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REGIONAL LOW FLOW ANALYSIS FOR NARMADA BASIN

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ABSTRACT

The term low flow is broadly used to describe stream flows that are significantly below average or below normal flow levels. Reliable estimation of low stream flows is necessary to investigate drought characteristics of the basin and to describe the capability of a stream to supply requirements for river navigation, municipal and for industrial supplies, liquid water disposal, irrigation and maintenance of suitable conditions for aquatic life. The important characteristics in the study of low stream flow are the magnitude, frequency and duration. Regional models are developed relating the flow characteristics with climatological, hydrogeological and morphological factor for estimation of low flow characteristics for ungauged sites.

In the report a regional hydrological model is developed for estimating flow characteristics at ungauged sites of Narmada basin using climatological, hydrological and morphological variables. The model is developed by relating the low flow characteristics with other variables of nine sub basins of Narmada. Correlation analysis suggested that the variables like drainage area, slope of maximum stream length and percentage clay in soil could be the prime independent variable which could be related to the flow characteristics. Normal monsoon and nonmonsoon rainfall did not show the correlation with ten day flow duration characteristics. Mean annual minimum flow characteristics of flow indicated the correlation with base flow index and the rainfall of December month. Factor analysis indicated the highest ranking of the independent variables in the model are drainage area followed by slope of maximum stream length and percentage clay in soil. The model showed the adjusted coefficient of determination greater than 0.95. The mean annual minimum flow model indicated the highest ranking of base flow index followed by rainfall of December month. The models explains the adjusted coefficient of determination greater than 0.91. The verification results of both the flow characteristics are also presented.

1.0: INTRODUCTION

Hydrological drought in general is below normal water availability in streams, reservoirs, lakes, tanks, aquifer and in soil moisture. Whipple (1966) defined a drought year as one in which the aggregate runoff is less than the long term average runoff. Yevjevich (1967) defined the term hydrological drought as the deficiency in water supply, or deficiency in precipitation, effective precipitation, runoff or in accumulated water in various storages. Linsley et. al. (1975) defined hydrological drought as a period during which stream flows are inadequate to supply established uses under a given water management system. Therefore, the quantification and prediction of water availability is essential for water resource planning and to meet the increasing demand. The deficits in surface water resources are mainly reflected through low stream flows, which is also a measure of drought. The hydrological drought phenomenon, related to surface water can therefore be better studied through low stream flows. The magnitude and the frequency of occurrence of low flow are the important characteristics of low flow. Keeping this in view an attempt has been made to formulate regional low flow equation for Narmada Basin based on climatological, hydrological and morphological variables of the basin.

2.0: REVIEW

Stream flow especially the low flow is one important parameter which reflects the magnitude and severity of hydrological drought. The low flow is defined as the annual occurring minimum flow of short duration. For defining low flow, the parameters magnitude, frequency and areal extent are needed. The magnitude of low flow determines the amount of water available for specified uses over a given period. The frequency of occurrence of low flow events reflects the risk of failure of availability of certain flow . Several concepts relating to low flow, magnitude and duration of low flow are given in Institute of Hydrology (1980).

The low flow is defined by Institute of Hydrology (1980) as low or no rain, absolute minimum or lowest flow, by a series of low flow and discharge not exceeded in certain fixed days . The other low flow characteristic is the flow duration, this gives idea about the length of record. The lower end of the flow duration curve is an expression of the low flow characteristics of the stream. This characteristic of low flow is the rate at which the flow is recorded in the absence of the rain. The frequency curve of annual low flows of a stream describes both natural variation in stream flow and the variation due to regularities. Weisman (1978) characterized the low flow by defining the longest run length in a year below a given threshold flow as an extreme value run and prepare frequency curve of threshold flow for various run length.

The information needed while analysing the low flow is the magnitude, duration and frequency of low flow. For describing a low flow, Salas (1980) defined the low flow variables as low flow volume, discharge, stage and duration. The methodology for low flow computation can be divided into three main groups as deterministic, statistical and stochastic approaches. There are various methods available in literature to analyse low flows for both gauged and ungauged catchments and catchments with adequate and inadequate data. The deterministic models are basically conceptual models. These models are assumed to follow a definite law of certainty. It may be applied to the situations, when it is difficult to provide a statistical description of low flow to investigate drought. Gusti and Mayer (1978), Prakash (1981A), and Dholakia (1985) attempted to deterministic approaches for computing low flows for drought analysis.

Hall (1968) analysed the low flow during drought and indicated that the hydrograph of low flow essentially represents the base flow. Prakash (1981B) discussed a deterministic approach for estimating the contribution of irrigation return flow, rainfall and upstream releases to an effluent stream under drought conditions. Verma (1979) proposed a non linear storage routing equation in combination with the base flow recession to predict low flow for effluent streams.

Various statistical approaches are available in literature to analyse low flows both for gauged and ungauged catchments. It include low flow duration curve, low flow frequency analysis, study of deficit volume of stream flow. In analysing the stream flow, the simplest technique is to construct a flow duration curve.

The flow duration curve is a cumulative frequency curve that shows the percentage of time during which specified discharge

were equalled or exceeded during the period of record. The procedure of constructing flow duration curve is given by Institute of Hydrology (1980). Depending upon the record of data the guidelines suggested by Institute of Hydrology (1980) are as follows;

1. If data are more than ten years, then these data will not need any adjustment or standardization as these data record will provide an accurate flow duration curve.

2. If data is between two to ten years then one have to devide flow data by average flow over the period of record before analysis.

3. If the period of record is less than two years, then one can use the empirical methods to estimate the data.

The weakness of flow duration curve is that, it deals only with discrete value of flow and reveals nothing about the sequences of low flow. Flow duration value of 90, 95 and 99 percent are normally used as measure of stream low flow potential in hydrological drought studies.

Stochastic models produces a synthetic record of hydrologic data having an equal likelihood of occurrence as the historical record. Stochastic modelling for stream flow generation have been used by superimposing a random fluctuation on a deterministic component using the basic statistics of the historical records.

Askew et. al. (1971) observed that existing synthetic stream flow generation models fail to accurately reproduce historical critical periods. James et. al. (1981) compared the stochastic stream flow model for drought analysis and found that ARMA-Markov and ARMA models are the best overall models in terms of preserving short and long term persistence of stream flow sequences.

The low stream flow is affected by many factors. Some of the factors are classified into groups of climatic factors, hydrogeological factors, morphological factors, morphometrical factors and social factors.

The climatic factors includes precipitation, evaporation, humidity and temperature. The amount of precipitation, intensity and its distribution over time is reflected in both surface water and ground water storage. Graphical relationships are reported between precipitation and low flow are by McMahon and Arenas (1982) and UNESCO (1982).

The hydrogeological factors are the geology of the basin and groundwater. The soil properties and the soil strata affects the low flows. The basin which have unconsolidated sands and gravel produce a sustained flow while on the other hand, the basin consist of unfractured igneous rocks and, clays produce a little flow. The ground water storage depends upon the geological structure and hydrogeological condition of the basin.

The Morphological factors like basin relief and the presence of lakes and swamp affects the low flow (Singh and Stall, 1974). The morphometrical factors like basin area, slope channel storage affects the low flow. The social factors are the urbanization and development of storage structures.

Estimation of low flow at ungauged site or the regionalization depends on hydrological knowledge of region. The low flow at ungauged site can be obtained by the relationship between the flow characteristics and one or more basin and other characteristics. To achieve the objective, it is necessary to do regional study of all possible gauged site for flow characteristics and variables affecting the flow. Flow duration curves are widely used to obtain flow characteristics. Much of the literature on flow duration curves concentrated upon graphical methods for constructing a flow duration curve is by Foster (1934) and Searcy (1959).

Regionalization of discharge commonly uses one of three basic procedures as below;

a) Fit a statistical distribution or graphical method for constructing a flow duration curve to individual flow data. Relate the distribution parameters to physical basin characteristics.

b) as reported in (a), but relate discharge with specified return period to physical characteristics, and

c) as reported in (a) using individual flow gauge data, but transforming the discharge to non-dimensional form by dividing by the mean discharge and relating to physical characteristics.

Regionalization and relating the statistical or flow parameters for short or long series data is presented by Dalrymple (1960), NERC (1975), Pilgrim (1989) and Riggs (1990). To identify objectively homogeneous hydrological regions, multivariate techniques have been widely applied using either hydrological characteristics or catchment characteristics. Cluster analysis, discriminant analysis, analysis of variance and principal component analysis are the tools commonly used for the investigation of regional floods (Mosley, 1981; Waylen and Woo, 1984; Gottschalk, 1985' Wiltshire, 1985). The Euclidean distance method of clustering is most commonly used. Hence the similarity between clustering variables were measured by Euclidean distance.

The similarity measure is highly dependent upon the scale of measurement used in the cluster analysis. The characteristics that are measured in large numbers will contribute more to the similarity measure than the characteristics recorded in smaller number. The characteristics could be standardized by using the eigenvalue based on the assumption that the principal components play the same important part in grouping the clusters. Therefore, the characteristics were standardized to have the same weight in cluster analysis. Before cluster analysis is applied to group the catchments, the clustering variable should be suitably chosen for analysis because of its influence on the results.

3.0: STUDY AREA AND DATA

The development of regional equations for low flow characteristics for Narmada basin, the flow data at twelve gauge sites; Mohgaon on Burhner river, Hridaynagar on Banjar river, Gadarwara on Shakkar, Belkheri on Sher river, Patan on Hiran river, Manot on main Narmada river Chhigaon on Ganjol river, Kagon on Beda river, Chhotatawa on Ginnor river, Tikola on Hathi river Bareli on Barna river and Maheshwar on Tindoni river is considered. The location of sub basins considered for analysis are reported in Fig. 1 and Fig 2. Daily discharge data measured at 8.00 a.m. were collected from Central Water Commission, New Delhi. The flow data availability and length of records is

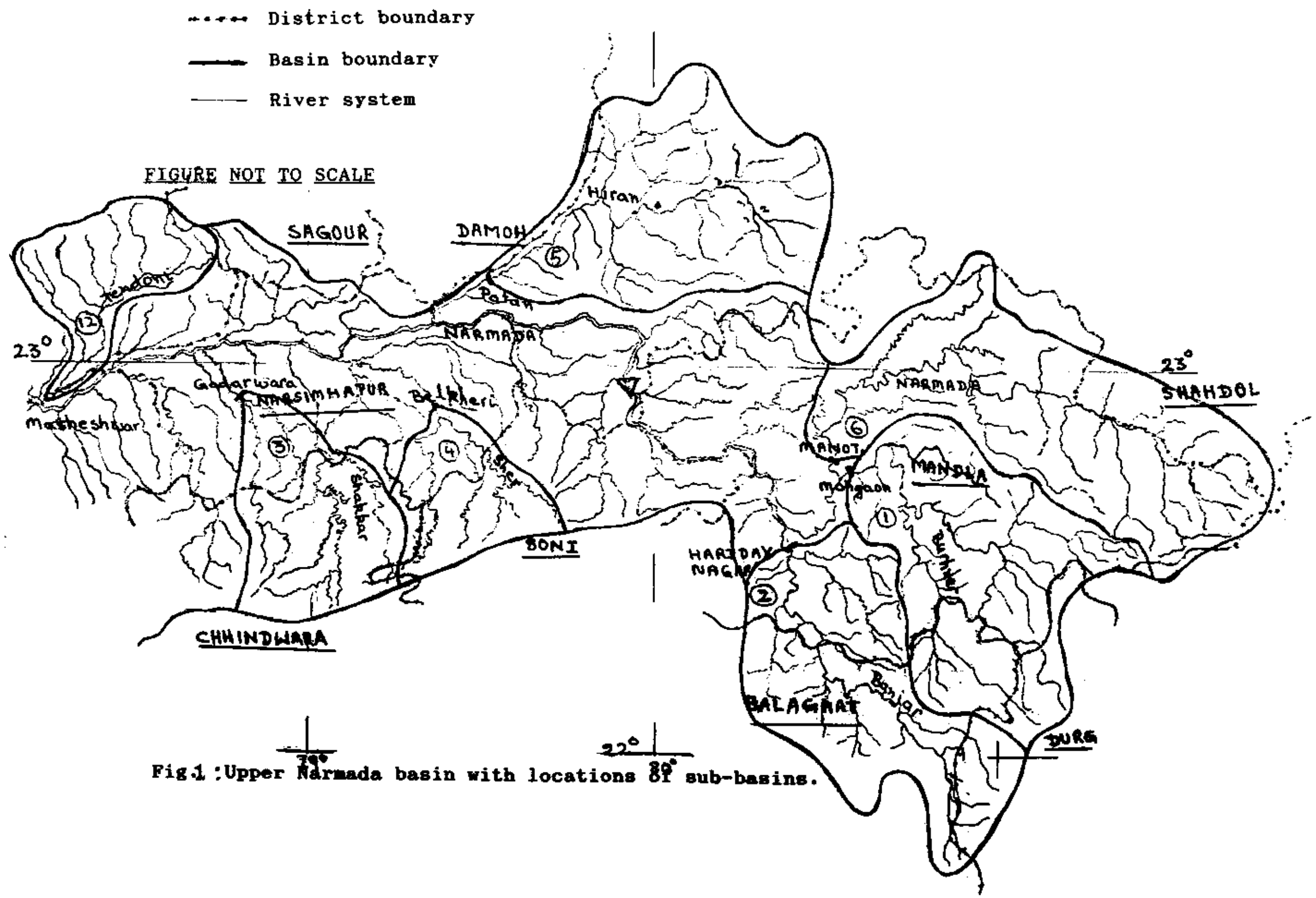

Fig.1 :Upper Narmada basin with locations of sub-basins.

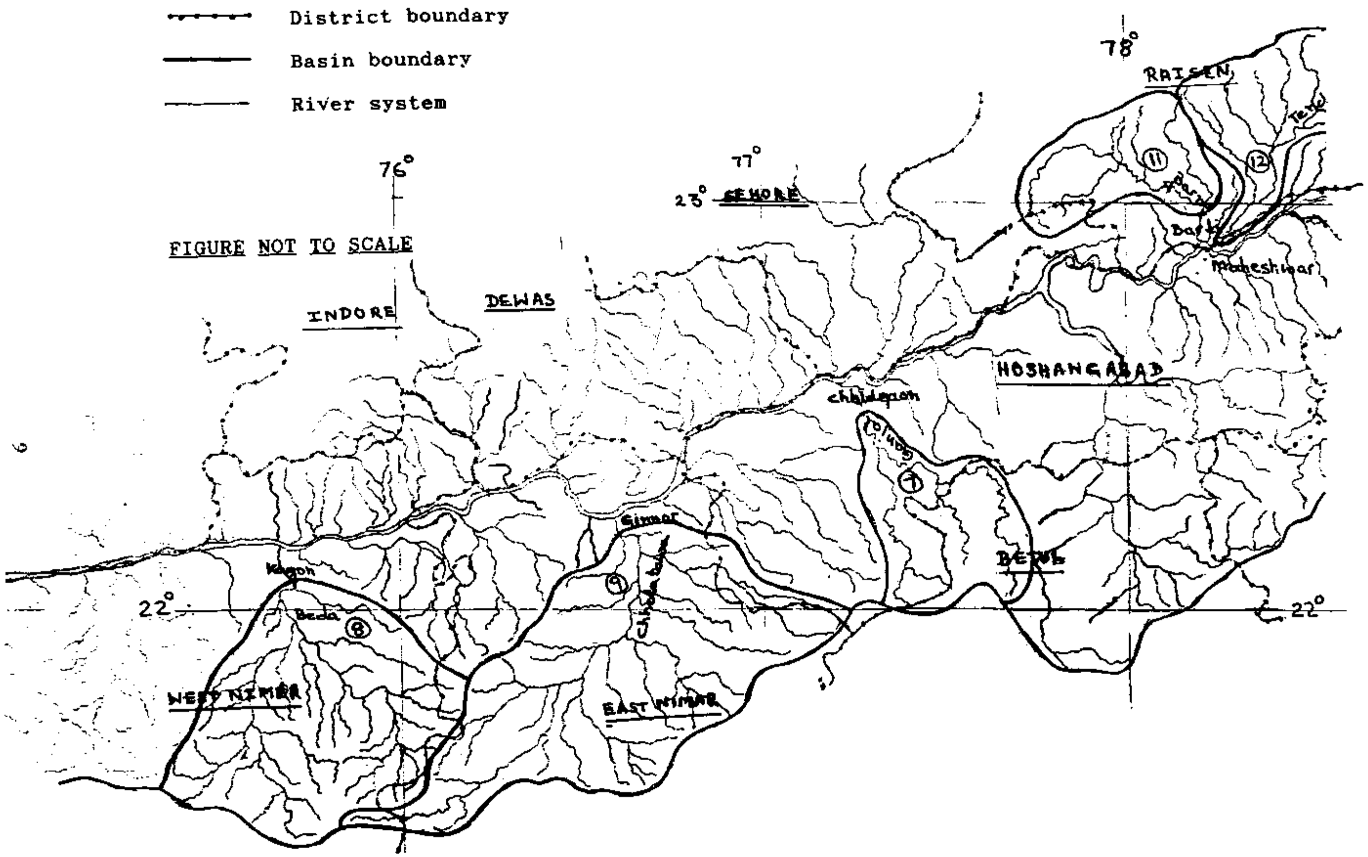

Fig. 2: Middle Narmada basin with locations of sub-basins.

reported in Table 1.

Table 1: Daily discharge data availability of twelve sub basins in Narmada basin.

Sl. no.	Name of Sub-basin	Name of gauge site	Starting date of record	Ending date of record	Data length (Years)
1.	Burhner	Mohgaon	1.6.77	31.5.93	15
2.	Banjar	Hridaynagar	1.6.77	31.5.93	16
3.	Shakkar	Gadarwara	1.6.77	31.5.93	16
4.	Sher	Belkheri	1.6.77	31.5.93	16
5.	Hiran	Patan	1.6.78	31.5.93	15
6.	Narmada	Manot	1.6.77	31.5.93	16
7.	Ganjal	Chhidaon	1.6.77	31.5.93	16
8.	Beda	Kagon	1.6.78	31.5.93	15
9.	Ginnor	Chhotatawa	1.6.71	31.5.93	22
10.	Hatni	Tikola	1.6.85	31.5.93	8
11.	Barna	Bareli	1.6.85	31.5.93	8
12.	Tindoni	Maheshwar	1.6.85	31.5.93	8

4.0: METHODOLOGY AND ANALYSIS

The methodology for regionalization of low flow consists of the following steps. The preparation of data includes the analysis for flow duration curve, and flow frequency curve from the data reported in table 1 and estimation of hydrological, meteorological and soil variables of basin. For development and verification of the regional flow model the following analysis are carried out. First is the estimation of the correlation analysis of all the flow characteristics and variables in order to identify the independent correlated variables, in the second step the principal component analysis and factor analysis has been done in order to define the principle components and their percentage of variance in the regional model for flow characteristics, in the third step the analysis for hydrologically homogeneous grouping is carried by cluster analysis on flow characteristics, the forth step is the formation of model similar to the models reported in literature and in the fifth and final step the verification of the model is done with available data.

4.1: Analysis for Low Flow Characteristics

In this section the flow data is subjected to different analysis. It includes the analysis of ten daily flow duration curve and estimated values of ten daily flow at 95, 75 and 50 percent probability. The values of ten daily mean annual minimum are also estimated for the period from November 1st to March 31st of each year. Yearly mean and minimum flow of all the sites are subjected to statistical analysis.

4.1.1: The flow duration curve

The daily flow data are analysed to develop flow duration curve. The methodology used to analyse and develop the flow duration curve is as described by Institute of Hydrology (1980). A computer programme is developed with option to analyse the flow data for 1 day, 7 daily, 10 daily and monthly mean flow. The programme initially considers the starting date as June 1 and ending date as May 31, but has option to change the starting and ending date to avoid the period of zero flow in estimation. A ten day flow duration curve for all the sites is shown in Fig. 3.

The statistical summary of low flow based on twelve sub basins at 95 %, 75 % and at 50 % for different days duration is reported in Table 2. It can be seen that standard deviation reduces with increasing average at the same time the skewness increases.

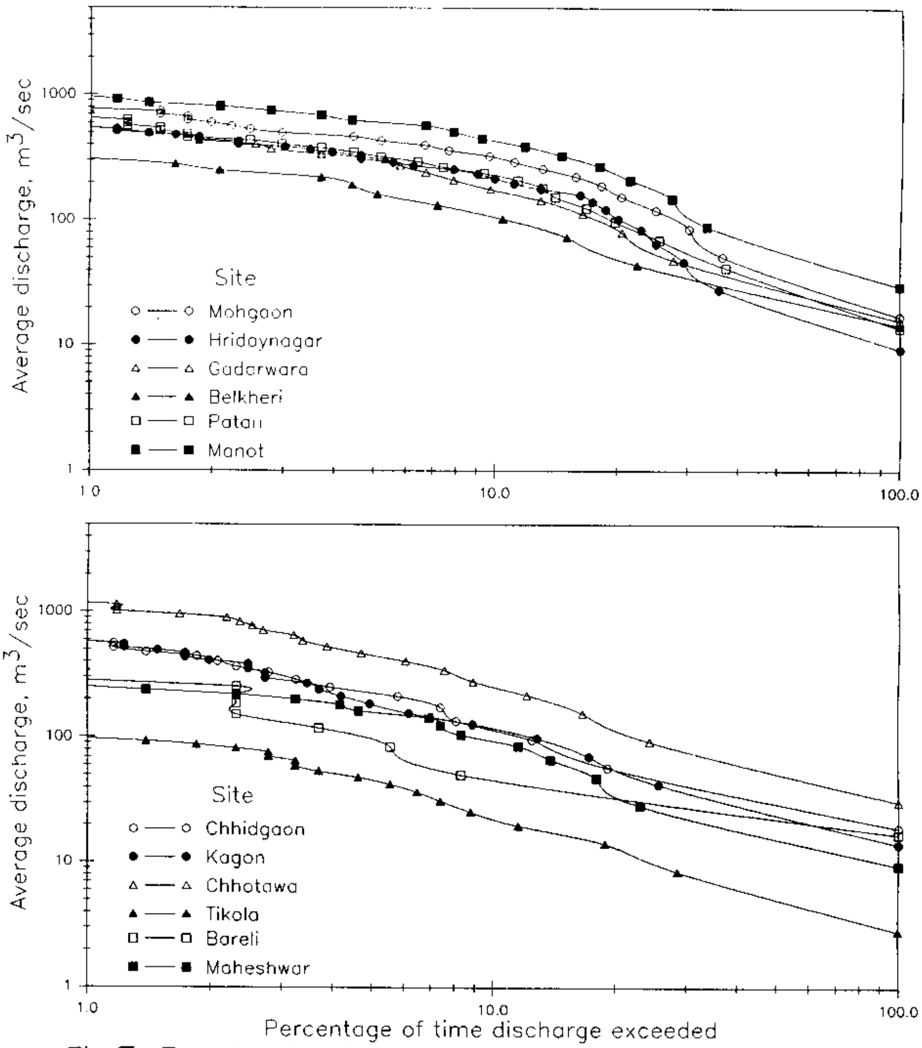

Fig.3: Ten day low flow duration curves for different sites.

Table 2: Statistical summary of mean low flow based on the data of twelve sub basins of Narmada.

Sl. No.	Number of stations	Low Flow measure	Low flow, m3/sec Days average, days 5	7	10	15	30
Mean							
1.	12	Q95	47.81	43.09	38.41	32.67	23.45
2.	12	Q75	54.31	49.06	44.02	37.89	28.10
3.	12	Q50	67.60	61.32	55.66	48.89	38.36
Standard deviation							
1.	12	Q95	33.14	31.20	28.21	21.58	13.30
2.	12	Q75	36.97	34.76	31.56	24.72	16.00
3.	12	Q50	44.59	41.84	38.23	31.22	22.10
Skewness							
1.	12	Q95	1.09	1.04	1.18	0.58	0.07
2.	12	Q75	1.06	1.00	1.14	0.59	0.12
3.	12	Q50	1.02	0.95	1.06	0.60	0.23

The programme calculates a straight line fitting of flow duration curve between log of average discharge and log of percentage of time the discharge exceeded and calculates for Q95(10), Q75(10), Q50(10). The values of ten day flow at different percentile for duration starting from July 1st and ending on March 31st is plotted in Fig. 4, Fig. 5 and Fig. 6 for Q95(10), Q75(10), Q50(10).

The behaviour of flow duration curve indicates a similarity among the sites. However, variation in the values of discharge, at different percentages of time discharge exceeded also exists among sites at low percentage. At high percentage, the flow duration curve has similar values. It suggests that the estimated flow duration curves could bifurcate at low percentage and will merge in to one at high percentage.

4.1.2: Statistical analysis by grouping

The statistical analysis of mean annual flow has also been carried out for grouped mean, coefficient of variance,

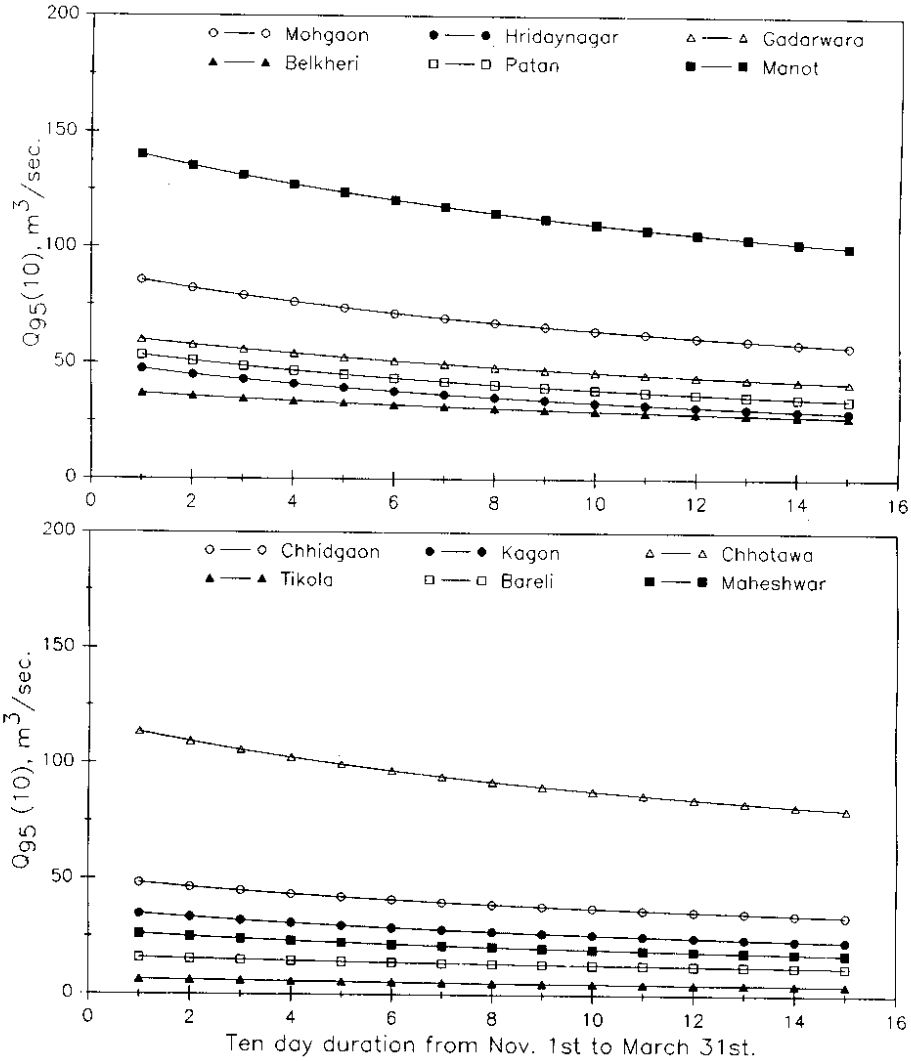

Fig.4: Average Q_{95} (10) flow for different 10 days duration.

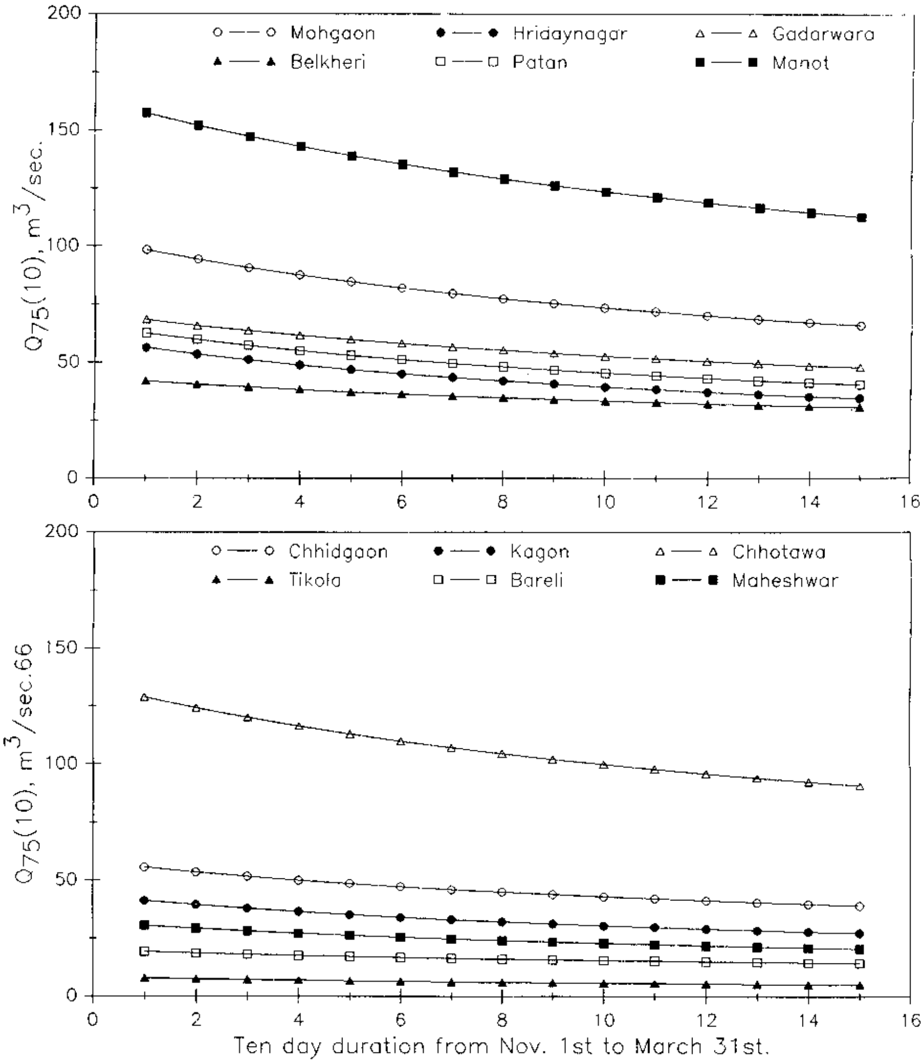

Fig.5: Average Q_{75} (10) flow for different 10 days duration

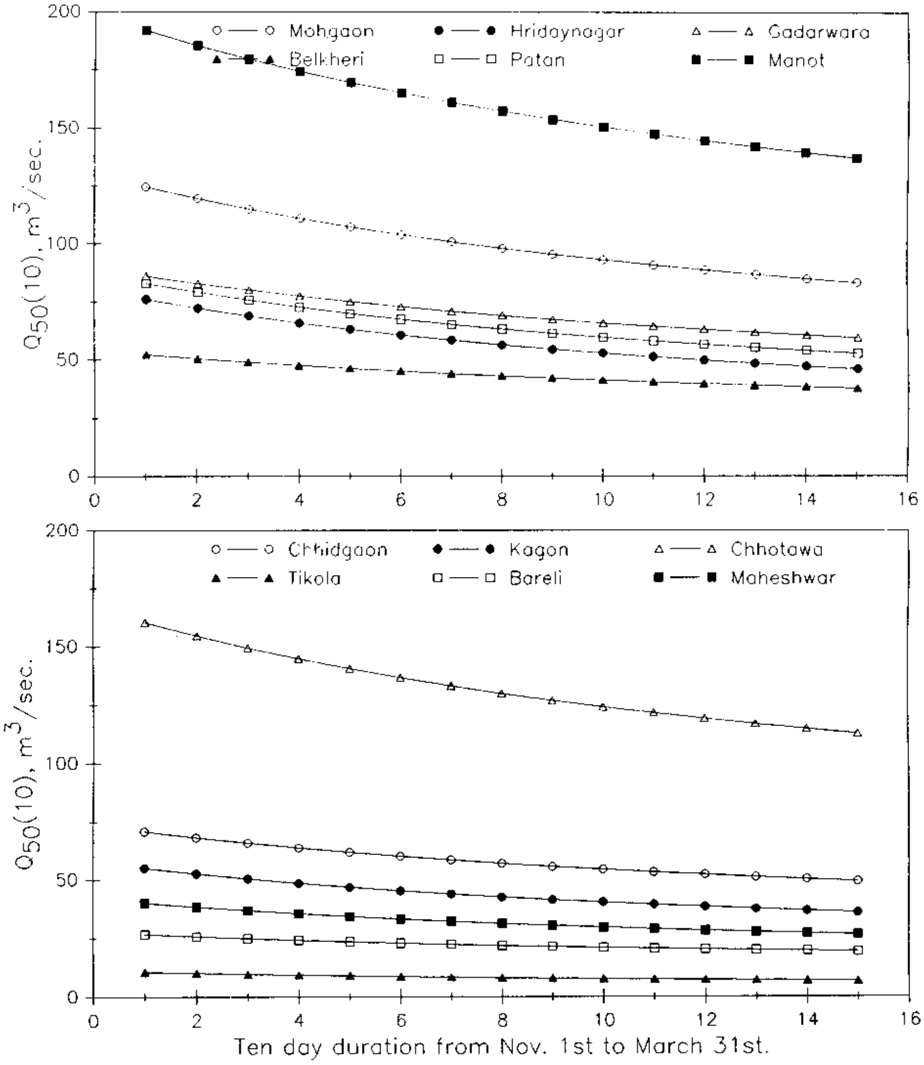

Fig. 6: Average Q_{50} (10) flow for different 10 days duration.

coefficient of skewness and for coefficient of Kurtosis. Following equations were used for the analysis of mean coefficient of variance, coefficient of skewness and coefficient of Kurtosis.

$$\text{Mean} = Qm = \frac{1}{N} \sum_{i=1}^{NC} Ei\ Qi \quad --(1)$$

$$\text{Standard deviation} = SD = \frac{1}{N-1} \sum_{i=1}^{NC} Ei\ (Qi - Qm)^{**2} \quad --(2)$$

$$\text{Coefficient of variance} = SD / Qm \quad --(3)$$

$$\text{Coefficient of skewness} = \frac{1}{(N-1)\ (N-2)} \ \frac{\sum_{i=1}^{NC} Ei\ (Qi - Qm)^{**3}}{SD^{**3}} \quad --(4)$$

$$\text{Coefficient of Kurtosis} = \frac{1}{(N-1)\ (N-2)\ (N-3)} \ \frac{\sum_{i=1}^{NC} Ei\ (Qi - Qm)^{**4}}{SD^{**4}} \quad --(5)$$

Where; E is number of events in class Q (discharge), NC is the number of classes in which data is grouped. The above programme also calculates the statistical property of grouped data and is reported in Table 3.

Table 3: Statistical information of estimated mean annual flow.

Sl. No.	Name of basin	Gauged site	Mean low flow	Coefficient of		
				Variance	Skewness	Kurtosis
1.	Burhner	Mohgaon	94.13	1.63	2.83	12.61
2.	Banjar	Hridaynagar	62.17	1.71	2.52	9.47
3.	Shakkar	Gadarwara	59.28	1.84	4.01	23.43
4.	Sher	Belkheri	37.50	1.78	6.15	62.05
5.	Hiran	Patan	68.38	1.77	3.43	17.27
6.	Narmada	Manot	132.62	1.60	3.09	15.84
7.	Ganjal	Chhidaon	49.29	2.07	5.77	45.51
8.	Beda	Kagon	45.61	2.08	5.12	34.35
9.	Ginnor	Chhotatawa	98.31	2.00	4.59	28.08
10.	Hatni	Tikola	9.86	2.09	5.05	33.51
11.	Barna	Bareli	29.68	2.56	10.17	123.43
12.	Tindoni	Maheshwar	31.75	1.98	4.80	33.17

The statistical analysis of groped data indicates a high variation in the mean flow of the sub basins considered. At the same time the values of coefficient of variance, coefficient of skewness and coefficient of Kurtosis are high and supports the variation.

4.1.3: Estimation of mean annul minimum and its statistical properties

The programme calculates minimum value of each year for length of record considered and at the same time the programme reports, the number of times the minimum value had occurred as zero in order to avoid the presence of zero values in the record and suggest for further shorting of annual duration. A subroutine calculates the mean annual minimum its coefficient of variance, coefficient of skewness and coefficient of Kurtosis report in Table 4. The ten daily mean annual minimum for the duration starting from November 1st to March 31st for different sites is shown in Fig. 7.

Table 4: Statistical properties of mean annual minimum flow.

Sl.No of basin	Mean annual minimum with with zero values	Coefficient of			No.of years record	Mean annual minimum with out zero values
		Variance	Skewness	Kurtosis		
1	1.29	.67	.61	3.20	1	1.38
2	1.03	1.11	2.09	8.76	2	1.18
3	5.37	.32	1.10	4.41	0	5.37
4	2.76	.54	.62	4.11	1	2.94
5	6.53	.40	-.40	2.56	0	6.53
6	2.96	.59	.97	3.94	0	2.96
7	2.32	.33	-1.21	4.23	0	2.32
8	1.12	1.29	1.22	4.69	8	2.40
9	0.47	1.47	1.93	6.91	8	.74
10	2.10	1.82	2.05	7.96	5	5.60
11	2.47	.73	-.08	4.24	2	3.29
12	0.55	.89	.90	5.12	2	.73

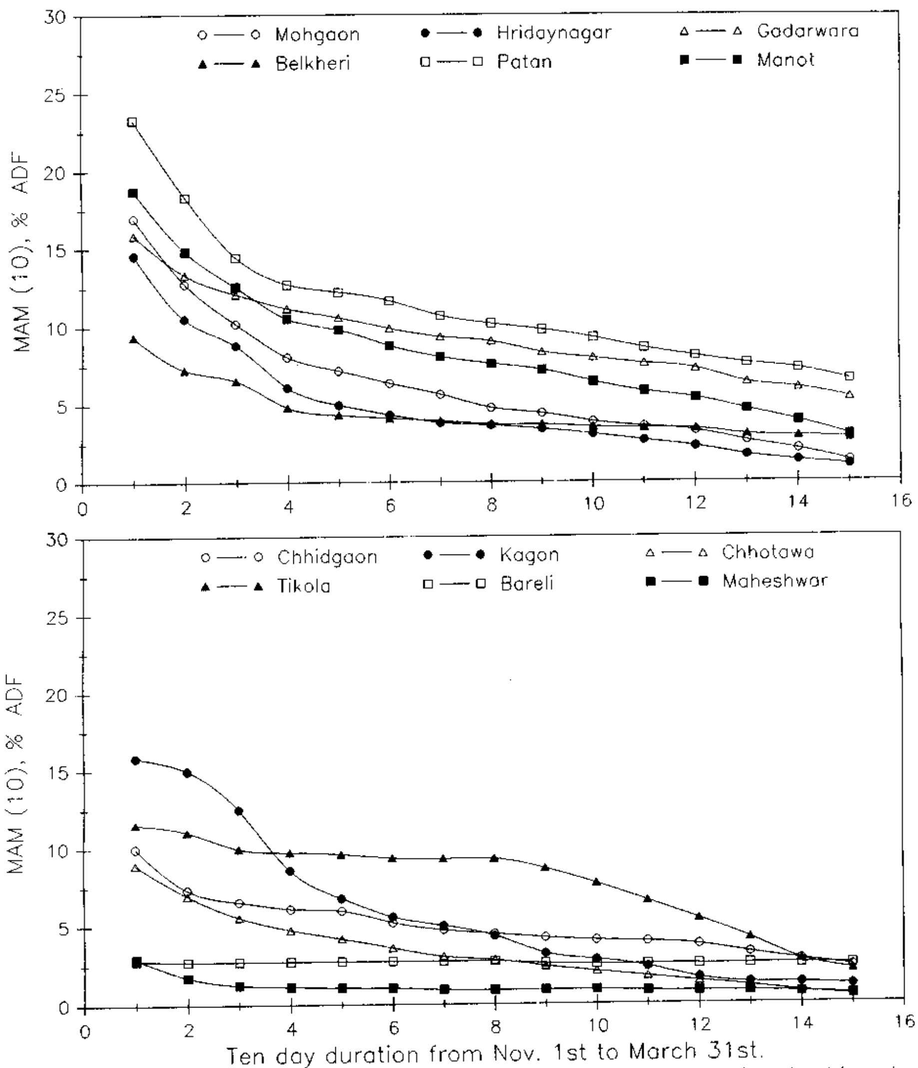

Fig.7: Average ten day mean annual flow from Nov. 1st to March 31.

For the case when a minimum value in a year is observed zero the mean annual minimum is again calculated by skipping that zero value. The mean annual minimum with zero values in it, its coefficient of variance, coefficient of skewness and coefficient of kortosis along with the mean annual minimum excluding zero values is reported in Table 4.

4.1.4: Estimation of base flow index

Two major hydrological characteristics identified and used in the model are the Base Flow Index (BFI). A number of regional low flow studies including Wright (1974), Klaassen and Pilgrim (1975). Institute of Hydrology (1980) and Pirt and Douglas (1982) have highlighted the importance of base flow index for indexing the hydrogeology of the catchment if flows are successfully to be predicted at the ungauged site.

The developed programme estimates base flow index using smoothing and separation rules on the mean daily flow hydrograph. The method is based on an idea by L'vovich (1972) and calculates the BFI. The programme calculates the minimum of three days consecutive period and searches for turning point in this sequence of minima. The published separation procedure (Institute of Hydrology, 1980) uses five days instead of three only because the catchments are not very fast responding.

The BFI values ranges from 0.1 to 1.0 for a very flashy river to very stable river. In present case the values of BFI ranges from minimum 0.11 to 0.24 and therefore all the sub basins could be considered as flashy or fast responding (Table 5). Regression relationships are derived relating BFI to low flow characteristics.

Table 5: Selected lowflow, geographical and other characteristics and variables of the sub basins of Narm

Basin code		B21	B20	B15	B17	B18	B22	B10	B7	B8	B2
Basin name		Burh	Banj	Shak	Sher	Hira	M.River	Ganjal	Beda	Ginnor	Hatni
Gauge site		Mohg	Hriday	Gadar	Belkh	Patan	Manot	Chaidg	Kagon	Cho.Tawa	Tikola
DL, Yrs		15	16	16	16	15	16	16	15	22	8
Q95(10),	m3/sec	57.43	28.91	41.78	26.93	34.26	100.43	34.05	23.17	80.22	4.21
Q75(10),	m3/sec	65.88	34.33	47.62	30.51	40.19	112.67	39.07	27.26	90.93	5.02
Q50(10),	m3/sec	83.38	46.11	59.61	37.78	52.84	137.23	49.46	36.01	112.74	6.81
MAM ZE,	% ADF	1.29	1.03	5.37	2.76	6.53	2.96	2.32	1.12	0.47	2.10
MAM,	% ADF	1.38	1.18	5.37	2.94	6.53	2.96	2.32	2.40	0.74	5.60
BFI,	Ratio	0.20	0.18	0.20	0.18	0.24	0.21	0.16	0.17	0.17	0.19
NOS,	Numbers	1266.00	730.00	983.00	514.00	621.00	1923.00	481.00	1410.00	1002.00	639.00
SO,	Numbers	6.00	5.00	5.00	5.00	5.00	6.00	5.00	6.00	6.00	5.00
MSL,	Cm	59.24	63.51	56.84	31.26	46.66	95.47	51.43	43.08	44.23	43.65
MXL,	Cm	65.45	63.71	58.02	34.15	53.96	102.13	55.08	47.29	63.24	43.65
AREA,	Cm2	663.07	495.67	360.87	241.79	484.78	805.16	284.00	650.53	838.92	334.89
ELOUT,	m	585.00	501.00	860.00	400.00	386.00	585.00	300.00	176.00	416.00	300.00
ELMSL,	m	950.00	700.00	1099.00	641.00	605.00	1059.00	710.00	820.00	500.00	460.00
ELMXL,	m	888.00	700.00	1099.00	800.00	582.00	962.00	700.00	849.00	700.00	460.00
L1,	Cm	648.12	399.29	469.63	280.73	411.29	993.09	310.33	849.56	799.42	432.05
L2,	Cm	196.27	130.03	130.73	83.40	143.15	271.60	74.36	249.22	187.60	99.63
L3,	Cm	65.38	56.74	83.82	49.36	65.15	100.22	37.85	131.53	182.89	57.01
L4,	Cm	58.62	47.91	53.80	27.25	22.19	69.32	68.37	36.26	42.04	29.77
L5,	Cm	30.49	27.30	32.71	3.18	40.33	31.63	0.38	36.03	30.08	12.67
L6,	Cm	40.47	0.00	0.00	0.00	0.00	70.91	0.00	10.45	4.45	0.00
TL,	Cm	1039.34	661.28	770.69	443.92	682.11	1536.76	491.28	1313.06	1246.49	631.13
O1,	Numbers	520.00	280.00	458.00	238.00	269.00	838.00	228.00	670.00	482.00	298.00
O2,	Numbers	116.00	74.00	100.00	49.00	67.00	190.00	52.00	155.00	108.00	68.00
O3,	Numbers	27.00	14.00	16.00	8.00	19.00	37.00	10.00	32.00	21.00	12.00
O4,	Numbers	6.00	3.00	4.00	2.00	5.00	10.00	2.00	7.00	6.00	3.00
O5,	Numbers	3.00	1.00	1.00	1.00	1.00	3.00	1.00	2.00	2.00	1.00
O6,	Numbers	1.00	0.00	0.00	0.00	0.00	1.00	0.00	1.00	1.00	0.00
TN,	Numbers	673.00	372.00	579.00	298.00	361.00	1079.00	293.00	867.00	620.00	382.00
MSL,	Km	148.10	158.78	142.10	78.15	116.65	238.68	128.58	107.70	110.57	109.13
MXL,	Km	163.63	159.28	145.05	85.38	134.90	255.33	137.70	118.23	158.10	109.13
SAAR,	mm	1547.70	1533.80	1317.00	1353.30	1271.60	1543.60	1189.20	831.50	880.00	828.00
SNAR,	mm	198.56	186.13	172.85	181.31	142.30	207.41	132.70	78.80	93.90	54.60
ST.DIA,	mm	1.51	0.73	0.05	0.05	0.04	1.71	0.04	0.04	0.04	0.04
CLAY,	%	15.00	23.00	30.40	30.40	30.00	11.80	36.00	30.00	30.00	30.00
AV.CN,	Av.CN	71.16	69.92	72.00	72.00	78.88	75.96	65.98	74.13	74.48	82.91
FOREST,	%	0.58	0.63	0.58	0.57	0.33	0.43	0.76	0.48	0.44	0.21

Where: **DL**, Data length; **Q95(10)**, Ten daily mean annual flow at 95 percentile; **Q75(10)**, Ten daily mean percentile; **Q50(10)**, Ten daily mean annual flow at 50 percentile; **MAM ZE**, Mean annual minimum with zer annual minimum Without zero values; **BFI**, Base flow index; **NOS**, Number of breaks; **SO**, Stream Order; **MSL**, **MXL**, Maximum stream length; **AREA**, Area; **ELOUT**, Elevation at outlet of stream; **ELMSL**, Elevation of main Elevation of maximum stream end; **L1**, Length of first order stream; **L2**, Length of second order stream; order stream; **L4**, Length of fourth order stream; **L5**, Length of fifth order stream; **L6**, Length of sixth Total length of streams; **O1**, Number of segments in first order streams; **O2**, Number of segments in second Number of segments in third order streams; **O4**, Number of segments in fourth order streams; **O5**, Number o order streams; **O6**, Number of segments in sixth order streams; **TN**, Total number of segments; **MSL**, Main Maximum stream length; **SAAR**, Seasonal annual normal rainfall; **SNAR**, Nonmonsoon annual normal rainfall; **ST.** diameter; **CLAY**, Percent clay; **AV.CN**, Wetted average curve number; **FOREST**, Percent forest area.

Here, I would like to indicate that base flow index is not an independent variable, but is a flow characteristics its self derived from the flow data. It is therefore, the base flow index is a flow characteristics not a variable. But in the literature the base flow index is widely used as a variable other than the flow characteristics, Institute of Hydrology (1989).

4.2: Estimation of Physical Variables

The possible important meteorological, soil, vegetation and geomorphological variables are identified and estimated for each catchment. The meteorological variable considered is the normal rainfall, the soil variables considered are the soil texture and percent clay in the soil and the vegetation variables considered are the curve number and percent of forest in the area. A number of geomorphological variables are selected and estimated by using ILWIS (Package on International Land and Water Imaging System) on 1:250,000 Scale toposheets provided by Survey of India.

4.2.1: Meteorological variables

The meteorological variables considered are the weighted normal monsoon rainfall, weighted normal non-monsoon rainfall and the weighted normal rainfall of all the months. It makes a total of 14 variables. The normal rainfall of the districts are used to estimate the weighted normal rainfall of sub basins based on the weights of districts following in the sub basin. The weights of the district falling in selected sub basins, normal monthly rainfall and weighted rainfall is reported in Table 6, Table 7 and Table 8 respectively.

Table 6: Weights of the districts falling in selected sub basin of Narmada.

Basin code	Basin name	Site name	Number of districts falling in sub basin			Weights of each district in subbasin		
B21	Burh	Mohg	Mandla	Balaghat	Durg	0.75	0.15	0.10
B20	Banj	Hriday	Mandla	Balaghat	Durg	0.35	0.45	0.20
B15	Shak	Gadar	Chhid	Narsim	NIL	0.70	0.30	0.00
B17	Sher	Belkh	Seoin	Narsim	Chhid	0.60	0.30	0.10
B18	Hira	Patan	Jabalpur	Damoh	NIL	0.95	0.05	0.00
B22	M.River	Manot	Mandla	Shahdol	NIL	0.85	0.15	0.00
B10	Ganjal	Chhid	Betul	Hoshanga	NIL	0.50	0.50	0.00
B7	Beda	Kagon	West Nima	NIL	NIL	1.00	0.00	0.00
B8	Ginnor	Cho.Tawa	East Nima	NIL	NIL	1.00	0.00	0.00
B3	Hatni	Tikola	Jhabua	NIL	NIL	1.00	0.00	0.00
B12	Bareli	Barna	Raisen	NIL	NIL	1.00	0.00	0.00
B13	Tendoni	Mahseh	Raisen	NIL	NIL	1.00	0.00	0.00

Table 7: Normal monthly rainfall (mm) of the districts of selected sub basins of Narmada.

District	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	SNAR
Shahdol	39.90	35.70	24.20	18.80	15.10	185.30	387.30	393.60	217.50	54.50	17.50	7.40	213.1
Mandla	27.80	34.70	24.50	17.20	16.40	196.20	492.70	447.80	226.50	59.70	18.40	7.70	206.4
Durg	13.50	27.50	16.60	18.30	16.40	200.50	355.50	333.30	206.90	63.70	13.50	4.40	173.9
Balaghat	17.80	29.60	18.50	16.20	11.80	211.70	557.90	445.20	232.60	62.70	13.30	5.90	175.8
Seoni	24.20	32.50	24.40	18.90	16.70	195.00	429.20	350.20	204.70	58.60	19.80	10.30	205.4
Jabalpur	26.40	23.30	13.20	6.20	6.90	135.70	424.20	380.00	190.80	42.70	15.70	9.00	143.4
Narsimhap	15.90	17.30	12.10	6.50	10.90	148.30	421.20	385.00	216.50	40.80	17.60	8.70	129.8
Damoh	20.40	13.80	11.80	5.80	8.50	124.20	400.00	382.30	196.70	36.10	16.30	8.60	121.3
Chhindwar	20.20	28.30	20.80	14.80	16.40	187.10	418.70	326.30	200.60	60.90	20.30	9.60	191.3
Hoshangab	14.10	9.40	7.20	2.50	9.90	156.20	439.50	361.70	230.30	34.00	21.30	8.40	106.8
Betul	17.70	17.10	15.60	8.00	13.10	154.70	336.40	258.70	175.50	50.50	28.50	8.10	158.6
Raisen	22.40	11.10	8.50	3.30	7.90	159.20	473.30	371.10	214.10	29.90	21.60	8.00	112.7
E. Nimar	8.80	5.30	4.00	1.50	9.30	138.20	282.60	196.60	168.70	33.90	23.00	8.10	93.9
W. Nimar	2.50	1.70	2.90	1.70	8.40	133.10	265.30	183.80	170.50	37.10	19.40	5.10	78.8
Jhabua	4.50	1.90	1.50	0.70	9.10	116.30	283.30	211.50	162.30	25.50	9.50	1.90	54.6

Where: **SNAR**, Nonmonsoon annual normal rainfall; **SAAR**, Seasonal annual normal rainfall.

4.2.2: Soil variables

The major soil groups in Madhya Pradesh specially the area following in Narmada basin is Skeletol soils, Red and Yellow soils and Black soils (deep black soils, medium black soils, shallow black soils). Soil texture and average presence of clay content is extracted from Alexander (1985) and reported in Table9.

Table 8: Weighted normal monthly rainfall (mm) of selected sub basins of Narmada.

Basin code	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	SNAR	S
B21	24.87	33.22	22.81	17.16	15.71	196.95	488.76	435.96	225.46	60.55	17.15	7.10	198.56	1547
B20	20.44	30.97	20.22	16.97	14.33	204.04	494.60	423.73	225.33	61.85	15.13	6.23	186.13	1533
B15	18.91	25.00	18.19	12.31	14.75	175.46	419.45	343.91	205.37	54.87	19.49	9.33	172.85	1317
B17	21.31	27.52	20.35	14.77	14.93	180.20	425.75	358.25	207.83	53.49	19.19	9.75	181.31	1353
B18	26.10	22.83	13.13	6.18	6.98	135.12	422.99	380.12	191.10	42.37	15.73	8.98	142.30	1271
B22	29.62	34.85	24.46	17.44	16.21	194.57	476.89	439.67	225.15	58.92	18.26	7.66	207.41	1543
B10	15.90	13.25	11.40	5.25	11.50	155.45	387.95	310.20	202.90	42.25	24.90	8.25	132.70	1189
B7	2.50	1.70	2.90	1.70	8.40	133.10	265.30	183.80	170.50	37.10	19.40	5.10	78.80	831
B8	8.80	5.30	4.00	1.50	9.30	138.20	282.60	196.60	168.70	33.90	23.00	8.10	93.90	880
B3	4.50	1.90	1.50	0.70	9.10	116.30	283.30	211.50	162.30	25.50	9.50	1.90	54.60	828
B12	22.40	11.10	8.50	3.30	7.90	159.20	473.30	371.10	214.10	29.90	21.60	8.00	112.70	1330
B13	22.40	11.10	8.50	3.30	7.90	159.20	473.30	371.10	214.10	29.90	21.60	8.00	112.70	1330

Where: **SNAR**, Nonmonsoon annual normal rainfall; **SAAR**, Seasonal annual normal rainfall.

Table 9: Soil type, percent clay and weighted geometric mean diameter of the respective soils in the districts of Narmada basin.

Distt.	Name of soil	% clay in soil	Soil type	% Clay	% Silt	% Sand	Weigh G. M diame
Mandla	Skeletal soil	< 10	Hard mass of sand stone	-	-	-	2.00
Balaghat	Red and yellow soils	= 30	Silty Loam, Silty Clay Loam	30.00	60.00	10.00	0.03
Durg	Red and yellow soils	= 30	Silty Loam, Silty Clay Loam	30.00	60.00	10.00	0.03
Chhindwar	Shallow black soil	15-30	Sandy Clay Loam, Silty Clay Loam	22.00	55.00	13.00	0.04
Narsim	Deep black soil	40-60	Clayey to Silty Clay	50.00	40.00	10.00	0.03
Seoin	Shallow black soil	15-30	Sandy Clay Loam, Silty Clay Loam	22.00	55.00	13.00	0.04
Jabalpur	Medium black soil	20-40	Silty coarse in texture	30.00	60.00	10.00	0.03
Damoh	Medium black soil	20-40	Silty coarse in texture	30.00	60.00	10.00	0.03
Shahdol	Medium black soil	20-40	Sandy Clay Loam, Silty Clay Loam	22.00	55.00	13.00	0.04
Hoshanga	Deep black soil	40-60	Clayey to Silty Clay	50.00	40.00	10.00	0.03
Betul	Shallow black soil	15-30	Sandy Clay Loam, Silty Clay Loam	22.00	55.00	13.00	0.04
West Nima	Medium black soil	20-40	Silty coarse in texture	30.00	60.00	10.00	0.03
East Nima	Medium black soil	20-40	Silty coarse in texture	30.00	60.00	10.00	0.03
Sehore	Medium black soil	20-40	Silty coarse in texture	30.00	60.00	10.00	0.03
Raisen	Medium black soil	20-40	Silty coarse in texture	30.00	60.00	10.00	0.03
Jabua	Medium black soil	20-40	Silty coarse in texture	30.00	60.00	10.00	0.03
Dewas	Medium black soil	20-40	Silty coarse in texture	30.00	60.00	10.00	0.03
Borada	Medium black soil	20-40	Silty coarse in texture	30.00	60.00	10.00	0.03

Information extracted from Alexander (1985).
Mean diameter of clay, silt and sand respectively 0.0010 mm, 0.0260 mm and 1.0250 mm.

From the texture class and average clay content, of the soil, the silt and clay content has been extracted. Also from the information of texture class and nature of soil, the mean particle diameter of soil has been extracted. The mean particle diameter has been used to estimate weighted geometric mean diameter based on the weights of districts following in the basin. Weighted percentage clay and weighted mean particular diameter are use as the variables of soil in the model.

4.2.3: Vegetation variables

In vegetation group, the variables considered are the percentage of forest in the area combining reserve forest, protected and unclassified forest. Another variable is weighted curve number based on classifying the vegetation under reserve forest, protected and unclassified forest together, and in to the crop land and grass land (Forest Atlas of India 1972). The area under each class of vegetation was measured and reported in Table 10. The estimated variables like total forest, weighted curve number of each sub basin is also reported in Table 10.

Table 10: Percent vegetation, weighted curve number of each sub basin of Narmada.

Basin sl no.	Basin code	Percent of area under RF	PF	Cro	Gra	RF+PF	Weighted CN
1	B21	0.53	0.05	0.42	0.00	0.58	71.16
2	B20	0.45	0.17	0.37	0.00	0.63	69.92
3	B15	0.07	0.51	0.42	0.00	0.58	72.00
4	B17	0.30	0.26	0.43	0.00	0.57	72.00
5	B18	0.12	0.22	0.65	0.02	0.33	78.88
6	B22	0.31	0.12	0.57	0.00	0.43	75.96
7	B10	0.50	0.26	0.24	0.00	0.76	65.98
8	B7	0.47	0.01	0.52	0.00	0.48	74.13
9	B8	0.37	0.08	0.46	0.10	0.44	74.48
10	B3	0.00	0.21	0.79	0.00	0.21	82.91
11	B12	0.51	0.05	0.44	0.00	0.56	71.74
12	B13	0.09	0.11	0.80	0.00	0.20	83.02

Where: **CN**, Curve number; **RF**, Reserve forest (CN=58); **PF**, Protected forest (CN=60); **Cro**, Crop land (CN=89); **Gra**, Grass land (CN=79).

The allocated curve number for different type of vegetation like reserve forest is 58, for protected and unclassified forest is 60, for crop land is 89 and for gross land is 79. These values are used in estimation of weighted curve number of the basin.

Table 11: Measured/ estimated characteristics and variables of the sub basins of Narmada for first correla

Basin code		B21	B20	B15	B17	B18	B22	B10	B7	B8	B3
Basin name		Burh	Banj	Shak	Sher	Hira	M.River	Ganjal	Beda	Ginnor	Hatni
Gauge site		Mohg	Hriday	Gadar	Belkh	Patan	Manot	Chaidg	Kagon	Cho.Tawa	Tikola
DL, Yrs		15	16	16	16	15	16	16	15	22	8
Q95(10),	m3/sec	57.43	28.91	41.78	26.93	34.26	100.43	34.05	23.17	80.22	4.21
Q75(10),	m3/sec	65.88	34.33	47.62	30.51	40.19	112.67	39.07	27.26	90.93	5.02
Q50(10),	m3/sec	83.38	46.11	59.61	37.78	52.84	137.23	49.46	36.01	112.74	6.81
MAM ZE,	% ADF	1.29	1.03	5.37	2.76	6.53	2.96	2.32	1.12	0.47	2.10
MAM,	% ADF	1.38	1.18	5.37	2.94	6.53	2.96	2.32	2.40	0.74	5.60
BFI,	Ratio	0.20	0.18	0.20	0.18	0.24	0.21	0.16	0.17	0.17	0.19
NOS,	Numbers	1266.00	730.00	983.00	514.00	621.00	1923.00	481.00	1410.00	1002.00	639.00
TL,	Km	2598.36	1653.20	1926.73	1109.80	1705.26	3841.90	1228.20	3282.64	3116.21	1577.83
LO1,	Km	1300.00	700.00	1145.00	595.00	672.50	2095.00	570.00	1675.00	1205.00	745.00
TN,	Numbers	673.00	372.00	579.00	298.00	361.00	1069.00	293.00	867.00	620.00	620.00
AREA,	Km2	4144.19	3097.94	2255.44	1511.19	3029.88	5032.25	1775.00	4065.81	5243.25	2093.06
DD,	Km2/m	0.63	0.53	0.85	0.73	0.56	0.76	0.69	0.81	0.59	0.75
DD1O,	Km2/m	0.31	0.23	0.51	0.39	0.22	0.42	0.32	0.41	0.23	0.36
SMSL,	%	0.25	0.13	0.17	0.31	0.19	0.20	0.32	0.60	0.08	0.15
SMXL,	%	0.19	0.12	0.16	0.47	0.15	0.15	0.29	0.57	0.18	0.15
SF,	Nu/Km2	0.16	0.12	0.26	0.20	0.12	0.21	0.17	0.21	0.12	0.18
MLC,	Km	2.05	2.26	1.96	2.16	2.75	2.00	2.55	2.33	3.11	2.47
SAAR,	mm	1547.70	1533.80	1317.00	1353.30	1271.60	1543.60	1189.20	831.50	880.00	828.00
SNAR,	mm	198.56	186.13	172.65	181.31	142.30	207.41	132.70	78.80	93.90	54.60
ST.DIA,	mm	1.51	0.73	0.05	0.05	0.04	1.71	0.04	0.04	0.04	0.04
CLAY,	%	15.00	23.00	30.40	30.40	30.00	11.80	36.00	30.00	30.00	30.00
AV.CN,	Av.CN	71.16	69.92	72.00	72.00	78.88	75.96	65.98	74.13	74.48	82.91
FOREST,	%	0.58	0.63	0.58	0.57	0.33	0.43	0.76	0.48	0.44	0.21

Where: TL, Total length of streams; LO1, Length of first order streams; TN, Total number of segments; A DD, Drainage density; DD1O, Drainage density of first order streams; SMSL, Average slope of main s Average slope of maximum stream length; SF, Stream frequency; MLC, Mean length of stream channels.

4.2.4: Geomorphological variables

The geomorphological characteristics used as independent variable in the regression were obtained from the 1:250,000 toposheets. The drainage map including the basin boundary were digitized on computer with the help of ILWIS (International Land and Water Imaging System) software. The digitized map of sub basins considered in the analysis are reported in Fig. 8 through Fig. 19. The selected geomorphological and other characteristics and its estimated values are reported in Table 5. The selected physical characteristics and its estimated values are reported in Table 11. This table also includes other variables and the characteristics.

4.3: Correlation Analysis of Selected Characteristics and Variables

In first step twenty three characteristics and variables are subject to correlation analysis. This includes the flow characteristics, Geomorphological variables, rainfall variables, soil variables and vegetation variables. The correlation analysis provides the interrelation and the cross correlation between the characteristics and the variables. Correlation matrix of the characteristics and the variables is reported in Table 12.

From the correlation matrix only those variables are selected which are interrelated with flow characteristics and are not cross correlated with any other variable selected in the model. Thus, only three variables namely basin area (AREA), slope of maximum stream length (SMXL) and percentage clay in soil (CLAY) are found independent to each other and related to flow characteristics. The mean annual minimum flow characteristics is found related with only base flow index (BFI).

The other variables like total number of streams (NOS), total length of stream (TL), length of first order stream (LO1), total number of segments (TN), drainage density (DD), drainage density of first ordered streams (DD10), slope of main channel length (SMSL), stream frequency (SF), mean channel length (MLC),

FIGURE NOT TO SCALE

Fig. 8: Sub-basin Burhner of Narmada and its river system.

FIGURE NOT TO SCALE

Fig. 9 : Sub-basin Banjar of Narmada and its river system.

FIGURE NOT TO SCALE

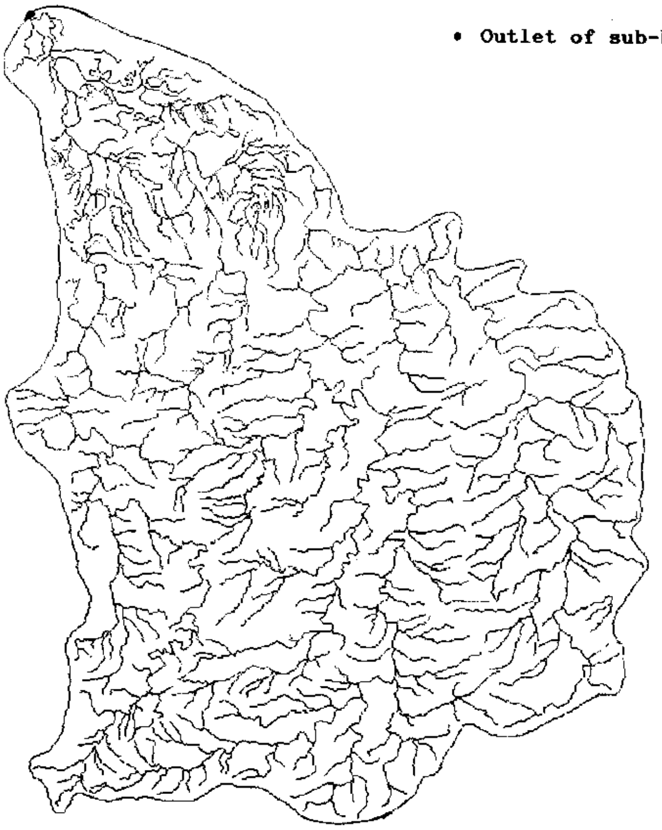

Fig.10: Sub-basin Shakkar of Narmada and its river system.

FIGURE NOT TO SCALE

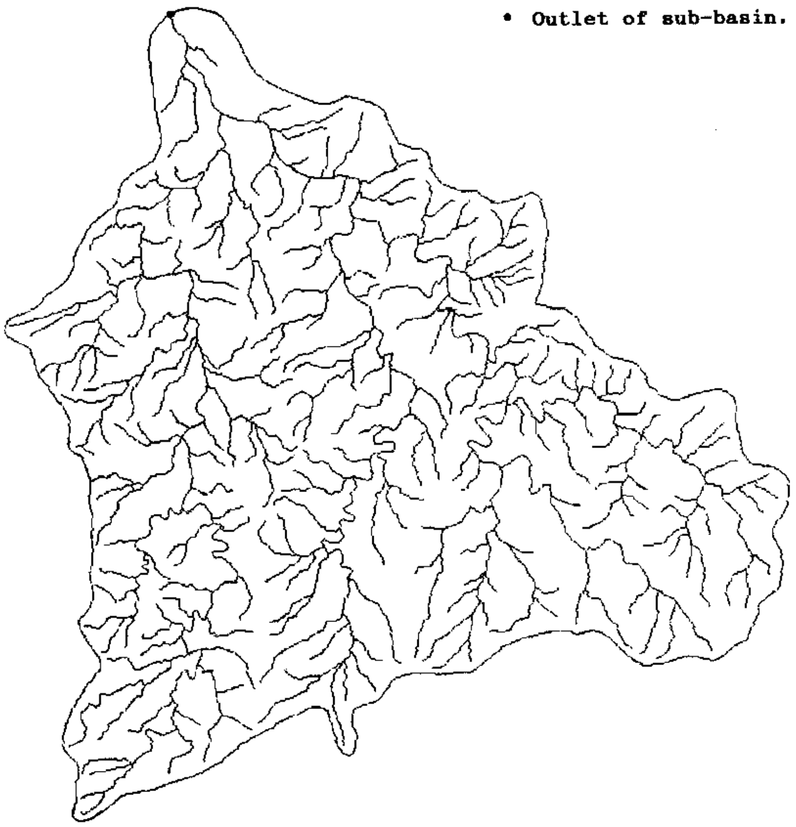

Fig.11: Sub-basin Sher of Narmada and its river system.

FIGURE NOT TO SCALE

• Outlet of sub-basin.

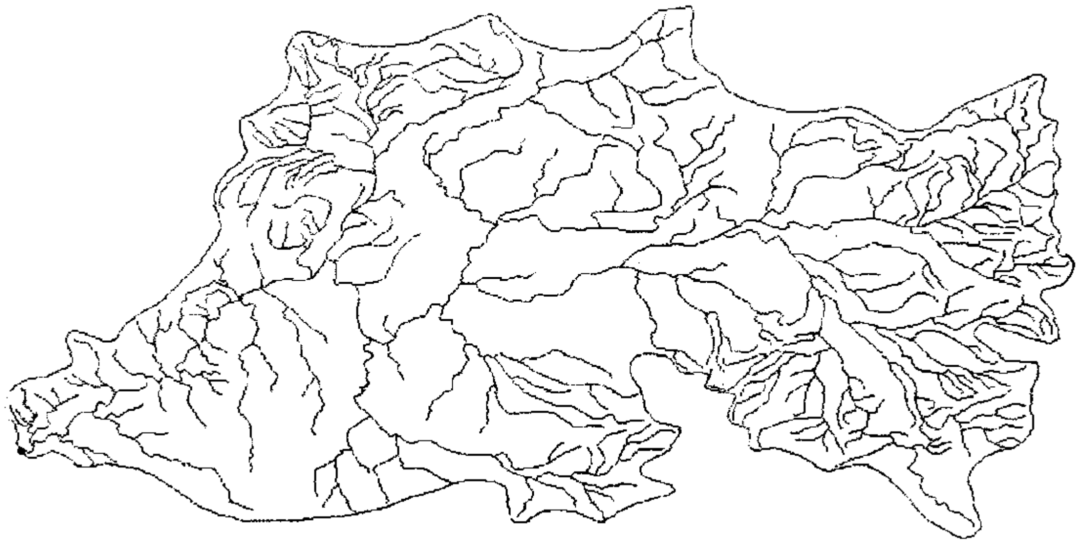

Fig.12: Sub-basin Hiran of Narmada and its river system.

FIGURE NOT TO SCALE

• Outlet of sub-basin.

Fig.13: Sub-basin of Narmada up to Manot and its river system.

FIGURE NOT TO SCALE

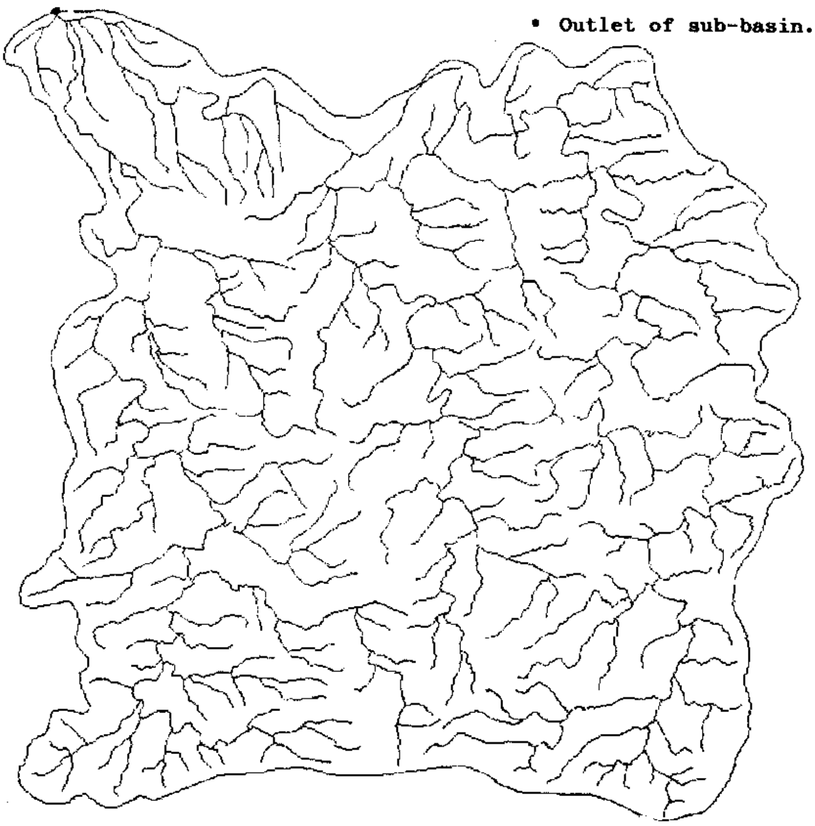

Fig. 14: Sub-basin Ganjal of Narmada and its river system.

FIGURE NOT TO SCALE

• Outlet of sub-basin.

Fig. 15 : Sub-basin Beda of Narmada and its river system.

FIGURE NOT TO SCALE

Outlet of sub-basin.

Fig. 16 : Sub-basin Chhotatawa of Narmada and its river system.

FIGURE NOT TO SCALE

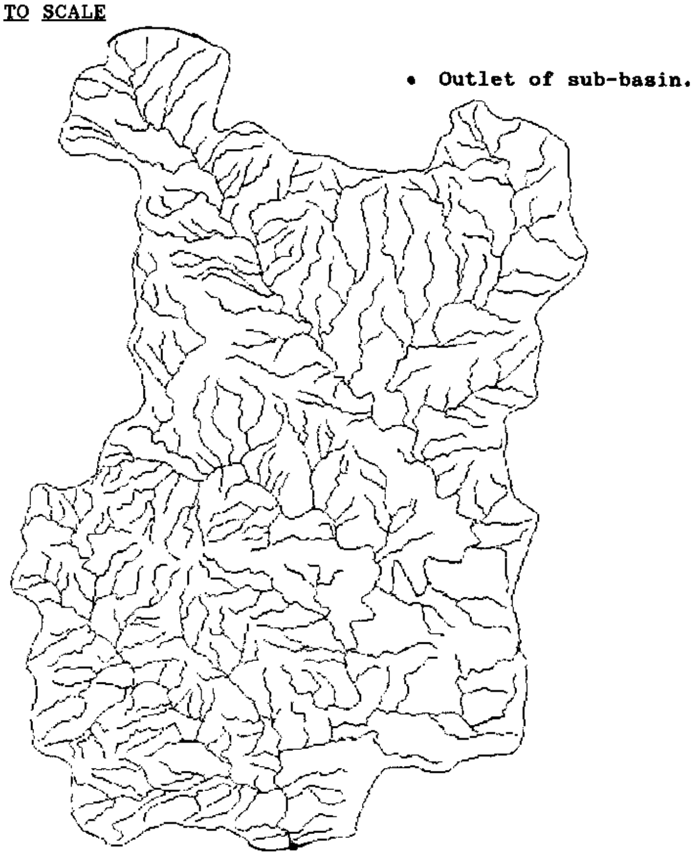

Fig. 17 : Sub-basin Tikola of Narmada and its river system.

FIGURE NOT TO SCALE

Fig. 18 : Sub-basin Barna of Narmada and its river system.

FIGURE NOT TO SCALE

• Outlet of sub-basin.

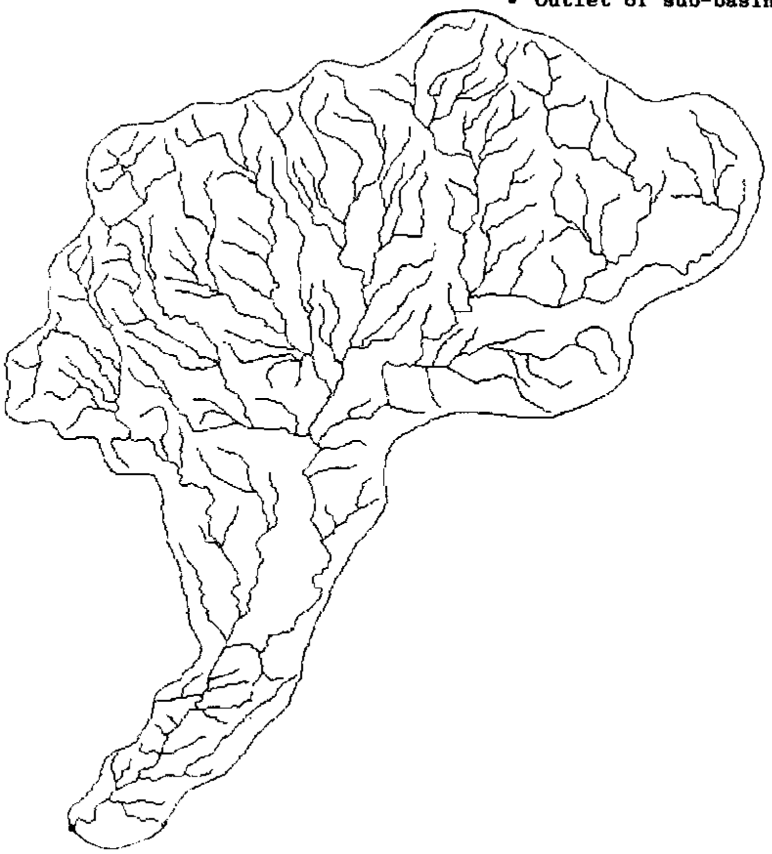

Fig. 19: Sub-basin Tendoni of Narmada and its river system.

Table 12: Correlation matrix of the measured/ estimated characteristics and variables of sub basin Narmada.

Characteristics		VAR1	VAR2	VAR3	VAR4	VAR5	VAR6	VAR7	VAR8	VAR9	VAR10	VAR11	VAR12
Q95(10)	VAR1	1.00	0.99	0.99	-0.01	-0.10	0.48	0.75	0.78	0.73	0.52	0.80	0.04
Q75(10)	VAR2	0.99	1.00	0.99	-0.01	-0.10	0.48	0.75	0.78	0.73	0.52	0.81	0.03
Q50(10)	VAR3	0.99	0.99	1.00	-0.01	-0.10	0.49	0.75	0.79	0.73	0.51	0.82	0.01
MAM ZB	VAR4	-0.01	-0.01	-0.01	1.00	0.97	0.59	-0.04	-0.14	-0.04	-0.22	-0.21	0.22
MAM	VAR5	-0.10	-0.10	-0.10	0.97	1.00	0.51	-0.03	-0.12	-0.02	-0.15	-0.21	0.30
BFI	VAR6	0.48	0.48	0.49	0.59	0.51	1.00	0.48	0.42	0.44	0.01	0.45	-0.03
NOS	VAR7	0.75	0.75	0.75	-0.04	-0.03	0.48	1.00	0.94	0.99	0.79	0.83	0.37
TL	VAR8	0.78	0.78	0.79	-0.14	-0.12	0.42	0.94	1.00	0.96	0.77	0.94	0.23
LO1	VAR9	0.73	0.73	0.73	-0.04	-0.02	0.44	0.99	0.96	1.00	0.81	0.82	0.44
TN	VAR10	0.52	0.52	0.51	-0.22	-0.15	0.01	0.79	0.77	0.81	1.00	0.61	0.42
AREA	VAR11	0.80	0.81	0.82	-0.21	-0.21	0.45	0.83	0.94	0.82	0.61	1.00	-0.08
DD	VAR12	0.04	0.03	0.01	0.22	0.30	-0.03	0.37	0.23	0.44	0.42	-0.08	1.00
DD10	VAR13	0.14	0.13	0.11	0.29	0.33	0.15	0.46	0.27	0.50	0.36	-0.02	0.95
SMSL	VAR14	-0.55	-0.55	-0.56	-0.23	-0.08	-0.44	-0.05	-0.09	-0.00	0.22	-0.29	0.43
SMXL	VAR15	-0.56	-0.57	-0.59	-0.31	-0.17	-0.54	-0.21	-0.19	-0.14	0.05	-0.37	0.41
SF	VAR16	0.12	0.11	0.10	0.30	0.34	0.14	0.46	0.27	0.50	0.39	-0.03	0.96
MLC	VAR17	-0.20	-0.20	-0.20	-0.25	-0.23	-0.43	-0.53	-0.27	-0.48	-0.21	-0.09	-0.53
SAAR	VAR18	0.09	0.09	0.09	0.18	0.06	0.21	0.01	-0.22	-0.09	-0.05	-0.19	-0.17
SNAR	VAR19	0.37	0.37	0.37	0.28	0.15	0.53	0.30	0.06	0.20	-0.02	0.06	0.01
ST.DIA	VAR20	0.64	0.64	0.65	-0.14	-0.21	0.38	0.69	0.54	0.60	0.52	0.55	-0.05
CLAY	VAR21	-0.63	-0.63	-0.64	0.12	0.18	-0.39	-0.71	-0.58	-0.63	-0.60	-0.59	0.06
AV.CN	VAR22	0.03	0.03	0.02	0.06	0.07	0.12	0.01	0.09	0.03	0.33	0.10	-0.14
FOREST	VAR23	-0.06	-0.06	-0.06	-0.02	-0.03	-0.10	-0.03	-0.13	-0.05	-0.34	-0.16	0.18

Continued.

	VAR13	VAR14	VAR15	VAR16	VAR17	VAR18	VAR19	VAR20	VAR21	VAR22	VAR23
VAR1	0.14	-0.55	-0.56	0.12	-0.20	0.09	0.37	0.64	-0.63	-0.14	0.03
VAR2	0.13	-0.55	-0.57	0.11	-0.20	0.09	0.37	0.64	-0.63	-0.15	0.04
VAR3	0.11	-0.56	-0.59	0.10	-0.20	0.09	0.37	0.65	-0.64	-0.15	0.05
VAR4	0.29	-0.23	-0.31	0.30	-0.25	0.18	0.28	-0.14	0.12	0.07	-0.11
VAR5	0.33	-0.08	-0.17	0.34	-0.23	0.06	0.15	-0.21	0.18	0.13	-0.18
VAR6	0.15	-0.44	-0.54	0.14	-0.43	0.21	0.53	0.38	-0.39	-0.21	0.17
VAR7	0.46	-0.05	-0.21	0.46	-0.53	0.01	0.30	0.69	-0.71	-0.15	0.06
VAR8	0.27	-0.09	-0.19	0.27	-0.27	-0.22	0.06	0.54	-0.58	-0.08	-0.01
VAR9	0.50	-0.00	-0.14	0.50	-0.48	-0.09	0.20	0.60	-0.63	-0.13	0.02
VAR10	0.36	0.22	0.05	0.39	-0.21	-0.05	-0.02	0.52	-0.60	0.33	-0.40
VAR11	-0.02	-0.29	-0.37	-0.03	-0.09	-0.19	0.06	0.55	-0.59	-0.08	0.01
VAR12	0.95	0.43	0.41	0.96	-0.53	-0.17	0.01	-0.05	0.06	-0.12	-0.02
VAR13	1.00	0.26	0.23	0.99	-0.73	0.01	0.27	0.10	-0.09	-0.26	0.13
VAR14	0.26	1.00	0.89	0.28	0.00	-0.35	-0.49	-0.27	0.27	0.18	-0.25
VAR15	0.23	0.89	1.00	0.24	0.10	-0.46	-0.53	-0.46	0.43	0.15	-0.23
VAR16	0.99	0.28	0.24	1.00	-0.72	0.01	0.25	0.11	-0.10	-0.23	0.11
VAR17	-0.73	0.00	0.10	-0.72	1.00	-0.50	-0.75	-0.56	0.52	0.50	-0.49
VAR18	0.01	-0.35	-0.46	0.01	-0.50	1.00	0.86	0.64	-0.61	-0.02	0.17
VAR19	0.27	-0.49	-0.53	0.25	-0.75	0.86	1.00	0.71	-0.67	-0.35	0.41
VAR20	0.10	-0.27	-0.46	0.11	-0.56	0.64	0.71	1.00	-0.97	-0.15	0.17
VAR21	-0.09	0.27	0.43	-0.10	0.52	-0.61	-0.67	-0.97	1.00	-0.01	-0.03
VAR22	-0.23	0.07	0.06	-0.21	0.41	-0.06	-0.23	-0.07	-0.08	1.00	-0.99
VAR23	0.28	-0.06	-0.05	0.26	-0.47	0.11	0.28	0.07	0.08	-0.99	1.00

mean monsoon rainfall (SAAR), mean non-monsoon rainfall (SNAR), weighted mean particle diameter (ST. Dia), weighted average curve number (AV.CN) and weighted forest percentage (FOREST) were found interrelated to each other or independent to flow characteristics.

It was observed that the weighted monsoon and non-monsoon rainfall does not show any correlation with the flow characteristics. Therefore, the correlation analysis was again carried out between the flow characteristics, selected variables (on the basis of first correlation) and the normal weighted rainfall of all the months. The estimated correlation coefficient are shown in Table 13. It can be seen that the rainfall of the month of December is related to mean annual minimum flow in addition to earlier selected variable. The finally selected characteristics and variables are reported in Table 14 and its correlation matrix is reported in Table 15.

4.3.1: Principal component and factor analysis

The multivariate techniques like principal component and factor analysis also predicts the variables which could be principal component in the regression equation being developed. The principal component analysis results into the percentage of variance explained in the model by each variable. Based on the variance of variable in the model, the principal variables could be selected. The factor analysis yields the results of principal component analysis and the eigen values. Higher the eigen value, higher is the contribution of variable in the model. The results of analysis are reported in Table 16 and Table 17.

Table 13: Correlation matrix of the selected characteristics and variables and weighted normal monthly rainfall of different months for sub basins of Narmada.

Characteristics		VAR1	VAR2	VAR3	VAR4	VAR5	VAR6	VAR7	VAR8	VAR9	VAR10
Q95(10)	VAR1	1.00	0.99	0.99	-0.01	0.48	0.60	-0.56	-0.63	0.17	0.34
Q75(10)	VAR2	0.99	1.00	0.99	-0.01	0.48	0.81	-0.57	-0.63	0.16	0.34
Q50(10)	VAR3	0.99	0.99	1.00	-0.01	0.49	0.82	-0.59	-0.64	0.16	0.35
MAM ZE	VAR4	-0.01	-0.01	-0.01	1.00	0.59	-0.21	-0.31	0.12	0.40	0.33
BFI	VAR5	0.48	0.48	0.49	0.59	1.00	0.45	-0.54	-0.39	0.29	0.58
AREA	VAR6	0.80	0.81	0.82	-0.21	0.45	1.00	-0.37	-0.59	-0.19	0.08
SMXL	VAR7	-0.56	-0.57	-0.59	-0.31	-0.54	-0.37	1.00	0.43	-0.49	-0.56
CLAY	VAR8	-0.63	-0.63	-0.64	0.12	-0.39	-0.59	0.43	1.00	-0.51	-0.68
JAN	VAR9	0.17	0.16	0.16	0.40	0.29	-0.19	-0.49	-0.51	1.00	0.76
FEB	VAR10	0.34	0.34	0.35	0.33	0.58	0.08	-0.56	-0.68	0.76	1.00
MAR	VAR11	0.34	0.34	0.34	0.28	0.52	0.04	-0.49	-0.67	0.73	0.98
APR	VAR12	0.35	0.35	0.35	0.14	0.49	0.13	-0.44	-0.71	0.59	0.95
MAY	VAR13	0.46	0.45	0.45	0.01	0.37	0.18	-0.35	-0.60	0.36	0.80
JUNE	VAR14	0.24	0.24	0.24	-0.11	0.15	0.01	-0.38	-0.69	0.58	0.84
JULY	VAR15	-0.07	-0.07	-0.07	0.15	0.03	-0.35	-0.38	-0.48	0.89	0.72
AUG	VAR16	0.07	0.07	0.07	0.25	0.25	-0.20	-0.47	-0.59	0.93	0.84
SEPT	VAR17	0.01	0.01	0.00	0.00	-0.01	-0.28	-0.32	-0.56	0.80	0.75
OCT	VAR18	0.38	0.38	0.39	0.19	0.61	0.24	-0.48	-0.64	0.42	0.90
NOV	VAR19	-0.04	-0.05	-0.07	-0.31	-0.64	-0.24	0.35	0.55	-0.41	-0.66
DEC	VAR20	0.02	0.02	0.00	0.58	0.16	-0.44	-0.19	0.30	0.43	0.22

Continued.

	VAR11	VAR12	VAR13	VAR14	VAR15	VAR16	VAR17	VAR18	VAR19	VAR20
VAR1	0.34	0.35	0.46	0.24	-0.07	0.07	0.01	0.38	-0.04	0.02
VAR2	0.34	0.35	0.45	0.24	-0.07	0.07	0.01	0.38	-0.05	0.02
VAR3	0.34	0.35	0.45	0.24	-0.07	0.07	0.00	0.39	-0.07	0.00
VAR4	0.28	0.14	0.01	-0.11	0.15	0.25	0.00	0.19	-0.31	0.58
VAR5	0.52	0.49	0.37	0.15	0.03	0.25	-0.01	0.61	-0.64	0.16
VAR6	0.04	0.13	0.18	0.01	-0.35	-0.20	-0.28	0.24	-0.24	-0.44
VAR7	-0.49	-0.44	-0.35	-0.38	-0.38	-0.47	-0.32	-0.48	0.35	-0.19
VAR8	-0.67	-0.71	-0.60	-0.69	-0.48	-0.59	-0.56	-0.64	0.55	0.30
VAR9	0.73	0.59	0.36	0.58	0.89	0.93	0.80	0.42	-0.41	0.43
VAR10	0.98	0.95	0.80	0.84	0.72	0.84	0.75	0.90	-0.66	0.22
VAR11	1.00	0.97	0.87	0.88	0.71	0.82	0.78	0.91	-0.57	0.23
VAR12	0.97	1.00	0.91	0.92	0.63	0.73	0.72	0.95	-0.62	0.07
VAR13	0.87	0.91	1.00	0.86	0.40	0.50	0.59	0.91	-0.31	0.09
VAR14	0.88	0.92	0.86	1.00	0.74	0.76	0.86	0.82	-0.44	-0.02
VAR15	0.71	0.63	0.40	0.74	1.00	0.97	0.95	0.44	-0.41	0.20
VAR16	0.82	0.73	0.50	0.76	0.97	1.00	0.93	0.58	-0.53	0.21
VAR17	0.78	0.72	0.59	0.86	0.95	0.93	1.00	0.56	-0.33	0.09
VAR18	0.91	0.95	0.91	0.82	0.44	0.58	0.56	1.00	-0.63	-0.00
VAR19	-0.57	-0.62	-0.31	-0.44	-0.41	-0.53	-0.33	-0.63	1.00	0.20
VAR20	0.23	0.07	0.09	-0.02	0.20	0.21	0.09	-0.00	0.20	1.00

Table 14: Finally selected variable for development of the model.

Basin sl no.	Basin code	Q95(10) m3/sec	Q75(10) m3/sec	Q50(10) m3/sec	AREA Km2	SMXL %	CLAY %	MAM ZE m3/sec	BFI	DEC mm
1	B21	57.43	65.88	83.38	4144.19	0.19	15.0	1.29	0.20	7.10
2	B20	28.91	34.33	46.11	3097.94	0.12	23.0	1.03	0.18	6.23
3	B15	41.78	47.62	59.61	2255.44	0.16	30.4	5.37	0.20	9.33
4	B17	26.93	30.51	37.78	1511.19	0.47	30.4	2.76	0.18	9.75
5	B18	34.26	40.19	52.84	3029.88	0.15	30.0	6.53	0.24	8.98
6	B22	100.43	112.67	137.23	5032.25	0.15	11.8	2.96	0.21	7.66
7	B10	34.05	39.07	49.46	1775.00	0.29	36.0	2.32	0.16	8.25
8	B7	23.17	27.26	36.01	4065.81	0.57	30.0	1.12	0.17	5.10
9	B8	80.22	90.93	112.74	5243.25	0.18	30.0	0.47	0.17	8.10
10	B12	12.01	14.33	19.39	1411.69	0.37	30.0	2.47	0.11	8.00
11	B13	17.58	20.47	26.60	1603.88	0.38	30.0	0.55	0.14	8.00

Table 15: Correlation matrix of finally selected Characteristics and variables.

Character- -istics		VAR1	VAR2	VAR3	VAR4	VAR5	VAR6	VAR7	VAR8	VAR9
Q95(10)	VAR1	1.00	0.99	0.99	0.80	-0.56	-0.63	-0.01	0.48	0.02
Q75(10)	VAR2	0.99	1.00	0.99	0.81	-0.57	-0.63	-0.01	0.48	0.02
Q50(10)	VAR3	0.99	0.99	1.00	0.82	-0.59	-0.64	-0.01	0.49	0.00
AREA	VAR4	0.80	0.81	0.82	1.00	-0.37	-0.59	-0.21	0.45	-0.44
SMXL	VAR5	-0.56	-0.57	-0.59	-0.37	1.00	0.43	-0.31	-0.54	-0.19
CLAY	VAR6	-0.63	-0.63	-0.64	-0.59	0.43	1.00	0.12	-0.39	0.30
MAM ZE	VAR7	-0.01	-0.01	-0.01	-0.21	-0.31	0.12	1.00	0.59	0.58
BFI	VAR8	0.48	0.48	0.49	0.45	-0.54	-0.39	0.59	1.00	0.16
DEC	VAR9	0.02	0.02	0.00	-0.44	-0.19	0.30	0.58	0.16	1.00

Table 16: Results of the factor analysis for ten day low flow.

Variable name	Eigen value	Percent variance	Cumulative percent
AREA	1.942	64.8	64.8
SMXL	.660	22.0	86.8
CLAY	.397	13.2	100.0

Table 17: Results of the factor analysis for mean annual minimum flow.

Variable name	Eigen value	Percent variance	Cumulative percent
BFI	1.163	58.2	58.2
DEC	.836	41.8	100.0

For the characteristics of flow duration, the three variables identified are the basin area, the slope of maximum stream length and the percentage clay in the soil based on the principal component and factor analysis. For the characteristics of flow frequency, the identified variables are base flow index and the normal monthly rainfall of the month of December. The similar results are indicated by the correlation analysis.

4.4: Identification of Hydrological Homogeneous Region and Clustering

To define objectively homogeneous hydrological region, the multivariate techniques like correlation analysis between groups, cluster analysis and the discrimination analysis have widely been used. The correlation analysis is carried out between the eleven data groups reported in table 15. The results of correlation matrix is reported in Table 18. It can be seen that each grouped data was highly correlated to the data of any other group considered in the analysis. It suggest for a homogeneity in between the data groups and support that the data is coming from the same population.

Table 18: Correlation matrix between the groups of finally selected variables.

Basin		VAR1	VAR2	VAR3	VAR4	VAR5	VAR6	VAR7	VAR8	VAR9	VAR10	VAR11
B21	VAR1	1.00	1.00	1.00	0.99	1.00	0.99	0.99	0.99	1.00	0.99	0.99
B20	VAR2	1.00	1.00	0.99	0.99	1.00	0.99	0.99	1.00	0.99	0.99	0.99
B15	VAR3	1.00	0.99	1.00	1.00	0.99	0.99	1.00	0.99	1.00	0.99	0.99
B17	VAR4	0.99	0.99	1.00	1.00	0.99	0.99	1.00	0.99	0.99	0.99	0.99
B18	VAR5	1.00	1.00	0.99	0.99	1.00	0.99	0.99	1.00	1.00	0.99	1.00
B22	VAR6	0.99	0.99	0.99	0.99	0.99	1.00	0.99	0.99	1.00	0.99	0.99
B10	VAR7	0.99	0.99	1.00	1.00	0.99	0.99	1.00	0.99	0.99	0.99	0.99
B7	VAR8	0.99	1.00	0.99	0.99	1.00	0.99	0.99	1.00	0.99	0.99	0.99
B8	VAR9	1.00	0.99	1.00	0.99	1.00	1.00	0.99	0.99	1.00	0.99	0.99
B12	VAR10	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	1.00	1.00
B13	VAR11	0.99	0.99	0.99	0.99	1.00	0.99	0.99	0.99	0.99	1.00	1.00

Further values of Q95(10) and MAM (10) are reduced to their specific values in order to have equal weights of the variables controlling the flow characteristics YU(1996). The specific values are obtained as below;

Specific Q95(10) = Q95(10) * SLOPE / AREA * CLAY --(6)

Specific MAM(10) = MAM(10) / BFI * DEC (Rainfall) --(7)

Cluster analysis was applied to specific Q95(10), and specific MAM(10) with there coefficient of variations. Specific values, coefficient of variation and similarity matrix of clustering specific Q95(10) is reported below in Table 19. It can be seen that the estimated distance between the groups are similar and is equal to one in all cases. It suggests that the clustering based on the variable Q95(10) makes one single cluster of all the samples considered.

Table 19: Clustering variable {specific Q95(10)}, coefficient of variation and the results of clustering analysis.

Sl. no. of group	Specific Q95(10)	Coefficient of variation	Clustering groups		Distance level
1	.018	.873			
2	.005	.965	1	5	1.00
3	.010	.929	2	6	1.00
4	.028	.800	1	7	1.00
5	.006	.959	1	2	1.00
6	.025	.816	1	3	1.00
7	.015	.888	1	4	1.00
8	.011	.922	1	8	1.00
9	.009	.933	1	9	1.00
10	.010	.924	1	11	1.00
11	.014	.899	1	10	1.00

The specific value, coefficient of variation and similarity of distance matrix of specific mean annual minimum flow of ten day duration is reported in Table 20. From the distance matrix, it can be seen that the observation number nine and eleven fall in one group with value of distance criteria as -1.0. However the rest of the observations fall in another group. The sample No. 9 is sub basin Chhota Tawa located on the left bank of river Narmada and the sample No.12 is sub basin Tendoni and falls on the right bank of river Narmada. The specific physical reasoning for this clear cut distinction of the group could not be suggested, but it could be because of the presence of zero minimum flows, improper identification of proper principal components, improper estimation of flow variables and other reasons. It needs further research on the clustering of flow frequency curve.

Table 20: Clustering variable {specific MAM(10)}, coefficient of variation and the results of clustering analysis.

Sl. no. of group	Specific Q95(10)	Coefficient of variation	Clustering groups		Distance level
1	.908	.440			
2	.918	.434	1	3	1.00
3	2.878	.775	2	6	1.00
4	1.573	.030	9	11	1.00
5	3.030	.869	1	4	1.00
6	1.840	.135	1	2	1.00
7	1.758	.084	1	7	1.00
8	1.292	.203	1	5	1.00
9	.341	.789	8	10	1.00
10	2.807	.731	1	8	1.00
11	.491	.697	1	9	-1.00

4.4.1: Clustering analysis of flow duration curve

The clustering analysis was also applied to flow duration curve. For this, the estimated values of ten day flow duration curve at 95%, 75% and 50% were used. The values are normalized to specific values and the coefficient of variation is estimated as discussed earlier and subjected to the clustering analysis. The similarity matrix (distance) is reported in Table 21.

Table 21: Coefficient of variation of specific Q95(10), Q75(10), Q50(10), and the results of clustering analysis.

Sl. no. of group	Coefficient of variation Q95(10)	Q75(10)	Q50(10)	Clustering groups		Distance level
1	.018	.020	.025			
2	.005	.006	.008	1	8	1.00
3	.010	.011	.014	2	10	1.00
4	.028	.031	.039	3	6	1.00
5	.006	.007	.009	4	11	1.00
6	.025	.029	.035	1	7	1.00
7	.015	.018	.022	4	9	1.00
8	.011	.013	.017	1	2	.99
9	.009	.010	.013	3	4	.99
10	.010	.013	.017	1	5	.99
11	.014	.016	.021	1	3	.99

The distance between the possible grouping is hardly 0.01 percent and therefore suggests for one single group or cluster. It is, therefore, the ten day flow duration curve in the range of Q50 to Q95 could be represented by single estimated curve. Further analysis is needed in the range of Q10 to Q50 for development of syntactic flow duration curves for the region.

4.5: Regional Equations

Multiple regression analysis is carried out to develop regional flow equation between flow characteristics and mutually independent variables highly correlated to flow characteristics. The form of the equation selected similar to equation proposed by Institute of Hydrology and is as below;

$$Q = AV1 + BV2 + CV3 \qquad \text{--(8)}$$

where; Q is the low flow characteristics, V1, V2 and V3 are the variables (mutually independent and highly correlated to Q), A, B and C are coefficient of variables in the regression equation. In order to have a better fitting of the model, the values are transformed by applying root transformation as suggested by Institute of Hydrology (1989). The square root transformed characteristics and variables are reported in Table 22.

Table 22: Root transformed values of the variable selected for the model development.

Basin sl no.	Basin code	Q95(10)	Q75(10)	Q50(10)	AREA	SMXL	CLAY	MAM ZE	BFI	DEC
2	B20	5.38	5.86	6.79	55.66	0.35	4.80	1.02	0.42	2.50
3	B15	6.46	6.90	7.72	47.49	0.41	5.51	2.32	0.45	3.05
4	B17	5.19	5.52	6.15	38.87	0.68	5.51	1.66	0.42	3.12
5	B18	5.85	6.34	7.27	55.04	0.38	5.48	2.55	0.49	3.00
6	B22	10.02	10.61	11.71	70.94	0.38	3.44	1.72	0.46	2.77
7	B10	5.84	6.25	7.03	42.13	0.54	6.00	1.52	0.40	2.87
8	B7	4.81	5.22	6.00	63.76	0.75	5.48	1.06	0.41	2.26
9	B8	8.96	9.54	10.62	72.41	0.42	5.48	0.69	0.41	2.85
10	B12	3.47	3.79	4.40	37.57	0.61	5.48	1.57	0.33	2.83

4.5.1: Regional low flow equation

The square root transformed values of the table 22 as percentage of average discharge at different percentage of exceedence is related to square root of variables by a multiple regression equation of the following form;

$$Q^{1/2} = A(AREA)^{1/2} + B(SMXL)^{1/2} + C(CLAY)^{1/2} \quad \text{- -(9)}$$

Where; Q is the low flow characteristics and A,B and C are fitted coefficients and Q is replaced by Q95(10) or Q75(10) or Q50(10). The results of multiple regression analysis including the constants and their statistics are reported in Table 23. The multiplicative power equations thus could be written as below;

$$\{Q95(10)\}^{1/2}=0.123(AREA)^{1/2}-3.241(SMXL)^{1/2}+0.223(CLAY)^{1/2} \quad \text{- -(10)}$$

$$\{Q75(10)\}^{1/2}=0.130(AREA)^{1/2}-3.503(SMXL)^{1/2}+0.261(CLAY)^{1/2} \quad \text{- -(11)}$$

$$\{Q50(10)\}^{1/2}=0.143(AREA)^{1/2}-4.006(SMXL)^{1/2}+0.336(CLAY)^{1/2} \quad \text{- -(12)}$$

Table 23: Model fitting of significant variable in the multiple regression for the regional low flow equation.

Independent variable	Constants	Coefficient	Std. error	t-value	sig. level
AREA	A	0.12348	0.028167	4.3841	0.0046
SMXL	B	-3.24118	3.855403	-0.8407	0.4327
CLAY	C	0.22394	0.482777	0.4639	0.6591
R-SQ. (ADJ.)	= 0.9548				
AREA	A	0.13060	0.028782	4.5379	0.0039
SMXL	B	-3.50346	3.939548	-0.8893	0.4081
CLAY	C	0.26167	0.493314	0.5304	0.6149
R-SQ. (ADJ.)	= 0.9587				
AREA	A	0.14379	0.029711	4.8399	0.0029
SMXL	B	-4.00610	4.066699	-0.9851	0.3626
CLAY	C	0.33650	0.509236	0.6608	0.5333
R-SQ. (ADJ.)	= 0.9652				

Equations 10, 11 and 12 could be used for the estimation of low flows at particular probability for ungauged sites in Narmada basin.

4.5.2: Regional minimum flow equation

For the realization of minimum flow, the regression analysis between the flow characteristics as ten day mean annual minimum flow and the variables the base flow index (BFI) and normal rainfall of December is carried out. The multiple regression of the square root transformed values considered the equation as below;

$$M^{1/2} = E(BFI)^{1/2} + F(DEC)^{1/2} \quad --(13)$$

Where; M is the low flow characteristics as the ten day mean annual minimum, MAM(10). The results of multiple regression is reported in Table 24.

$$M^{1/2} = 0.9968(BFI)^{1/2} + 0.4166(DEC)^{1/2} \quad --(14)$$

Table 24: Model fitting of significant variable in the multiple regression for the regional minimum flow equation.

Independent variable	Constants	Coefficient	Std. error	t-value	sig. level
BFI	E	0.99681	3.651751	0.2730	0.7928
DEC	F	0.41665	0.550079	0.7574	0.4735
R-SQ. (ADJ.) = 0.9012					

It can be seen from the table that the variables has relatively low significance level in the model at the same time the correlation coefficient is 0.90 . A low significance is probability because the rivers are not perineal and dries up vary fast in the non-monsoon season. To have a better information regarding the ten day mean annual minimum, the period of series for estimating the ten day mean annual minimum be reduced at the same time cluster analysis of ten day flow frequency curve is required.

4.5.3: Verification of regional flow equation

The developed regional flow equations for the low flow and the minimum flow are subject to verification for two randomly selected sub basin, Burhner and Tindoni. The verification results are reported in Table 26 and Table 27 separately for low flow and mean annual minimum flow.

Table 25: Verification results of the developed regional models for low flow.

Basin code	Flow Variable	Transformed variables AREA	SMXL	%Clay	Observed m3/sec	Estimated m3/sec	Percent error
B21	Q95(10)	64.375	0.436	3.873	57.43	54.813	4.557
	Q75(10)	64.375	0.436	5.477	65.88	69.122	-4.922
	Q50(10)	64.375	0.436	5.477	83.38	87.491	-4.930
B13	Q95(10)	40.048	0.616	5.477	17.58	17.420	0.909
	Q75(10)	40.048	0.616	5.477	20.47	20.287	0.893
	Q50(10)	40.048	0.616	5.477	26.60	26.340	0.977

Table 26: Verification results of the developed regional models for mean annual minimum flow.

Basin code	Flow Variable	Transformed variables BFI	DEC	Observed m3/sec	Estimated m3/sec	Percent error
B21	MAM. ZE	0.447	2.665	1.290	2.421	-87.681
B13	MAM. ZE	0.374	2.828	0.550	2.407	-337.628

The low flow indicated a very low percent error between observed and estimated valve. The verification of mean annual minimum is not good and indicates a very high percent error at the order of 337.6 percent between observed and estimated. It is possibly because the flows in the river because to low in the month of March end. It may be possibly because the flow during this period is not the low flow but is the irrigation return flow and suggests that the duration of series be reduced to have effective equations. Further it needs to study the regionalization of the flow frequency curve and its clustering.

5.0: RESULTS AND DISCUSSION

The percentage of time the discharge exceeded is observed to be varying among the sites selected for the study. At low percent the variation in the value is high and at high percentage the variation is low (Fig.3.).

The low flow duration curves are reported in Fig. 3 and indicates a similar behaviour among the sites.

The estimated values of flow of every ten day mean at 95 percent and 75 percent for the duration from November 1st to March 31st are normally flat except for one or two cases. It suggests that most of the basin considered are fast responding and the low flow beyond 75 percent becomes negligible Fig 4 and

Fig. 5. At 50 percent the curves are not flat and response of the variable could be batter assumed and estimated for this probability Fig. 5.

The statical analysis ten day mean low flow at Q95, Q75 and Q50 also suggest for variability from year to year and average flow reduces with increasing average days Table 2.

Ten day mean annual minimum as a percentage of ADF indicates the variability in flow duration from November 1st to March 31st. In some cases, the flow is seen increasing onwards form November. It indicated the possibility of return flow from the irrigation. This low flow can not be modeled and regionalized. In some cases the curves are almost flat and suggests for the possibility of no response of the variables on the flow Fig. 7.

The correlation analysis indicated that the low flow is interrelated to basin area, slope of maximum stream length and of percentage clay in the soil. Rest all the variable are not needed to be incorporated in the regional model Table 12. The correlation analysis for ten day mean annual minimum is related to base flow index and the normal rainfall of December month Table 13.

The principal component and factor analysis supports the above interrelation and indicates the priority level of independent variable in the model as AREA, SMXL and CLAY for the low flow (Table 16) and BFI and DEC for annual minimum flow (Table 17).

The correlation analysis of the group data (Table 18) and the cluster analysis of specific low flow (Table 19) indicates one single cluster of all the sites. The clusters of mean annual minimum (Table 20) indicated the possibility of two groups and suggests for the cluster analysis of flow frequency curves and possible reduction of annual period.

The clustering analysis of flow duration curve in the range of Q95 to Q50 indicated one single cluster and suggest for one single estimated flow duration curve for all the sites (Table 21).

The regional low flow equation selects the variables of basin area (AREA), slope of maximum stream length (SMXL) and percentage clay in the soil (CLAY). A high level of correlation is obtained between the square root transformed character and variable. The mean annual minimum also indicated high correlation with variables of base flow index (BFI) and the normal rainfall of the month of December (DEC).

6.0: CONCLUSION

1. The percentage of average discharge is observed to be varying among the sites considered possibly due to effect of other controlling variables.

2. Correlation, principal component and factor analysis suggest that low flow could be the function of basin area, slope of maximum stream length and percentage clay in the soil. The cluster analysis suggested on single cluster of all the sites considered in the analysis. Developed regional flow equation are well established and show a high correlation and works well while verification on two known sub basins.

3. The mean annual minimum flow could be related with base flow index and the normal rainfall of December month. The cluster analysis suggest two main group among the sites considered for analysis. Developed regional flow equation shows a high correlation. But files on verification grounds.

7.0: SUGGESTION FOR FURTHER STUDY

The failure of regional mean annual minimum flow equation during verification suggests further development on falling grounds.

1. The length of data considered in the analysis is up to March 31st. This is the period when the flow is either very low or there is no flow. This condition of flow could be due to irrigation return flow and does not exhibit any relation with the variable considered for model formation. The analysis is required for shorter annual duration.

2. Regional equations for flow duration curve and flow frequency curve for full range should be developed. It will also yield in the annual duration to be considered in such type of studies.

3. The clustering analysis of regional flow duration curve and regional flow frequency curve will yield in to the estimated regional flow duration and regional flow frequency curves.

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