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On evaluating design storm for a hilly catchment with inadequate raingauge network

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ABSTRACT. Procedural steps involved in the estimation of design storm rainfall for a hilly catchment with inadequate raingauge network has been discussed and applied for evaluation of *Standard Project Storm* and *Maximum Probable Storm* for the *Barak* basin (upto Silchar), located in south Assam. Attempt has been made to correlate normal monsoon seasonal rainfall on the windward and lee sides to the elevation of the hills surrounding the catchment. Utilising these relationships normal seasonal rainfall for the ungauged stations situated inside the basin has been estimated and the normal seasonal isohyetal pattern evolved for the basin. Isopercental technique has been used for assessing isohyetal pattern for the major flood-producing rainstorms and their weighted rainfall depths obtained for the basin and maximised for the moisture charge.

1. Introduction

The areal and time distribution of seasonal and storm rainfall in a project basin forms an important part of the study before preparing the plans and designs for water and power projects. This naturally depends upon the estimation of total catchment rainfall and its areal distribution in the project basin during a specified interval of time. Thus the problem is one of drawing isohyetal patterns which in an extremely hilly area can be very much in error if the precipitation network is inadequate and due consideration is not given to the orographic obstructions to the wind flow.

With a view to evolve procedural steps to tackle the problem of evaluating design storms for hilly catchments from whatever little data are available at our disposal. We have undertaken this pilot study of *Barak* river basin located in lower Assam which has very unusual topographic features and is surrounded by hill ranges on all sides and having extremely meagre network inside the basin.

2. Physical features of the Barak river basin

The *Barak*, known as Surma valley in its down stream reaches is next to the *Brahmaputra* as main drainage channel in Assam. The basin is surrounded by the north Cachar hills in the north, Manipur hills in the east, Lushai hills in the south and Khasi-Jaintia hills in the distant west. The catchment is mostly hilly and the plains region lies near the eastern extremity of the Surma valley. The *Barak* river rises a little east of Maothana on the southern slopes of mount Japvo which forms the northern boundary of Manipur. After its westerly and then southerly course it takes a sharp turn to north. It then turns west again after its junction with the tributary *Jiri*. The *Jiri* rises in steep north Cachar hills which run, almost east-west with increasing elevation towards east. There is another tributary *Sonai* which has its source in the Lushai hills situated at the southern periphery of the basin. The general relief characteristics of the basin are shown in the reference map at Fig. 1.

3. Raingauge network

For the purpose of this study the *Barak* basin upto Silchar has been demarcated into two portions, *viz.*, (*i*) upto Naraindar and (*ii*) between Naraindar and Silchar. The raingauge network in the *Barak* basin upto Silchar (Fig. 1) which has total area of about 18,675 sq. km consists of 8 raingauge stations which includes 2 meteorological observatories. The portion of the basin upto Naraindar site which has an area of about 14,532 sq. km has only 2 raingauge stations within the catchment while the remaining stations are situated in the intermediate catchment between Naraindar and Silchar sites. As is seen from the map (Fig. 1) the raingauges are mostly located on the periphery of the basin and the major portion of the basin upto Naraindar is unrepresented.

4. Rainfall distribution in the basin and associated synoptic situations

Most of the annual rainfall in this region occurs during the southwest monsoon season which normally sets in the first week of June and withdraws during the second week of October. But the noteworthy feature of this region is the frequent occurrence of showers during the premonsoon period particularly in the month of May due to

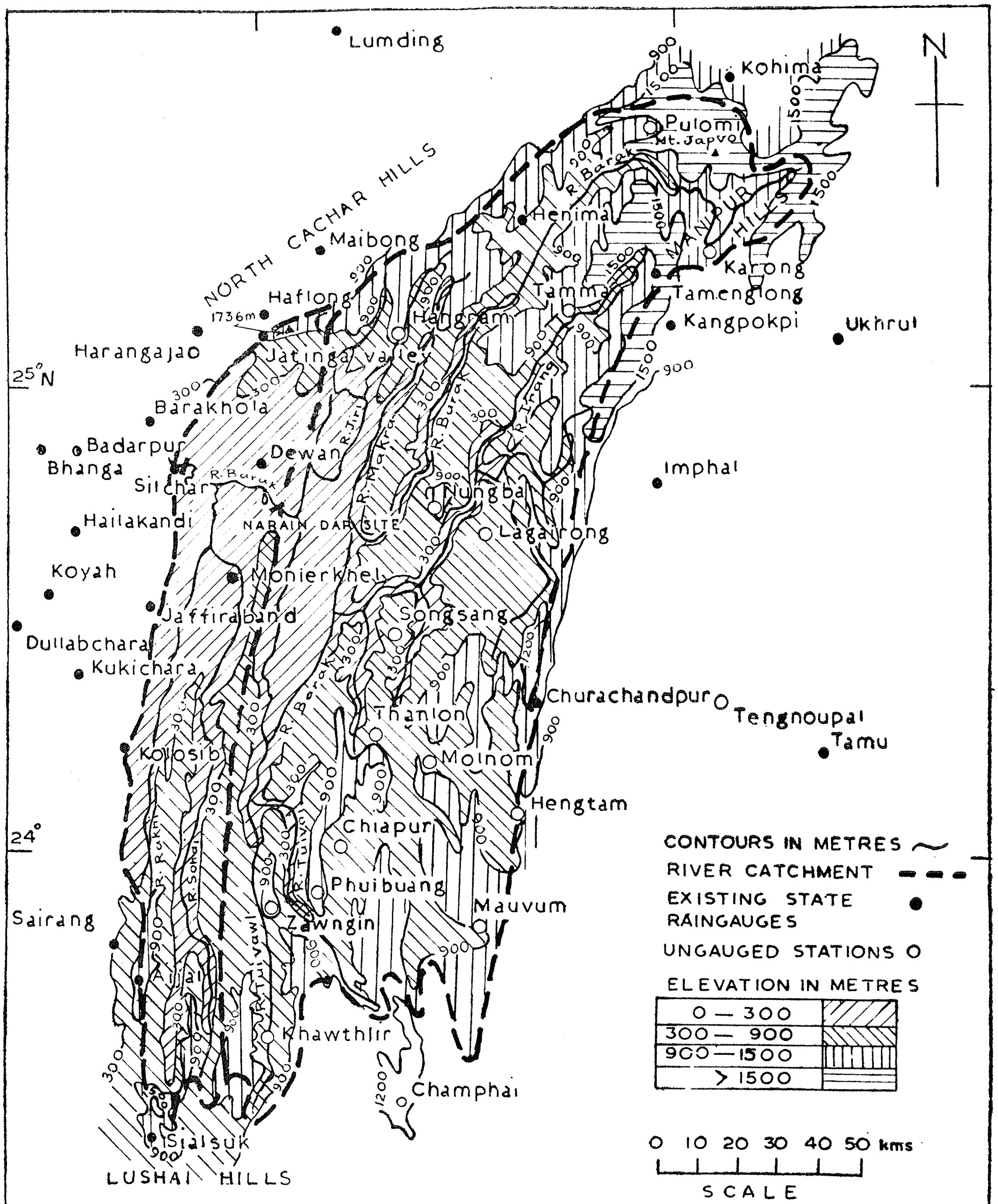

Fig. 1. Barak river catchment upto Silchar — Contours and raingauge network

which the basin gets sufficiently saturated during the premonsoon period, resulting in heavy runoff during the monsoon months of June and July. Therefore, for this hydrometeorological study, the period May-October has been considered as rainy season for the region.

The principal synoptic features causing rainfall in *Barak* basin and adjoining areas have been

TABLE 1

Station	Approx. ht. a.s.l. (m)	Normal seasonal rainfall (May-October) (cm)
	Cachar District	
Silchar	29	270·9
Barkhola	Below 150	299·0
Dewan		253·9
Monierkhel		259·5
Hailakandi		242·7
Badarpur		272·8
Jaffirband		239·2
Koyah		239·9
Kukichara		211·5
Bhanga		308·1
Karimganj		319·3
Patharkandi		252·8
Dullabchara		222·0
	United Khasi & Jaintia Hills District	
Jowai	1390	316·3
	Mikir & North Cachar Hills District	
Haflong	682	179·3
Jatinga Valley	900	393·8
Harangajao	450	302·8
Maibong	300	120·1
	Naga Hills District	
Kohima	1406	168·2
Dimapur	Below 150	132·6
Wokha	1500	250·8
Henima*	900	151·4*
	Mizo Hills (Lushai Hills) District	
Aijal	1097	195·6
Sairang	300	181·7
Slalsuk	1200	388·5
Champhai	1200	164·7
Lungleh	900	330·6
Damagiri	300	230·4
Kolosib	600	242·9
	Nowgong District	
Lanka	150	101·9
Lumding	149	109·8
	Manipur District	
Imphal	801	112·3
Taminglong	1500	341·7
Kongpokpi	1200	263·3
Ukhrul	1800	145·3
Churachandpur*	1200	131·3
	Tripura District	
Kailashahr	29	208·2
Khowai	Below 150	179·0
Dharamnagar		210·0
Sabrum		199·7
Amarpur		124·0
	Upper Chindwin District	
Mawik	150	174·0*
Paungbyin	158	183·9*
Tamu	150	205·0*
Kalewa	150	159·8*
Kalemyo	150	162·7*
Maseim	150	160·3*
Kindat	150	165·1*
Homalin	131	226·6*
	Chin Hills District	
Tiddim	1500	125·8*
Fortwhite	1200	296·7*

*Data based on 1940 normals

examined and it was found that rainspells of storm intensity were generally associated with the following situations —

(*i*) Strengthening of the Bay of Bengal current of southwest monsoon over south Assam.

(*ii*) Movement of low pressure systems over Assam and adjoining West Bengal in a northerly and northeasterly direction. The monsoon depressions/storms which form in the Bay of Bengal during the beginning of monsoon period have a tendency to move in a northerly or northeasterly direction. After crossing East Pakistan or Sunderbans coast these intense low pressure systems dissipate off Khasi-Jaintia and adjoining hills and in the process fairly widespread rain with locally heavy falls occurs in this region. As monsoon season advances, these depressions/storms change their tracks and enter coast in a northwesterly or westerly direction. During the months of July and August, land depressions form over Gangetic West Bengal or the Bay depressions in the region get recurved and strengthen monsoon activity in this region.

(*iii*) Another noteworthy synoptic situation which occasionally has been associated with heavy rainfall in the area is the formation of

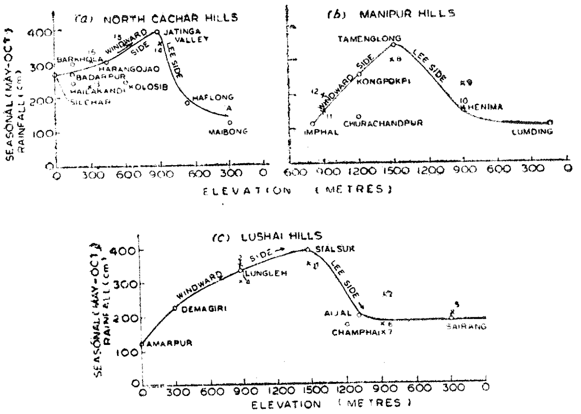

Fig. 2. Elevation-barrier-rainfall relationship

upper air troughs at lower levels over the Head Bay and adjoining northeast India. The well-defined cyclonic circulation in the lower levels induces moist currents over this region and orographic rain occurs in the hilly region and adjoining plains.

5. Effect of topography on rainfall distribution

With a view to ascertain the effect of topography on the spatial distribution of rainfall in the region, seasonal (May-October) normal rainfall based on 50-year data of the existing raingauge stations in and around the *Barak* basin has been compiled from 1950 normals (India met. Dep. 1962) wherever available. For the remaining stations including those of Burma, 1940 (India met. Dep., 1947) normals have been utilised. The seasonal normal rainfall values for the individual stations are shown in Table 1. The seasonal normal rainfall distribution has been examined with respect to relief characteristics of the region, the general pattern of the prevailing surface winds and normal upper air pattern (India met. Dep., 1943 and Ramakrishan *et al.* 1960) during the monsoon months. It is found that there are three regions of heavy rainfall corresponding to the windward sides of the three hill ranges surrounding the *Barak* basin and immediately on the lee sides of these ridges rainfall decreases sharply. At the northwestern extremity of the basin rainfall increases gradually on the southwestern side of north Cachar hills apparently due to prevailing southerly to southwesterly moist wind during the rainy season. Jatinga has maximum normal seasonal rainfall of 394 cm and on its lee side Haflong records less than 200 cm which decreases further at Maibong. Similar orographic orientation to rainfall distribution is observed with respect to Lushai hills situated at the southern extremity of the basin as reflected by the gradual increase in rainfall on the windward slopes of these ridges with Sailsuk recording 389 cm of rainfall and on the lee side of these hills rainfall decreases sharply as indicated by Aijal and Sairang. The prevailing winds, during the rainy season near and over the Manipur hills on the northeastern side of the basin are generally from east to southeasterly direction. These southeasterly winds shed their moisture on the eastern and southern slopes of the ridges resulting in gradual increase in rainfall on the windward side with maximum at Tamenglong located at the elevation of about 1500m and decreasing on the west and northwestern side of the hills. This pattern of distribution of seasonal normal rainfall in and around the catchment shows that rainfall increases with elevation on the prevailing windward side of the ridges and decreases rather sharply on the lee side. This conclusion is also supported by the studies of Sarker (1966) on orographic rainfall with particular reference to Western Ghats. Since a major portion of the catchment under study is located on the lee side of the hills, an attempt has, been made to correlate seasonal rainfall to the elevations of the barriers surrounding the *Barak* basin.

6. Elevation-barrier-rainfall relationship

When rainfall distribution in this region is examined along with the synoptic situations associated with the rainspells in the area, as discussed earlier, it can be reasonably assumed that most of the rainfall on the windward side occurs due to simple lifting of the wind stream by hill slopes. The effect of orography in stimulating convective activity may only be more predominant in the initial stages of rainstorm. The persistence of rainstorm to 3-day durations and their widespread nature over the basin may be attributed to the general storminess sustained by convective activity over the area.

For deriving the elevation-rainfall relationship, good raingauge network representing various topographical features and situated at different elevations is required. However, best use is made of the available meagre rainfall data in arriving at elevation-rainfall relationship by the procedure described below.

Here each hill range has been considered separately. All stations that are situated on the windward and lee-ward sides of the ridges have been examined separately. The first step involved in developing this relationship is a judicious selection of stations *vis-a-vis* their locations on either sides of the hills keeping in view the orographic influence on rainfall distribution.

During the rainy season, the south and western sectors of north Cachar hills are exposed to moist prevailing winds. The seasonal (May-October) normal rainfall values of these stations have been plotted against their increasing elevations. The stations on the lee side of this hill have been selected and their normal seasonal rainfall plotted against their decreasing heights. The curve thus obtained is shown at Fig. 2(a). Similar curves are prepared for Manipur hills and Lushai hills on the basis of available rainfall normals data and keeping in view the direction of prevailing winds. These curves are depicted in Figs. 2(b) and 2(c) respectively. Due to paucity of adequate data and cross effects of inflow barriers with respect to *Barak* basin the stations values given at Table 1 depict anomalies at places with respect to their elevation *vis-a-vis* their actual normal seasonal rainfall values. But these do not generally exceed 20 per cent. This limitation could have been overcome if there had been few more raingauge stations at representative heights inside the basin. This would have enabled us to prepare isoanomaly chart for the basin, and by subtracting algebraically the anomaly values from those obtained from elevation rainfall curves for further refinement.

Next step involved in this analysis was to select some representative stations or spots inside the catchment and picking up their approximate heights from the contour map, fixing their location with respect to the prevailing winds for the three hills and then interpolating their seasonal rainfall values from the curves given at Fig. 2. The seasonal normal rainfall thus obtained are given at Table 2. These values have been utilised to supplement available normal seasonal (May-October) data. On the basis of rainfall values given in Tables 1 and 2 seasonal normal isohyetal pattern is drawn. Keeping in view the principles outlined by Satakopan (1951). Since due care has been taken of the effect of topography this pattern (Fig. 3) now depicts a fairly accurate pattern of areal distribution of rainfall in the catchment.

TABLE 2

Station	Approx. ht. a.s.l. (m)	Interpolated normal seasonal (May-Oct) rainfall (cm)
Pulomi	1200	260·0
Karong	1200	260·0
Tamma	1200	265·0
Hangram	1200	260·0
Nungba	900	153·0
Lagairong	900	153·0
Songsang	1000	185·0
Thanlon	1100	195·0
Molnom	1100	195·0
Hengtam	900	185·0
Chiapur	1000	195·0
Mauvum	900	180·0
Zawngin	1100	225·0
Phuibuang	1100	225·0
Khawthlir	600	280·0
Point "A" Long. 93° 00′ E Lat. 25° 23′ N	300	150·0

7. Selection of rainstorms

Since paucity of rainfall data for the *Barak* basin presented a serious handicap in the study, the selection of heavy rainspells has been done from the available published rainfall records (1901—1959) of stations not only inside the basin but surrounding it also for the rainy season of May to October. Flood reports for the basin for the available period were also consulted. From the preliminary selection of the rainspells 8 rainstorms which had their heavy rainfall centres on the periphery of the *Barak* basin and had yielded comparatively higher average catchment rainfall were considered for detailed study and are listed below :

Storm Date	Highest recorded storm point rainfall (cm)	Raingauge station
10-12 Jun 1929	86·7	Kukichara
	98·7	Lungleh
21-23 Jul 1934	17·2	Silchar
3-5 Jun 1936	38·6	Badarpur
19-21 Sep 1938	62·2	Jatinga Valley
5-7 May 1941	45·7	Koyah
26-28 May 1944	38·1	Jatinga Valley
9-11 Jul 1946	38·7	Tamenglong
13-15 Jun 1959	53·1	Dullabchara

8. Storm analysis by isopercental technique

For areas like the one under study, the simple interpolation technique for storm isohyetal analysis will not yield accurate results particularly when the raingauge network is meagre. For such regions, World Meteorological Organisation (WMO 1969) has recommended isopercental technique of storm analysis. This technique is based on the assumption that in the area where precipitation is orographically oriented, the rainstorm patterns will more or less conform to the

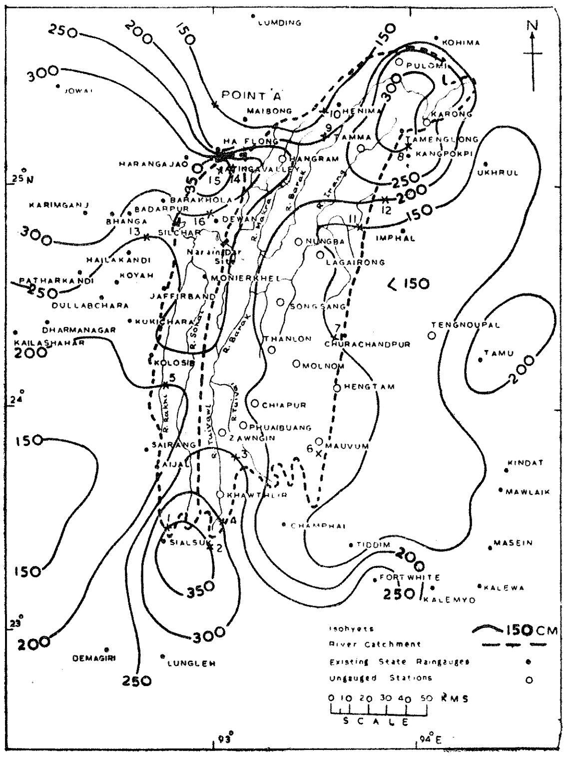

Fig 3. Barak river catchment upto Silchar Seasonal (May-October) isohyets

normal seasonal isohyetal pattern provided the direction of prevailing wind flow during the storm period is in general agreement with the seasonal wind pattern. Therefore, prevailing wind patterns during the rainstorm periods were examined *vis-a-vis* the corresponding seasonal wind pattern (India met. Dep. 1943) during the rainy season and were found to be in general agreement. Further rainfall distribution of the rainspells in this regions was also found to be similar to the seasonal rainfall distribution. Consequently, for the *Barak* basin, isopercental technique was considered as correct approach for arriving at the design storm values. In this method of analysis, the storm rainfall at existing raingauges for various durations are first expressed as percentage of seasonal normal values. These percentage ratios for all the stations for different durations are plotted on the basin map and isopercental charts prepared. These patterns graphically represent the intensity of storm relative to the seasonal rainfall. For this study such maps were prepared for max. 1-day, 2-day and 3-day average rainfall for all the 8 storms on the basis of existing raingauge network and the isolines were drawn which extended in the ungauged portion of the catchment.

These isopercental maps for various durations were then superimposed on the seasonal normal map (Fig. 3). The isopercental values at other representative ungauged stations and points inside the basin, were found out for each of the 1-day, 2-day and 3-day storm durations for all the storms. The isopercental values thus obtained were converted to actual and computed rainfall depths and plotted in the basin maps. Isohyetal analysis was carried out for all the 8 storms. All the isohyetal maps were then planimetered and average depths of rainfall over the catchment upto Naraindar and Silchar obtained for 1-day, 2-day and 3-day durations of the storms. It was found that the storm of June 1929 was the heaviest on record and yielded maximum weighted catchment rainfall depths for 1-day, two consecutive days and three consecutive days of the storm. The isopercental map of this storm and the isohyetal map prepared on the basis of the technique described above are shown at Figs. 4 and 5 respectively.

The weighted rainfall depths of this storm for the *Barak* basin upto Naraindar, between Naraindar and Silchar and the total catchment upto Silchar are given below:

Period	Weighted rainfall (cm)		
	Barak catchment upto Naraindar	Intermediate catchment between Naraindar and Silchar	Total catchment upto Silchar
Max. 1-day (10 June 1929)	16·2	27·1	18·6
Max. 2-day (10-11 June 1929)	26·5	40·1	29·5
Max. 3-day (10-12 June 1929)	28·3	42·9	31·5

Since the above values are the highest recorded weighted rainfall depths for the respective catchments and are based on more than 40-year data, these can be considered as *Standard Project Storm* values. For obtaining maximum probable storm their values need to be maximised for moisture charge and storm efficiency.

9. Moisture maximisation

In the absence of radiosonde data, precipitable water during the storm and maximum precipitable water is computed on the basis of surface dew points. For determining the storm efficiency, the rate of inflow of moisture has to be considered which implies evaluating moisture charge with respect to representative wind speed. This could

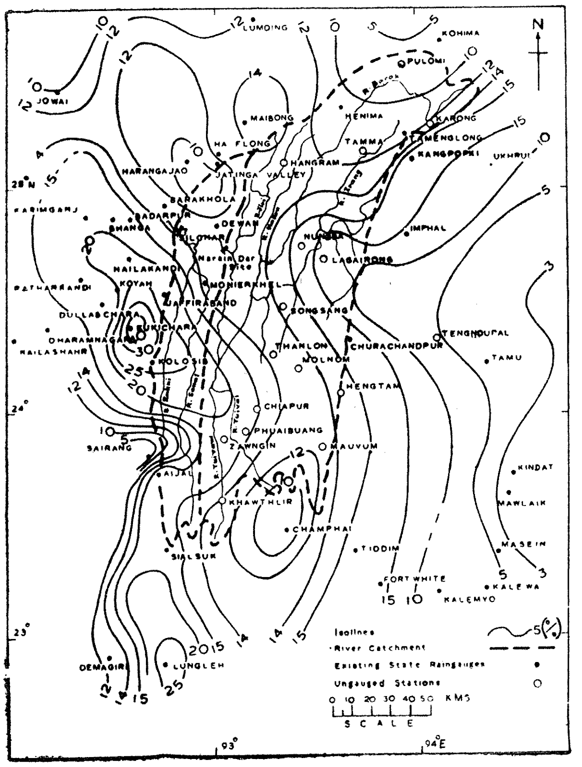

Fig. 4 Barak river catchment upto Silchar Isocentral pattern, 10-12 June 1929

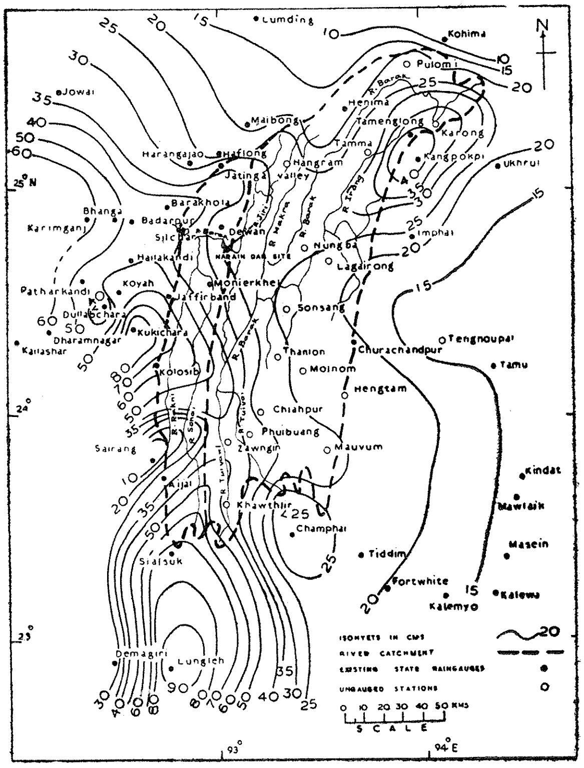

Fig. 5. Storm isohyetal pattern 10-12 June 1929
Isohyet in cm

not be attempted due to lack of relevant upper air wind speed data as pointed out above and also because in this hilly region surface wind velocities get affected due to the local effects of topography. Therefore, the moisture adjustment factor for maximising the storms has only been calculated from the available dew point data on the basis of procedure recommended by World Meteorological Organisation (WMO 1969).

There are three observatory stations in and near the *Barak* basin where dew point temperatures are recorded, *viz.*, Silchar, Imphal and Aijal, but the long term data of only Silchar is available. However, the dew point data of Imphal and Aijal which were available since 1938 and 1952 respectively were also examined. It was found that their dew point and even minimum temperature records were not continuous and were incomplete for the month of June and hence could not be utilized. Moreover, the heavy rainfall centres are located on Silchar side which is also situated on the windward direction of the north Cachar hills. Its dew point data has therefore, been taken into consideration. Since single observation dew point data have been used, due care was taken in selection of dew points as suggested by World Meteorological Organisation (WMO 1969). Maximum dew point recorded at Silchar during the first fortnight of June was 29·0°C. The persisting dew point for the storm of 10-12 June 1929 was 22·8°C. While selecting the persisting dew point, it was ensured that dew point temperatures did not exceed the minimum temperature of the day (Dhar and Mhaiskar 1968). Average elevation of the inflow barrier for the basin is considered to be of the order of 900 m. The surface maximum storm dew points have been reduced to 1000-mb level and corresponding precipitable water (Smithsonian Inst. 1963) obtained upto 500-mb level as suggested by Shenoy *et al.* (1970).

The precipitable water and the moisture maximisation factor for the basin has been computed as follows —

Maximum Dew Point reduced to 1000 mb =28·7°C
Inflow Barrier =900 m
Precipitable water (1000—500 mb) =9·1 cm
Precipitable water (1000mb—900 m) =2·1 cm

Persisting Dew Point reduced to 1000 mb during storm of 10-12 June 1929 =22·5°C
Precipitable water (1000—500 mb) =6·0 cm
Precipitable water (1000mb—900 m) =1·5 cm

Moisture maximisation factor taking into consideration inflow barrier is equal to

$$\frac{\text{Adjusted max. precipitable water for Barak Basin}}{\text{Adjusted precipitable water for the highest recorded storm}}$$

$$= \frac{7 \cdot 0}{4 \cdot 5} = 1 \cdot 55$$

Derivation of Probable Maximum Storm for the Basin — For estimation of probable maximum storm for the *Barak* basin it is recommended that the *Standard Project Storm* values may be increased by 55 per cent and the values thus obtained are —

Duration	Barak catchment upto Naraindar	Intermediate catchment between Naraindar &Silchar	Total catchment upto Silchar
1-D-ay	25·1	42·0	28·8
2-Day	41·1	62·1	45·7
3-Day	43·9	66·5	48·8

The above values represent the optimum rainfall depths in cm for the basins for estimation of maximum probable flood.

10. Limitations

The handicaps encountered in the derivation of design storm have already been mentioned while discussing various steps involved in this study. Generally required upper air data are not available to maximise the highest recorded storm for storm efficiency. In this region major contribution to heavy rainfall results from the moist winds impinging the hill slopes and the storm need to be maximised by use of "two dimensional" orographic model taking into consideration laminer flow. But in absence of requisite rawin and pibal data, this approach to maximising storms in this region was not considered feasible.

11. Conclusions

(*i*) In case of hilly catchments with scanty raingauge network, design rainstorm evaluation can be done by multi-phase analysis consisting of — (a) Establishing elevation barrier rainfall relationship, (b) Evaluating normal seasonal rainfall pattern with respect to hilly and ungauged areas, (c) Evolving the isopercental pattern of the major storms, (d) Depth-duration analysis and (e) Derivation of moisture adjustment factor.

(*ii*) Rainstorms for the *Barak* basin generally do not exceed 3-day duration.

(*iii*) The heavy and maximum flood-producing rainstorms in the catchment have occurred in the month of June.

(*iv*) The storm of 10-12 June 1929 was highest on record and its rainfall depths for various durations may be used for the estimation of *Standard Project Flood.*

(*v*) Moisture adjustment factor was of the order of 1·55.

(*vi*) *Standard Project Storm* values when maximised by 55 per cent will give maximum probable storm values for estimation of maximum probable flood for the *Barak* basin upto Naraindar and Silchar.

12. Acknowledgements

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