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Statistical forecasting of heavy rain and floods in the river *Teesta*

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ABSTRACT. In this paper association of various heavy rain-producing synoptic systems with intervals of average areal precipitation in the catchment of the river *Teesta* have been studied by the method of two-way contingency tables for use in quantitative precipitation forecasting.

1. Introduction

The hydrological forecasting depends on an accurate and well distributed observational data from an adquate representative network. With our present status of development of synoptic meteorology, only qualitative forecasts can be given 24 to 48 hours in advance, since quantitative precipitation forecasting on the basis of usual synoptic charts seem to be almost impossible mainly due to the lack of knowledge of microscle structure of various heavy rain producing weather systems. Particularly, in the area where rainfall is partially orographic the situation becomes further difficult due to inadequate knowledge of interaction of orography and rain producing synoptic systems.

Banerji and Rao (1964, 1969) derived quantitative precipitation forecasts by evaluation of vertical velocity and divergence from the synoptic charts for areas free from orographic effects. Many numerical methods exist for calculation of rainfall rates for either non-orographic or purely orographic rainfall. These models cannot be successfully applied to our region due to the presence of unknown interaction of orography and rain producing synoptic systems.

The Teesta catchment is situated between Lat. 26.5 deg. N and 28.1 deg. N and Long. 88.0 deg. E and 88.8 deg. E with its more than 80 per cent area lying in mountainous region. This area is mainly affected by seasonal monsoon trough and low level westerly trough during the flood seasons. In absence of suitable numerical model for predicton of rainfall in this area, an attempt has been made to study association of heavy rainfall with various rain producing synoptic systems with different ranges of average areal precipitation. Intitutively, the physical justification in favour of such studies lie in the fact that if qualitative forecasts with categories isolated, scattered etc can be made 24 to 48 hours in advance with sufficient accuracy, forecasts for intervals of average areal precipitation should also be possible as the latter corresponds to an alternative categorisation of heavy rain in a certain area. However, the synoptic systems giving rise to any category of rainfall should be known before hand.

2. The data and analysis

The data of five months of principal flood season June to October for the period 1974 to 1978 have been used. The average areal precipitation has been derived by isohyetal method from all available rainfall reports. The rainfall data have been highly irregular with many breaks. The rainfall stations whose data have been included for evaluation of average areal precipitation are shown in Fig. 1. The storms with 10 mm or more of average areal precipitation have only been considered. In grouping the average areal precipitations, the limits for which quantitative precipitation forecasts are issued by India Met. Dep. have been used though from the statistical point of view this grouping is not very satisfactory as all the synoptic systems have average rain in the range 20 to 30 mm.

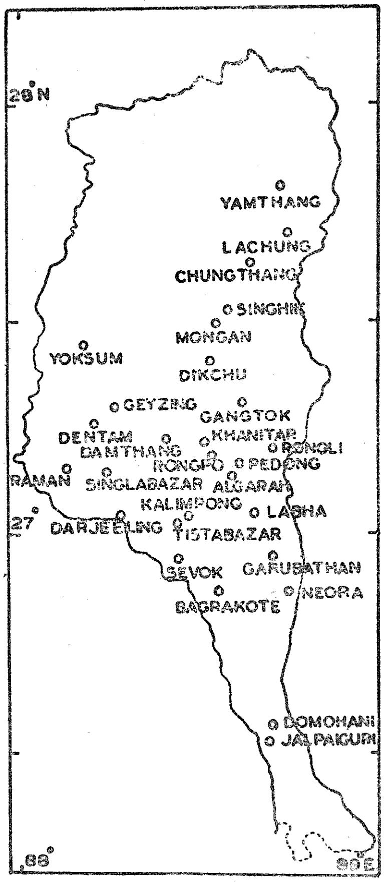

Fig. 1. Rainfall stations in Teesta catchment

Gupta and Abbi (1972) have obtained monthly average areal precipitation for the subdivision of Teesta catchment lying south of 27 deg. 30 min. N. The catchment average determined by the authors are higher as the subdivisions of Teesta catchment north of 27 deg. 30 min. N gets lesser rain during the monsoon seasons due to high altitude. The averages corrected on the basis of available data of eight rainfall stations Dikchu, Mangan, Singhik, Chungthang, Lachen. Lachung, Yamthang and Thangu for the period 1957 to 1975 have been calculated for comparing monthly heavy average rainfall frequencies observed during 1974 to 1978.

For the synoptic situations corresponding to heavly rainfall, inference for northeast India and *Indian Daily Weather Reports* have been used. The weather charts available in Flood Meteorological Office, Jalpaiguri have also been consulted. We have categorised the heavy rain producing synoptic systems into following six categories:

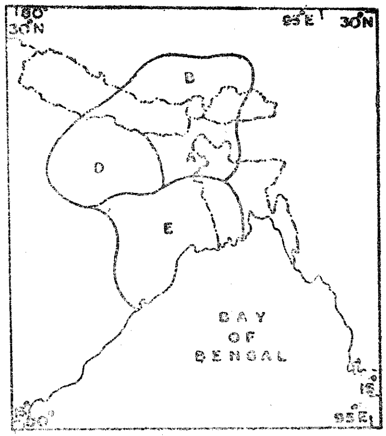

Fig. 2. Area under synoptic situations A, B, D and E

A: Low pressure areas and depressions lying 1 deg.-2 deg. south of foot hills including seasonal trough.

B: Westerly trough in low levels lying over eastern Tibet, Nepal. Bhutan, Sikkim and Sub-Himalayan West Bengal.

C: Seasonal monsoon trough not appearing in lower levels as in break monsoon conditions.

D: Low pressure areas and depressions over east Uttar Pradesh, northeast Madhya Pradesh and Bihar plains.

E: Low pressure areas and depressions over Orissa, Bihar plateau and Gangetic West Bengal.

X: When none of A, B, C, D and E prevail.

The category X has been found to include some cases of cyclonic storms and depressions in different sectors of the Bay of Bengal and the cases associated with onset of monsoon in the catchment area. The area under A, B, D and E are shown in Fig. 2.

The contingency tables of heavy average areal precipitation exhibit considerable heterogeneity due to low frequencies in some cells. However, to estimate association with different ranges of average areal precipitation, we have calculated Yule's coefficient of association by reducing the original contingency table into a number of 2×2 contingency tables. Yule's coefficient of association for 2×2 contingency table is given by

$$Q = \frac{n_{11}n_{22} - n_{21}n_{12}}{n_{11}n_{22} + n_{21}n_{12}} \times 100$$

where n_{ij} is the frequency of heavy average rain of i^{th} range in j^{th} month (or Synoptic Situation). For frequencies less than 5, this coefficient

TABLE 1

The frequency distribution of heavy average areal precipitation in the five months of flood season based on data of 1974-1978

Range (mm)	Jun	Jul	Aug	Sep	Oct	Total
11-25	75	78	75	49	10	287
26-50	36	37	29	19	3	124
51 or more	2	7	1	2	0	12
Total	113	122	105	70	13	423

TABLE 2

The frequency distribution of heavy average areal precipitation in association with various heavy rain producing synoptic systems

Synoptic situation range (mm)	A	B	C	D	E	X	Total
11–25	100	67	31	28	27	34	287
26–50	48	26	18	8	8	16	124
52 or more	5	3	2	1	0	1	12
Total	153	96	51	37	35	51	423

TABLE 6

Monthly distribution of average areal precipitation and frequency of heavy average areal precipitation

	Jun	Jul	Aug	Sep	Oct	Total
Monthly average areal precipitation in cm	49.1	57.9	48.7	30.9	12.4	199.0
Percentage of total flood season average areal precipitation realised	24.7	29.2	24.2	15.6	6.3	100.0
Percentage of heavy areal precipitation during flood season realised	26.6	28.8	25.0	16.5	3.1	100 0

has been calculated after applying Yate's correction to the 2×2 contingency tables. The test of significance of associations have been carried out by evaluating χ^2–statistic and the probability level at which associations are significant have been tabulated.

The frequency of occurrence of flood in the river *Teesta* has been treated exactly in the manner of treatment of heavy rain frequencies. The crossing of water level at Domohani bridge point the flood alert minima has been considered as a case of flood. The flood risk associated with j^{th} month (or Synoptic Situation) and range of average a real precipitation, has been evaluated by the ratio :

$$p_{ij} = \frac{n'_{ij}}{n_{ij}} \times 100$$

where n'_{ij} and n_{i_j} are the frequencies of flood and heavy average rain with j^{th} synoptic situation and i^{th} range of average areal precipitation. This may be interpreted as conditional probability of flood when a particular synoptic situation prevails and a particular range of average areal precipitation is expected.

TABLE 4

The values of Yule's coefficient of association of heavy average areal precipitation with different months of the flood season. The figures in the brackets are the percentage probability level at which associations are significant

Range (mm)	Jun	Jul	Aug	Sep	Oct
11–25	—4.6 (30.34)	—12.3 (72.86)	11.1 (63.44)	6.0 (32.92)	12.9 (32.10)
more than 26	4.6 (30.34)	12.3 (72.86)	—11.1 (63.44)	—6.0 (32.92)	—12.9 (32.10)
more than 51	—16.6 (36.16)	56.6 (97.80)	—40.4 (68.26)	14.5 (31.08)	16.2 (17.68)

TABLE 5

The values of Yule's coefficient of association of heavy average areal precipitation with different synoptic systems . The figures in the brackets are the percentage probability level at which associations are significant)

Range (mm)	A	B	C	D	E	X
11-25	—8.8 (59.06)	5.8 (35.44)	—17.5 (75.10)	20.8 (71.20)	24.8 (78.10)	—3.1 (7.60)
>26	8.8 (59.06)	—5.8 (35.44)	17.5 (75.10)	—20.8 (71.20)	—24.8 (78.10)	3.1 (7.60)
>51	11.9 (31.10)	17.3 (41.20)	32.6 (65.78)	20.4 (36.15)	—35.6 (40.0)	2.1 (2.00)

TABLE

The frequency distribution of flood in five months of flood season based on data of 1974-1978. (The figures in the brackets are the conditional probabilities of flood)

Range (mm)	Jun	Jul	Aug	Sep	Oct	Total
11–25	5 (6.7)	3 (3.9)	1 (1.3)	0 (0)	0 (0)	9 (3.1)
26–50	7 (19.4)	7 (19.0)	14 (48.3)	3 (15.8)	0 (0)	31 (25.0)
51 or more	1 (50.0)	5 (71.4)	0 (0)	0 (0)	0 (indeterminate)	6 (50.0)
Total	13 (11.5)	15 (12.3)	15 (14.3)	3 (4.3)	0 (0)	46 (1.1)

The results of analyses have been tabulated in Tables 1-7.

3. Discussion of results and conclusions

The frequencies of heavy rain in July in each range of average areal precipitation is higher than those of other months, followed closely by month of June. A study of associations with months reveals that though the associations are in general insignificant at usual probability levels in all the months except July and August, their signs clearly bring out the nature of rainfall observed in these months. The month of June has insignificant associations with all ranges. The small positive association of the June rainfall with the range more than 26 mm is due to the fact that heavy rains are observed over the catchment area when monsoon sets as a strong current. The month of July has significantly high positive association with higher ranges of precipitation and negative association with the range 11-25 mm. The reverse is observed in August which is posi-

TABLE 7

The frequency distribution of floods in association with various heavy rain producing synoptic systems. (The figures in the brackets are the conditional probabilities of floods)

Range (mm)	A	B	C	D	E	X	Total
11-25	8 (8.0)	0 (0)	0 (0)	0 (0)	0 (0)	1 (2.9)	9 (3.1)
26-50	8 (16.7)	8 (30.8)	4 (22.2)	2 (25.0)	3 (37.5)	6 (37.5)	31 (25.0)
⩾51	3 (60.0)	2 (66.7)	1 (50.0)	0 (0)	0 (indeterminate)	0 (0)	6 (50.0)
Total	19 (12.4)	10 (10.4)	5 (9.8)	2 (5.4)	3 (8.6)	7 (13.7)	46 (1.1)

tively associated with the range 11-25 mm and negatively associated with higher ranges. The months of September and October have insignificant associations with all the ranges. However, the signs of the associations in these months indicate the fact that they are primarily associated with the range 11-25 mm though the possibility of very heavy rains are not ruled out.

The results of association analysis with reference to synoptic situations bring out that the main rain producing synoptic system are A and C only. The insignificant associations everywhere exhibited by B suggests that the rainfall associated with it is almost independent and all the ranges are likely according to their marginal relative frequencies. The synoptic situations D and E are positively associated with the range 11-25 mm only though the possibility of very heavy rainfalls cannot be ruled out under these. The frequencies of synoptic situation X in higher ranges of average areal precipitation are due to the cases of onset of monsoon in catchment areas included in it. The onset of monsoon causes precipitation depending on the strength of monsoon current at the onset. The synoptic situation associated with Bay depressions, however, do not cause heavy rain in general.

While the heavy average areal precipitation frequencies reach their maximum in July, the flood risk is highest in August. One possible reason for this phenomena is the fact that the catchment is saturated with moisture in August after the heavy rain spells of June and July and higher percentage of precipitation is converted into surface runoff. The occurrence of flood with lower average areal precipitation in June, July and August are due to the fact that the heavy rains are not evenly distributed throughout the catchment in these months and floods are caused due to heavy rains in the lower catchment. September onwards the heavy rains appear to be well distributed and no flood occurs with lower average areal precipitation (This phenomena is due to the marked activity of seasonal trough in June to August).

The main flood causing synoptic situations are A, B and C only. The high flood risk associated with synoptic situation X is primarily due to the cases of onset of monsoon included in it. The synoptic situations D and E, however, cause floods in the waning of phase of monsoon and even very severe floods also have been noticed in presence of these synoptic situations in past.

In view of high agreement in percentage of heavy rain frequencies and average areal precipitation of the flood season realised in different months we may conclude that the remarks apply to 'normal' years.

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