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Semi quantitative forecasts for Baghmati/Adhwara Group of rivers/Kamala Balan catchments by synoptic analogue technique

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सार – इस शोध पत्र में 22 वर्षों (1982–2003) की अवधि के आँकड़ों के आधार पर बागमती अधवारा नदी समूह/कमला–बलान जल ग्रहण क्षेत्रों के लिए अर्द्धमात्रात्मक वर्षण पूर्वानुमान जारी करने का प्रयास किया गया है। इस अध्ययन से यह पता चलता है कि अर्द्ध मात्रात्मक वर्षण पूर्वानुमान विश्वस्त रूप से जारी करना संभव है। भारत–नेपाल सीमा पर वहाँ की स्थानीय स्थलाकृति और इसकी ढालू प्रवणता ऐसे मुख्य कारक हैं जिनके कारण दक्षिणी पश्चिमी मानसून ऋतु के दौरान भीषण बाढ़ आती है और यह बाढ़ दरभंगा शहर के लिए समस्याएँ उत्पन्न करती है।

ABSTRACT. An attempt has been made to issue semi-quantitative precipitation forecasts for Baghmati/Adhwara Group of rivers/Kamala-Balan catchments based upon 22 years data (1982-2003). The study reveals that it is possible to issue semi-quantitative precipitation forecast with confidence. Local topography and its steep gradient on Indo-Nepal Border are main factors that give birth to severe floods during south west monsoon and pose problems to Darbhanga City.

Key words – Synoptic, Catchments, Quantitative precipitation forecast (QPF), Mean rainfall, Frequency, Range, Seasonal trough, Homogeneous, Rainstorm, Vigorous, Active, Oscillation.

1. Introduction

In the past so many persons studied different river catchments from synoptic angles and formulated methods for quantitative precipitation forecast. Rao (1973) applied the synoptic typing method for a selected area in North East India for a period of 1961 to 1967 and identified four synoptic systems. 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*. (1993) studied different types of synoptic situations and correlated them with their resulting rainstorms over Gomati river catchment in Uttar Pradesh based upon data of 1976-1980 and prepared synoptic analogue for forecast range of areal rainfall. Prasad and Prasad (1993) studied distribution of rainy days rainfall and associated synoptic Analogues for forecast range for areal rainfall. Singh *et al.* (1995) studied five types of synoptic situations for punpun river catchments based upon data of 1982-1993 and prepared synoptic analogues for forecast range of areal rainfall. Jha (2006) studied for Gandak catchments by synoptic analogue technique based upon data of 1982-2003. Ram and Pangasa (2000) studied for Ghaghra catchments by synoptic analogue technique. In this paper attempts have been made to identify the different synoptic systems and its location which are accountable for average area precipitation in the ranges of 11-25 mm, 26-50 mm. 51-100 mm and more than 100 mm during the monsoon period in the above catchments, which are not meteorologically homogeneous.

During its 445 kms journey the Ganges flows across the middle of Bihar (Fig. 1). Its north bank tributaries (1) Kosi and Mahananda. (2) Baghmati. Adhwara groups and Kamala-Balan (3) Gandak and Burhi Gandak constitute

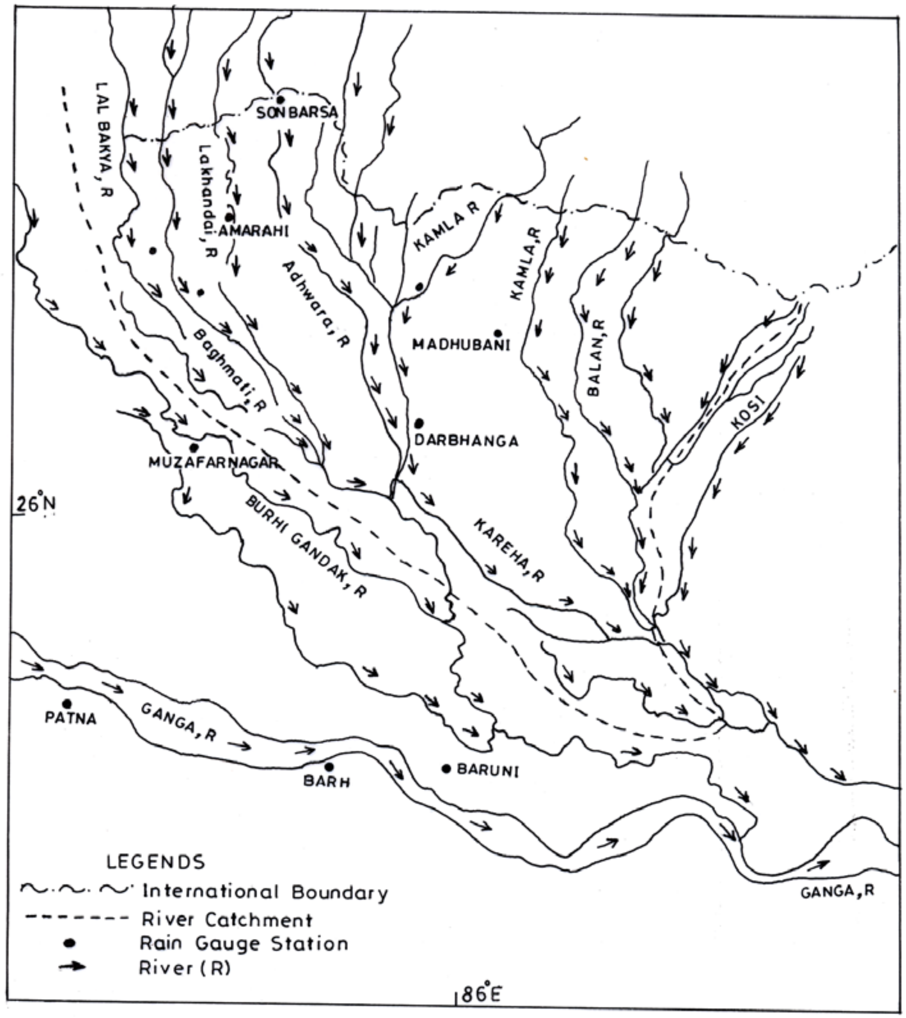


Fig. 1. Locator map of Baghmati, Adhwara, Kamala-Balan catchments

three river zones of Bihar plains. Zone 2 consists of 3 sub basins.

(a) The Kamala-Balan sub basin in east

(b) The Baghmati sub-basin in the west

(c) The Adhwara sub-basin in the central portion

The Kamala-Balan : The Kamala river originates in the Mahabharata ranges of hills in Nepal at an elevation of 1525 meters and debouches into the Terai region of Nepal through a gorge near Chisapani and crosses Indo-Nepal border at Bagraha above Jainagar. It is joined by Sori, Dhauri and Balan 10 kms down stream of Indo-Nepal border and the combined water flows near Jhanjharpur through Railway Bridge No 88 about 43 kms below Darjea. The total catchment area of the Kamala-Balan is 5445 sq kms out of which 2980 sq kms in India and 2462 sq kms in Nepal. About 54% of its total drainage area lies in the plains, 17% in the Terai region and 29% in the hilly region. Average annual rainfall varies from 1380 mm to 1210 mm and 83% receives from June to September. The total river length is 328 kms out of which 120 kms in Bihar. The Kamala-Balan carries heavy sediment load as a result of which it has been constantly meandering. Its abandoned and semi-living courses are all over the district of Darbhanga (Fig. 1), The flood gradient of the Kamala from Chisapani to Jainnagar is quite sleep thereafter it is flatter.

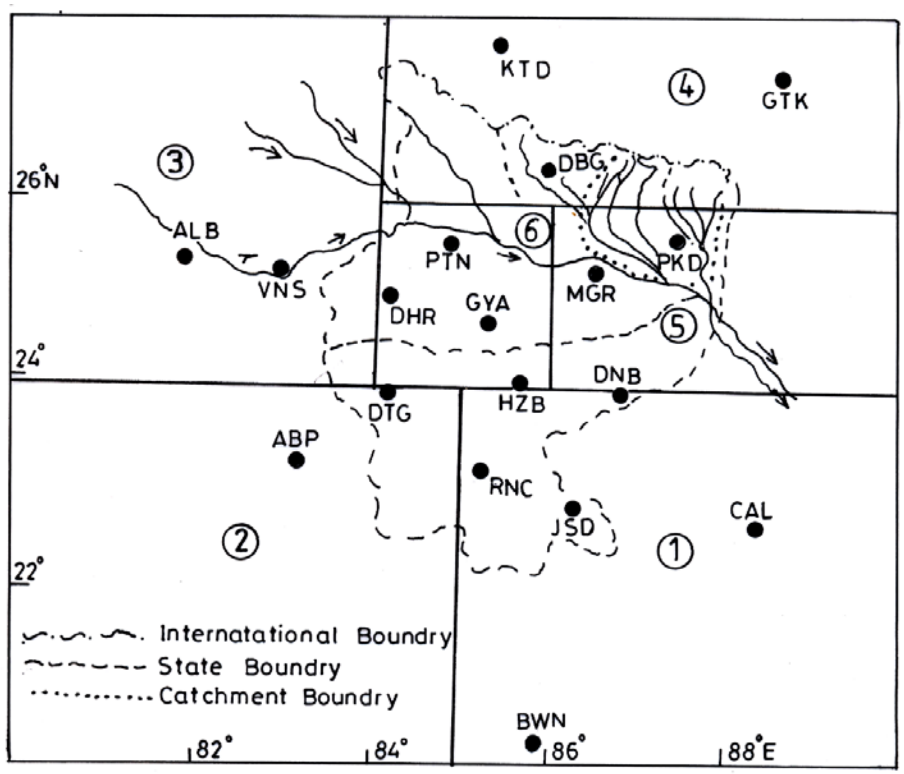


Fig. 2. Different zones of Baghmati, Adhwara, Kamala-Balan, basin

The Adhwara Group of rivers : A network of rivers *viz*., Adhwara, Jamura, Sikao, Barhand, Khiroi, Marha, Rato, Dans, Thanano and Darbhanga Baghmati also known as Adhwara group of rivers originates from the foot hills of Nepal. River catchments after travelling the whole basin interconnected and interlinked they join together and finally form two distinct drainage channels namely Khiroi and Darbhanga Bagmati which two meet just about Ekmighat road and the combined channel flowing southwards ultimately falls into the river Kareh (Baghmati) just above Hayaghat Railway bridge.

The main cause of flooding in the Adhwara sub-basin is inadequate capacity of the river to accommodate flood discharge. In Indian territory, the gradient being very flat, various tributaries combine their flow through a single channel having inadequate capacity resulting in widespread inundation.

It comprises north eastern part or Muzzaffarpur and north western parts or Darbhanga district. The total catchments area of the Adhwara group or rivers is approximately 4960 sq kms of which 2360 sq kills is in Nepal.

Baghmati River : River Baghmati originates from Sheopuri range of hills in Nepal. It enters Indian territory about 2.5 kms upstream of Railway Bridge No. 89 at Dheng on Sitamarhi Naharkatiaganj section of north eastern Railway. The total catchment area of the basin is approximately 13400 sq kms out of which 3.749 sq kms lie in Nepal. The total length of the river is 589 kms out which 394 kms in Bihar. Average annual rainfall is 1180 mm and 85% receives from June to September. There are three tributaries of river Baghmati namely Lakhandei, the Lalbakya and Adhwara system. Lakhandei originates near the foothills of the Himalayas in Nepal at an elevation of 610m and has total catchments area of 1061 sq km up to its outfall into Baghmati. After being joined by Adhwara group, river Baghmati outfalls into river Kosi upstream of Baltara in Munger district. The river spills on both sides in its middle and lower reaches from Dheng to Muzafferpur-Darbhanga road crossing as bank ful capacity of the river is not more than 560 cumecs against flood discharge of 2.832 cumecs (Fig. 1).

There are eleven raingauge stations in entire Zone II. *viz*., Dheng Bridge, Runisaidpur, Benibad, Hayaghat under Baghmati sub-basin Sonebarsa, Kamtaul, Saulighat,

TABLE 1

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

Synoptic code	June		July		August		September	
	Frequency	Mean rainfall (mm)	Frequency	Mean rainfall (mm)	Frequency	Mean rainfall (mm)	Frequency	Mean rainfall (mm)
$S_{1,1}$	6	13.1	15	8.0	23	4.4	10	5.6
$S_{1,2}$	1	2.8	6	3.3	14	4.7	5	19.7
$S_{1,3}$	-	-	-	-	-	-	1	2.5
$S_{1,4}$	-	-	-	-	-	-	-	-
$S_{1,5}$	-	-	-	-	3	0.7	-	-
$S_{1,6}$	4	31.9	-	-	-	-	-	-
$S_{2,1}$	35	12.0	100	5.4	113	9.2	74	5.2
$S_{2,2}$	18	4.4	42	4.7	36	4.8	42	8.5
$S_{2,3}$	10	2.7	15	17.7	20	8.3	41	13.8
$S_{2,4}$	3	38.4	-	-	-	-	3	2.3
$S_{2,5}$	4	4.8	7	15.9	8	22.4	7	4.1
$S_{2,6}$	3	15.7	15	28.1	7	10.2	15	12.9
$S_{3,1}$	18	8.1	41	8.6	45	8.0	31	2.9
$S_{3,2}$	5	4.4	15	7.0	11	9.0	17	3.3
$S_{3,3}$	9	25.7	27	14.6	23	15.5	24	8.4
$S_{3,4}$	5	13.1	10	36.7	2	6.0	24	6.9
$S_{3,5}$	6	13.4	8	13.3	12	13.1	12	8.2
$S_{3,6}$	18	21.2	30	13.2	28	12.9	16	9.6
$S_{4,1}$	2	0.0	2	2.7	-	-	2	0.3
$S_{4,2}$	12	8.0	30	9.1	16	3.6	33	6.2
$S_{4,3}$	2	2.9	1	6.6	3	10.0	1	1.3
$S_{4,4}$	6	8.5	73	23.7	27	39.2	19	11.9
$S_{4,5}$	2	31.7	5	12.8	3	24.1	-	-
$S_{4,6}$	31	13.6	102	15.1	62	14.8	52	15.3
$S_{5,1}$	-	-	-	-	-	-	-	-
$S_{5,2}$	-	-	3	8.1	-	-	-	-
$S_{5,3}$	3	2.9	-	-	4	23.2	2	1.4
$S_{5,4}$	-	-	1	19.0	2	28.7	1	20.4
$S_{5,5}$	-	-	1	27.4	-	-	-	-
$S_{5,6}$	-	-	2	4.5	5	3.0	2	3.0

Ekmighat under Adhwara group and Jainagar, Jhanjharpur, Balan under Kamala-Balan sub-basin and all the stations are discharge sites also all the above stations are connected by w/t sets and rainfall as well as discharge data are being collected during rainy season.

2. Data and methodology

The area lying between the parallels of Latitudes 20° - 28° N and Longitude 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 of IMD based upon the languages used in daily weather bulletins.

1.	20° - 24° N & 85° - 90° E	Gangetic West Bengal and adjoining area 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 area of East Madhya Pradesh.
4.	26° - 28° N & 84° - 90° E	Bihar plains and adjoining areas or Sub-Himalayan West Bengal.
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.

Zone 4 covers half the area of the catchments especially in sub-montane districts of Bihar and Zones 5 & 6 take care or the lower portions of the Catchments.

There are five groups of synoptic systems responsible for active/vigorous monsoon conditions over the catchments given below according to priority.

S_1 Cyclonic storm/deep depression/land depression.

S_2 Low/Well marked low pressure areas either forming over sea or land.

S_3 Upper air circulations.

S_4 Monsoon trough at msl at 0.9 km asl.

S_5 North South trough in lower levels/superimposed westerly trough in mid-trospospheric/higher levels.

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 Meteorological work at Patna starts w.e.f. 15th June every years. As such data under study have been used from 15th June to 30th September for the period 1982-2003, Synoptic situations based upon 0300 UTC surface and 0000 UTC upper air charts responsible for the issuance of quantitative precipitation forecasts between the ranges 11-25 mm, 26-50, 51-100 mm and more than 100 mm and the realised average areal precipitation on the next day, have been collected date wise and month wise. All the values of average areal precipitation of the catchments have been collected against the particular synoptic condition situated in a particular zone month wise and again weightage average rainfall have been calculated.

3. Results and discussion

3.1. Table 1 shows frequencies of S_1, S_2, S_3, S_4 and S_5, in June to September with monthly mean rainfall. The role played by $S_{1,1}$ $S_{1,2}$ and $S_{1,6}$ has been examined. In August $S_{1,1}$ occurred 23 times *i.e.*, maximum with minimum mean rainfall of 4.4 mm and $S_{1,2}$ 14 times with mean rainfall of 4.7 mm. The tracks of Bay depressions in July and August are within a narrow felt, they move in west to west north west in July and north west wards in August up to 25° N (Rao, 1976). They give maximum rainfall in south west quadrant *i.e.*, away from the catchments areas under study and as such least mean rainfall in August followed by July. $S_{1,6}$ and $S_{1,1}$ occurred 4 and 6 times in June with mean rainfall 23 mm and 13 mm respectively with advancing phase of monsoon in early June. $S_{1,2}$ occurred 5 times in September with mean rainfall 20 mm due to retreating phase of monsoon.

The role played by $S_{2,1}$, $S_{2,2}$, $S_{2,3}$, $S_{2,4}$, $S_{2,5}$ and $S_{2,6}$ has been examined. A large number of lows, except remnant of depressions, form *in situ* north of latitude 20° N over Bihar and South Uttar Pradesh during July, August and September and affects the catchments. $S_{2,3}$ occurred 15, 20 and 41 times and gave 18 mm, 8 mm and 14 mm mean rainfall during July, August and September respectively. A majority of lows develop over northwest Bay and adjoining central Bay cross the land and affect the catchments. $S_{2,1}$ occurred 35, 100, 113 and 72 times and gave 12 mm, 5.4 mm, 9.2 mm and 5.2 mm mean rainfall during June, July, August and September respectively. Local topography and steep gradient play a dominant role over catchments with lows.

$S_{3,3}$ occurred 9, 27, 23 and 24 times and gave 26 mm, 15 mm, 16 mm and 8 mm during June, July, August and September where as $S_{3,4}$ due to local topography gave 13 and 37 mm mean rainfall in June and July.

S_4 due to frequent oscillations towards north from normal position, during break situations when it shifts to the foothills of the Himalayas and during its eastern wing bending towards Assam, plays a dominant role over the catchments. As such $S_{4,6}$ occurred 31, 102, 62 and 52

TABLE 2

Showing Average Areal Precipitation more than 100mm in the catchments (1982-2003)

S. No.	Synoptic code	Year	Date	AAP > 100 mm
l.	$S_{1,6}$	1997	29 June	116.1
2.	$S_{2,1}$	2003	23 June	116.9
3.	$S_{4,4}$	1987	31 July	168.3
4.	$S_{2,1}$	1993	30 July	102.6
5.	$S_{4,4}$	1987	10 August	159.6
6.	$S_{4,6}$	1987	11 August	110.8
7.	$S_{2,1}$	1994	8 August	105.8
8.	$S_{3,6}$	1996	30 August	105.3
9.	$S_{2,2}$	1989	28 September	113.3

times and gave mean rainfall 14 mm, 15 mm, 15 mm and 15 mm during June, July, August and September respectively. $S_{4,4}$ occurred 73 and 27 times and gave mean rainfall 24 mm and 39 mm during July and August respectively.

North-south trough in lower troposphere forms east of 80° E over the plains during weak monsoon condition and gives good amount of rainfall during July and August over the catchments. Rainfall is enhanced when it comes under the grip of westerly trough in the rear due lower level convergence and upper level divergence. $S_{5,3}$ occurred 4 times and gave 23 mm mean rainfall during August.

3.2. Table 2 shows the average areal precipitation > 10 cm on a single day over the catchments. The catchments received >10 cm of rainfall on 9 occasions out of which 2 in June, 2 in July, 4 in August and 1 in September during 1982-2003. $S_{4,4}$ contributed the highest amount of 168.3 mm rainfall on 31st July 1987 and the next highest of 159.6 mm on 10th August 1987.

Such occasions occurred due active/vigorous monsoon conditions in the catchments and 1987, 1994, 1997, 2000, 2003 were the years when recurrence of severe floods took place in the catchments and made the life of people miserable.

Inferences issued by weather office Patna and associated rainfall >10 cm with weather charts are given below:

The role of Monsoon trough on sea level chart (S.L.C.) and associated upper air trough.

INDIAN DAILY WEATHER REPORT
WEATHER MAP AT 0830 HRS (IST) (0300 UTC)
Wednesday 12 August 1987 (21 Sravana 1909 Saka)

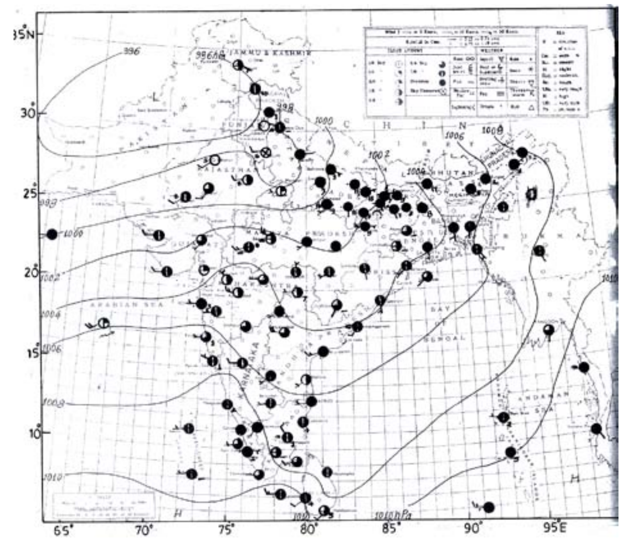
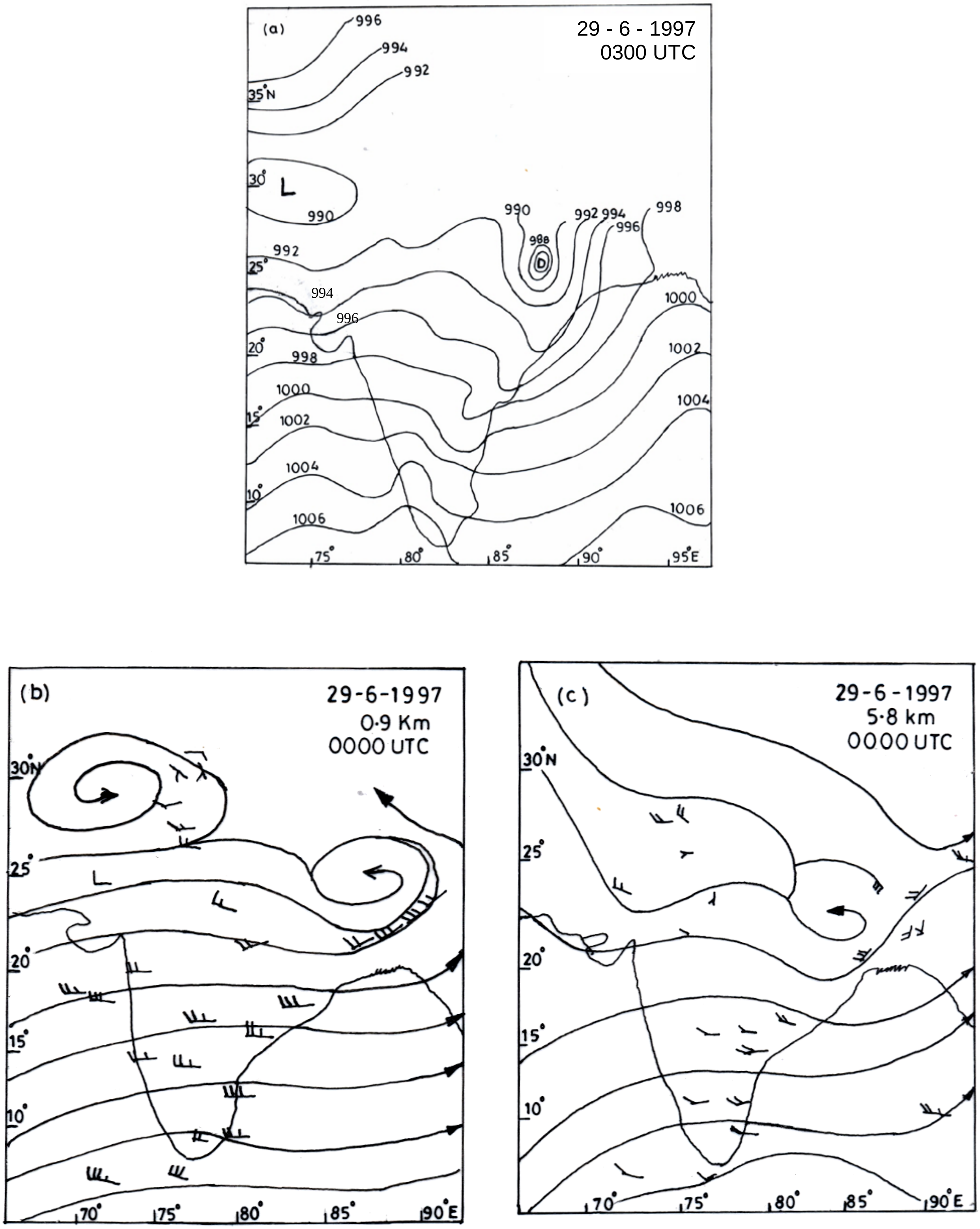


Fig. 3. Surface chart of 12 August (*Courtesy* : IMD, Pune)

(*i*) On 31st July 1987 the eastern portion of monsoon trough on SLC shifted close to the foothills of the Himalayas. The catchments received 168.3 mm rainfall.

(*ii*) On 9th August 1987, the trough line on sea level chart shifted close to the foothills of the Himalayas with associated upper air trough extended up to 4.5 km asl. The catchment received 51.7 mm rainfall. On 10th August 1987 the position remained the same and subsequent rainfall was 159.6 mm. On 11th August 1987, the trough line shifted southwards and passed through Karnal, Lucknow, Purnea and thence ENE wards, associated U/A trough extended up to 4.5 km asl and the catchment received ll0.8 mm rainfall. On 12th August 1987, the trough line on sea level chart (SLC) passed through Pilani, Lucknow, Gaya, Sabour and thence ENE wards associated trough extended up to 4.5 km asl. The catchment received 54.8 mm of rainfall (Fig. 3) surface chart of 12th August 1987 appended courtesy IMD Pune).

The role of depression : On 29 June 1997 monsoon been vigorous over Bihar. Yesterday's Deep Depression has moved NNW wards and lay centred at 290300 UTC 50 km SE wards of Patna. Associated cycir extended up to mid tropospheric level. System likely to move in NL'Y direction. Trough of lopar passed from NW Rajasthan to N'Bay across UP, centre of Depression and GWB. The catchment record 116.1 mm of average rainfall [Fig. 4(a)]. surface chart and Figs. 4 (b&c) upper air charts are appended.



Figs. 4(a-c). (a) Surface chart of 0300 UTC of 29 June 1987 and (b&c) Upper air charts of 29 June 1987 at 0.9 km & 5.8 km (*Courtesy* : IMD, Pune)

TABLE 3

Showing Amount of average Areal Precipitation (AAP) in mm in the catchments by Synoptic systems month wise, Season wise and its percentage (1982-2003)

Synoptic systems	June	July	August	September	Total	Percentage
S_1	19.0 f = 11	8.5 f = 21	4.2 f = 40	9.8 f = 16	41.5	20%
S_2	9.4 f = 73	9.6 f = 179	8.9 f = 184	8.5 f = 181	36.4	18%
S_3	15.2 f = 61	13.1 f = 131	9.7 f = 121	4.4 f = 166	42.4	20%
S_4	11.6 f = 55	18.0 f = 213	12.8 f = 167	11.3 f = 109	53.7	27%
S_5	2.9 f = 3	10.5 f = 10	14.3 f =15	3.5 f = 10	31.2	15 %
Total	58.1	59.7	49.9	37.5	205.2	
Percentage	28%	29%	24%	18 %		

N. B. "f" stands for frequency

3.3. Table 4(a) shows the frequencies of different synoptic systems that were responsible for areal average precipitation (AAP) between 11-25 mm, 2650 mm and 51-100 mm. The frequencies of $S_{1,1}$ were 4 and 2 times between 11-25 mm in August and September once in July between 26-50 mm and once each in June and July between 51-100 mm. $S_{1,2}$ occurred once between 51-100 mm in September.

The system gave rainfall between 11-25 mm when associated cyclonic circulation between 4.5 km asl to 5.8 km asl, between 26-50 mm when associated cyclonic circulation above mid tropospheric level and between 51-100 mm and more than 100 m when associated cyclonic circulation above mid tropospheric level tilting southward with height and with active/vigorous monsoon conditions.

The role played by $S_{2,1}$, $S_{2,2}$, $S_{2,3}$ and $S_{2,6}$ has been examined. $S_{2,1}$ occurred maximum number of times in August followed by July during these two peak monsoon months. $S_{2,1}$ occurred 5, 10, 21 and 9 times between. 11-25 mm during June, July, August and September respectively, it occurred 3, 2, 9 and 3 times between 26-50 mm during above months, and 2,1 and 2 times between 51-100 mm in June, July and August respectively. $S_{2,3}$ occurred 3 times above 51 mm during retreating phase of monsoon in September. $S_{2,6}$ occurred 3 times between 51-100 mm during peak month of July. Lows follow the same pattern as depressions in forecasting in different ranges.

The role played by $S_{3,1}$, $S_{3,3}$, $S_{3,4}$ and $S_{3,6}$ has been examined. They played important roles during July and August. $S_{3,1}$ occurred 6 and 5 times between 11-26 mm, 3 and 2 times between 26-50 mm and 1 and 2 times between 51-100 mm in July and August respectively. $S_{3,3}$ occurred 2 times each between 51-100 mm in June, July and August respectively. $S_{3,3}$ sometimes creates havoc when it comes under the grip of westerly diffluent trough in the rear due upper air divergence and lower level convergence.

$S_{4,4}$ and $S_{4,6}$ play dominant role during monsoon season. $S_{4,4}$ occurred 21 and 6 times between 11-25mm, 17 times between 26-50 mm and 8 and 7 times above 51mm in July and August respectively. $S_{4,6}$ occurred 35 and 10 times between 11-25 mm 21 and 7 times between 2650 mm in July and August and 1, 1, 6 and 3 times between 51-100mm during June, July, August and September. Local topography and steep gradient are responsible for so much areal average rainfall (AAP).

The role played by $S_{5,3}$ and $S_{5,4}$ has been examined. This system is responsible for flash floods in Baghmati river. $S_{5,3}$ occurred 2 and 1 times between 11-25 mm and 26-50 mm during August. This system especially diffluent trough is not located easily due lack of upper air data in time.

3.4. Table 3 shows that depression (S_1) alone contribute 20% of the seasonal average areal precipitation in the catchments, low pressure (S_2) 18% upper air cyclonic circulation (S_3) 20%, oscillations of seasonal trough (S_4) 20% westerly troughs (S_5) contribution 15%. The combined contribution of all the systems were 28%, 29%, 24% and 18% of seasonal rainfall in June, July, August and September respectively.

TABLE 4(a)

Frequency of different synoptic systems which contributed AAP between 11-25 mm, 26-50 mm and 51-100 mm of 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
$S_{1,1}$	-	-	1	-	1	1	4	-	-	2	-	-
$S_{1,2}$	-	-	-	-	-	-	1	1	-	1	-	1
$S_{1,3}$	-	-	-	-	-	-	-	-	-	-	-	-
$S_{1,4}$	-	-	-	-	-	-	-	-	-	-	-	-
$S_{1,5}$	-	-	-	-	1	-	-	-	-	-	-	-
$S_{1,6}$	-	-	1*	-	-	-	-	-	-	-	-	-
$S_{2,1}$	5	3	1+1*	10	2	1*	21	9	1+1*	9	3	-
$S_{2,2}$	1	1	-	4	2	-	5	1	-	5	2	1*
$S_{2,3}$	-	-	-	2	7	-	3	-	1	4	6	2+1
$S_{2,4}$	1	-	1*	-	-	-	-	-	-	-	-	-
$S_{2,5}$	1	-	-	2	2	-	-	1	2	1	-	-
$S_{2,6}$	2	-	-	3	3	3	2	1	-	5	1	-
$S_{3,1}$	5	1	-	6	3	1	5	2	2	3	-	-
$S_{3,2}$	1	-	-	4	1	-	1	-	1	-	1	-
$S_{3,3}$	-	2	2	7	1	2	7	1	2	3	2	-
$S_{3,4}$	3	-	-	1	1	4	1	-	-	1	3	-
$S_{3,5}$	-	2	-	3	1	-	5	-	-	1	-	1
$S_{3,6}$	2	-	4	8	4	1	5	4	1*	1	-	1
$S_{4,1}$	-	-	-	-	-	-	-	-	-	-	-	-
$S_{4,2}$	2	1	-	3	3	-	2	-	-	5	1	-
$S_{4,3}$	-	-	-	-	-	-	-	1	-	-	-	-
$S_{4,4}$	3	-	-	21	17	8	6	7	5+2*	4	3	-
$S_{4,5}$	-	2	-	1	1	-	1	-	1	-	3	-
$S_{4,6}$	5	8	1	35	21	1	10	7	5+1*	9	8	3
$S_{5,1}$	-	-	-	-	-	-	-	-	-	-	-	-
$S_{5,2}$	-	-	-	-	-	-	-	-	-	-	-	-
$S_{5,3}$	-	-	-	-	-	-	2	1	-	-	-	-
$S_{5,4}$	-	-	-	-	1	-	-	1	-	1	-	-
$S_{5,5}$	-	-	-	-	1	-	-	-	-	-	-	-
$S_{5,6}$	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 4(b)

Verification of synoptic analogues of QPF for Kamala-Balan/Adhwara group of rivers etc catchments during 2005 flood season

S. No.	Date	Actual average areal rainfall (mm)	Associated synoptic system zone wise	QPF issued
1.	22 Jun	23.9	$S_{4,2}$	11-25
2.	23 Jun	11.0	$S_{4,6}$	11-25
3.	05 Jul	19.3	$S_{2,2}$	11-25
4.	12 Jul	10.6	$S_{4,6}$	11-25
5.	13 Jul	25.2	$S_{3,6}$	11-25
6.	15 Jul	50.1	$S_{3,6}$	11-25
7.	16 Jul	26.1	$S_{4,4}$	26-50
8.	17 Jul	13.0	$S_{4,4}$	11-25
9.	19 Jul	23.8	$S_{4,4}$	11-25
10.	20 Jul	23.3	$S_{4,6}$	11-25
11.	21 Jul	17.0	$S_{4,6}$	11-25
12.	22 Jul	11.5	$S_{3,1}$	11-25
13.	06 Aug	25.2	$S_{3,2}$	11-25
14.	07 Aug	17.5	$S_{4,4}$	26-50
15.	08 Aug	17.1	$S_{4,4}$	11-25
16.	09 Aug	25.4	$S_{4,4}$	11-25
17.	11 Aug	24.4	$S_{4,4}$	01-10
18.	13 Aug	25.0	$S_{4,6}$	01-10
19.	14 Aug	24.8	$S_{4,4}$	11-25
20.	19 Aug	16.0	$S_{3,1}$	01-10
21.	23 Aug	24.0	$S_{3,3}$	01-10
22.	24 Aug	23.4	$S_{3,6}$	11-25
23.	25 Aug	80.0	$S_{4,4}$	11-25
24.	04 Sep	17.3	$S_{4,6}$	01-10
25.	05 Sep	11.1	$S_{4,6}$	11-25

3.5. The results so derived were verified during 2005 flood season for each rain storm with actual areal rainfall of 10 mm or more and the results are shown in Table 4(b). The year 2005 was a good monsoon year 2005 out of 25 such cases in one case it was out by two stages and in six cases out by one stage. In 18 cases the results matched well. Forecast (QPF) were not issued due to the below warning levels of the river.

Results can be improved if we get Nepal data in time and by opening two upper air station in North Bihar.

4. Conclusion

(*i*) Local topography or the catchments and its steep gradient in Nepal territory on Indo-Nepal border are favourable regions where moist air mass during south west monsoon season converges and slight perturbation in weather system gives copious of rainfall.

(*ii*) S_1 type weather occurs maximum number of times in August but contributes lower average areal precipitation in range follows by July. The tracks of Bay depressions in July and August are within a narrow belt, they move in west/northwest wards in July and northwest wards in August up to 25° N and give maximum rainfall in south west quadrant *i.e*., away from the catchments. Depressions early in June, with a advancing monsoon sometimes may take a north northeast track and are much spread out. September is more or less like June (Rao, 1976). As such we can issue QPF between 11-25 mm with $S_{1,1}$ and $S_{1,2}$ systems when associated cyclonic circulation extends up to mid-tropospheric level, if it is more tilting south wards with height then 26-50 mm and during vigorous/active monsoon condition between 51-100 mm.

(*iii*) As shown in Table 3, the month of August witnesses the maximum number of low pressure Areas (S_2) on Sea level charts affecting the catchments. Then comes September, July and June respectively contributing 18% of seasonal rainfall, QPF can be issued with $S_{2,1}$, $S_{2,2}$, $S_{2,3}$ and $S_{2,6}$ between 11-25 mm when associated cyclonic circulation is below 6 km above mean sea level and between 26-50 if it is well marked with associated Cyclonic Circulation up to mid tropospheric level tilting southward with height and 51-100 mm with active/vigorous monsoon condition specially with $S_{2,1}$, $S_{2,1}$ and $S_{2,3}$ (Retreating phase in September).

(*iv*) S_3 system contributes 20% of the seasonal average areal precipitation and occurs maximum in September then in July and August. QPF can be issued between 11-25 mm with $S_{3,1}$ and $S_{3,6}$ with upper air circulations up to 4.5 km if it is up to mid troposphere level then between 26-50 mm and with active/ vigorous condition between 51-100 mm as the case may be.

(*v*) S_4 system occurs maximum in July fol1ows by August, September and June respectively with seasonal rainfall of 27% due to frequent oscillations of monsoon trough towards north from normal position and during break monsoon situation the catchments receive copious of rainfal1 resulting in severe floods. QPF can be issued between 11-25 mm if the trough extends up to 0.9 km above sea level and if it more then between 26-50 m between July and August and between 51-100 mm during active/vigorous monsoon condition, with $S_{4,4}$ and $S_{4,6}$ systems. The latent instability of the air mass enhances rainfall in the trough when it is over Bihar and east Uttar Pradesh even without a low.

(*vi*) S_5 system contributed 15% of the seasonal rainfal1 with maximum rainfall in August and then July. Rainfal1 being enhanced in a break situation by a westerly trough extending right up to the plains. So long as it is in rear or over the catchments providing divergent field and S_2, S_3, S_4, at lower level providing convergences the catchments receive widespread rainfall with heavy fall in sub-montane districts of Bihar Plains and Nepal territories. QPF can be issued between 11-25 mm and 26-50 mm according to intensities of the systems with $S_{5,3}$ or $S_{5,4}$ in July and August. Such type of situation occurred in July 1993 when flash flood occurred in Baghmati river and drought situation changed into flood within two days of heavy rainfall.

RS/RW data of Lucknow/Gorakhpur provide input for westerly troughs and satellite picture for convective activities to forecasters.

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References

Abbi, S. D. S., Singh, Rajinder, Khanna, B. S. and Katyal, K. N., 1979, "Forecasting of (Semi) quantitative precipitation over Bhagirathi catchments by synoptic analogue method", *Vayu mandal*, **9**, 1 & 2, 16-22.

Jha, T. N. 2005, "Quantitative precipitation forecasts over Gandak catchments", *Mausam*, **57,** 2, 341-345.

Lal, J., Dey, J. S. and Kapoor, K. K., 1983, "Semi-quantitative precipitation forecasts for Gomati catchments by Synoptic Analogue method", *Mausam*, **34**, 3, 309-312.

Prasad, M. C. and Prasad, G., 1993, "Distribution of rainy days, rainfall and associated Synoptic features in the river catchments of Bihar", *Vayu Mandal*, **23**, 3 & 4, 69-76.

Ram, L. C. and Pangasa, N. K., 2000, "Semi quantitative precipitation for Ghaghra catchments : by Synoptic Analogue method", *Mausam*, **51**, 1, 85-88.

Rao, D. V. L. N., 1973, "Quantitative precipitation forecasting", IMD Prepub, Sci, Rep. No. 187.

Rao, Y. P., 1976, "South West Monsoon", 107-224.

Singh, K. M., Prasad, M. C. and Prasad, G., 1995, "Semi-quantitative precipitation forecasts for river Pun-Pun by Synoptic Analogue method", *Mausam*, **46**, 2, 149-154.