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Semi-quantitative precipitation forecasts for Kosi/Mahananda catchment by synoptic analogue method

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सार – इस शोध पत्र में सिनॉप्टिक एनॉलॉग पद्धति से कोसी/महानन्दा जलग्रहण के लिए अर्द्धमात्रात्मक वर्षण पूर्वानुमान जारी करने का प्रयास किया गया है। 22 वर्षों 1982–2003 के आँकड़ों के अध्ययन से यह पता चला है कि अर्द्धमात्रात्मक पूर्वानुमान जारी करना संभव है।

जलग्रहण क्षेत्र की स्थानीय स्थ्लाकृति और कोसी में भीमनगर से छतरा/बराहक्षेत्र तथा दार्जलिंग के पहाडी क्षेत्र तक सीधे ढाल वाले अनुकूल क्षेत्र है जहाँ बंगाल की खाडी और अरब सागर की नमी युक्त वायु राशि निम्न क्षोभ मंडल में दक्षिणी पश्चिमी मानसून के समय अभिसरित होती है। 500 हे.पा. पर द्रोणी विशेष रूप अपसरित होती हुई नमी युक्त वायु तेजी से ऊपर उठती है जिसके कारण पर्वतीय प्रभावों के अलावा बिहार और नैपाल के हिमालय क्षेत्र के उप पर्वतीय जिलों में भारी/बहुत भारी वर्षा होती है। इसके परिणामस्वरूप पूर्णिया/कटिहार/सहरसा/किशनगंज/माधेपुरा जैसे घनी आबादी वाले जिलों में भयंकर बाढ़ आती है और इस क्षेत्र की अर्थव्यवस्था पर बहुत अधिक दुष्प्रभाव पडता है।

ABSTRACT. An attempt has been made to issue semi-quantitative precipitation forecasts for Kosi/Mahananda catchment by synoptic analogue method. Based upon 22 years of data (1982 - 2003) the study reveals that it is possible to issue semi-quantitative forecasts with confidence.

Local topography of the catchments and its steep gradient from Bhim nagar to Chatra / Brahkshetra in Kosi and hills in Darjeeling are favourable regions where moist air masses of the Bay of Bengal and the Arabian Sea during South West Monsoon in lower troposphere converge and trough at 500 hPa especially diffluent in rear creates divergence and moist air mass is pulled up resulting in heavy / very heavy rainfall in sub montane districts of Bihar and Nepal Himalaya in addition to orographic effects. This gives birth to severe floods and makes the life of densely populated districts of Pumea / Katihar / Saharsa / Kisanganj / Madhepura miserable and badly affects the economy of the region.

Key words – Synoptic, Catchments, Quantitative Precipitation Forecasts (QPF), Mean rainfall, Frequency, Range, Seasonal trough, Homogeneous rainstorm, Vigorous, Active, Oscillation.

1. Introduction

Rao (1973) identified four synoptic systems and applied the synoptic method for a selected areas in north east India for a period of 1961 to 1967. Abbi *et al*. (1979) studied the movement of cyclonic storms/depressions/ monsoon trough for a period of 1960-1976 with respect to Bhagirathi catchment and prepared analogue maps depicting the associated rainfall distribution. Lal *et al*. (1983) studied different types of synoptic situations and correlated them with their resulting rain storms over Gomati river catchment in Uttar Pradesh based upon data of 1976-1980 and prepared synoptic analogues for forecast range of areal rainfall. Prasad and Prasad (1993) studied distribution of rainy days, rainfall and associated features for different river catchments in Bihar. Singh *et al*. (1995) studied five types of synoptic situations for Pun pun river catchment based upon data of 1982-1993 and prepared synoptic analogues for forecast range of real rainfall. Ram and Pangasa (2000) studied for Ghaghra catchment by synoptic analogue technique. Jha (2006) studied for Gandak catchment by synoptic analogue techniques based upon data of 1982-2003. In this paper attempts have been made to identify the different synoptic systems and its location which are accountable for average areal precipitation in the ranges of 11-25 mm, 26-50 mm,

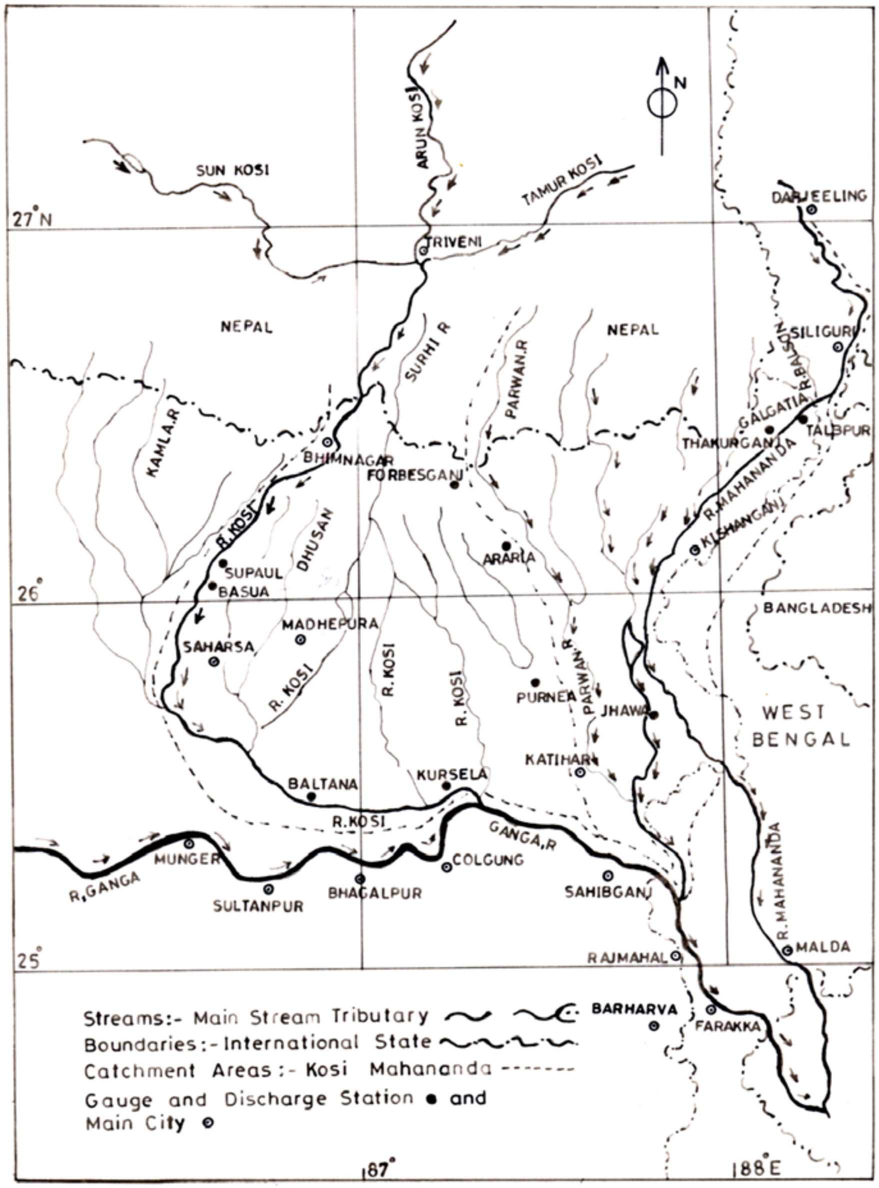


Fig. 1. Locator map of Kosi/Mahananda basin

51-100 mm and more than 100 mm during the monsoon period in the above catchments which are meteorologically homogeneous in plain areas.

Flood Meteorological Office (F.M.O.) Patna of India Meteorological Department (IMD) issues Quantitative Precipitation Forecast (QPF) for the Kosi and Mahananda basin. The total area covered by these two river basins is 28440 sq km for which FMO Patna has been issuing QPF during flood season.

The Kosi basin

The Kosi is formed by the confluence of three rivers, the Sun Kosi, the Arun Kosi and the Tamur Kosi all taking their origin in the Himalayan region of Nepal and Tibet.

The total drainage is 74,500 sq. km of which 11,000 sq km lie within India and 5,957 sq km is under glaciers and snow. The Tamur Kosi has the steepest slopes. Mount Everest and Mount Kanchanjunga lie in the catchment of the Arun Kosi.

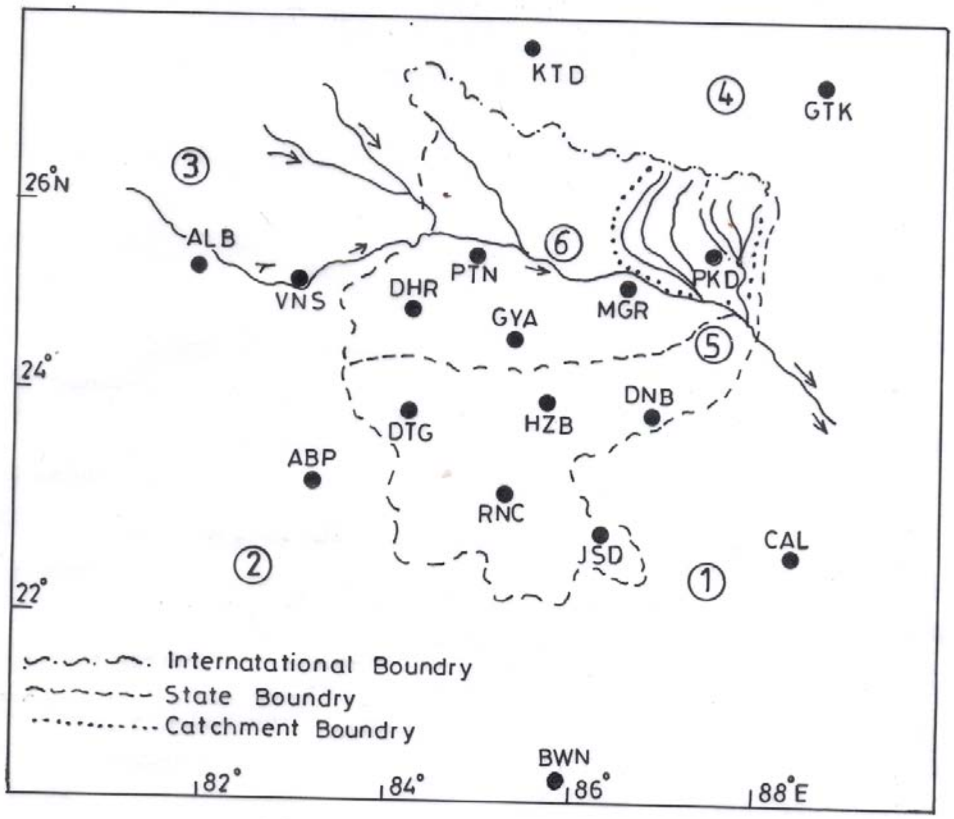


Fig. 2. Different zones in Kosi/Mahananda basin

After the confluence, the river flows through a narrow gorge for 10 km and enters the plain at Chatra. After traversing a further 25 km, it enters India near Hanuman Nagar. It forms the boundary between India and Nepal for a distance of 20 km. The Kosi has been causing a lot of destruction by lateral movement like the yellow River of China. As its water carry heavy silt load the river has steep gradient, there is a tendency for it to move side ways. Thus in about 200 years the river has moved laterally 112 km from Purnea to its present position. After running for 320 km below Chatra. The Kosi joins the Ganga near Kursela (Fig. 1). The river length in Bihar is 260 km and average annual rainfall is 1590 to 1380 mm and in hilly area 3500 mm and about 80% of it receives from June to October. Hydrological problems are (*i*) Enormous Siltation Problems, (*ii*) River Shifting Problems, (*iii*) Drainage Congestion Problems, (*iv*) Flood Problems.

The Mahananda basin

The Mahananda rises in the hills of Darjeeling district at an elevation of 2100 m with a number of tributaries *viz*., Balsan, Mechi, Ratwa and Kankai. It debouches into plains near Siliguri. Mahananda is joined by river Mechi 33 kms downstream of Taibpur. The Kankai is an erratic stream and as it rises in Nepal hills, it carries a lot of silt. The tributary Kankai joins Mahananda on the right side above Dhengraghat. Below Dhengraghat the river flows in a meandering course and bifurcates into two branches *e.g*., Jhawa and Barsoi. The Jhawa branch flows in a southerly direction forming the boundary between Bihar and West Bengal and then joins the Ganga upstream of Farakka barrage. The Barsoi branch flows in a south-easterly direction and enters West Bengal. It then flows south forming the boundary between India and Bangladesh for about 6 kms and enters Bangladesh to join Padma (Ganga) at Godagiri ghat. (*Source* : RASHTRIYA BARH AYOG VOL I. March 1980 and Mid Ganga Division IV, Patna).

The total catchment area of the Mahananda basin is 25,043 sq km out of which 17,440 sq km in India, 6,340 sq km in Bihar and 11,100 sq km in West Bengal. The length of the river is 376 km and an average rainfall

1,563 mm in India (*Source* : 2nd Bihar State Irrigation commission Report). It is only rainfed and so practically dries up during summer. The basin experiences flood almost every year. In its lower reaches in the Malda district, drainage congestion occurs when the level in the Ganga remains high.

There are seventeen rain gauge stations in the entire consists of Kosi & Mahananda Basin, *viz*., Barahkshetra* (Nepal), Chatra (Nepal), Birpur*, Basua*, Forbesganj, Nirmali, Supaul, Baltara*, Purnea, Kursela*, under Kosi basin, Taipur*, Thakurganj, Dhengraghat*, Jhawa*, Araria, Chargharia and Galgalia under Mahananda basin. All the stations having asterisk marks are discharged sites also and connected by W/T sets. Rainfall as well as discharge data are being received through Mid Ganga Division IV of Central Water Commission situated at Patna during rainy season.

2. Method and data

The area lying between the parallels of latitudes 20°- 28° N and longitudes 80° - 90° E has been selected and divided into six zones as shown in Fig. 2. These six zones take care of location of weather systems, its intensities and movements with respect to different rivers catchments under the jurisdiction of Flood Meteorological Office Patna based upon the languages used in daily weather bulletins.

1.	20° - 24° N & 85° - 90° E	Gangetic West Bengal and adjoining areas of North West Bay, Orissa, Jharkhand and Bangladesh.
2.	20° - 24° N & 80° - 85° E	East Madhya Pradesh and Chatisgarh adjoining areas of Jharkhand and Orissa.
3.	24° - 28° N & 80° - 84° E	East Uttar Pradesh and adjoining areas of East Madhya Pradesh.
4.	26° - 28° N & 84° - 90° E	Bihar plains and adjoining areas of Sub Himalayan West Bengal and part of middle Himalayan Region.
5.	24° - 26° N & 86° - 90° E	Bihar plains and adjoining areas of Gangetic West Bengal.
6.	24° - 26° N & 84° - 86° E	Bihar plains.

The catchment areas under study are lying between 86° 30' E to 88° 15' E and 25° N to 27° N as such zones 4 and 5 are taking care of the catchment.

As per Forecasting Manual Part III of India Meteorological Department (1972) there are five groups of synoptic systems responsible for active/ vigorous monsoon conditions over the catchments and these are :

S. No.	*Synoptic systems*
S_1	Cyclonic storm / Deep depression / Depression / Land Depression.
S_2	Low / well marked low pressure either forming over sea or land.
S_3	Upper air circulations.
S_4	Monsoon trough at msl or at 0.9 km asl.
S_5	North-South trough in lower level westerlies / super imposed westerly, mid tropospheric / higher level westerly troughs.

Note : The symbol $S_{4},_{4}$ stands for seasonal trough at 0.9 km asl passes through Bihar plains and adjoining areas of Sub Himalayan West Bengal *i.e.*, 1st figure stands for weather systems S_4 and 2nd figure stands for its location in Zone 4.

Flood season at Patna starts w.e.f. 15th June every year. As such data under study have been used from 15th June to 30th September for the period 1982-2003. Based on the Synoptic situations based upon 0300 UTC surface and 0000 UTC upper air charts quantitative precipitation forecasts have been issued in the ranges 11-25 mm, 26-50 mm, 51-100 mm and more than 100 mm and the realized average areal precipitation on the next day have been collected date wise and monthwise for this study. All the values of average precipitation of the catchment have been collected against the particular synoptic condition situated in a particular zone month wise and again weighted average rainfalls have been calculated. Arithmatic mean method has been used for calculations as mentioned in Manual of Hydrometeorology, India Meteorological Department (1972).

3. Results and discussion

3.1. Table 1 depicts frequency of S_1, S_2, S_3, S_4 and S_5 in June to September with mean rainfall. S_1, $_1$ occurred

TABLE 1

Different synoptic situation with location, frequency and mean rainfall (mm) month wise from June on September (1982-2003)

Synoptic code (1)	June		July		August		September	
	Frequency	Mean rainfall (mm)	Frequency	Mean rainfall (mm)	Frequency	Mean rainfall (mm)	Frequency	Mean rainfall (mm)
$S_{1,1}$	7	17.5	9	8.5	12	3.6	9	30.9
$S_{1,2}$	1	0.5	7	19.1	8	15.0	4	7.4
$S_{1,3}$	-	-	-	-	-	-	-	-
$S_{1,4}$	-	-	-	-	-	-	-	-
$S_{1,5}$	-	-	-	-	-	-	-	-
$S_{1,6}$	1	79.2	-	-	-	-	-	-
$S_{2,1}$	35	11.6	80	6.7	106	10.1	71	11.7
$S_{2,2}$	17	13.8	32	9.4	44	9.3	44	13.2
$S_{2,3}$	15	14.6	7	24.3	20	22.4	38	21.5
$S_{2,4}$	2	49.2	-	-	3	25.5	3	11.7
$S_{2,5}$	5	38.0	5	28.2	5	52.5	5	8.8
$S_{2,6}$	1	19.7	12	20.8	5	14.1	13	51.4
$S_{3,1}$	19	7.5	37	9.7	38	10.8	32	12.6
$S_{3,2}$	4	5.8	18	15.4	14	11.6	16	10.8
$S_{3,3}$	8	31.2	21	20.2	22	17.4	20	9.8
$S_{3,4}$	6	19.7	11	26.6	4	25.7	25	9.6
$S_{3,5}$	5	14.5	6	17.2	11	13.8	10	11.4
$S_{3,6}$	20	16.8	28	19.3	27	14.7	14	12.2
$S_{4,1}$	2	27.4	2	14.5	-	-	2	4.6
$S_{4,2}$	16	15.2	34	20.1	23	16.6	28	7.8
$S_{4,3}$	2	31.0	-	-	3	136	1	24.3
$S_{4,4}$	11	21.2	69	30.8	29	28.3	31	18.9
$S_{4,5}$	8	20.4	7	21.3	-	-	-	-
$S_{4,6}$	15	19.8	81	21.8	56	27.6	40	23.6
$S_{5,3}$	-	-	2	26.5	2	22.6	1	21.3
$S_{5,4}$	-	-	3	16.7	1	29.3	2	37.8
$S_{5,5}$	-	-	2	51.2	-	-	-	-
$S_{5,6}$	-	-	2	40.7	-	-	-	-

7, 9, 12 and 9 times in June, July, August and September with mean rainfall 17.5 mm, 8.5 mm 3.6 mm and 30.9 mm respectively. During advancing phase of monsoon in June and retreating respectively. During advancing phase of monsoon in June and retreating phase in September convective activities are more as such catchment area received more rainfall in September followed by June in comparision to July and August the peak months for Depression with $S_{1,\,1}$.

$S_{2,1}$ less intense than depression followed the same pattern as $S_{1,1}$, $S_{2,4}$ affected hilly areas of the catchment and occurred 2 and 3 times in June and August with mean rainfall 49.2 mm and 25.5 mm respectively. $S_{2,5}$ directly affected the plain areas of catchment and occurred 5, 5 and 5 times in June, July and August with mean rainfall 38.0 mm, 28.2 mm and 52.5 mm respectively. $S_{2,6}$ occurred 13 times in September with mean rainfall 51.4 mm during retreating phase of monsoon.

TABLE 2

AAP more than 100 mm in the catchments due to synoptic system in a single day

Synoptic code	Year	Date	AAP > 100 mm
$S_{2,\ 5}$	1987	02 August	120.4
$S_{4,\ 6}$	1987	13 August	118.1
$S_{4,\ 6}$	1989	01 August	102.0
$S_{4,\ 4}$	1995	12 August	100.7
$S_{2,\ 3}$	1989	29 September	111.0
$S_{4,\ 4}$	1995	27 September	132.3
$S_{2,\ 6}$	1999	24 September	128.6
$S_{2,\ 6}$	1999	25 September	175.2

$S_{3,\ 3}$ occurred 8 times in June with mean rainfall 31.2 mm during advancing phase of monsoon.

S_4 during frequent oscillations towards north from normal position or during break monsoon conditions or its eastern wing bending towards Assam gave more rainfall during monsoon season. As such $S_{4,\ 4}$ occurred 11, 69, 29 and 31 times during June, July, August and September with mean rainfall 21.2 mm, 30.8 mm, 28.3 mm and 18.9 mm and so was the case with $S_{4,\ 6}$ which occurred 15, 81, 56 and 40 times in June, July, August and September with rainfall 19.8 mm, 21.8 mm 27.6 mm and 23.6 mm respectively.

Among all the systems S_5 as an upper trough in westerlies especially diffluent trough in rear gave heavy to very heavy rainfall in Nepal.

Himalaya areas and Submontane districts of Bihar and caused flash floods in river catchments of north Bihar. $S_{5,3}$ occurred twice in July and gave 26 mm; $S_{5,4}$ occurred 2 and 1 time in August and September and gave 29 mm and 38 mm respectively and $S_{5,5}$ occurred twice in July having mean rainfall of 51 mm.

3.2. Table 2 depicts the catchments received average areal precipitation >10cm on 8 days within 22 years. The catchments received the highest rainfall of 17cm due S2, 6 on 25th September 1999, 13 cm on 24th September 1999, again 13 cm due $S_{1,1}$ on 27th September 1995. Such situations in September occurred due retreating phase of mansoon and presence of heavy convective activities in areas 1986, 1987, 1995, 1997, 1999, 2000 were the favourable years due active/vigorous condition.

A few cases of typical weather situations responsible for rainfall > 10 cm are given below:

The role of trough line on sea level chart and associated upper air trough, shifting towards foothills of the Himalayas and its bending towards Assam side.

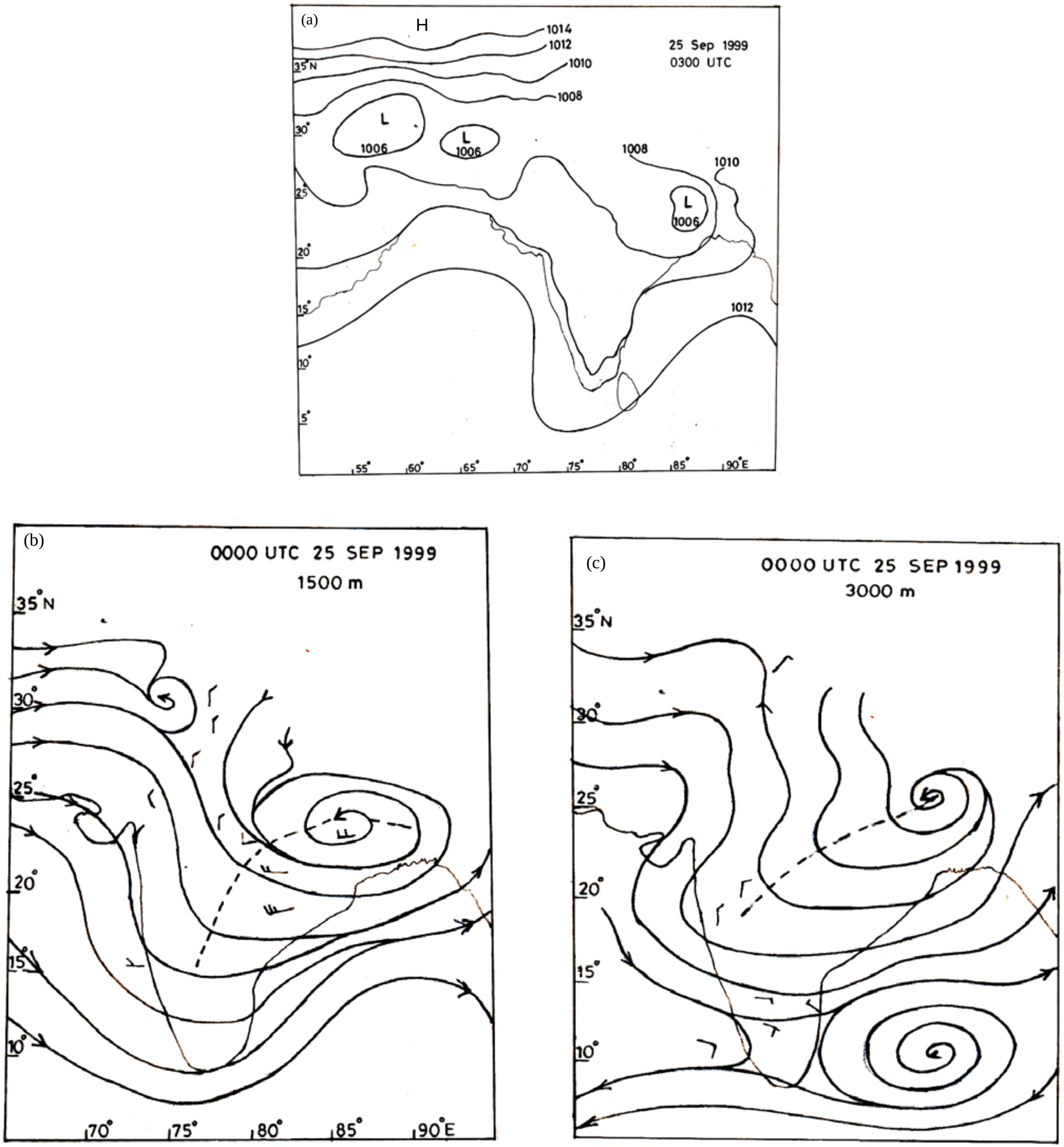
(*i*) On 1st August 1987, a trough line on sea level chart passed through RRK, BRL, FZD, PTN, and thence to AGT. Associated upper air trough extended up to 3.1 km above sea level. This system gave 121.7 mm of rainfall over the catchments.

(*ii*) Again on 10th August 1987, the axis of the seasonal trough on sea level chart shifted close to the foothills to the Himalayas the catchments areas received 111.3 mm to rainfall.

(*iii*) On 12th August, 1987, the trough line on sea level chart passed through Pilani, Lucknow, Gaya, Sabour and thence ENE wards. Associated upper air trough extended up to 4.5 km above sea level. The catchments received 165.1 mm of rainfall.

The role of depression - On 24th September, 1995 at 0300 UTC an upper air circulation layover North Andhra adjoining coastal Orissa and North West Bay extending up to mid tropospheric level (MLT). It intensified further and lay as low pressure area at 1200, UTC, over NW Bay and adjoining areas. On 25th at 0300 UTC, it lay as low pressure areas (LOPAR) over North West Bay and adjoining land areas of Orissa with associated upper air cyclonic circulation extended up to 7.6 km above sea level tilting southwards with height and by evening at 1200 UTC it became well marked low pressure (WML) with its centre close to Baripad (Orissa) with associated cyclonic circulation extending up to MTL. It intensified further and moved WNWly direction and became depression by 1200 UTC. It moved in NNEly direction and lay on 27th at 0300 UTC over Bihar Plateau with its centre close to Dhanbad with associated upper air circulation extending upto MTL. It moved in a NEly direction and by 1200 UTC became well marked low pressure over eastern parts of Bihar plains and adjoining S.H.W.B. with associated cyclonic circulation extending upto MTL. This system as depression on 27th near Dhanbad with its movements towards NEly direction gave 132.7 mm of rainfall over the catchment areas.

The role of low pressure area - South west monsoon was active over Bihar on 24th September 1999. Yesterday's low pressure area lay at 0300 UTC over central parts of Bihar with upper air cyclonic circulation extended upto MTL. The axis of the seasonal trough on sea level chart passed through MPR, SDI, centre of Lopar



Figs. 3. (a-c). (a) Surface chart and (b&c) upper air charts of 25 September 1999. (*Country* : IMD, Pune)

and thence southeast wards into Bay. This system gave 128.6 mm of rainfall.

Southwest monsoon had been vigorous over Bihar on 25th September 1999. Yesterday's low pressure area had intensified into Well marked Low Pressure (WML) and layover Bihar plains at 0300 UTC with associated cyclonic circulation extended upto MTL. Axis of the seasonal trough on mean sea level chart passed through LDN, MRD, KIR, GZP, centre of well marked low thence

TABLE 3

Amount of average areal precipitation (mm) and percentage in the catchments by different synoptic systems month wise (1982 - 2000)

Synoptic system	June	July	August	September	Total
Depression (S_1)	22.3 (9)	13.1 (16)	8.2 (20)	23.6 (13)	67.2 (19%)
Low pressure (S_2)	16.6 (75)	10.2 (136)	12.7 (183)	17.1 (174)	56.6 (16%)
Upper air circulation (S_3)	15.2 (62)	16.5 (121)	13.8 (116)	11.1 (117)	56.6 (16%)
Seasonal trough (S_4)	19.5 (54)	24.6 (193)	25.1(111)	17.5 (102)	86.7 (24%)
North South trough/mid & upper air westerly trough (S_5)	-	31.8 (9)	24.8 (3)	32.2 (3)	88.8 (25%)
Total	73.6 (21%)	96.2 (27%)	84.6 (24%)	101.5 (28%)	355.9

Note - Month wise frequencies are given in brackets

Southeast wards to Bay. Pressure change was minus 2 hPa. This system gave average rainfall of 175.2 mm over the catchment areas [Figs. 3 (a-c)]. Surface charts and upper air charts of 25th are enclosed courtesy I.M.D., Pune).

3.3. Table 3 shows that depressions (S_1) alone contributed 19% of seasonal average areal precipitation in the catchment, low pressures (S_2) 16%, upper air cyclonic circulations, (S_3) 16%, oscillation of seasonal troughs, (S_4) 24% and (S_5) 25%. The combined contribution of all the systems was 21 %, 27%, 24%, 28% of the seasonal rainfall in June, July, August and September respectively. Seasonal rainfall is more during retreating phase of monsoon in September due intense convective activities in catchment areas.

3.4. Table 4(a) depicts the frequencies of different synoptic systems that were responsible for average areal precipitation (AAP) between 11-25 mm, 26-50 mm and 51-100 mm. The frequencies of $S_{1,\,1}$ were 3, 3, 1 and 4 in June, July, August and September between 11-25 mm, it occurred in June and September between 51-100 mm 1 time each and one time greater than 100 mm in September.

$S_{2,1}$ Occurred 11, 22, 28, 25 times in June, July, August and September respectively between 11-25 mm. It occurred 3, 3, 6 and 3 times between 26-50 mm in June, July, August and September and one time in June, 2 times in September between 51-100 mm. $S_{2,2}$ occurred 8, 5, 10 and 9 times between 11-25 mm, 3, 5, 6 and 7 times between 26-50 mm in June, July, August and September respectively, twice greater than 51 mm in September. $S_{2,\,3}$ occurred 7, 3, 6 and 14 times between 11-25 mm, 2, 1, 5 and 5 times between 26-50 mm in June, July, August and September respectively between and once in July and 5 times in September between 51-100 mm. $S_{2,6}$ occurred 1, 6 and 4 times between 11-25 mm in June, July and September respectively. It occurred 3, 1 and 2 times between 26-50 mm in July, August and September respectively once in July and 4 times in September greater than 51 mm.

$S_{3,1}$ occurred 3, 11, 10 and 7 times between 11-25 mm in June, July, August and September respectively. It occurred 1, 3, 4 and 3 times between 26-50 mm in June, July, August and September respectively and 2 times in September between 51-100 mm. $S_{3,3}$ occurred 2, 6, 6 and 3 times between 11-25 mm in June, July, August and September respectively, 1, 3, 4 and 3 times between 26-50 mm in June, July, August and September respectively, 2, 2 and 1 time between 51-100 mm in June, July and August respectively.

$S_{4,4}$ occurred 6, 24, 8, 16 times between 11-25 mm, 4, 25, 7 and 5 times between 26-50 mm in June, July, August and September respectively, 11, 4 and 1 time between 51-100 mm in July, August and September respectively. $S_{4,6}$ occurred 12, 38, 21 and 10 times between 11-25 mm, 3, 23, 7 and 11 times between 26-50 mm, 3, 5, 17 (one > 10 cm) and 4 (one > 10 cm) between 51-100 mm in June July, August and September respectively.

$S_{5,3}$ occurred 2 and 1 time between 11-25 mm in July and August respectively and 1 time between 26-50 mm in July. $S_{5,4}$ occurred 2 times between 11-25 mm in July and 1, 1, 2 times between 26-50 mm in July, August and September respectively.

3.5. The results so derived were verified during 2005 flood season for each rainstorm with actual average areal rainfall of more than 10 mm and the results are shown in Table 4(b). Out of 43 cases, seven cases were out by one stage. Forecasts (QPF) were not issued due to the below warming levels of the rivers. And the actual rainfall matched well with the QPF range based on

TABLE 4 (a)

Frequency of different synoptic systems which contributed Average Areal Precipitation (AAP) between 11-25 mm, 26-50 mm and 51-100 mm rainfall during June to September (1982-2003)

Synoptic code	June			July			August			September		
	11-25	26-50	51-100	11-25	26-50	51-100	11-25	26-50	51-100	11-25	26-50	51-100
$S_{1,1}$	3	-	1	3	-	-	1	-	-	4	-	1+1*
$S_{1,2}$	-	-	-	3	1	-	-	-	2	1	-	-
$S_{1,3}$	-	-	-	-	-	-	-	-	-	-	-	-
$S_{1,4}$	-	-	-	-	-	-	-	-	-	-	-	-
$S_{1,5}$	-	-	-	-	-	-	-	-	-	-	-	-
$S_{1,6}$	-	-	1	-	-	-	-	-	-	-	-	-
$S_{2,1}$	11	3	1	22	3	-	28	6	-	25	3	2
$S_{2,2}$	8	3	-	5	5	-	10	6	-	9	7	1+1*
$S_{2,3}$	7	2	-	3	1	1	6	5	1	14	5	5
$S_{2,4}$	-	1	1	-	-	-	2	-	-	1	-	-
$S_{2,5}$	2	1	-	2	1	1	-	5	1*	3	-	-
$S_{2,6}$	1	-	-	6	3	1	-	1	-	4	2	2+2*
$S_{3,1}$	3	1	-	11	3	-	10	4	-	7	3	2
$S_{3,2}$	2	-	-	5	3	1	4	1	-	4	3	-
$S_{3,3}$	2	1	2	6	3	2	6	4	1	3	3	-
$S_{3,4}$	2	2	-	4	3	1	1	2	-	4	2	1
$S_{3,5}$	2	1	-	3	1	-	5	2	-	2	2	-
$S_{3,6}$	4	-	-	8	-	2	9	5	1	1	4	-
$S_{4,1}$	-	-	1	1	-	-	-	-	-	-	-	-
$S_{4,2}$	5	-	2	20	-	1	6	4	2	6	1	-
$S_{4,3}$	1	1	-	-	-	-	3	-	-	1	-	-
$S_{4,4}$	6	4	-	24	25	11	8	7	4	16	5	1
$S_{4,5}$	2	1	-	5	1	-	4	1	-	-	1	-
$S_{4,6}$	12	3	3	38	23	5	21	7	16+1*	10	11	3+1*
$S_{5,3}$	-	-	-	2	1	-	1	-	-	-	-	-
$S_{5,4}$	-	-	-	2	1	-	-	1	-	-	2	-
$S_{5,5}$	-	-	-	1	-	-	-	-	-	-	-	-
$S_{5,6}$	-	-	-	-	2	-	1	-	-	-	-	-

Note : * more than 10 cm

TABLE 4 (b)

Verification of synoptic analogues of QPF for Kosi/Mahananda catchments during 2005 flood season

S. No.	Date	Actual average areal precipitation (mm)	Associated synoptic systems zone wise	QPF issued
1.	20 Jun	25	$S_{3,3}$	-
2.	21 Jun	25	$S_{4,6}$	11-25
3.	22 Jun	50	$S_{4,2}$	11-25
4.	23 Jun	17	$S_{4,6}$	26-50
5.	30 Jun	23	$S_{1,2}$	01-10
6.	01 Jul	11	$S_{4,2}$	11-25
7.	02 Jul	21	$S_{4,6}$	11-25
8.	03 Jul	15	$S_{4,6}$	11-25
9.	04 Jul	15	$S_{4,2}$	11-25
10.	05 Jul	17	$S_{4,2}$	11-25
11.	11 Jul	20	$S_{3,3}$	11-25
12.	12 Jul	15	$S_{3,3}$	11-25
13.	13 Jul	17	$S_{3,6}$	11-25
14.	14 Jul	20	$S_{3,6}$	11-25
15.	15 Jul	50	$S_{3,6}$	26-50
16.	16 Jul	30	$S_{4,4}$	26-50
17.	17 Jul	12	$S_{4,4}$	11-25
18.	19 Jul	23	$S_{4,4}$	11-25
19.	20 Jul	25	$S_{4,6}$	11-25
20.	22 Jul	11	$S_{3,1}$	11-25
21.	05 Aug	25	$S_{3,3}$	11-25
22.	06 Aug	25	$S_{3,2}$	11-25
23.	07 Aug	32	$S_{4,4}$	26-50
24.	09 Aug	24	$S_{4,4}$	11-25
25.	10 Aug	12	$S_{4,4}$	26-50
26.	11 Aug	25	$S_{4,4}$	11-25
27.	12 Aug	11	$S_{4,4}$	11-25
28.	14 Aug	25	$S_{4,4}$	01-10
29.	15 Aug	15	$S_{4,2}$	11-25
30.	17 Aug	10	$S_{4,6}$	01-10
31.	18 Aug	10	$S_{3,5}$	01-10
32.	19 Aug	13.3	$S_{3,1}$	01-10
33.	20 Aug	11	$S_{3,6}$	11-25
34.	21 Aug	24	$S_{3,6}$	11-25
35.	22 Aug	14	$S_{3,3}$	11-25
36.	23 Aug	10	$S_{3,6}$	01-10
37.	24 Aug	25	$S_{3,6}$	11-25
38.	25 Aug	25	$S_{4,4}$	11-25
39.	26 Aug	11	$S_{4,1}$	11-25
40.	03 Sep	25	$S_{4,6}$	01-10
41.	04 Sep	24	$S_{4,6}$	11-25
42.	05 Sep	25	$S_{4,6}$	11-25
43.	06 Sep	11	-	11-25

synoptic analogues in 35 cases. Results can be improved if one or two upper stations are opened in North Bihar and by reception of rainfall data of Nepal stations on real time basis.

4. Conclusion

(*i*) The regions of the Nepal Himalayas and sub-montane regions on the Indian side often lie ahead of the 500 hPa trough especially diffluent in nature can be referred to as a region of high level divergence. The monsoon air mass in the lower troposphere from the Bay of Bengal and some times from Arabian Sea converage and is pulled up high level divergence resulting in heavy to very heavy rainfall in sub-montane districts of Bihar and Nepal in addition to orographic effects (Ramaswamy-1985). As such Kosi/Mahananda catchment areas get more rainy days and maximum number of heavy rainfall occasions in comparision to other catchments of North Bihar during South west monsoon. (Prasad and Prasad, 1993).

(*ii*) S_1 type weather occur maximum number of times in August but contributes minimum average areal precipitation follows by July with seasonal contribution of 19%. It contributes maximum average areal precipitation in September follows by June due to convective activities during advancing phase of monsoon in June and retreating phase in September. As such QPF can be issued between 11-25 mm from June to September with $S_{1,1}$ and $S_{1,2.}$ During September when recurvature takes place QPF can be issued between 51-100 mm or more with vigorous/active monsoon condition otherwise between 26-50 mm.

(*iii*) The month of August witnesses the maximum number of low pressure systems (S_2) on sea level charts affecting the catchment then comes September, July and June respectively contributing 16% of the seasonal rainfall but gives maximum areal average precipitation in September follows by June, August and July. We can issue QPF between 11-25 mm with $S_{2,1}$, $S_{2,2}$, $S_{2,3}$ and $S_{2,6}$ when associated cyclonic circulation above 4.5 km asl but below 6 km and between 26-50 mm when S_2 is well marked with associated cyclonic circulation up to mid tropospheric or above and between 51-100 mm during retreating phase in September with vigorous/active monsoon condition.

(*iv*) S_3 system contributes 16% of the seasonal precipitation and occurs maximum in July, then in September and August with maximum average areal precipitation in July and minimum in September. OPF can be issued between 11-25 mm with $S_{3,1}$, $S_{3,2}$, $S_{3,3}$, $S_{3,4}$, $S_{3,5}$ and $S_{3,6}$ when associated cyclonic circulation upto 4.5 km asl and if it is upto mid tropospheric level then between 26-50 mm and between 51-100 with vigorous/active monsoon condition with $S_{3,1}$ in September with $S_{3,3}$ in June, July and August and with $S_{3,6}$ in July and August.

(*v*) S_4 system due to its frequent oscillations from normal position, contributes 24% of the seasonal rainfall in the catchments and maximum occasions in July then in August as shown in Table 3. Sometimes it shifts to the foothills of the Himalayas during break situation and on few occasions its eastern wing bends towards Assam side QPF can be issued with $S_{4,2}$, $S_{4,4}$ and $S_{4,6}$ between 11-25 mm in majority of cases if it extends upto 1.5 km asl, if it extends more then between 26-50 mm especially in July, August and September and between 51-100 mm during break situation and when its eastern wing bends towards. Assam side and with associated active/vigorous monsoon condition.

(*vi*) S_5 system contributes 25% of the seasonal rainfall in the catchment and occurs maximum in July. In the case of lower level trough in westerly (North-South trough) QPF can be issued between 11-25 mm with $S_{5,3}$, $S_{5,4}$, $S_{5,5}$, $S_{5,6}$ in July with $S_{5,3}$ and $S_{5,4}$ in August and with mid/upper air trough in westerly between 26-50 mm with $S_{5,3}$, $S_{5,4}$ and $S_{5,6}$ in July and $S_{5,4}$ in August and September and with $S_{5,5}$ between 51-100 mm in July. The presence of diffluent trough in westerly at 500 hPa in the rear makes a lot of difference and submontane districts of Bihar plains and Nepal Himalayas get copious of rainfall. The upper air at Gorakhpur and Lucknow is used to locate trough at 500 hPa or at higher levels and satellite pictures for convective activities.

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