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On Long Range Forecast of monsoon rainfall in the catchment areas of Damodar valley

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ABSTRACT. For the purposes of long term planning for storage and conservation of water, the Damodar Valley Corporation engineers wanted a long range forecast of monsoon rainfall in respect of the different catchments of the river Damodar. The problem was studied by correlation method and an attempt was made to forecast the June-September and June-July rainfall in the catchment areas by means of regression equations.

1. Introduction

The river Damodar rises in Chotanagpur plateau in Bihar. It flows through Bihar and West Bengal and joins the river Hooghly before entering into the Bay of Bengal. For a multi-purpose development of the river Damodar, a Corporation was set up in the year 1948. Four big dams were constructed at Konar, Panchet, Tilaiya and Maithon on the river Damodar and its tributary Barakar for purposes of flood control, hydro-electric development, irrigation and navigation. To help the Damodar Valley Authorities in their meteorological requirements, a meteorological unit was also set up under the control of India Meteorological Department.

2. Requirements for daily reservoir operation

For predicting the daily inflow into the reservoir, daily rainfall reports from stations within the catchment area controlled by each dam are collected and sent to the Flood Forecasting Division along with the 24-hour quantitative precipitation forecast and outlook for subsequent 24 hours in respect of each of the catchments. Based on such reports and forecasts the engineers estimate the inflow and plan their daily reservoir operation programme.

3. Requirement for long-term planning for use and conservation of water

Apart from supply of water for hydro-electric generation and for irrigation and navigation purposes, there has also been a considerable demand for supply of water to various industrial concerns which have rapidly grown up recently in and around the Damodar Valley area. The Damodar Valley Authorities are, therefore, concerned with a more judicious planning for use and conservation of water. For a successful long-term planning in this respect, the Corporation engineers desired to have, before the onset of the monsoon, an idea about the expected rainfall during June to September as well as during the first two months of the monsoon season (June-July).

4. Correlation study

In order to help the engineers in their long term operational programme, an attempt was made to study the above problem by correlation methods. The catchments with respect to which the problem was studied are—(*i*) Barakar Catchment, (*ii*) Damodar Catchment and (*iii*) Combined area of Barakar and Damodar Catchments. Fig. 1 shows a map of the Damodar Valley area with the catchment boundaries demarcated on it. It may be seen that the catchment areas are small and are of the order of 6000 to 11,000 sq. km.

The whole area lies in a region of the country, *i.e.*, northeast India where the coefficient of variation of monsoon rainfall is as low as 8 per cent (Banerji 1950). The coefficient of variation being low, it appears that for these smaller areas in northeast India it may not be possible, with the help

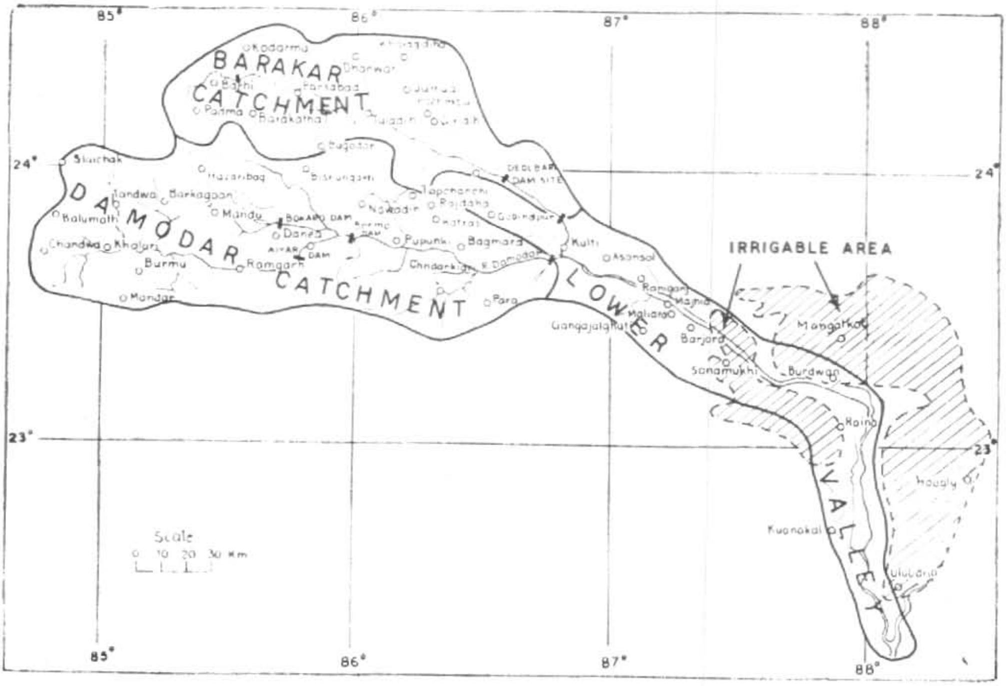

Fig. 1. Map showing catchments of River Damodar and irrigable area

of any regression equation, to issue the long range forecast with a greater precision than what may be attained by an intelligent guess. Pramanik and Rao (1953) had earlier worked out the correlation coefficients of monsoon rainfall in the Damodar Valley with about 20 meteorological factors but no promising result was noticed. In the present paper an attempt has been made to study in detail the distribution and characteristics of monsoon rainfall and calculate its correlation coefficients in respect of each of the catchments of the river, with a large number of meteorological factors, so as to build up, if possible, a regression equation for issue of long range forecast of monsoon rainfall.

5. Compilation of data

Monthly rainfall data of June to September in respect of all the available stations (India Meteorological Department observatories and State raingauge stations), lying in the different catchment areas, were collected from the rainfall publications for 66 years (1891—1956). The average monthly rainfall in each of the months June to September in respect of the divisions was worked out and the mean rainfall for the combined months (June—September) and (June-July) were then computed. Departure of rainfall from the mean value was also calculated for each year.

6. Test for departure from normal distribution

The standard deviation, mean deviation and coefficient of variation and other relevant statistics were worked out for the rainfall (June—September) and (June-July) and the values in respect of Barakar-Damodar catchment are given in Table 1.

The test for departure from normality was carried out on the basis of Standard Tables (Pearson and Heartley 1954). It is found that the distribution of rainfall during June-September and June-July in respect of all the divisions was normal.

TABLE 1

'Statistics' concerning the rainfall during June–September and June–July in the Barakar–Damodar Catchment

Rainfall characteristics	Jun–Sep	Jun–Jul
Normal (M)	42·17″ (1071·1 mm)	21·03″ (534·2 mm)
Standard deviation(σ)	6·41	4·67
Mean deviation (D)	5·20	3·70
Highest rainfall	56·85″ (1444·0 mm)	32·03″ (813·6 mm)
(year)	(1953)	(1893)
Highest rainfall expressed as % of mean	135	152
Lowest rainfall	29·44″ (747·8 mm)	10·36″ (263·1 mm)
(year)	(1903)	(1903)
Lowest rainfall expressed as % of mean	70	49
Range	27·41″ (696·2 mm)	21·67″ (550·4 mm)
Range expressed as % of mean	65	103
D/σ	0.81	0·79

TABLE 2

Results of Normality Test

	(*a*)	(*b*)	(*c*)	(*d*)
I. (*June–September*) *rainfall 1891–1956*				
Barakar catchment	45	±22	86	17
Damodar catchment	49	±20	87	15
Combined area of Barakar and Damodar catchments	49	±19	87	15
II. (*June–July*) *rainfall 1891–1956*				
Barakar catchment	33	±31	80	24
Damodar catchment	33	±30	81	23
Combined area of Barakar and Damodar catchments	35	±29	81	22

(*a*) Percentage of occasions with rainfall within ± 10 per cent of normal

(*b*) Limits (in percentage of normals) within which rainfall is expected to lie on 4 to 1 chance of success

(*c*) Lowermost limit below which rainfall is not expected to fall on 4 to 1 chance of success (per cent)

(*d*) Coefficient of variation (per cent)

According to normal tables prepared by Fisher and Yates (1953) and Savur and Rao (1932), the confidence limits within which the rainfall is expected to lie and the level below which the rainfall is not expected to fall on 4 to 1 chance of success were worked out. The percentage chance of success for forecast of rainfall to lie within ±10 per cent of the normal was also worked out for each catchment area. These results are presented in Table 2. Though not based on data for the same period, it may be interesting to compare the rainfall characteristics of the Damodar Valley catchments with those of northeast India (Banerji 1950). It is seen that the extreme variations of rainfall, standard deviation and coefficient of variation in respect of Damodar Valley catchments are larger than those for the northeast India. It appears, therefore, that although on the basis of normal distribution it is possible to forecast the monsoon rainfall in northeast India on 4 to 1 chance of success so that it will lie within ±10 per cent of the normal, the same is, however, not possible in respect of the Damodar Valley catchments as the limits within which forecast value will lie are too wide to have any practical value. Studies by correlation methods were, therefore, made to find out suitable meteorological factors, which influence the monsoon rainfall over Damodar Valley area, so as to build a regression equation to forecast rainfall within narrower limits.

7. Selection of suitable meteorological factors and their compilation

As the monsoon current over the country is due to differential heating of the land and water bodies, it was assumed that the temperature and pressure conditions in the pre-monsoon months over the land and water might have some influence on the onset and distribution of the monsoon rains in the country. Hence to start with, the meteorological factors were chosen on the basis of broad understanding of the expected physical relationship between the rainfall and the antecedent factors like temperature, pressure etc. A number of other factors, both Indian and extra-Indian, were also selected for working out the correlation coefficient.

TABLE 3

Statement of correlation coefficients of monsoon rainfall (June—September) in the catchments of Damodar Valley area with some meteorological factors

Serial No.	Factors (F)	Barakar catchment	Damodar catchment	Combined Barakar and Damodar catchments	No. of years
1	South American Pressure (mm) ¼(Feb—May) (1891—1956)	0·23* (1891—56)	0·11 (1891—56)	0·21 (1891—56)	66
2	Mean Dec Temp. at Leh (°F) (1891—1955)	0·20 (1892—56)	0·30* (1892—56)	0·22 (1892—56)	60 (excl. 5 yrs)
3	Chotanagpur Temp. range (°F) ⅓ (Dec—Feb) (1891/92—1955/56)	0·23* (1892—56)	0·15 (1892—56)	0·20 (1892—56)	64 (excl. 1 yr)
4	Mean pressure gradient between Port Blair and New Delhi (inch) ⅓(Mar—May) (1891—1956)	—0·17 (1891—56)	—0·30* (1891—56)	—0·27* (1891—56)	62 (excl. 4 yrs)
5	Mean Temp. anomaly between Port Blair and New Delhi (°F) ⅓ (Dec—Feb) (1891/92—1954/55)	—0·25* (1892—55)	—0·16 (1892—55)	—0·21 (1892—55)	57 (excl. 7 yrs)
6	Sydney Temp. (°F) ⅓ (Mar—May) (1891—1940)	—0·25 (1891—40)	—0·22	—0·24	50
7	Capetown precipitation (inch) ⅓ (Mar—May) (1891—1940)	—0·15 (1891—40)	—0·31*	—0·25	50
8	Colombo pressure (inch) ⅓ (Mar—May) (1891—1940)	—0·24 (1891—40)	—0·09	—0·16	50
9	Colombo Temp. (°F) ⅓ (Dec—Feb) (1890/91—1939/40)	—0·30* (1891—40)	—0·26	—0·29*	50
10	Colombo Temp. (°F) ⅓ (Mar—May) (1891—1940)	—0·14 (1891—40)	—0·29*	—0·24	50
11	Colombo precipitation (inch) ⅓ (Dec—Feb) (1890/91—1939/40)	—0·29* (1891—40)	—0·14	—0·22	50
12	Tokyo precipitation (mm) ⅓ (Dec—Feb) (1890/91—1936/37)	—0·25 (1891—37)	—0·09	—0·16	47
13	Rangoon pressure (inch) ⅓ (Mar—May) (1891—1940)	—0·24 (1891—40)	—0·16	—0·27	50
14	Rangoon precipitation (inch) ⅓ (Dec—Feb) (1890/91—1939/40)	—0·32* (1891—40)	—0·39**	—0·38**	50

* Significant at 5 per cent level ** Significant at 1 per cent level

Data of various factors chosen were collected from the year 1891 onwards by reference to India Meteorological Department publications—(1) *Indian Daily Weather Reports*, (2) *Monthly Weather Reports* and (3) *Annual Summary*, and *World Weather Records* published by the Smithsonian Institute, Washington. Most of these data were available for a period of 50 years and more.

8. Regression formula for the prediction of monsoon rainfall

The correlation coefficients between various meteorological factors and June—September rainfall in the catchment area were calculated by using the expression—

$$r = \frac{\Sigma xy - (\Sigma x.\ \Sigma y)/N}{\left\{\Sigma x^2 - (\Sigma x)^2/N\right\}\left\{\Sigma y^2 - (\Sigma y)^2/N\right\}}$$

where r is the correlation coefficient, x and y are the departures of the meteorological factors and the monsoon rainfall from their respective series averages and N is number of pairs of observations.

June—September rainfall in the above mentioned catchment areas was correlated with more than 100 meteorological factors.

TABLE 4

Statement of correlation coefficients of rainfall (June—July) in the catchments of Damodar Valley area with some meteorological factors

Serial No.	Factors (F′)	Barakar catchment	Damodar catchment	Combined Barakar and Damodar catchments	No. of years
1	Port Darwin Pressure (inch) ⅓ (Mar-May) (1900—1956)	—0·24* (1900—56)	—0·17	—0·21	57
2	Laurie Island precipitation (mm) ⅓ (Dec-Feb) (1908/09—1939/40)	—0·34* (1909—40)	—0·12	—0·28	32
3	Rangoon precipitation (inch) ⅓ (Dec-Feb) (1890/91—1939/40)	—0·28* (1891—40)	—0·34*	—0·34*	50
4	Capetown precipitation (inch) ⅓ (Mar-May) (1891—40)	—0·33* (1891—40)	—0·47**	—0·43**	50
5	Tokyo Temp. (°C) ⅓ (Dec-Feb) (1890/91—1935/36)	—0·29* (1891—36)	—0·17	—0·24	46
6	Capetown Pressure (inch) ⅓ (Mar-May) (1891—1940)	+0·05 (1891—40)	+0·29*	+0·21	50
7	Capetown Temp. (°F) ⅓ (Dec-Feb) (1890/91—1939/40)	—0·02 (1891—40)	—0·09	—0·21	50
8	Capetown precipitation (inch) ⅓ (Dec-Feb) (1890/91—1939/40)	—0·29* (1891—40)	—0·13	—0·19	50
9	Sydney precipitation (inch) ⅓ (Mar-May) (1891—1940)	0·12 (1891—40)	0·24	0·20	50

* Significant at 5 per cent level ** Significant at 1 per cent level

A few important C.Cs. are presented in Table 3. Although the period of the data of all the factors is not uniform, tests on the basis of Walker's criteria as extended by Savur and Rao (1932) were applied on those correlation coefficients having a run of data of 45 years or more. It was found on examination that none of these factors was significant even at 5 per cent level. Ordinary *t*-test was, however, applied on individual correlation coefficients on the basis of Fisher and Yates (1953) Tables and the correlation coefficients found significant at 5 per cent and 1 per cent levels were marked with single and double asterisks respectively. Of these, the factors which are significant or nearly significant at 5 per cent level were used to work out the multiple correlation coefficients and the regression equation. The regression formulae were worked out in respect of the catchment areas —Damodar catchment, Barakar catchment and combined Damodar and Barakar catchments. The formulae are presented in Table 5.

The curves showing the actual and calculated departures of rainfall for the monsoon period of 1891—1956 and 1891—1940 respectively are given in Figs. 2—4. The curves showing calculated departures could not be extended beyond 1940 as the data of one factor were not available from 1941 onwards. It may be seen from these curves that there has been some general agreement in the trend shown by the two curves, although there are certain occasions when the calculated and actual values differ to some extent.

In this connection, it may be noticed, that the limits within which the forecast can be made on 4 to 1 chance of success on the basis of the regression formulae (Table 5) are ±17 per cent, ±16·5 per cent and ±16 per cent in respect of Barakar, Damodar and combined catchments respectively. The regression equations could, therefore, narrow down the limits of forecast by only 3 to 5 per cent than what is possible on the assumption of normal distribution.

A few more factors were tried to arrive at a result better than what is shown in Figs. 2–4 but even after repeated attempts, no noticeable improvement in the result was seen by applying other equations.

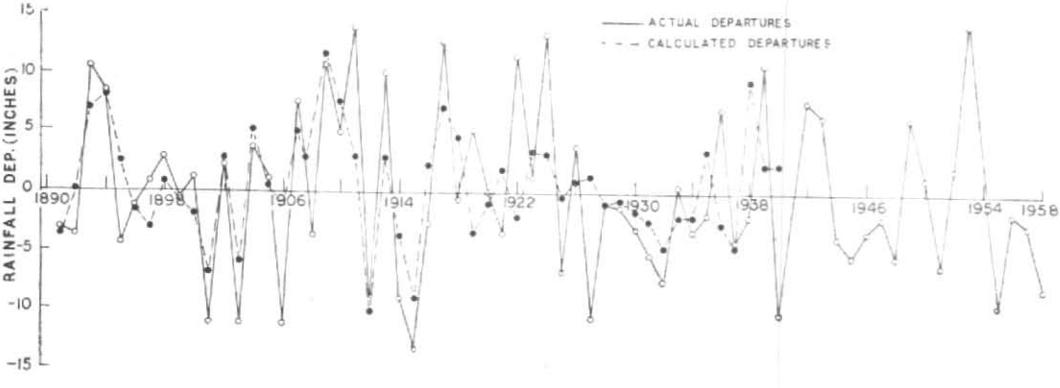

Fig. 2. Barakar Catchment (June—September)

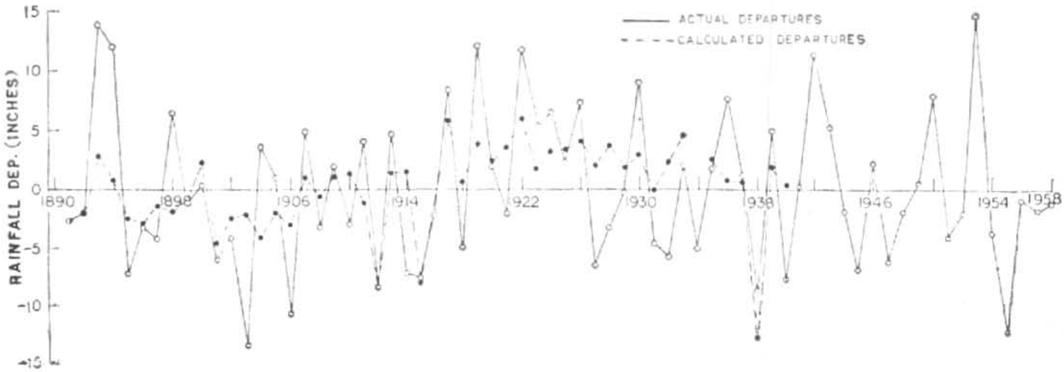

Fig. 3. Damodar Catchment (June—September)

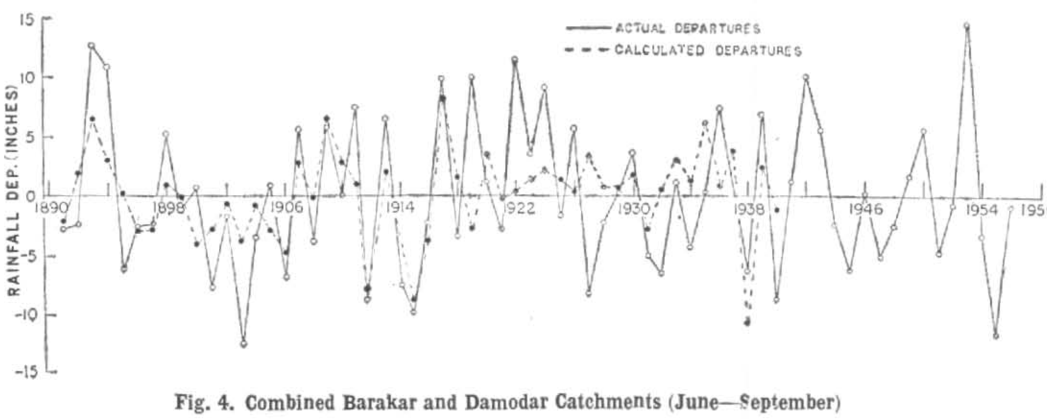

Fig. 4. Combined Barakar and Damodar Catchments (June—September)

9. Regression formulae for the prediction of (June-July) rainfall

The departure series of the June-July rainfall in different catchments of the Damodar Valley area were correlated with a number of different meteorological factors and the correlation coefficients with respect to a few important factors only are presented

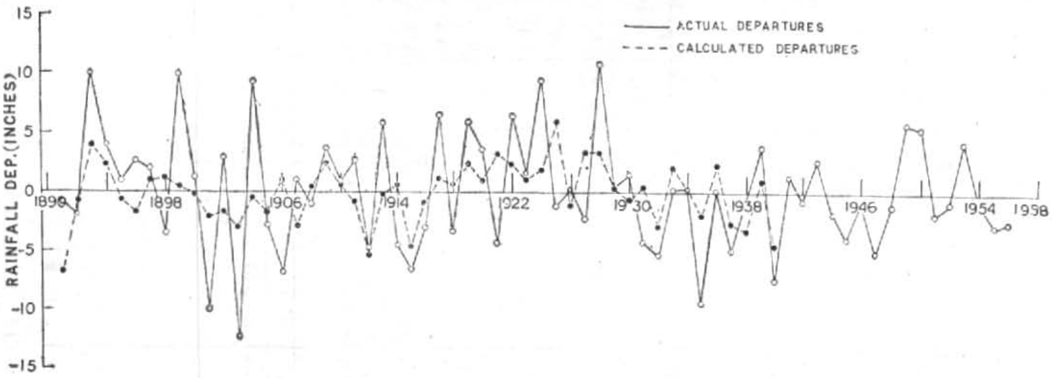

Fig. 5. Barakar Catchment (June—July)

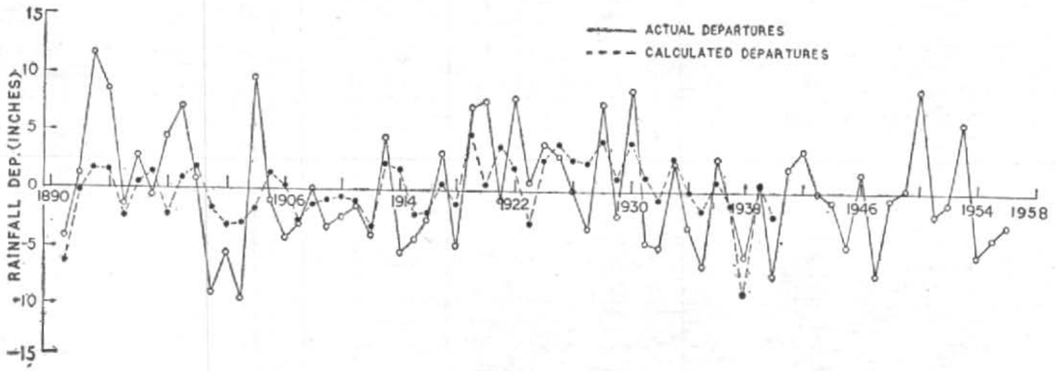

Fig. 6. Damodar Catchment (June—July)

in Table 4. Significance test on the basis of Walker's criteria was applied on 41 factors whose period of data was about 50 years. It is seen from the test that only one value of the correlation coefficient with Cape Town precipitation (March—May) is significant at 5 per cent level. The values of those correlation coefficients which are found to be significant on the basis of t-test at 5 per cent and 1 per cent levels were marked with single and double asterisks respectively.

It is seen that out of these factors only six in Barakar catchment, three in Damodar catchment and two in combined Barakar and Damodar catchments were significant at 5 per cent level. An attempt was made to work out the regression equations in respect of June-July rainfall in Barakar and Damodar catchments. These two regression formulae are given in Table 5. In this connection it may be mentioned that the factor Laurie Island precipitation 1/3 (December-February) which has a correlation coefficient of —0·34 with rainfall in Barakar catchment is omitted from the formulae because the period of data is only 32 years. Further, the factor Sydney precipitation 1/3 (March—May) is included in the forecast formula for (June-July) rainfall in Damodar catchment as its correlation coefficient is nearly significant at 5 per cent level.

Curves showing the actual departure and the calculated departure of (June-July) rainfall are given in Figs. 5 and 6. It may be seen from the two curves that though the trend in the two curves is generally maintained, the predicted values, however, fall short of the actual in many cases. This is because of the low value of the multiple correlation coefficients, *viz.*, 0·49 and 0·54.

TABLE 5

Tentative Regression Formulae

Catchment	Period of forecast	Regression Formulæ	R	Residual variance %
Damodar	(*a*) Jun-Sep	—0·334—3·697F (14)—1·162F (10)—56·036F(4)+ +1·477F(7)—0·477F(5)	0·54	71
	(*b*) Jun-Jul	—0·010—2·350F′ (4) —1·913F′ (3) —0·324F′(9)+ +26·028F′ (6)	0·54	71
Barakar	(*a*) Jun-Sep	—0·172—4·919F(14)—1·756F(11)—140·654F(8)— —1·520F(9) —0·042F (12)	0·62	56
	(*b*) Jun-Jul	0·073—2·140F′ (4) —1·481F′ (5) — 41·715F′ (1)— —0·963F′(3)	0·49	76
Combined Barakar-Damodar	Jun-Sep	—0·554—3·857F (14) —1·253F (9) — 1·126F (6)— —61·237F(4)—78·051F(13)	0·58	66

F and F′ numbers relate to factor numbers in Tables 3 and 4

10. Conclusion

It may be seen that a detailed study by the correlation method was made to establish a regression formula for forecasting the monsoon rainfall (June-September) and (June–July) rainfall in the catchment areas of Damodar.

A large number of factors representing different meteorological elements of stations in the country and outside, which might have some direct or indirect influence on the monsoon rains in the valley, were tried systematically to arrive at the tentative regression equations given in Table 5. It has, however, to be noticed that in each of these equations, the multiple C.C. is low and is significant only at 1 per cent level. Further, these formulae could reduce the limits of the forecast range by only 3—5 per cent than what is possible on the assumption of normal distribution. No better result could be achieved by the correlation methods, inspite of utilising a large number of near and remote factors. It is, therefore, admitted that the regresssion equations derived will have limited practical application. Nevertheless, these studies have thrown light on the type of results that may be expected by application of correlation methods for forecasting rainfall over a small area in northeast India.

While long range forecast of monsoon rainfall, on the basis of these equations have been attempted on an experimental basis, such forecasts have not been supplied to the D.V.C. engineers for any operational use.

11. Acknowledgement

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