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RAINFALL- RUNOFF MODELLING FOR WATER AVAILABILITY STUDY IN KEN RIVER BASIN USING SCS-CN MODEL AND REMOTE SENSING APPROACH

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ABSTRACT

Estimation of runoff from a natural catchment is essentially required for the planning, management and evaluation of the available water resources. Much hydrologic research has been directed at understanding the hydrologic processes involved with the gauged watershed and applying this knowledge to predict the runoff values needed for the efficient water resources development and management.

Simulation of rainfall-runoff process for ungauged catchments is one of the important areas of modern research. All well established techniques like unit hydrograph technique, conceptual models and physically based modeling requires a certain amount of historical data for establishing various parameters. However, due to sparse gauging network available in most of the Indian catchments, particularly for small catchments, it becomes very difficult for such techniques to be directly applicable.

The water availability study for the Ken river system is proposed to be carried out in two parts. In this report an attempt has been made to evaluate the direct surface runoff in the smaller basins, where gauging sites are not available. In continuation of this work, the base flow components will be worked out using suitable models and flow duration curve techniques will be employed for assessing the dependable flows in these ungauged sub-basins.

In the present study as Part - I of the water availability study in Ken river basin, Rainfall - Runoff Modelling in the Sonar, Bearma and Bebas river basins which are the sub-basins of the Ken River system have been carried out using the SCS Curve Number model. This is a widely used hydrological model for calculating direct runoff from ungauged catchments, has been applied for calculating the runoff using rainfall and curve number (CN). The SCS curve number is a quantitative descriptor of the land use / land cover / soil complex characteristics of a watershed. The CN is an index that represents the watershed runoff potential.

The latest technique of satellite remote sensing provides a real time and a reasonably accurate information of the prevailing land use patterns at a faster rate and less tedious way as compared to the conventional methods. In this study various land use classes have been interpreted using the IRS 1A, LISS-II satellite imageries. The large sub-basins of river Ken namely, Sonar and Bearma, has been further sub-divided into smaller basins and the runoff for each of these sub-basins have been computed, after establishing their respective SCS curve numbers. The runoff from these smaller sub-basins were summed up, taking the effect of the time lag , if any, and the discharges were predicted at the Garhakota G/D site on R. Sonar at the Gaisabad G/D site on river Bearma. These predicted runoff values at these gauging stations are quite in agreement with the available observed surface runoff, which implies that the sub-basin wise runoff estimation is satisfactory.

1.0 INTRODUCTION

The scarcity of available land and water resources which is an outcome of the growing population has necessitated its proper planning and management. The planning and management of water resources is also imperative due to the regional imbalances in the available water. To overcome the problem created by temporal and spatial variations in water availability, hydrologists attempt to make predictions of water availability. Detailed analysis of surface water flow rate is highly important to such fields as municipal and industrial water supply, flood control, stream flow forecasting, reservoir design, irrigation, water quality management schemes, and design of many other engineering works.

The relation between the precipitation and runoff is very complex and is influenced by various storm and basin characteristics. The derivation of these relationships between the rainfall over a catchment area and the resulting stream flow in a river is a fundamental problem of interest for the hydrologist. In most of the developing countries, plenty of rainfall records are usually available but the stream flows which is essentially required for the assessment of water resources, is rarely available.

Runoff processes operating at any particular location varies from time to time. Large variations in hydrologic characteristics occur over small, apparently homogeneous areas to such an extent that all the runoff processes , namely, overland flow, saturated overland flow and thorough flow may occur during a single storm event. Associated with the recognition of several processes producing storm runoff, has been the concept that storm runoff may be generated from only a small part of the drainage basin. In addition to this, the *'contributing areas'* in the basin may vary in extent in different seasons and during the progress of a storm.

The type of runoff process and the location of the *'source areas'*, whether close to the outlet and adjacent to the stream channels or on ridges remote from the stream channels, has a considerable influence on the resulting hydrograph. However, practical methods for estimating runoff have seldom been developed to explicitly account for these differences. Uniform or average conditions, at least over sub-areas are generally assumed.

Estimating runoff or discharge from rainfall measurements involves many complexities and is very much dependent on the time-scale being considered. For short durations (hours), the complex inter-relationships between rainfall and runoff is not easily defined. But as the time period lengthens, the relation becomes simpler until, on an annual basis, a straight line correlation may be obtained. The time interval used in the measurement of the two variables effects the derivation of any relationship, although with continuously recorded rainfall and stream discharge, this constraint is removed and only the purpose of the study influences the choice of the time interval. Hence, relating a flood peak to a heavy storm requires continuos records, but determining water yield from a catchment can be accomplished satisfactorily using relationships between the totals of monthly or annual rainfall and runoff.

Before planing of any project, the first and foremost task is to assess its available water at different times of the year. Water availability is the lifeline of any irrigation or multi-purpose scheme. The success of the scheme depends on how accurate have been the estimation of total quantity of water available and its variability. Proper estimation of water availability is therefore essential.

In this report, the discharges at the outlets of various sub-basins were estimated by applying the SCS Curve Number model. The IRS 1A, LISS-II satellite imageries were analyzed for arriving at the land use classifications prevailing in these sub-basins. The estimated discharges at the outlets of these sub-basins has been summed up, considering the effect of the time-lag, if any, and the discharges were predicted at the outlet of the basin, where a G/D site and the stream flow data is already available. As there is not much variation between the calculated and observed surface runoff at these G/D sites, it implies that the estimated discharges at the outlet of these sub-basins are proper and can be employed for further water resources planning and management. This report will enable in assessing the water potential for each of the sub-basins of the major basins considered in the study, which may also be helpful for designing various water resources projects in future.

2.0 REVIEW OF LITERATURE

In hydrologic analysis, it is often useful to develop relationships between rainfall and runoff, for water availability studies. Such relationships are useful for generation of runoff from longer period of rainfall which are generally applied. The estimation of water availabilty is necessary in water resources development not only for economic appraisal of the project but also for checking the reliability and general pattern of availability of water from year to year.

So when rainfall data is available for longer periods and runoff data is available for shorter period, it is necessary to develop rainfall-runoff relation to compute rainfall series. The relationships between rainfall and runoff is usually complex. These relationships are influenced by various factors such as storm pattern , antecedent conditions and basin characteristics etc. Due to the complexities and the frequent paucity of adequate data, many formula which have been developed are only approximate. The following rainfall runoff relations are generally developed for computing runoff series depending upon particular requirement and data.

(I) Annual and seasonal rainfall - runoff relation.
(II) Monthly rainfall - runoff relation.
(III) Storm rainfall - runoff relation.

These relations are attempted through linear and non-linear regression models or through conceptual models.

2.1 REGRESSION MODELS

In humid climate, annual yield of small watersheds may be much smaller than those of rivers because the later contain high base flow. In arid and semi-arid climate annual yield of smaller watershed may be greater than those of larger streams and rivers that have channel transmission losses and no base flow.

2.1.1 Annual and Seasonal Rainfall Runoff Relationships

Various research have been done to formulate rainfall - runoff relationship in various parts of India and abroad. These relationships are mainly area specific and presented in tabular form.

TABLE 1-A: ANNUAL RAINFALL - RUNOFF RELATIONSHIPS.

S.N	NAME OF SCIENTIST	AREA	RELATIONSHIP	CONSTANTS
1.	Binnies Percentages	Nagpur	R=K*P	K= to 0.40 for P= 50.80 to 111.76 cms.
2.	Barlow's Tables	U.P.	R= Percentage of P	10 % to 50 % ; 5 types of catchment depending upon topography and soil.
3.	Khosla Formula	Maharastra & Karnataka	R = P - L and L = X*T	X= 0.43 to 0.57 Generally 0.50
4.	Inglis Formula		Plains; R =0.85*P -12 inches Ghats: R= {(P-7)/100}*P	-
5.	Justin's Formula	-	R = K*(P)**n in inches (Logarithmic curve)	n = 2
6.	Parker's Study	Germany, U.S.	R =P - L L = a + b*P or $L = a + b_s{*}P_s + b_w{*}P_w$	b = 0.16
7.	Schreiber's Formula	-	R = P - E $E = [P*\{1 - e **(E_p / P)\}]$	-
8.	Panchang's Formula	Betwa in M.	R = P*C**(T - 32)	C = 0.973 to 0.984
9.	U.P. I. R.I.	Roorkee	R = K* P**a	a = 0.60 to 1.10 K = 0.364 to 5.45
10.	Raghunath, Das & Thomas	Nilgiries	$R = \{P_m^{1.44}.A^{0.63}.R_f^{0.66}\} / \{15.19F_f^{1.33}.L_s^{2.05}.T_m^{2..34}\}$ cms.	Catchment Area: 7.54 to 334.6 sq. Km Mean elevation: 900 m to 2200 m. Ave. Annual Precipitation 75.9 to 172.0 cms. Mean Annual Temp.: 14.77 to 21.22 ^{0}C

TABLE 1-B : MONTHLY RAINFALL - RUNOFF RELATIONSHIPS.

S.N	SEASON	TYPE OF CATCHMENT	RELATIONSHIP
1.	Monsoon Months	Small Catchment Large catchment	$RO_m = a(P_m - I_m)$ $RO_m = b_1(P_m - I_m) + b_2(P_m - I_m)$
2.	Non-Monsoon months		$RO_m = a + b(RO_{m-1})$ $RO_m = a(RO_{m-1})^b$

2.1.2 Storm Rainfall-Runoff relations

The rainfall runoff relation correlates storm rainfall, antecedent basin conditions, storm duration and the resulting runoff. As in any statistical correlation the basic data being used to develop rainfall relation must be as consistent and reliable as possible. Only the storm rainfall which produced the runoff should be included, and the small showers which occurred after the hydrograph had started to recede should not be included if they have little effect on the amount of runoff. Similarly showers occurring sometime before the storm should be excluded from the storm rainfall and included in antecedent precipitation if such an index is utilized.

The basic technique used by the U.S. Weather Bureau is the co-axial graphical method.

2.2 CONCEPTUAL MODELS

In recent years a number of mathematically sophisticated methods of hydrologic analysis have been developed. All these methods and those proposed in the earlier years for hydrologic design are essentially techniques of hydrologic modeling. The complicated hydrologic phenomena can be better approximated by modeling only. A brief description of the modeling approaches of the rainfall runoff process used in hydrologic models are being discussed below.

2.2.1 Principle of Conceptual Models

The process of modeling a physical system can be divided into three phases -

1. Model formulation
2. Model Calibration
3. Model verification

From all the above discussion it is clear that as we consider bigger catchment, the process is effected more by channel characteristics. It is possible to develop suitable and simple rainfall runoff relationships for any time interval i.e.on daily, monthly seasonal ar annual basis.

3.0 SCS CURVE NUMBER MODEL

The hydrologic model developed by USDA Soil Conservation Service is used in the study for estimating the runoff values. SCS model is a widely and commonly used model internationally for water resources management and planning . It is quite simple and can be applied to urban and sub-urban areas as well as on agricultural watersheds.

In this method the runoff depth (i.e., effective rainfall) is a function of total rainfall depth and curve number, usually represented by CN, which is an index that represent watershed runoff potential for a given Antecedent Moisture Condition (A.M.C.). The SCS runoff curve number is a quantitative descriptor of the land use/ land-cover / soil characteristics of the watershed. For the establishment of curve number of a basin the information on hydrologic soil group, hydrologic condition, treatment or practices and land use / land-cover are utilised. The curve number varies in the range of 1 to 100, being a function of antecedent moisture condition and the following catchment properties producing runoff namely, (i) hydrologic soil type, (ii) land use and treatment practices and (iii) ground surface condition.

In the SCS curve number model, if actual runoff is referred as Q and potential runoff (i.e., total rainfall) as P, with P >= Q, then the actual retention is P-Q; and potential retention (or potential maximum retention) S, will always follow the relation, S>= P-Q.

The model is based on the assumption of proportionality between retention and runoff in the following form.

$$(P-Q)/S = Q/P \qquad \text{----------} \quad (3.1)$$

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 SCS curve number model. P, Q and S are expressed in the same units.

For practical applications, equation 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 the runoff begins.

The modified equation can be expressed in the following form.

$$(P-Ia-Q)/S = Q/(P-Ia) \qquad \text{-----------} \quad (3.2)$$

where Ia = initial abstraction.
Solving for Q from equation 3.2, we have

$$Q = (P-Ia)**2/ (P-Ia+S) \qquad \text{-----------} \quad (3.3)$$

which is subject to the limitation that P>=Ia

To simplify the equation 3.3, the initial abstraction is related to potential retention. Some researchers have developed the following relationship between initial abstraction and potential maximum retention for Indian conditions.

(a) For black cotton soil regions (Antecedent Moisture Condition - I) and for all other regions

$$Ia = 0.30*S \qquad \text{------------} \quad (3.4)$$

Therefore equation (3.4) reduces to

$$Q = (P-0.30*S)**2 / (P+0.70*S) \qquad \text{------------} \quad (3.5)$$

(b) For black cotton soil regions (Antecedent Moisture Condition - II and - III) :

$$Ia = 0.10*S \qquad \text{------------} \quad (3.6)$$

Therefore equation (3.6) reduces to

$$Q = (P-0.10*S)**2 / (P+0.90*S) \qquad \text{------------ (3.7)}$$

Since potential maximum retention varies widely, it is expressed in terms of curve number in the following form :

$$S = (25400/CN)-254 \qquad \text{------------ (3.8)}$$

where,

CN = runoff curve number (dimensionless) and

S = surface retention in mm

The runoff curve numbers vary with the specific combination of hydrologic soil cover complexes , hydrologic soil group, land use and treatment practices, hydrologic surface condition and antecedent moisture condition. All these have direct bearing on the amount of runoff produced by a watershed.

3.1 Hydrologic Soil Group

The hydrologic soil group describes the type of soil. The soils are classified into four hydrologic soil groups as defined by U.S. Soil Conservation Services (1964) as A, B, C and D according to their infiltration rates; which is obtained for a bare soil after prolonged wetting.

3.2 Antecedent Soil Moisture Condition

The Antecedent Moisture Condition (AMC) is an index of runoff potential for a storm event. The AMC accounts for the recent history of rainfall; and consequently it is a measure of the amount of the moisture stored by the catchment. The AMC is an attempt to account for the variation in curve number at a site from storm to storm.

3.3 Hydrologic Condition

The hydrologic condition indicates the effect of cover type and treatment on the infiltration and runoff and is generally estimated from density of plant and residue cover on sample areas. A good hydrologic condition indicates that the soil usually has a low runoff potential for the given hydrologic soil group, cover type and treatment.

Some factors to consider in estimating the effect of cover on infiltration are (i) canopy or density of lawns, crops or other vegetative areas; (2) amount of year round cover; (3) amount of grass or close seeded legumes in rotations; (4) percentage of residue cover; and (5) degree of surface roughness.

The three levels of antecedent moisture condition, i.e., AMC - I, II and III, depend on the total rainfall in the 5-day period preceding a storm. AMC-I has the lowest runoff potential with the soil 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 rainfall. However the rainfall amounts corresponding to different antecedent moisture conditions depend on the geographic or climatic conditions of the region.

4.0 PROBLEM DEFINITION

The river Ken is an inter-state river and the lifeline for many of the districts in Madhya Pradesh and Uttar Pradesh. Most of the districts lying in the catchment area of this river face acute water shortages year after year during the peak summer season. The flows in most of the tributaries are very meager and depends entirely on the south-west monsoon which occurs from mid-June to the end of September. As such most of the tributaries have very low flows as they are rainfed and run only during the monsoon period. The prevailing land use pattern in the study area clearly indicates that the major portions are either cultivated land or forests. Presently, the cultivation of crops mainly depend on the monsoon rainfall. The average annual rainfall in the basin is fairly good and ranges between 1200 - 1250 mm. But owing to the poor water management practices being followed here, the percentage of irrigated area in the study area is very less, i.e., in the range of 2-3 % of the total geographical area. In this report water availability studies have been carried out for arriving at the dependable flows in each of the ungauged sub-basins of the rivers, Sonar, Bearma and Bebas, which will be helpful in the possible exploitation of the existing water resources.

5.0 DESCRIPTON OF THE STUDY AREA

5.1 Ken River Basin

5.1.1 Location, catchment area and tributaries

The river Ken is an inter-state river system flowing between the states of Madhya Pradesh and Uttar Pradesh. The basin lies between north latitudes 23° 20' and 25° 20' and east longitudes of 78° 30' and 80° 32'. The river Ken originates near the village Ahirgawan in Jabalpur district of M.P. at an altitude of 550.0 m above mean sea level and joins the river Yamuna, which is a major tributary of river Ganga, near Chilla village in U.P., at an elevation of about 95.0 m above m.s.l. It forms the common boundary between Panna and Chattarpur districts in M.P. and state boundary between Chattarpur district of M.P. and Banda district of U.P. After forming the boundary between Chattarpur and Banda districts, it enters U.P. at the village Ganchhar in Banda district. The river has a total length of 427 kms., out of which 292 kms. lies in M.P. and 84 kms lies in U.P. and 51 kms. forms the common boundary between M.P. and U.P. The basin lies between north latitudes 23° 20' and 25° 20' and east longitudes of 78° 30' and 80° 32'.

The total catchment area of the Ken river basin is 28058 sq. kms., out of which 24,472 sq.km lies in Madhya Pradesh and the balance 3586 sq.km lies in Uttar Pradesh. The index map of Ken basin is presented as Fig. 1. The important tributaries of river Ken are Sonar, Bearma, Kopra, Bewas, Urmil, Mirhasan, Kutni, Kail, Gurne, Patan, Siameri, Chandrawal, Banne, etc.. among others. The longest tributary Sonar is 227 km in length and lies wholly in M.P. In terms of catchment area also, the largest tributary is Sonar with a catchment area of 12620 sq.kms. The map showing the Ken river and its tributaries is presented as Fig. 2.

5.1.2 Topography and geology

In the physiographic division, the Ken basin lies partly in Vindhyan scrap land and mainly in Bundelkhand uplands. The average elevation of the plains is about 328 m. above m.s.l. In the upper reaches of the basin, there are thick forests whereas the

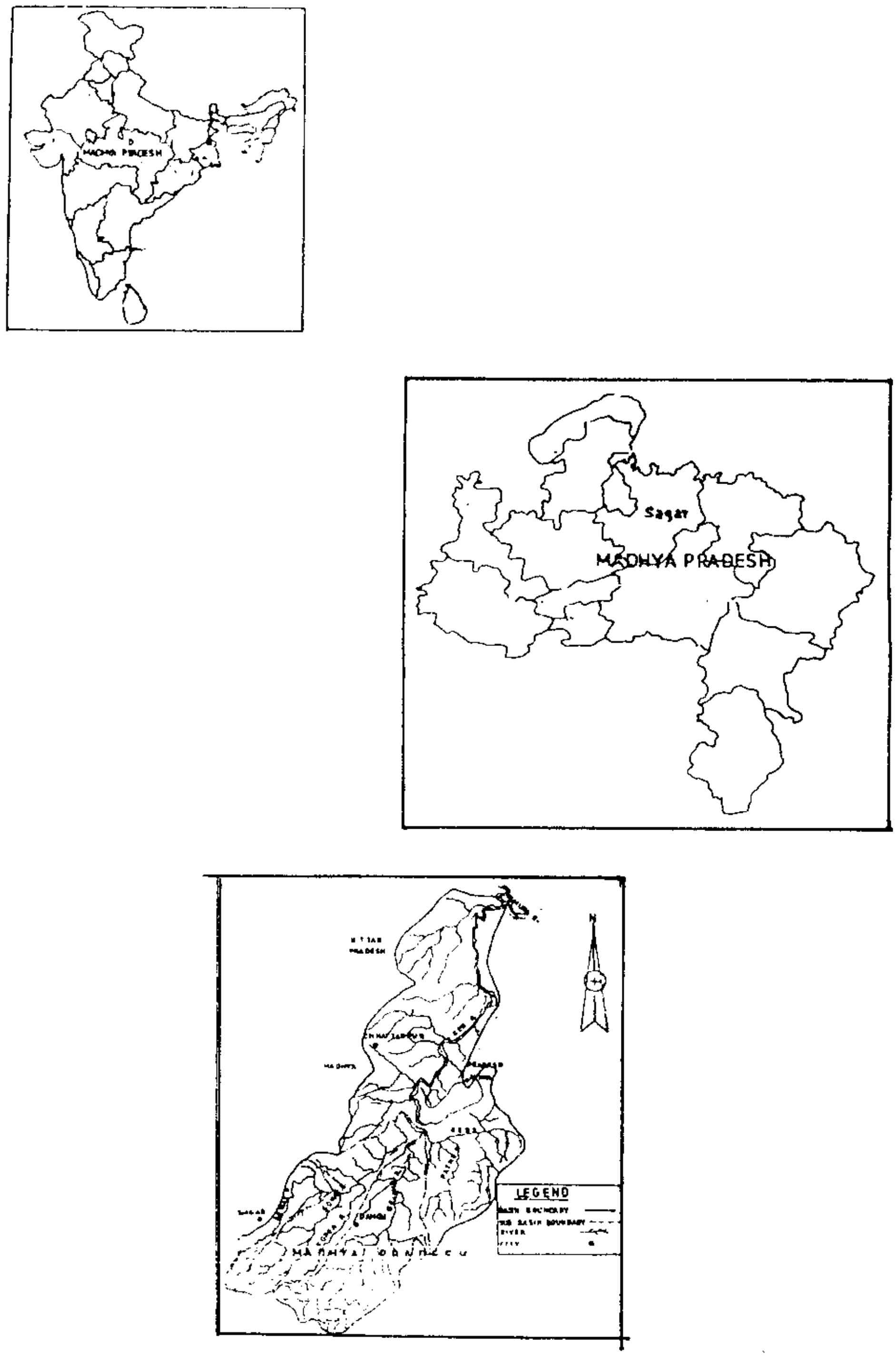


FIG. 1 :- INDEX MAP OF THE KEN RIVER BASIN.

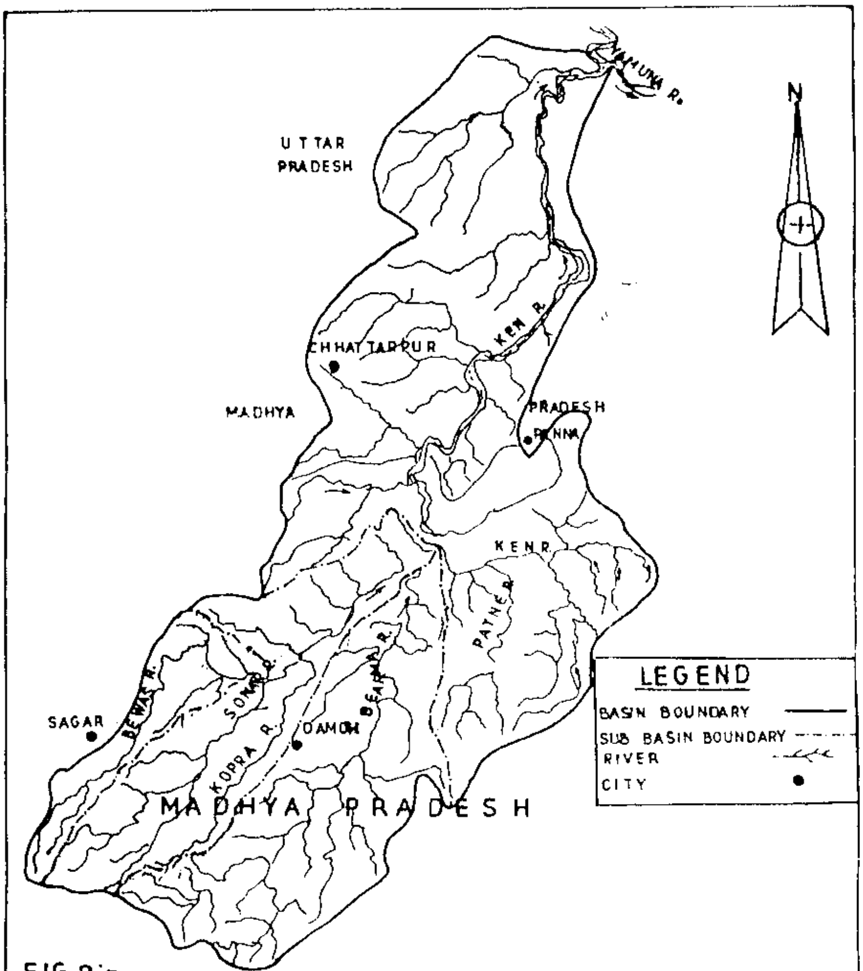


FIG.2:-
MAP SHOWING THE KEN RIVER AND ITS TRIBUTARIES.

middle and lower reaches are culturable areas. The soil varies from mixed red and black soils to medium black soils. In some northern most part of the basin sandy soils are also available.

The major part of the basin lies in districts of Sagar, Damoh and Chattarpur. The oldest rock formation is represented by Bundelkhand granites of Archians, which are exposed in the northern part of the basin. These rocks are overlain by siliceous, limestone and white quartzites of Bijawar group. The Bijawar group is overlain by Semri, Kaimur and Bhander stages of Vindhyan super group. Smaller patches of Deccan traps are also seen. In the lower reaches of the basin mostly three-fourth part is occupied by Archean granite rocks. Extensive areas of the granite terrain is covered with alluvium, especially in the northern and western parts of the basin.

5.1.3 Rainfall pattern

The rainfall pattern within the basin indicates a decreasing trend while proceeding from south to north. The average annual rainfall varies from 1250 mm near its origin to 800 mm near its junction with Yamuna river. The average annual rainfall of the basin is about 1150 mm. The basin is fed by south-west monsoon which starts from middle of June and lasts till the end of September. About 90 % of the rainfall occurs during the month of June to September.

5.2 Sonar Sub-Basin Upto Garhakota

5.2.1 Location, catchment area and tributaries

The river Sonar is an important tributary of River Ken. The Sonar sub-basin is located between north latitudes of 23° 20' and 23° 50' and east longitudes of 78° 30' and 79° 15'. It is a leaf shaped elongated catchment, with an average width of about 40 km.

The Sonar basin is bounded by Bearma basin (a sub-basin of river Ken) on the east side and by Dhasan basin (a sub-basin of R.Betwa) on the west side and the Vindhyan ranges on the south and lies fully in Madhya Pradesh. Sagar and Damoh are the major districts falling in this sub-basin and parts of Panna, Chattarpur and Raisen districts also fall in the basin. The total catchment area of the Sonar basin is 6550 sq. kms. The major tributaries of Sonar are Bewas, Dehar, Kaith and Baink on the left bank and Kopra and Bearma on the right bank. The map showing the location of Sonar river system upto Garhakota is presented as Fig. 3.

5.2.2 Topography and geology

The stratiography of the local formation encountered in the basin consists of deccan traps, lameta beds vindhyan systems and alluvial soil. The rocks of Vindhyan system consists of sandstone and shales with limestone and are found in large parts of the basin. Few outcrops of basalt are also found in the form of silts in the Vindhyan sandstones. Black cotton soils are mostly found in the entire basin.

5.2.3 Hydrometeorology

The sub-basin lies in the medium rainfall zone. More than 90% of the annual rainfall occurs during June to October due to the south-west monsoon. The average rainfall for Sagar district is 1245 mm. and that of Damoh district is 1225 mm. The climatic conditions in the sub-basin varies from semi-arid to dry with a hot summer from March to May, monsoon season from June to October and winter from November to February. There are 12 raingauge stations located in and around Sonar basin out of which only three raingauge stations namely, Sagar, Rehli and Deori influence the catchment of Sonar upto Garhakota G/D site.

5.2.4 Land use

The total geographical area of the Sonar sub-basin is 6550 sq. kms. which comprises of about 33% forests, 42% net sown area and remaining area under permanent pastures, miscellaneous crops, culturable waste and fallow land. The catchment area of Sonar upto Garhakota is 1384.41 sq. km. and comprises of about 21% forests, 70 % agricultural land remaining are scrub and barren land. The major crops grown in the sub-basin are wheat, paddy, maize, sunflower among other crops like jowar, groundnut and soyabean. Presently, only about 2% of the total geographical area of the total basin is irrigated out of which 44% is through surface water and the remaining 56% by groundwater irrigation.

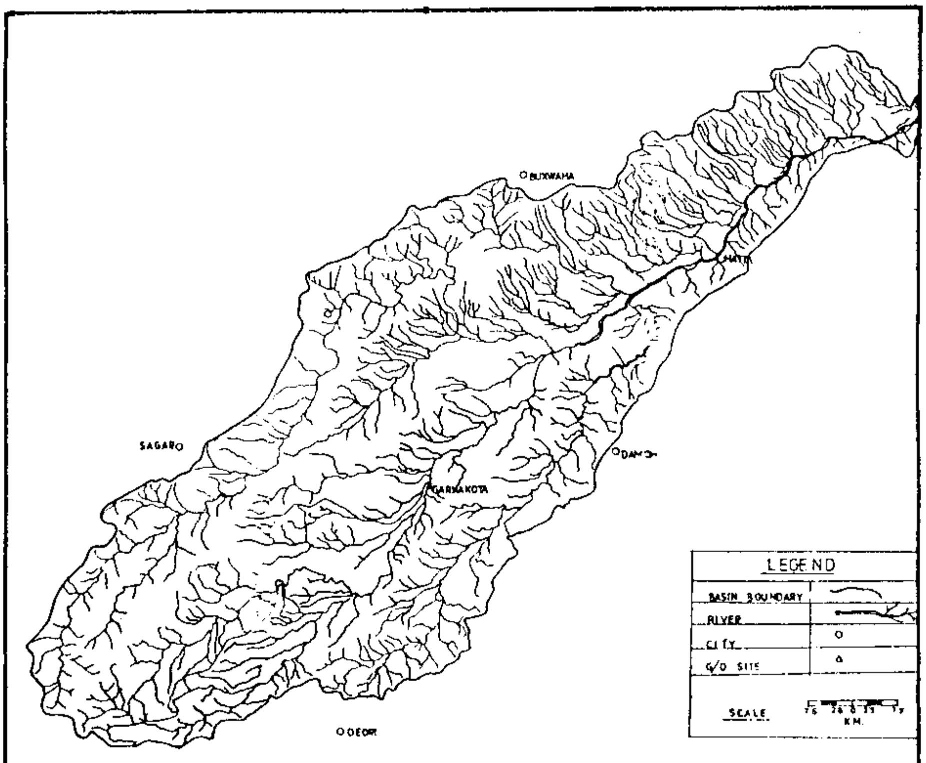


FIG. - 3.
MAP SHOWING THE SONAR RIVER SYSTEM AND GARHAKOTA G/D. SITE

5.2.5 Raingauge and discharge measurement sites

In the Sonar sub-basin, a gauge-discharge site is located at Garhakota, which is being monitored by Central Water Commission. The catchment area of the Sonar basin upto Garhakota is 1384.41 sq. kms. which is (21 %) of the total area of Sonar basin. There are 3 raingauge stations which influence the catchment of the Sonar sub-basin upto Garhakota, namely, Sagar, Rehli and Deori. The daily rainfall data for these stations for the period from 1992 to 1995 were used in the analysis, for which the concurrent discharge data were also available.

5.3 Bearma Sub-basin Upto Gaisabad

5.3.1 Location, catchment area and tributaries

The river Bearma is also an important tributary of river Ken. This sub-basin is located between north latitudes of 23^0 07' and 24^0 18' and east longitudes of 78^0 54' and 80^0 00'. The Bearma sub-basin is bounded by Sonar basin on the west, the Ken sub-basin on the east and by the Vindhyan ranges on the south and lies completely in Madhya Pradesh. Parts of Narsinghpur, Jabalpur, Sagar, Damoh and Panna districts are drained by river Bearma. Some of the important tributaries are Lamti, Sun, Bamner, Guraiya, Godhar and Mala. The total catchment area of the basin is 5890 sq.km. It is a leaf shaped elongated basin. A G/D site is located at Gaisabad on river Bearma. The catchment area of Bearma upto Gaisabad is about 5709 sq.km. The map showing the Bearma river system upto Gaisabad is presented as Fig. 4.

5.3.2 Topography and geology

The lower reaches of the sub-basin lie in a very undulating plateau, with steeply sloping hills at few places. As per the reports of the National Bureau of Soil Survey and Land use Planning, about 40 % of the area is comprised of undulating plateau. The geological formation of the region consists of vindhyan system, lameta beds, deccan traps and alluvial soils.

5.3.3 Hydrometeorology

The sub-basin lies in the medium rainfall zone and more than 90 % of the annual rainfall occurs during the months of June to October by the south-west

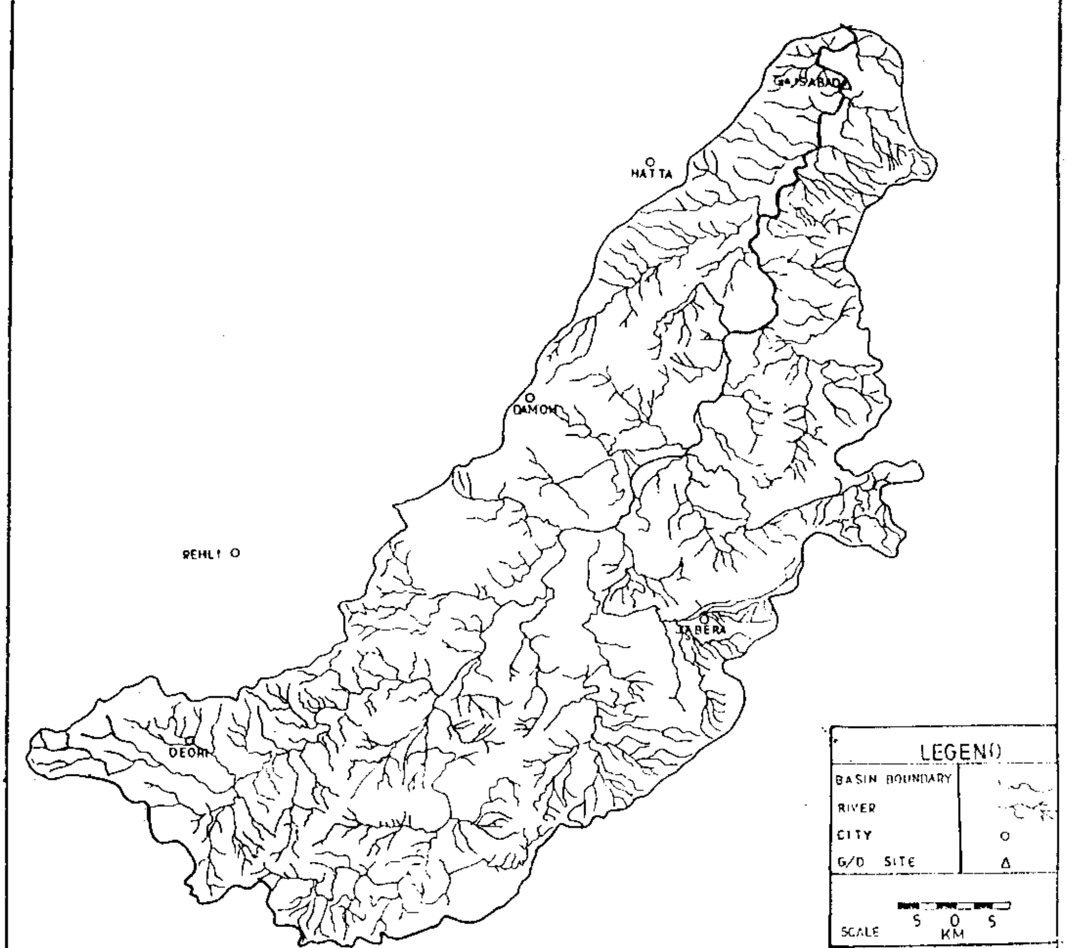


FIG.4:- MAP SHOWING THE BEARMA RIVER SYSTEM AND GAISABAD G/D SITE

monsoons. The average rainfall for the basin is about 1235 mm. The climatic conditions prevailing in the basin varies from semi-arid to dry. There are seven raingauge stations which are influencing the catchment upto Gaisabad namely, Deori, Rehli, Tendukheda, Damoh, Jabera, Hatta and Pawai.

5.3.4 Land use

The Bearma basin is located mostly in Sagar and Damoh districts and is covered to a large extent by forests, shrubs and grasslands. Out of the total geographical area of the Bearma sub-basin, about 36 % is covered by forests, 37 % area is of agricultural land, 5 % is barren and fallow lands and the remaining area is under permanent pastures, miscellaneous crops, culturable waste and fallow land. The predominant crops grown in the basin are wheat, paddy, oil seeds, pulses and grams. The agriculture of the catchment is mostly rain fed. About 3 % of the total area is irrigated by surface water and 2 % by ground water.

5.3.5 Raingauge and discharge measurement sites

A gauge-discharge site is located at Gaisabad in the Bearma basin, which is being monitored by Central Water Commission. The G/D site at Gaisabad is almost at the last reach of the river just about 16 km. before the confluence with the river Sonar, and its catchment area is 5709 sq.kms. There are seven raingauges influencing the catchment of Bearma upto Gaisabad. The daily rainfall data of these raingauge stations for the period from 1992 to 1995 were used in the analysis, for which concurrent discharge data were also available.

5.4 Bebas Sub-Basin Upto Rajghat Damsite

5.4.1 Location, catchment area and tributaries

The river Bebas is an important tributary of river Sonar which is a tributary of river Ken. The Bebas sub-basin is located between north latitudes of 23° 24' and 23° 46' and east longitudes of 78° 31' and 78° 45'. It is a leaf shaped elongated catchment.

The Bebas basin is bounded by Sonar basin (a sub-basin of river Ken) on the east side and by Dhasan basin (a sub-basin of R.Betwa) on the west side and the vindhyan ranges on the south and lies fully in Madhya Pradesh. Sagar and Raisen are the major districts falling in this sub-basin. The total catchment area of the Bebas basin is 488.56 sq. kms. The map showing the location of Bearma river system upto Rajghat damsite is presented as Fig. 5.

5.4.2 Topography and geology

The stratiagraphy of the local formation encountered in the basin consists of deccan traps, lameta beds vindhyan systems and alluvial soil. Black cotton soils are mostly found in the entire basin.

5.4.3 Hydrometeorology

The sub-basin lies in the medium rainfall zone. More than 90% of the annual rainfall occurs during June to October due to the south-west monsoon. The average rainfall for Sagar district is about 1245 mm. The climatic conditions in the sub-basin varies from semi-arid to dry with a hot summer from March to May, monsoon season from June to October and winter from November to February. Only three raingauge stations namely, Sagar, Rahatgarh and Deori influence the catchment of Bebas upto Rajghat damsite.

5.4.4 Land use

The catchment area of Bebas upto Rajghat damsite is 488.56 sq. km. and comprises of about 20 % forests and , 56 % agricultural land.The major crops grown in the sub-basin are wheat, paddy, maize, sunflower among other crops like jowar, groundnut and soyabean.

5.4.5 Raingauge and discharge measurement sites

In the Bebas basin, a gauge-discharge site is located at Rajghat damsite. The catchment area of the Bebas basin upto Rajghat damsite is 488.56 sq. kms. There are 3 raingauge stations which influence the catchment of the Bebas basin upto Rajghat damsite, namely, Sagar, Rahatgarh and Deori. The daily rainfall data for these stations for the period from 1992 to 1995 were used in the analysis. The discharge data for the period 1993 to 1995 was used for carrying out the study.

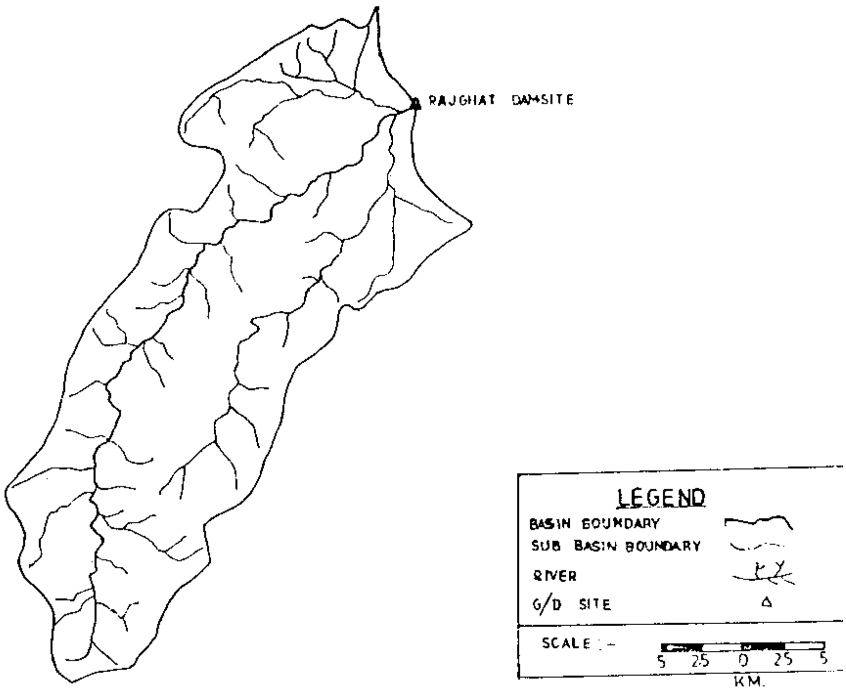


FIG.5:- MAP SHOWING THE BEBAS RIVER SYSTEM AND RAJGHAT DAMSITE.

6.0 DATA USED

Depending on the availability of rainfall and discharge data, the following basins were selected for carrying out the water availability studies.

1. Sonar river basin upto Garhakota G/D site.
2. Bearma river basin upto Gaisabad G/D site.
3. Bebas river basin upto Rajghat dam site.

The following data have been used in the study.

6.1 Rainfall Data

The daily rainfall data for the monsoon period from June to October for the years 1992 to 1995 have been used. The list of raingauges influencing the different basins is given below in Table - 2.

TABLE - 2: LIST OF RAINGAUGE STATIONS

S.No	BASIN	BASIN UPTO	RAINGAUGE STATION
01.	Sonar	Garhakota	Sagar, Rehli and Deori
02.	Bearma	Gaisabad	Deori, Rehli, Damoh, Jabera, Tendukheda,Hatta and Pawai
03.	Bebas	Rajghat Damsite	Sagar, Deori, Rahatgarh

6.2 Discharge Data

The daily discharge data used in the study and the list of gauge-discharge sites is given below in Table - 3. As the discharge data for river Sonar at the outlet of the basin was not available, the study was limited upto Garhakota G/D site. Similarly as the discharge data for river Bebas was not available at its point of confluence with river Sonar, the study is limited upto Rajghat damsite.

TABLE - 3 : LIST OF GAUGE-DISCHARGE SITES

S.No.	BASIN	DISCHARGE SITES	CATCHMENT AREA (sq.km.)	PERIOD
01.	Sonar	Garhakota	1384.41	1992-95
02.	Bearma	Gaisabad	5709.00	1992-95
03.	Bebas	Rajghat Damsite	488.56	1993-95

6.3 SOI Toposheets

The following Survey of India toposheets as given in Table - 4 have been used in the preparation of base maps and for other references.

TABLE - 4 : LIST OF SOI TOPOSHEETS USED

S.No.	SCALE OF MAP	MAP IDENTIFICATION NUMBERS
01.	1 : 2,50,000	54 P, 55 I, 55 M
02.	1 : 50,000	54 P / 12,16
		55 I / 9,10,11,14,15
		55 M / 1,2,3,4,5,6,7,8,9,10,11,12,13

6.4 SATELLITE IMAGERIES

The following LISS II satellite imageries as given in Table - 5 have been used in the preparation of land use / land cover maps.

TABLE - 5: LIST OF SATELLITE IMAGERIES USED

S.No.	PATH/ROW	SCENE	DATE OF PASS
1.	26 - 51	A1	13 Apr, 1989 & 11 Dec, 1989
2.	26 - 51	A2	13 Apr, 1989 & 11 Dec, 1989
3.	26 - 51	B1	13 Apr, 1989 & 11 Dec, 1989
4.	26 - 51	B2	13 Apr, 1989 & 11 Dec, 1989
5.	27 - 51	B2	28 May,1989 & 20 Nov, 1989

6.5 SOIL MAPS

The soil maps have been prepared from the soil information of the basin and with reference to the map on soil region prepared by the National Atlas of India, Calcutta.

6.6 GROUND TRUTH VERIFICATION

A few places in each basin have been selected for ground truth verification and marked on satellite imageries for land use classification.

7.0 METHODOLOGY

The methodology adopted in assessing the water availability in the Ken river catchment is explained in the following steps.

7.1 Processing and Analysis of Primary Data

The processing and analysis of the basic data is done for adjusting the data for its consistency. In the case of missing data, suitable methods like double mass curve technique may be adopted for making the data consistent.

7.2 Preparation of the Basin Map

Initially, the tracing of the basin upto a control point, i.e., upto the gauge-discharge site indicating the boundaries and a few control points is prepared from the Survey of India toposheets. The main river and a few important places are marked on this tracing.

7.3 Demarcation of Sub-basins

With the help of the Survey of India toposheets, the drainage network is marked on the base map. Depending on the prevailing drainage pattern, the basin upto the G/D site is then sub-divided into smaller sub-basins and the sub-basins are demarcated therein on the base maps. This map indicating the basin and sub-basin boundaries will now serve as the base map on which all further information needs to be incorporated, depending on the type of analysis for which such maps are to be prepared.

7.4 Computation of Sub-basin Mean Aerial Rainfall

On the base map depicting the various sub-basins, raingauge stations falling in and around the study area are marked. Thiessen polygons are then prepared and after measuring the area of each polygon falling in a sub-basin using a digital planimeter, the weights for each of the raingauge station influencing each of the sub-basin is found. The sub-basin wise average daily rainfall is then calculated.

7.5 Preparation of Soil Map

With the help of the soil information of the basin and after referring the National Atlas of India, Calcutta, on the soil regions and geology etc., soils are classified as per the Soil Conservation Service soil classification system. This information is then transferred on to the base map for preparation of the soil map.

7.6 Preparation of Land Use Map

False Colour Composite (FCC) of IRS1A, LISS-II, for both pre-monsoon and post-monsoon season period have been used for identifying the land use classes in various sub-basins. The base maps prepared earlier with the sub-basin boundaries marked on it, are then super-imposed over the satellite FCC prints and the boundaries of the various land use/land cover classes are then demarcated, keeping in mind, the fundamentals of visual interpretation. The results are then compared with the limited ground truth data available and the necessary modifications wherever required, are transferred to this land use map.

7.7 Determination of Curve Number from Land Use Maps and Soil Maps

For establishment of the runoff curve number, the information on hydrologic soil group, hydrologic condition, land treatment or practices and landuse / land cover are required. These information are acquired from field surveys and interpretation of satellite imageries. Since the land use land cover classes derived from IRS 1A, LISS-II, FCC prints were far more generalised, the runoff curve number compatible with IRS 1A, LISS-II data are given in Table - 6, which has been used for finding the curve number.

With the help of the land use map prepared from IRS 1A, LISS-II, satellite imageries, and the soil maps, the runoff curve number for each of the land use classes

TABLE - 6 : SCS RUNOFF CURVE NUMBERS FOR HYDROLOGIC SOIL COVER COMPLEXES COMPATIBLE WITH IRS-1A DATA (AMC - II)

	COVER	CN FOR SOIL GROUP			
LAND USE	HYDROLOGIC CONDITION	A	B	C	D
CULTIVATED	POOR	66	76	82	84
	GOOD	62	72	78	82
	PADDY	95	95	95	95
ORCHARDS		40	54	68	72
FOREST	DENSE	26	40	58	61
	OPEN	28	44	60	64
PASTURE		68	79	86	89
WASTELAND		71	80	85	88
ROADS/RUNWAY		73	83	88	90
HARD SURFACE		77	86	91	93

were found with the help of Table - 6, depending on the hydrologic condition, soil group and antecedent moisture condition. The composite curve number for each of the sub-basin is then worked out. The corresponding CCN for the AMC-I and AMC-III condition have also been determined.

7.8 Estimation of Sub-basin Runoff

The SCS Curve Number model is used in the computation of sub-basin runoff, using the composite curve number and mean Aerial rainfall for the sub-basin. Substituting the value of the sub-basin composite curve number in equation (3.8), the potential maximum retention, S, is computed. Using this value of 'S' and the mean Aerial rainfall, 'P', in equation (3.7), the sub-basin runoff depth was computed, which is subsequently converted into discharge units (cumecs) after multiplying and dividing by the sub-basin area and time constants respectively.

7.9 Estimation of the Direct Surface Runoff at the G/D Site

Before the computation of the total basin runoff, the time of concentration needs to be calculated. The time of concentration is defined as the time taken by a drop of water to reach the outlet of the basin from the farthest point of the catchment. The time of concentration is calculated using the Kirpich's formula, where the inputs are the main stream river length and mean slope of the main stream. The main stream river lengths have been measured using the digital curvimeter. All the sub-basin runoff was then summed up, after incorporating for the time lag wherever applicable, and the total basin runoff at the gauging site is thus estimated.

7.10 Base low Separation from Observed Discharge Data

The base flow is to be deducted from the total runoff hydrograph to obtain the direct runoff hydrograph (DRH), to be used subsequently for the comparison with the calculated flows at the G/D site. The hydrographs are then prepared and by using the straight line technique, the base flow is separated.

7.11 Comparison of the Calculated and Observed Direct Surface Runoff

The hydrographs of the calculated and observed surface runoff were then plotted on the same graph, to ascertain the accuracy with which the flows were estimated. Also, the monthly and seasonal totals of the calculated and observed runoff are to be tabulated for comparison and presentation.

8.0 ANALYSIS

8.1 Processing and Analysis of Data

The rainfall data of all the raingauge stations falling in and around the study area have been collected and processed for missing data using the double mass curve technique. All the data have been analysed for the consistency.

8.2 Preparation of Basin Maps

With the help of Survey of India toposheets, the basin boundaries were marked for river Sonar upto Garhakota gauge-discharge site, for river Bearma upto Gaisabad gauge-discharge site and for river Bebas upto Rajghat damsite where the flows are measured regularly. The main river, the G/D site and a few important control points have been marked on each of the three basin maps.

8.3 Demarcation of Sub-basins

On the basin map prepared as above, the basin has been further sub-divided into smaller sub-basins depending on the prevailing drainage pattern and contours, in the range of about 200 to 300 sq.km. The Sonar river basin upto Garhakota G/D site has been divided into six sub-basins. The map showing the Sonar river basin upto Garhakota and its various sub-basins marked therein is presented as Fig. 6. The Bearma basin upto Gaisabad G/D site has been divided into twenty seven sub-basins. The map showing the Bearma river basin upto Gaisabad and its various sub-basins marked therein is presented as Fig. 7. Similarly, Bebas river basin upto Rajghat dam G/D site has been divided into two sub-basins. The map showing the Bebas river basin upto Rajghat damsite and its various sub-basins marked therein is presented as Fig. 8.

8.4 Computation of Sub-basin Mean Areal Rainfall

On the base map depicting the various sub-basins, the raingauge stations falling in and around the basin have been marked. The Thiessen polygons were then prepared and after measuring the area of each polygon in a sub-basin with the help of digital

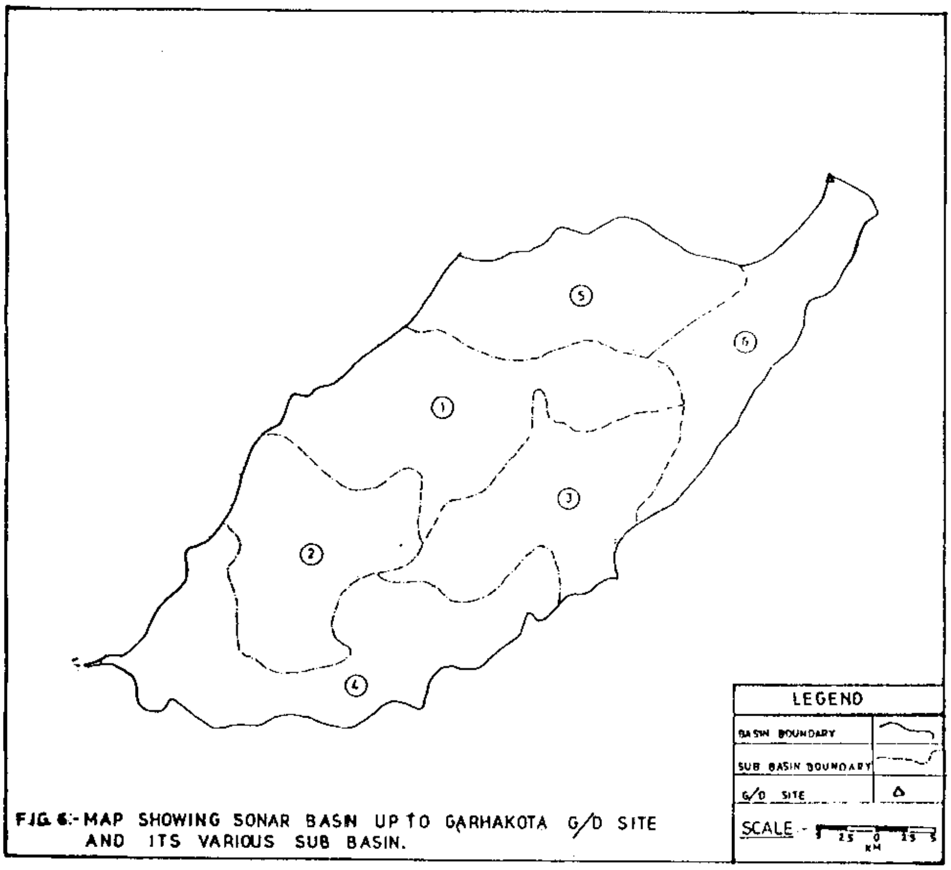


FIG. 6:- MAP SHOWING SONAR BASIN UP TO GARHAKOTA G/D SITE AND ITS VARIOUS SUB BASIN.

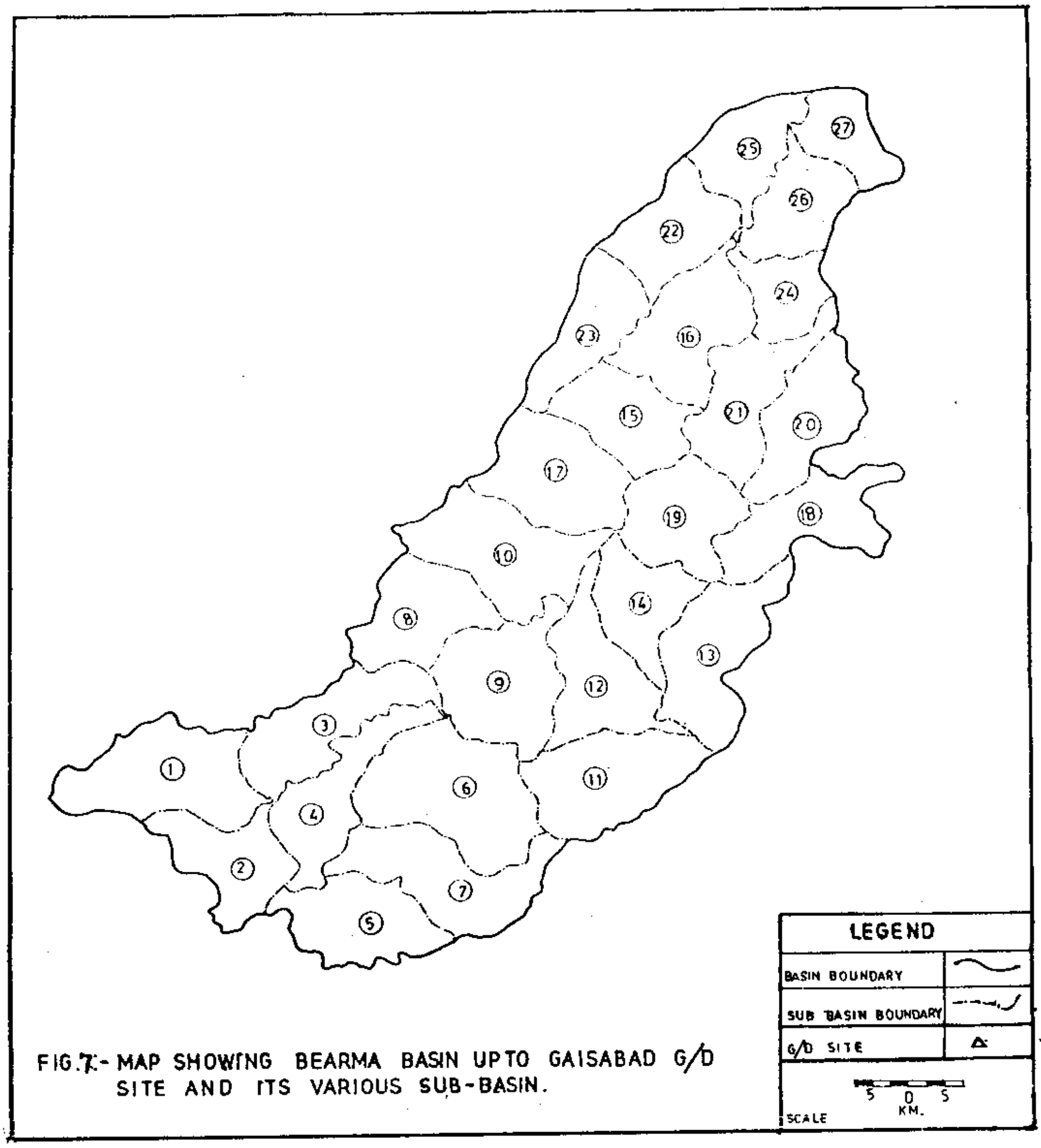


FIG.7.- MAP SHOWING BEARMA BASIN UPTO GAISABAD G/D SITE AND ITS VARIOUS SUB-BASIN.

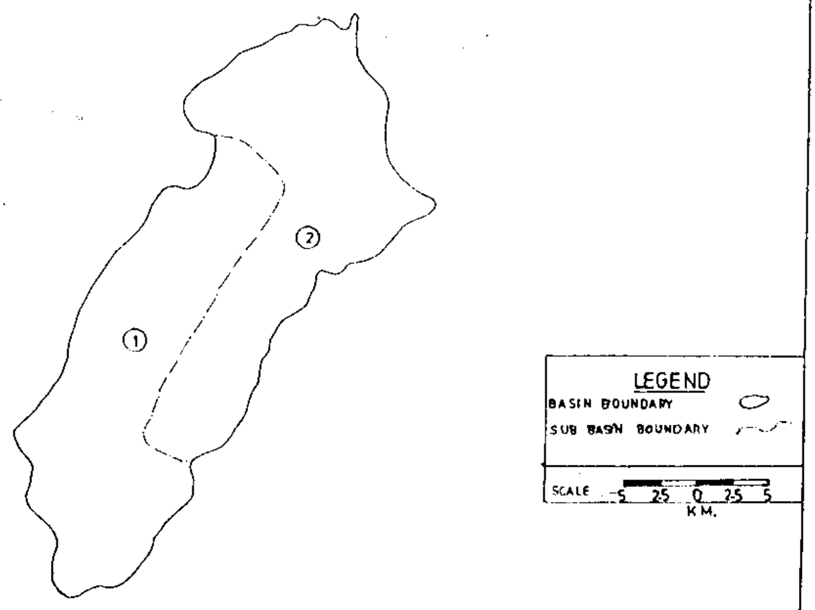


FIG. 8:- MAP SHOWING BEBAS BASIN UPTO RAIGHAT DAMSITE AND ITS VARIOUS SUB-BASINS.

planimeter, the weights of influencing rain gauge stations for each sub-basin have been found. Then mean aerial rainfall has been computed. The map showing the raingauge stations influencing the catchment and Thiessen polygons for Sonar up to Garhakota Bearma upto Gaisabad and Beabas upto Rajghat damsite have been presented as Fig. 9, Fig. 10 & Fig. 11 respectively. The area of the various sub-basins and the weights of the raingauge stations influencing these sub-basins of Sonar up to Garhakota, Bearma upto Gaisabad and Bebas upto Rajghat damsite are given in Table - 7, Table - 8 and Table - 9 respectively.

8.5 Preparation of Soil Maps

The soil maps prepared for Sonar up to Garhakota, Bearma upto Gaisabad and Beabas upto Rajghat damsite are presented as Fig. 12, Fig. 13 and Fig. 14 respectively

10.6 Preparation of Landuse Maps

The landuse/land cover maps for Sonar up to Garhakota, Bearma upto Gaisabad and Beabas upto Rajghat damsite have been prepared using pre-monsoon and post- monsoon IRS 1A, LISS-II, false color composite prints. The following five land use classes have been found in these basins, namely, forests, agriculture land, barren/fallow lands, scrubs and water bodies. The map showing the landuse classification for the various sub-basins in Sonar up to Garhakota, Bearma upto Gaisabad and Bebas upto Rajghat damsite are presented as Fig. 15, Fig. 16 and Fig. 17 respectively.

The area of various land use classes falling under different hydrologic soil groups in each sub-basin have been measured using digital planimeter. The sub-basin wise landuse for Sonar up to Garhakota, Bearma upto Gaisabad and Bebas upto Rajghat damsite are given in Table - 10, Table -11 and Table - 12 respectively.

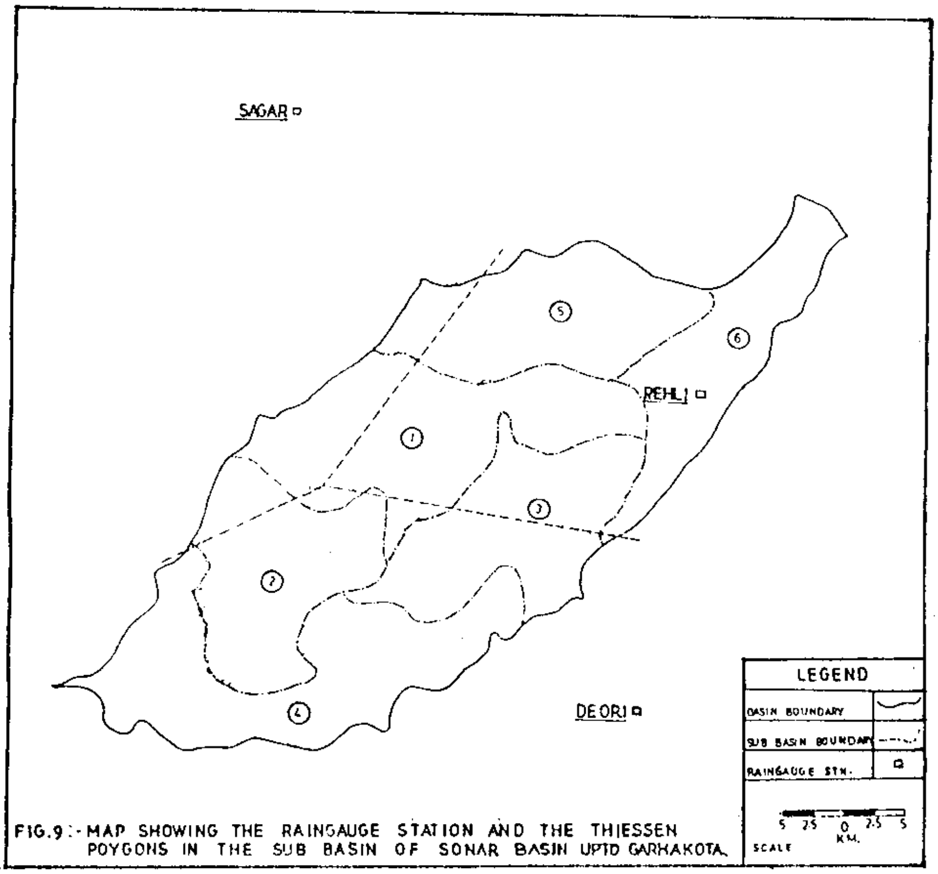


FIG.9 :- MAP SHOWING THE RAINGAUGE STATION AND THE THIESSEN POYGONS IN THE SUB BASIN OF SONAR BASIN UPTO GARHAKOTA.

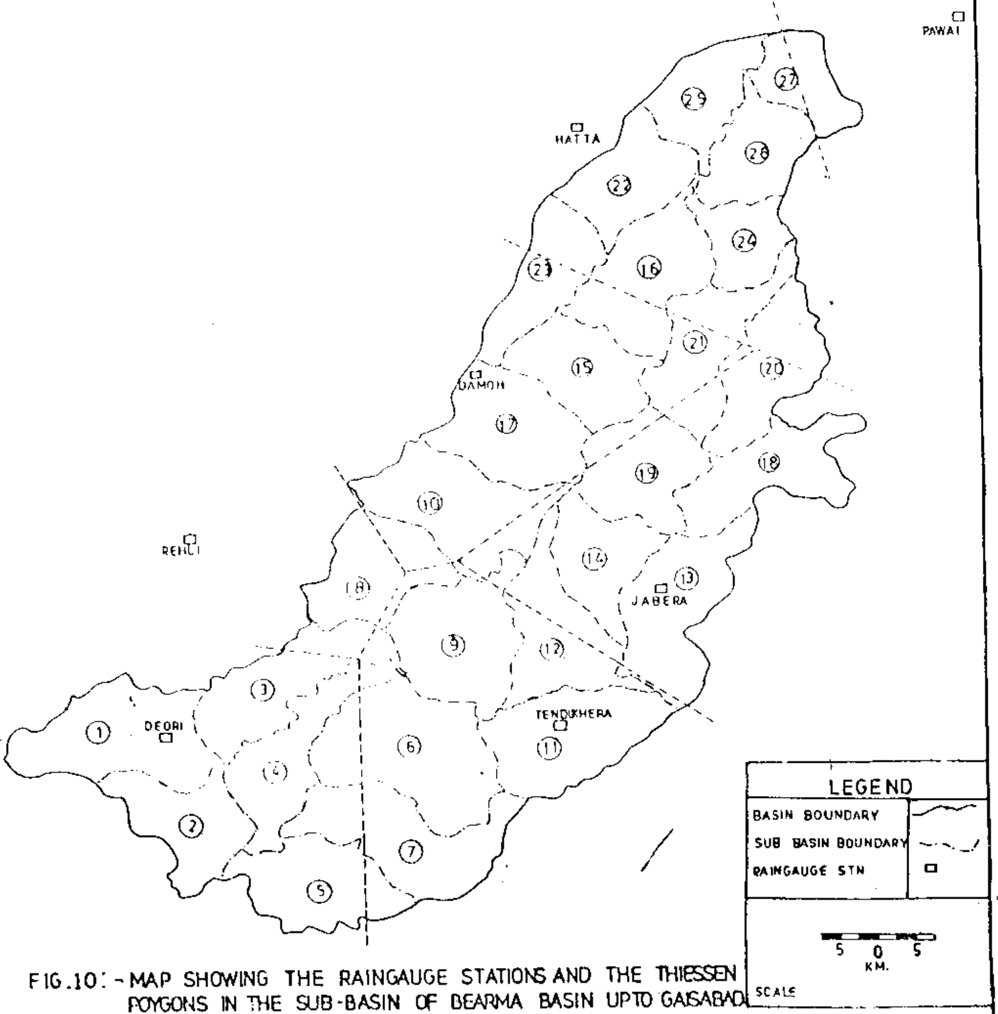


FIG.10: - MAP SHOWING THE RAINGAUGE STATIONS AND THE THIESSEN POYGONS IN THE SUB-BASIN OF BEARMA BASIN UPTO GAISABAD

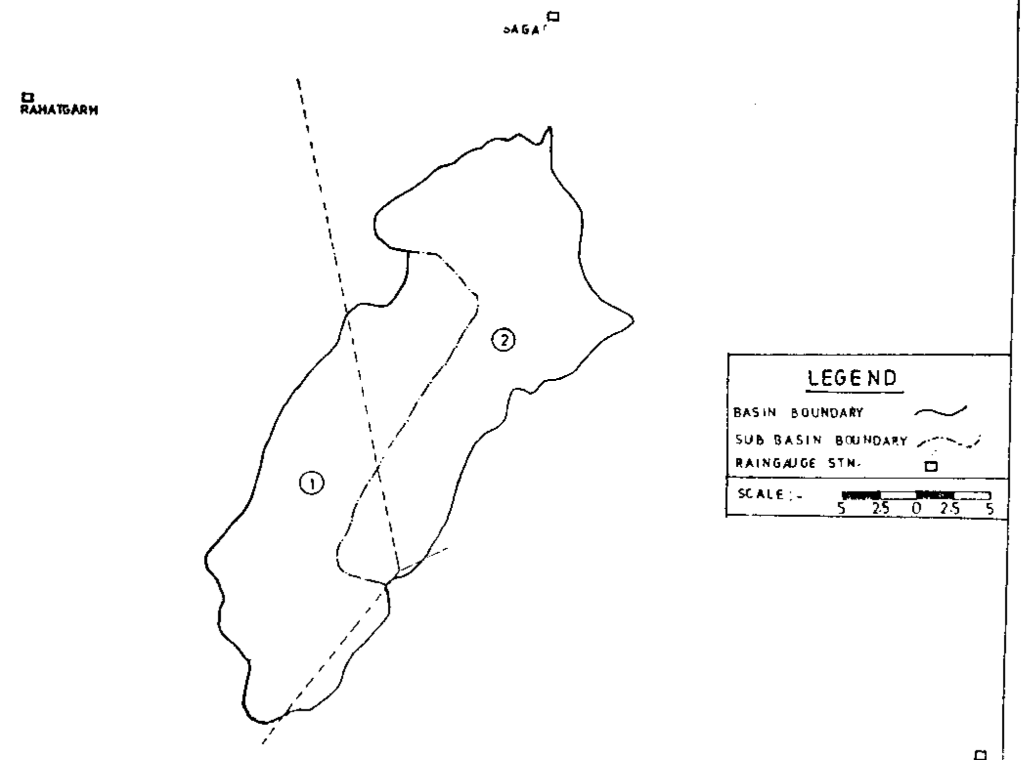


FIG.11 :- MAP SHOWING THE RAINGAUGE STATION AND THE THIESSEN POYGONS IN THE SUB-BASINS OF BEBAS BASIN UPTO DAMSITE.

TABLE - 7 : AREA OF THE VARIOUS SUB-BASINS OF SONAR UPTO GARHAKOTA AND THIESSEN WEIGHTS OF THE RAINGAUGE STATIONS INFLUENCING THESE SUB-BASINS

S.No	NAME OF THE SUB-BASIN	AREA SQ.KM.	WEIGHTS FOR R.G. STATIONS		
			SAGAR	REHLI	DEORI
1	1	271.18	0.29	0.63	0.08
2	2	243.68	0.14	0	0.86
3	3	206.8	0	0.43	0.57
4	4	285.01	0	0	1
5	5	211.49	0.13	0.87	0
6	6	166.25	0	1	0
	TOTAL AREA	1384.41			

TABLE - 8 : AREA OF THE VARIOUS SUB-BASIN OF BEARMA UPTO GAISABAD AND THE THIESSEN WEIGHTS OF THE RAINGAUGE STATIONS INFLUENCING THEM

S.No	SUB-BASIN	AREA	WEIGHTS OF RAINGUAGE STATIONS						
			DEORI	REHLI	TENDU-KHEDA	DAMOH	JABERA	HATTA	PAWAI
1	1	288.32	1						
2	2	157.7	1						
3	3	204.24	0.62	0.21	0.17				
4	4	203.64	0.93		0.07				
5	5	211.88	0.85		0.15				
6	6	303.21	0.22		0.78				
7	7	265.34	0.25		0.75				
8	8	205.63		0.66	0.14	0.2			
9	9	268.25			0.95		0.05		
10	10	277.5			0.02	0.8	0.18		
11	11	268.75			1				
12	12	214.38			0.6		0.4		
13	13	189.52			0.05		0.95		
14	14	181.85					1		
15	15	188.75				1			
16	16	253.24				0.35		0.65	
17	14	245.1				1			
18	18	208.54					1		
19	19	203.58				0.16	0.84		
20	20	204.37				0.02	0.55	0.43	
21	21	226.76				0.4	0.17	0.43	
22	22	197.25						1	
23	23	173.5				0.58		0.42	
24	24	126.31							
25	25	153.65						1	
26	26	167.5						1	
27	27	120.63						0.4	0.6

TABLE - 9 : AREA OF THE VARIOUS SUB-BASINS OF BEBAS UPTO DAMSITE AND THIESSEN WEIGHTS OF THE RAINGAUGE STATIONS INFLUENCING THESE SUB-BASINS

S.No	NAME OF THE SUB-BASIN	AREA SQ.KM.	WEIGHTS FOR R.G. STATIONS		
			DEORI	SAGAR	RAHATGARH
1	1	246.81	0.06	0.25	0.69
2	2	241.75	0.07	0.01	0.92
	TOTAL AREA	488.56			

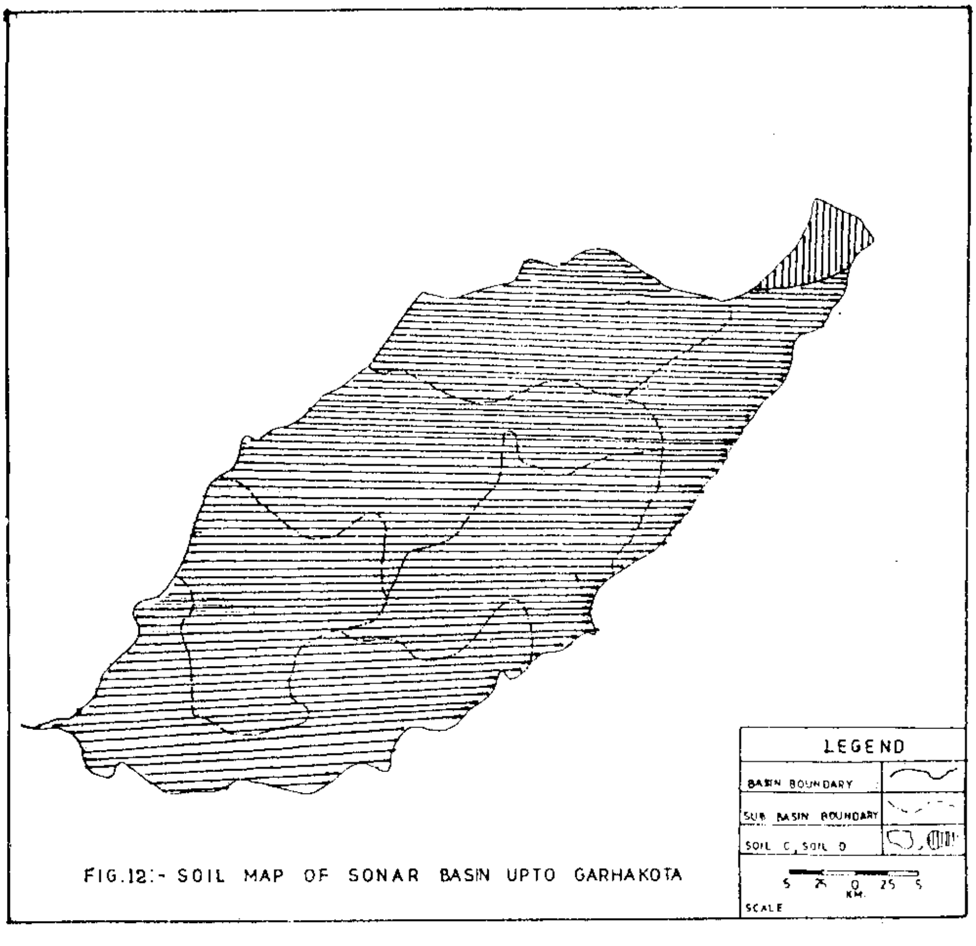


FIG.12:- SOIL MAP OF SONAR BASIN UPTO GARHAKOTA

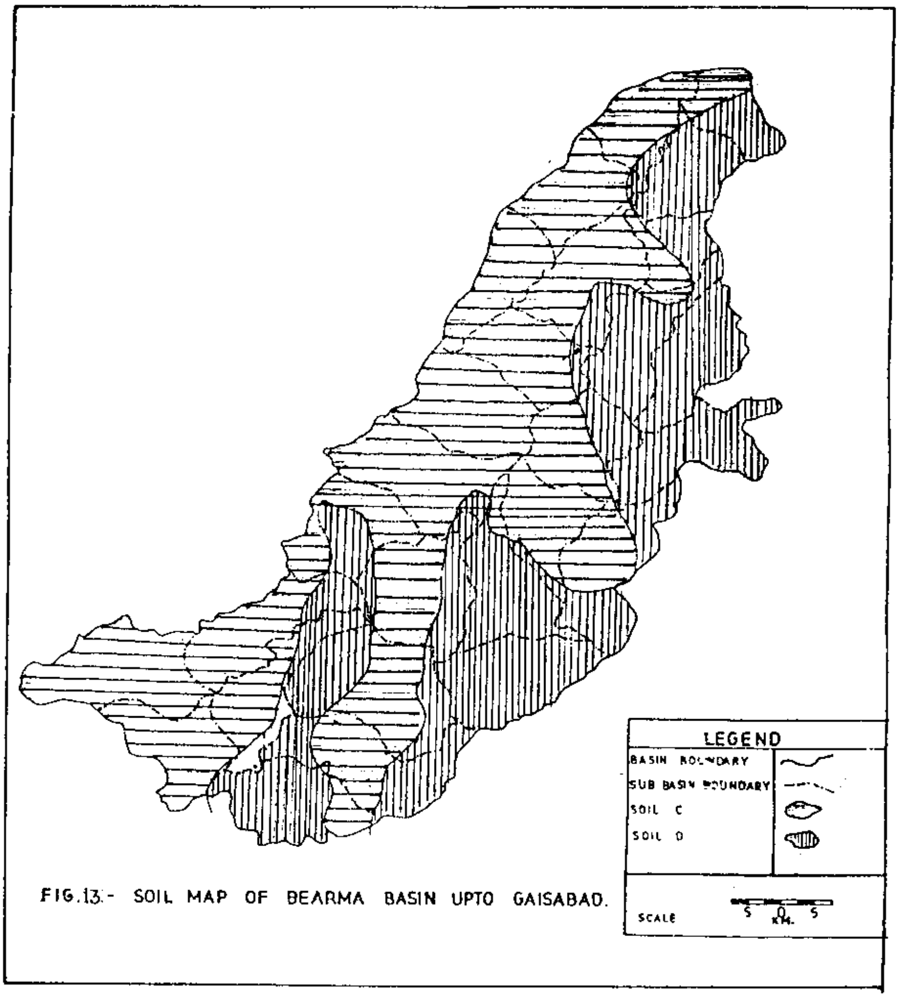


FIG.13.- SOIL MAP OF BEARMA BASIN UPTO GAISABAD.

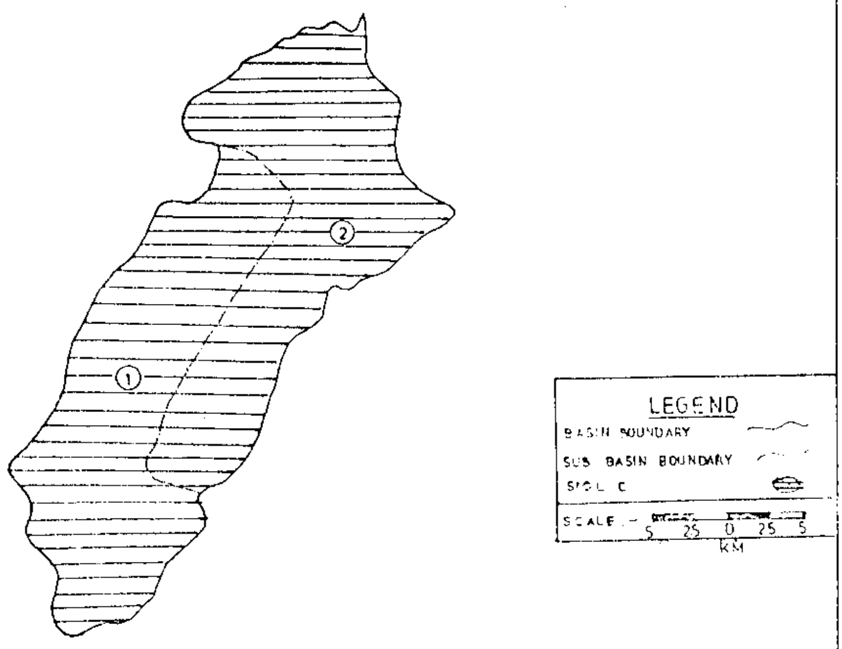


FIG.14:- SOIL MAP OF BEBAS BASIN UPTO RAJGHAT DAMSITE.

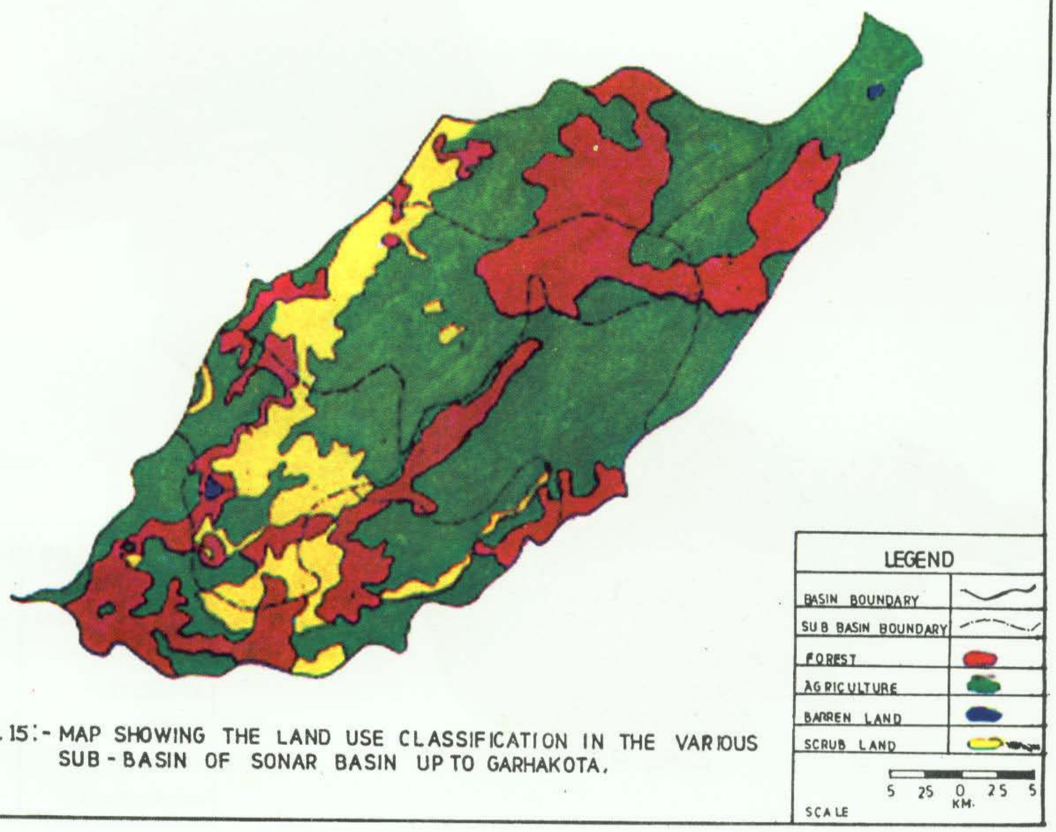


FIG. 15:- MAP SHOWING THE LAND USE CLASSIFICATION IN THE VARIOUS SUB-BASIN OF SONAR BASIN UP TO GARHAKOTA.

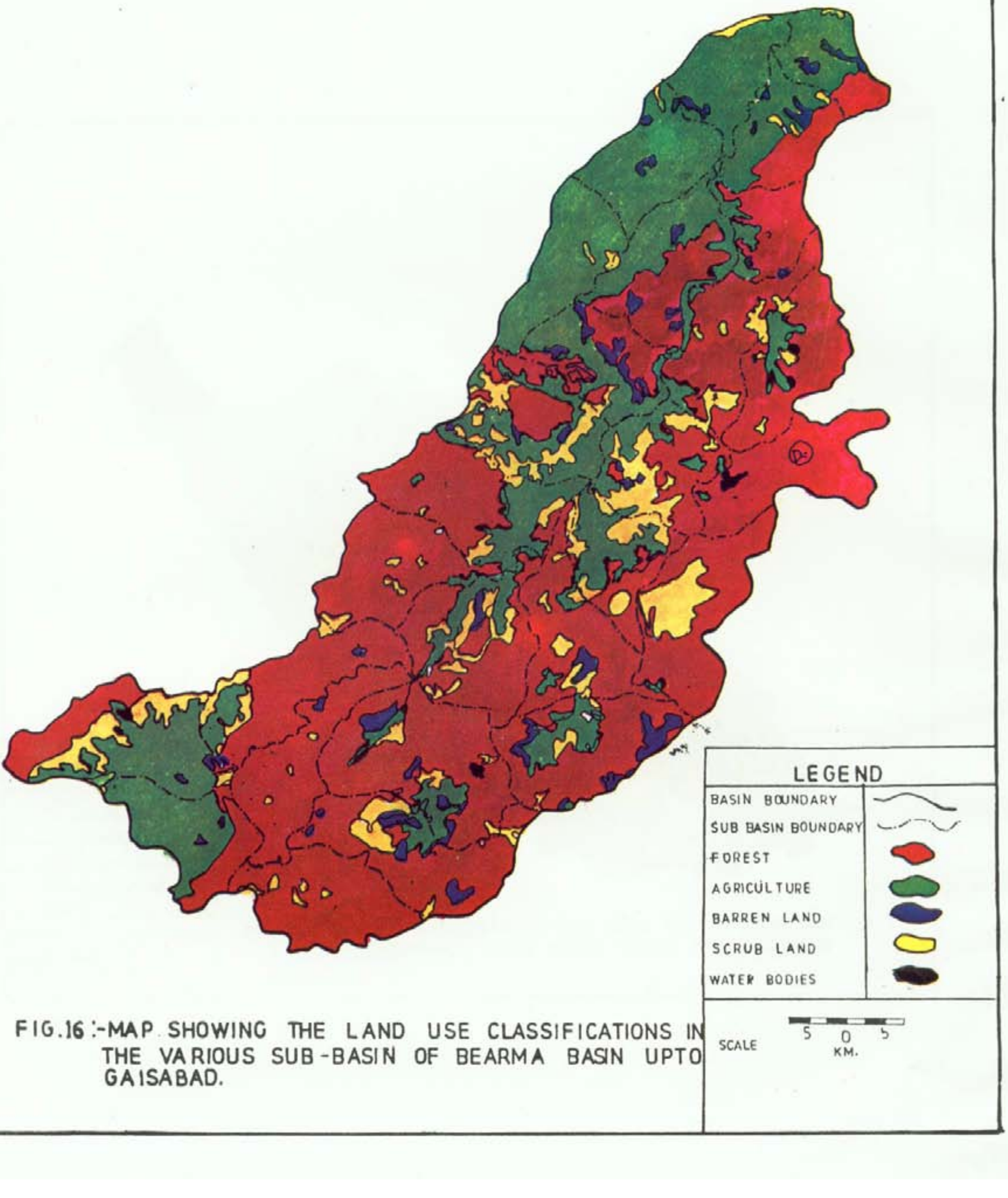


FIG.16 :-MAP SHOWING THE LAND USE CLASSIFICATIONS IN THE VARIOUS SUB-BASIN OF BEARMA BASIN UPTO GAISABAD.

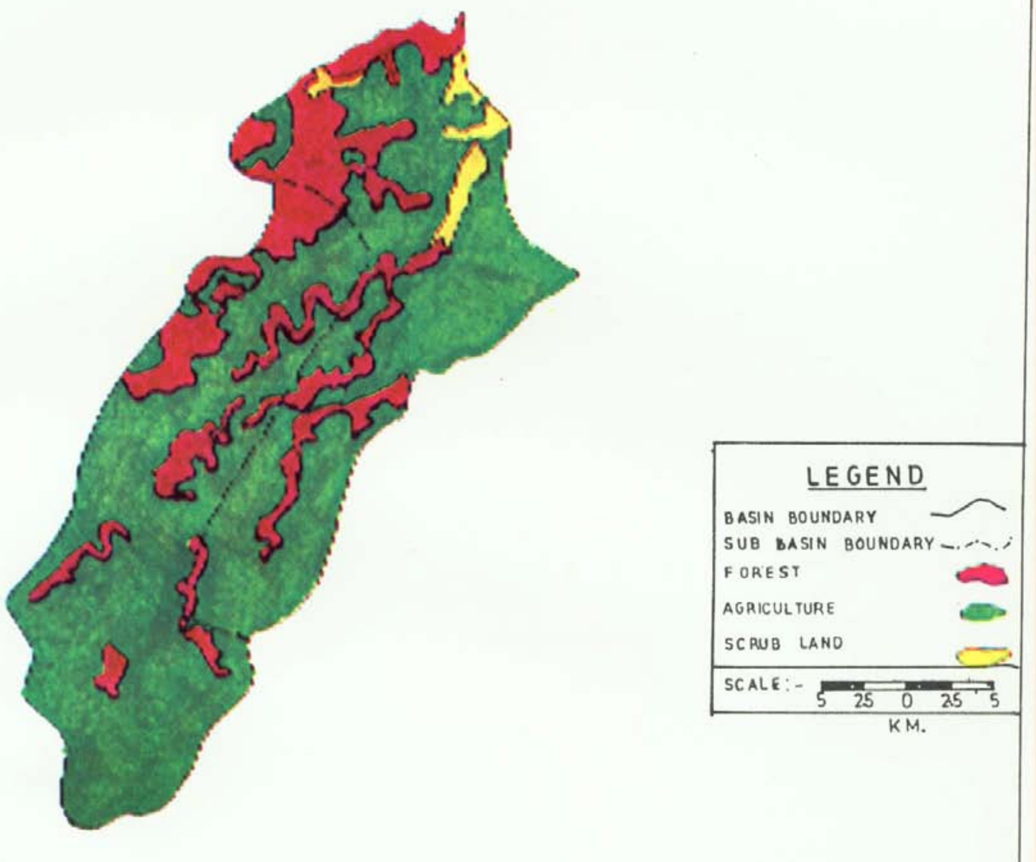


FIG. 17.- MAP SHOWING THE LAND USE CLASSIFICATION IN THE VARIOUS SUB-BASINS OF BEBAS BASIN UPTO RAJGHAT DAMSITE.

TABLE - 10 : LAND USE PARTICULARS AND CURVE NUMBER FOR SUB-BASINS O UPTO GARHAKOTA

S.No	SUB-BASIN	LAND USE	CURVE NUMBER			
			SOIL GROUP - C		SOIL GROUP - D	
			AREA	CN	AREA	CN
1	1	FOREST	16.25	70		
		SHRUBS	47.5	73		
		WATER BODIES	0.6	70		
		AGRICULTURE	206.83	83		
2	2	FOREST	34.99	70		
		SHRUBS	75.65	73		
		WATER BODIES				
		AGRICULTURE	133.04	83		
3	3	FOREST	39.37	70		
		SHRUBS				
		WATER BODIES				
		AGRICULTURE	167.43	83		
4	4	FOREST	106.53	70		
		SHRUBS	31.24	73		
		WATER BODIES				
		AGRICULTURE	147.24	83		
5	5	FOREST	42.65	70		
		SHRUBS	13.75	73		
		WATER BODIES				
		AGRICULTURE	155.09	83		
6	6	FOREST	48.44	70		
		SHRUBS				
		BARREN			0.5	90
		AGRICULTURE	62.81	83	54.5	87

TABLE - 11 : LAND USE PARTICULARS AND CURVE NUMBER FOR SUB-BASINS OF BEARMA UPTO GAISABAD

S.No	SUB-BASIN	LAND USE	CURVE NUMBER			
			SOIL GROUP - C		SOIL GROUP - D	
			AREA	CN	AREA	CN
1	1	FOREST	75.24	70		
		SHRUBS	60.42	73		
		WATER BODIES	2.16	70		
		AGRICULTURE	14.82	83		
		BARREN	7.38	88		
2	2	FOREST	56.15	70		
		SHRUBS				
		WATER BODIES				
		AGRICULTURE	94.69	83		
		BARREN	9.43	88		
3	3	FOREST	112.68	70		
		SHRUBS	20.82	73	1.32	78
		WATER BODIES				
		AGRICULTURE	27.59	83	44.96	87
		BARREN	0.2	88		
4	4	FOREST	121.52	70	77.07	77
		SHRUBS	1.83	73	1.01	78
		WATER BODIES				
		AGRICULTURE				
		BARREN	2.31	88	1.21	90
5	5	FOREST	42.69	70	165.14	77
		SHRUBS			8.49	78
		WATER BODIES				
		AGRICULTURE				
		BARREN	0.5	88	1.52	90

6	6	FOREST	122.09	70	111.7	77
		SHRUBS	7.02	73	8.64	78
		WATER BODIES	0.5	70	0.81	77
		AGRICULTURE	27.32	83	7.41	87
		BARREN	15.53	88	7.11	90
7	7	FOREST	62.54	70	137.88	77
		SHRUBS	29.86	73	6.99	78
		WATER BODIES				
		AGRICULTURE	13	83		
		BARREN	11.46	88	7.93	90
8	8	FOREST	129.11	70	64.43	77
		SHRUBS	2.38	73	4.17	78
		WATER BODIES				
		AGRICULTURE	3.18	83		
		BARREN	5.71	88		
9	9	FOREST	88.42	70	89.91	77
		SHRUBS	36.84	73	8.77	78
		WATER BODIES				
		AGRICULTURE	29.22	83	12.7	87
		BARREN	6.86	88		
10	10	FOREST	170.45	70	5.72	77
		SHRUBS	26.93	73		
		WATER BODIES				
		AGRICULTURE	66.88	83	12.06	87
		BARREN				

11	11	FOREST		70	172.53	77
		SHRUBS		73	13.9	78
		WATER BODIES				
		AGRICULTURE			42.87	87
		BARREN			43.85	90
12	12	FOREST	15.07	70	166.53	77
		SHRUBS	2.54	73	11.44	78
		WATER BODIES			0.71	
		AGRICULTURE	2.54	83	6.35	87
		BARREN			12.7	90
13	13	FOREST	55.26	70	75.75	77
		SHRUBS			2.54	78
		WATER BODIES				
		AGRICULTURE	55.27	83		
		BARREN	3.81	88		
14	14	FOREST	60.15	70	12.7	77
		SHRUBS	30.28	73	3.81	78
		WATER BODIES				
		AGRICULTURE	69.89	83		
		BARREN				
15	15	FOREST	60.1	70	10.13	77
		SHRUBS	6.6	73		
		WATER BODIES				
		AGRICULTURE	82.21	83	6.99	87
		BARREN	23.25	88	2.54	90

16	16	FOREST	75.09	70	33.67	77
		SHRUBS	4.01	73		
		WATER BODIES				
		AGRICULTURE	131.91	83	8.26	87
		BARREN	3.18	88	1.27	90
17	17	FOREST	69.5	70		
		SHRUBS	54.93	73		
		WATER BODIES				
		AGRICULTURE	108.72	83		
		BARREN	14.39	88		
18	18	FOREST			198.36	77
		SHRUBS			5.08	78
		WATER BODIES			6.99	
		AGRICULTURE			1.52	87
		BARREN				
19	19	FOREST	40.57	70	47.97	77
		SHRUBS	52.1	73	12.7	78
		WATER BODIES			0.3	77
		AGRICULTURE	38.09	83	13.35	87
		BARREN	1.42	88		
20	20	FOREST			168.53	77
		SHRUBS			12.33	78
		WATER BODIES			0.61	77
		AGRICULTURE			23.2	87
		BARREN			3.05	90
21	21	FOREST	16.52	70	175.42	77
		SHRUBS			27.16	78
		WATER BODIES				
		AGRICULTURE			11.38	87
		BARREN				

22	22	FOREST				
		SHRUBS	1.22	73		
		WATER BODIES				
		AGRICULTURE	188.26	83	5.08	87
		BARREN	5.93	88		
23	23	FOREST				
		SHRUBS	4.14	73		
		WATER BODIES				
		AGRICULTURE	172.21	83		
		BARREN	0	88		
24	24	FOREST	25.1	70	74.77	77
		SHRUBS				
		WATER BODIES				
		AGRICULTURE	26.43	83		
		BARREN	0.81	88	1.27	90
25	25	FOREST				
		SHRUBS	5.72	73	2.54	78
		WATER BODIES				
		AGRICULTURE	127.45	83	15.89	87
		BARREN	4.57	88		
26	26	FOREST			61.62	77
		SHRUBS			5.18	78
		WATER BODIES				
		AGRICULTURE	4.46	83	89.45	87
		BARREN			9.53	90
27	27	FOREST			32.2	77
		SHRUBS				
		WATER BODIES				
		AGRICULTURE	44.57	83	33.23	87
		BARREN	2.93	88	7.7	90

TABLE - 12 : LAND USE PARTICULARS AND CURVE NUMBER FOR SUB-BASINS OF BEBAS UPTO RAJGHAT DAMSITE

S.No	SUB-BASIN	LAND USE	CURVE NUMBER			
			SOIL GROUP - C		SOIL GROUP - D	
			AREA	CN	AREA	CN
1	1	FOREST	40.45	70		
		SHRUBS				
		WATER BODIES				
		AGRICULTURE	206.36	83		
2	2	FOREST	58.31	70		
		SHRUBS	14.69	73		
		WATER BODIES		-		
		AGRICULTURE	168.75	83		

8.7 Determination of Curve Number

With the help of Table - 6, landuse map and soil map, the curve number for each of the classes falling in the sub-basin have been determined. The composite curve number for each sub-basin has been found. The corresponding CCN for AMC-I and AMC-III condition have also been determined. The CCN for each sub-basin of Sonar up to Garhakota, Bearma upto Gaisabad and Beabas upto Rajghat damsite are given in Table - 13, Table -14 and Table - 15 respectively.

8.8 Estimation of Sub-basin Runoff

Using SCS model, the daily direct runoff for each of the sub-basin of Sonar up to Garhakota, Bearma upto Gaisabad and Beabas upto Rajghat damsite have been calculated for the monsoon period for the years 1992 to 1995. The monthly and seasonal totals of direct runoff for each of the sub-basin of Sonar up to Garhakota, Bearma upto Gaisabad and Beabas upto Rajghat damsite have also been computed and given in Table - 16, Table -17 and Table - 18 respectively.

8.9 Estimation of Direct Surface Runoff at the G/D Site

All the sub-basin runoff was then summed up, after incorporating for the time lag wherever applicable, and the total basin runoff has been calculated. The monthly and seasonal totals of direct runoff for Sonar up to Garhakota, Bearma upto Gaisabad and Bebas upto Rajghat damsite have also been computed and given in Table - 19.

8.10 Baseflow Separation from Observed Runoff

Using Straight line technique, base flow has been separated from observed runoff data after preparation of hydrographs from the observed discharges.

8.11 Comparison of Calculated and Observed Direct Surface Runoff

The graph showing comparison of calculated and observed daily runoff for Sonar basin upto Garhakota for the monsoon period (June to Oct.) for the year 1993

TABLE - 13 : THE COMPOSITE CURVE NUMBER FOR DIFFERENT AMC CONDITIONS FOR VARIOUS SUB-BASINS OF SONAR UPTO GARHAKOTA

S.No	SUB-BASIN	COMPOSITE CURVE NUMBER		
		AMC-II	AMC-I	AMC-III
1	1	80	63	91
2	2	78	60	90
3	3	80	63	91
4	4	76	58	89
5	5	80	63	91
6	6	81	64	92

TABLE - 14 : THE COMPOSITE CURVE NUMBER FOR DIFFERENT AMC CONDITIONS FOR VARIOUS SUB-BASINS OF BEARMA UPTO GAISADBAD

S.No	SUB-BASIN	COMPOSITE CURVE NUMBER		
		AMC-II	AMC-I	AMC-III
1	1	78	60	90
2	2	79	62	91
3	3	76	58	89
4	4	73	54	87
5	5	76	58	89
6	6	76	58	89
7	7	76	58	89
8	8	73	54	87
9	9	76	58	89
10	10	75	57	88
11	11	81	64	92
12	12	78	60	90
13	13	77	59	89
14	14	76	58	89
15	15	78	60	90
16	16	77	59	89
17	17	77	59	89
18	18	77	59	89
19	19	76	58	89
20	20	78	60	90
21	21	77	59	89
22	22	83	67	93
23	23	83	67	93
24	24	77	59	89
25	25	83	67	93
26	26	83	67	93
27	27	83	67	93

TABLE - 15 : THE COMPOSITE CURVE NUMBER FOR DIFFERENT AMC CONDITIONS FOR VARIOUS SUB-BASINS OF BEBAS UPTO RAJGHAT DAMSITE

S.No	SUB-BASIN	COMPOSITE CURVE NUMBER		
		AMC-II	AMC-I	AMC-III
1	1	81	64	92
2	2	79	62	91

TABLE - 16 : ESTIMATED MONTHLY RUNOFF FOR VARIOUS SUB-BASINS FOR SONAR UPTO GARHAKOTA (M.C.M)

YEAR	MONTH	SUB-BASIN WISE CALCULATED RUNOFF					
		1	2	3	4	5	6
1992	JUN	0	7.32	2.73	10.38	0.04	0.07
	JUL	11.22	9.35	8.75	10.41	9.78	8.46
	AUG	84.15	35.71	48.09	34.3	76.15	67.98
	SEP	60.12	10.72	26.88	7.35	53.64	45.37
	OCT	0	0	0	0	0	0
	TOTAL	155.5	63.09	86.46	62.43	139.61	121.88
1993	JUN	9.16	4.65	5.48	5.43	11.03	11.12
	JUL	3.84	14.29	7.02	19.13	3.63	3.43
	AUG	33.51	24.32	24.29	27.93	31.31	28.84
	SEP	37.2	23.15	18.66	25.22	29.88	26.76
	OCT	0	0	0	0	0	0
	TOTAL	83.71	66.41	55.45	77.72	75.85	70.16
1994	JUN	11.8	7.68	8.99	8.69	10.71	9.62
	JUL	131.04	69.18	77.6	76	114.82	98.47
	AUG	97	60.03	69.28	69.7	85.24	74.23
	SEP	8.56	7.81	7.13	10.04	8.17	7.63
	OCT	0	0	0	0	0	0
	TOTAL	248.41	144.71	163	164.44	218.94	189.96
1995	JUN	0	0	0	0	0	0
	JUL	17.24	24.42	14.22	27.92	18.35	17.48
	AUG	21.53	34.16	25.63	45.56	19.02	17.41
	SEP	31.5	8.35	12.51	8.52	29.74	26.37
	OCT	0	0	0	0	0	0
	TOTAL	70.27	66.93	52.37	82	67.1	61.25

TABLE - 17 : ESTIMATED MONTHLY RUNOFF FOR VARIOUS SUB-BASINS GAISABAD
(ALL VALUES IN MILLION CUBIC METERS)

YEAR	MONTH	SUB-BASIN WISE CALCULATED RUNOFF								
		1	2	3	4	5	6	7	8	9
1992	JUN	12.87	7.9	2.33	5.22	5.51	0.04	0.08	0	0
	JUL	9.83	8.1	5.33	7.99	5.85	6.47	12.2	7.81	8.29
	AUG	68.1	39.55	49.57	38.82	45.17	66.18	57.49	58.98	63.82
	SEP	22.17	13.07	22.06	12.59	15.58	29.55	25.32	40.99	30.57
	OCT	0	0	0	0	0	0	0	0	0
	TOTAL	113	68.61	79.28	64.62	72.1	102.23	95.09	107.78	102.67
1993	JUN	2.03	1.22	2.13	1.28	2.04	0.35	0.31	1.42	0.42
	JUL	11.72	7.38	6.16	5.25	11.12	4.12	7.96	1.13	4.14
	AUG	31.81	18.31	17.89	16.66	19.66	27.51	23.81	17.47	26.63
	SEP	43.47	24.88	25.19	26.03	28.78	39.26	34.24	20.51	35.42
	OCT	0	0	0	0	0.09	0	0	0	0
	TOTAL	89.03	51.79	51.37	49.22	61.69	71.23	66.32	40.54	66.61
1994	JUN	10.21	5.97	8.98	5.87	8.65	21.97	32.92	7.56	27.77
	JUL	55.97	32.28	44.08	30.5	36.62	91.82	78.2	61.2	97.05
	AUG	91.86	52.64	70.06	55.97	66.66	111.86	96.88	77.75	107.22
	SEP	10.75	6.18	5.97	6.13	3.64	5.58	4.78	4.14	3.98
	OCT	0	0	0	0	0	0	0	0	0
	TOTAL	168.8	97.06	129.09	98.48	115.56	231.23	212.78	150.65	236.02
1995	JUN	1.97	1.2	0.42	0.64	0.74	1.02	0.81	0.12	0.65
	JUL	23.82	13.53	8.64	13.24	20.42	16.29	14.91	13.51	21.39
	AUG	35.68	20.92	28.7	20.58	22.47	42.7	24.17	21.27	37.71
	SEP	4.81	2.86	3.73	2.3	1.86	0.88	0.77	12.97	2.24
	OCT	0	0	0	0	0	0	0	0	0
	TOTAL	66.28	38.51	41.5	36.77	45.48	60.89	40.67	47.87	62

YEAR	MONTH	SUB-BASIN WISE CALCULATED RUNOFF								
		10	11	12	13	14	15	16	17	18
1992	JUN	0.08	0	0	0.05	0.19	0	0	0.12	0.25
	JUL	6.23	9.86	11.38	10.59	10.3	6.6	11.89	7.02	11.22
	AUG	49.37	76.95	58.75	55.28	53.8	33.92	41.32	41.2	61.7
	SEP	46.65	36.05	27.89	32.42	32.02	34.7	66.11	43.44	36.76
	OCT	0	0	0	0	0	0	0	0	0
	TOTAL	102.3	122.86	98.01	98.34	96.31	75.22	119.32	91.79	109.93
1993	JUN	1.55	0.84	0.46	0.18	0.18	1.58	0.88	1.16	0.43
	JUL	4.65	5.38	2.79	1.98	1.7	2.82	2.66	2.82	2.15
	AUG	22.21	34.89	19.99	13.96	12.55	20.89	25.11	24.52	15.24
	SEP	35.71	42.3	26.64	19.83	18.88	32.96	37.23	40.61	21.79
	OCT	0	0	0	0	0	0	0	0	0
	TOTAL	64.11	83.41	49.88	35.95	33.31	58.24	65.88	69.1	39.6
1994	JUN	14.39	37.48	17.74	12.65	10.93	9.66	10.51	11.06	9.98
	JUL	78.37	115.37	70.59	48.46	44.03	66.08	54.06	80.35	52.26
	AUG	110.8	122.18	85.85	70.88	68.04	88.37	75.6	110.31	78.02
	SEP	0.11	5.28	3.09	3.19	3.28	0.02	0	0.02	3.77
	OCT	0	0	0	0	0	0	0	0	0
	TOTAL	203.6	280.31	177.28	135.17	126.27	164.13	140.17	201.74	144.03
1995	JUN	0.56	1.14	1.65	1.95	1.85	0.73	0.86	0.6	1.81
	JUL	13.49	23.19	13.34	10.31	12.74	12.52	10.17	14.63	15.4
	AUG	62.15	45.67	25.35	17.89	17.28	56.81	25.16	70.44	20
	SEP	3.72	3.33	0.91	3.54	4.85	3.56	6.71	4.29	5.64
	OCT	0	0	0	0	0	0	0	0	0
	TOTAL	79.92	73.33	41.26	33.69	36.71	73.61	42.9	89.97	42.85

YEAR	MONTH	SUB-BASIN WISE CALCULATED RUNOFF								
		19	20	21	22	23	24	25	26	27
1992	JUN	0.13	0.01	0	0	0	0.02	0	0.03	0.31
	JUL	12.41	12.5	9.2	18.06	18.93	11.87	16.76	12.9	21.44
	AUG	55.19	48.78	40.08	52.18	45.9	37.14	40.65	35.63	59.08
	SEP	35.21	48.97	50.75	75.3	66.23	45.17	58.65	43.28	52.1
	OCT	0	0	0	0	0	0	0	0	0
	TOTAL	103	110.25	100.03	145.54	131.05	94.21	116.06	91.83	132.94
1993	JUN	0.57	0.51	0.3	1.01	0.89	0.72	0.79	1.89	3.15
	JUL	1.35	2.77	2.33	4.95	7.13	4.11	5.33	6.71	5.85
	AUG	14.04	19.85	15.4	20.18	24.36	14.67	20.53	24.98	17.2
	SEP	19.98	26.59	29.5	41.13	36.18	18.35	32.04	31.64	21.58
	OCT	0	0	0	0	0	0	0	0	0
	TOTAL	35.93	49.72	47.53	67.27	68.56	37.86	58.69	65.22	47.78
1994	JUN	26.58	19.42	10.79	14.6	12.84	7.16	11.37	9.19	9.84
	JUL	48.39	39.25	50.31	43.43	35.43	14.61	31.38	48.75	23.96
	AUG	76.8	65.64	74.45	58.87	51.78	34.75	45.86	68.38	45.08
	SEP	2.95	0.78	0.18	0	0	1.96	0	0	6.73
	OCT	0	0	0	0	0	0	0	0	0
	TOTAL	154.7	125.09	135.73	116.9	100.05	58.49	88.6	126.32	85.62
1995	JUN	1.79	1.32	0.77	0.64	0.56	0.03	0.5	2	0.48
	JUL	12.33	14.48	13.68	11.86	18.02	7.81	15.96	14.28	11.65
	AUG	23.49	15.85	26.19	15.76	13.86	9.23	12.28	36.16	16.85
	SEP	2.47	4.03	3.5	9.21	8.1	2.37	7.18	3.43	5.29
	OCT	0	0	0	0	0	0	0	0	0
	TOTAL	40.09	35.69	44.14	37.47	40.55	19.44	35.91	55.88	34.26

TABLE - 18 : ESTIMATED MONTHLY RUNOFF FOR VARIOUS SUB-BASINS OF BEBAS UPTO DAMSITE (MCM)

YEAR	MONTH	SUB-BASIN - 1	SUB-BASIN - 2
1992	JUN	0	0
	JUL	17.95	11.23
	AUG	89.33	81.49
	SEP	60.5	50.59
	OCT	0	0
	TOTAL	167.79	143.31
1993	JUN	10.07	2.27
	JUL	10.51	9.04
	AUG	64.66	48.57
	SEP	39.19	45.71
	OCT	0	0
	TOTAL	124.42	105.59
1994	JUN	40.43	9.03
	JUL	82	59.94
	AUG	100.54	81.7
	SEP	8.74	0.82
	OCT	0	0
	TOTAL	231.7	151.49
1995	JUN	14.02	0.22
	JUL	31.71	25.6
	AUG	25.93	25.16
	SEP	0.44	20.36
	OCT	0	0
	TOTAL	72.1	71.33

TABLE - 19 : MONTHLY AND SEASONAL SURFACE RUNOFF FOR SONAR AT GARHAKOTA, BEARMA AT GAISABAD AND BEBAS AT RAJGHAT DAMSITE

YEAR	MONTH	SONAR UPTO GARHAKOTA		BEARMA UPTO GAISABAD		BEBAS UPTO DAMSITE	
		CALCULATED	OBSERVED	CALCULATED	OBSERVED	CALCULATED	OBSERVED
1992	JUN	20.53	0	19.17	0.00	0.01	NA
	JUL	57.97	39.91	380.79	231.81	29.18	NA
	AUG	257.2	310.93	714.19	1125.22	94.92	NA
	SEP	157.08	178.46	703.72	1394.46	74.81	NA
	OCT	0	5.87	0.00	0.00	0.18	NA
	TOTAL	492.78	535.17	1817.86	2751.48	199.10	NA
							0.00
1993	JUN	46.86	2.15	48.11	10.72	12.34	10.92
	JUL	51.32	54.94	215.51	74.77	14.03	18.93
	AUG	170.18	198.57	626.89	549.18	60.59	156.25
	SEP	127.93	147.62	496.61	705.42	49.36	102.20
	OCT	0	23.41	5.40	5.86	0.01	1.54
	TOTAL	396.29	426.69	1392.52	1345.96	136.33	289.84
1994	JUN	57.4	57.09	477.19	348.29	49.46	35.71
	JUL	397.72	399.77	1342.39	1541.10	141.94	104.80
	AUG	338.82	419.93	1409.51	2214.10	111.34	159.22
	SEP	31.56	82.98	57.83	122.65	7.29	20.50
	OCT	0	8.92	0.00	0.00	2.42	0.00
	TOTAL	825.5	968.69	3286.92	4226.13	312.44	320.23
1995	JUN	2.25	0	46.39	24.15	14.24	0.00
	JUL	73.56	79.4	357.85	294.61	32.04	62.53
	AUG	163.27	170.77	481.11	620.69	29.32	52.46
	SEP	69.42	88.56	83.60	106.80	11.91	36.70
	OCT	0	5.39	0.00	0.00	0.52	0.57
	TOTAL	308.5	344.12	968.96	1046.25	88.04	152.26

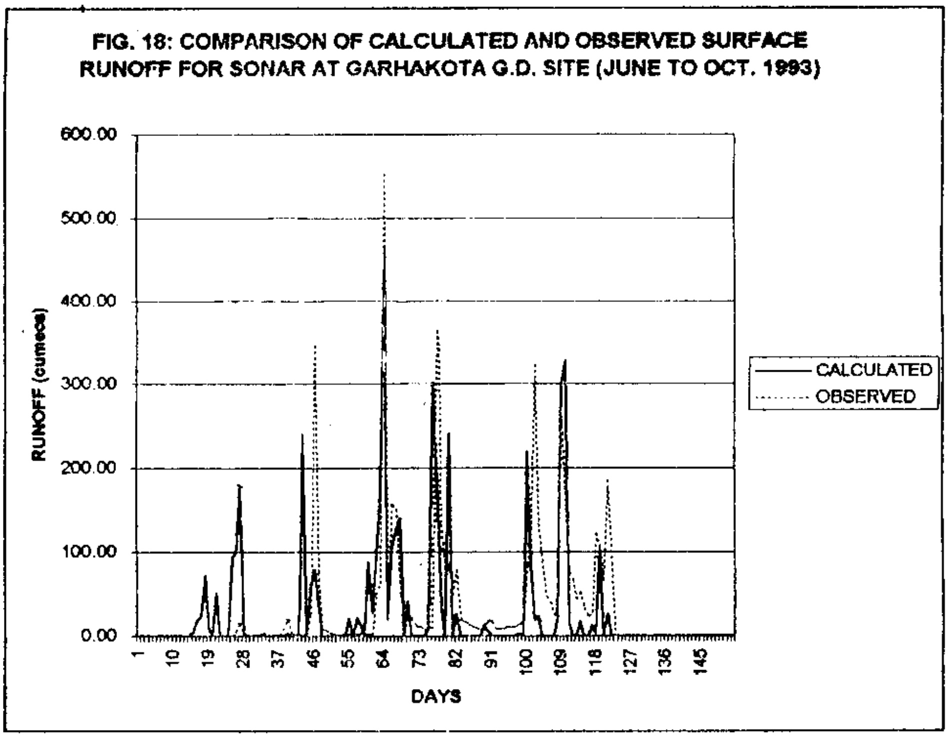


FIG. 18: COMPARISON OF CALCULATED AND OBSERVED SURFACE RUNOFF FOR SONAR AT GARHAKOTA G.D. SITE (JUNE TO OCT. 1993)
600.00
500.00
400.00
300.00
200.00
100.00
0.00
RUNOFF (cumecs)
1
10
19
28
37
46
55
64
73
82
91
100
109
118
127
136
145
DAYS
CALCULATED
OBSERVED

calculated and observed surface runoff for Sonar at Garhakota G.D. site is presented in Fig.19. Similarly, the graph showing comparison of calculated and observed daily runoff for Bearma basin upto Gaisabad for the monsoon period (June to Oct.) for the year1992 has been presented in Fig. 20. The bar chart showing the comparison of monthly calculated and observed surface runoff for Bearma at Gaisabad G.D. site is presented in Fig. 21. The graphs showing comparison of calculated and observed daily runoff for Bebas basin upto Rajghat damsite for the monsoon period (June to Oct.) for the year 1994 has been presented in Fig. 22. The bar chart showing the comparison of monthly calculated and observed surface runoff for Bebas upto Rajghat damsite is presented in Fig. 23.

FIG. 19: COMPARISON OF MONTHLY CALCULATED AND OBSERVED SURFACE RUNOFF
FOR SONAR AT GARHAKOTA G.D. SITE

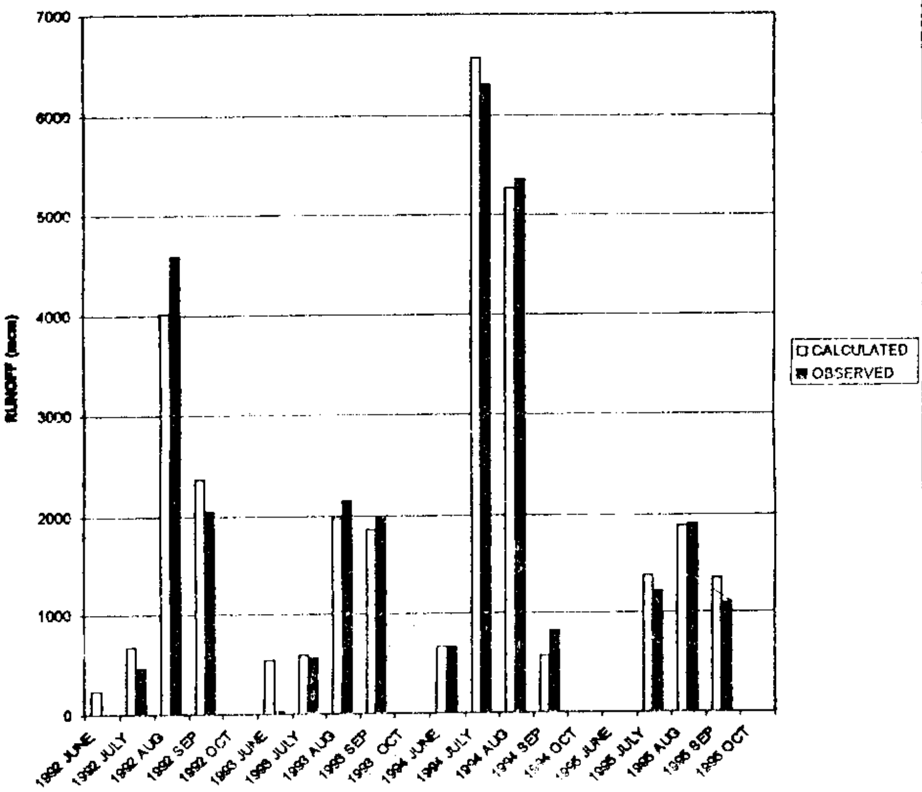


FIG. 29: COMPARISON OF CALCULATED AND OBSERVED SURFACE RUNOFF FOR BEARMA UPTO GAISABAD G.D. SITE (1992)

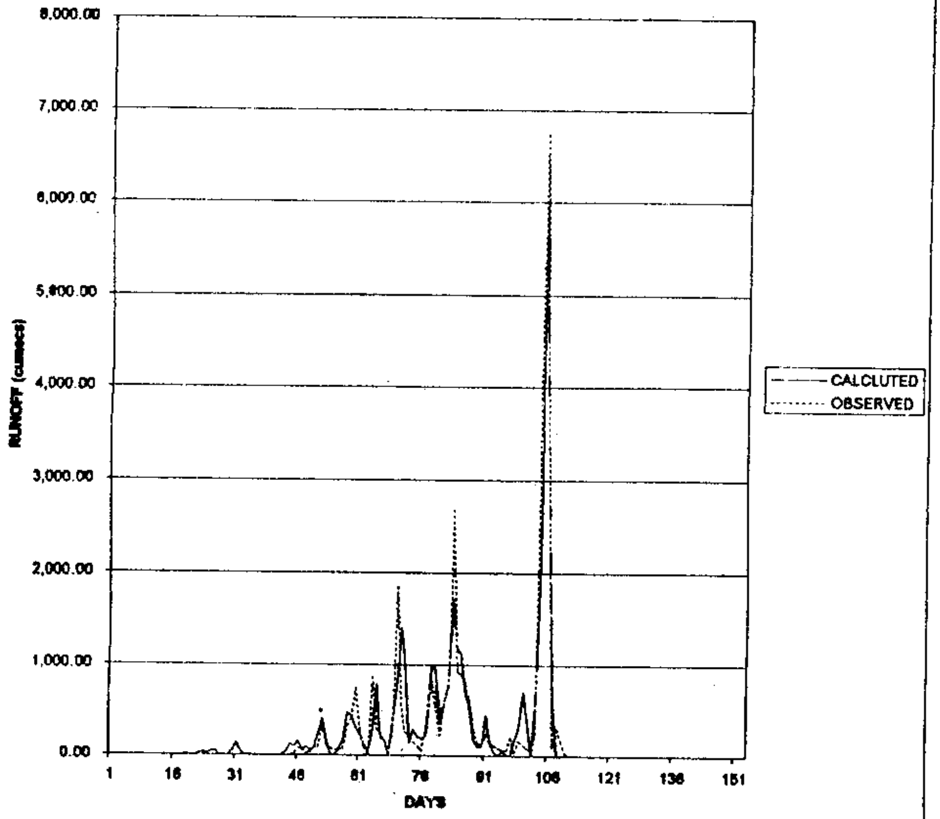


FIG. 21: COMPARISON OF MONTHLY CALCULATED AND OBSERVED SURFACE RUNOFF FOR BEARMA AT GAISABAD G.D. SITE

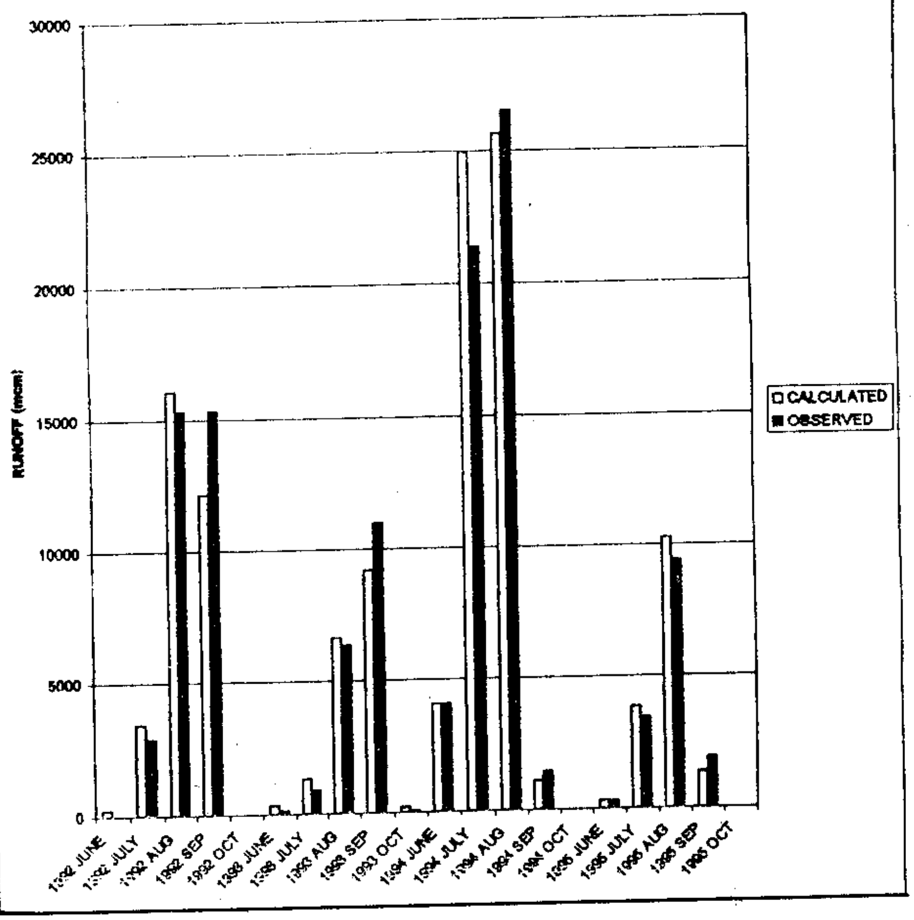
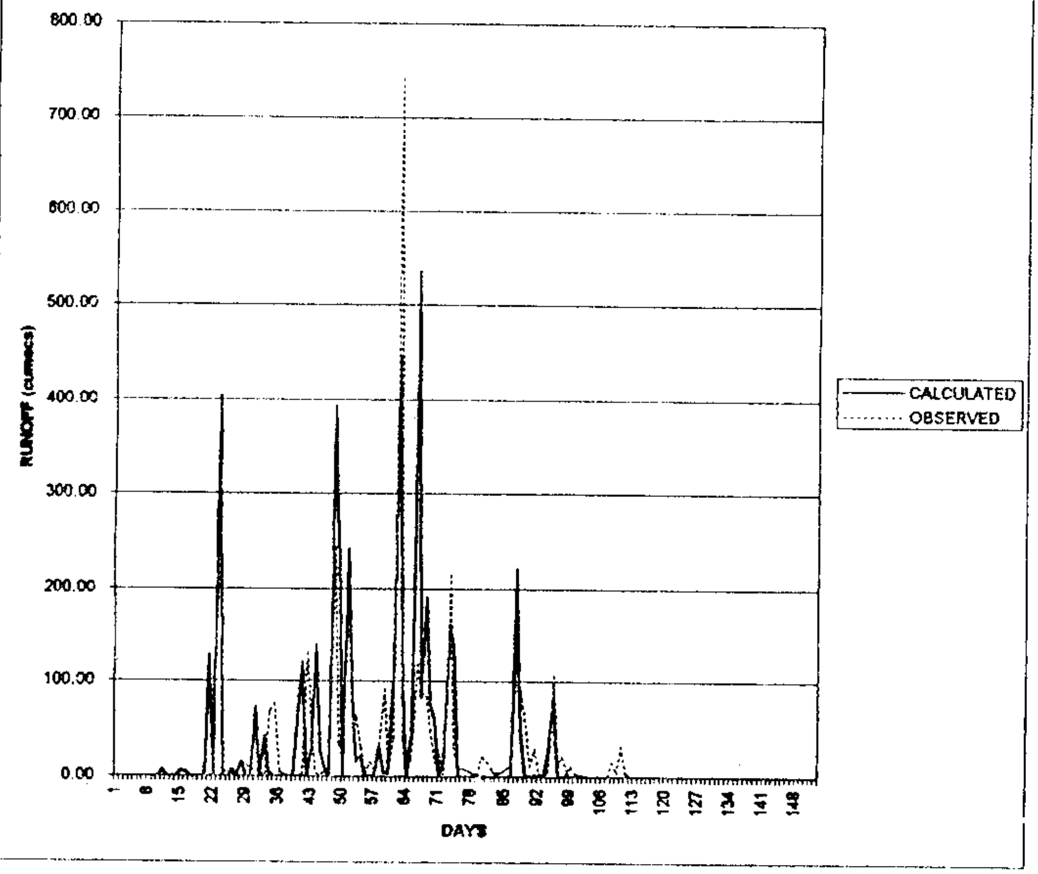


FIG. 22: COMPARISON OF CALCULATED AND OBSERVED SURFACE RUNOFF FOR BEBAS AT RAJGHAT DAMSITE (JUNE TO OCT, 1994)



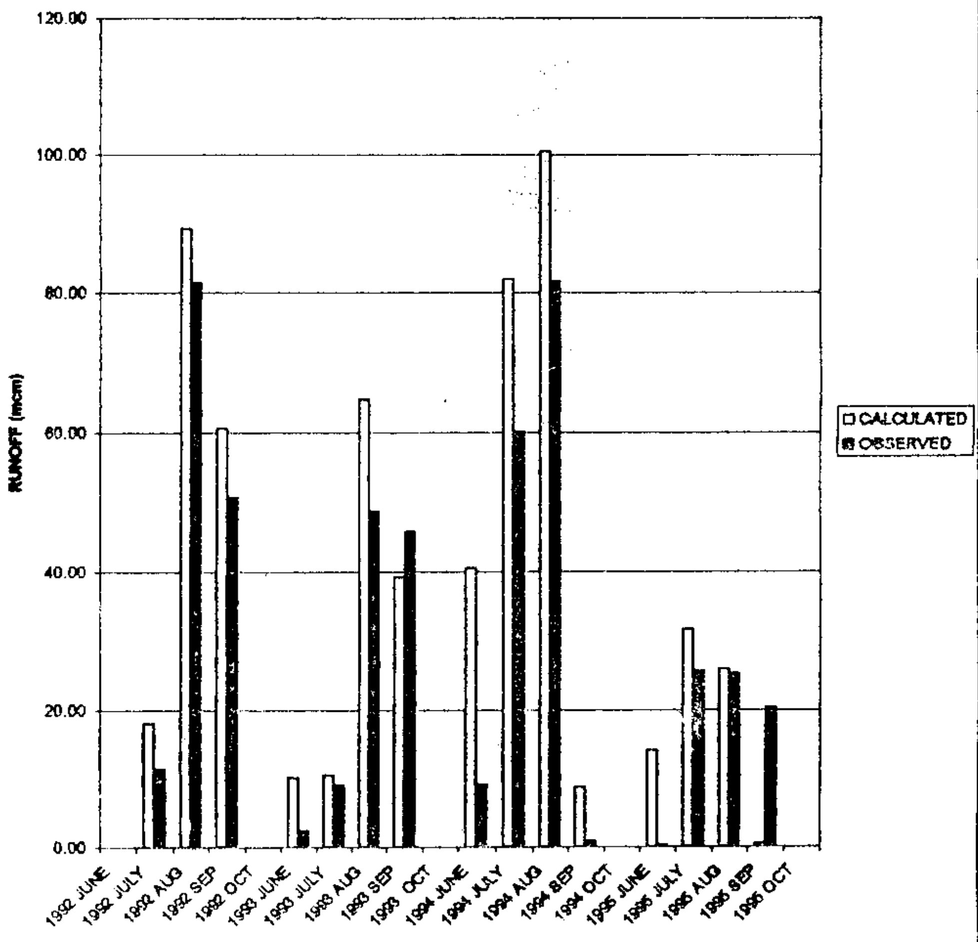


FIG. 23: COMPARISION OF MONTHLY CALCULATED AND OBSERVED SURFACE RUNOFF FOR BEBAS AT RAJGHAT DAMSITE

9.0 RESULTS AND DISCUSSIONS

The results obtained after the critical analysis provide a basic insight into the hydrology of river Ken and its various tributaries. The results may be summarised as under.

1. Out of the total 12 raingauge stations located in and around the Sonar basin, only 3 raingauge stations have been found to influence the catchment of Sonar upto Garhakota gauge-discharge site, viz., Sagar, Rehli and Deori whereas all the seven raingauge stations situated in and around the Bearma basin influence the catchment upto Gaisabad gauge-discharge site. Similarly only 3 raingauge stations influence the catchment of Bebas upto Rajghat damsite.

2. It has been observed that the rivers and its tributaries have very low flows and the area is subjected to frequent water scarcity problem, despite the average annual rainfall of the study area being about 1200 to 1250 mm.

3. The preparation of land use maps from the IRS-1A, LISS II, satellite imageries and its subsequent verification with the ground truth data indicates that the land use mapping carried out for various sub-basins is fairly satisfactory and can be relied for the estimation of the curve number. Similarly, land use maps can also be prepared for the remaining sub-basins, wherever required, for assessing the water potential by SCS model.

4. The figures showing the comparison of the calculated and observed daily surface runoff indicates that for most of the years there is not much of a variation between the observed and calculated flows, although some peak events do not match. However there is not much variation in the calculated and observed monthly surface runoff.

5. The figures showing the comparison of the calculated and observed daily runoff clearly indicate that the method employed in estimating the total basin rainfall, by finding the time of concentration and adjusting for the time lag wherever necessary, is correct. For the Bebas and Sonar river basins the time lag was less than one day, whereas for the Bearma basin upto Garhakota, the time lag varied between 1 to 2 days. The figures clearly indicate that the effects of time lag have been well incorporated in estimating the total basin surface runoff, as the pattern of the hydrographs are same for both calculated and observed runoff.

6. The bar charts showing the comparison of the calculated and observed monthly surface runoff at the G.D. sites, indicate that as the variation in the observed and calculated runoff is not much, the SCS model can be satisfactorily applied to the area under study.

7. From the tables depicting the calculated and the observed surface runoff, on a monthly basis there are some variations, but on a seasonal basis, the variations are not much and the results may be considered to be satisfactory.

10.0 CONCLUSIONS

The following conclusions have been drawn from the analysis.

1. Satellite data can be effectively used for mapping land use and land cover. The use of remote sensing for determination of land uses saves time and is less expensive as compared to conventional methods. The satellite based remote sensing has advantages like large area coverage and capability to provide information over all accessible and inaccessible regions. However the success of remote sensing depends on the accurate interpretation of the false color composites.

2. The data length of four years is not adequate for a comprehensive analysis, even though the present analysis gives an insight into the water yield computing techniques and the low flow pattern prevailing in these basins. The data length should be sufficient enough to be compatible with the project life of the water resources scheme. As the information on discharge data was limited, the study was carried for a period of four years to verify the results obtained by the model. As it is seen that the variation between the calculated and observed surface runoff is not much, this technique can now be applied for the previous years, where only rainfall data is available, assuming the land use pattern to be similar to the present land use.

3. In this report, the rainfall- runoff relation has been established using SCS model. The comparison of the observed and calculated daily surface runoff shows that the SCS model can be applied satisfactorily for these small sub-basins where runoff data is not available.

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