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FORECASTING OF NON-MONSOON FLOWS FOR RIVER MAHANADI AT HIRAKUD

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SYNOPSIS

The flow rates of most of the streams in India follow a yearly cycle. Consequently, the minimum flows occur in the same non-monsoon season (Nov.-May) which often does not have much rain. The major flow during this period is derived from the antecedent precipitation contributions during monsoon season (June-Oct.) available in the form of ground water storage. The lag between the antecedent precipitation and non-monsoon runoff enables one to forecast the flow one or more months in advance of the beginning of the forecast period. This paper describes a methodology for forecasting the flows during non-monsoon season utilizing the base flow recession curves and incremental precipitation at various probability levels. This methodology has been tested using monthly rainfall and flow data of non-monsoon season for Mahanadi river at Hirakud. Split sample approach has been used in which part of data has been used for calibration and remaining part for testing the performance, which is quite encouraging.

1.0 INTRODUCTION

The flow rates of most of the streams in India follow a yearly cycle. Nearly 90% of annual rainfall and runoff is received during monsoon months of June to October. Consequently, low flows of a particular stream usually occur during non-monsoon season (Nov.-May) each year. This season is often rainless and the low flows are generally base flows in the streams, derived from precipitation (recharge to ground water) during antecedent monsoon season. Such seasonal lag between monsoon precipitation and non-monsoon runoff enables low flows to be forecast for use in water quality monitoring and water supply. In general, the most reliable forecasts can be made on streams which do not vary much in their non-monsoon flows from year to year. As most ground water recharge occurs during the monsoon season, it is appropriate to consider forecasting of low flows of non-monsoon season beginning with November or December. However, during

non-monsoon season also, some runoff contribution is derived from rainfall in that season. As such forecast of non-monsoon flows would require not only baseflows due to recharge from antecedent monsoon season, but also likely additional contribution to flow from rainfall in non-monsoon season.

Since, non-monsoon season accounts for around 10% of annual runoff, it also represents dry weather situation. Any deficiency in rainfall in preceding monsoon season is directly reflected in the form of extremely low flows during the non-monsoon season. Forecasting of non-monsoon flows is, therefore, very much necessary for study and management of drought which constitute one hydrological extreme, the other one being floods. Since the base flow derived from ground water is the main source of low flow, its forecast can be estimated from a base flow recession curve projected forward in time or from amount of recharge to ground water in preceding monsoon season. Monthly flows are generally used in planning and management of water resources.

Riggs and Hanson (1969) have discussed various methods for seasonal low flow forecasting including use of recession curves, when the main source of water in low flow season is from water stored in ground, i.e. as base flow. Systematic water availability studies for Mahanadi river basin at three sites viz. Hirakud, Tikarpara and Naraj sites were carried out at National Institute of Hydrology, Roorkee (1986) using monthly data of rainfall and runoff. Non-monsoon flows for period, November to May, were assumed as a constant proportion of total annual flows for the water year (June-May). Total non-monsoon flows were further distributed in individual flows for seven months in the ratio of average monthly flow for the concerned month to average non-monsoon flow. Goel (1986-87) presented a study for forecasting of monsoon (June to October) rainfall and runoff for monthly periods using regression approach; and rainfall and runoff data for Hirakud site on river Mahanadi. Seth (1988) used data for basins/subbasins of Mahanadi river for monsoon months to arrive at regional monthly rainfall runoff relationships after testing both linear and non-linear forms. Long term low flow forecasts for the entire low flow period, non-monsoon months can thus be made for river where the rainfall component of runoff during that period is not significant, as is the case of Mahanadi river at Hirakud.

In the present study, a simple methodology was developed for forecasting of total flow for non-monsoon season in advance at the end of October and also monthly flows for each of the months from December to May, and it was tested using monthly rainfall and monthly flow data for river Mahanadi upto Hirakud, as discussed in susequent sections of this paper.

2.0 METHODOLOGY

The methodology adopted in the study is as follows:

(A) Relationships for total non-monsoon flows:

As mentioned earlier, the total flows during non-monsoon season, Q_{NM}(mm) consist mostly of baseflow and some contribution from non-monsoon rainfall R_{NM}(mm). Accordingly, following alternate relationships were studied:

$$Q_{NM} = A + B\,R_M + C\,R_{NM} \quad \ldots \quad (1)$$

$$Q_{NM} = A + B\,Q_M + C\,R_{NM} \quad \ldots \quad (2)$$

where,

R_M = Total rainfall for preceding monsoon season in mm.;

Q_M = Total flow for preceding monsoon season in mm.;

A, B, C, are regression parameters.

(B) Relationships for monthly non-monsoon flows

These relationships are based on exponential nature of the baseflow recession curve. In order to account for change in shape of recession curve with magnitude of flows during non-monsoon season, it is assumed that recession constant K would vary with Q_{NM} for each non-monsoon season and flow Q_o for the month of November. The form of relationship is as follows:

$$Q_i = Q_o\, e^{-\frac{i}{K}} + F_i\,R_i + C_i \quad \ldots \quad (3)$$

where,

Q_i represents monthly flow in mm.;

R_i monthly rainfall in mm., and

F_i is monthly coefficient for months of December, January, February, March, April or May, and

Q_o is monthly runoff in mm for November

K represents recession constant as a function of corresponding total non-monsoon flow Q_{NM} and Q_o.

C_i is constant for particular month.

(C) Rainfall probability

In order to account for anticipated increase in baseflow due to likely amount of current rainfall R_i in non-monsoon months of December to May, a probability study of monthly rainfall in these months was carried out to determine probability of years with rainfall and probability of rainfall magnitudes.

$$\text{Probability of rainfall in a month or season} = \frac{\text{No. of years with some rainfall in that month or season}}{\text{Total number of years}}$$

The probability of rainfall magnitudes is ascertained by simple procedure of arranging the series in ascending order and estimating rainfall for 10, 50, 90, % levels for each of the six months and also for non-monsoon season.

(D) Steps of analysis procedure

The main steps are as follows:

(i) Divide available monthly data record of rainfall and flow in two parts and use first part for calibration and second part for testing of the methodology;

(ii) Develop relationshiops for total non-monsoon flow using equations (1) or (2) for calibration period record and judge its performance based on correlation coefficients and reproduction of flow for independent period record, and select the form of relationship;

(iii) For each year of calibration period record, estimate value of recession constant K neglecting rainfall effect and using approximate form:

$$\frac{Q_{NM} - Q_o}{Q_o} = \sum_{i=1}^{6} e^{-i/k} \qquad \ldots \quad (4)$$

Equation (4) could be solved using non-linear optimization procedure such as Newton 's method.

(iv) Using equation (3) and value of K for particular year, estimate F_i and C_i for each of the month of December to May,

(v) Carry out rainfall probability study to estimate probability of rainfall and magnitudes of rainfall for months of Dec. to May and non-monsoon season at different levels;

(vi) Test the methodology using relationships derived as above by computing predicted and forecasted flows for non-monsoon season and also months of Dec. to May for independent data record assuming rainfall as given for particular season/month for prediction and rainfall of different probabilities for forecasting runs. Compare predicted values with actual flows for corresponding month/season.

3.0 DATA USED

The monthly rainfall and runoff data in mm for monsoon and non-monsoon periods for river Mahanadi upto Hirakud Dam site, for years 1946 to 1979, which was readily available from another study (NIH, 1986-87) was used in this study. The 34 year data was considered under different alternatives and discussed in next section.

4.0 ANALYSIS AND RESULTS

The analysis was carried out as discussed below:

(A) Relationship for total non-monsoon flows

Using equations (1) and (2) regression relationships were developed using data for 29 years, keeping last 5 years as independent data for testing. In order to study the effect of sample size on values of parameters A, B and C, all possible samples of consecutive data sets of length 20, 24 and 29 years were used. Average values of parameters for both cases viz. eqns.(1) and (2) are given in Table 1.

Table 1 : Parameter Values

Equation used	Sample length (years)	No. of Samples	Parameter values A	B	C	Correlation coefficient
1	20	10	-12.55	0.02	0.05	0.794
	24	6	-10.64	0.02	0.05	0.774
	29	1	-9.08	0.02	0.03	0.758
2	20	10	4.34	0.03	0.04	0.866
	24	6	5.48	0.03	0.03	0.836
	29	1	6.73	0.03	0.02	0.802

It is seen that only parameter A is affected to some extent as sample size varies. The relationship of equation (2) gives better correlation as compared to equation (1). The parameter values for sample length of 29 years were adopted for testing with independent data. The values of observed and computed non-monsoon flows for 5 years of independent data for both cases are given in Table 2.

Table 2 : Test with Independent Data

Sl. No.	Year	Non-monsoon Flows (mm) Observed	Computed Using Eqn.(1)	Using Eqn.(2)
1.	1975	29.52	22.06	21.48
2.	1976	11.01	17.07	19.14
3.	1977	22.04	21.35	21.79
4.	1978	21.94	19.59	21.51
5.	1979	10.24	9.99	12.36

From Table 2, it is seen that Eqn. (1) performs somewhat better as compared to Eqn.(2). As such, both these equations were used for further analysis for forecasting studies.

(B) Relationships for monthly non-monsoon flows

Using relationships given in equation (4), assuming rainfall to be negligible, recession constant K was evaluated for given Q_{NM} and Q_o for each of 29 years. The monthly data of 29 years was classified under two categories: (i) with zero rainfall in particular month; and (ii) with non-zero rainfall in that month.

For months with zero and non-zero rainfall adopting K value for each corresponding year as obtained above, values of monthly coefficient F_i and constant C_i of equation (3) were evaluated for six non-monsoon months viz. December to May. Their values are given in Table 3.

Table 3 : Monthly Parameters

Month	Parameter F_i	Parameter C_i
December	0.04	-0.98
January	0.02	-0.54
February	0.03	-0.28
March *	0.00	-0.00
April	0.10	-0.76
May *	0.00	-0.00

*Parameters F_i and C_i not significant and hence assumed as zero

(C) Rainfall probability

Probabilities of non-zero rainfall were computed for non-monsoon period (Nov. to May) as a whole and for individual months from December to May. Rainfall in mm for different probabilities of exceedance were also computed as given in Table 4.

Table 4 : Rainfall Probability Estimates

Month	Probability of non-zero rainfall	Rainfall (mm) for Probability of Exceedance (%)		
		10	50	90
November	0.853	30.70	1.900	0.109
December	0.618	12.48	0.400	0.153
January	0.912	25.34	5.000	0.102
February	0.971	31.08	6.200	0.680
March	0.971	46.20	5.300	0.880
April	1.000	14.52	8.500	1.100
May	1.000	31.18	11.000	3.500
Non-monsoon (Nov. to May)	1.000	130.38	79.300	30.660

(D) Prediction and forecasting studies

For prediction studies of monthly non-monsoon flows for December to May, using known values of R_M, R_{NM} and Q_M in equations (1) and (2), corresponding values of Q_{NM} were computed. These values were used alongwith observed values of Q_o (flow for November) in equation (4) to obtain values of recession constant K by Newton's method. Monthly runoff values for December to May for 29 year period (1946-1974) were then predicted using equation (3) alongwith respective values of F_i, R_i and C_i for the months. It was seen that results involving use of equation (2) were comparatively much better than that for equation (1), as reflected by reproduction of monthly flow values. Prediction and forecasting studies for individual months were therefore, made using Q_{NM} estimates from equation (2) only, for 1975 to 1979.

The observed values of rainfall (mm) and runoff (mm) for monsoon, non-monsoon periods and month of November for 1975 to 1979 are given in Table 5.

Table 5 : Monsoon, Non-monsoon and November Rainfall and Runoff for 1975 to 1979

Year	Monsoon		Non-monsoon		November	
	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)	Rainfall (mm)	Runoff (mm)
1975	1349.80	484.064	28.30	29.520	0.80	16.271
1976	1080.50	375.851	66.00	11.007	6.30	4.568
1977	1240.60	448.849	90.00	22.038	27.10	8.993
1978	1130.80	420.431	115.30	21.942	16.30	8.849
1979	780.90	152.938	53.70	10.240	9.60	3.957

The results of prediction runs for independent data of 1975 to 1979 for Dec. to May involving use of equations(2), (3) and (4) are given in Table 6.

Table 6 : Observed and Predicted Monthly Runoff (mm) Values for 1975 to 1979

Month	Year				
	1975	1976	1977	1978	1979
December					
Observed	5.67	2.83	5.10	5.98	2.90
Predicted	3.16	2.79	4.52	5.30	1.91
January					
Observed	3.15	1.33	2.24	2.79	1.10
Predicted	0.51	2.57	2.83	3.31	1.64
February					
Observed	2.22	0.82	2.58	2.85	0.82
Predicted	0.13	2.42	2.25	2.62	1.15

Table 6 (contd.)

March					
Observed	1.19	0.74	2.27	0.74	0.74
Predicted	0.07	2.12	1.19	1.17	1.00
April					
Observed	0.60	0.30	0.44	0.30	0.30
Predicted	0.50	2.45	0.88	0.57	0.80
May					
Observed	0.42	0.42	0.42	0.42	0.42
Predicted	0.00	1.44	0.43	0.43	0.51

Inspite of simple methodology and rainfall data limitations due to large size of catchment (83400 Km^2) of river Mahanadi upto Hirakud, the performance of prediction runs with independent data are quite satisfactory. The methodology was used for typical forecasting runs for these five years, assuming monthly rainfall of different probabilities of exceedance viz. 10%, 50%, and 90%.

For the forecasting runs, non-monsoon rainfall of specific probability of exceedance for seven non-monsoon months i.e. Nov. to May were used to obtain corresponding values of R_{NM}. Known value of Q_M for monsoon period of each of the years 1975 to 1979 was used alongwith these R_{NM} estimates to compute corresponding Q_{NM} values using equation (2). These values of Q_{NM} alongwith given values of November flow Q_o were used in equation (4) to obtain recession constant K. The equation (3) was then used to compute monthly flow values for Dec. to May with monthly rainfall of specific probability of exceedance. Table 7 gives forecasted values for three different levels of probabilities of exceedance.

Table 7 : Forecasting of Monthly Flows (mm) for Rainfall of Different probabilities of Exceedance

Month	Year				
	1975	1976	1977	1978	1979
December					
10% Probability	6.03	3.63	5.61	5.45	2.82
50% Probability	3.28	2.76	4.26	4.07	1.80
90% Probability	2.92	2.69	4.11	3.92	1.70
January					
10% Probability	2.57	3.67	4.09	3.94	2.72
50% Probability	0.67	2.59	2.59	2.42	1.50
90% Probability	0.39	2.40	2.34	2.17	1.27

Table 7 (contd.)

February					
10% Probability	1.70	3.98	3.44	3.31	2.95
50% Probability	0.20	2.37	1.67	1.53	1.26
90% Probability	0.0	2.09	1.37	1.23	0.97
March					
10% Probability	0.42	3.0	1.89	1.78	1.91
50% Probability	0.08	2.01	1.02	0.92	0.95
90% Probability	0.05	1.89	0.92	0.83	0.83
April					
10% Probability	0.86	3.39	1.97	1.88	2.29
50% Probability	0.11	1.73	0.68	0.61	0.75
90% Probability	0.64	0.86	0.0	0.0	0.0
May					
10% Probability	0.07	2.43	0.87	0.80	1.33
50% Probability	0.01	1.33	0.34	0.30	0.46
90% Probability	0.0	1.21	0.29	0.25	0.38

5.0 REMARKS

The methodology discussed in this paper provides a simple procedure for forecasting monthly non-monsoon flows for Dec. to May, from known information regarding total monsoon flows and November flow; and monthly rainfall of specific probabilities of exceedance. This procedure is quite useful for river basins, where most of non-monsoon flows is derived from base flow, as reflected by results obtained in this study.

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