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Flood meteorology of Ganga basin in Bihar : A synoptic analogue study

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ABSTRACT. A detailed survey has been made from available records of all past synoptic situations which resulted in heavy rainfall in different subcatchments of Ganga basin in Bihar in different months of the monsoon season. Most of these spells are associated with either a low pressure system or break monsoon condition. While the heavy rain associated with break condition is confined to the immediate vicinity of the monsoon trough, effect of a low pressure system extends much beyond its location. It has been possible to delineate an area for each month and each individual subcatchment, location of a low pressure system within which is fraught with risk of heavy rainfall in that particular subcatchment. This area has been termed as the risk zone for the subcatchment.

1. Introduction

Out of all the aspects of meteorology and climatology of a river basin the most important for flood forecasting are the conditions under which flood producing heavy rains are possible in the basin. In this article an attempt has been made to summarise these conditions in respect of Ganga basin in Bihar from available past records. The basic methodology is the same as in all synoptic analogue studies. So is the basic presumption that the broadly consistent and generally repetitive character of all large scale weather manifestations provide a very useful forecasting tool.

1.1. *The flood season in Gangetic plains of Bihar*

The period from the beginning of June to the middle of October is the duration of monsoon as also the flood season in the Gangetic plains of Bihar. The flood risk, however, is not uniform during the entirety of the season. The risk which depends as much on recent rain as on antecedent rain is naturally very low during the first few weeks of the rainy season. At that time not only the antecedent conditions but also the actual rainfalls are not favourable for floods. Monsoon rainfall in Bihar (as elsewhere in Gangetic plains) starts at a low key in June, attains its peak in July and August, falls off in September till by second week of October it stops entirely on withdrawal of monsoon. The flood risk, therefore, goes on increasing with the advance of monsoon because of the dual effects of increased rainfall and favourable antecedent conditions. The reduced rainfall in September, however, does not affect this increasing trend. This is so not only because the antecedent condition is very favourable but also because of a particular feature of September rainfall. Though the total rainfall during September is less than that during July or August, there is a significant increase in the intensity of rainfall per rainy day in September. In other words September rainstorms are fewer in number but are more intense than their counterparts in earlier months.

1.2. *Synoptic meteorology of heavy rain in Ganga Basin in Bihar*

The two major synoptic features which cause heavy rainfall in Bihar are the monsoon disturbances — low pressure areas and depressions — and break monsoon conditions. Break monsoon conditions, however, affect only the upper Gangetic plains drained by tributaries originating in the Himalayas during the mid-monsoon months of July and August. The geographical distribution of rainfall obtaining in a break condition is relatively well defined. On the contrary the rain-

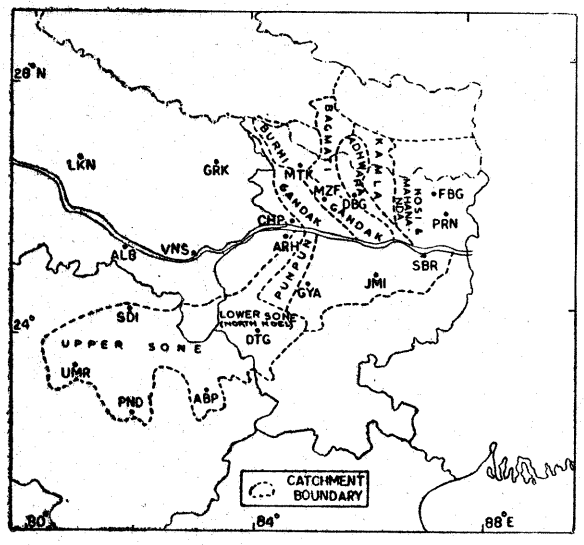

Fig. 1. Catchments of tributaries of *Ganga* in Bihar

fall pattern associated with a migrating monsoon disturbance is rather complex. Firstly, the heavy rainfall extends much beyond the location of a disturbance. Secondly, the rainfall distribution depends, apart from factors related to the intensity of the system, upon the track of the disturbance and time of the season. The depressions of mid-monsoon period do show some broad similarities in their rainfall pattern in that the rainfall is mostly confined to the left forward sector of the disturbance but those of the late monsoon period, September and October, are known to have an erratic pattern of rainfall. These facts together make rainfall forecasting under a depression situation a tricky job for a flood meteorologist particularly when he is dealing with a small forecast area such as a river catchment. This demands a detailed knowledge, on the part of the forecaster, about (*i*) the tracks of the disturbances which affect a given catchment during the particular monsoon month, and (*ii*) the geographical limit of the location of a disturbance from where it can cause heavy rainfall in the catchments. With this object in view a detailed survey has been made from available records of all past synoptic situations which gave heavy rain in different subcatchments of Ganga basin in Bihar in different months of the monsoon season. Results of the survey are summarised below:

1.3. *River systems of Ganga basin in Bihar— A brief description*

The *Ganga* in Bihar is joined by several important tributaries (Fig. 1). The major left bank tributaries (or northern tributaries) which have their source regions mostly in Nepal Himalayas are, the *Ghagra,* the *Gandak,* the *Burhi Gandak,* the *Bagmati,* the *Adhwara* group, the *Kamla,* the *Kosi* and the *Mahananda* from west to east. The principal right bank tributaries (or southern tributaries) which originate from central Indian plateau are the *Sone* & the *PunPun.* The catchment east of *PunPun* is drained by a number of small seasonal streams, the *Phalgu,* the *Paimar,* the *Goithana,* the *Sakri,* the *Badua,* and the *Chandan,* which flow only during the southwest monsoon period.

2. Heavy rainfall events and associated synoptic systems — A historical account since 1901

Heavy rainfall events in the subcatchment of right bank & left bank tributaries of *Ganga* in Bihar and upper catchments of *Sone* since 1901 were compiled. The 24-hr point rainfall of 10 cm as the base value, and two or more stations recording this amount of rainfall in a subcatchment unit were used as the criterion for compilation of heavy rainfall events. *Storm Track Atlas* and *Indian Daily Weather Reports* were consulted to identify the synoptic features associated with each heavy rainfall event.

2.1. *Synoptic systems affecting right bank tributaries*

Though not all the heavy rainfall events were explained by the recognisable surface systems which were recorded in the two documents, it was found that the Bay depressions and low pressure areas of the monsoon season constitute, by far, the chief synoptic features which caused heavy rainfall activities in the sub-catchments of right bank tributaries. A few isolated events were also associated with 'active' or 'well marked' seasonal monsoon trough. In one or two cases even under 'break' conditions coupled with steep pressure gradient, that is strong westerlies (with a southerly component), heavy rainfall events were recorded in the catchment of tributaries east of *PunPun.* In later years when the upper air data became available, a few incidents could be recognised as associated with upper air troughs and upper air cyclonic circulations also.

In many of the events associated with Bay depressions it was observed that heavy rainfall occurred in the southern catchments when the disturbance was centred over. Bay or even earlier during its formative stage. Similar phenomenon was observed when the development took place over land areas of Gangetic West Bengal or Bangladesh. In some cases *in situ* formation of disturbance and even conditions prior to its formation, in the vicinity of a catchment also gave rise to the occurrence of heavy rainfall.

The effect of Bay depressions in causing incidence of heavy rainfall in the different subcatchments of right bank is not uniform. The number of heavy rainfall events and percentage number assignable to the Bay depressions (including those not in the direct field of the disturbance but occurring with the disturbance located away

TABLE 1

Percentage frequency of heavy rainfall events associated with Bay depressions in the catchments of right bank tributaries of *Ganga* in Bihar

Catchment	June		July		August		September		October	
	1	2	1	2	1	2	1	2	1	2
Sone upper catchment (Sone, Gopath, Rihand, Kanhar)	10	60	22	35	29	45	14	86	—	—
Sone lower catchment (North Koel)	14	50	30	53	34	35	25	60	1	—
Pun Pun catchment	7	57	17	24	24	37	13	54	1	—
Catchment east of Pun-Pun	16	63	15	14	24	17	17	89	11	73

Col. 1 : Total No. of events selected,

Col. 2 : Percentage No. of events accounted for by the Bay depressions.

in Bay or Gangetic West Bengal or Bangladesh) is shown in Table 1. It will be seen that the largest number of heavy rainfall events in any catchments occurred in the month of August followed by July, September and June. However, the proportion of heavy rainfall events which were caused by the Bay depressions is generally maximum in the month of September, that in July being the minimum. In the months of July & August percentage frequency of heavy rainfall events associated with Bay depressions reduces as we go eastward from the upper catchment of *Sone* to those of tributaries east of *PunPun* so much so that not a single event in the right most subcatchment (east of *PunPun*) in the month of July was associated with the direct field of Bay depression. Only on two occasions heavy rainfall occurred as a 'precursor' phenomenon when the system was located over Bay. In *PunPun* subcatchment there was only a single event of 1 July 1925 which occurred in direct field of Bay depression. On two or three other occasions only precursor rainfall phenomenon was observed when depression was located over Bay or adjoining Gangetic West Bengal. This is commensurate with the fact that depression track in the month of July are concentrated in a narrow band south of 25 deg. N and the depressions move generally in westnorthwesterly direction. The subcatchment of *PunPun* and the one east of it have, therefore, practically no chance of coming under their influence in the month of July. The subcatchment east of *PunPun* is comparatively less affected in the month of August also. The higher frequency of heavy rainfall events in the month of August as compared to July can be ascribed to the fact that the depression tracks in August have a more northwesterly course and also have a larger latitudinal scatter so that the subcatchments have better chance of coming under their influence. The higher percentage frequency for the months of June & September (Table 1, Col. 2) for all subcatchments is obviously due to the fact that the depression tracks in these two months are spread out (Rao 1976) and have a tendency to move in a more northerly direction and recurve. This makes the subcatchments come under the influence of depressions more frequently in these two months.

The table further shows that the incidence of heavy rainfall in the catchments of *Sone, North Koel* and *PunPun* is confined upto the month of September, barring an isolated occurrence in the month of October, whereas this incidence stretches well into October in the case of the subcatchment east of *PunPun*. This is due to the fact that most of the disturbances in this month recurve towards northeast after initial northwest/north movement, by passing the other subcatchments and affecting only this portion of the Ganga Basin in Bihar (south of *Ganga*).

2.2. *Synoptic systems affecting left bank tributaries*

'Break' monsoon condition was the predominent feature which accounted for majority of the heavy rainfall events in July & August in the subcatchments of left bank tributaries. The seasonal monsoon trough located in northerly latitude belt running across the subcatchments also produced some of the events. The Bay depressions/low pressure areas of July & August do not, in general, affect these catchments. There was a solitary event of 29-30 July 1965 in *Burhi Gandak* during the entire period since 1901, which was caused by a Bay depression. The subcatchment lay entirely to the right of the track of depression in this case, and the rainstorm realised was a very severe one. It is unusual for the rainfall distribution of this kind to occur in the month of July. Another isolated incidence occurred in the month of August in the same subcatchment in association with a low pressure area which formed *in situ*. Here again the location of the catchment was to the north of the 'low'.

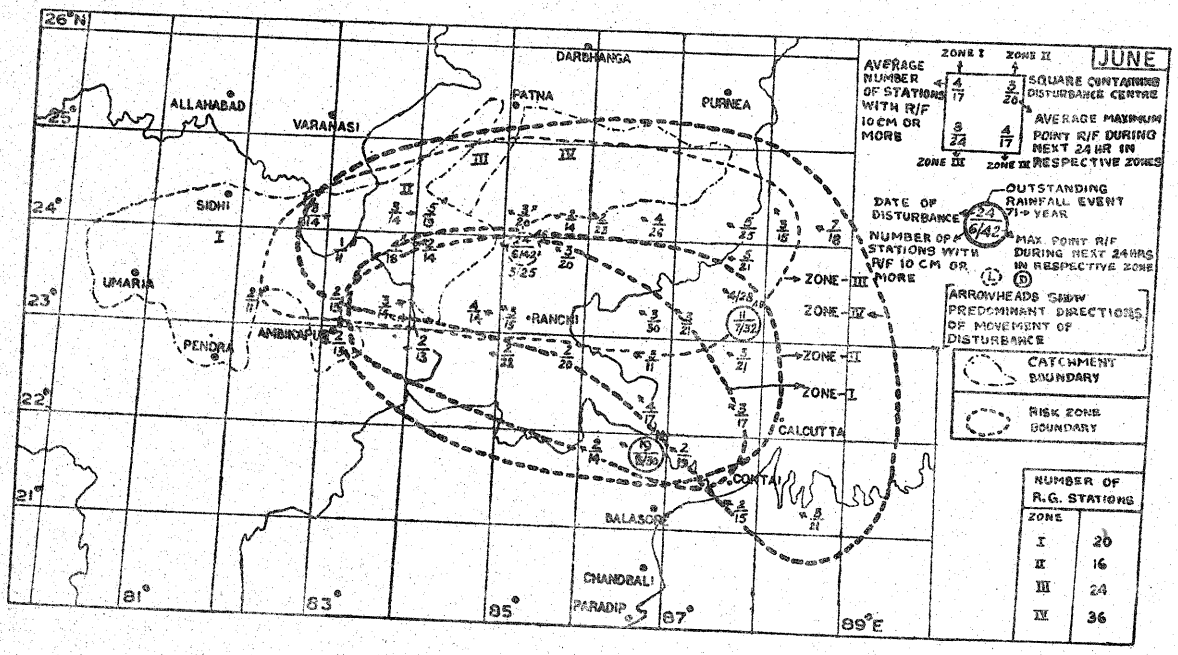

Fig. 2. Four south bank zones, No. of raingauge stations, risk zone boundary in the subcatchment during June

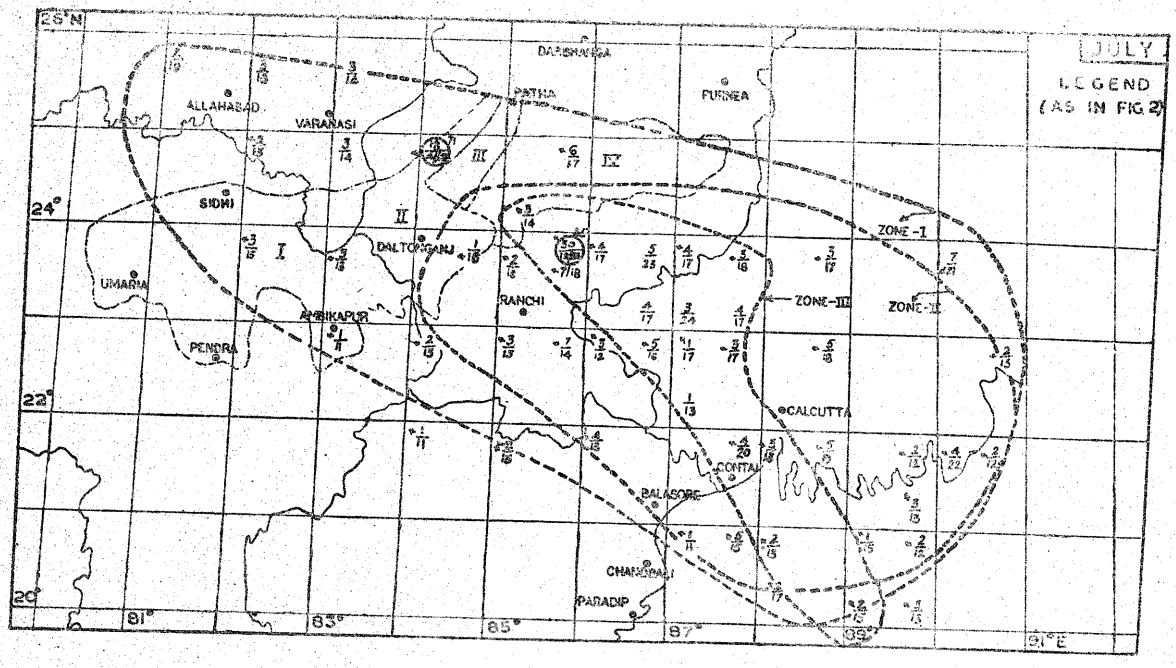

Fig. 3. Four south bank zones, No. of raingauge stations, risk zone boundary in the subcatchment during July

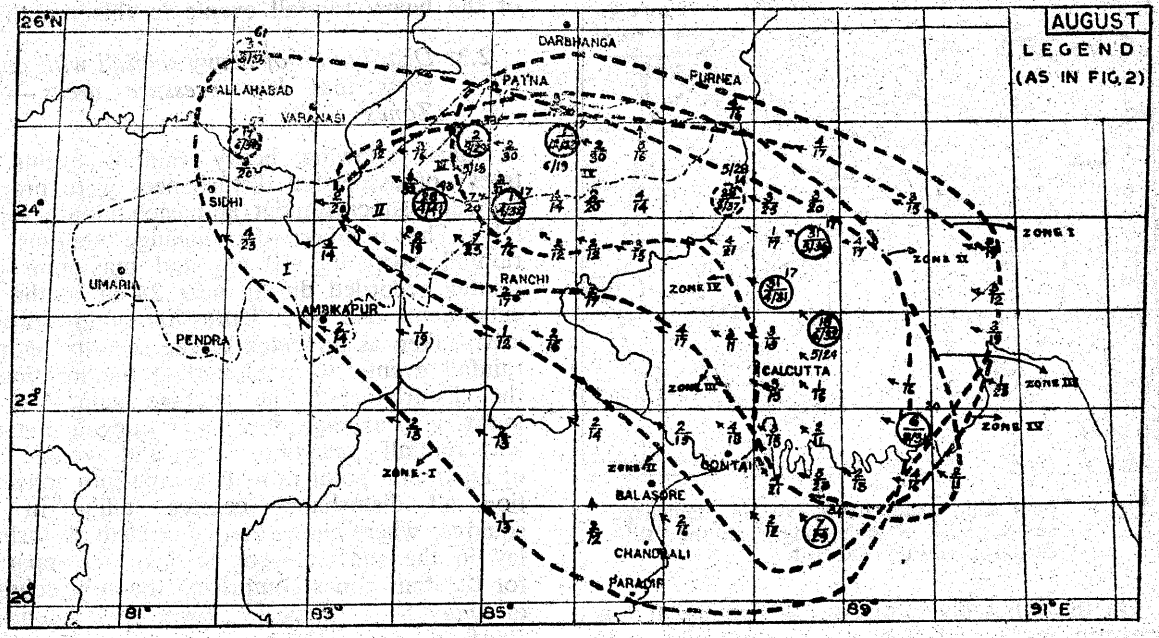

Fig. 4. Four south bank zones, No. of raingauge stations, risk zone boundary in the subcatchment during August

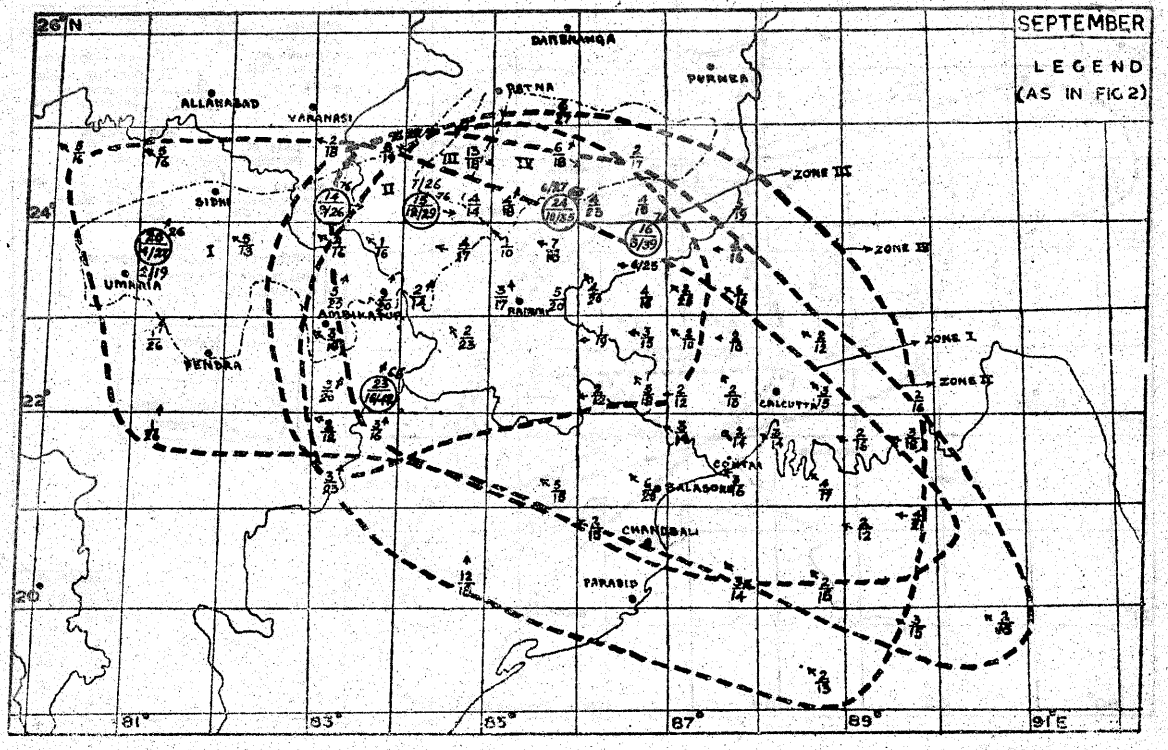

Fig. 5. Four south bank zones, No. of raingauge stations, risk zone boundary in the subcatchment during September

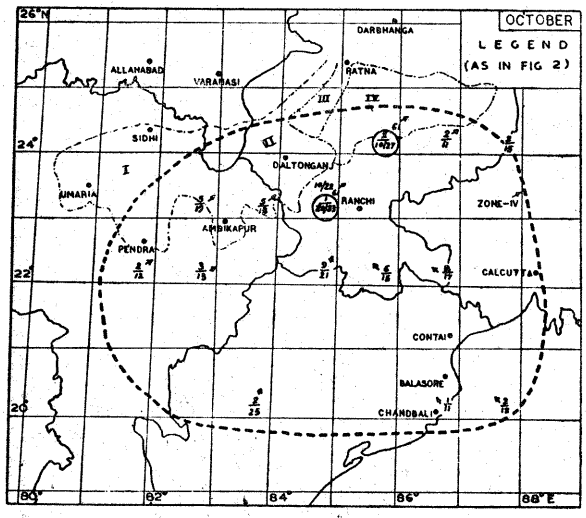

Fig. 6. Four south bank zones, No. of rainguage stations, risk zone boundary in the subcatchment during October

On the other hand, in June & September low pressure areas and depressions were the main systems which accounted for most of the heavy rainfall events. 'Break' monsoon situations appeared only on isolated occasions. These subcatchments were also affected in the month of October mostly in the first week and occasionally upto second and third weeks. Depressions were the synoptic features which accounted for most of the heavy rainfall events in this month too.

2.3. *Distribution of heavy rainfall with depressions and low pressure areas — Risk Zones*

Charts showing heavy rainfall events and tracks of associated disturbances were prepared for each subcatchment and each month separately. The number of raingauge stations with rainfall exceeding 10 cm and maximum point rainfall recorded during next 24 hr in the subcatchments due to a depression or low pressure area, taken as an index of the severity of heavy rainfall events, were plotted at the locations of the disturbances. The average values of this index, *viz.*, average number of raingauge stations with rainfall exceeding 10 cm and average value of maximum point rainfall, taking into consideration all disturbance centres falling in deg. squares, where more than one such disturbance lay in the square, were worked out separately for the four zones comprising the subcatchments of *upper Sone* (Zone I), *lower Sone* (Zone II), *PunPun* (Zone III) and east of *PunPun* (Zone IV) in the south bank portion of Ganga basin, and three zones comprising the subcatchments of *Gandak & Burhi Gandak* (Zone I), *Bagmati, Adhwara* group, *Kamla* (Zone II), and *Kosi, Mahananda* (Zone III) in the north bank portion. These are schematically presented in

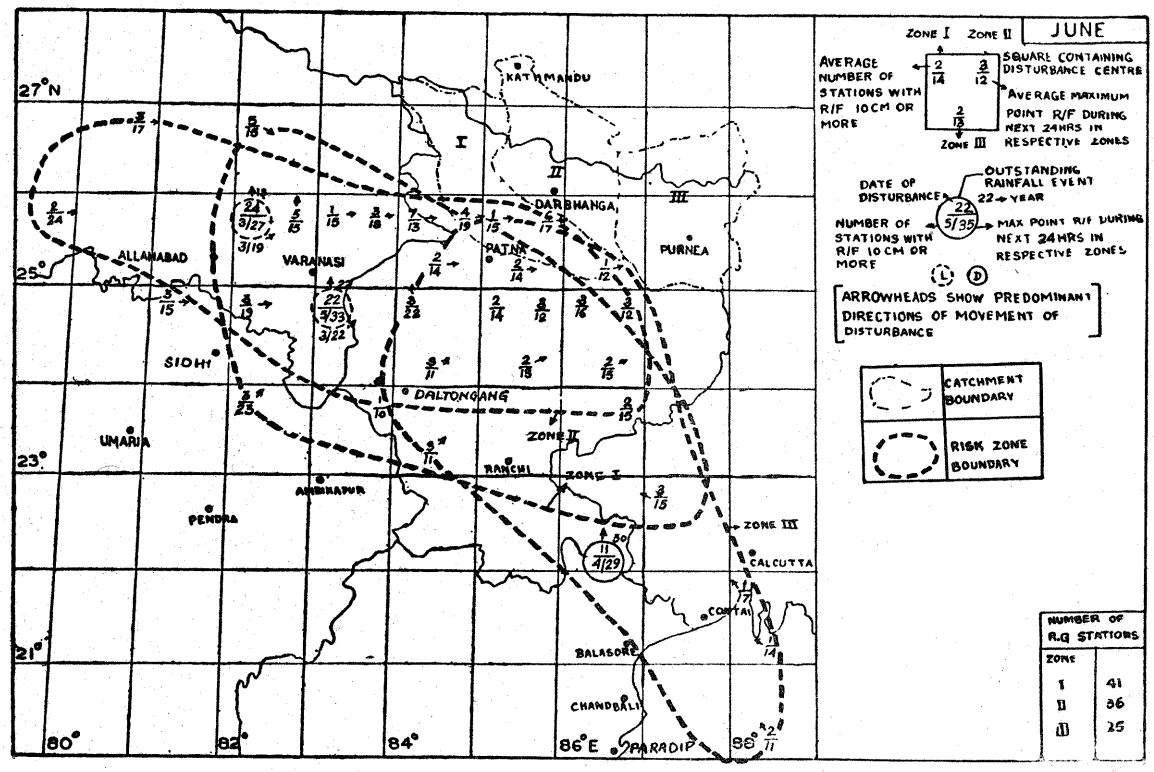

Fig. 7. Three north bank zones, No. of raingauge stations, risk zone boundary in the subcatchment during June

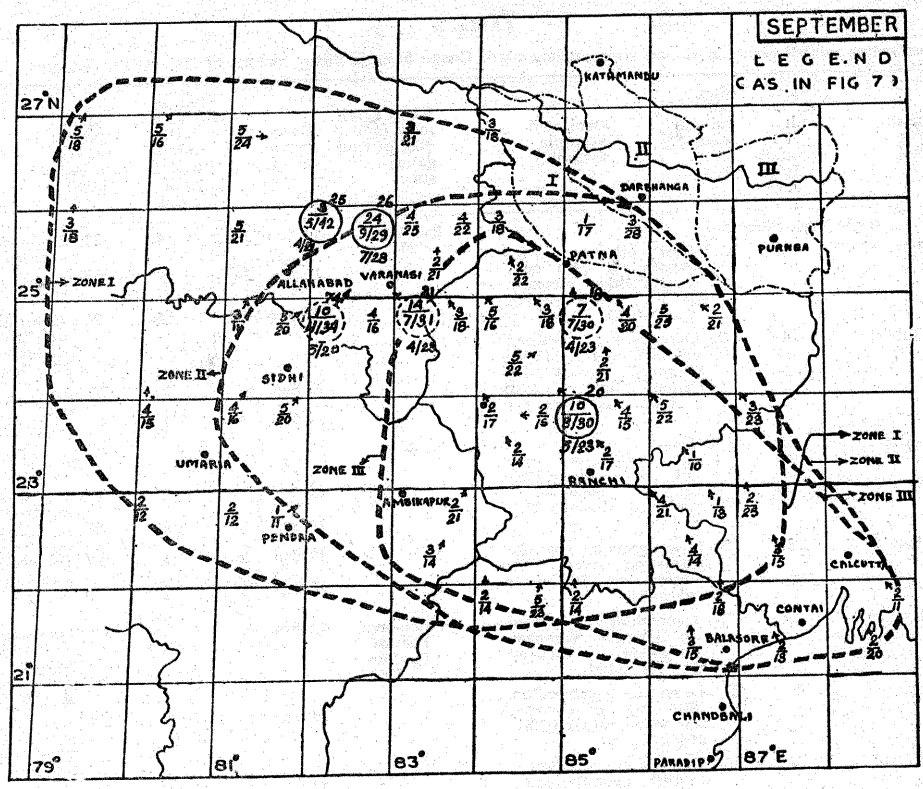

Fig. 8. Three north bank zones, No. of raingauge stations, risk zone boundary in the subcatchment during September

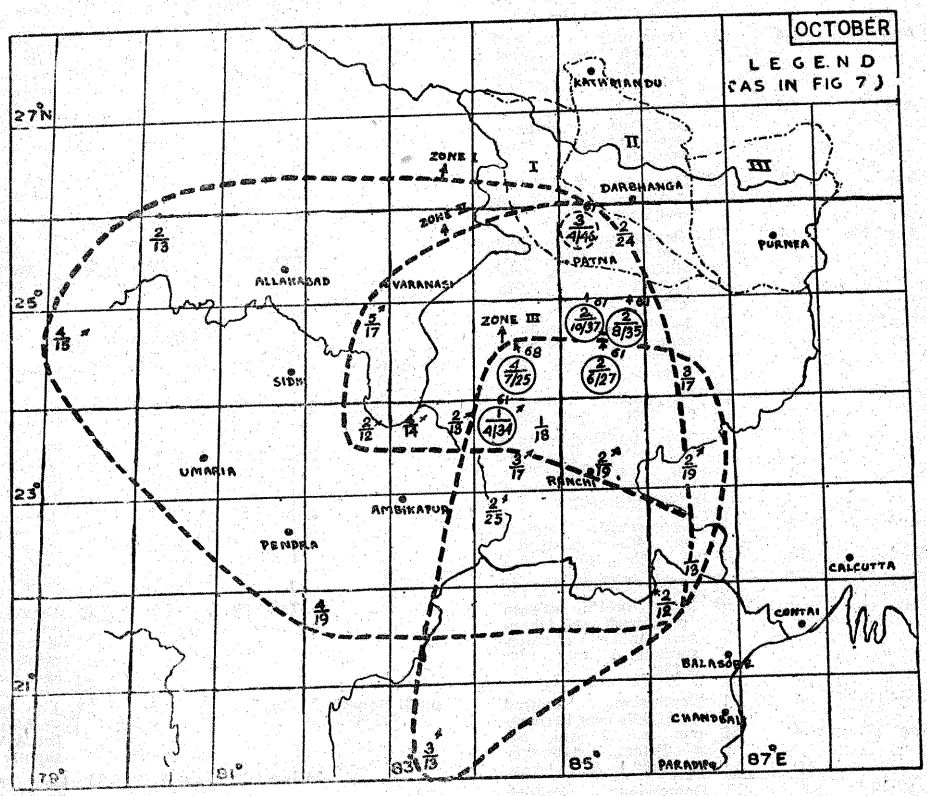

Fig. 9. Three north bank zones, No. of raingauge stations, risk zone boundary in the subcatchment during October

TABLE 2

Outstanding rainfall events in various river catchments of Ganga basin in Bihar and associated synoptic features

River catchment (and No. of rain gauge stns.)	Date of heavy rainfall	No. of R.G. with point rainfall >10 cm	Max. point rainfall recorded (cm)	Associated synoptic feature
	Right Bank tributaries			
Upper Sone (20)	25 Jun '46	6	42	Low pressure area centred on 24th near Ranchi (Bihar plateau), on 25th near Pendra (East M.P.).
	19 Jul '71	4	28	Depression ; centred on 18th near Dehri (Western parts of Central Bihar) on 19th near Varanasi SE (U.P.)
	18 Aug '53	6	30	Low pressure : *in situ* formation over U.P. : Centred on 17th near Allahabad, stationary between 17th & 18th.
	6 Aug '61	3	27	Low pressure ; *in situ* formation over U.P. centred on 5th near Varanasi.
	22 Aug '75	3	26	Depression ; centred on 21st near Varanasi, stationary between 21st & 22nd.
	21 Sep '26	4	27	Depression ; centred on 20th East of Umaria, stationary between 20th and 21st.
Lower Sone (North Koel) (16)	20 Jun ' 11	8	36	Depression ; centred on 19th near Baripada (North Orissa), on 20th near Ranchi.
	1 Jul ' 25	12	22	Depression ; centred on 30th June near Hazaribagh (Bihar plateau).
	19 Aug ' 07	6	32	Depression ; centred on 18th near Calcutta, on 19th between Midnapore & Calcutta.
	1 Aug ' 17	5	36	Depression ; centred on 31 Jul near Berhampore (Gangetic West Bengal).
	2 Aug ' 17	12	32	On 1 Aug SE of Patna, stationary between 1st and 2nd.
	7 Aug ' 20	8	31	Depression on 6th over coastal Bangladesh about 2° East of Calcutta), on 7th west of Ranchi.
	22 Aug ' 33	5	29	Land depression ; centred on 21st near Dehri, on 22nd near Varanasi.
	22 Aug ' 34	7	29	Depression ; centred on 21st over NW
	23 Aug ' 34	3	20	Bay, on 22nd between Ranchi & Jamshedpur, on 23rd about 1° West of Daltonganj (Bihar plateau).
	15 Sep ' 76	8	19	Depression ; centred on 14th southwest
	16 Sep ' 76	13	18	of Dehri, on 15th
	17 Sep ' 76	8	39	south of Gaya (Central
	18 Sep ' 76	7	19	Bihar), on 16th between Hazaribagh and Dhanbad (Bihar, plateau), stationary on 17th & 18th.
PunPun (24)	1 Aug ' 17	4	31	Depression, centred on 31 July near Berhampur on 1 Aug SE
	2 Aug 17	4	32	of Patna, stationary between 1 & 2 Aug
	28 Aug ' 40	4	27	Depression ; centred on 27th over coastal
	29 Aug ' 40	4	41	Gangetic West Bengal south of Calcutta, on 28th near Daltonganj, statonary between 28th & 29th.
PunPun (24)	11 Sep ' 36	4	23	Low pressure ; *in situ* formation over central
	12 Sep ' 36	5	28	Bihar near Jamui on 11th, stationary.
	27 Sep ' 60	5	25	Depression ; centred on 26th north of Ambikapur (M.P.), on 27th NE of Dehri.
	19 Sep ' 67	9	22	Low pressure area ; centred on 18th north of
	20 Sep ' 67	8	32	Gaya, stationary between 18th & 19th, on 20th SE of Patna as a depression.
	15 Sep ' 76	9	26	Depression ; centred on 14th SW of Dehri ,
	16 Sep ' 76	12	29	on 15th south of Gaya ,
	17 Sep ' 76	4	29	on 16th between Dhanbad & Hazaribagh,
	18 Sep ' 76	5	19	stationary on 17th & 18th.
Catchment East of PunPun (36)	12 Jun ' 49	7	32	Depression : centred on 11th between Dumka & Dhanbad, stationary between 11th & 12th.
	29 Aug ' 14	3	37	Low pressure area ; *in situ* formation near Malda on 27th, stationary on 28th.
	24 Sep ' 65	16	42	Depression ; centred
	25 Sep ' 65	10	35	on 23rd near Ambikapur, on 24th east of Gaya.
	18 Sep ' 67	8	19	Low pressure area ;
	19 Sep ' 67	6	29	*in situ* formation over Bihar plateau on
	20 Sep ' 67	5	25	17th, centred on 18th north of Gaya, stationary between 18th & 19th, on 20th SE of Patna as a depression.
	19 Sep ' 76	10	22	Depression, centred
	20 Sep ' 76	3	44	on 18th between Hazaribagh & Dhanbad stationary upto 19th·
	2 Oct ' 61	20	33	Depression ; centred
	3 Oct ' 61	19	27	on 1st near Daltonganj, on 2nd SW of Jamui (central Bihar), on 3rd as a low between Patna & Bhagalpur.
	Left bank tributaries			
Gandak (8)	12 Jul ' 34	2	25	'Break' condition.
	7 Sep ' 18	2	30	Low pressure area ; centred on 6th between
	8 Sep ' 18	2	30	Hazaribagh & Dhanbad, stationary between 6th & 7th, on 8th near Muzaffarpur.
	11 Sep ' 20	2	30	Depression centred on 10th near Hazaribagh, on 11th as low near Ballia (Bihar-U.P. border).
	3 Oct ' 59	3	26	Depression ; centred on 2nd near Jashpurnagar (East M.P. Bihar border), on 3rd as a low near Daltonganj.
Burhi Gandak (33)	25 Jun ' 13	3	27	Low pressure ; centred on 24th between Allahabad & Varanasi, moved slightly north 25th.
	23 Jun ' 22	5	33	Low pressure, entred on 22nd SW of Dehri on 23rd near Ballia.
	28 Jun ' 38	8	27	'Break' condition.
	21 Jul ' 40	8	20	Do.
	22 Jul ' 40	4	34	
	23 Jul ' 40	3	23	

TABLE 2 (*contd*)

River catchment (and No. of rain gauge-stns.)	Date of heavy rainfall	No. of R.G. with point rainfall >10 cm	Max. point rainfall recorded (cm)	Assocated synoptic feature
Burhi Gandak (33)	29 Jul ' 65	3	24	Depression, centre on 28th SW of Jamshedpur, on 29th as a low near Gaya.
	30 Jul ' 65	17	26	
	24 Aug ' 66	3	30	'Break' condition.
	11 Sep ' 20	6	30	Depression ; centred on 10th near Hazaribagh, on 11th as a low near Ballia.
	15 Sep ' 21	6	31	Low pressure area; centred on 14th SW of Dehri, on 15th near Allahabad.
	17 Sep ' 24	3	23	Low pressure area ; centred on 16th Between
	18 Sep ' 24	8	26	Jamui and Dhanbad stationary on 17th.
	4 Sep ' 25	4	42	Depression ; centred on 3rd near Varanasi.
	16 Sep ' 56	4	29	Low pressure ; centred on 15th west of Ballia, on 17th NE of Ballia.
	10 Sep ' 74	6	20	Low pressure area : Centred on 9th near
	11 Sep ' 74	8	34	Dhanbad, on 10th between Allahbad and
	12 Sep ' 74	3	20	Varanasi, on 11th near Azamgarh
	2 Oct ' 61	4	34	Depression ; centred on 1st between Daltonganj and Hazaribagh on 2nd between Jamui and Hazaribagh, on 3rd as a low between Patna and Bhalgapur.
	3 Oct ' 61	10	37	
	4 Oct ' 61	4	46	
Bagmati (9)	28 Jun ' 38	3	26	'Break' condition.
	24 Aug ' 66	2	31	Do.
	19 Sep ' 24	3	24	Low pressure area ; centred on 18th near Dehri.
	18 Sep ' 33	3	24	Low pressure area ; centred on 17th near Sidhi (Northeast M.P.) moving NW'wards.
Adhwara group (14)	24 Aug ' 66	4	30	'Break' condition.
	11 Sep ' 20	5	21	Depression ; centred on 10th near Hazaribagh, on 11th near Ballia.
	4 Sep ' 25	2	27	Low pressure area; centred on 3rd near Varanasi.
Adhwara Group (14)	18 Sep ' 35	3	25	Low pressure area ; centred on 17th near Sidhi moving NE
	29 Sep ' 42	4	23	Depression ; centred on 28th near Jharsuguda, on 29th near Gaya, on 30th as a low near Muzaffarpur.
	30 Sep ' 42	2	21	
	21 Sep ' 67	2	28	Depression ; centred on 20th SE of Patna.
	3 Oct ' 61	4	23	Depression ; centred on 2nd between Jamui and Hazaribagh on 3rd as a low between Patna & Bhagalpur.
Kamla (13)	27 Jul ' 57	3	32	'Break' condition.
	21 Jul ' 60	2	35	Do.
	6 Jul ' 65	3	19	Do.
	7 Jul ' 65	4	30	
	4 Aug ' 57	3	22	Do.
	5 Aug ' 57	4	42	
	6 Aug ' 57	2	34	
	25 Sep ' 26	7	29	Low pressure area ; centred on 24th between Allahabad and Varanasi
	22 Sep ' 67	3	28	Low perssure area ; centred on 21st near Darbhanga.
	3 Oct ' 61	3	35	Depression ; centred on 2nd between Jamui and Hazaribagh, on 3rd as a low between Patna & Bhagalpur.
Kosi & Mahananda (25)	12 Jun ' 50	4	29	Depression ; centred on 11th near Jamshedpur on 12th as a low west of Bhagalpur
	9 Jul ' 65	7	23	'Break' condition.
	25 Sep ' 65	9	21	Depression ; centred on 24th between Gaya and Daltoganj on 25th as a low NE of Gaya.
	3 Oct ' 61	6	27	Depression; centred on 2nd between Jamu & Hazaribagh, on 3rd as a low between Patna & Bhagalpur.
	5 Oct ' 68	7	25	Depression ; centred on 4th near Gaya

Figs 2-6 corresponding to the months June to October for south bank zones and Figs. 7-9 for the months June, September & October for north bank zones. Some of the most outstanding rainfall events characterised by a large number of stations with rainfall exceeding 10 cm and a very high maximum point rainfall have also been plotted in appropriate locations in the degree squares. The major rainfall events with associated synoptic features in various subcatchments are listed in Table 2.

The squares containing these disturbances for each zone have been enveloped by closed curves. This curve for a zone represents the limit of location of disturbances from where this can cause heavy rainfall in that particular zone. This boundary has been termed as the 'risk zone' for

the subcatchment. Each point in this zone may be deemed as heavy rainfall-risk location of the depressions/lows for the respective subcatchment. The most conspicuous feature of all these charts is the extension of the risk zone boundaries much further away from the subcatchment units.

These charts can be used as an operational aid in the formulation of subcatchmentwise forecasts of heavy rainfall. It is also possible to estimate the likely spatial distribution of rainfall exceeding 10 cm by referring to the number of raingauge stations indicated in the degree squares and the total number of raingauge stations in the subcatchment, which are also shown alongside in the respective diagrams. This technique of heavy rainfall forecasting can be extended to forecasting of different rainfall ranges on similar lines and estimates of quantitative precipitation can be framed by taking weighted averages.

3. Conclusion

The Ganga Basin in Bihar can be considered as comprising of two distinct sub-divisions with reference to synoptic systems producing heavy rainfall — the catchments of right bank tributaries and the catchments of left bank tributaries.

The Bay depressions/low pressure areas are the principal synoptic systems which affect the south bank tributaries during the entire southwest monsoon period. However, the effect of those disturbances in different subcatchments, *viz.*, *Upper Sone, Lower Sone* (*North Koel*), *PunPun* and the one east of *PunPun* varies from month to month. The striking feature in this regard revealed by the present study is that the July depressions do not generally affect the catchments of *PunPun* and the one east of *PunPun* while the catchment east of *PunPun* is the only one affected in the month of October; others do not come under their influence in this month.

The northern-half of the basin experiences heavy rainfall associated mostly with systems: (*i*) break monsoon condition and (*ii*) depressions/low pressure areas. 'Break' condition is the predominant feature giving rise to heavy rainfall in mid-monsoon months of July & August. Depressions/low pressure areas are the principal systems in the months of June, September & October. The occurrence of heavy rainfall events in the month of June are much isolated except in the catchment of *Burhi Gandak*. The July & August depressions do not generally affect these catchments.

The severity of rainstorms and the frequency of occurrence of severe rainstorms in a major portion of the Ganga Basin in Bihar is the highest in the late monsoon period, *viz.*, September & October.

On some occasions heavy rainfall commences in a catchment when the disturbance is far away.

Further, there may be serious departures in the traditional rainfall patterns associated with a monsoon disturbance. For instance, severe rainstorms may occur to the east of a westward moving monsoon depression/low pressure area even in the mid monsoon months of July & August, in sharp contrast to the general belief that the heavy rainfall is confined to the left forward sector of the system in these two months even though such occasions are very rare. The synoptic conditions leading to such unusual phenomenon need further investigations.

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