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Rainfall distribution in India in relation to latitude, longitude and elevation

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ABSTRACT. An analysis of the normal rainfall of 167 observatory stations distributed over India and the neighbourhood has been made using regression equations representing monthly and annual rainfall as a linear function of latitude, longitude and elevation above sea level. The multiple CCs are high, being 0·8 to 0·9 except in some months.

The anomalies after eliminating the systematic variations have also been studied. These bring to light other factors which influence rainfall, *viz.*, the orographic effects and the effect of lee-side of mountains.

1. Introduction

Jagannathan (1948a, 1948b) studied the distribution of the mean temperature and the mean diurnal range of temperature in India by expressing them as linear functions of latitude, longitude and height above mean sea level of the stations with the data of 167 meteorological stations distributed over India and neighbourhood. He pointed out that similar parameters in respect of any element associated with the same set of stations could easily be obtained by utilising the matrix of multipliers he had presented. Derivation of similar parameters in respect of the distribution of rainfall has been attempted here. Rainfall normals in respect of all except three stations mentioned in Table 1 are available in *India met. Dep. Mem.* (1949).

As the alternative stations selected are very close, the same matrix of multipliers has been used for the present purpose. The stations selected and the regions in which they fall are shown in Fig. 1.

2. Method of analysis

The rainfall r of a place has been represented as linear functon of latitude L, longitude l and height above mean sea level of the station H for all the twelve months and the year as a whole.

$$r = A + b_1 L + b_2 l + b_3 H \qquad (1)$$

where A, b_1, b_2, b_3 are regression coefficients.

The units employed in calculations are latitude 1minute, longitude 1 minute, elevation 1 foot and rainfall 1 cent. The partial regression coefficients of normal rainfall for any month on latitude, longitude and elevation can readily be obtained from the following —

$$bn_1 = m_{11}\Sigma\phi fn + m_{12}\Sigma\lambda fn + m_{13}\Sigma hfn \qquad (2)$$

$$bn_2 = m_{21}\Sigma\phi fn + m_{22}\Sigma\lambda fn + m_{23}\Sigma hfn \qquad (3)$$

$$bn_3 = m_{31}\Sigma\phi fn + m_{32}\Sigma\lambda fn + m_{33}\Sigma hfn \qquad (4)$$

where m_{ij} is the i, j^{th} element in the matrix of multipliers and bn_1, bn_2, bn_3 are the partial regression coefficients, n representing the particular month or the year. ϕ, λ, h are the deviations from the respective means of latitude, longitude and elevation of the stations, fn the deviation of the mean rainfall of the station from the mean rainfall of the region during the particular month or year considered.

The standard errors of the regression coefficients are $s\sqrt{m_{11}}$, $s\sqrt{m_{22}}$, $s\sqrt{m_{33}}$, where s^2 = residual variance $= \Sigma(f-f')^2/(n-4)$, where f and f' are observed and calculated deviations for the mean values of rainfall.

The multiple correlation coefficients have been calculated from —

$$R^2 = (b_1\Sigma\phi f + b_2\Sigma\lambda f + b_3\Sigma hf)/\Sigma f^2$$

The regression coefficients and the standard errors for the different months and the year have been tabulated along with the multiple correlation coefficients (Tables 2—5). In this study generally 5 per cent level of significance has been used for testing.

3. Discussion

Region I — This region consists of the western half of the Peninsula in the tropics. The regression on latitude is significant in all months except in August and September. The negative values indicate that the rainfall decreases as we go northwards. The regression in longitude is insignificant. The elevation regressions are not significant except in January when it is significantly positive and in June when it is significantly negative.

It is significant to note in this connection that the rainfall for January which occurs mostly in the extreme south of the region is due to the passage westwards of storms and depression which form in the Bay of Bengal or due to strong northeast monsoon. The high level stations on the Western Ghats get more rain, and lower level stations get comparatively less rainfall, while in the month of June the majority of the number of high level stations considered are to the lee side of the Ghats which receive less rainfall and thus a negative

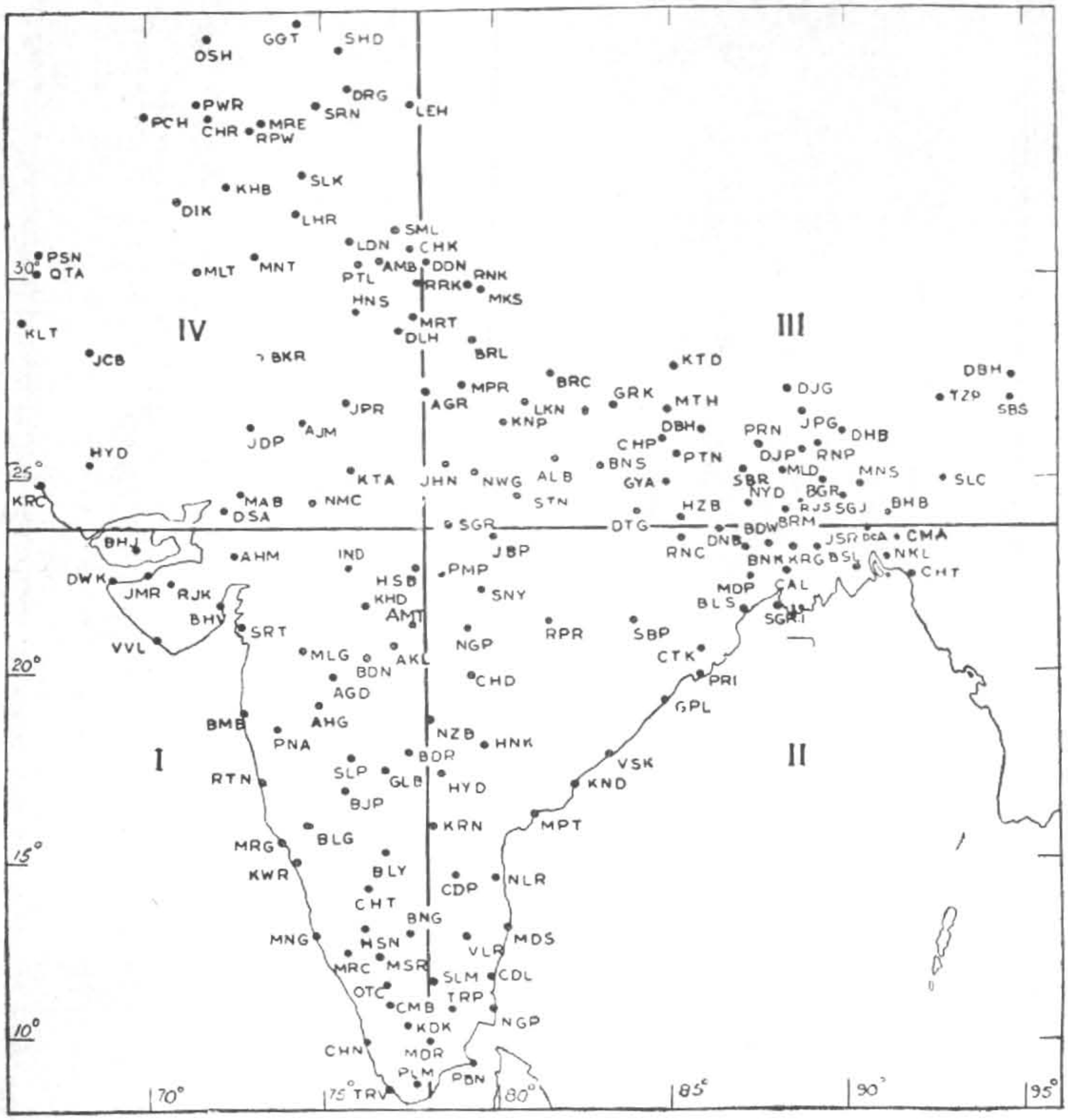

Fig. 1. 167 meteorological stations and the four divisions

relationship is indicated.* In July, August and September the multiple correlation coefficients are less than 0·4 and not significant. In June and October they are 0·5 while in the rest of the months they vary from 0·6 to 0·9. The independence of the rainfall with respect to these parameters during the height of monsoon is of interest.

Region II — The region comprises of the eastern half of the Peninsula. The southwest monsoon rainfall increases with latitude and northeast monsoon decreases with latitude. The regression on longitude shows a general increase of rainfall towards the coast in these months. The regression on elevation is significantly positive in March and April, and July, August and September. The multiple CCs are 0·8 to 0·9 except in December and January when they are 0·6 — 0·7.

Region III — It comprises of northeast India. The regression on latitude is significant and positive in January, February and August indicating that the northerly stations get more rain while in the rest of the months they are not significant. The regression on longitude is significant and positive in all the months except in October, December and January, suggesting that the more easterly stations get more rainfall.

The elevation of the stations does not appear to have any effect on the rainfall except in January and February when the higher level stations get more rainfall. The multiple CCs are all significant and range from 0·5 in August to 0·9 in October.

*For a proper understanding of the relationship of elevation and aspect of orography on rainfall, it is necessary to separate out t e windward and leeward sides. This is being studied separately.

TABLE 1

Stations for which rainfall data are not available				Stations substituted			
Stations	Lat.	Long.	Ht. (ft)	Stations	Lat.	Long.	Ht. (ft) (approx.)
1. Rampur Boalia	24 22	88 36	70	1. Lalgola	24 12	88 17	60
2. Patiala	30 20	76 28	818	2. Lehal	30 22	76 22	800
3. Chakrata	30 43	77 54	6922	3. Ambari	30 28	77 54	4000

TABLE 2

Regression coefficients of rainfall on latitude, longitude and height
Region I (42 stations)

	Regression coefficients of rainfall on			Multiple correlation coefficient
	Latitude	Longitude	Height	R
January	— ·0724± ·0308	+ ·0078± ·0602	+ ·0130± ·0045	·63
February	— ·0448± ·0174	+ ·0305± ·0341	+ ·0039± ·0026	·61
March	— ·1138± ·0231	+ ·0049± ·0452	+ ·0049± ·0034	·74
April	— ·4323± ·0485	— ·0681± ·0949	+ ·0131± ·0072	·87
May	— ·9215± ·1171	— ·2254± ·2291	— ·0020± ·0173	·82
June	—2·2917± ·6756	—1·3064±1·3217	— ·2383± ·0997	·54
July	—1·5977± ·7637	—1·7584±1·4940	— ·1775± ·1127	·39
August	— ·7440± ·4430	— ·4540± ·8667	— ·0700± ·0654	·29
September	— ·0199± ·1835	+ ·5422± ·3595	— ·0087± ·0261	·29
October	—1·1746± ·2036	— ·1028± ·3983	+ ·0285± ·0300	·52
November	— ·6913± ·0929	— ·0274± ·1816	+ ·0211± ·0130	·87
December	— ·2247± ·0550	— ·0109± ·1076	+ ·0156± ·0081	·69
Annual	—8·1852±2·0298	—3·3917±3·9706	— ·4340±0·2997	·59

TABLE 3

Regression coefficients of rainfall on latitude, longitude and height
Region II (40 stations)

	Regression coefficients of rainfall on			Multiple correlation coefficient
	Latitude	Longitude	Height	R
January	— ·2147± ·0598	+ ·1007± ·0678	+ ·0200± ·0176	·63
February	+ ·0090± ·0289	+ ·1162± ·0328	+ ·0128± ·0085	·78
March	— ·0527± ·0335	+ ·2668± ·0380	+ ·0217± ·0085	·89
April	— ·3837± ·1023	+ ·6789± ·1161	+ ·0737± ·0301	·76
May	— ·5650± ·2038	+1·2516± ·2312	+ ·1050± ·0598	·80
June	+ ·5668± ·2610	+1·3063± ·2950	+ ·1209± ·0768	·90
July	+1·5904± ·4130	+ ·5317± ·4685	+ ·2683± ·1215	·87
August	+ ·9626± ·3836	+ ·8705± ·4351	+ ·2836± ·1128	·84
September	+ ·3266± ·1929	+ ·6074± ·2188	+ ·1566± ·0567	·83
October	—1·1832± ·1968	+ ·8484± ·2231	— ·0175± ·0579	·84
November	—1·5772± ·3206	+ ·4565± ·3637	— ·0227± ·0943	·81
December	— ·8558± ·2013	+ ·3214± ·2283	+ ·0354± ·0592	·73
Annual	—1·3489±1·9809	+7·4842±2·2467	+1·0463±0·5827	·66

TABLE 4

Regression coefficients of rainfall on latitude, longitude and height
Region III (45 stations)

	Regression coefficients of rainfall on			Multiple correlation coefficient
	Latitude	Longitude	Height	R
January	+ ·2564 ± ·0207	— ·0125 ± ·0200	+ ·0071 ± ·0034	·72
February	+ ·2379 ± ·0767	+ ·0933 ± ·0234	+ ·0145 ± ·0040	·72
March	+ ·2639 ± ·1795	+ ·3315 ± ·0547	+ ·0120 ± ·0094	·69
April	+ ·7071 ± ·3885	+ ·9248 ± ·1184	+ ·0778 ± ·0202	·78
May	+ ·7719 ± ·4709	+1·5459 ± ·1435	+ ·0180 ± ·0245	·80
June	+ ·7917 ± ·7135	+1·8220 ± ·2174	+ ·0697 ± ·0371	·80
July	+1·5043 ± ·8272	+ ·8059 ± ·2521	+ ·0777 ± ·0430	·53
August	+1·3857 ± ·6902	+ ·5723 ± ·2102	+ ·0571 ± ·0359	·50
September	+ ·7797 ± ·4794	+ ·8707 ± ·1481	+ ·0241 ± ·0249	·68
October	— ·2195 ± ·1848	+ ·5727 ± ·5630	+ ·0103 ± ·0096	·87
November	— ·1435 ± ·0960	+ ·0937 ± ·0293	+ ·0048 ± ·0050	·55
December	+ ·0887 ± ·1031	— ·0115 ± ·0314	+ ·0047 ± ·0054	·69
Annual	+6·4052 ± 2·9417	+7·7599 ± 0·8965	+0·2955 ± 0·1525	·80

TABLE 5

Regression coefficients of rainfall on latitude, longitude and height

Region IV (40 stations)

	Regression coefficients of rainfall on			Multiple correlation coefficient
	Latitude	Longitude	Height	R
January	+ ·1666 ± ·0697	+ ·0093 ± ·0619	+ ·1040 ± ·0046	·68
February	+ ·1501 ± ·0649	— ·0352 ± ·0577	+ ·0201 ± ·0043	·78
March	+ ·3578 ± ·0896	— ·1241 ± ·0795	+ ·0166 ± ·0059	·76
April	+ ·2500 ± ·0891	— ·0829 ± ·0791	+ ·0156 ± ·0059	·68
May	+ ·1034 ± ·0542	+ ·0534 ± ·0481	+ ·0105 ± ·0036	·66
June	— ·4402 ± ·1226	+ ·5635 ± ·1088	+ ·0192 ± ·0082	·71
July	—1·6060 ± ·4109	+1·5336 ± ·3648	+ ·0580 ± ·0273	·67
August	—1·5065 ± ·4130	+1·4947 ± ·3666	+ ·0802 ± ·0274	·66
September	— ·6445 ± ·1638	+ ·7976 ± ·1454	+ ·0197 ± ·0109	·73
October	+ ·0667 ± ·1318	+ ·0799 ± ·0283	— ·0041 ± ·0021	·53
November	+ ·0052 ± ·0129	— ·0045 ± ·0115	+ ·0032 ± ·0008	·61
December	+ ·0845 ± ·0339	— ·0327 ± ·0301	+ ·0081 ± ·0022	·72
Annual	—2·9491 ± 1·3412	+4·1063 ± 1·1907	+0·1941 ± ·0891	·59

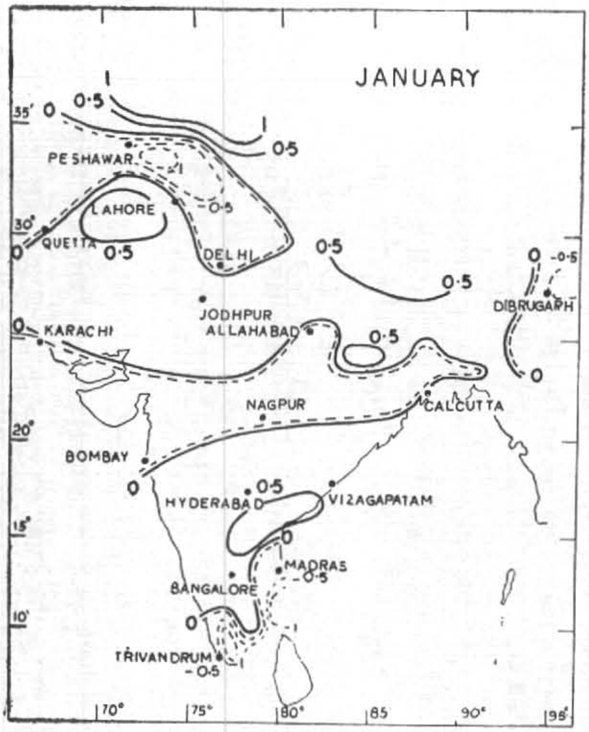

Fig. 2. Anomalies (calculated — observed) of rainfall in inches

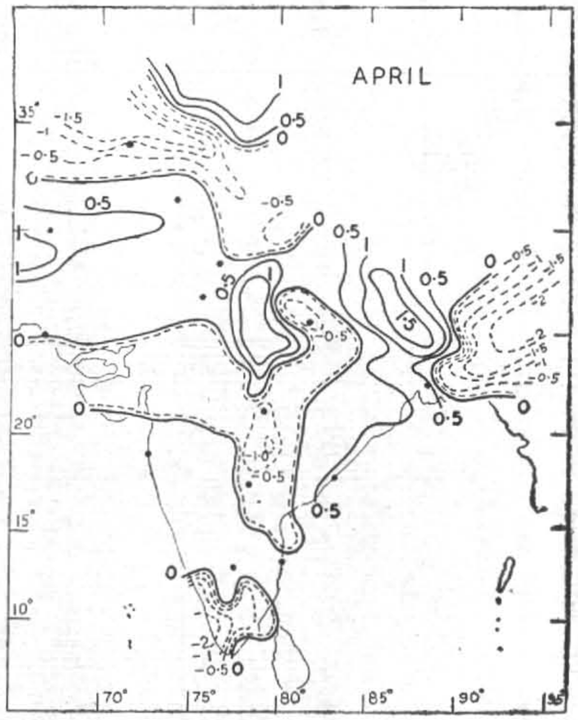

Fig. 3. Anomalies (calculated — observed) of rainfall in inches

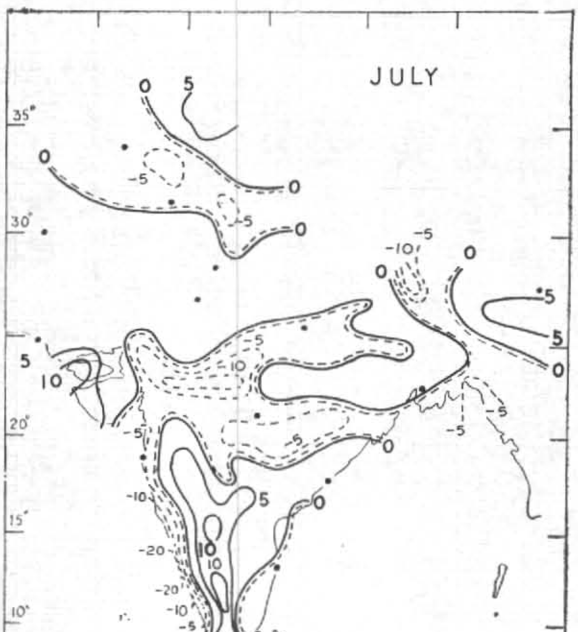

Fig. 4. Anomalies (calculated — observed) of rainfall in inches

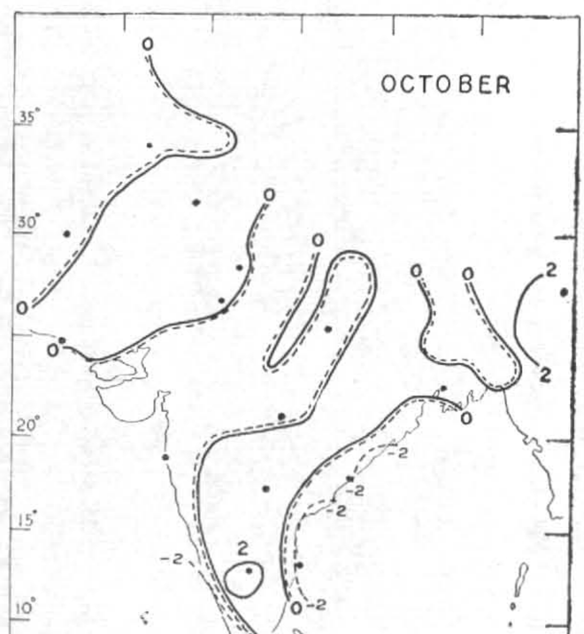

Fig. 5. Anomalies (calculated — observed) of rainfall in inches

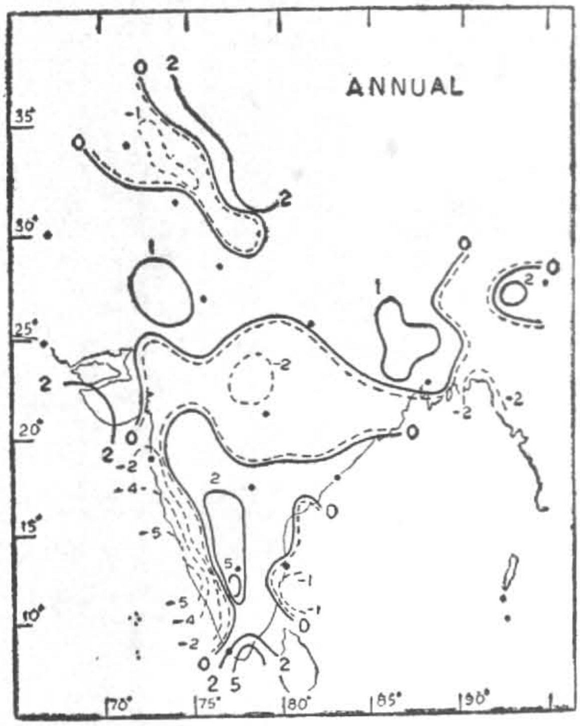

Fig. 6. Anomalies (calculated — observed) of rainfall in inches

Region IV — This comprises northwest India. The regression on latitude is positive and significant during December to April and significant but negative during June to September indicating that the rainfall during December to April which is due to western disturbances is more to the north while the monsoon rainfall during June to September decreases northwards.

The positive regression on longitude indicates that the rainfall is higher towards east during June to October. The positive regression on elevation is significant except during September and October. The multiple CCs range from 0·5 in October to 0·8 in February. The multiple correlation coefficient R for the annual rainfall is 0·6.

4. Anomalies

With a view to compare rainfall calculated from the regression equations with the actual, the anomalies (calculated *minus* observed) for the four regions were calculated and plotted on the charts. Five of these charts — January, April, July, October and Annual — are shown in Figs. 2-6. These anomaly charts besides indicating the goodness of fit reveal some interesting features which are detailed below. The negative anomalies suggest that we must search for factors other than latitude, longitude and elevation for causing rainfall while positive anomalies indicate other orographic influences which inhibit rainfall.

During December to March the negative anomalies occur over the extreme south of the Peninsula including the Coromandel coast and also a strip of the country extending from Konkan, Kathiawar coast to Orissa and a third over the northwest part of the country extending from west Uttar Pradesh northwestward. To a large extent it can be said that these represent the rainfall due to depressions, devoid of the influence of latitude, longitude and elevation.

Noteworthy areas of positive anomalies are Himalayan regions including Kashmir.

During the hot weather season, April and May, the actual rainfall is more than the calculated over the southern part of west coast, the interior Tamilnad, over Assam and East Pakistan and over the central and northwestern parts outside the arid tracts. This is a season in which rainfall due to local convective phenomena occur with greater intensity over most of the parts mentioned above and the excessive rain is probably accounted by these. The rest of the country exhibits positive anomalies.

During June to September, west coast of the Peninsula, East Pakistan, the sub-Himalayan West Bengal and the central parts of the country exhibit negative anomalies. The positive anomalies on the leeward side of Western Ghats are noteworthy.

During October and November notable regions of positive anomalies are the interior Peninsula and negative anomalies over the coastal regions to the east and southwest of the Peninsula.

The above analysis shows the broad features of the rainfall pattern associated with the latitude, longitude and elevation in the particular regions concerned. However, for a closer understanding of the relationship of rainfall with the orography in particular, the study will have to be restricted to small regions with varied orography. Attempts into this direction are in progress.

5. Acknowledgement

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