TR (BR) 148

REGIONAL LOW FLOW ANALYSIS USING MORPHOLOGICAL FACTORS FOR UPPER NARMADA

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1995-96

PREFACE

In the analysis of hydrological drought, it is basically agreed that drought is a period during which stream flows are inadequate to supply established water use under a given water management system. The below normal availability is reflected through deficient rainfall and low stream flow. The reliable estimation of low stream flows is necessary to investigate drought characteristics of the basin. Further, the question of quality of the environment often depends on the availability of low river flows.

The low flow computation methods can be divided into three main groups, namely, deterministic, statistical and stochastic approaches. These approaches are used for defining the magnitude, frequency and duration of low flows. There are various methods available in literature to analyse low flow for both gauged and ungauged catchments with adequate and inadequate data.

In the present report an attempt has been made to formulate a regional low flow equation for upper Narmada considering 15 to 16 years data of six sub-basins. The developed multiplicative power equation could be used for the estimation of percentage of average discharge at different probability for ungauged sites in upper Narmada region. This study has been conducted by Avinash Agarwal, Scientist 'C' of Drought Studies Division.

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ABSTRACT

The term low flow is broadly used to describe stream flows that are significantly below average or normal flow levels. Reliable estimation of low stream flows is necessary to investigate drought characteristics of the basin. The important variables in the study of low stream flows are the magnitude, frequency and duration. Regional models are developed relating the flow characteristics with climatic, hydrogeological and morphological factor for estimation of low flow variables.

In the report a regional hydrological model is developed for estimating flow duration curve at ungauged sites of upper Narmada basin using only morphological variables. The model is developed by relating the low flow characteristics with basin characteristics of six sub-basins of upper Narmada. The analysis of variance and correlation analysis suggested that the characteristics related to total length of channel, drainage area and slope of the catchment could be the main marphologicalvariables in the model. Based on the correlation analysis, the variable as total length of channels, drainage density and slope of the main channel length are used in the development of hydrological model. It is also observed that the variable, the total length of the channel explains the maximum variance in the model followed by drainage density and slope of main channel length. The models developed explains the adjusted coefficient of determination greater than 0.90.

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 mágnitude 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 a regional low flow equation for upper Narmada Basin based on morphological variables ot 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).

Several concepts relating to low flow are given. 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.

A good work on 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). The objective of this report is to present the regionalization of low flow in upper Narmada basin with morphological variables.

3.0: STUDY AREA AND DATA

The development of regional low flow relationships for upper Narmada basin, is carried out considering flow data at six gauge sites; Mohgaon on Burhner river, Hridaynagar on Banjar river, Gadarwara on Shakkar, Belkheri on Sher river, Patan on Hiran river and Manot on Narmada river. 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 reported in Table 1.

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

S.No.	Name of Sub-basin	Name of gauge site	Starting date of record	Ending date of record
1.	Burhner	Mohgaon	1.6.77	31.5.93
2.	Banjar	Hridaynagar	1.6.77	31.5.93
3.	Shakkar	Gadarwara	1.6.77	31.5.93
4.	Sher	Belkheri	1.6.77	31.5.93
5.	Hiran	Patan	1.6.78	31.5.93
6.	Narmada	Up to Manot	1.6.77	31.5.93

4.0: METHODOLOGY AND ANALYSIS

The methodology for regionalization of low flow consists of the following steps. Analysis for flow duration curve, estimation of physical characteristics of basin, analysis of variance, correlation of basin variables and modelling regional flow equation.

4.1: Analysis for 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 to analyse the flow data for 1 day, 7 daily, 10 daily and monthly 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 no flow in the streams.

Ten day flow duration curve of six sites are presented in Fig. 1. The behaviour of flow duration curve indicates similarity among them. However, variation in the percentage of average discharge at different percentage of times discharge exceeded

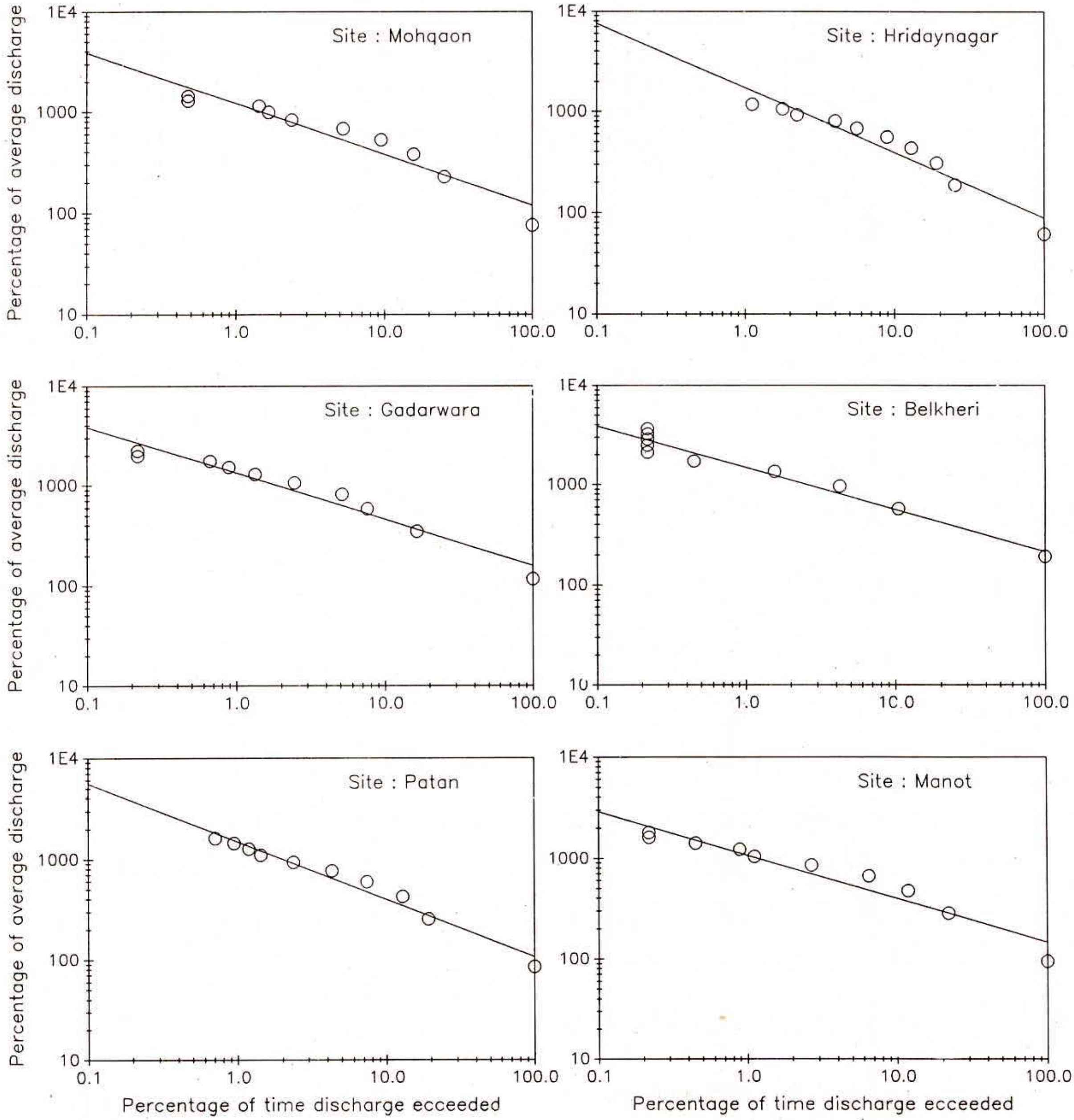

Fig. 1: Ten day flow duration curve at different sites in upper Narmada.

also exists. The value of $Q95_{10}$, $Q75_{10}$, $Q50_{10}$ are estimated by fitting a straight line between log of percentage of average discharge and log of percentage of time discharge exceeded. The values are reported in Table 2.

Table 2: Estimated ten daily flow at Q95, Q75 and Q50 percentage of time exceeded.

Percentage of average discharge, m^3/day	Name of sub-basin and gauge site					
	Burhner/ Mohgaon	Banjar/ Hriday-nagar	Shakkar/ Gadar-wara	Sher/ Belkheri	Hiran/ Patan	Narmada Manot
$Q95_{10}$	122.17	91.74	162.14	217.35	109.60	150.32
$Q75_{10}$	137.62	106.83	180.86	240.16	125.52	166.47
$Q50_{10}$	168.80	138.72	218.12	285.01	158.39	198.30

4.1.2: Statistical analysis of grouped data

The statistical analysis of grouped data has also been carried out for mean, coefficient of variance, 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.

$$\text{Mean} = Q_m = \frac{1}{N} \sum_{i=1}^{NC} E_i \; Q_i \qquad --(1)$$

$$\text{Standard deviation} = SD = \frac{1}{N-1} \sum_{i=1}^{NC} E_i \; (Q_i - Q_m)^2 \qquad --(2)$$

$$\text{Coefficient of variance} = SD / Q_m \qquad --(3)$$

$$\text{Coefficient of skewness} = \frac{1}{(N-1)\,(N-2)} \; \frac{\sum_{i=1}^{NC} E_i \; (Q_i - Q_m)^3}{SD^3} \qquad --(4)$$

$$\text{Coefficient of Kurtosis} = \frac{1}{(N-1)\,(N-2)\,(N-3)} \; \frac{\sum_{i=1}^{NC} E_i \; (Q_i - Q_m)^4}{SD^4} \qquad --(5)$$

Where; E is number of events in class Q, NC is the number of classes in which data is grouped. The statistical results of the grouped data is reported in Table 3.

Table 3: Statistical information of measured flow data.

Gauged Site/ sub-basin		Mean	Coefficient of		
			Variance	Skewness	Kurtosis
Mohgaon	Burhner	169.71	1.24	2.99	13.55
Hridaynagar	Banjar	161.99	1.35	2.63	10.01
Gadarwara	Shakkar	198.24	1.22	4.27	25.36
Belkheri	Sher	259.04	.99	6.97	73.32
Patan	Hiran	170.78	1.33	3.66	18.85
Narmada up to	Manot	181.41	1.15	3.38	17.78

The analysis indicated that the discharge of Sher basin is quite different than other five sub-basin. To support that the flow of Sher basin is different than other sub basins the cluster analysis is carried out by the method of average and centroid. The analysis results into two clusters one including the sub basins Burhner, Banjar, Shakkar, Hiran and Narmada up to Manot and the other consist of only Sher sub-basin. Since the sub-basins considered in the analysis are only six, the grouping of data into two clusters is avoided and regional flow equation has been tried considering all sub-basins together.

4.2: Estimation of Physical Characteristics

The physical characteristics used as independent variable in the regression were obtained from the drainage map. The drainage map including the basin boundary were digitized on computer with the help of ILWIS (International Land and Water Imaging System) software. The selected physical characteristics and its estimated values are reported in Table 4.

Table 4: Physical characteristics of the sub-basins.

Physical characteristics and unit		Name of sub-basin and gauge site					
		Burhner/ Mohgaon	Banjar/ Hriday-nagar	Shakkar/ Gadar-wara	Sher/ Bel-kheri	Hiran/ Patan	Narmada up to Manot
NOS	Numb.	1266.0	730.0	983.0	514.0	621.0	1923.0
SO	Numb.	6.0	5.0	5.0	5.0	5.0	6.0
ELOUT	m.	585.0	501.0	860.0	400.0	386.0	585.0
ELMSL	m.	950.0	700.0	1099.0	641.0	605.0	1059.0
ELMXL	m.	888.0	700.0	1099.0	800.0	582.0	962.0
MSL	Km.	148.1	158.7	142.1	78.1	116.6	238.6
MXL	Km.	163.6	159.2	145.0	85.3	134.9	255.3
TL	Km.	2598.3	1653.2	1926.7	1109.8	1705.2	3841.9
LO1	Km.	1300.0	700.0	1145.0	595.0	672.5	2095.0
TN	Numb.	673.0	372.0	579.0	298.0	361.0	1069.0
AREA	Km^2	4144.1	3097.9	2255.4	1511.1	3029.8	5032.2

Where; NOS: Number of breaks in drainage map, SO: Stream order, ELOUT: Elevation at outlet, ELMSL: Elevation of main stream end, ELMXL: Elevation of maximum stream end, MSL: Main stream length, MXL: Maximum stream length, TL: Total length of all streams, LO1: Length of first order streams, AREA: Drainage area. TN: Total numbers of segments,

Using the measured physical characteristics of the sub-basins as reported in Table 4, the variables related to length, area and slope of the basins are estimated and reported in Table 5.

Table 5: Physical variables estimated by using the measured physical characteristics.

Physical characteristics and unit		Name of sub-basin and gauge site					
		Burhner/ Mohgaon	Banjar/ Hriday-nagar	Shakkar/ Gadar-wara	Sher/ Bel-kheri	Hiran/ Patan	Narmada up to Manot
NOS	Numb.	1266.00	730.00	983.00	514.00	621.00	1923.00
TL	Km.	2598.35	1653.20	1926.73	1109.80	1705.28	3841.90
LO1	Km.	1300.00	700.00	1145.00	595.00	672.50	2095.00
TN	Numb.	673.00	372.00	579.00	298.00	361.00	1069.00
AREA	Km^2	4144.19	3097.94	2255.44	1511.19	3029.88	5032.25
DD	Km^{-1}	0.63	0.53	0.85	0.73	0.56	0.76
DD10	Km^{-1}	0.31	0.23	0.51	0.39	0.22	0.42
SMSL	%	0.25	0.13	0.17	0.31	0.19	0.20
SMXL	%	0.19	0.12	0.16	0.47	0.15	0.15
SF	$N\backslash Km^2$	0.16	0.12	0.26	0.20	0.12	0.21
MLC	Km	2.05	2.26	1.96	2.16	2.75	2.00

Where;
LO1: Total length of first order streams, DD: Drainage density,
DD1O: Drainage density of first order streams,
SMSL: Main stream slope, SMXL: Maximum stream slope,
SF: Stream frequency, MLC: Mean length of channel.

4.3: Correlation of Basin Variables

The basin variable reported in Table 5 are subjected to correlation analysis in order to quantify the interrelation among the variables and to select the independent variables for regional flow equation. The correlation matrix of the variables is reported in Table 6.

Table 6: The Correlation matrix of the physical variables.

Variables	NOS	TL	LO1	TN	AREA	DD	DD1O	SMSL	SMXL	SF	MLC
NOS	1.0	0.9	0.9	1.0	0.8	0.3	0.3	-0.1	-0.4	0.3	-0.5
TL	0.9	1.0	0.9	0.9	0.9	0.2	0.2	-0.1	-0.4	0.2	-0.4
LO1	0.9	0.9	1.0	1.0	0.8	0.4	0.4	-0.0	-0.3	0.4	-0.5
TN	1.0	0.9	1.0	1.0	0.8	0.4	0.4	-0.0	-0.4	0.4	-0.5
AREA	0.8	0.9	0.8	0.8	1.0	-0.1	-0.1	-0.2	-0.6	-0.1	-0.1
DD	0.3	0.2	0.4	0.4	-0.1	1.0	0.9	0.2	0.2	0.9	-0.6
DD1O	0.3	0.2	0.4	0.4	-0.1	0.9	1.0	0.2	0.2	1.0	-0.7
SMSL	-0.1	-0.1	-0.0	-0.0	-0.2	0.2	0.2	1.0	0.8	0.2	-0.1
SMXL	-0.4	-0.4	-0.3	-0.4	-0.6	0.2	0.2	0.8	1.0	0.2	-0.1
SF	0.3	0.2	0.4	0.4	-0.1	0.9	1.0	0.2	0.2	1.0	-0.7
MLC	-0.5	-0.4	-0.5	-0.5	-0.1	-0.6	-0.7	-0.1	-0.1	-0.7	1.0

The criteria of variables being independent is selected on the basis of the correlation among them being is less than 0.3. Thus, only three variables namely total length of stream (TL), drainage density (DD) and slope of main channel (SMSL) are found independent to each other. The other variables like length of first order streams (LO1), total number of streams (NOS), drainage area (AREA), drainage density of first ordered streams (DD1O), slope of maximum channel length (SMXL), stream frequency (SF) and mean channel length (MLC) were found interrelated to each other or to the independent variables selected. The correlation of selected independent physical variables was again estimated to check and confirm the independent variables and reported in Table 7.

Table 7: The correlation matrix of selected independent physical variables.

Variables	TL	DD	SMSL
TL	1.00	0.24	-0.14
DD	0.24	1.00	0.25
SMSL	-0.14	0.25	1.00

4.3.1: Principal component analysis

The results of principal component analysis suggests the percentage of variance explained by each independent variable and the results are reported in Table 8.

Table 8: Results of principal component analysis of selected physical variables.

Variables	Percent of variance	Cumulative percent of variance.
Total length of channel (TL)	42.91	42.91
Drainage Density (DD)	38.12	81.03
Slope of main channel (SMSL)	18.97	100.00

The variability explained by the total length of channel is highest in the order of 42.91 percent and by slope of main channel is lowest in the order of 18.97 percent.

4.4: Modelling Regional Flow Equation

The statistics of the stream flow like percentage of average discharge at different percentage of exceedence is related to physical variables by a multiple linear regression equation of the following form.

$$Q_x = A \cdot V_1^B \cdot V_2^C \cdot V_3^D \cdot \qquad --(6)$$

Where; Q_x is the low flow statistic and V1, V2 and V3 are the physical variables that can easily be measured at an ungauged site. A,B,C and D are fitted model parameters. In the present case. Q_x is replaced by $Q95_{10}$ or $Q75_{10}$ or $Q50_{10}$. Variable V1, V2, V3 are replaced by total length of drainage system (TL) drainage density (DD) and slope of the main channel (SMSL). Equation 2 thus could be modified as below:

$$Q_x = A \cdot TL^B \cdot DD^C \cdot SMSL^D \cdot \qquad --(7)$$

The results of multiple linear regression analysis is as below including the constants and their statistics are reported in Table 9.

Table 9: Estimated constant and model statistics of multiplicative power models for the regional low flow equations.

Independent variable	Estimated constants	Standard error	Significance level	Observed value	Estimated value
Multiplicative power model for $Q95_{10}$					
lnA	7.6391	.7748	.0101	122.16	131.23
B	-0.2037	.1018	.1835	91.74	88.76
C	1.2026	.2467	.0397	162.14	171.82
D	0.4277	.1459	.0994	217.34	207.73
				109.60	111.78
Degrees of freedom = 5				150.32	140.02
Adjusted coefficient of determination = .91					
Standard error of full regression = .0923					
Multiplicative power model for $Q75_{10}$					
lnA	7.7240	.7412	.0091	137.61	147.30
B	-0.2102	.0974	.1636	106.83	103.46
C	1.1267	.2362	.0413	180.85	191.18
D	0.3943	.1396	.1058	240.16	229.96
				125.52	128.00
Degrees of freedom = 5				166.46	155.56
Adjusted coefficient of determination = .91					
Standard error of full regression = .0883					
Multiplicative power model for $Q50_{10}$					
lnA	7.8697	.6837	.0075	168.79	179.59
B	-0.2214	.0898	.1327	138.72	134.58
C	0.9965	.2179	.0447	218.12	229.59
D	0.3372	.1287	.1201	285.01	273.77
				158.39	161.52
Degrees of freedom = 5				198.30	186.33
Adjusted coefficient of determination = .90					
Standard error of full regression = .0814					

The multiplicative power equations thus could be written as below;

$$Q95_{10} = 2077.8 * TL^{-0.2037} * DD^{0.1018} * SMSL^{0.1459} \quad --(8)$$

$$Q75_{10} = 2262.1 * TL^{-0.2102} * DD^{1.1267} * SMSL^{0.3944} \quad --(9)$$

$$Q50_{10} = 2616.9 * TL^{-0.2215} * DD^{0.9965} * SMSL^{0.3372} \quad --(10)$$

Equation 8, 9, and 10 could be used for the estimation of low flows at different probability levels for ungauged sites in upper Narmada basin.

5.0: RESULTS AND DISCUSSION

The percentage of average discharge is observed to be varying among the sites selected for the study. Overall it is found that the minimum (91.74) is at site Hridaynagar and maximum (287.01) is at Belkheri. It is found to be varying in the range of 91.74 to 217.35 against $Q95_{10}$, 106.83 to 240.16 against $Q75_{10}$ and 138.72 to 285.01 against $Q50_{10}$. The variation is wide and indicates the need for the analysis of regional homogeneity and cluster analysis.

The statistical analysis and the information of coefficient of variance, coefficient of skewness and coefficient of kurtosis suggest the discharge data of Sher sub basin is not homogeneous with others. The cluster analysis further supports a different cluster for the data of only Sher sub-basin. Since the sites considered in the analysis are only six, and all being the sub-basins from main Narmada basin, hydrological homogeneity is assumed.

The correlation analysis of eleven variables suggested that the variables like total length of stream, drainage density and slope of the main channel are only the independent variables and could be related with flow variable. The other variables are either related among themselves or to the variables selected for modelling.

The principal component analysis suggest that the variability explained by the total length of channels is highest and that is followed by drainage density and subsequently by slope of main channel.

The developed multiple power models showed the adjusted coefficient of determination greater than 0.9 with standard error of full regression less than 0.1.

6.0: CONCLUSION

1. The percentage of average discharge is observed to be varying among the sites considered.

2. The statistical information of the Sher sub basin is different than the other five considered in the analysis.

3. The cluster analysis suggest two groups. One group of Sher sub-basin and in the other group is of rest of the five sub-basins.

4. The correlation analysis suggest that there could be maximum three morphological variables related to catchment characteristics. One being in the group of length parameter, other in the group of area parameter and third one should be related to slope parameter.

5. Principal component analysis suggest that the variability of

channel length in the model is highest and is followed by drainage área and slope of main channel.

SUGGESTION FOR FURTHER STUDY

It has been suggested that the regional low flow equation should also have climatological and hydrological variables tested for possible inclusion in the regression model. It was also suggested that a good fit in the regression model is no indication of correctness of the relationship and it should be based on the physical reasoning and should be tested through verification. The objective of this report was only to develop regression model based on morphological variables. Above comments and suggestions will be incorporated in the report suggested for year 1996-97.

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