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Exceptional heavy rainfall over Ajoy, Mayurakshi and Kansabati catchments and QPF verification during flood season of September 2009

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सार – पश्चिमी बंगाल और झारखंड राज्य की जलग्रहण क्षेत्र वाली तीन प्रमुख नदियाँ हैं अजय, मयुराक्षी, कंसावती हैं। जहाँ पर सितंबर 2009 माह में बाढ़ मौसम के दौरान लगातार दो दिनों तक बहुत भारी वर्षा हुई। इन जलग्रहण क्षेत्रों में भारी वर्षा के दौरान भारी वर्षा होने और दामोदर घाटी निगम (डी. वी. सी.) जलाशयों से एक साथ छोड़े गए जल से पश्चिमी बंगाल के कुछ जिलों में बाढ़ की स्थिति में बढ़ोतरी हुई है। मौसम चार्टों पर आधारित सिनाप्टिक लक्षणों, उपग्रह के मेघ चित्रों और रेडार के चित्रों का विश्लेषण करने के लिए इन्हे निरूपित किया गया है। 6 और 7 सितंबर 2009 की परिमाणात्मक वर्षण पूर्वानुमान (क्यू. पी. एफ) की जाँच करने के लिए अगले दिन के 0300 यू. टी. सी. पर अभिलेखित की गई वर्षा के अनुसार वास्तविक क्षेत्रीय वर्षा के औसत (ए. ए. पी.) भी प्राप्त किए गए।

ABSTRACT. Ajoy, Mayurakshi, Kansabati are three important river catchments of West Bengal and Jharkhand state, received very heavy rainfall during two consecutive days of flood season in the month of September 2009. The contribution of heavy rainfall & combined discharges from Damodar Valley Corporation (DVC) reservoirs during the period of heavy rainspells over these catchments enhanced flood situation in some districts of West Bengal. The synoptic features based on weather charts, cloud imageries of satellite and radar pictures have been taken to analyse. The realized areal average precipitation (AAP) as per rainfall recorded at 0300 UTC of next day have also been taken to verify the quantitative precipitation forecast (QPF) of 6&7 September 2009.

Key words – Synoptic, Catchments, Quantitative Precipitation Forecast (QPF), Areal Average Precipitation (AAP), UTC.

1. Introduction

Ajoy, Mayurakshi and Kansabati are three important river catchments of Gangetic West Bengal and adjoining Jharkhand. Exceptionally heavy rainfall occurred in these river catchments on 6^{th} and 7^{th} September amounting 15 to 19 cm rainfall in some stations of these catchments. Heavy to very heavy rainfall over these basins during the rainstorm period resulted heavy discharge of water surpassing the carrying capacity of water of these rivers. The water holding capacity of the rivers are also decreased due to siltation in river beds. So the heavy spells of rain over these catchments along with combined discharge from Damodar Valley Corporation (DVC) reservoirs from Maithon over Barokar, Punchet over Damodar river and through Durgapur Barrage caused substantial damage in six districts of Gangetic West Bengal.

The geographical position and geomorphic character of these catchment regions Figs. (1& 2) are prone to flood situation all most every year, specially in the downstream of the river in Gangetic West Bengal (GWB) under heavy rain spell during later part of monsoon season. The hydrometeorology of three river catchments (*Courtesy* : Central Water Commission, Asansol) is given below:

1.1. *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 upstring 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

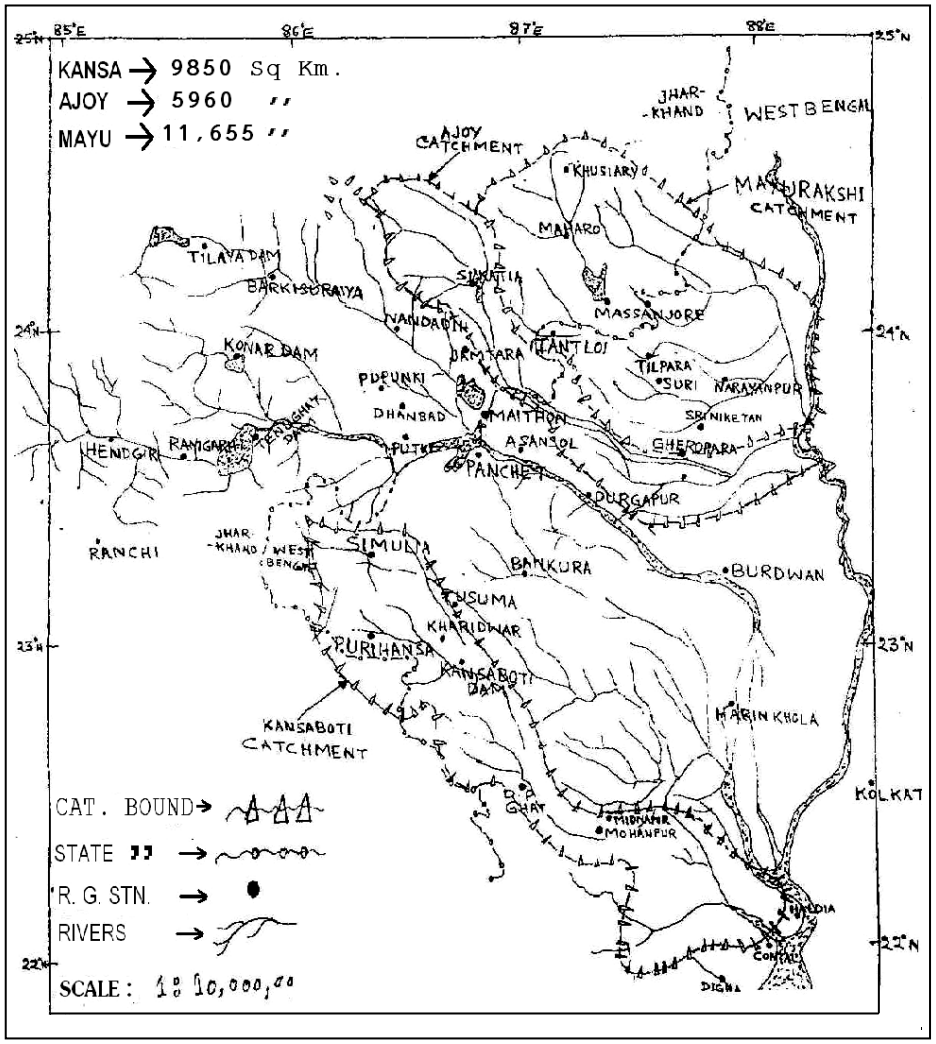

Fig. 1. Locator map of Ajoy, Mayurakshi and Kansabati catchment

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.

1.2 *Kangsabati Basin*

River Kangsabati, 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 southeasterly direction and discharges into river Hoogly. 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 Palasi khal (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 annul rainfall of Kansabati basin is 1120 mm.

1.3. *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,

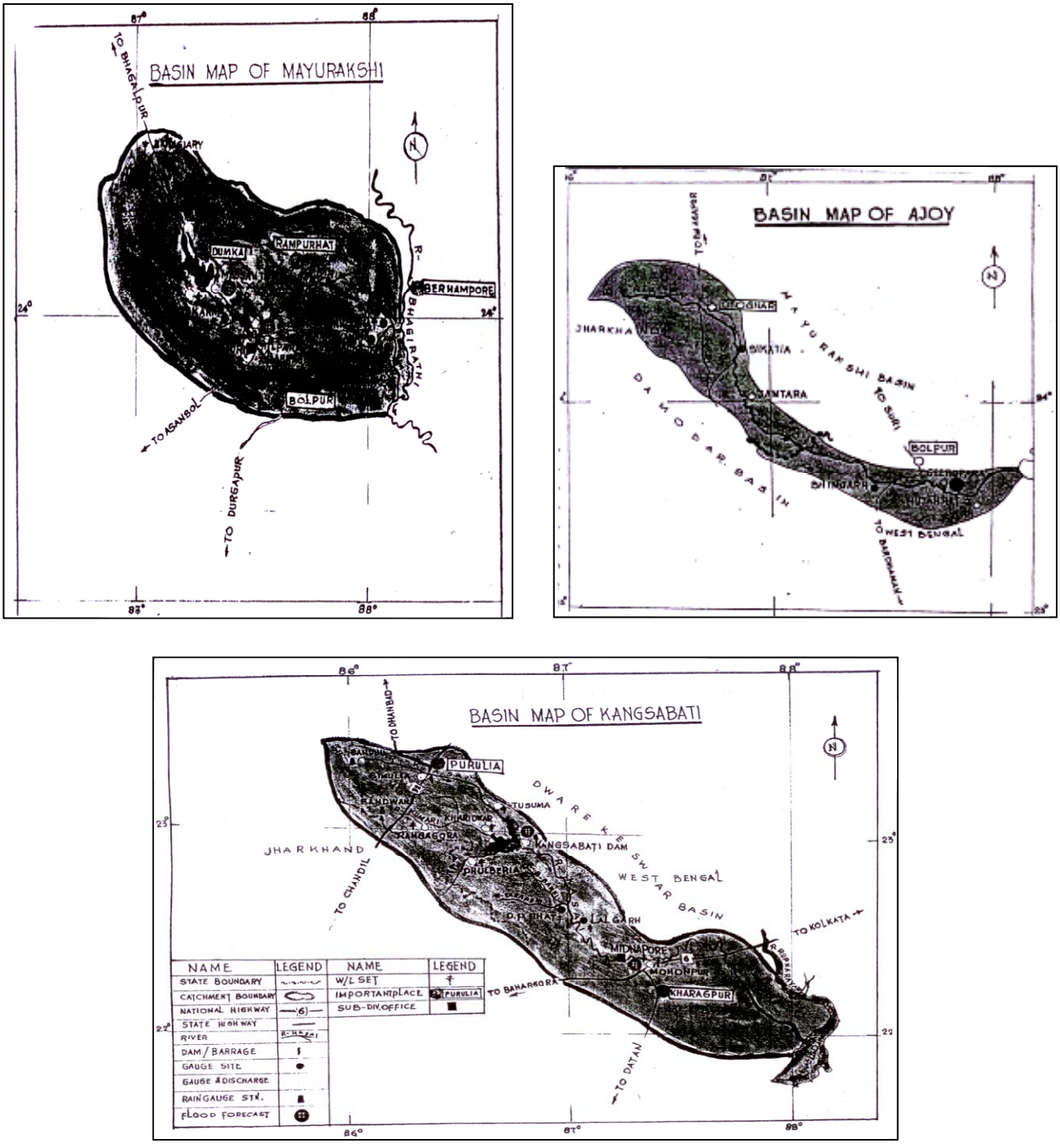

Fig. 2. Three river basin Maps

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.

The catchment basin area of the river is about 11655 sq km covering parts of Jharkhand and West Bengal. The

TABLE 1

Information of raingauge station over Ajoy, Mayurakshi, Kansabati and Damodar catchments

Name of station	Lat. (°N)	Long. (°E)	Height ASL	District	State	Scheme under which installed. (FMO, CWC, IMD, Class-I, II etc.)	Mode of communication. Telephone, Telex, FAX, Tele-gram, email, Sate-llite, TP/WT/ post	Catchment/ Sub-catchment	Data reception
Kharidwar	23.00	86.38	N/A	Purulia	West Bengal	CWC *	CWC R.T	Kangsabati	R*
Purinhansa	23.04	86.22	N/A	Purulia	West Bengal	CWC *	CWC R.T	Kangsabati	R*
Tusuma	23.08	86.43	N/A	Purulia	West Bengal	CWC *	CWC R.T	Kangsabati	R*
Simulia	23.18	86.22	N/A	Purulia	West Bengal	CWC *	CWC R.T	Kangsabati	R*
Phulberia	22.55	86.37	N/A	Purulia	West Bengal	CWC *	CWC R.T	Kangsabati	R*
Mohanpur	22.24	87.21	N/A	Midnapur	West Bengal	CWC *	CWC R.T	Kangsabati	R*
Midnapur	22.25	87.19	N/A	Midnapur	West Bengal	CWC *	CWC R.T	Kangsabati	R*
D.P.Ghat	22.36	87.00	N/A	Midnapur	West Bengal	CWC *	CWC R.T	Kangsabati	R*
KangsabatiDam	22.56	86.48	140.09m	Bankura	West Bengal	CWC *	CWC RT & Post	Kangsabati	R/M*
Gheropara	23.36	87.42	38 m	Birbhum	West Bengal	CWC *	CWC RT & Post	Ajoy	R/M*
Hetampur	23.45	87.20	N/A	Birbhum	West Bengal	FMO	Post	Ajoy	M*
Mankar	23.29	87.33	59 m	Burdwan	West Bengal	FMO	Post	Ajoy	M*
Mangalkote	23.32	87.54	28 m	Burdwan	West Bengal	FMO	Post	Ajoy	M*
Sikatia	24.09	86.15	N/A	Dumka	Jharkhand	CWC *	CWC RT	Ajoy	R/M*
Jamtara	23.57	86.47	183.66m	Jamtara	Jharkhand	FMO	Post	Ajoy	M*
T.K.Gram	24.07	87.00	310m	Dumka	Jharkhand	FMO	Post	Ajoy	M*
Deoghar	24.29	86.42	254m	Deoghar	Jharkhand	FMO	Post	Ajoy	M*
Jagdishpur	24.17	86.30	324m	Deoghar	Jharkhand	FMO	Post	Ajoy	M*
Madhupur	24.16	86.37	256m	Deoghar	Jharkhand	FMO	Post	Ajoy	M*
Narayanpur	23.51	87.53	N/A	Murshidabad	West Bengal	CWC *	CWC RT	Mayurakshi	R*
Salar	23.45	88.07	72m	Murshidabad	West Bengal	FMO	Post	Mayurakshi	M*
Kandi	23.58	88.03	20m	Murshidabad	West Bengal	FMO	Post	Mayurakshi	M*
Suri	23.53	87.32	76m	Birbhum	West Bengal	FMO	Post	Mayurakshi	R/M*
Rampurhat	24.11	87.48	75m	Birbhum	West Bengal	FMO	Post	Mayurakshi	M*
Murarai	24.26	87.53	24m	Birbhum	West Bengal	FMO	Post	Mayurakshi	M*
Nalhati	24.17	87.50	N/A	Birbhum	West Bengal	FMO	Post	Mayurakshi	M*
Rajnagar	23.54	87.30	85m	Birbhum	West Bengal	FMO	Post	Mayurakshi	M*
Tantloi	24.04	87.09	101m	Birbhum	West Bengal	CWC	CWC RT &Post	Mayurakshi	R/M*
Tilpara Barrage	23.56	87.33	N/A	Birbhum	West Bengal	CWC *	CWC RT	Mayurakshi	R *
Labpur	23.50	87.49	N/A	Birbhum	West Bengal	FMO	Post	Mayurakshi	M *
Khusiary	24.31	87.10	N/A	Dumka	Jharkhand	CWC *	CWC RT	Mayurakshi	R *
Maharo	24.19	87.14	140.48 m	Dumka	Jharkhand	CWC *	CWC RT	Mayurakshi	R/M *
Messenjore	24.07	87.26	97.0 m	Dumka	Jharkhand	CWC *	CWC RT	Mayurakshi	R/M *
Jormundi	24.24	87.04	N/A	Dumka	Jharkhand	FMO	Post	Mayurakshi	M *
Dumka	24.16	87.15	149.0m	Dumka	Jharkhand	FMO	Post	Mayurakshi	M *
Kathikund	24.22	87.25	N/A	Dumka	Jharkhand	FMO	Post	Mayurakshi	M *
Ramgarh	24.33	87.15	300.0m	Dumka	Jharkhand	FMO	Post	Mayurakshi	M *
Barmasia	24.14	87.22	305.0m	Dumka	Jharkhand	FMO	Post	Mayurakshi	M *
Ghormara	24.25	86.54	257.0m	Deoghar	Jharkhand	FMO	Post	Mayurakshi	M *
Horinkhola	22.48	87.54	N/A	Hooghly	West Bengal	CWC *	CWC RT	Damodar	R *
Asansol	23.42	87.02	N/A	Burdwan	West Bengal	CWC *	CWC RT	Damodar	R *
Durgapur	23.28	87.19	N/A	Burdwan	West Bengal	CWC *	CWC RT	Damodar	R *
Hindegirh	23.41	85.16	N/A	Ranchi	Jharkhand	CWC *	CWC RT	Damodar	R *
Pupunki	23.38	86.25	N/A	Dhanbad	Jharkhand	CWC *	CWC RT	Damodar	R *
Maithan	23.46	86.52	N/A	Dhanbad	Jharkhand	CWC *	CWC RT	Damodar	R *
Panchet	23.37	86.47	N/A	Dhanbad	Jharkhand	CWC *	CWC RT	Damodar	R *
Putki	23.36	86.36	N/A	Dhanbad	Jharkhand	CWC *	CWC RT	Damodar	R *
Konar	23.54	85.50	N/A	Hazaribagh	Jharkhand	CWC *	CWC RT	Damodar	R *
Ramghar	23.38	85.43	N/A	Hazaribagh	Jharkhand	CWC *	CWC RT	Damodar	R *
Tilaya	24.21	85.38	N/A	Hazaribagh	Jharkhand	CWC *	CWC RT	Damodar	R *
Barkisuraiya	24.10	85.55	N/A	Giridih	Jharkhand	CWC *	CWC RT	Damodar	R *
Nandadih	24.00	86.32	N/A	Giridih	Jharkhand	CWC *	CWC RT	Damodar	R *
Tenughat	23.43	85.52	291.74m	Bokaro	Jharkhand	CWC *	CWC RT	Damodar	R /M*

R*-On real time basis during monsoon R/M*- On real time basis during monsoon, Rest Monthly.

M*- Monthly basis throughout the year CWC*- Stations are maintained and manned by CWC but data available to FMO Asansol.

TABLE 2

Rainfall(mm) on 6, 7 September 2009 & district wise monthly normal rainfall of September over the catchments

S. No.	Station	State	District	Monthly Normal R/F of September	Rainfall (mm)	
					6th Sep 2009	7th Sep 2009
1.	Tilaiya Dam	Jharkhand	Hazaribagh	234.7	37.6	216.4
2.	Hendegir	Jharkhand	Hazaribagh	234.7	39.2	191.0
3.	Ramgarh	Jharkhand	Hazaribagh	234.7	38.2	155.6
4.	Konar Dam	Jharkhand	Hazaribagh	234.7	55.2	187.2
5.	Barkisuraiya	Jharkhand	Giridih	224.6	42.8	N/A
6.	Nandadih	Jharkhand	Giridih	224.6	19.4	173.0
7.	Tenughat Dam	Jharkhand	Giridih	224.6	56.6	138.6
8.	Khusiary	Jharkhand	Dumka	262.8	75.6	22.0
9.	Mahro	Jharkhand	Dumka	262.8	48.8	22.4
10.	Massanjore Dam	Jharkhand	Dumka	262.8	27.4	26.2
11.	Pupnki	Jharkhand	Dhanbad	245.5	49.6	94.8
12.	Putki	Jharkhand	Dhanbad	245.5	52.4	54.8
13.	Panchet Dam	Jharkhand	Dhanbad	245.5	38.8	165.0
14.	Maithon Dam	Jharkhand	Dhanbad	245.5	25.8	155.0
15.	Jamtara	Jharkhand	Jamtara	N/A	11.6	229.3
16.	Sikatia	Jharkhand	Deoghar	232.9	22.6	-
17.	Asansol	West Bengal	Burdwan	240.3	34.4	145.2
18.	Durgapur Barrage	West Bengal	Burdwan	240.3	36.2	28.4
19.	Harinkhola	West Bengal	Hooghly	219.8	36.4	26.20
20.	Gheropara	West Bengal	Birbhum	258.9	40.0	-
21.	Tantloi	West Bengal	Birbhum	258.9	23.0	15.2
22.	Tilpara Barrage	West Bengal	Birbhum	258.9	28.2	15.6
23.	Suri	West Bengal	Birbhum	258.9	43.8	15.6
24.	Narayanpur	West Bengal	Murshidabad	228.2	48.0	4.4
25.	Simulia	West Bengal	Purulia	254.3	90.0	39.4
26.	Purihansha	West Bengal	Purulia	254.3	N/A	41.0
27.	Kharidwar	West Bengal	Purulia	254.3	104.0	20.2
28.	Tusuma	West Bengal	Purulia	254.3	113.4	38.4
29.	Phulberia	West Bengal	Purulia	254.3	126.0	22.0
30.	D.P.Ghat	West Bengal	Midnapur	310.3	106.0	2.4
31.	Mohanpur	West Bengal	Midnapur	310.3	172.8	18.6
32.	Midnapur	West Bengal	Midnapur	310.3	177.0	19.2
33.	Kangsabati Dam	West Bengal	Bankura	246.9	87.2	110.8
34.	Bankura	West Bengal	Bankura	246.9	69.0	139.0

river causes floods in the plains of Birbhum and Murshibada district. Average monthly rainfall (May-October) of the catch ment is 160.91 mm.

Many authors have studied the heavy rainfall analysis and its synoptic features. Gore *et al.* (2006) studied disastrous weather events of extreme heavy rainfall in West Bengal. Basu (2001) reported the monsoon rainfall variability with comparative study in meteorological sub-division of West Bengal. Extreme rainfall studies in various zone of the country have also been done by many authors like Banerjee *et al*. (1967) and Dhar & Ramachandran (1970). Prasad & Agarwal (1996) and Saseedharan *et al*. (1995) made rainfall studies over Bombay and Kerala state respectively. Very heavy rainfall studies in the northern states like Punjab, Himachal Pradesh and Haryana have been made by Deasi *et al.* (1996). Ganeshan *et al*. (2000) also made the study of depression, cyclonic storm, in the Bay of Bengal with very heavy rainfall. Sridharan *et al*. (2005) also studied the unusual winter precipitation over Tamilnadu in 2002 and Prasad *et al*. (2006) made the diagnostic study of some flood producing rainfall events in Bangladesh.

The objective of this study is to know the typical synoptic situation leading to excessive heavy rainfall over Ajoy, Mayurakshi and Kansabati catchments during 2009 monsoon season of 6th and 7th September by considering district normal rainfall during the period 1941-1990 of the concerned river catchments. Attempt have also been made to identify the synoptic situation with its position which is accountable for average areal precipitation (AAP) in the ranges of 11-25 mm & 26-50 mm. over the catchment with respect to verification of quantitative precipitation forecast(QPF) issued on 6th, 7th September, 2009.

2. Data & methodology

The area lying between the parallel of Latitudes around 22°-25° North and Longitude 85°-88° East of three catchments has been taken for the study. The DVC (Damodar Valley Corporation) catchment is located between the Ajoy and Kansabati cathments (Fig. 1). The rainfall data of all available stations of three catchments during heavy rainfall period of 6th, 7th September have been collected from Flood Meteorological Office, Asansol along with the QPF issued and verification results based on realized average areal precipitation (AAP) of next day. The surface and upper air charts, satellite pictures have been collected from RMC Kolkata and Radar picture also received from CDR Kolkata. Districts monthly normal rainfall (1941-1990) value of the concerned catchments of Jharkhand and West Bengal (WB) for September month have been taken from IMD publication. The area lying between the parallel of latitudes around 22-25° North and longitude 85-88° East of three catchments has been taken for the study (Table 1).

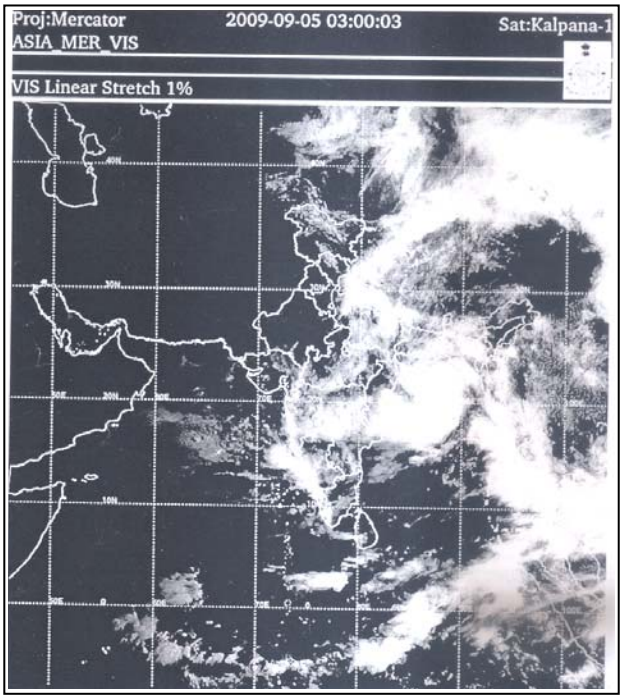

Fig. 3. Satellite imagery of the deep depression over northwest Bay of Bengal (5 September 2009)

3. Results and discussion

The average monthly rainfall over the district of Ajoy, Mayurakshi and Kansabati catchment in the month of September ranges between 23-26 cm in the districts of Jharkhand and the same is between 22-31 cm for the district of GWB (Table 2). The gradient of land and local topography are responsible for much variation of rainfall, specially in the upstream of river catchment of Jharkhand. Many stations of Kansabati catchment received maximum rainfall on 6th September as the Deep Depression moved over the catchment from 5-6 September and later rainfall increased over Ajoy and Mayurakshi catchment due to west ward movement of the system over Jharkhand and neighbourhood from 6-7th September. On 6th September, many stations of Kansabati catchment received greater than 10 cm to 18 cm rainfall which was the southwest sector during movement of the system like Midnapore (17.7 cm) and Mohanpur (17.3 cm). Similarly, some stations of Ajoy catchment like Jamtara, Nandadih etc. received 22.9 and 17.3 cm rainfall on 7th September which is 80-90% of monthly normal rainfall. Comparatively, Mayurakshi basin received less rainfall being the northeast side and away from the system during the movement of

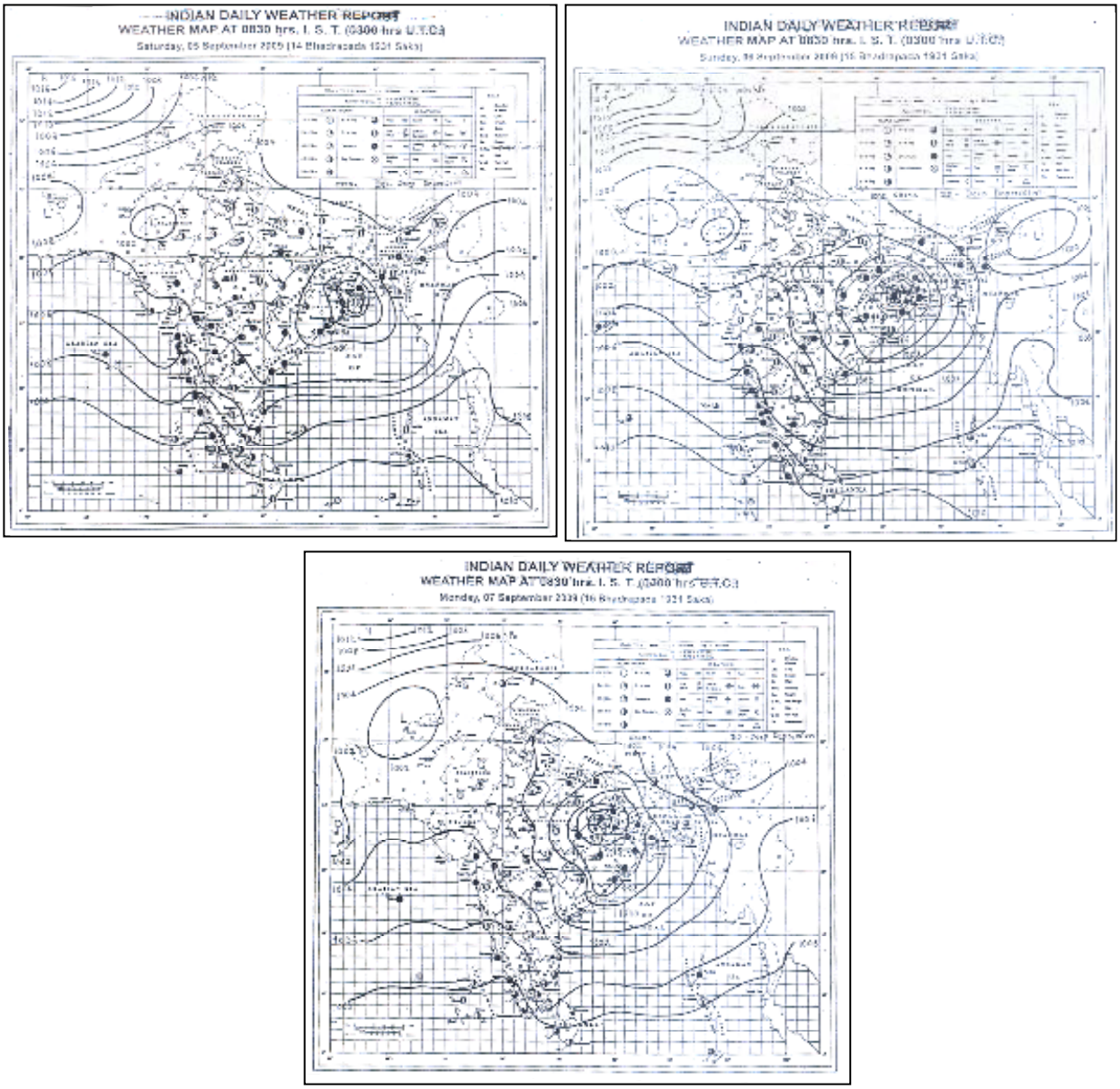

Fig. 4. Surface chart of 5th - 7th September, 2009 (*Courtesy* : IMD, Pune)

Deep Depression on 6th and 7th September. Basu *et al*. (2004) observed the significant coefficient of skewness and kurtosis (positively skewed and leptokurtic) for all the district of GWB in September month and also increasing trend of monsoon rainfall anomaly finding out the nature of variation of monthly monsoon rainfall district wise and sub division wise from 1931-1998 of West Bengal. Gore *et al*. (2006) reported that the frequency distribution of extreme heavy rainfall events in 24 hrs in West Bengal is mostly in the range of 200-400 mm and month wise temporal variability of extreme heavy rainfall in 24 hrs during 1875-2000 showed maximum frequency during the month of September.

A low pressure area formed over west central Bay of Bengal and neighbourhood on 3rd September 2009. It was well marked over north west Bay of Bengal off Orissa coast on 4th September 2009 In the morning of 5th September 2009, it concentrated into a Depression and then moved north west wards after intensifying into a Deep-Depression on the same day about 70 km south east of Balasore. Moving north west wards, it crossed the West

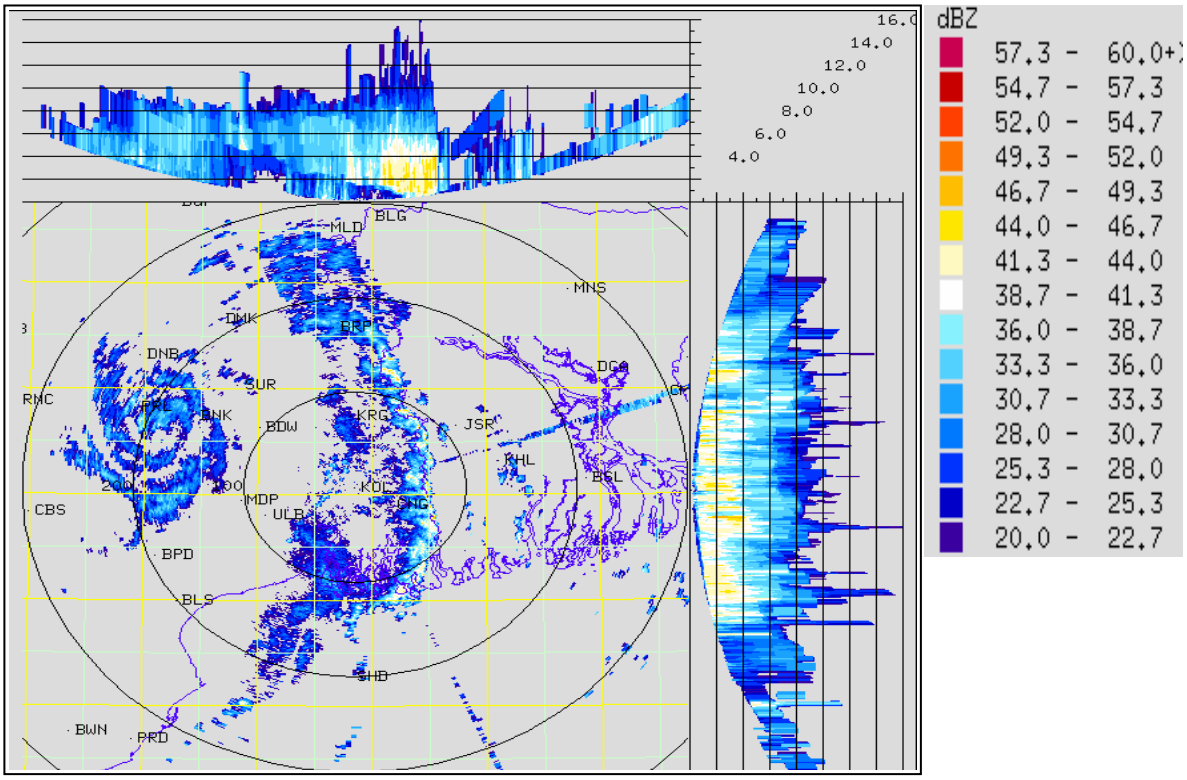

Fig. 5. Radar Reflectivity from DWR Kolkata of Deep Depression (6th September 2009/0000 UTC)

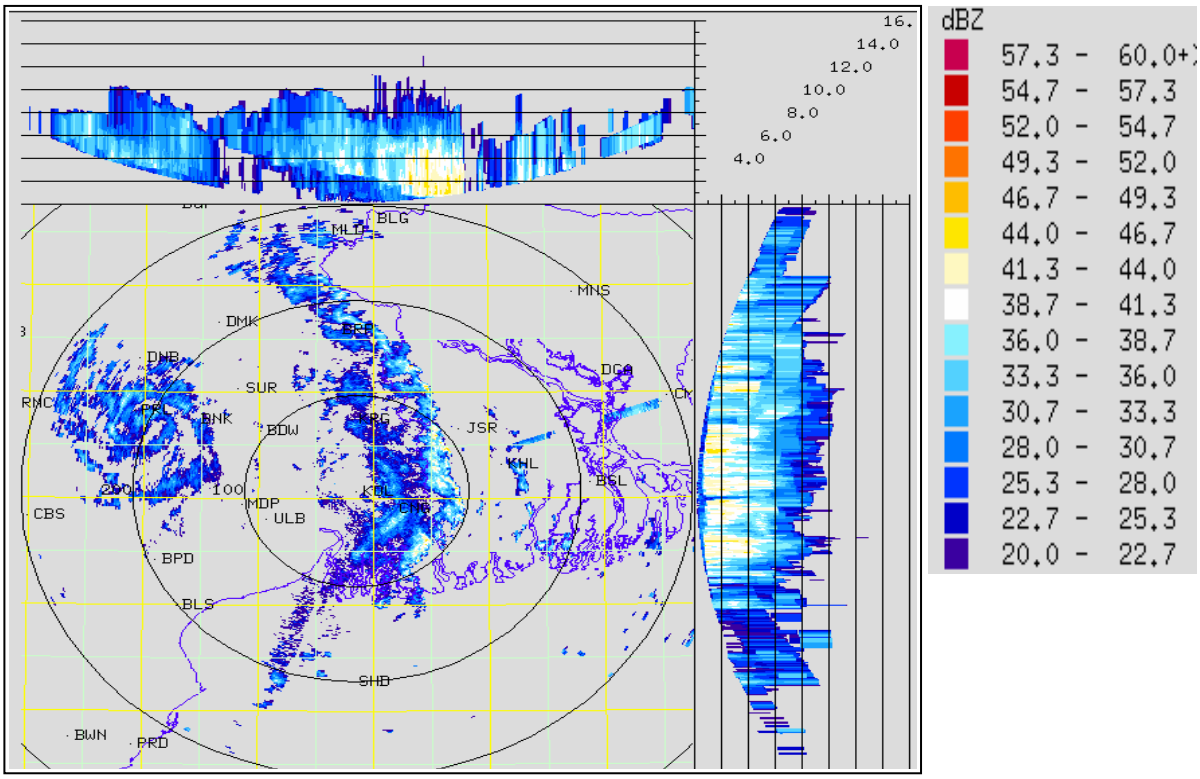

Fig. 6. Radar Reflectivity from DWR Kolkata of Deep Depression (6th September 2009/0020 UTC)

TABLE 3

Verification of QPF issued on 6th -7th September, 2009 over the catchments

Date	Mayurakshi		Ajoy		Kansabati	
	QPF	Realised	QPF	Realised	QPF	Realised
06 September 2009	26-50	14.6	26-50	36.3	11-25	19.0
07 September 2009	26-50	10.1	26-50	17.5	26-50	6.8

Bengal coast near Digha and was over GWB near Midnapore in the afternoon of 5th September 2009 (Fig. 4). It appeared over Jharkhand near 100 km north of Jamshedpur in the morning and about 50 km north of Ranchi in the afternoon of 6th September 2009. It further moved west northwest wards and was over Daltongang in the morning of 7th September 2009 and weakened into a Depression during afternoon. It further weakened into well marked low (WML) over Jharkhand in the afternoon of 7th September 2009. It further moved to north east Madhya Pradesh and neighbourhood on 8th September 2009 and remained there from 8th to 10th September 2009 as Well Marked Low.

From the upper air analyzed chart of stream line and isobaric pattern (Fig. 4) over India and neighbouring area during the period (5th to 7th September, 2009), it is observed that monsoon trough remained to the south of its normal position and cyclonic circulation at 850 hPa over GWB and adjoining north east Bay extending upto 300 hPa observed along with diffused heat low and the cross Equatorial flow along the Equatorial Bay (Equator 5° North / 5° South). The sea surface temperature of the southwest and southeast sector of Bay of Bengal was warmer than normal having positive anomaly during the period of September (IMD, 2010).

The Doppler Radar Kolkata tracked the system and observed almost circular eye surrounded by spiral bands (Figs. 5 & 6). The maximum radial wind as observed from PPI(V) was in the range of 22-26 mps at a height of 0.8 km above ground level at 0700 UTC at a distance of 80 km southwest from DWR and the horizontal wind estimated from DWR products VVP_2 is 45 kts at a height of 0.9 km (IMD, 2010).

Satellite picture observation from 5th- 7th September, 2009 (Fig. 3) revealed that equatorial long clouding band is confined from a large area extending from southeast to northwest of Bay of Bengal and it is oriented from southeast and southwest and northeast and northwest direction. The clouding concentrated with maximum intensity was reported by satellite imageries from 5th September, 2009 covering most of the area of Gangetic WB and adjoining coastal Orissa. It moved in the same day in the afternoon towards northwest wards dissipitating over GWB and coastal Orissa and Jharkhand on 6th- 7th September, 2009.

Heavy rainfall and associated QPF generally issued based on synoptic situation and its movement over and adjoining areas of catchments like cyclonic circulation (CYCIR), Trough of low pressure area (LOPAR), Monsoon Trough, LOPAR/WML/DEPRESSION/Deep Depression etc. The DD lay over Jharkhand with its centre in the morning of 6th September about 100 km North of Jamsedpur with associated CYCIR extending upto mid-tropospheric level. Hence, QPF of 26-50 mm was issued on the day for Mayurakshi and Ajoy catchments and 11-25 mm for Kansabati catchment (Table 3) based on synoptic situation of 0300 UTC surface, 0000 UTC upper air and change chart observing the pressure departure field and analysed basin map of three catchments. It was realized on the next day (7th September) within forecast range over Ajoy (36.3 mm) and Kansabati catchments (19.0 mm) and out by one stage over Mayurakshi catchment (14.6 mm) and southwest monsoon was vigorous over Jharkhand and GWB. In the morning of 7th September, the DD remained practically stationary over Jharkhand closed to Daltongang with associated CYCIR extending upto mid-tropospheric level and the southwest Monsoon trough prominently passed through and over the catchments. Hence QPF of, 26-50 mm was issued for all three catchments on 7th September. However, the catchments QPF issued for Myurakshi and Kansabati was out by two stage and Ajoy by one stage (7.5 mm), because the DD weakened rapidly into well-marked-low in the evening of the 7th September, moving northeast Madhya Pradesh afterwards.

Incessant heavy rainfall associated with the formation and west ward movement of the DD over the northwest Bay of Bengal during 5th-7th September, 2009 along with convective activity in the form of thunder

showers caused floods in six district of GWB and situation was further deteriorated by heavy discharge of water from the reservoirs of the Damodar Valley Corporation barrage at Maithon, Panchet and Durgapur due to heavy rains in the catchment area. The flood badly affected six districts of GWB inundating a large area of standing crops and caused substantial loss of revenue to the farmers. The flood also claimed six life and 1.7 million people were marooned and several villages along with thousands kutcha houses and roads were badly damaged.

4. Conclusions

(*i*) The study has revealed that west ward movements of DD from the Bay of Bengal during 5^{th}-7^{th} September, 2009 along with south ward tilting of Monsoon Trough caused exceptionally heavy rainfall over Ajay, Mayurakshi and Kansabati catchment.

(*ii*) The floods were also caused due to heavy discharge of water from the reservoirs of DVC claiming six lives, affecting 17 Lakh people and inundating large area of standing crops, villages etc.

(*iii*) Further study on the topography and drainage condition of the catchment needs to be done.

(*iv*) Synoptic analogue model (SAM) for issuance of QPF for the river catchments may be developed.

(*v*) River discharge and gauge height data in relation to run off coefficients during heavy rainfall periods may also be studied for QPF.

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References

Banerjee, P., Mukhopadhyay, P. K., Hansda, B. K. and Chatterjee, S. D., 1967, "Abnormal rainfall over Calcutta on 10^{th} October, 1965", *Indian J. Met. & Geophysics*, **18**, p291.

Basu, G. C., 2001, "A feature of Monsoon Rainfall and its variability with comparative study in Meteorological sub-divisions of West Bengal", *Mausam*, **54**, 4, 736-746.

Basu, G. C. and Goldar, R. N., 2004, "A study of catastrophe flood in September, 2000 over Gangetic West Bengal by a rational method of rainfall-runoff", *Mausam*, **55**, 1, 197-204.

Desai, D. S., Thade, N. B. and Huprikar, M. G., 1996, "Very heavy rainfall over Punjab, Himachal Pradesh and Haryana during 24-27 September 1988 case study", *Mausam*, **47**, 3, 269-274.

Dhar, O. N. and Ramchandran, G., 1970, "Short duration analysis of Kolkata rain", *Indian J. Met. & Geophysics*, **21**, 93-102.

Ganesan, G. S., Muthuchami, A. and Ponnuswamy, A. S., 2000, "Heavy rain at Chennai and its relation to cyclonic disturbances", *Mausam*, **51**, 1, 17-24.

Gore, P. G., Joshi, P. R. and Dikshit, S. K., 2006, "Disastrous weather events of extreme heavy rainfall in West Bengal", *Mausam*, **57**, 3, 513-517.

India Meteorological Department, 2010 "Cyclones and depressions over the north Indian Ocean during 2009", *Mausam*, **61**, 3, 271-290.

Prasad, T. and Agarwal, A. L., 1996, "A day of exceptionally heavy rainfall near Bombay", *Mausam*, **47**, 4, 425-428.

Prasad, K., Afroz, Romee, Sarkar, M. A. and Rahman, Mizahur, 2006, "A diagnostic study of some flood producing rainfall events in Bangladesh with a limited area analysis-forecast system", *Mausam*, **57**, 3, 475-488.

Saseedharan, S. A., Singh, K. K., Bahadur, J. and Dhar, O. N., 1995, "1 to 10 days extreme rainfall studies for Kerala state," *Mausam*, **46**, 2, 175-180.

Sridharan, S. and Muthuchami, A., 2005, "Unusual winter precipitation over Tamilnadu in 2002", *Mausam*, **56**, 2, 489-495.