MAUSAM, **69**, 2 (April 2018), 297-308

551.579 : 551.577 (540.33 : 540.29)

A Synoptic analogue model to issue QPF over Gangetic West Bengal and adjoining Jharkhand

S. CHATTOPADHYAY and S. SENGUPTA

Regional Meteorological Centre, Kolkata — 700 027, India

(*Received 10 May 2016, Accepted 21 March 2018*)

e mail : sumanchatterjee1966@gmail.com

सार – इस शोध पत्र में पश्चिम बंगाल के छह गांगेय क्षेत्रों तथा इससे लगे झारखंड की नदियों नामतः मयूराक्षी, अजय, कंसाबटी, दामोदर, बाराकर तथा दामोदर घाटी कॉरपोरेशन के जल ग्रहण क्षेत्रों में वर्ष 1990 से 2014 तक के 25 वर्षों में मॉनसून ऋतु के दौरान प्रतिदिन हुई वर्षा के आंकडों को भिन्न-भिन्न समूहों के (11-25 मि.मी., 26-50 मि.मी. 51-100 मि.मी. और इससे अधिक) तीन AAP समूहों में बॉटकर आकाशीय औसत वर्षा (AAP) के डेटा का विश्लेषण किया गया है इसमें मुख्य रूप से सूखा और 01-10 मि. मी. वर्षा के डेटा को शामिल नहीं किया गया है इसमें मुख्य सिनॉप्टिक विशेषताओं जैसेः- माध्म समुद्र तल में द्रोणी (ट्रफ), निम्न दाब का क्षेत्र, चिह्नित निम्न दाब का क्षेत्र, चक्रवातीय तूफान तथा प्रतिदिन का चक्रवातीय परिसंचरण और नदियों के जलग्रहण क्षेत्रों के अनुसार उनकी स्थितियाँ । जैसेः- जलग्रहण क्षेत्र से ज्यादा, जलग्रहण क्षेत्र के आसपास के इलाके (उत्तर या दक्षिण में 200 कि. मि. के अन्दर) और जलग्रहण क्षेत्र के बाहर (उत्तर या दक्षिण में 200 कि. मि. से दूर) का भी अध्ययन किया गया है। आकाशीय औसत वर्षा के संबंध में छह जलग्रहण क्षेत्रों के अलग-अलग श्रेणियों की सिनॉप्टिक विशेषताओं की जॉच की गई है। वर्ष 1990 से 2014 की अवधि के दौरान आकाशीय औसत वर्षा (AAP) का प्रतिशत आवृति के वितरण का सिनॉप्टिक लक्षण की श्रेणी के अनुरूप होने से मात्रात्मक वर्षा पूर्वानुमान (QPF) देने के लिए सिनॉप्टिक एनालॉग मॉडल (SAM) को विकसित करने में मदद मिली है। सिनॉप्टिक एनालॉग मॉडल से प्राप्त परिणामों का सत्यापन वर्षा के आंकडों से किया गया है और 2015 के मानसून ऋतु में सभी जलग्रहण क्षेत्रों में हुई आकाशीय औसत वर्षा की गणना की गई है। इस शोध पत्र में भिन्न-भिन्न स्किल्स स्कोर्स को भी दर्शाया गया है।

ABSTRACT. In this study the Areal Average Precipitation (AAP) data for each day over each of the six catchments of Gangetic West Bengal (GWB) and adjoining Jharkhand namely river catchments of Mayurakhshi, Ajoy, Kansabati, Damodar, Barakar and Lower Valley of Damodar Valley Corporation during monsoon season for 25 years from 1990 to 2014 have been analyzed by grouping the AAP in three different ranges (11-25 mm, 26-50 mm, 51-100 mm and more), excluding Mainly Dry and 01-10 mm. The associated main synoptic features *viz*., trough at mean sea level, low pressure area, well marked low pressure area, cyclonic storm and cyclonic circulation for each day and their location with respect to the river catchments, *viz*., over the catchment, neighbourhood of the catchment (within 200 km South or North) and outside the catchment (more than 200 km South or North) have also been studied. The association of AAP ranges over six catchments with different categories of synoptic features has been examined. The distribution of percentage frequency of AAPs associated with the category of synoptic feature for the period 1990 to 2014 has led to development of a Synoptic Analogue Model (SAM) for issue of Quantitative Precipitation Forecast (QPF). The results obtained from SAM have been verified for rainfall data and calculated AAPs of monsoon season of 2015 over all the catchments and different skills scores also presented in this study.

Key words – Quantitative Precipitation Forecast (QPF), Synoptic Analogue Model (SAM), Average Areal Precipitation (AAP), Damodar river basin.

1. Introduction

The river Damodar is flood prone mainly due to reasons which are physiographic, meteorological and socio-economic in nature. Damodar valley area covers the area from longitude 84.7° E to 88.5° E and latitude from 22.1° N to 24.5° N. Damodar River is a tributary of the Hooghly River. It flows more or less in the west to east direction through Jharkhand and West Bengal. In the present paper efforts have been made to identify the various synoptic systems and their locations which are accountable for rainfall during South West monsoon season over Gangetic West Bengal and Jharkhand during 25 years period 1990 to 2014. Precipitation forecast over a small catchment area is a challenging work before the meteorologists and becomes more when the question of issue of QPF arises in the ranges of 11-25 mm, 26-50 mm, 51-100 mm and more. Several methods are used for issue of such forecast and Synoptic Analogue Model (SAM) is being used by meteorologists since long. Accurate Synoptic Analogue Model requires a comprehensive study of the rain fall pattern (AAP) and associative Synoptic

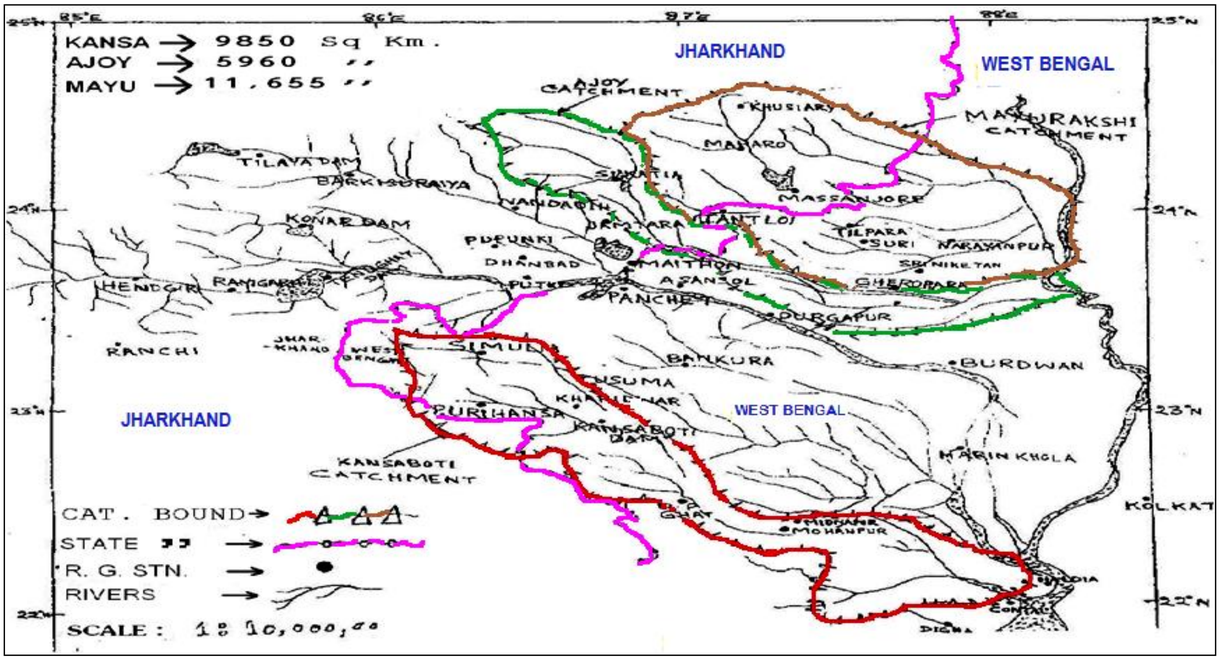

Fig. 1. Map of Mayurakshi, Ajoy and Kansabati catchments and rain gauge stations

features details in each river catchment. Data for a long period are basic requirement for an effective and associative synoptic situations with accurate position of the each synoptic system are very important for model development. In the past, Lal *et al*. (1983) developed a synoptic analogue model for QPF over Gomoti catchment. Kamaljit Ray and Sahu (1998) did a similar study over Sabarmati river basin. Ram and Kaur (2004) studied QPF over Yamuna basin taking 9 (nine) synoptic systems. Raha *et al*. (2009) have studied synoptic analogue method for QPF over Teesta basin and heavy rainfall warning over Teesta basin and adjoining North Bengal and Sikkim. Chakraborty and Sen (2012) also used a synoptic analogue model for QPF over Damodar catchments using 15 years period dataset. In the present study Synoptic analogue technique applied with different approach for determination of QPF over all six catchments of Gangetic West Bengal (GWB) and adjoining Jharkhand using 25 years dataset.

1.1. *Damodar catchment*

The river originates in the hills of Chotanagpur in Jharkhand and drains a fan shaped catchment of about 22,015 sq. km. This 250 km long river has frequently been exposed to large scale flood damage in the past 200 years or so. The Valley is also critically poised in relation to the path of the monsoon rains that account for around 90% of the total annual precipitation in the Valley. It has a number of tributaries and sub-tributaries, such as Barakar, Konar, Bokaro,Haharo, Jamunia, Ghari, Guaia, Khadia and Bhera. Average annual rainfall in Damodar catchment is 1272.1 mm.

1.2. *Barakar catchment*

The Barakar is the most important tributary of the Damodar. It originates near Padma in Hazaribagh district and flows through Jharkhand before meeting the Damodar near Dishergarh in West Bengal. The Damodar and the Barakar trifurcates the Chotanagpur plateau. The rivers pass through hilly areas with great force, sweeping away whatever lies in their path. Average annual rain fall in Barakar Catchment is 1260.2 mm.

1.3. *Lower valley*

Lower Valley lies in the Gangetic plain and it covers four districts, namely Burdwan, Hooghly, Howrah and East Midnapur. Other rivers in Lower Valley are Rupnarayan, Kana Damodar, Hooghly, Banka etc. Average annual rainfall in Lower Valley is 1329.2 mm and average annual rain fall is more in the Southern part of lower valley (1650.1 mm). Its total length from its source in the hills of Chotanagpur plateau in Jharkhand to its confluence with Hooghly in West Bengal is about 541 km, half of which is in Jharkhand and the remaining half is in West Bengal. It takes a southerly turn from Burdwan town and joins river Hooghly about 50 km upstream from Kolkata. The Damodar valley covers an area of 22,015 sq. km in Jharkhand and West Bengal.

Kansabati, Ajoy and Mayurakshi catchments cover total 27465 sq. km and main rivers are Ajoy, Mayurakshi, Rupnarayan, Mundeshwari and Hooghly. Area covered by these catchments from latitude 22° N to 25° N and longitude from 85.8° E to 88.7° E. The study area covers 25 districts in Jharkhand and Gangetic West Bengal. Upper part of these areas is Hilly area and part of Chotanagpur plateau and lower part is plain land.

1.4. *Ajoy basin*

The river Ajoy originates from the Santhalpargana hills near Deoghar in Jharkhand and it flows through Deoghar and Jamtara districts of Jharkhand and then through Birbhum/Burdwan districts of West Bengal before emptying itself into river Bhagirathi just upstream of Katwa town in the district of Burdwan. The total length of the river is about 290 km of which the lower reach of about 142 km is in West Bengal. The principal tributaries of the river are the Parthro, Jayanti and Hinglow. The monthly average rainfall in this basin is 66.48 mm.

The total catchment area of the river is about 5960 sq. km of which about 3060 sq. km lies in the hilly areas of the Jharkhand and the remaining area of 2900 sq. km is in the plains of West Bengal where it causes floods in the district of Birbhum and Burdwan. Large areas of these districts suffer from inundation whenever floods of Ajoy synchronize with those of the Mayurakshi, Pagla, Bansloi and Bhagirathi.

1.5. *Kansabati basin*

River Kansabati, also known as Kasai in upstream reaches, originates from Bhaski hill at an elevation of 725 m in the Purulia upland about 12 km north of Jhalda town in West Bengal. The river flows generally in a south easterly direction and discharges into river Hooghly. The principal tributary is river Kumary. The total length of the river Kansabati is approximately 370 km.

The river drains an area of about 9850 sq. km. In the lower reach, it bifurcates into the Palasikhal (Old Cossye) which outfalls into Rupnarayan river while the other branch called New Cossye forms the Haldi. It causes floods in the alluvial plains of Mednipur District. Average annual rainfall of Kansabatibasin is 1120 mm.

1.6. *Mayurakshi basin*

The river Mayurakshi originates from Trikut hill at an altitude of 753 m in Deoghar district of Jharkhand. It flows through the district of Dumka in Jharkhand and Birbhum in West Bengal before it weds in the Bhagirathi. On its way, it is joined by the Dwaraka and Brahmani rivers. The other tributaries of the river are Siddheswari, Bakreswar and Kopai. In the lower reach, several spill channels such as the Manikornika, Kanamore, Gambhari etc. offshoot from the Mayurkashi and then discharge into the lower pockets of Hijal Beel in Murshidabad. From the Beel, the river Babla starts its journey finally draining into the river Bhagirathi. The total length of Mayurakshi is about 203 km of which 90 km is in Jharkhand.

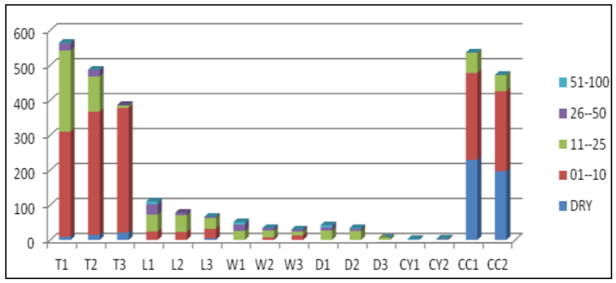

Fig. 2. Synoptic systems and its contribution for standard ranges of QPF over Mayurakshi catchment

The catchment basin area of the river is about 11655 sq. km covering parts of Jharkhand and West Bengal. The river causes floods in the plains of Birbhum and Murshidabad district. Average monthly rainfall (May-October) of the catchment is 160.91 mm.

2. Data and methodology

Daily rainfall Data of 84 observatories for the period of 1990 to 2015 has been collected from Regional Meteorological Centre, Kolkata of India Meteorological Department and location of these rainguage stations is depicted in Figs. (1&5). Name of different stations in different catchments are mentioned below.

(*i*) Barakar catchment (6294 sq. km) has 16 part time observatories, namely Maithon, Jamua, Tuladih, Nandadih, Maheshmunda, Barkatha, Palgang, Dhamwar, Suriya, BarkiSuriya, Parsabad, Hiridih, Kodarma, Tilaiya, Barhi and Padma.

(*ii*) Damodar Catchment (11,524 sq. km) has 28 part time observatories namely Panchet, Nawadih, Chandrapura, Peterbar, Mandu, Konar, Hazaribagh, Ramgarh, Bhurkunda, Barkagaon, Hendigir, Khalari, Mandar, Sindri, Chandwa, Rajgang, Rajdha, Bishungarh, Daroo, Chandankiary, Burmu,Shillaichak, Phusro, Dhanbad, Putki, Dumri, Gansadih and Bokaro.

(*iii*) Lower Valley (4197 sq. km) has 3 part time observatories at Asansol, Luchipur and Durgapur.

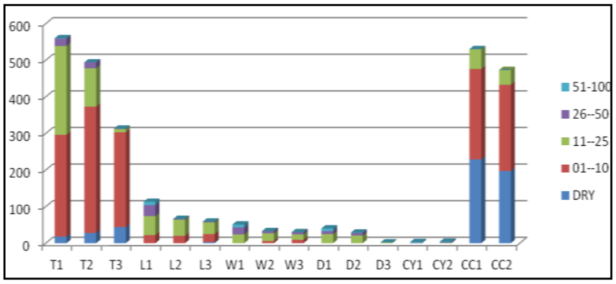

Fig. 3. Synoptic systems and its contribution for standard ranges of QPF over Ajoy catchment

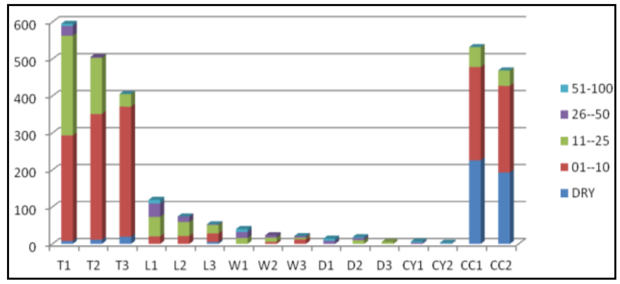

Fig. 4. Synoptic systems and its contribution for standard ranges of QPF over Kansabati catchment

(*iv*) Mayurakshi catchment (11656 sq. km) has 20 stations namely Tantloi, Tilpara, Suri, Nalhati, Rajnagar, Rampurhat, Labpur, Murarai, Narayanpur, Salar, Kandi, Khusiary, Maharo, Massenjore, Jormundi, Ramgarh, Barmasia, Deoghar, Ghormara and T. K. Gram.

(*v*) Ajoy catchment (5960 sq. km) has 7 stations *viz.*, Geropara, Mongalkote, Mankar, Sikatia, Jamtara, Madhupur and Jagadishpur.

(*vi*) Kansabati Catchment (9850 sq. km) has 10 stations *viz.*, D. P. Ghat, Mohanpur, Kharidwar, Tusuma, Phuberia, Kansabati Dam, Midnapur, Lalgarh, Simulia and Purihansa.

In this study the daily AAPs for monsoon seasons of past twenty five years (1990-2014) have been considered for six river catchments of Gangetic West Bengal and adjoining Jharkhand *viz.*, Kansabati, Ajoy and Mayurakshi catchments (map shown in Fig. 1) and Damodar, Barakar catchments and Lower Valley (map shown in Fig. 5). After generation of isohyets based on realised rain fall data of each catchment the AAPs have been calculated by analysing the isohyets drawn over the maps (Scale : 1 cm = 10 km) for each day during monsoon season 15th June to 30th September. The rain fall data are taken of about 84 stations distributed over the catchments and neighbourhood have been used for an authentic isohyetal analysis. Computation of AAPs has been done by weighting the average rainfall between contours by the area between contours (area calculated using digital planimeter), totalling these values and dividing by the total area.

The associated Synoptic features have been studied from analysed weather charts (0000/0300 UTC) both surface and upper air and summary of synoptic features issued from Area Cyclone Warning Centre (ACWC), Kolkata. The most prominent Synoptic situation of the day has been considered and on the basis of its influence monsoon rainfalls over the catchments have been studied.

The Six most important synoptic systems namely trough on sea level chart (T), low pressure area (L), well marked low pressure area (W), depression/ deep depression (D), Cyclonic Circulation (CC) and Cyclonic Storm (CY) have been chosen for this study. The location of the systems with respect to the catchment is another important factor for amount of precipitation and as such location have been classified into three categories for systems T, L, W and D each and two categories for the systems CC and CY mentioned above. Thus in total there are 16 (4 × 3 + 2 × 2) categories of synoptic systems have been studied and named as T1, T2, T3, L1, L2, L3, W1, W2, W3, D1, D2, D3, CC1, CC2, CY1 and CY2. Details of the symbols are mentioned below.

T1 : Trough line over the catchment that is normal position,

T2 : Trough line with in 200 km South or North of the catchment,

T3 : Trough line more than 200 km South or North of the catchment,

L1 : Low pressure area over the catchment that is normal position,

L2 : Low pressure area within 200 km South or North of the catchment,

L3 : Low pressure area above 200 km South or North of the catchment,

W1 : Well marked low pressure area over the catchment that is normal position,

W2 : Well marked low pressure area within 200 km South or North of the catchment,

W3 : Well marked low pressure area more than 200 km South or North the catchment,

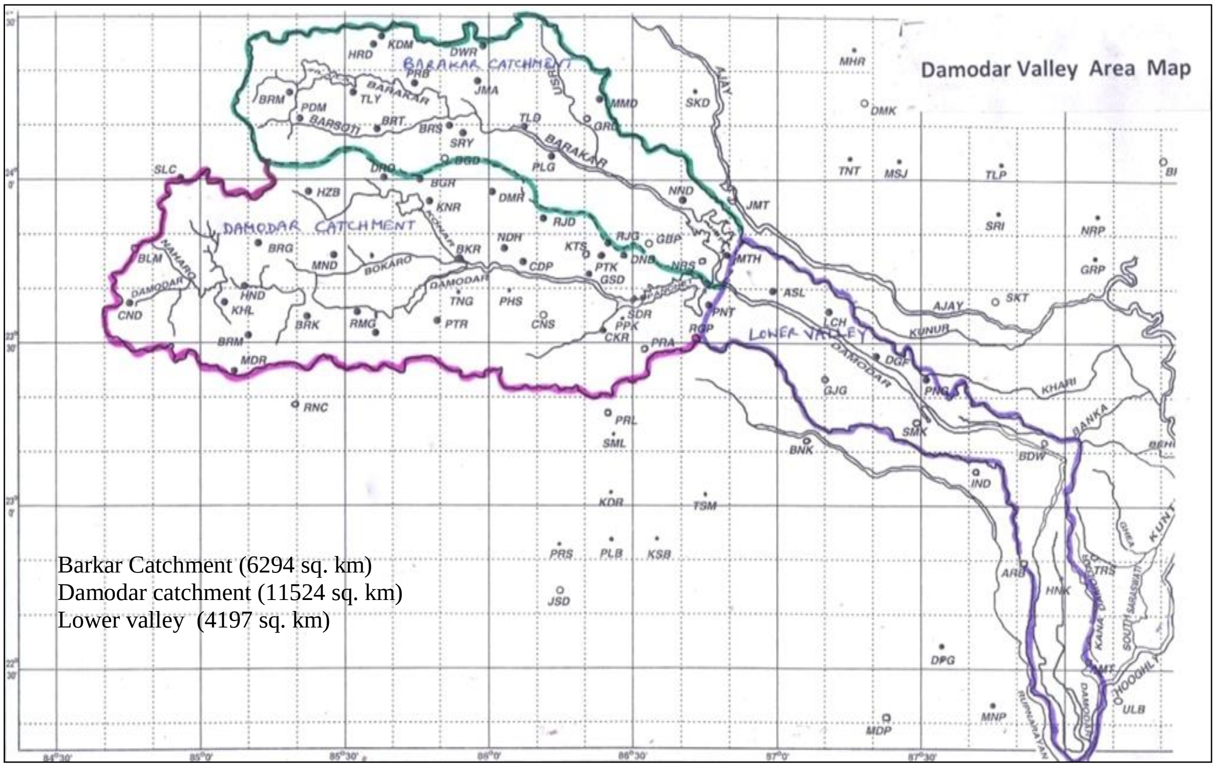

Fig. 5. Map of Damodar valley area and position of rain gauge stations

TABLE 1

Position of different synoptic systems

Synoptic systems	Position of the synoptic system
For Damodar valley area	
TI, L1, W1, D1, CC1	Over catchments
T2, L2, W2, D2, CC2	North Odisha, South Bihar, South Sub Himalayan West Bengal
T3, L3, D3, W3	Central & South Odisha, South GWB, Chattisgarh, East Madhya Pradesh, East Uttar Pradesh, East Bay of Bengal
CY1	East, North and North East Bay of Bengal, Odisha, Chattisgarh, Bihar
CY2	Uttar Pradesh, Madhya Pradesh, West and Central Bay of Bengal
For Kansabati, Ajoy, Mayurakshi catchments	
TI, L1, W1, D1, CC1	Over catchments
T2, L2, W2, D2, CC2	Central Odisha, East Jharkhand, Sub Himalayan West Bengal
T3, L3, D3, W3	South Odisha, West Jharkhand, West Bangladesh, East and North Bay of Bengal, South Odisha
CY1	Central and West Bay of Bengal, Bihar, Jharkhand, Chattisgarh
CY2	Uttar Pradesh, Madhya Pradesh, Southwest Bay of Bengal

TABLE 2

Verification of model in 2015 for six catchments

Synoptic systems	Range	Kansabati catchment		Ajoy catchment		Mayurakshi catchment		%age
		Correct	Incorrect	Correct	Incorrect	Correct	Incorrect	
Trough	11-25	30	05	29	05	31	05	85.3
	26-50	02	00	01	00	01	01	80.0
	>50	-	-	-	-	-	-	-
Low pressure	11-25	04	02	05	02	04	02	76.4
	26-50	03	01	02	01	02	01	63.6
	>50	01	00	01	00	01	00	100
Well marked Low	11-25	02	01	02	01	02	01	75.0
	26-50	02	01	02	01	02	01	62.5
	>50	01	00	01	01	01	00	75.0
Depression	11-25	-	-	-	-	-	-	-
	26-50	01	00	01	00	01	01	75.0
	>50	02	01	01	01	01	01	66.6
Cyclonic storm	11-25	-	-	-	-	-	-	-
	26-50	01	00	01	01	01	00	75.0
	>50	02	00	02	00	02	00	100
Cyclonic circulation	11-25	01	01	01	01	01	00	75.0
	26-50	-	-	-	-	-	-	-
	>50	-	-	-	-	-	-	-
	Total	52	12	49	14	50	13	
	Percentage	81.2	18.8	77.7	22.3	79.2	20.8	-
Synoptic systems	Range	Damodar catchment		Barakar catchment		Lower valley		%age
		Correct	Incorrect	Correct	Incorrect	Correct	Incorrect	
Trough	11-25	25	04	24	05	24	03	84.8
	26-50	01	00	01	00	01	01	75.0
	>50	-	-	-	-	-	-	-
Low pressure	11-25	06	02	05	02	06	01	78.2
	26-50	02	01	02	01	02	01	66.7
	>50	00	00	00	00	00	00	-
Well marked Low	11-25	03	01	03	01	03	00	81.8
	26-50	02	01	02	01	02	01	66.7
	>50	00	00	00	00	00	00	-
Depression	11-25	-	-	-	-	-	-	-
	26-50	01	00	01	00	01	01	75.0
	>50	01	00	01	00	01	01	66.6
Cyclonic storm	11-25	-	-	-	-	-	-	-
	26-50	-	-	-	-	-	-	-
	>50	-	-	-	-	-	-	-
Cyclonic circulation	11-25	01	01	01	01	01	00	75.0
	26-50	-	-	-	-	-	-	-
	>50	-	-	-	-	-	-	-
	Total	42	10	40	11	41	9	80.4
	Percentage	80.8	19.2	78.4	21.6	82.0	18.0	-

TABLE 3

Verification of quantitative precipitation forecast using synoptic analogue method during monsoon season in 2015 over Damodar, Barakar catchments and Lower valley (Deterministic Forecast Verification)

S. No.	Different skill score	Damodar catchment			Barakar catchment			Lower valley		
		A.A.P. ranges in mm			A.A.P. ranges in mm			A.A.P. ranges in mm		
		11-25	26-50	Average	11-25	26-50	Average	11-25	26-50	Average
1.	Probability of Detection (POD)	0.92	0.75	0.84	0.86	0.63	0.75	0.87	0.67	0.77
2.	False Alarm Rate (FAR)	0.16	0.25	0.21	0.21	0.29	0.25	0.13	0.40	0.26
3.	Missing Rate (MR)	0.08	0.25	0.17	0.13	0.37	0.20	0.13	0.33	0.23
4.	Correct Non Occurrence (C-NON)	0.93	0.98	0.95	0.92	0.98	0.95	0.95	0.97	0.96
5.	Critical Success Index (CSI)	0.78	0.60	0.69	0.70	0.50	0.60	0.77	0.46	0.61
6.	Biased for occurrence (BIAS)	1.10	1.00	1.05	1.10	0.87	0.98	1.00	1.11	1.05
7.	Percentage Correct (PC)	81.3	75.4	78.3	80.6	81.6	81.1	82.1	79.6	80.8
8.	True Skill Score (TSS)	0.85	0.73	0.79	0.78	0.62	0.70	0.82	0.64	0.73
9.	Heidke Skill Score (HSS)	0.71	0.74	0.73	0.76	0.65	0.71	0.83	0.61	0.72

TABLE 4

Verification of quantitative precipitation forecast using synoptic analogue method during monsoon season in 2015 over Mayurakshi, Ajoy and Kansabati catchments (Deterministic forecast verification)

S. No.	Different skill score	Mayurakshi catchment			Ajoy catchment			Kansabati catchment		
		A.A.P. ranges in mm			A.A.P. ranges in mm			A.A.P. ranges in mm		
		11-25	26-50	Average	11-25	26-50	Average	11-25	26-50	Average
1.	Probability of Detection (POD)	0.84	0.70	0.77	0.70	0.86	0.78	0.89	0.67	0.78
2.	False Alarm Rate (FAR)	0.17	0.30	0.23	0.21	0.30	0.26	0.13	0.40	0.26
3.	Missing Rate (MR)	0.15	0.30	0.23	0.14	0.30	0.22	0.10	0.33	0.22
4.	Correct Non Occurrence (C-NON)	0.93	0.97	0.95	0.91	0.97	0.94	0.95	0.97	0.96
5.	Critical Success Index (CSI)	0.72	0.54	0.63	0.70	0.54	0.62	0.79	0.47	0.63
6.	Biased for occurrence (BIAS)	1.02	1.00	1.01	1.09	1.00	1.05	1.02	1.11	1.07
7.	Percentage Correct (PC)	82.6	70.0	76.3	78.7	70.1	74.4	87.1	60.2	76.7
8.	True Skill Score (TSS)	0.78	0.68	0.73	0.77	0.68	0.73	0.85	0.64	0.75
9.	Heidke Skill Score (HSS)	0.77	0.59	0.68	0.75	0.59	0.67	0.87	0.61	0.74

DI : Depression over the catchment that is normal position,

D2 : Depression with in 200 km South or North of the catchment,

D3 : Depression more than 200 km South or North of the catchment.

CYI : Cyclone with in 500 km South or North of the catchment,

CY2 : Cyclone more than 500 km South or North from the catchment,

CC1 : Cyclonic circulation over the catchment,

TABLE 5

Impact of different synoptic systems over Mayurakshi, Ajoy and Kansabati catchments in the distribution of rain falls based on the data from 1990-2014

Synoptic Situation	A.A.P. (mm)		Frequency of A.A.P. in different ranges in mm (% frequency)						Total	F.C. range
	Mean	S.D.	DRY (00)	01-10	11-25	26-50	51-100	Highest observed range		
Mayaurakshi catchment										
T1	6.2	1.7	09(1.6)	301(53.4)	232(41.1)	21(3.7)	01(0.2)	54.5	564	01-10
T2	4.3	2.9	15(3.1)	352(72.2)	101(20.8)	19 (3.9)	0	34.2	487	01-10
T3	4.1	2.2	21(5.4)	357(92.5)	07 (1.8)	01(0.3)	0	28.3	386	01-10
L1	13.3	4.9	0	24(21.8)	49(44.5)	29(26.4)	08 (7.3)	78.3	110	11-25
L2	12.4	5.4	0	23(29.5)	48(61.6)	07(8.9)	0	46.3	78	11-25
L3	11.6	5.1	04(6.1)	28(42.4)	31(46.9)	03(4.6)	0	36.4	66	11-25
W1	18.4	6.7	0	0	26(50.9)	18(35.3)	07 (13.8)	80.4	51	11-25
W2	16.9	5.9	0	7(20.6)	20(58.8)	07(20.6)	0	41.3	34	11-25
W3	14.9	4.9	0	13(43.3)	11(36.7)	6(20)	0	38.2	30	11-25
D1	28.2	8.6	0	0	27(64.3)	09(21.4)	06(14.3)	83.7	42	26-50
D2	26.2	9.1	0	0	26(76.5)	06(17.6)	02(5.9)	63.2	34	26-50
D3	23.9	8.1	0	0	06	0	0	24.6	06	11-25
CY1	38.2	8.8	0	0	0	01	02	97.8	03	26-50
CY2	29.3	8.1	0	0	01	02	01	92.6	04	26-50
CC1	5.3	2.3	229	249	58	0	0	23.6	536	01-10
CC2	3.9	2.1	197	229	46	0	0	21.6	472	01-10
Ajoy catchment										
T1	5.2	2.4	18(3.2)	278(49.6)	243(43.4)	20(3.6)	01(0.2)	55.8	560	01-10
T2	4.7	1.8	28 (5.7)	345(69.8)	105(21.3)	16(3.2)	0	42.8	494	01-10
T3	3.6	2.1	44 (10.7)	359(86.9)	09(2.2)	01(0.2)	0	32.9	413	01-10
L1	13.4	4.8	0	22(19.5)	52(46.0)	30(26.5)	09(8)	75.6	113	11-25
L2	12.2	5.0	0	20(28.9)	44(63.9)	05(7.2)	0	45.9	69	11-25
L3	11.5	5.7	3(5.1)	22(37.3)	32(54.2)	02(3.4)	0	.40.4	59	11-25
W1	18.2	6.6	0	0	24(47.1)	19(37.3)	08(15.6)	83.7	51	11-25
W2	17.2	5.9	0	06(18.2)	21(63.6)	06(18.2)	0	46.7	33	11-25
W3	14.7	5.1	0	09(30)	15(50)	06(20)	0	36.8	30	11-25
D1	27.2	8.7	0	0	25(62.5)	08(20)	07(17.5)	85.2	40	26-50
D2	25.8	7.3	0	0	21(72.4)	07(24.1)	01(3.5)	73.4	29	26-50
D3	22.9	6.8	0	0	02(100)	0	0	24.3	02	11-25
CY1	38.2	8.6	0	0	0	01(33.3)	02(66.7)	95.3	03	26-50
CY2	29.3	7.3	0	0	01(25)	02(50)	01(25)	90.4	04	26-50
CC1	3.9	2.6	229(44.4)	247(47.9)	40(7.7)	0	0	22.8	516	01-10
CC2	3.6	1.9	197(40.4)	236(48.5)	54(11.1)	0	0	20.7	487	01-10
Kanshabati catchment										
T1	5.6	1.6	08(1.4)	284(48.5)	270(45.7)	26(4.4)	6(1)	56.2	587	01-10
T2	4.2	2.1	11(2.2)	340(67.3)	152(30.1)	02(0.4)	0	43.1	505	01-10
T3	3.8	1.8	19(4.9)	351(90.7)	17(4.4)	0	0	24.4	387	01-10
L1	12.8	4.6	0	20(16.8)	53(44.5)	36(30.3)	10(8.4)	77.2	119	11-25
L2	11.6	5.2	0	21(28.4)	38(51.3)	15(20.3)	0	46.3	74	11-25
L3	11.2	5.5	5(6.7)	45(60)	23(30.7)	2(2.6)	0	41.0	75	11-25
W1	17.4	6.4	0	0	16(40)	16(40)	8(20)	84.2	40	11-25
W2	16.6	6.8	0	10(35.7)	12(42.9)	6(21.4)	0	46.9	28	11-25
W3	15.3	5.4	0	24(72.7)	5(15.1)	4(12.2)	0	37.3	33	11-25
D1	26.8	8.3	0	0	0	8(57.2)	6(42.8)	86.2	14	26-50
D2	25.6	8.6	0	0	10(55.5)	6(33.3)	2(11.2)	74.1	18	26-50
D3	24.2	7.9	0	0	5(100)	0	0	24.1	05	11-25
CY1	36.2	9.1	0	0	0	3(50)	3(50)	96.4	06	26-50
CY2	28.4	8.4	0	0	0	1(33.3)	2(66.7)	91.2	03	26-50
CC1	4.8	2.7	227(42.4)	252(47.1)	54(10.5)	0	0	21.9	535	01-10
CC2	3.8	1.8	198(41.8)	234(49.4)	42(8.8)	0	0	20.4	474	01-10

*There is no frequency in the range >100 mm

TABLE 6

Impact of different synoptic systems over Damodar, Barakar catchments and lower valley of D. V. area in the distribution of rain falls based on the data from 1990-2014

Synoptic Situation	A.A.P. (mm)		Frequency of A.A.P. in different ranges in mm (% frequency)						Total	F.C. range
	Mean	S. D.	DRY (00)	01-10	11-25	26-50	51-100	Highest observed range		
Damodar catchment										
T1	5.3	2.0	20(3.1)	321(50.1)	275(42.9)	23(3.6)	02(0.3)	57.3	641	01-10
T2	4.7	2.7	31(5.3)	402(68.8)	149(25.5)	02(0.4)	0	44.8	584	01-10
T3	3.9	2.2	42(8.9)	402(84.9)	29(6.2)	0	0	23.7	473	01-10
L1	13.9	4.7	00	32(24.6)	59(45)	39(29.9)	11(8.5)	78.2	131	11-25
L2	12.8	5.3	00	38(41.3)	39(42.4)	15(16.3)	0	46.8	92	11-25
L3	11.7	4.6	07(9.6)	42(57.5)	22(30.1)	02(2.8)	0	41.3	73	11-25
W1	18.6	5.8	00	00	20(42.5)	18(38.3)	09(19.2)	86.2	47	11-25
W2	16.1	5.2	00	12(37.5)	14(43.7)	06(18.8)	0	47.2	32	11-25
W3	14.9	4.7	00	18(64.3)	06(21.4)	04(14.3)	0	37.1	28	11-25
D1	27.2	7.1	00	00	0	11(57.9)	08(42.1)	87.2	19	26-50
D2	26.2	8.3	00	00	13(65)	05(25)	02(10)	73.8	20	26-50
D3	23.8	9.1	00	00	05(100)	0	0	25.2	05	11-25
CY1	40.8	10.3	00	00	0	04(50)	04(50)	97.6	08	26-50
CY2	29.6	9.8	00	00	0	01(33.3)	02(66.7)	91.8	03	26-50
CC1	4.3	2.9	376(47.3)	368(46.3)	50(6.4)	0	0	23.5	794	01-10
CC2	3.2	2.3	291(40.3)	390(54)	41(5.7)	0	0	21.1	722	01-10
Barakar Catchment										
T1	5.0	1.7	17(2.6)	315(48.9)	282(43.8)	29(4.5)	01(0.2)	58.2	644	01-10
T2	4.4	2.5	33(5.8)	396(68.9)	142(24.8)	03(0.5)	00	45.1	574	01-10
T3	3.3	2.4	47(9.9)	397(83.7)	30(6.4)	0	0	24.3	474	01-10
L1	13.7	5.3	00	38(26.6)	56(39.2)	37(25.8)	12(8.4)	79.2	143	11-25
L2	12.4	4.9	00	40(43)	36(38.7)	17(18.3)	00	47.2	93	11-25
L3	11.9	4.7	10(13.9)	40(55.6)	21(29.3)	01(0.2)	0	41.4	72	11-25
W1	19.1	6.2	00	01(2.2)	18(40)	17(37.8)	09(20)	87.4	45	11-25
W2	16.4	5.8	00	16(51.6)	10(32.2)	05(16.2)	0	46.3	31	11-25
W3	14.2	5.2	00	17(65.4)	06(23)	03(11.6)	0	37.6	26	11-25
D1	28.1	6.3	00	00	0	09(52.9)	08(47.1)	87.6	17	26-50
D2	27.0	7.9	00	00	11(61.1)	05(27.8)	02(11.1)	74.2	18	26-50
D3	24.0	8.4	00	00	04(100)	00	0	24.6	04	11-25
CY1	41.3	11.1	00	00	0	04(50)	04(50)	98.2	08	26-50
CY2	29.7	10.3	00	00	0	01(33.3)	02(66.7)	90.8	03	26-50
CC1	5.1	3.2	377(47.6)	359(44.9)	58(7.5)	0	0	24.2	794	01-10
CC2	3.7	1.8	392(54.1)	287(39.4)	47(6.5)	0	0	22.0	726	01-10
Lower Valley										
T1	6.1	2.2	10(1.5)	362(52.8)	285(41.5)	26(3.8)	03(0.4)	58.1	686	01-10
T2	4.3	1.9	15(2.9)	342(66.7)	154(30)	02(0.4)	0	45.2	513	01-10
T3	3.7	2.4	21(5.1)	362(87.6)	30(7.3)	0	0	22.3	413	01-10
L1	13.7	5.5	0	25(18.5)	62(45.9)	36(26.7)	12(8.9)	79.5	135	11-25
L2	12.4	6.4	0	27(33.7)	38(47.5)	15(18.8)	0	47.3	80	11-25
L3	11.3	4.7	8(10.2)	48(61.6)	20(25.6)	02(2.6)	0	41.8	78	11-25
W1	18.9	6.9	0	0	20(43.4)	16(34.8)	10(21.8)	87.4	46	11-25
W2	17.4	7.5	0	15(48.5)	10(32.2)	06(19.3)	0	47.3	31	11-25
W3	14.8	5.2	0	28(71.8)	07(17.9)	04(10.3)	0	37.6	39	11-25
D1	30.2	8.4	0	0	0	08(57.1)	06(42.9)	88.4	14	26-50
D2	28.2	9.1	0	0	12(60)	06(30)	02(10)	75.2	20	26-50
D3	23.8	6.9	0	0	04(100)	0	0	24.3	04	11-25
CY1	39.2	7.6	0	0	0	03(37.5)	05(62.5)	98.6	08	26-50
CY2	27.9	7.8	0	0	0	01(33.3)	02(66.7)	92.3	03	26-50
CC1	4.7	2.3	379(47.1))	376(46.7)	50(6.2)	0	0	23.9	805	01-10
CC2	3.9	2.0	404(50.7(	352(44.2)	41(5.1)	0	0	20.8	797	01-10

*There is no frequency in the range >100 mm

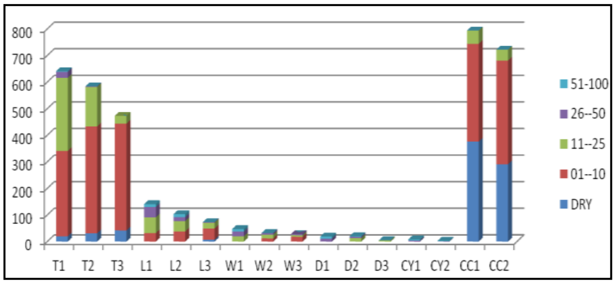

Fig. 6. Synoptic systems and its contribution for standard ranges of QPF over Damodar catchment

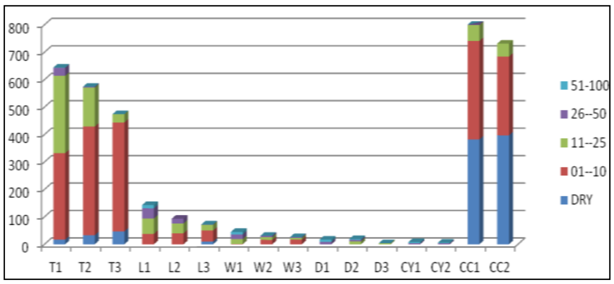

Fig. 7. Synoptic systems and its contribution for standard ranges of QPF over Barakar catchment

CC2 : Cyclonic circulation within 200 km South or North of the catchment.

All synoptic systems have positive effect due to their movement towards these catchments.

3. Results and discussion

3.1. *Data analysis and synoptic analogue model development*

The synoptic features of each day as per 0300/ 1200 UTC Weather Charts, Cloud imageries and inferences have been noted from ACWC Kolkata have been recorded. Prominent system/systems over and nearby the catchments area are considered. The realised AAPs as per rainfall data recorded at 0300 UTC of next day have been arranged as per categories mentioned above. Issuing QPFs and realised AAP and also associated Synoptic features are arranged in Tables (5&6) for catchments Kansabati, Ajoy, Mayurakshi, Damodar, Barakar and Lower Valley respectively. The analysed results are shown in composite bar diagrams (Fig. 2, Fig. 3, Fig. 4, Fig. 6, Fig. 7 and Fig. 8). As per characteristics of southwest monsoon the same synoptic system causes different AAPs in different months of the monsoon.

For synoptic feature T1 the most favourable QPF range is 11-25 mm in three catchments. Percentages of

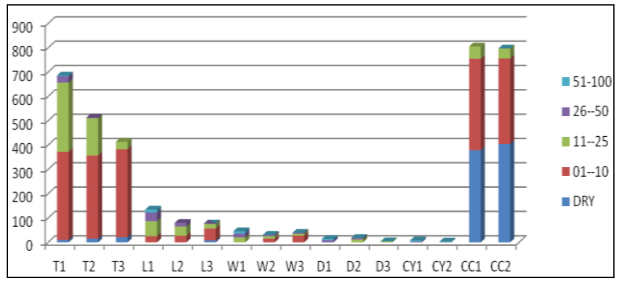

Fig. 8. Synoptic systems and its contribution for standard ranges of QPF over Lower valley

correct forecast in the range 11-25 mm for synoptic system T1 are 39%, 38%, 39%, 38%, 36%, 33% at Damodar, Barakar, Lower Valley, Kansabati, Ajoy, Mayurakshi catchments respectively. For Synoptic feature L1 the most favourable QPF range is 26-50 mm in the six catchments. Percentages of correct forecast in the range 26-50 mm are 30%, 32%, 31%, 30%, 24% and 23% at Damodar, Barakar, Lower Valley, Kansabati, Ajoy, Mayurakshi catchment respectively. No definite synoptic feature or synoptic features is or are well correlated with QPF ranges >50 mm. But it is found most of the rainstorm occurred due to synoptic situations W1, D1, CY1 and sometimes for L1. For same synoptic systems in different periods of monsoon months AAP are different due to active and vigorous monsoon conditions and different coexist synoptic features and also upper air cyclonic circulations. Details have mentioned in the Tables (5&6) including percentage of correct forecast. Skill Scores in 51-100 mm and above are not computed because rain fall in these ranges occurred a few days and heavy rainfall observed at isolated places and also in a few places due to synoptic systems L1, L2, L3, D1, D2, D3 etc. mainly in the range 26-50 mm.

From the results of this study a Synoptic Analogue Model (SAM) can be developed for issue of QPF over these catchments. It is observed that for a particular catchment if the main synoptic system is categorically specified then the probability of occurrence of AAP is high and accurate. Moreover if other details of synoptic features such as upper air circulations associated with trough, low, well marked low, depression systems and also their movements and location of the systems are studied correctly which predict the amount of precipitation in the most probable range of realised rain fall values and issue better QPF in a definite range.

The result of the study of QPF for six catchments using synoptic Analogue Method (SAM) for the period 1990-2014 are summarised in the Table (5&6) following points may be inferred.

(*i*) Total 16 (sixteen) types of synoptic systems have been mentioned during monsoon period 1990-2014.

(*ii*) Out of 2903 days during 1990-2014 of monsoon months (June to September) in Mayurakshi, Ajoy and Kansabati catchments it is found that AAP were in the range of 01-10 mm and below for 2048 days (70.6%) in Mayurakshi catchment, 2063 days (71.1%) in Ajoy catchment and 2049 days (70.5%) in Kansabati catchment. 11-25 mm and above for 855 days (29.4%) in Mayurakshi catchment, 840 days (28.9%) in Ajoy catchment and 854 days (29.5%) in Kansabati catchment. Important synoptic systems which were favourable for AAP in the range 11-25 mm and above were Trough over the catchment (T1), low pressure area over the catchment (L1), adjoining Jharkhand and Bihar (L2), Bay of Bengal and East Uttar Pradesh (L3), Depression over the catchment (D1), Adjoining Jharkhand and Bihar (D2), Bay of Bengal (D3). Percentage of contributions have been mentioned in Table 5 and graphically shown in Figs. (2-4).

(*iii*) Out of 3672 days during 1990-2014 of monsoon months (June to September) and October in Damodar catchment, Barakar catchment and Lower Valley it is found that AAP were in the range of 01-10 mm and below for 2792 (76%) days in Damodar catchment, 2783 (75.8%) in Barakar catchment and 2774 (75.5%) in Lower Valley. AAP in the range of 11-25 mm and above for 880 days (24%) in Damodar catchment, 889 days (24.2%) in Barakar catchment and 898 days (24.5%) in Lower Valley, Important synoptic systems which were favourable for AAP in the range 11-25 mm and above were Trough over the catchment (T1), Low pressure are over the catchment (L1), adjoining Bihar, Gangetic West Bengal (L2), East Uttar Pradesh, East Madhya Pradesh and Chhattisgarh (L3), Depression over the catchment (D1), adjoining Bihar East Uttar Pradesh, Gangetic West Bengal (D2), Bay of Bengal (D3) and percentage of contributions for each synoptic systems have been mentioned in Table 6 and graphically shown in Figs. (6-8).

(*iv*) Based on the study during the period 1990-2014 monsoon season only six (6) types of synoptic systems have been identified for which computed mean AAP lies in the range of 11-25 for synoptic situations, Low pressure and Well marked low pressure area over the catchment (L1,W1), Low pressure and Well marked low pressure area over Jharkhand/Gangetic West Bengal and Bihar (L2, W2), Low pressure and Well marked low pressure area over East Uttar Pradesh, Odisha, North Bay and North East Bay of Bengal (L3 and W3). Mean AAP in the range 26-50 mm and above for synoptic situations, Depression and Cyclonic storm over the catchment (D1, CY1, Bihar, East Madhya Pradesh, East Uttar Pradesh, Chhattisgarh, Odisha, Bihar and Bay of Bengal etc. (D2, CY1, CY2).

3.2. *Verification of the model*

The model has been tested for issue of QPF in the monsoon season 2015 and the result is shown in the Table 2. It is found that considering all categories of synoptic features mentioned above the QPF yields 81.2%, 77.7%, 79.2%, 80.8%, 78.4% and 82.0% correct at Kansabati, Ajoy, Mayurakshi, Damodar, Barakar catchments and Lower Valley respectively and 18.8%, 22.3%, 20.8%, 19.2%, 21.6% and 18.0% are incorrect (Table 2). However, when details of the other coexist synoptic features were considered together the accuracy would improve further. Result of the verification of QPF using 6×6 and 2×2 contingencies table are presented in Table (3 & 4). Heidke Skill Score (HSS) have been found for Damodar Catchment 0.71 and 0.74 (avg 0.73), Barakar Catchment 0.76 and 0.65 (avg 0.71), Lower Valley 0.83 and 0.61 (avg 0.72), Mayurakshi Catchment 0.77 and 0.59 (avg 0.68), Ajoy Catchment 0.75 and 0.59 (avg 0.67) and Kansabati Catchment 0.87 and 0.61 (avg 0.74) respectively in ranges 11-25 mm and 26-50 mm. Validation of Quantitative precipitation forecast (QPF) during SouthWest Monsoon season over Damodar, Barakar catchments and Lower Valley area at QPF ranges 11-25 mm, 26-50 mm and 51-100 mm in 2015 is mentioned in Table 3. Validation of QPF during Southwest monsoon season over Mayurakshi, Ajoy and Kansabati catchments at QPF ranges 11-25 mm, 26-50 mm and 51-100 mm is mentioned in Table 4.

4. Conclusions

(*i*) This study and SAM model may be used for issuing QPF for six river Catchments of Gangetic West Bengal and adjoining Jharkhand. It may be helpful for issuing accurate warning during monsoon season and especially during flood situation which may reduce loss of lives and properties.

(*ii*) Flood control of the region depend on the operation of total 8 (eight) dams and one barrage at Durgapur. Correct QPF over these catchments is very important for operation of Dams.

(*iii*) Daily QPF based run off model can be developed to correlate AAP and inflow of these Dams.

(*iv*) Further study and modification of the model is very important for hydrological analysis and economy of the states.

Acknowledgment

The authors are grateful to Dr. S. Bandyopadhyay, DDGM and Shri H. R. Biswas Sc. 'E', RMC Kolkata for encouraging to take up this study.

Disclaimer : The views expressed in this research paper are those of the authors' and do not necessarily reflect the views of the organisation to which they are affiliated.

References

Chakraborty, P. K. and Sen, A. K., 2012, "A Synoptic Analogue model for quantitative precipitation forecast over Damodar Valley area", *Mausam*, **63**, 2, 330-334.

Lal. J., Day, J. S. and Kapoor, K.K., 1983 "Semi -quantitative precipitation forecast for Gomoti catchment by synoptic analogue method", *Mausam*, **34**, 3, 309-312

Raha G. N., Bhattacharjee, K., Joardar, A., Mallik, R., Dutta, M. and Chakraborty, T. K., 2009, "Quantitative Precipitation Forecast (QPF) for Teetsa basin and heavy rain fall warning over Teesta basin and adjoining areas in north Bengal and Sikkim using synoptic analogue method", *Mausam*, **60**, 4, 491-504.

Ram, L. C. and Kaur, S., 2004, "Quantitative precipitation forecasts for upper Yamuna catchment by Synoptic analogue method", *Mausam*, **55**, 3, 508-511.

Ray, K. and Sahu, M. L., 1998, "A synoptic analogue model for QPF of River Sabarmati basin", *Mausam*, **49**, 4, 499-502.