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Quantitative Precipitation Forecast (QPF) for Teesta basin and heavy rainfall warning over Teesta basin & adjoining areas in north Bengal & Sikkim using synoptic analog method

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सार – इस शोध–पत्र में तीस्ता जलग्रहण क्षेत्र के लिए मात्रात्मक वर्षण पूर्वानुमान (क्यू.पी.एफ.)जारी करने की पद्धति प्रस्तुत की गई है। तीस्ता जलग्रहण क्षेत्र के लिए 10 वर्षों (1998-2007) के आँकड़ों का विश्लेषण करके सिनॉप्टिक एनालॉग मॉडल तैयार किया गया है। तीस्ता द्रोणी में दक्षिण–पश्चिम मानसून ऋतु 2008 (01 जून से 30 सिंतबर) के दौरान अनुकूल सिनॉप्टिक परिस्थितियों के संबंध में वास्तविक औसत क्षेत्रीय वर्षण (ए.ए.पी.) के साथ इस मॉडल से प्राप्त परिणामों की पुष्टि की गई और इन परिणामों से यह पता चला है कि अगले दिन इस द्रोणी मुं आकलित दिन–प्रतिदिन के क्यू.पी.एफ. और अनुकूल वास्तविक ए.ए.पी. का अच्छा सहसंबंध रहा। इसके अतिरिक्त, इस शोध पत्र में भारी वर्षा की घटनाओं का भी अध्ययन किया गया है।

ABSTRACT. This article presents the method to issue Quantitative Precipitation Forecast (QPF) for Teesta catchment. A synoptic analog model has been developed analyzing 10 years (1998-2007) data for Teesta catchment. The outcomes are then validated with the realized Average Areal Precipitation (AAP) for the corresponding synoptic situations during south-west monsoon season 2008 (1st June to 30th September) over Teesta basin and results revealed that there exists a good agreement between day-to-day QPF with corresponding realized AAP calculated over this basin next day. In addition, occurrence of heavy rainfall has also been studied in this paper.

Key words – Synoptic analog method, Quantitative Precipitation Forecast (QPF), Average Areal Precipitation (AAP), Teesta, Basin, Heavy rainfall, Warning, Percentage Correct (PC).

1. Introduction

The qualitative or generalized use of rainfall forecasts in flood warnings has started since early 1900s. However, the use of Quantitative Precipitation Forecast (QPF) in quantitative flood forecasting is a relatively high risk approach as the scale of most meteorological models is relatively large as compared to the scale of catchments that are hydrologically modeled. Even slight differences in the location of rainfall maximum on a synoptic scale can have a profound effect on the amount of rainfall and flooding as is experienced in even medium sized catchments. The difficulties are more pronounced for smaller catchments even so during flash flood.

Flood Meteorological Office, Jalpaiguri issues QPF for Teesta basin, heavy rainfall warning & outlook for subsequent two days for the three districts of north Bengal (Jalpaiguri, Darjeeling & Coochbehar) and Sikkim and disseminates AAP over Teesta & Jaldhaka basins to the users. QPF for this region is a very difficult task due to its mountainous topography and lack of synoptic data over this area. Jalpaiguri & Coochbehar districts are at the foot hills of Himalayas and most parts of Darjeeling district & Sikkim are in mountainous region. About 250 cm to 400 cm of rainfall with heavy to very heavy falls for about 10 to 20 days occurs during the months of south-west monsoon season (June to September) in the rain gauge stations of foot hills of Sub Himalayan West Bengal (SHWB) and Sikkim. The significant rainfall occurs due to presence of trough (*i.e.*, trough of low or monsoon trough on sea level chart) over SHWB and foot hills of Himalayas and close proximity of the strong synoptic systems like low/depression/upper air circulation over and around SHWB and Sikkim. The rainfall occurs mostly during late night & early hours of morning due to prolonged thunderstorm activity. Because of typical topographical feature thunder storm activity is

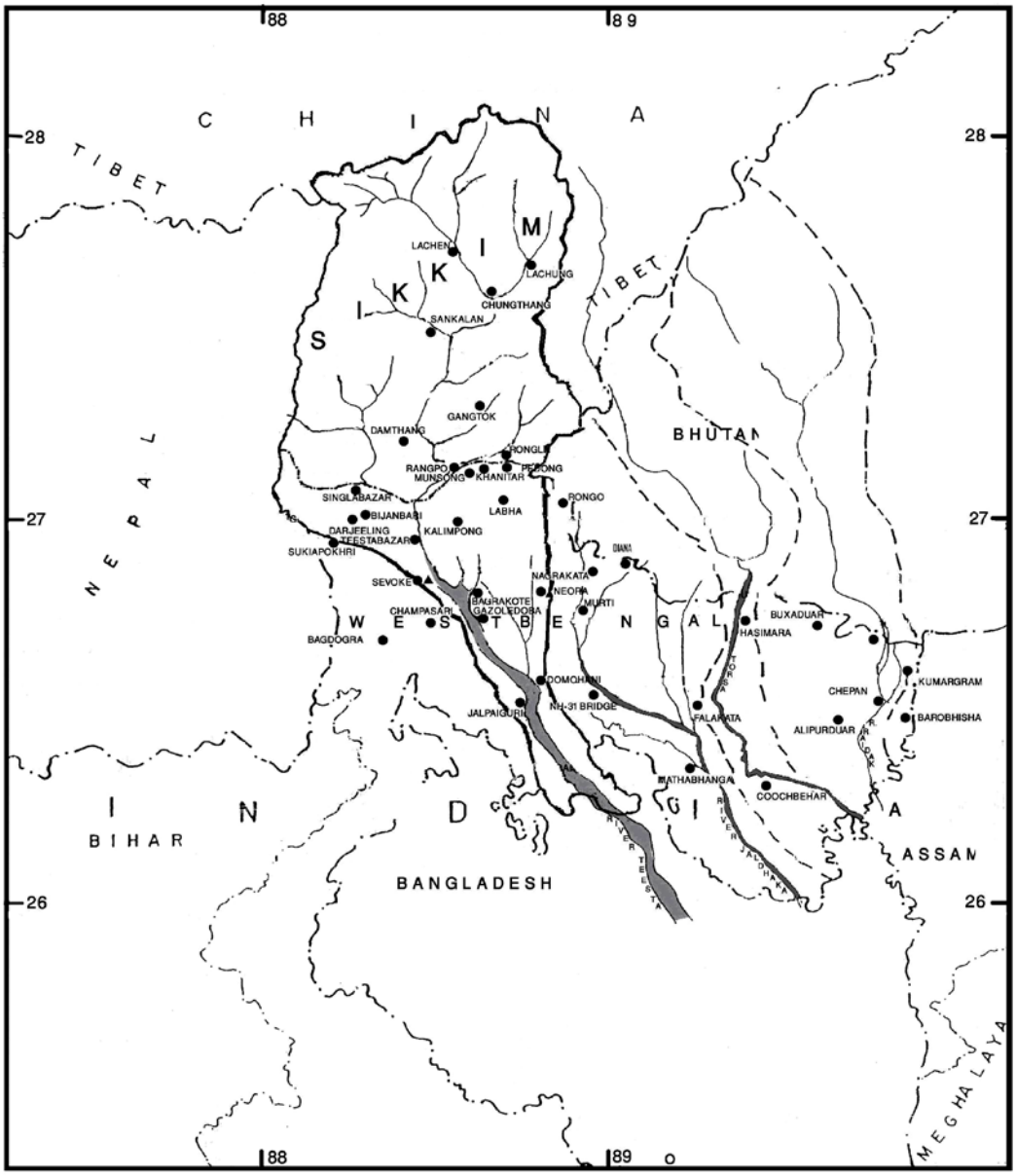

Fig. 1. Teesta catchment along with important rain gauge stations over North Bengal and Sikkim

experienced due to strong instability in conjunction with moisture incursion in the lower levels without having any significant synoptic situations invariably after a gap of two/three days of dry spells. So, prediction of QPF for Teesta basin is a very challenging task for the forecasters.

A few works had been carried out on synoptic analog model related studies over the river catchments in India by several scientists *viz*., Abbi *et al*. (1970), Rao *et al*. (1970), Abbi *et al*. (1979), Lal *et al*. (1983). Bhattacharya and Bhattacharya (1980) have studied the diurnal variation of rainfall during south-west monsoon season in the rivers catchments of Teesta, Jaldhaka, Torsa and Raidak using six years data (1971-1976). Major rainstorms over Teesta catchment have been studied by Biswas and Bhadram (1984). Lahiri (1981) have discussed the method of forecasting of rain and floods in the Teesta River. Dhar *et al*. (1996) have studied the rainfall over Teesta basin up to Teesta Bridge based upon five years (1958 to 1962) data. Rao *et al.* (1997) have shown that

TABLE 1

Various features of rainfall distribution during south-west monsoon season for the period 1998 to 2007 over Teesta basin and adjoining areas in North Bengal and Sikkim

Station	Basin	Average seasonal rainfall (cm)	Mean frequency of rainy days	Average no. of days with rainfall (65 mm & above)	Highest rainfall recorded (mm)	Day on which highest rainfall recorded	No. of days of extreme heavy rainfall (25 cm and above)
Jalpaiguri	Teesta	283	73	14	474.0	10 Jul 1999	4
Domohoni		262	73	12	347.2	10 Jul 1999	6
Neora		310	83	13	531.8	18 Jun 1998	6
Sevoke		336	85	17	315.5	15 Jun 2007	1
Siglabazar		132	61	3	153.4	27 Jun 1999	0
Khanitar		134	66	3	161.4	28 Jun 1999	0
Gangtok		234	100	4	188.0	04 Jun 2002	0
Chungthang		106	87	0	80.3	11 Sep 2006	0
Damthung		211	91	4	156.2	28 Jun 1999	0
Lachen		103	89	0	123.0	12 Jul 2003	0
Bagrakote		336	82	15	301.0	23 Aug 2005	2
Diana	Jaldhaka	311	83	13	404.4	23 Jun 2004	6
Nagrakata		296	86	13	323.6	03 Aug 2000	3
Murti		289	81	13	294.4	10 Jul 1999	2
NH-31		227	69	10	423.4	06 Jul 2006	4
Falakata		265	65	13	298.0	11 Jul 1999	2
Mathabhanga		221	66	9	325.6	06 Jul 2000	3
Rongo		429	100	19	322.1	30 Jun 2002	5
Alipurduar	Raidak	284	73	13	351.0	08 Sep 2004	6
Chepan		303	73	14	466.8	08 Sep 2004	10
Buxaduar		395	79	19	400.8	07 Jul 2003	7
Kumargram		341	73	17	322.0	22 Jun 2000	8
Barobhisha		258	70	11	375.4	04 Aug 1998	3
Hasimara	Torsa	298	74	14	362.4	21 Jun 2000	8
Champasari	Mahananda	282	77	14	202.6	01 Jul 2002	0

statistical analog procedure gives a good idea for predicting average areal precipitation semi-quantitatively for Teesta basin.

In this present study, day-to-day synoptic situations and AAP over Teesta basin during south-west monsoon season (1st June to 30 September) for the period 1998 to 2007 have been taken into consideration for finding out the existence of correlation between them, if any, so that QPF for Teesta basin may be issued with more accuracy. In addition, impact of different synoptic systems in the distribution of heavy rainfall (65 mm and above) during this season over Teesta basin & adjoining areas in north Bengal & Sikkim has also been studied. Further, the results of finding of this study have been validated with the realized AAP and heavy rainfall during south-west monsoon season 2008.

2. Description of the catchments

Teesta river originates in the glaciers of the Himalayas in Sikkim. More precisely, it originates as Chhombo Chhu from a glacial lake Khangchung Chho at an elevation of 5,280 m in the northeastern corner of

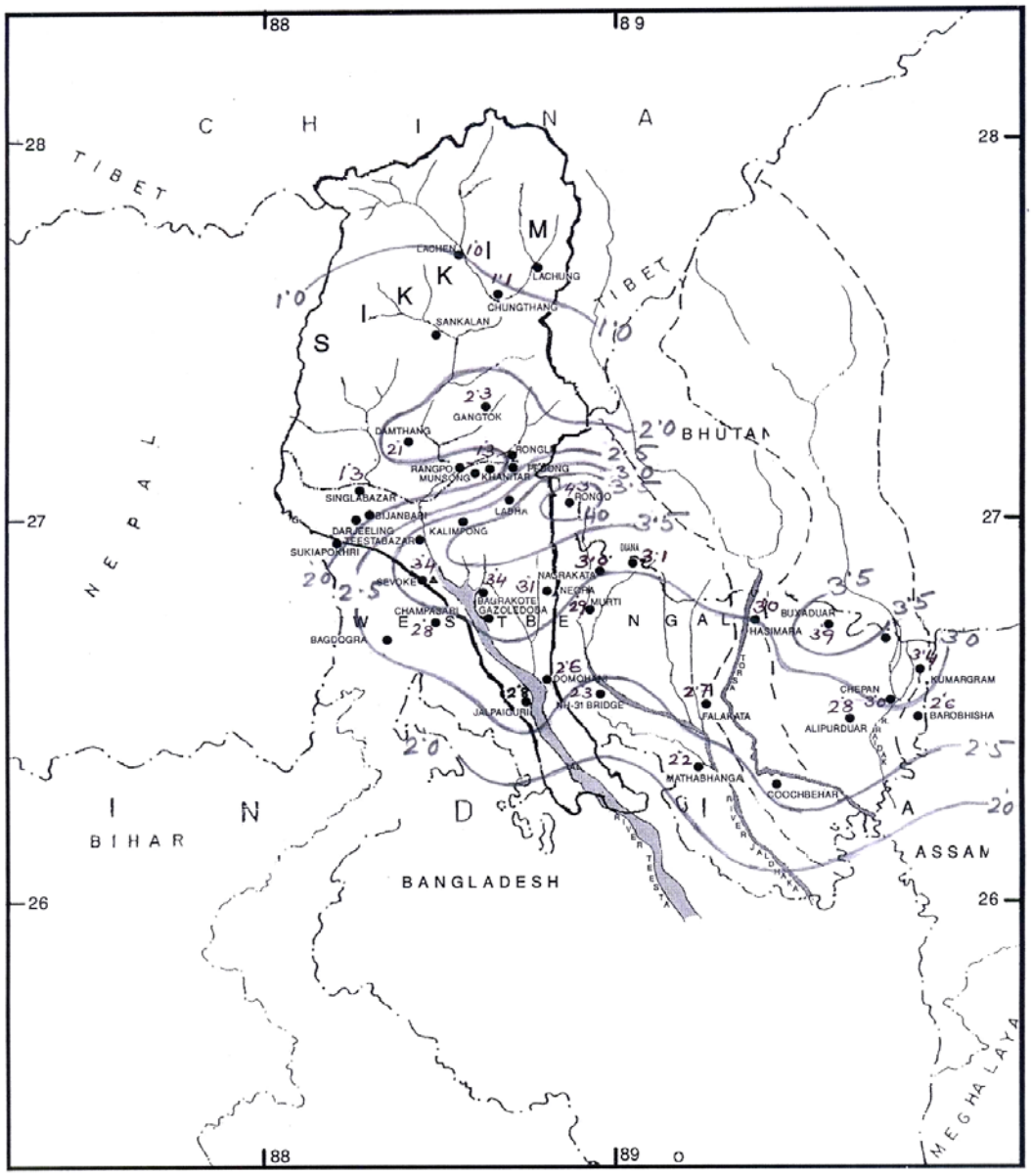

Fig. 2. Mean rainfall distributions (in 100 of cms) during south-west monsoon season over Teesta catchment and its neighbourhood based on 10 years data (1998 to 2007)

Sikkim state. Teesta Khangse glacier and Chho Lhamo are also considered as the source of Teesta river by many authors. Along its north to south course from its origin to the plains, the river receives drainage from a number of tributaries on either side of its course. The tributaries on the eastern flank are shorter in course but larger in number whereas the tributaries on the western flank are much longer with larger drainage areas, consequently contributing much more amount of discharge to the main Teesta river. The left bank tributaries, on the other hand, originate from semi-permanent and much smaller snow-fields as compared to right bank tributaries. In the Sub-Himalayan plains, it is joined by a number of tributaries *viz*., Leesh, Geesh, Chel, Neora from the north-eastern end and the Karala from the north-western end.

Teesta catchment has an area of 10205 sq km of which 7714 sq km lies in the mountainous region from its origin to Teesta Bazar (in Darjeeling district), 465 sq km lies in the hilly region from Teesta Bazar to Sevoke (in Darjeeling district) and rest 2026 sq km in plains from Sevoke to Mekhliganj (through Jalpaiguri district). Huge amount of water enters into the Teesta catchment in the form of rain and snow which is drained off as the

discharge of water by a system of drains of the Teesta and its tributary streams. Southern portion of the catchment is open to the moist southerly/south westerly monsoon current. Frequency of the heavy rainfall is highest along the southern portion of foot hills (wind-ward side). The river catchments along with the rain gauge stations over North Bengal and Sikkim are depicted in the Fig. 1.

The various features of rainfall during south-west monsoon season for the period 1998 to 2007 over Teesta basin and adjoining areas in North Bengal and Sikkim are summarized in the Table 1. Further, mean rainfall distributions based on 10 years data (1998 to 2007) over the Teesta catchment is depicted in the Fig. 2. From the Table 1, it is observed that during the study period, on an average Gangtok and Rongo experience maximum number of rainy days (100) whereas Neora rainfall observatory recorded highest one day rainfall (53 cm on 18th June 1998) during the months of south-west monsoon season. On the other hand, it is seen that the station Rongo receives highest amount of average rainfall (429cm) whereas the mean frequencies of heavy rainfall is maximum over Buxaduar and Rongo (19) during the months of south-west monsoon season.

3. Data and method

The important parameters which have been considered in this study are (*i*) Synoptic situations (*ii*) corresponding AAP and (*iii*) heavy rainfall realized on the next day. For synoptic situations and their area of locations, daily "Morning Inference" for Kolkata region issued by Area Cyclone Warning Centre (ACWC), Regional Meteorological Centre, Kolkata has been used and AAPs are calculated by isohyetal analysis of rainfall data in the Teesta river basin over SHWB & Sikkim using grid method. If on a particular day, there are more than two systems in the morning inference of RMC, Kolkata, then the systems which are having most significant influences (based on closeness to the catchment and intensity) on the rainfall distribution over the catchment have been taken into consideration. Moreover, the troughs (monsoon trough or trough of low on sea level chart) over Gangetic West Bengal and Orissa have been considered only in absence of any other synoptic situation. For synoptic systems and area of locations, system codes and area codes have been used as given below:

Codes:

System codes : Synoptic codes denoting the synoptic systems.

D = Depression

L = Low

C = Upper air cyclonic circulation

T = Monsoon trough or trough of low on Sea Level Chart

NST = North-South trough of low/trough in monsoon westerlies

Area codes : Area codes denoting the area consisting of the central region of the system or passing over it in case of trough.

1 = Over the catchment (SHWB & Sikkim),

2 = Bihar,

3 = Jharkhand,

4 = Gangetic West Bengal,

5 = Bangladesh,

6 = Assam & Meghalaya,

7 = Arunachal Pradesh,

8 = North Bay of Bengal,

9 = Orissa,

10 = Chhattisgarh & East Madhya Pradesh,

11 = East Uttar Pradesh & adjoining Bihar,

12 = Uttar Pradesh,

13 = Northwest Madhya Pradesh,

14 = West central Bay, Andhra Pradesh and Telengana

System code followed by the area code describes the synoptic system affecting the catchment. *e.g.*

C2T1 = Upper air cyclonic circulation over Bihar and trough passing through SHWB & Sikkim.

L4 = Low over Gangetic West Bengal.

Results of this study have been validated with the realized average areal precipitation (AAP) over Teesta

TABLE 2

Summary of the results of Q.P.F for the period 1998 to 2007

Synoptic situation code	AAP (mm)		Frequency of A.A P in different ranges in mm (% frequency)						Total	F/C range
	Mean	S.D.	00	1-10	11-25	26-50	51-100	>100		
L1	4.5	0.0	0(0)	1(100)	0(0)	0(0)	0(0)	0(0)	1	01-10mm
L2	6.9	5.5	1(14)	3(43)	3(43)	0(0)	0(0)	0(0)	7	01-10mm
L3	6.7	6.5	1(3)	30(86)	3(9)	1(3)	0(0)	0(0)	35	01-10mm
L4	4.9	4.2	2(8)	22(85)	2(8)	0(0)	0(0)	0(0)	26	01-10mm
L5	7.0	2.9	0(0)	5(83)	1(17)	0(0)	0(0)	0(0)	6	01-10mm
L6	3.5	0.0	0(0)	1(100)	0(0)	0(0)	0(0)	0(0)	1	01-10mm
L8	3.5	3.1	20(12)	137(85)	4(2)	0(0)	0(0)	0(0)	161	01-10mm
L9	4.8	4.1	3(10)	25(83)	2(7)	0(0)	0(0)	0(0)	30	01-10mm
L10	3.4	3.4	10(24)	31(74)	1(2)	0(0)	0(0)	0(0)	42	01-10mm
L11	10.4	5.8	0(0)	5(56)	4(44)	0(0)	0(0)	0(0)	9	01-10mm
L12	4.6	2.2	0(0)	6(100)	0(0)	0(0)	0(0)	0(0)	6	01-10mm
L13	3.5	3.0	4(10)	35(90)	0(0)	0(0)	0(0)	0(0)	39	01-10mm
L14	4.6	4.2	8(14)	44(76)	6(10)	0(0)	0(0)	0(0)	58	01-10mm
D2	1.8	0.0	0(0)	1(100)	0(0)	0(0)	0(0)	0(0)	1	01-10mm
D3	14.0	8.3	0(0)	2(25)	5(63)	1(13)	0(0)	0(0)	8	**11-25mm**
D4	4.1	5.9	2(33)	3(50)	1(17)	0(0)	0(0)	0(0)	6	01-10mm
D8	3.6	4.1	4(15)	20(77)	2(8)	0(0)	0(0)	0(0)	26	01-10mm
D9	6.8	6.4	2(13)	10(63)	4(25)	0(0)	0(0)	0(0)	16	01-10mm
D10	8.0	4.4	0(0)	7(58)	5(42)	0(0)	0(0)	0(0)	12	01-10mm
D12	1.5	0.9	0(0)	2(100)	0(0)	0(0)	0(0)	0(0)	2	01-10mm
D13	5.0	4.6	1(20)	3(60)	1(20)	0(0)	0(0)	0(0)	5	01-10mm
D14	7.1	5.0	0(0)	4(80)	1(20)	0(0)	0(0)	0(0)	5	01-10mm
C1	5.6	5.7	2(8)	18(75)	4(17)	0(0)	0(0)	0(0)	24	01-10mm
C2	7.0	7.2	2(3)	44(70)	16(25)	1(2)	0(0)	0(0)	63	01-10mm
C3	4.7	3.7	2(4)	42(91)	2(4)	0(0)	0(0)	0(0)	46	01-10mm
C4	7.1	7.8	2(3)	58(81)	10(14)	2(3)	0(0)	0(0)	72	01-10mm

TABLE 2 (*Contd.*)

Synoptic situation code	AAP (mm)		Frequency of A.A P in different ranges in mm (% frequency)						Total	F/C range
	Mean	S.D.	00	1-10	11-25	26-50	51-100	>100		
C5	4.9	6.3	2(20)	7(70)	1(10)	0(0)	0(0)	0(0)	10	01-10mm
C6	2.9	1.2	0(0)	6(100)	0(0)	0(0)	0(0)	0(0)	6	01-10mm
C8	3.7	3.2	10(14)	58(83)	2(3)	0(0)	0(0)	0(0)	70	01-10mm
C9	4.7	3.2	0(0)	8(89)	1(11)	0(0)	0(0)	0(0)	9	01-10mm
C10	6.4	7.3	3(10)	24(77)	3(10)	1(3)	0(0)	0(0)	31	01-10mm
C11	5.4	4.4	2(13)	13(81)	1(6)	0(0)	0(0)	0(0)	16	01-10mm
C12	6.8	3.7	0(0)	6(75)	2(25)	0(0)	0(0)	0(0)	8	01-10mm
C13	4.8	3.1	0(0)	4(100)	0(0)	0(0)	0(0)	0(0)	4	01-10mm
C14	4.0	3.7	3(13)	18(78)	2(9)	0(0)	0(0)	0(0)	23	01-10mm
T1	15.0	9.8	1(1)	53(33)	96(59)	12(7)	1(1)	0(0)	163	**11-25mm**
T4	9.4	6.0	0(0)	31(66)	16(34)	0(0)	0(0)	0(0)	47	01-10mm
T9	1.5	0.2	0(0)	2(100)	0(0)	0(0)	0(0)	0(0)	2	01-10mm
C1T1	9.7	8.5	0(0)	17(71)	5(21)	2(8)	0(0)	0(0)	24	01-10mm
C2T1	13.7	9.4	0(0)	16(44)	17(47)	3(8)	0(0)	0(0)	36	**11-25mm**
C3T1	6.0	3.2	0(0)	4(100)	0(0)	0(0)	0(0)	0(0)	4	01-10mm
C5T1	6.9	3.1	0(0)	5(83)	1(17)	0(0)	0(0)	0(0)	6	01-10mm
C11T1	14.0	12.2	0(0)	5(50)	4(40)	1(10)	0(0)	0(0)	10	**11-25mm**
C13T1	10.0	7.1	0(0)	3(75)	1(25)	0(0)	0(0)	0(0)	4	01-10mm
NST	5.4	4.0	1(3)	28(88)	3(9)	0(0)	0(0)	0(0)	32	01-10mm
L2T1	27.4	12.4	0(0)	0(0)	2(67)	1(33)	0(0)	0(0)	3	**11-25mm**
L12T1	7.7	1.7	0(0)	3(100)	0(0)	0(0)	0(0)	0(0)	3	01-10mm
L13T1	1.7	1.2	0(0)	2(100)	0(0)	0(0)	0(0)	0(0)	2	01-10mm
Total			88(07)	872(72)	234(19)	25(02)	01(0)	00(0)	1220	

catchment and heavy rainfall (65 mm and above) over Teesta basin & adjoining areas in North Bengal & Sikkim during south-west monsoon season 2008. Further, in order to make more quantitative, performance of QPF has been verified using various contingency (6 × 6 and 2 × 2) tables. In this study, QPF during south-west monsoon season 2008 have been verified using Percentage Correct (PC), Heidke Skill Score (HSS) and Critical Success Index (CSI) from 6 × 6 contingency table and Probability of Detection (POD), False Alarm Rate (FAR), Missing Rate (MR), Correct Non-occurrence (C-NON), Critical Success Index (CSI), Biased for Occurrence (BIAS), Percentage Correct (PC), True Skill Score (TSS) and Heidke Skill Score (HSS) from 2 × 2 contingency table.

TABLE 3

Impact of different synoptic systems in the distribution of rainfall over Teesta catchment based on data of 1998-2007

Type of system	Total frequency	Mean A.A.P.	Frequency of occurrence of A.A.P. (% frequency)					
			00 (mm)	1-10 (mm)	11-25 (mm)	26-50 (mm)	51-100 (mm)	>100 (mm)
Low	421	4.4	49(12)	345(82)	26(06)	01(00)	00(00)	00(00)
Depression	81	6.1	09(11)	52(64)	19(23)	01(01)	00(00)	00(00)
Cyclonic circulation	382	5.5	28(07)	306(80)	44(12)	04(01)	00(00)	00(00)
Trough	212	13.6	01(00)	86(41)	112(53)	12(06)	01(00)	00(00)
Cyclonic circulation with trough	84	11.5	00(00)	50(60)	28(33)	06(07)	00(00)	00(00)
Low with trough	08	13.6	00(00)	05(63)	02(25)	01(12)	00(00)	00(00)

4. Results and analysis

4.1. *Quantitative Precipitation Forecast (QPF) for Teesta basin*

The results of the study of Quantitative Precipitation Forecast (QPF) for Teesta basin using Synoptic Analog Method for the period 1998 to 2007 are summarized in the Table 2. From this table, following points may be inferred-

(a) Total forty eight (48) types of synoptic situations have been identified during 1998 to 2007.

(b) Out of 1220 days during 1998 to 2007 of monsoon months (June to September), it has been found that the AAPs were in the range of

(*i*) 1- 10 mm and below for 960 days (79%) and

(*ii*) 11-25 mm and above for 260 days (21%).

(c) Most important systems which were favorable (more than 25% cases) for AAP in the range 11-25 mm and above were as follows:

(*i*) Low over Bihar and trough passing through SHWB & Sikkim (L2T1) for 3 occasions (100%);

(*ii*) Depression over Jharkhand (D3) for 6 occasions (76%);

(*iii*) Trough over SHWB and Sikkim (T1) for 109 occasions (67%);

(*iv*) Upper air cyclonic circulation over Bihar and trough passing through SHWB & Sikkim (C2T1) for 20 occasions (55%);

(*v*) Upper air cyclonic circulation over East Uttar Pradesh & adjoining Bihar and trough passing through SHWB & Sikkim (C11T1) for 5 occasions (50%);

(*vi*) Low over East Uttar Pradesh and adjoining Bihar (L11) for 4 occasions (44%);

(*vii*) Low over Bihar (L2) for 3 occasions (43%);

(*viii*) Depression over Chhattisgarh & East Madhya Pradesh (D10) for 5 occasions (42%);

(*ix*) Trough over Gangetic West Bengal (T4) for 16 occasions (34%);

(*x*) Upper air cyclonic circulation over SHWB and Sikkim and trough passing through it (C1T1) for 7 occasions (29%) and

(*xi*) Upper air cyclonic circulation over Bihar (C2) for 17 occasions (27%);

(d) Important synoptic systems (with frequencies 25 days or more) for which realized AAP were below 10.5 mm were:

(*i*) Low over Jharkhand (L3) – 31/35 (*i.e.*, 31 out of 35 occasions);

(*ii*) Low over Gangetic West Bengal (L4) – 24/26;

(*iii*) Low over North Bay of Bengal (L8) – 157/ 161;

(*vi*) Low over Orissa (L9) – 28/30;

(*v*) Low over Chhattisgarh and East Madhya Pradesh (L10)- 41/42;

TABLE 4

Validation of Quantitative Precipitation Forecast (QPF) for southwest monsoon season 2008

Serial Number	Synoptic situation code	Number of cases realized	QPF Range (mm)	Realized mean AAP (mm)	Number of cases when QPF is		
					Correct (%)	Out by one stage (%)	Out by two stages (%)
1	"L3"	2	01-10mm	9.0	1(50)	1(50)	0(0)
2	"L5"	1	01-10mm	1.7	1(100)	0(0)	0(0)
3	"L8"	15	01-10mm	4.2	14(93)	1(7)	0(0)
4	"L9"	2	01-10mm	13.4	1(50)	1(50)	0(0)
5	"L10"	4	01-10mm	12.5	1(25)	3(75)	0(0)
6	"L13"	2	01-10mm	9.8	1(50)	1(50)	0(0)
7	"L14"	5	01-10mm	3.6	5(100)	0(0)	0(0)
8	"D3"	1	11-25mm	15.6	1(100)	0(0)	0(0)
9	"D4"	1	01-10mm	10.3	1(100)	0(0)	0(0)
10	"D8"	2	01-10mm	7.9	2(100)	0(0)	0(0)
11	"D9"	2	01-10mm	3.9	2(100)	0(0)	0(0)
12	"D10"	2	01-10mm	2.5	2(100)	0(0)	0(0)
13	"C2"	9	01-10mm	8.9	7(78)	2(22)	0(0)
14	"C3"	6	01-10mm	7.5	4(67)	2(33)	0(0)
15	"C4"	7	01-10mm	7.9	4(57)	3(43)	0(0)
16	"C5"	5	01-10mm	9.6	2(40)	3(60)	0(0)
17	"C8"	13	01-10mm	6.8	9(69)	4(31)	0(0)
18	"C9"	3	01-10mm	6.2	3(100)	0(0)	0(0)
19	"C10"	1	01-10mm	3.7	1(100)	0(0)	0(0)
20	"C11"	1	01-10mm	0.0	0(0)	1(100)	0(0)
21	"T1"	26	11-25mm	15.4	24(92)	2(8)	0(0)
22	"T4"	6	01-10mm	13.0	2(33)	4(67)	0(0)
23	"C2T1"	1	11-25mm	13.0	1(100)	0(0)	0(0)
25	"C5T1"	1	01-10mm	0.5	1(100)	0(0)	0(0)
26	"NST"	4	01-10mm	6.9	4(100)	0(0)	0(0)
	Total	122		7.8	94(77)	28(23)	0(0)

(*vi*) Low over North West Madhya Pradesh (L13)- 39/39;

(*vii*) Low over West central Bay, Andhra Pradesh, Telangana (L14) - 52/58;

(*viii*) Depression over North Bay of Bengal (D8) – 24/26;

(*ix*) Upper air circulation over Bihar (C2) – 46/63;

(*x*) Upper air cyclonic circulation over Jharkhand (C3) – 44/46;

(*xi*) Upper air cyclonic circulation over Gangetic West Bengal (C4) – 60/72;

(*xii*) Upper air cyclonic circulation over North Bay of Bengal (C8) – 68/70;

(*xiii*) Upper air cyclonic circulation over Chhattisgarh and east Madhya Pradesh (C10) – 27/31;

(*xiv*) Trough over Gangetic West Bengal (T4) – 31/47 and

(*xv*) North-South trough of low/ trough in monsoon westerlies (NST) – 29/32.

Overall impact of different synoptic systems on the rainfall distributions over Teesta catchment during the study period are summarized in the Table 3. From this table, it is clear that in case of Depression, the mean AAP was 6.1 mm and out of 81 occasions, 20 occasions (25%) were responsible for 10.5 mm and above rainfall; for Low, it was 4.4 mm and 27 (6%) cases out of 421 cases were responsible for 10.5 mm and above rainfall; for Upper air cyclonic circulation, it was 5.5 mm and 48 (13%) occasions out of 382 occasions were responsible for 10.5 mm and above rainfall; for Trough, it was 13.6 mm and 125 (59%) occasions out of 212 were responsible for 10.5 mm and above rainfall and for Cyclonic circulation & Trough passing through SHWB and Sikkim, it was 11.5 mm and 34 (40%) occasions out of 84 occasions were responsible for 10.5 mm and above rainfall.

Thus, based on the study during the period 1998-2007, only five types of synoptic situations have been identified for which computed mean A.A.P. lies in the range of 11-25 mm *viz*., (*i*) Trough over SHWB and Sikkim (T1) (*ii*) Upper air cyclonic system over Bihar with trough passing through SHWB & Sikkim (C2T1) (*iii*) Upper air cyclonic circulation over East Uttar Pradesh & adjoining Bihar with trough passing through SHWB & Sikkim (C11T1), (*iv*) Low over Bihar with trough passing through SHWB & Sikkim (L2T1) and (*v*) Depression over Jharkhand (D3).

In conformity with earlier studies, it is observed that whenever a monsoon trough or trough of low passes through SHWB and Sikkim, the situation demands for issue of QPF in the range 11-25mm whereas presence of a low, depression or a cyclonic circulation over Bay of Bengal, probability of occurrence of rainfall in the AAP range 11-25 mm and above is minimum and the situation warrants for issue of Q.P.F. in the range 1-10mm. But when the low or depression takes northerly course and lies over Bihar, East Uttar Pradesh or Jharkhand, the probability of occurrence of rainfall in the AAP range 11-25 mm and above increases. Depending on the proximity and intensity of the system the situation warrants for issue of QPF in the range 11-25 mm. Otherwise, when the low or depression takes westerly/ north-westerly course *i.e*., more south to the normal monsoon trough line, we may issue QPF in the range 1-10 mm.

The above developed statistics have been validated with the realized A.A.P. during south-west monsoon season 2008 over Teesta basin and the results are shown in the Table 4. It has been seen from the tables that the realized AAPs are in good agreement with the forecast.

TABLE 5

Results of the verification of Quantitative Precipitation Forecast using Synoptic Analog Method during June-September 2008 applying 6 × 6 contingency table

Categorical Forecast		
Type of skill		Skill score
Percentage Correct (PC)		77.0
Critical Success Index (CSI)	CSI_{00-00}	0.0
	CSI_{01-10}	0.7
	CSI_{11-25}	0.5
Heidke Skill Score (H.S.S.)		0.5

Out of 122 cases, QPF has been tallied with the AAP on 94 cases (77%), out by one stage on 28 cases (23%) and out by two stages nil.

Results of the verification of QPF using 6 × 6 and 2 × 2 contingencies tables are presented in the Table 5 and Table 6 respectively. From Table 5, it has been found that the value of Percentage Correct (PC) and Heidke Skill Score (HSS) are 77 and 0.5 respectively. From Table 6, average value of Probability of Detection (POD), False Alarm Rate (FAR), Missing Rate (MR), Correct Non-occurrence(C-NON), Critical Success Index (CSI), Biased for Occurrence (BIAS), Percentage Correct (PC), True Skill Score (TSS) and Heidke Skill Score (HSS) have been found to be 0.7, 0.2, 0.3, 0.7, 0.6, 0.9, 77.9, 0.5 and 0.5 respectively.

4.2. *Heavy rainfall (65 mm and above) warning for Teesta basin & adjoining areas in north Bengal & Sikkim*

The results of the study of occurrence of heavy rainfall over Teesta basin & adjoining areas in North Bengal & Sikkim for the period 1998 to 2007 are summarized in the Table 7. From this table, following points may be inferred:

(a) Most important synoptic systems (with frequencies 15 days or more) which were favorable for the occurrence heavy rainfall (at least over isolated places) were as follows:

(*i*) Trough over SHWB & Sikkim (T1) - heavy rainfall observed for 133(82%) occasions out of 163:

(*ii*) Trough over Gangetic West Bengal (T4) - heavy rainfall observed for 31(66%) occasions out of 47;

(*iii*) Upper air cyclonic circulation over Bihar (C2) - heavy rainfall observed for 29(46%) occasions out of 63;

TABLE 6

Results of the verification of Quantitative Precipitation Forecast using Synoptic Analog Method during June-September 2008 applying 2 × 2 contingency table

Deterministic Forecast			
	Skill score		
Type of skill	A.A.P. range (01-10mm)	A.A.P. range (11-25mm)	Average
Probability of Detection (POD)	1.0	0.5	0.7
False Alarm Rate (FAR)	0.3	0.1	0.2
Missing Rate (MR)	0.0	0.5	0.3
Correct Non-occurrence (C-NON)	0.5	1.0	0.7
Critical Success Index (CSI)	0.7	0.5	0.6
Biased for Occurrence (BIAS)	1.3	0.6	0.9
Percentage Correct (PC)	77.0	78.7	77.9
True Skill Score (TSS)	0.5	0.5	0.5
Heidke Skill Score (HSS)	0.5	0.5	0.5

(*iv*) Upper air cyclonic circulation over Chhattisgarh and East Madhya Pradesh (C10) - heavy rainfall observed for 17(55%) occasions out of 31;

(*v*) Upper air cyclonic circulation over East Uttar Pradesh & adjoining Bihar (C11) - Heavy rainfall observed for 9 (56%) occasions out of 16;

(*vi*) Upper air cyclonic circulation over West central Bay, Andhra Pradesh and Telengana (C14) - Heavy rainfall observed for 11 (48%) occasions out of 23;

(*vii*) Upper air cyclonic circulation along with trough passing through SHWB & Sikkim (C1T1) - heavy rainfall observed for 19 (79%) occasions out of 24;

(*viii*) Upper air cyclonic circulation over Bihar along with trough passing through SHWB & Sikkim (C2T1) - heavy rainfall observed for 32 (89%) occasions out of 36;

(b) Synoptic situations which are not so favourable for occurrence of heavy rainfall over the area under study were as follows :

(*i*) Upper air cyclonic circulation over Bangladesh (C5) - heavy rainfall observed only in 1 (10%) occasion out of 10;

(*ii*) Upper air cyclonic circulation over North Bay of Bengal (C8) - heavy rainfall observed only in 14 (20%) occasions out of 70;

(*iii*) Upper air cyclonic circulation over Northwest Madhya Pradesh (C13) - heavy rainfall observed only in 1(25%) occasions out of 4;

(*iv*) Depression over North Bay of Bengal (D8) - heavy rainfall observed only in 7 (27%) out of 26;

(*v*) Depression over Orissa (D9) - heavy rainfall observed only in 4 (25%) occasions out of 16;

(*vi*) Depression over Chhattisgarh and East Madhya Pradesh (D10) – heavy rainfall observed only in 3(25%) out of 12;

(*vii*) Low over Gangetic West Bengal (L4) – heavy rainfall observed only in 5 (19%) occasions out of 26;

(*viii*) Low over North Bay of Bengal (L8) – heavy rainfall observed only in 37 (23%) occasions out of 161;

(*ix*) Low over Chhattisgarh and East Madhya Pradesh (L10) - heavy rainfall observed only in 7 (17%) occasions out of 42.

(c) From the Table 7, it can be seen that the following synoptic systems are responsible for the occurrence of heavy rainfall at a few or many or most places in the catchment of Teesta & adjoining areas in North Bengal & Sikkim:

TABLE 7

Results of heavy rainfall for the period 1998 to 2007

S. No.	System	Heavy rainfall observed at places Number (Percentage)				No. of occasions (%)		Total no. of cases	F/C of heavy rainfall at places
		Isolated	Few	Many	Most	Non-heavy rainfall	Heavy rainfall		
1	T1	56(34)	56(34)	19(12)	2(1)	30(18)	133(82)	163	Few
2	T4	22(47)	7(15)	2(4)	0(0)	16(34)	31(66)	47	Isolated
3	C1	8(33)	1(4)	0(0)	0(0)	15(63)	9(38)	24	
4	C2	24(38)	5(8)	0(0)	0(0)	34(54)	29(46)	63	Isolated
5	C3	12(26)	1(2)	0(0)	0(0)	33(72)	13(28)	46	
6	C4	20(28)	7(10)	0(0)	2(3)	43(60)	29(40)	72	
7	C5	1(10)	0(0)	0(0)	0(0)	9(90)	1(10)	10	
8	C6	3(50)	0(0)	0(0)	0(0)	3(50)	3(50)	6	Isolated
9	C8	11(16)	2(3)	1(1)	0(0)	56(80)	14(20)	70	
10	C9	3(33)	1(11)	0(0)	0(0)	5(56)	4(44)	9	Isolated
11	C10	10(32)	5(16)	2(6)	0(0)	14(45)	17(55)	31	Isolated
12	C11	7(44)	2(13)	0(0)	0(0)	7(44)	9(56)	16	Isolated
13	C12	3(38)	0(0)	0(0)	0(0)	5(63)	3(38)	8	
14	C13	0(0)	1(25)	0(0)	0(0)	3(75)	1(25)	4	
15	C14	7(30)	4(17)	0(0)	0(0)	12(52)	11(48)	23	Isolated
16	D2	0(0)	0(0)	0(0)	0(0)	1(100)	0(0)	1	
17	D3	4(50)	0(0)	0(0)	0(0)	4(50)	4(50)	8	Isolated
18	D4	2(33)	0(0)	0(0)	0(0)	4(67)	2(33)	6	
19	D8	6(23)	1(4)	0(0)	0(0)	19(73)	7(27)	26	
20	D9	4(25)	0(0)	0(0)	0(0)	12(75)	4(25)	16	
21	D10	3(25)	0(0)	0(0)	0(0)	9(75)	3(25)	12	
22	D12	0(0)	0(0)	0(0)	0(0)	2(100)	0(0)	2	
23	D13	1(20)	1(20)	0(0)	0(0)	3(60)	2(40)	5	
24	D14	2(40)	0(0)	0(0)	0(0)	3(60)	2(40)	5	
25	L1	1(100)	0(0)	0(0)	0(0)	0(0)	1(100)	1	
26	L2	1(14)	1(14)	0(0)	0(0)	5(71)	2(29)	7	
27	L3	8(23)	4(11)	0(0)	0(0)	23(66)	12(34)	35	
28	L4	5(19)	0(0)	0(0)	0(0)	21(81)	5(19)	26	
29	L5	1(17)	1(17)	0(0)	0(0)	4(67)	2(33)	6	
30	L6	1(100)	0(0)	0(0)	0(0)	0(0)	1(100)	1	Isolated
31	L8	35(22)	2(1)	0(0)	0(0)	124(77)	37(23)	161	
32	L9	6(20)	3(10)	0(0)	0(0)	21(70)	9(30)	30	
33	L10	5(12)	1(2)	1(2)	0(0)	35(83)	7(17)	42	
34	L11	2(22)	1(11)	0(0)	0(0)	6(67)	3(33)	9	
35	L12	3(50)	0(0)	0(0)	0(0)	3(50)	3(50)	6	Isolated
36	L13	12(31)	2(5)	0(0)	0(0)	25(64)	14(36)	39	
37	L14	17(29)	5(9)	0(0)	0(0)	36(62)	22(38)	58	
38	T9	0(0)	0(0)	0(0)	0(0)	2(100)	0(0)	2	
39	NST	8(25)	2(6)	0(0)	0(0)	22(69)	10(31)	32	
40	L2T1	0(0)	2(67)	0(0)	0(0)	1(33)	2(67)	3	Few
41	L12T1	3(100)	0(0)	0(0)	0(0)	0(0)	3(100)	3	Isolated
42	L13T1	0(0)	0(0)	0(0)	0(0)	2(100)	0(0)	2	
43	C1T1	14(58)	5(21)	0(0)	0(0)	5(21)	19(79)	24	Isolated
44	C2T1	20(56)	9(25)	2(6)	1(3)	4(11)	32(89)	36	Isolated
45	C3T1	1(25)	2(50)	0(0)	0(0)	1(25)	3(75)	4	Few
46	C5T1	1(17)	1(17)	0(0)	0(0)	4(67)	2(33)	6	
47	C11T1	1(10)	6(60)	0(0)	0(0)	3(30)	7(70)	10	Few
48	C13T1	3(75)	1(25)	0(0)	0(0)	0(0)	4(100)	4	Isolated
		Total				689(56)	531(44)	1220	

(*i*) Trough over SHWB & Sikkim (T1) – for 77 (58%) cases out of 133 cases of heavy rainfall;

(*ii*) Upper air cyclonic circulation over Jharkhand along with trough passing through SHWB & Sikkim (C3T1) - for 2 (67%) cases out of 3 cases of heavy rainfall;

(*iii*) Upper air cyclonic circulation over East Uttar Pradesh & adjoining Bihar along with trough passing through SHWB & Sikkim (C11T1) - for 6 (86%) cases out of 7 cases of heavy rainfall;

(*iv*) Low over Bihar along with trough passing through SHWB & Sikkim (L2T1) - for 2 (100%) cases out of 2 cases of heavy rainfall;

Thus, it is seen that out of 1220 days during monsoon months (June to September) of 1998-2007, number of days with heavy rainfall in the Teesta basin & adjoining areas were 531 (44%) [Number of days with heavy rainfall at isolated places were 357 (29%), at few places - 142 (12%), at many places - 27 (2%) and at most places only 5 (1%)] and number of days without heavy rainfall were 689 (56%).

Due to presence of trough over the region (T1) or systems associated with trough passing through the region, the frequency of heavy rainfall increases. Out of 255 days having systems with only trough or system associated with trough, heavy rainfall were reported for 205 days (80%) [at isolated places were 99 days (39%), at a few places 82 days (32%), at many places 21 days (8%) and at most places 3 days (1%) only] and that of non-heavy days were only 50 (20%). While due to other systems, the frequency of heavy rainfall were as follows: out of 965 days, heavy rainfall were reported for 326 days (34%) [at isolated places were 258 days (27%), at a few places 60 days (6%), at many places 6 days (1%) and at most places it was only 2 (<1%)] and that of non-heavy days were 639 days (66%).

Based on the 10-years study (1998-2007), only eighteen types of synoptic situations (out of 48 types) have been identified as most significant ones for which forecast for heavy rainfall warning for the catchment of Teesta & adjoining areas in North Bengal & Sikkim are to be issued. They are. (*i*) Trough over SHWB and Sikkim (T1); (*ii*) Trough over Gangetic West Bengal (T4); (*iii*) Upper air cyclonic circulation over Bihar (C2); (*iv*) Upper air cyclonic circulation over Assam & Meghalaya (C6); (*v*) Upper air cyclonic circulation over Orissa (C9); (*vi*) Upper air cyclonic circulation over Chhattisgarh and East Madhya Pradesh (C10); (*vii*) Upper air cyclonic circulation over East Uttar Pradesh & adjoining Bihar (C11); (*viii*) Upper air cyclonic circulation over West central Bay, Andhra Pradesh and Telengana (C14); (*ix*) Depression over Jharkhand (D3); (*x*) Low over Assam & Meghalaya (L6); (*xi*) Low over Uttar Pradesh (L12); (*xii*) Low over Bihar along with trough passing through SHWB & Sikkim (L2T1); (*xiii*) Low over Uttar Pradesh along with trough passing through SHWB & Sikkim (L12T1); (*xiv*) Upper air cyclonic circulation along with trough passing through SHWB & Sikkim (C1T1); (*xv*) Upper air cyclonic circulation over Bihar along with trough passing through SHWB & Sikkim (C2T1); (*xvi*) Upper air cyclonic circulation over Jharkhand along with trough passing through SHWB & Sikkim (C3T1); (*xvii*) Upper air cyclonic circulation over East Uttar Pradesh & adjoining Bihar along with trough passing through SHWB & Sikkim (C11T1) and (*xviii*) Upper air cyclonic circulation over North-West Madhya Pradesh along with trough passing through SHWB & Sikkim (C13T1).

Above findings have been validated with the synoptic situations and the associated rainfall realized on the next day during south-west monsoon season 2008 over Teesta basin & adjoining areas in North Bengal & Sikkim. It has been found that the occurrence of heavy rainfall over the study area is in good agreement with the forecast. Out of 122 cases, heavy rainfall warning has been tallied with the observed rainfall on 72 cases (59%).

5. Conclusions

Synoptic analog method is very easy to apply for issuing Q.P.F. The present study reveals that this method gives reasonable success for Teesta basin once the position and intensity of the synoptic system is known properly.

As per result of analysis, what can be revealed from the study carried out here is presented below :

(a) Presence of monsoon trough or trough of low over SHWB & Sikkim warrants for issue of Q.P.F. for Teesta basin in the range 11-25 mm.

(b) Depression over Jharkhand and Low/upper air cyclonic circulation over Bihar or East Uttar Pradesh along with trough over SHWB and Sikkim may warrant for issue of Q.P.F in the range 11-25 mm.

(c) Whenever a low, depression or a cyclonic circulation lies over Bay of Bengal and West central Bay, Andhra Pradesh and Telengana Q.P.F. may be issued in the range 1-10 mm.

(d) Only five types of synoptic situations have been identified for which computed mean A.A.P. lies in the range of 11-25 mm *viz*.,

(*i*) Trough over SHWB and Sikkim (T1) : Mean -15.0 mm, S D - 9.8 mm.

(*ii*) Upper air cyclonic system over Bihar with trough passing through SHWB & Sikkim (C2T1) : Mean -13.7 mm, S D - 9.4 mm.

(*iii*) Upper air cyclonic circulation over East Uttar Pradesh & adjoining Bihar with trough passing through SHWB & Sikkim (C11T1) : Mean -14.0 mm, S D - 12.2 mm.

(*iv*) Low over Bihar with trough passing through SHWB & Sikkim (L2T1) : Mean - 27.4 mm, S D - 12.4 and

(*v*) Depression over Jharkhand: Mean -14.0 mm, S D - 8.3 mm.

(e) Presence of synoptic systems such as: Trough over SHWB & Sikkim (T1), Low over Bihar along with trough passing through SHWB & Sikkim (L2T1), Upper air cyclonic circulation over Jharkhand along with trough passing through SHWB & Sikkim (C3T1) and Upper air cyclonic circulation over East Uttar Pradesh & adjoining Bihar along with trough passing through SHWB & Sikkim (C11T1) may warrant for issue heavy rainfall warning at a few places in the catchment of Teesta & adjoining areas in North Bengal & Sikkim.

(f) The occurrence of heavy rainfalls at a few or many or most places over this area are mainly due to the presence of trough (monsoon trough or trough of low on sea level chart) passing through SHWB & Sikkim. The presence of this trough for 2 or 3 days may cause disastrous flood situation in this area. On the other hand, the synoptic situations other than trough passing through SHWB & Sikkim may responsible for occurrence of heavy rainfall only at the isolated places for one or two days but may not create flood like situation over this region.

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