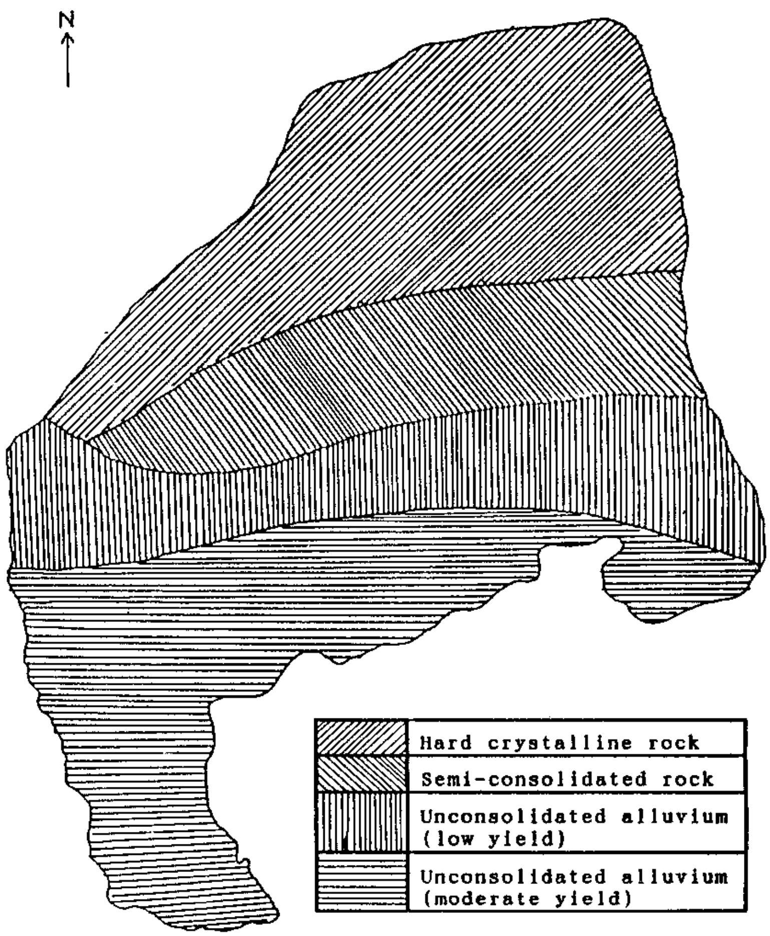

Fig. 2.5 Geological map of Hamidnagar basin

3.0 METHODOLOGY, DATA COLLECTION AND PROCESSING

In the present study, Hamidnagar sub-basin of Punpun basin is selected for the establishment of SCS runoff curve number and study of landuse changes. The following sections describe the SCS runoff curve number method and the procedure for determination of runoff curve numbers from land use map and soil information, and also from rainfall-runoff data. The analysis of data has also been discussed.

3.1 SCS Runoff Curve number method

The runoff curve number method is a procedure for hydrologic abstraction developed by the USDA Soil Conservation Service. In this method, runoff depth (i.e. effective rainfall) is a function of total rainfall depth and an abstraction parameter referred to as runoff curve number or simply curve number and is usually represented by CN. The curve number varies in the range 1 to 100, being a function of the following runoff producing catchment properties: (1) hydrologic soil type, (2) land use and treatment, (3) ground surface condition, and (4) antecedent moisture condition.

In the runoff curve number method, if actual runoff is referred as Q, and potential runoff (total rainfall) as P, with $P \geq Q$, then the actual retention, P-Q, and the potential retention (or potential maximum retention), S, will always have the relation $S \geq P-Q$.

The method is based on an assumption of proportionality between retention and runoff in the following form :

$$\frac{P-Q}{S} = \frac{Q}{P} \qquad (3.1)$$

which states that the ratio of actual retention to potential retention is equal to the ratio of actual runoff to potential runoff. This assumption underscores the conceptual basis of the runoff curve number method. P, Q and S are expressed in the same units e.g. cm or inches.

For practical applications, Eq. 3.1 is improved by reducing the potential runoff by an amount equal to the initial abstraction. The initial abstraction consists mainly of interception, infiltration and surface storage, all of which occur before runoff begins.

$$\frac{P-I_a-Q}{S}=\frac{Q}{P-I_a} \qquad (3.2)$$

in which I_a= initial abstraction.
Solving for Q from Eq. 3.2:

$$Q=\frac{(P-I_a)^2}{P-I_a+S} \qquad (3.3)$$

which is physically subject to the restriction that $P \geq I_a$ (i.e. the potential runoff minus the initial abstraction cannot be negative).

To simplify Eq. 3.3, initial abstraction is related to potential maximum retention. Vandersypen et. al. (1972) developed the following relationship between initial abstraction and potential maximum retention for Indian conditions:

(a) For black soil region (Antecedent moisture condition I) and for all other regions :

$$I_a=0.3S \qquad (3.4)$$

Therefore Eq. 3.3 reduces to

$$Q=\frac{(P-0.3S)^2}{P+0.7S}, \quad P\geq 0.3S \qquad (3.5)$$

(b) For black soil region (Antecedent moisture condition II & III):

$$I_a=0.1S \qquad (3.6)$$

Therefore Eq. 3.3 reduces to

$$Q=\frac{(P-0.1S)^2}{P+0.9S}, \quad P\geq 0.1S \qquad (3.7)$$

Eq. 3.7 is used with the assumption that the cracks which are typical of black soil when dry are filled.

Since potential maximum retention varies widely, it is expressed in terms of a runoff curve number, an integer varying in the range 1 to 100, in the following form:

$$S=\frac{2540}{CN}-25.4 \qquad (3.8)$$

in which CN is the runoff curve number (dimensionless) and S is in cm. Hence, the values of P and Q in Eqns. 3.5 and 3.7 are also to be expressed in cms.

The runoff curve numbers vary with hydrologic soil cover complexes. The hydrologic soil cover complex describes a specific combination of hydrologic soil group, land use and treatment, hydrologic surface condition, and antecedent moisture condition. All these have a direct bearing on the amount of runoff produced by a watershed. The hydrologic soil group describes the type of soil. The land use and treatment describes the type and condition of vegetative cover. The hydrologic condition refers to the ability of the watershed surface to enhance or impede direct runoff. The antecedent moisture condition accounts for the recent history of rainfall, and consequently it is a measure of the amount of moisture stored by the catchment. The runoff curve numbers for various hydrologic soil cover complexes for Indian conditions (AMC II and I_a=0.3S) are given in table 3.1 (Handbook

Table 3.1 Runoff curve numbers for hydrologic soil cover complexes for Indian conditions (AMC II and Ia=0.3S)*

Cover			Runoff CN for hydrologic soil group			
Land use	Treatment/ Practice	Hydrol. condn.	A	B	C	D
Cultivated	Straight row		76	86	90	93
	Contoured	poor	70	79	84	88
		good	65	75	82	86
	Contoured & terraced	poor	66	74	80	82
		good	62	71	77	81
	Bunded	poor	67	75	81	83
		good	59	69	76	79
	Paddy		95	95	95	95
Orchard	with under-story cover		39	53	67	71
	without under-story cover		41	55	69	73
Forest		dense	26	40	58	61
		open	28	44	60	64
		shrub	33	47	64	67
Pasture		poor	68	79	86	89
		fair	49	69	79	84
		good	39	61	74	80
Wasteland			71	80	85	88
Hard surface area			77	86	91	93

* Source : Handbook of Hydrology, 1972

of Hydrology, 1972). The corresponding curve numbers for AMC I and AMC III conditions are given in table 3.2 (SCS National Engineering Handbook, 1985).

Table 3.2 Corresponding curve numbers for three AMC conditions

AMC II	AMC I	AMC III	AMC II	AMC I	AMC III	AMC II	AMC I	AMC III
100	100	100	75	57	88	50	31	70
99	97	100	74	55	88	49	30	69
98	94	99	73	54	87	48	29	68
97	91	99	72	53	86	47	28	67
96	89	99	71	52	86	46	27	66
95	87	98	70	51	85	45	26	65
94	85	98	69	50	84	44	25	64
93	83	98	68	48	84	43	25	63
92	81	97	67	47	83	42	24	62
91	80	97	66	46	82	41	23	61
90	78	96	65	45	82	40	22	60
89	76	96	64	44	81	39	21	59
88	75	95	63	43	80	38	21	58
87	73	95	62	42	79	37	20	57
86	72	94	61	41	78	36	19	56
85	70	94	60	40	78	35	18	55
84	68	93	59	39	77	30	15	50
83	67	93	58	38	76	25	12	43
82	66	92	57	37	75	20	9	37
81	64	92	56	36	75	15	6	30
80	63	91	55	35	74	10	4	22
79	62	91	54	34	73	5	2	13
78	60	90	53	33	72	0	0	0
77	59	89	52	32	71			
76	58	89	51	31	70			

The three levels of antecedent moisture i.e. AMC I, AMC II and AMC III, depend on the total rainfall in the 5-day period preceding a storm. AMC I has the lowest runoff potential, with the soils being dry enough for satisfactory ploughing or cultivation to take place. AMC II has an average runoff potential while AMC III has the highest runoff potential, with the watershed practically saturated from antecedent rainfalls. However, the rainfall amounts corresponding to different antecedent moisture conditions, depend on the geographic or climatic conditions of the region. Hence, the values of AMC I, AMC II and AMC III derived for a particular region should not be used for other geographic or climatic regions.

3.2 Determination of CN from land use map and soil information (Direct method)

For the establishment of runoff curve number by direct method, information on hydrologic soil group, hydrologic condition, treatment or practices and land use/ cover are used. These information are acquired from field surveys and interpretations of satellite imageries. For large watersheds, the conventional techniques usually used for land use mapping are not only time consuming but expensive as well. The relatively new technique of satellite remote sensing which provides a real time and reasonably accurate information at a faster and less tedious way is chosen for the analysis. In the present study the landuse map of Punpun basin (developed from IRS 1A, LISS II, FCC prints by Lohani et. al., 1995) and its soil information are used to determine the runoff curve number for Hamidnagar sub-basin.

3.2.1 Land use map of Punpun basin

A brief description of the procedure adopted for the preparation of land use map of Punpun basin by lohani et. al.

(1995) is presented :

False colour composites (FCC) of IRS 1A, LISS II of both pre-monsoon and post-monsoon period for the year 1989 (Table 3.3)

Table 3.3 Details of IRS-1A, LISS II data

Type of Data	Path/Row	Scene	Date
Pre-Monsoon Data			
IRS-1A LISS II	P22-R50	B 1	April 9, 1989
IRS-1A LISS II	P22-R50	B 2	April 9, 1989
IRS-1A LISS II	P21-R50	A 1	April 8, 1989
IRS-1A LISS II	P21-R50	A 2	April 8, 1989
IRS-1A LISS II	P21-R50	B 2	April 8, 1989
Post-Monsoon Data			
IRS-1A LISS II	P21-R50	B 2	Nov. 14, 1989
IRS-1A LISS II	P21-R50	A 1	Nov. 14, 1989
IRS-1A LISS II	P21-R50	A 2	Nov. 14, 1989
IRS-1A LISS II	P22-R50	B 1	Dec. 7, 1989
IRS-1A LISS II	P22-R50	B 2	Dec. 7, 1989

were used for delineating the land use classes of Punpun basin. Initially, a tracing of the study area indicating the boundaries and a few control points was prepared from Survey of India toposheets and a base map supplied by the Hydrology Cell, Govt. of Bihar. This tracing was superimposed on the satellite FCC and boundaries of various land use/ land cover classes were demarcated keeping in view the fundamentals of visual interpretation. Then the results were compared with the limited ground truth data that were available and the modifications/ corrections were transferred to the base map. The Punpun basin was divided into six major classes, namely; agricultural land, forest land, water logged area, waste land, built up area and river and tributary. Further, since the land use/ land cover classes derived from IRS-1A, FCC data were far more generalized than that specified in table 3.1, runoff curve numbers compatible with IRS-1A, LISS II data were also developed (Table 3.4).

Table 3.4 Runoff curve numbers for hydrological soil cover complexes compatible with IRS-1A data

Sl. No.	Landuse	Hydrol. condn./ Cover	Runoff Curve Numbers for AMC II			
			A	B	C	D
1.	Cultivated	Poor	66	76	82	84
		Good	62	72	78	82
		Paddy	95	95	95	95
2.	Orchards		40	54	68	72
3.	Forest	Dense	26	40	58	61
		Open	28	44	60	64
4.	Pasture/Fallow		68	79	86	89
5.	Wasteland		71	80	85	88
6.	Roads/Runway		73	83	88	90
7.	Settlements/ Hard surface area		77	86	91	93

In the present study, the land use map of Punpun basin (developed from IRS 1A, LISS II, FCC prints by Lohani et. al., 1995) along with the runoff curve numbers compatible with IRS-1A, LISS II data are used for the establishment of runoff curve number of Hamidnagar sub-basin.

3.2.2 Soil information

The soil information of the study area was collected from the office of the Soil Survey and Land use Planning Centre, Sabour, Bhagalpur.

Five broad soil associations are found in Hamidnagar sub-basin of Punpun basin which are as follows:

a. Yellow-reddish yellow, medium deep, light textured catenary soils.

b. Hill and forest soils of steep slopes and highly dissected region.

c. Old alluvium yellowish red-yellow soils of foot hills.

d. Old alluvium reddish yellow-yellow-grey catenary soils.

e. Old alluvium Grey-greyish yellow, heavy textured cracking soils.

The entire area of Hamidnagar sub-basin has two groups of soils i.e. (a) Sedentary soils and (b) Old alluvial soils. The first three soil associations are sedentary, whereas the last two are old alluvial. Sedentary soils are classified under hydrological soil group 'B' while old alluvial soils under soil group 'C' (Fig. 3.1).

3.3 Determination of CN from rainfall-runoff data (Inverse method)

Though the runoff curve number method was developed primarily for ungauged catchments, however, where rainfall-runoff data are available, estimation of runoff curve numbers is obtained directly from data. These values complement, and in certain cases, may even replace the information obtained from direct method.

The present study area i.e. Hamidnagar sub-basin does not belong to black soil region. Hence, Eq. 3.5 along with Eq. 3.8 is used for the calculation of runoff curve numbers from rainfall-runoff data.

Rearranging Eq. 3.5 and expressing S in terms P & Q, we get

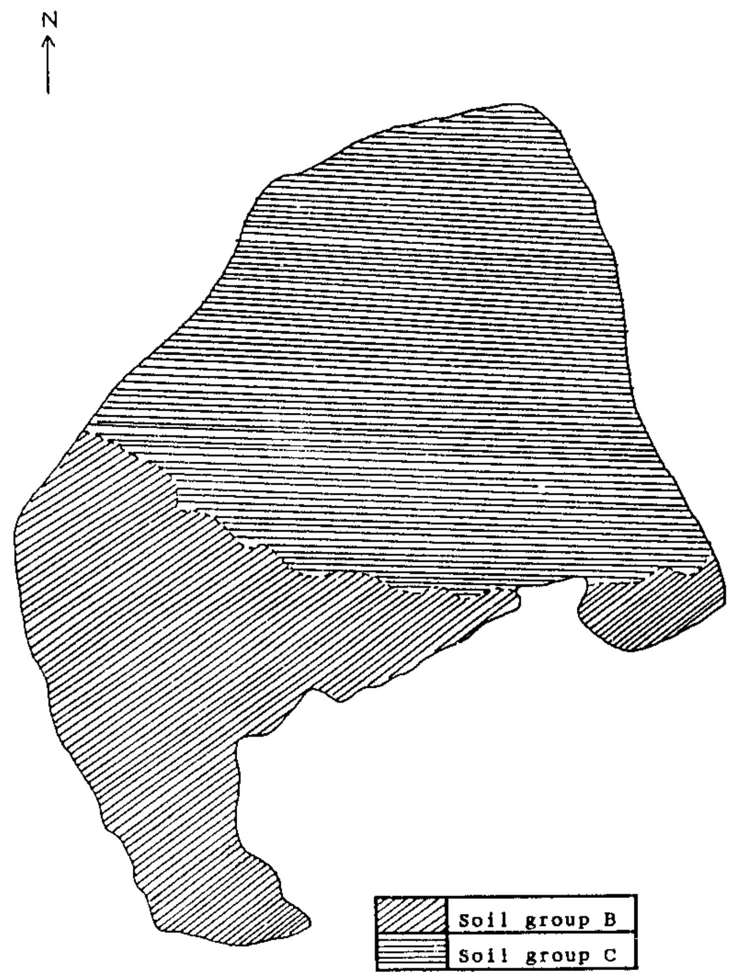

Fig. 3.1 Hydrologic soil map of Hamidnagar basin

$$S=\frac{(0.6P+0.7Q)\pm\sqrt{(0.6P+0.7Q)^2-0.36(P^2-QP)}}{0.18} \qquad (3.9)$$

Further simplifying Eq. 3.9, we get

$$S=\frac{(0.6P+0.7Q)\pm\sqrt{0.49Q^2+1.2PQ}}{0.18} \qquad (3.10)$$

Hence, it is observed from Eq. 3.10 that there exists two solutions of S in terms of P & Q. Further, from Eq. 3.5 it is observed that $P \geq 0.3S$.

Therefore, Eq. 3.10 can be assumed as :

$$S=\frac{(0.6P+0.7Q)+\sqrt{0.49Q^2+1.2PQ}}{0.18} \qquad (3.11)$$

and substituting Eq. 3.11 in $P \geq 0.3S$ we get

$$P \geq 0.3\left[\frac{(0.6P+0.7Q)+\sqrt{0.49Q^2+1.2PQ}}{0.18}\right] \qquad (3.12)$$

Rearranging (3.12) we get

$$0.21Q+\sqrt{0.49Q^2+1.2PQ} \leq 0 \qquad (3.13)$$

This condition does not arise since P & Q have positive values. Therefore, the assumption of inequality in Eq. 3.12 is incorrect and hence Eq. 3.11 is not a solution for S.

Again assuming that

$$S=\frac{(0.6P+0.7Q)-\sqrt{0.49Q^2+1.2PQ}}{0.18} \qquad (3.14)$$

Substituting Eq. 3.14 in $P \geq 0.3S$, we get

$$P \geq 0.3\left[\frac{(0.6P+0.7Q)-\sqrt{0.49Q^2+1.2PQ}}{0.18}\right] \qquad (3.15)$$

Rearranging (3.15) we get

$$0.21Q \le \sqrt{0.49Q^2+1.2Q} \qquad (3.16)$$

Since P & Q are positive, both sides of inequality in Eq. 3.16 are positive. Squaring both sides and rearranging, we get

$$0.4459Q^2+1.2PQ \ge 0 \qquad (3.17)$$

This condition is true since both P and Q are positive. Therefore the assumption is correct, and hence, Eq. 3.14 is the only solution for S. Substituting the value of S from Eq. 3.14 in Eq. 3.18 and rearranging we get,

$$CN = \frac{457.2}{4.572+0.6P+0.7Q-\sqrt{Q(0.49Q+1.2P)}} \qquad (3.18)$$

Knowing the values of P and Q in cms, the value of CN can be calculated directly from Eq. 3.18.

For the present study, seven storms are selected during the period 1977-1985 for determination of curve number of Hamidnagar sub-basin.

3.3.1 Discharge data

Gauge and discharge data at Hamidnagar barrage site, available from Water Resources Department, Govt. of Bihar, are used for analysis. These data are available from 1976 to 1986 for monsoon seasons with monitoring interval of 6 hours i.e. at 0600, 1200, 1800 and 2400 hours only.

3.3.1.1. Selection of storm hydrographs

In the present study, the discharge observed at Hamidnagar site are examined and seven single peaked hydrographs are selected for analysis. The duration of the total runoff hydrographs (TRH) are presented in col. 2 of Table 3.5. These storms are numbered from I to VII as indicated in col. 1 of Table

Table 3.5 TRH duration, DRH duration, total runoff volume and total runoff for the selected storms

Storm No.	TRH duration	DRH duration	Total runoff volume (M m^3)	Total runoff, Q, (cm)
I	24th Jul. to 5th Aug., 1977	28th Jul. to 4th Aug., 1977	75.659	2.283
II	8th Sep. to 20th Sep., 1977	9th Sep. to 15th Sep. 1977	78.575	2.371
III	22nd Sep. to 4th Oct., 1978	22nd Sep. to 2nd Oct. 1978	245.932	7.421
IV	2nd Sep. to 15th Sep., 1980	3rd Sep. to 11th Sep., 1980	173.620	5.239
V	28th Aug. to 3rd Sep., 1983	28th Aug. to 3rd Sep., 1983	40.331	1.217
VI	17th Sep. to 28th Sep., 1983	17th Sep. to 24th Sep., 1983	104.391	3.27
VII	19th Aug. to 27th Aug., 1985	20th Aug. to 27th Aug., 1985	113.173	3.415

3.5. The total runoff hydrograph corresponding to storm no. I is plotted as shown in Fig. 3.2.

3.3.1.2 Base flow separation

The base flow is deducted from the total runoff hydrograph to obtain the direct runoff hydrograph (DRH) which is required for determination of CN. As shown in Fig. 3.2, the base flow curve existing prior to the commencement of surface runoff is extended from point A till it intersects the ordinate drawn at the peak (point C in Fig. 3.2). This point is joined to point B by a straight line. An empirical equation for the time interval N (days) from the peak to the point B is

$$N = 0.83A^{0.2} \qquad (3.19)$$

where A = drainage area in km^2 and N is in days. The total drainage area for Hamidnagar sub-basin is 3314 km^2 and hence N = 4.2 days (from Eq. 3.19). Segments AC and CB demarcate the base

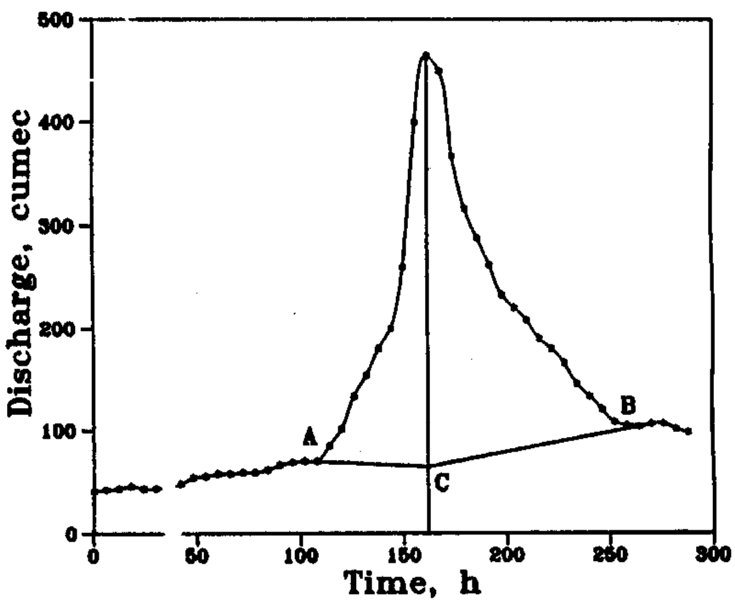

Fig. 3.2 Hydrograph showing base flow separation for storm no. I (Jul 24 to Aug 5, 1977)

flow and surface run ff. Base flow separation for the remaining hydrographs were perl rmed in a similar manner. The duration of the direct runoff hydrographs are shown in col. 3 of Table 3.5.

3.3.1.3 Calculation of surface runoff (Q)

The total volume of surface runoff (Mm^3) is determined by calculating graphically the area enclosed by the direct runoff hydrographs (col. 4 of table 3.5). These values are then divided with the total watershed area (i.e. 3314 km^2) and then converted to cm of runoff (Q) (col. 5 of table 3.5).

3.3.2 Rainfall data

Rainfall data of nine raingauge stations located in/around Hamidnagar sub-basin are obtained from various IMD and State Departments of Bihar. Daily rainfall data of these raingauge stations are available for 12-13 years (Table 3.6).

Table 3.6 Rainfall data availability of raingauge stations

Sl. No.	Raingauge Station	Period	No. of Years	Type of Station*
1.	Goh	1974-85	12	ORG
2.	Obra	1974-85	12	ORG
3.	Palmerganj	1974-86	13	SRRG
4.	Aurangabad	1974-86	13	ORG
5.	Gurua	1974-86	13	ORG
6.	Sherghati	1974-86	13	ORG
7.	Hariharganj	1974-86	13	ORG
8.	Nabinagar	1974-86	13	ORG
9.	Chattarpur	1974-86	13	ORG

* ORG -> Ordinary Raingauge
* SRRG -> Self-recording Raingauge

3.3.2.1 Thiessen Polygon

Thiessen polygon method has been applied to calculate the mean areal rainfall for Hamidnagar sub-basin. Fig. 3.3 shows the thiessen polygons for the raingauge stations of Hamidnagar sub-basin. The thiessen weights for each raingauge station are calculated and presented in table 3.7.

3.3.2.2 Time of Concentration

For selecting the duration of rainfall corresponding to the direct runoff hydrographs, the time of concentration needs to be calculated. The time of concentration, T_c, is defined as the time taken for a drop of water to reach the outlet from the farthest part of the catchment. In the present study, T_c is calculated

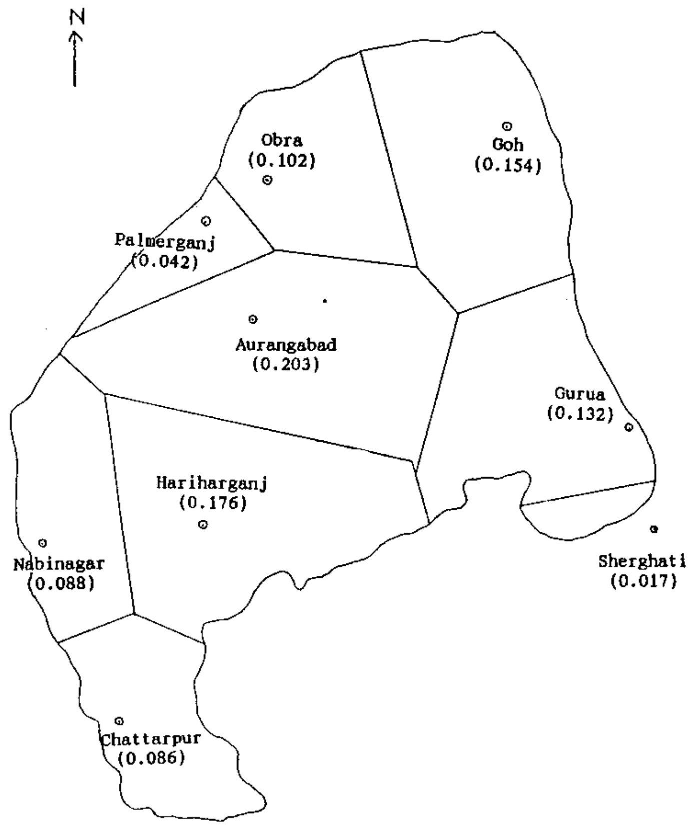

Fig. 3.3 Thiessen polygon of Hamidnagar basin with thiessen weight

Table 3.7 Thiessen weights of raingauge stations

Sl. No.	Raingauge Station	Area of Thiessen Polygon (sq. km)	Thiessen Weight
1.	Goh	510.356	0.154
2.	Obra	338.028	0.102
3.	Palmerganj	139.188	0.042
4.	Aurangabad	672.742	0.203
5.	Gurua	437.448	0.132
6.	Sherghati	56.338	0.017
7.	Hariharganj	583.264	0.176
8.	Nabinagar	291.632	0.088
9.	Chattarpur	285.000	0.086

using Kirpich's empirical equation:

$$T_c = 0.0195 L^{0.77} S^{-0.385} \qquad (3.20)$$

in which T_c = time of concentration, min; L = main stream length, m; and S = mean slope of the main stream, m/m.

For Hamidnagar sub-basin, L = 112000 m and S = 1.0662×10^{-3}. Hence,

$$T_c = 0.0195(112000)^{0.77}(0.0010662)^{-0.385}$$
$$= 2100 min$$
$$= 35 h$$

Since daily rainfall data are available, therefore T_c is taken as 1 day.

3.3.2.3 Selection of rainfall duration

Since T_c = 1 day, rainfall duration corresponding to each DRH starts from 1 day prior to beginning of DRH and continues upto 1 day prior to end of DRH (col. 2 of table 3.8).

3.3.2.4 Estimation of missing rainfall data

The rainfall data for one or two stations are not available for a few storms. These are estimated using the normal ratio

Table 3.8 Rainfall duration, total rainfall, and antecedent moisture content corresponding to the selected storms

Storm No.	Rainfall duration	Total Rainfall (cm)	Antecedent Moisture Content (cm)
I	27th Jul to 3rd Aug, 1977	15.99	2.70
II	8th Sep to 14th Sep, 1977	9.31	1.92
III	21st Sep to 1st Oct, 1978	20.26	1.57
IV	2nd Sep to 10th Sep, 1980	15.24	3.64
V	27th Aug to 2nd Sep, 1983	3.98	5.27
VI	16th Sep to 23rd Sep, 1983	11.09	2.44
VII	19th Aug to 26th Aug, 1985	8.26	4.85

method. The daily rainfall data (after estimation of missing rainfall data) for all the raingauge stations corresponding to the rainfall duration are presented in Appendix I.

3.3.2.5 Calculation of total rainfall

The daily mean areal rainfall is calculated using the thiessen weights of each raingauge station. These daily mean areal rainfall values are then summed up for the rainfall duration to get the total rainfall (P) corresponding to each DRH (col. 3 of table 3.8).

3.3.2.6 Calculation of antecedent moisture content

The daily rainfall data of each raingauge station for the 5-day period preceeding each storm are selected and the missing rainfall values are calculated using the normal ratio method (Appendix II). Subsequently, the antecedent moisture condition corresponding to each storm are calculated using the thiessen polygon method (col. 4 of table 3.8).

4.0 RESULTS AND DISCUSSION

The present study aims to establish the SCS runoff curve number and determine the land use changes for Hamidnagar sub-basin of Punpun basin. For this purpose, the landuse map of Punpun basin (developed by Lohani et. al., 1995, using IRS 1A, LISS II, FCC prints for the year 1989) and its soil information were used to establish the runoff curve number for Hamidnagar sub-basin (direct method). These results have been validated using rainfall-runoff data for the year 1989. Further, rainfall-runoff data for seven selected storms during the period 1977-1985 have also been used to determine the SCS runoff curve number for Hamidnagar sub-basin (inverse method). The SCS runoff curve numbers obtained by direct method and inverse method are then compared to study the landuse changes.

4.1 Establishment of SCS runoff curve number by direct method

The landuse map of Hamidnagar sub-basin was delineated from the landuse map of Punpun basin (developed by Lohani et. al., 1995) and is shown in Fig. 4.1. Six major classes are found in Hamidnagar sub-basin, namely, agricultural land, forest land, water logged area, waste land, built up area and river and tributary. The landuse map of Hamidnagar sub-basin was superimposed on the soil map (Fig. 3.1) to determine the area of different landuse/ cover classes under different hydrological soil groups (Table 4.1). The runoff curve numbers for AMC II for the area under each landuse category falling under different hydrological soil group have been determined using table 3.4 and are shown in table 4.1. The corresponding runoff curve numbers for AMC I and AMC III have been determined using table 3.2 and

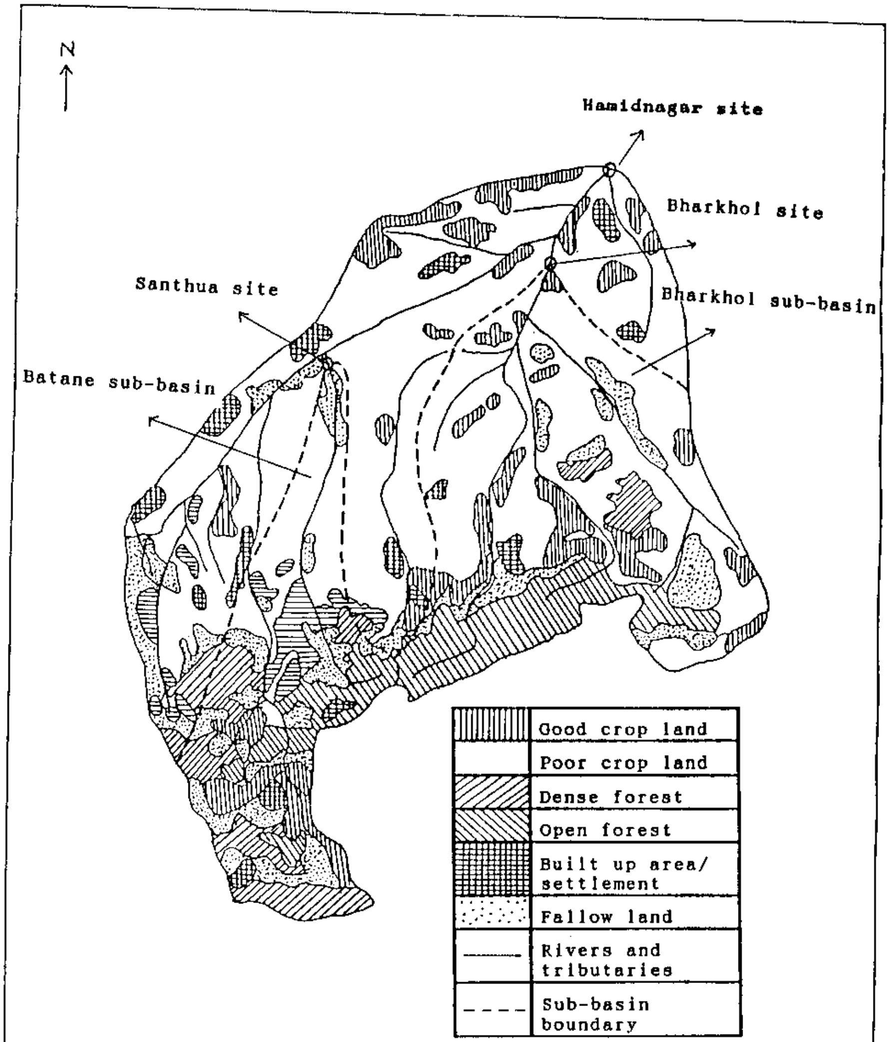

Fig. 4.1 Landuse map of Hamidnagar basin

Table 4.1 Weighted curve numbers for Hamidnagar sub basin obtained from IRS-1A data base

Sl. No.	Land use		Hydro logic soil group	Area (sq. km.)	Curve Numbers		
					AMC I	AMC II	AMC III
1.	Agricu-ltural Land	Good crop land	B	205.22	53	72	86
			C	203.16	61	78	90
		Poor crop land	B	369.37	58	76	89
			C	1625.02	66	82	93
2.	Forest	Dense	B	169.79	22	40	60
			C	38.55	38	58	76
		Open	B	233.64	26	44	64
			C	53.97	40	60	78
3.	Settlements		B	41.46	72	86	94
			C	51.67	80	91	96
4.	Fallow		B	210.88	62	79	91
			C	111.27	72	86	94
Total Area/Weighted Curve Number				3314	58	75	88

are shown in table 4.1. The weighted CN of Hamidnagar sub-basin was found by summing up the CN multiplied by the corresponding percentage of landuse. The weighted CN of Hamidnagar sub-basin for AMC I, AMC II and AMC III were found to be 58, 75 and 88 respectively.

4.1.1 Validation of established runoff curve number

The established runoff curve number has to be validated using rainfall and runoff data of Hamidnagar sub-basin for the year 1989. However, gauge and discharge data for Hamidnagar barrage site were not available for the year 1989. But, gauge and discharge data for two sites, namely, Bharkhol and Santhua (as shown in Fig. 4.1) which are within Hamidnagar sub-basin were available for the year 1989. The drainage area of Bharkhol site

(Bharkhol sub-basin) and Santhua site (Batane sub-basin) were delineated as shown in Fig. 4.1. The drainage area of Bharkhol sub-basin (1235.23 km^2) together with the drainage area of Batane sub-basin (624 km^2) cover around 60% of the total drainage area of Hamidnagar sub-basin. Therefore, in the present study the runoff curve numbers of Bharkhol sub-basin and Batane sub-basin were established and validated so as to obtain a reasonable estimate of the accuracy of the curve number developed for Hamidnagar basin.

The curve numbers for Bharkhol sub-basin and Batane sub-basin were determined in a similar manner as that for Hamidnagar basin and are presented in table 4.2. The weighted curve numbers for AMC II were found to be 75 and 63 for Bharkhol sub-basin and Batane sub-basin respectively. Hence, from table 3.2 the corresponding curve numbers for AMC I and AMC III were found to be 57 and 88; and 43 and 80 for Bharkhol sub-basin and Batane sub-basin respectively.

For calculation of runoff, rainfall data of two stations namely Aurangabad and Hariharganj, for the year 1989, were considered. Based on the rainfall data and estimated curve numbers, total annual runoff of the two sub-basins namely Batane and Bharkhol for the year 1989 were calculated using equations 3.5 and 3.8. The calculated runoff for Batane sub-basin and Bharkhol sub-basin were found to be 31.89 Mm^3 and 220.47 Mm^3 respectively whereas the observed runoff was 29.28 Mm^3 and 239.56 Mm^3 respectively. This shows that the calculated runoff is only about 9% more than the observed runoff for Batane sub-basin and only 8% less than the observed runoff for Bharkhol sub-basin.

Table 4.2 Weighted curve numbers for Batane sub-basin and Bharkhol sub-basin of Hamidnagar basin

Sl. No.	Land use		Hydro logic soil group	Bharkhol sub-basin		Batane sub-basin	
				Area (sq. km)	CN for AMC II	Area (sq. km)	CN for AMC II
1.	Agricu-ltural Land	Good crop land	B	31.69	72	106.56	72
			C	93.86	78	0	78
		Poor crop land	B	17.47	76	62.57	76
			C	739.52	82	59.74	82
2.	Forest	Dense	B	0	40	130.67	40
			C	38.60	58	0	58
		Open	B	147.50	44	123.18	44
			C	54.04	60	0	60
3.	Settlem-ents		B	0	86	28.34	86
			C	9.75	91	0	91
4.	Fallow		B	22.35	79	104.05	79
			C	80.45	86	8.89	86
Total Area/Weighted Curve Number				1235.23	75	624	63

This establishes the accuracy of curve numbers developed for Batane sub-basin and Bharkhol sub-basin and also gives a fair idea of the accuracy of curve number developed for Hamidnagar basin.

4.2 Establishment of SCS runoff curve number by inverse method

As stated earlier, estimations of runoff curve numbers from rainfall-runoff data complement and in certain cases even replace the information obtained from tables. The corresponding sets of rainfall-runoff data and also the antecedent rainfall for the selected storms (section 3.3) are shown in table 4.3. The corresponding curve numbers for each set of data were calculated

Table 4.3 Runoff curve numbers for the selected storms

Storm No.	TRH duration	Total runoff Q, (cm)	Total Rainfall P, (cm)	AMC (cm)	Runoff CN Eq. 3.18
I	24th Jul. to 5th Aug., 1977	2.283	15.99	2.70	51
II	8th Sep. to 20th Sep., 1977	2.371	9.31	1.92	71
III	22nd Sep. to 4th Oct., 1978	7.421	20.26	1.57	61
IV	2nd Sep. to 10th Sep., 1980	5.239	15.24	3.64	66
V	28th Aug. to 3rd Sep., 1983	1.217	3.98	5.27	85
VI	17th Sep. to 28th Sep., 1983	3.27	11.09	2.44	70
VII	19th Aug. to 27th Aug., 1985	3.415	8.26	4.85	81

by substituting the values of P and Q in Eq. 3.18 and are shown in table 4.3.

In order to ascertain a single runoff curve number for Hamidnagar sub-basin for AMC II and the corresponding curve numbers for AMC I and AMC III, the procedure developed by Ponce, 1989, is adopted. A brief description of this procedure is outlined here.

Corresponding sets of rainfall-runoff data for several storms and a wide range of AMC are to be collected. The values of runoff curve numbers for each set of rainfall-runoff data is to be determined using Eq. 3.18. The AMC II runoff curve number is that which separates the runoff curve number data into two parts (median value). The curve number with the lowest value corresponds to AMC I while the curve number with the highest value corresponds to AMC III.

As shown in table 4.3, the selected storms correspond to a wide range of AMC varying from 1.57 cm to 5.27 cm. From the curve numbers shown in table 4.3 it is observed that the median value is 70 while the least value is 51 and the maximum value is 85. Hence, the average curve number for AMC II of Hamidnagar sub-basin for the period from 1977 to 1985 is 70 while the corresponding curve numbers for AMC I and AMC III are 51 and 85 respectively. This procedure of determination of runoff curve numbers from rainfall-runoff data for various AMC conditions is also illustrated in Fig. 4.2.

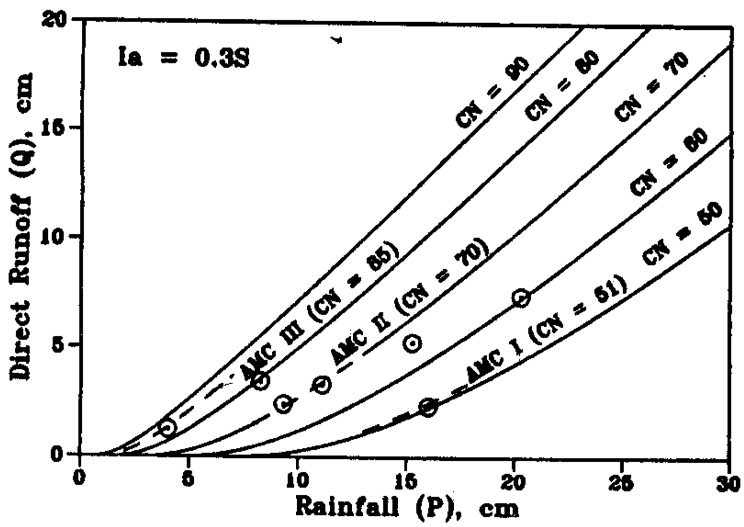

Fig. 4.2 Estimation of runoff curve numbers from measured data

4.3 Comparison of runoff curve numbers obtained by direct and inverse methods

The SCS runoff curve numbers for Hamidnagar sub-basin obtained by direct method for the year 1989 were found to be 58, 75 and 88 for AMC I, AMC II and AMC III respectively whereas the average curve numbers obtained by inverse method for the period 1977-1985 were found to be 51, 70 and 85 for AMC I, AMC II and AMC III respectively. This shows that there is an increase in the curve number value from the period 1977-85 to 1989. The curve number is a function of landuse, hydrologic soil group and AMC. The hydrologic soil groups of a basin does not change with time, hence a change of curve number for a particular AMC indicates a change in landuse of the basin. Therefore, in the present study, the increase in the curve number value of Hamidnagar sub-basin indicates that the basin has undergone landuse changes in such a way that areas with low curve numbers have been converted to areas with high curve numbers e.g. cutting of forests and their conversion into agricultural lands, fallow lands and settlements. Though the actual changes in each category of landuse could not be ascertained in the present study, a hypothetical example has been taken up to study the sensitivity of curve number to landuse changes.

Table 4.4 shows the hypothetical areas of different landuse/ cover classes for the period 1977-85 and the actual areas of different landuse/ cover classes for the year 1989 for Hamidnagar sub-basin. The hypothetical areas of different landuse/ cover classes for Hamidnagar sub-basin for the period 1977-1985 were chosen in such a manner that the weighted curve number was equal

Table 4.4 Hypothetical values (for the period 1977-1985) and actual values (for the year 1989) of area under different landuse category for Hamidnagar basin

Sl. No.	Land use		Hydro logic soil group	Area (sq. km.) Hypothetical (1977-85)	Area (sq. km.) Actual (1989)	Landuse change from 1977-85 to 1989*	CN for AMC II
1.	Agricultural Land	Good crop land	B	105.22	205.22	+100	72
			C	183.16	203.16	+20	78
		Poor crop land	B	269.37	369.37	+100	76
			C	1625.02	1625.02	0	82
2.	Forest	Dense	B	369.79	169.79	-200	40
			C	88.55	38.55	-50	58
		Open	B	433.64	233.64	-200	44
			C	103.97	53.97	-50	60
3.	Settlements		B	11.46	41.46	+30	86
			C	21.67	51.67	+30	91
4.	Fallow		B	40.88	210.88	+170	79
			C	61.27	111.27	+50	86
Total Area				3314	3314		

(1) Weighted curve number (hypothetical) for 1977-85 is 70.
(2) Weighted curve number (actual) for 1989 is 75.

* '+' sign indicates increase in area while '-' sign indicates decrease in area.

to that obtained by inverse method i.e. 70 for AMC II. From table 4.4 it is observed that cutting of 200 km^2 dense forest and 200 km^2 open forest in hydrological soil group B; and 50 km^2 dense forest and 50 km^2 open forest in hydrological soil group C and their conversion into different proportions of agricultural lands, fallow lands and settlements has resulted in the curvenumber changing from 70 to 75 for AMC II. In other words, cutting of a large forest area (500 km^2) and its conversion to other land uses has resulted in a small change in curve number value from 70 to 75. This shows the high sensitivity of land use changes to small changes of curve number.

However, a detailed study on landuse changes through remote sensing data over a sufficiently long period of time and rainfall-runoff data of various sub-basins of Hamidnagar basin is essential.

5.0 CONCLUSIONS

The following conclusions are drawn from the present study:

1. Satellite data can be effectively used for mapping land use and land cover. The use of remote sensing technique for determination of land uses not only saves time but is less expensive as compared to conventional methods like ground surveys. Further, the satellite based remote sensing has advantages like large area coverage, synoptic view and capability to provide information over all accessible and inaccessible regions. However, the success of remote sensing technique depends on the accurate interpretation of the false colour composites.

2. Rainfall-runoff data can also be effectively used for the determination of SCS runoff curve number. Since actual field data are involved, this method is more reliable for the determination of curve number for estimation of runoff. As is well known, the seasonal rainfall limits for the three levels of antecedent moisture condition depend on the geographic and climatic conditions of a region. But the method of runoff curve number determination using rainfall-runoff data does not require information on the seasonal rainfall limits for the three levels of antecedent moisture condition. Hence, this method is useful particularly for areas where the seasonal rainfall limits are not available or have not been developed. However, the selected sets of rainfall-runoff data should encompass a wide range of antecedent moisture conditions, from dry to wet, in order to have more reliable results.

3. The method of comparison of runoff curve numbers can only be used for the establishment of a general trend in the land use changes. However, for a detailed study on the land use changes, it is necessary to use satellite data at periodic intervals. The land use maps developed from these satellite data should either be verified with ground truth data or used to develop curve numbers and verify these curve numbers with the curve numbers obtained from rainfall-runoff data.

6.0 REFERENCES

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APPENDIX I

Rainfall data (mm) corresponding to storm No. I (Jul 27 - Aug 03, 1977)

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Jul 27	10.5	11	18.5	0	0	9.7	17	15.7	5
Jul 28	42	25	15	0	4	22.3	72	3.4	9
Jul 29	94	46	0	0	32.2	32.3	21	20.2	35
Jul 30	10.2	37	0	17	25	43.4	139	115	0
Jul 31	19.4	13	8	0	3.2	7.1	0	11	2
Aug 01	31.2	8	17	0	3	9.4	8.7	7.2	0
Aug 02	0	6	135	0	2.2	18.8	17.4	0	0
Aug 03	0	9.5	10	0	60	10.6	9.8	0	0

Rainfall data (mm) corresponding to storm No. II (Sep 08 - Sep 14, 1977)

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Sep 08	0	8	7	0	0	2.2	0	3.2	0
Sep 09	23.2	3	3	33.2	45.4	17.4	9	8.5	11
Sep 10	69.2	5.5	34	98.2	0	54.5	63	95.3	53
Sep 11	0	1	0	0	0	0.4	2	0	0
Sep 12	11	0	16.5	3.6	2	4.7	3	2.3	0
Sep 13	0	4	4	5.6	17.4	5.9	2	6.2	8
Sep 14	0	0	0	35.6	35	10.1	2	0	6

Rainfall data (mm) corresponding to Storm No. III (Sep 21 - Oct 01, 1978)

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Sep 21	0	2	0	0	0	0.5	0	2.2	0
Sep 22	24	0	0	52	14.6	14	2	15.4	0
Sep 23	8	4	0	5.8	2	5.4	3	13.2	6
Sep 24	30	7	6	57	40	22.2	14	0	16
Sep 25	20	15	18	35	60	66.8	180	115	72
Sep 26	19	18	190	26	68.4	89.3	76	95.2	201
Sep 27	5.5	55	14	0	2	14.4	25	9.2	3
Sep 28	0	5	0	0	2	1.1	0	2.4	0
Sep 29	0	0	0	0	0	0.4	0	3.2	0
Sep 30	0	0	0	2.4	0	0.3	0	0	0
Oct 01	0	5	26	0	0	4	2	0	1

Rainfall data (mm) corresponding to Storm No. IV (Sep 02 - Sep 10, 1978)

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Sep 02	27	0	19.8	10	0	12	12	25	2
Sep 03	30	5	0	17	46	19.9	47	1	8
Sep 04	78	6	39.5	5	9.3	21.3	19.2	8.2	3
Sep 05	9.2	30	29.7	24	35	20.2	11.2	10	12
Sep 06	9	36	13	35.5	37.6	22.1	16	10	16
Sep 07	0	0	0	0	28.3	6.8	17	8	2
Sep 08	10	0	11.3	42.5	28.3	14	12.2	1	4
Sep 09	0	0	0	4	0	3.7	8	13	4
Sep 10	4.5	0	21.6	19	74	17.7	15.2	12	0

Rainfall data (mm) corresponding to Storm No. V (Aug 27 - Sep 02, 1983)

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Aug 27	10	0	2.4	3.5	1.7	5.5	24.3	0	0
Aug 28	0	0	0	1	9.3	13.1	2.3	43	44
Aug 29	0	0	11.8	0	0	2.3	0	8	0
Aug 30	0	0	10	0	0	1.1	0	0	0
Aug 31	0	0	5	0	4.2	8.7	39.3	20	0
Sep 01	0	0	0	10	4.6	8.7	7.2	50	0
Sep 02	0	18	0	0	0	3	5.5	0	0

Rainfall data (mm) corresponding to Storm No. VI (Sep 16 - Sep 23, 1983)

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Sep 16	0	0	0	0	0	12.9	0	75	27.6
Sep 17	7	3.5	0	0	13	29.8	65.4	50	82
Sep 18	15.2	6	4	20	51	24.8	34.6	0	55.4
Sep 19	12	9	0	57	28	18.3	2	7	23.3
Sep 20	14	0	0	34.5	1.4	13.2	27	25	0
Sep 21	5	12	0	5	0.6	6	3.3	0	18
Sep 22	0	6	15	3	15	4.6	0	0	0
Sep 23	2	0	3	0	14.3	2.5	2	0	0

Rainfall data (mm) corresponding to Storm No. VII (Aug 19 - Aug 26, 1983)

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Aug 19	6	10.5	18	3	0	50.4	0	6	2
Aug 20	6.8	19.5	35	37	26	13.2	0	11	25
Aug 21	0	7.9	3	0	40	5.4	14	0	2.5
Aug 22	18	25	0	14	3	94.5	14.4	58	0
Aug 23	0	1.1	0	0	0	2.4	3.2	0	2.5
Aug 24	0	17.6	0	18	0	0	86.6	11	15
Aug 25	4	4.1	0	0	8	0	0	0	18
Aug 26	0	0.6	0	0	5	0	0	0	0

APPENDIX II

Table IIa 5-day Antecedent Rainfall in mm (Jul 22 - Jul 26, 1977) corresponding to Storm No. I

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Jul 22	0	0	0	0	2	0.2	0	0	0
Jul 23	0	0	0	0	0	0.1	0	1.2	0
Jul 24	18	0	38	0	0	8.9	0	6.4	10
Jul 25	20.2	8	8	0	30	13.1	12	15.6	11
Jul 26	19.4	6	4	0	1	5.9	4	3.4	7

Table IIb 5-day Antecedent Rainfall in mm (Sep 03 - Sep 07, 1977) corresponding to Storm No. II

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Sep 03	6.5	0	6	2	2	3.5	6	5.3	0
Sep 04	0	0	11	3	3	3	5	2.4	0
Sep 05	0	0	0	0	0	4.9	0.5	0	32
Sep 06	18.2	39	15	1.2	0	10.4	0	0	8
Sep 07	0	0	6	0	0	1.9	0	0	8

Table IIc 5-day Antecedent Rainfall(mm) (Sep 16 - Sep 20, 1977) corresponding to Storm No. III

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Sep 16	0	4	0	0	0	0.5	0	0	0
Sep 17	0	0	0	21.8	13	4.7	0	2.4	0
Sep 18	5	12	15	6	0	5.6	4	3.2	0
Sep 19	0	0	0	0	0	3.9	0	0	26
Sep 20	3.5	0	0	22.6	0	3.5	0	0	0

Table IId 5-day Antecedent Rainfall in mm (Aug 28 - Sep 01, 1980) corresponding to Storm No. IV

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Aug 28	17	0	0	29	46	15.3	0	6.6	20
Aug 29	3	0	0	0	3.2	1.9	8.5	0	0
Aug 30	0	0	0	0	60	7	0	0	0
Aug 31	0	0	0	0	0	0	0	0	0
Sep 01	0	12	0	11	2.3	3.3	0	0	0

Table IIe 5-day Antecedent Rainfall in mm (Aug 22 - Aug 26, 1983) corresponding to Storm No. V

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Aug 22	0	0	3.7	0	1.2	0.6	0	0	0
Aug 23	0	40	0	0	0	5	0	0	0
Aug 24	41	35	40	6.5	7.2	17.2	2.3	7.2	0
Aug 25	8	5	18	3	3.8	6.7	0	0	14
Aug 26	15	0	19	32.5	50.8	26.1	18	37	33

Table IIf 5-day Antecedent Rainfall in mm (Sep 11 - Sep 15, 1983) corresponding to Storm No. VI

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Sep 11	0	15.5	3	0	0.1	2.3	0	0	0
Sep 12	5	2.5	0	8	19.4	22.1	40	50	44
Sep 13	0	0	8	0	0	0.9	0	0	0
Sep 14	0	0	0	0	0	0	0	0	0
Sep 15	0	0	0	0	0	0	0	0	0

Table IIg 5-day Antecedent Rainfall in mm (Aug 14 - Aug 18, 1985) corresponding to Storm No. VII

Stn/ Date	Goh	Gurua	Sher-ghati	Obra	Auranga-bad	Palmer-ganj	Hariha-rganj	Chatta-rpur	Nabi-nagar
Aug 14	25	22	40	15	0	88.4	6.1	3	0
Aug 15	25	16.8	2	40	0	1	54.3	0	3.5
Aug 16	6	3	0	0	0	0	0	0	15
Aug 17	4.5	3.5	0	15	8	0	0	0	0
Aug 18	25	7.5	7	3	3	0	0	0	18

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