

**जल मौसम विज्ञान विभाग
भारत मौसम विज्ञान विभाग
पृथ्वी विज्ञान मंत्रालय**

**Hydromet Division
India Meteorological Department
Ministry of Earth Sciences**



भारत की नदियों के उपरेक्षित पर मात्रात्मक वर्षा पूर्वानुमान 2020 का सत्यापन

VERIFICATION OF QUANTITATIVE PRECIPITATION FORECAST (QPF) OVER RIVER SUB BASINS OF INDIA DURING 2020 SW MONSOON SEASON

B. P. Yadav, Ashok Kr. Das

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जल मौसम विज्ञान प्रभाग, भारत मौसम विज्ञान विभाग (पृथ्वी विज्ञान मंत्रालय)
Hydromet Division, India Meteorological Department (Ministry of Earth Sciences)
मौसम भवन, लोदी रोड, नई दिल्ली - 110003
Mausam Bhavan, Lodi Road, New Delhi - 110003

FOREWORD

Every year floods occurs in one or another part of the country due to high variability of rainfall over time and space. In India, the Hydromet services mainly in the form of Quantitative Precipitation Forecast (QPF), Heavy Rainfall warning, station wise significant rainfall etc. are provided by IMD to CWC for Flood Forecasting services. QPF is the main input for running any Hydrological model and issuing flood forecast. It is necessary to analyse the performance of operational Quantitative Precipitation Forecast (QPF) for its improvement.

It gives me great pleasure that Hydromet Division has brought out the publication "**Verification of Quantitative Precipitation Forecast (QPF) Over River Sub Basins of India during 2020 SW Monsoon Season**" based on the Operational QPF issued and the Observed rainfall received in the different sub basins under 14 FMOs. I am sure this report will be useful to FMOs for taking measures for further improving the accuracy of QPF which will ultimately lead to improved flood forecasting. I appreciate the concerned FMO and colleagues for improved forecast performance during 2020.

I appreciate the authors for their fine efforts made in bringing out this publication.

Dr. M. Mohapatra
Director General of Meteorology
India Meteorological Department

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CHAPTER 1

Introduction

Every year floods occurs in one or another part of the country. IMD is the nodal agency for issuing Quantitative Precipitation Forecast (QPF) for river Basins/ sub-Basins where as CWC is the nodal agency for issuing Flood Forecast. The QPF is the main input in the Flood Forecasting models for issuing flood forecast by CWC. IMD through its field offices called ‘Flood Meteorological Offices’ (FMOs) issues QPF on operational basis during flood season. There are 13 FMOs located at different parts of flood prone areas of the country, which are located at Agra, Ahmedabad, Asansol, Bengaluru, Bhubaneswar, Chennai, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi, Srinagar and Patna that caters to the river Basins mentioned in Table1. After the disastrous floods in the state of Jammu & Kashmir in September 2014, the government decided to issue flood forecast for Jhelum Basin on operational basis from flood season 2015. FMO, Srinagar started issuing QPF operationally for Jhelum river sub Basins from the flood season 2015 and supplied to CWC to support their flood forecasting activities. In addition to Jhelum, four new Basins namely, Pennar, Sankosh, Jaldhaka and Torsa are included for flood forecasting and for IMD, issuance of operational QPF’s. New river sub basins of State Kerala are also included to MC, Bengaluru for this activities in 2019 after the Kerala flood in 2018. IMD also provides similar support to Damodar Valley Corporation (DVC) for the river Basins of Barakar and Damodar. The location and area of jurisdiction of FMOs and DVC Kolkata are shown in Figure1. The main River basin under FMOs and DVC Kolkata along with the area under their jurisdictions and the number of sub-basins for which the QPFs were issued on operational basis are given in Table 1.

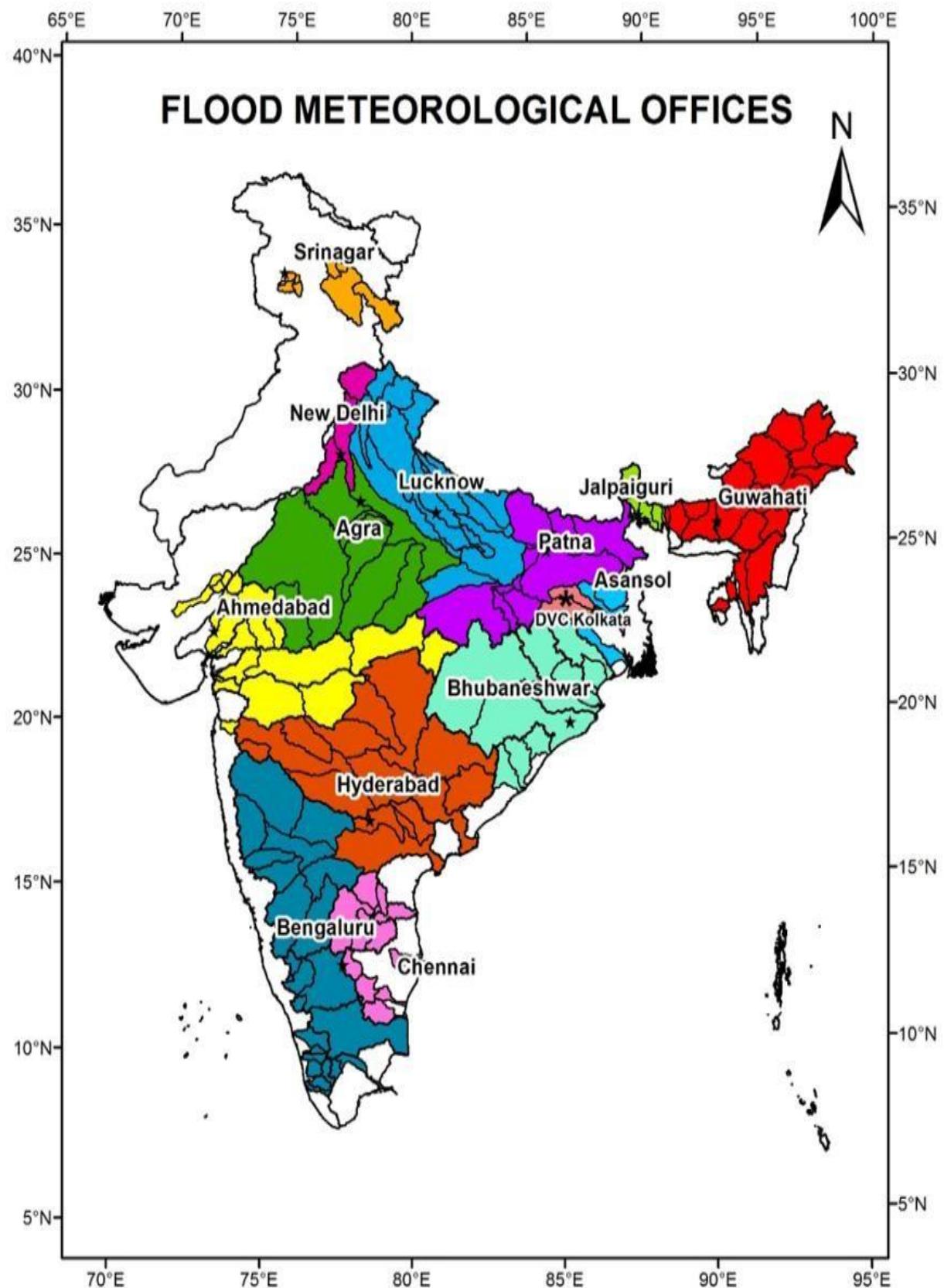


Figure 1: Map of Flood Meteorological offices with Sub-Basins in 2020

Flood Meteorological Service of IMD is provided through the FMOs. During flood season, daily QPF bulletin and Hydromet Bulletin are issued to Central Water Commission (CWC) for the purpose of operational flood forecasting. QPF bulletin is issued at 0930 hrs IST and Hydromet Bulletin at 1230 hrs IST. Categorical Sub-Basin wise QPF Forecast (FC) is issued for a lead-time of 7-days (forecast for 3 days and outlook for subsequent 4 days). If situation demands, QPF bulletins can be further modified in the evening.

Hydromet Bulletin contains the following information:

- Prevailing Synoptic situations
- Spatial and temporal distribution of rainfall
- Categorical Sub-Basin wise QPF for Day-1, Day-2, and Day-3. Following are the categories; 0, 0.1-10, 11-25, 26-50(26-37 & 38- 50), 51-100 (51-75 & 76-100) and >100 mm
- Probabilistic Quantitative Precipitation Forecast (PQPF)
- Heavy rainfall warnings for 3 days
- Sub-Basin wise past 24 hour realized rainfall
- Station wise observed significant rainfall (≥ 5 cm)
- Outlook for next 4 days

FMOs issue operational QPF by analysing surface weather charts, Upper air charts, Synoptic analogue, NWP model analysis & rainfall forecast, Satellite imageries & products and Radar products.

In addition to flood season, QPF Bulletins consists of sub-basin wise QPFs and heavy rainfall warning is issued by concerned FMOs and DVC during cyclone period or when there is a chance of heavy rainfall that may lead to flood.

The technical controls of FMOs are lying with Hydromet Division at HQ whereas the administrative controls are lying with their respective RMCs. The performance of QPF is verified for the flood season annually.

Table 1: Main River Basins/Sub-Basins under FMOs/MC /DVC with Jurisdiction area

S. No.	FMOs	Area (Km ²)	No of Sub-Basins	Main Basins/Sub-Basins
1	Agra	2,92,492	8	Chambal, Betwa, Ken, Yamuna
2	Ahmedabad	2,20,946	19	Narmada, Tapi, Daman Ganga, Sabarmati, Banas, Mahi
3	Asansol	23,669	3	Ajoy, Mayurakshi, Kangsabati
4	Bhubaneswar	2,44,670	9	Subarnarekha, Baitarni, Burhabalang, Vamsadhara, Brahmani, Mahanadi, Rushikulya
5	DVC, Kolkata	21,013	3	Damodar
6	Guwahati	1,82,195	20	Brahmaputra, Barak, Dehung, Lohit, Buridihing, Subansiri, N. Dhansiri, S. Dhansiri, Jiabharali, Kapili, Manas/ Beki, Sankosh

7	Hyderabad	6,11,056	16	Godavari, Manjira, Wainganga, Penganga, Wardha, Indravati, Sabari
8	Jalpaiguri	16,151	5	Teesta, Jaldhaka, Raidak
9	Lucknow	2,20,465	14	Ghaghra, Rapti, Ramganga, Gomti, Sai, Sahibi, Chhatang, Bhagirathi, Alaknanda, Ganga, Sharda
10	New Delhi	36,670	3	Yamuna upto Mathura, Sahibi
11	Patna	1,71,698	8	Kosi, Mahananda, Adhwara, Bagmati, Gandak, Punpun, Sone, Kanhar, North Koel
12	Srinagar	4,788	8	Jhelum
13	Bengaluru	3,05,049	26	Upper Cauvery, Middle Cauvery, Lower Cauvery, Hemavathi, Kabini, Harangi, Periyar, Upper Vaigai, Lower Vaigai, Upper Bhima, Upper Krishna, Middle Krishna, Lower Bhima, Upper Tungabhadra, Ghataprabha, Bennehalla, Hagari or Vedavati, Middle Tungabhadra, Lower Tungabhadra, Achankoil, Meenachil, Pamba, Bharathapuzha, Chalakudi, Upper Periyar, Lower Periyar
14	Chennai	6,05,708	11	Gummanur, Upper South Pennar, Korttalaiyar, Vellar, Lower South Pennar, Kunderu, Sagileru, Upper Pennar, Lower Pennar, Papagni, Cheyyeru
Total		29,56,570	153	

CHAPTER 2

Description of Different Flood Meteorological Offices

There are 13 FMOs and DVC Kolkata. This chapter gives a detailed account of river basins/sub-basins in respective of FMOs/DVC.

2.1 FMO Agra

The Flood Meteorological office, Agra was established in the year 1985 to issue QPF sub-basin wise in Lower basins of Yamuna River from Mathura. It lies in the states of Uttar Pradesh, Madhya Pradesh, Rajasthan and Haryana.

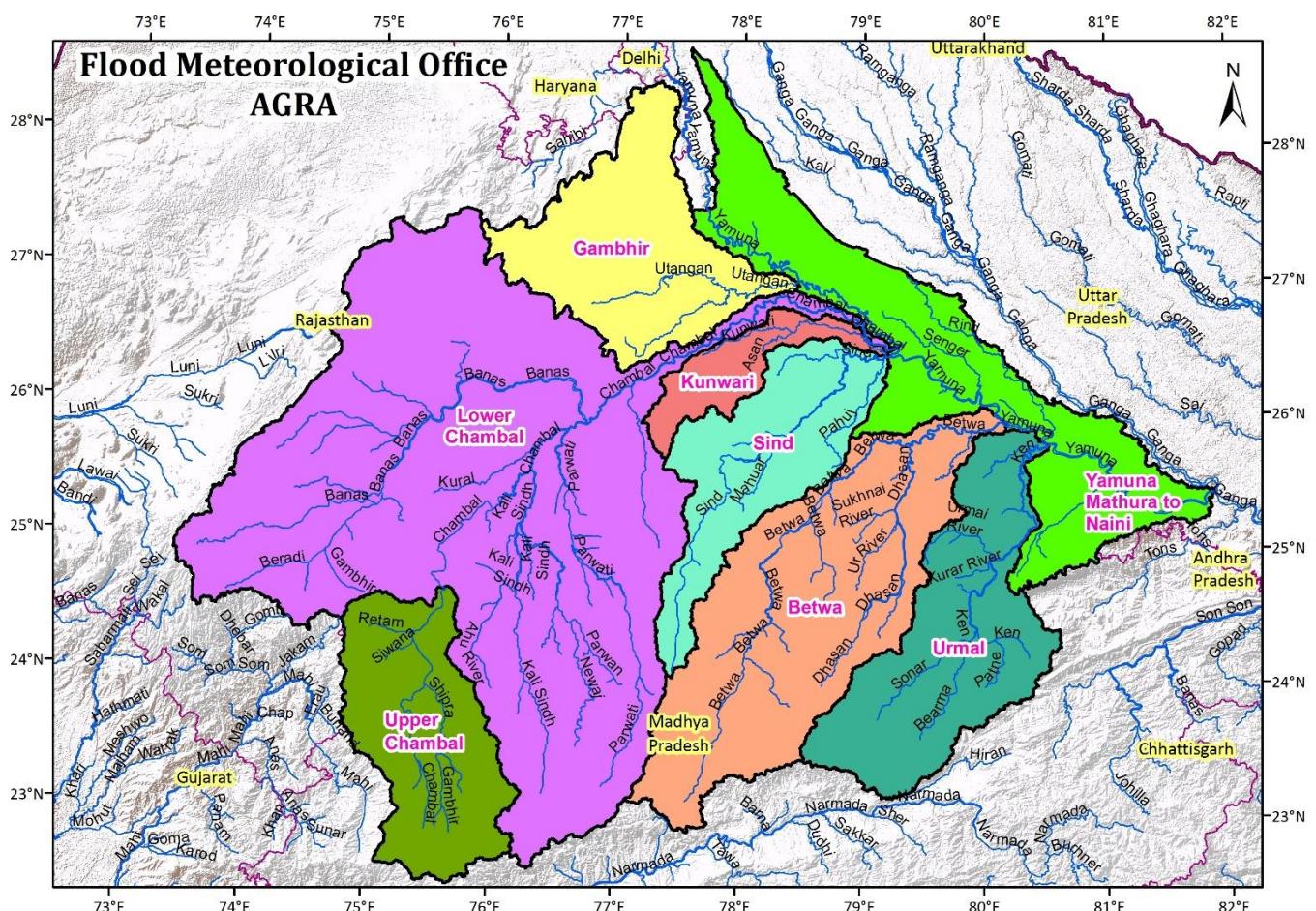


Figure 2: Map of FMO Agra with Sub-basins

There are total of 8 sub-basins under the FMO Agra. The name of basins, sub-basins with area (in Km²) are given in Table 2.

Table 2: Area-wise Basins/Sub-basins under FMO Agra

FMO Agra			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Banganga	Gambhir	24548.79
2	Chambal	Upper Chambal	21909.09
3		Lower Chambal	113969.31
4		Sind	20103.78
5		Kunwari	6765.69
6	Betwa	Betwa	42178.37
7	Ken	Ken	27607.31
8	Yamuna	Yamuna Mathura to Naini	35409.28
Total			292491.62

2.2 FMO Ahmedabad

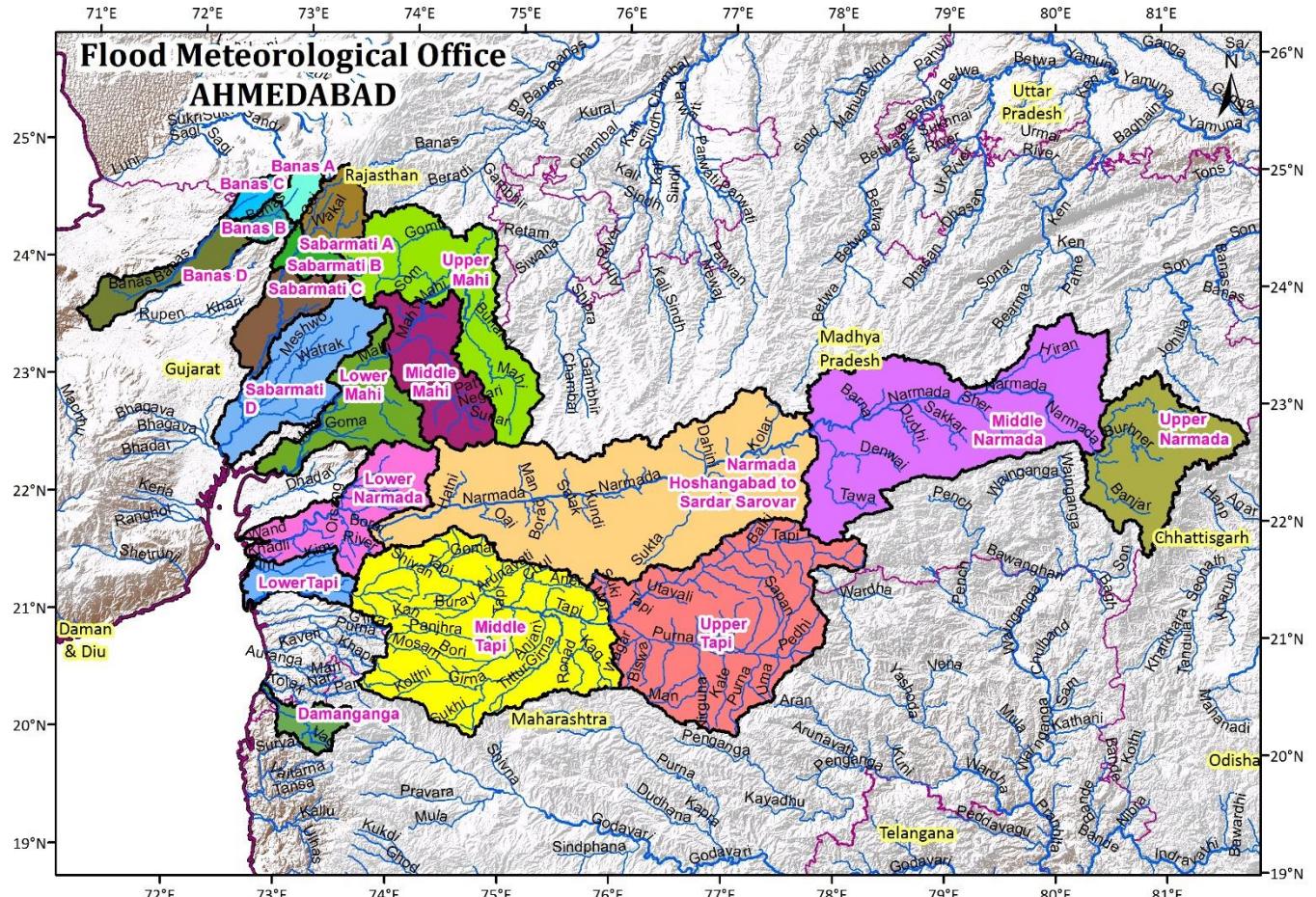


Figure 3: Map of FMO Ahmedabad with Sub-basins

The Flood Meteorological office, Ahmedabad was established in the year 1974 to issue QPF sub-basin wise in rivers Narmada, Tapi, Mahi, Sabarmati, Banas and Damanganga. It lies in the states of Madhya Pradesh, Gujarat, Rajasthan, Maharashtra and UT of Daman & Diu.

There are total of 19 sub-basins under the FMO Ahmedabad. The name of basins, sub-basins with area (in Km²) are given in Table 3.

Table 3: Area-wise Basins/Sub-basins under FMO Ahmedabad

FMO Ahmedabad			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Narmada	Upper Narmada	12441.93
2		Middle Narmada	30782.56
3		Narmada Hoshangabad to Sardar Sarovar	40543.9
4		Lower Narmada	9715.95
5	Tapi	Upper Tapi	28592.98
6		Middle Tapi	31221.03
7		Lower Tapi	3598.13
8	Mahi	Upper Mahi	15721
9		Middle Mahi	9231.46
10		Lower Mahi	8123.46
11	Sabarmati	Sabarmati A	3259.47
12		Sabarmati B	1827.7
13		Sabarmati C	4626.83
14		Sabarmati D	10697.66
15	Banas	Banas A	1376.87
16		Banas B	1282.91
17		Banas C	1205.89
18		Banas D	4450.55
19	Damanganga	Damanganga	2245.69
Total			220945.97

2.3 FMO Asansol

The Flood Meteorological office, Asansol was established in the year 1980 to issue QPF sub-basin wise in rivers Mayurakshi, Ajoy and Kangsabati. It lies in the states of West Bengal and Jharkhand.

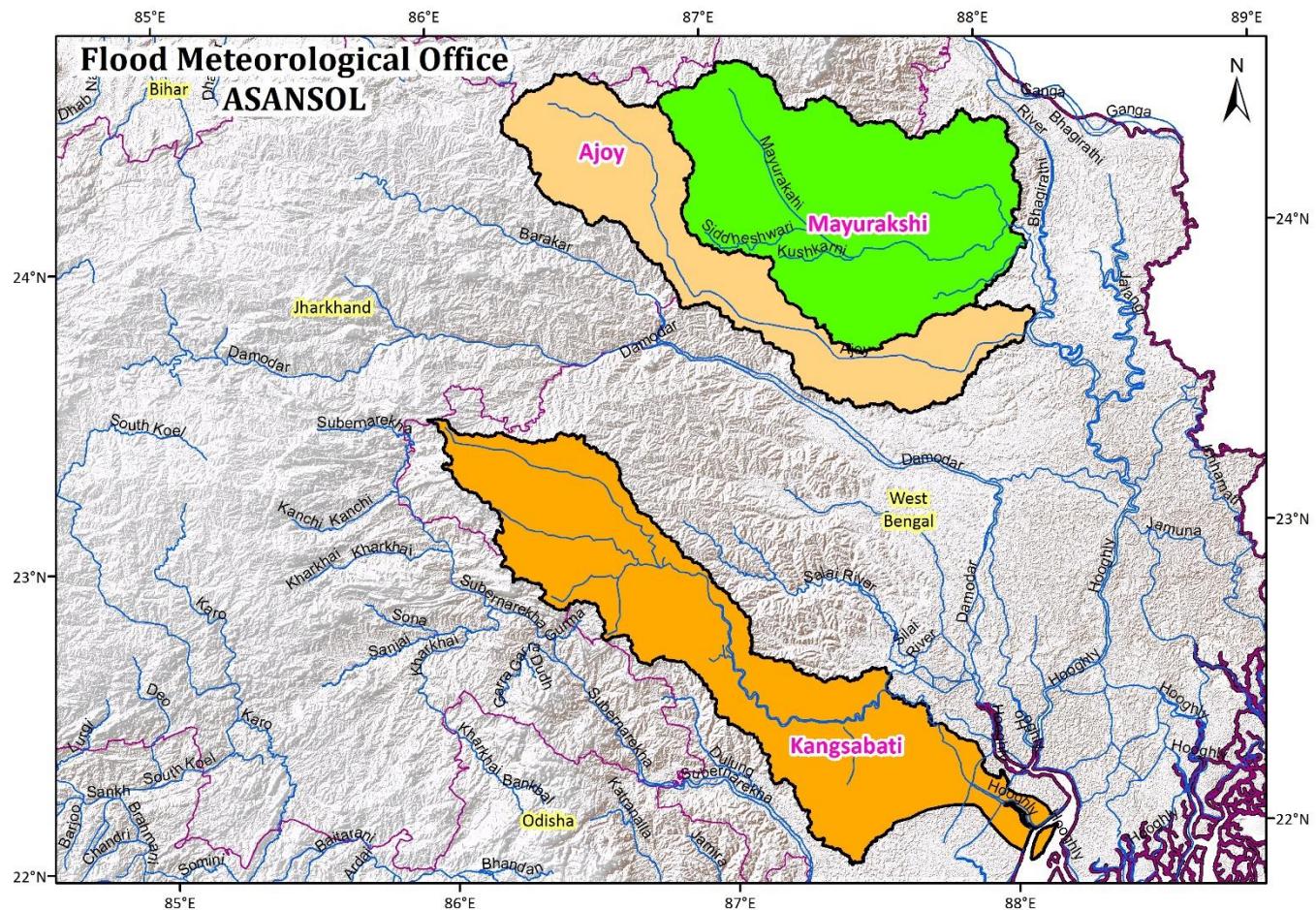


Figure 4: Map of FMO Asansol with Sub-basins

There are total of 3 sub-basins under the FMO Asansol. The name of basins, sub-basins with area (in Km²) are given in Table 4.

Table 4: Area-wise Basins/Sub-basins under FMO Asansol

FMO Asansol			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Kangsabati	Kangsabati	9256.1
2	Ajoy	Ajoy	5851.1
3	Mayurakshi	Mayurakshi	8561.37
Total			23668.57

2.4 FMO Bengaluru

The Flood Meteorological office, Bengaluru is established in the year 2016 to issue QPF sub-basin wise in rivers Cauvery, Krishna, Tungabhadra, Kabini, Harangi, Hemavathi, Ghataprabha, Bennehalla. It lies in the states of Maharashtra, Karnataka and Tamil Nadu.

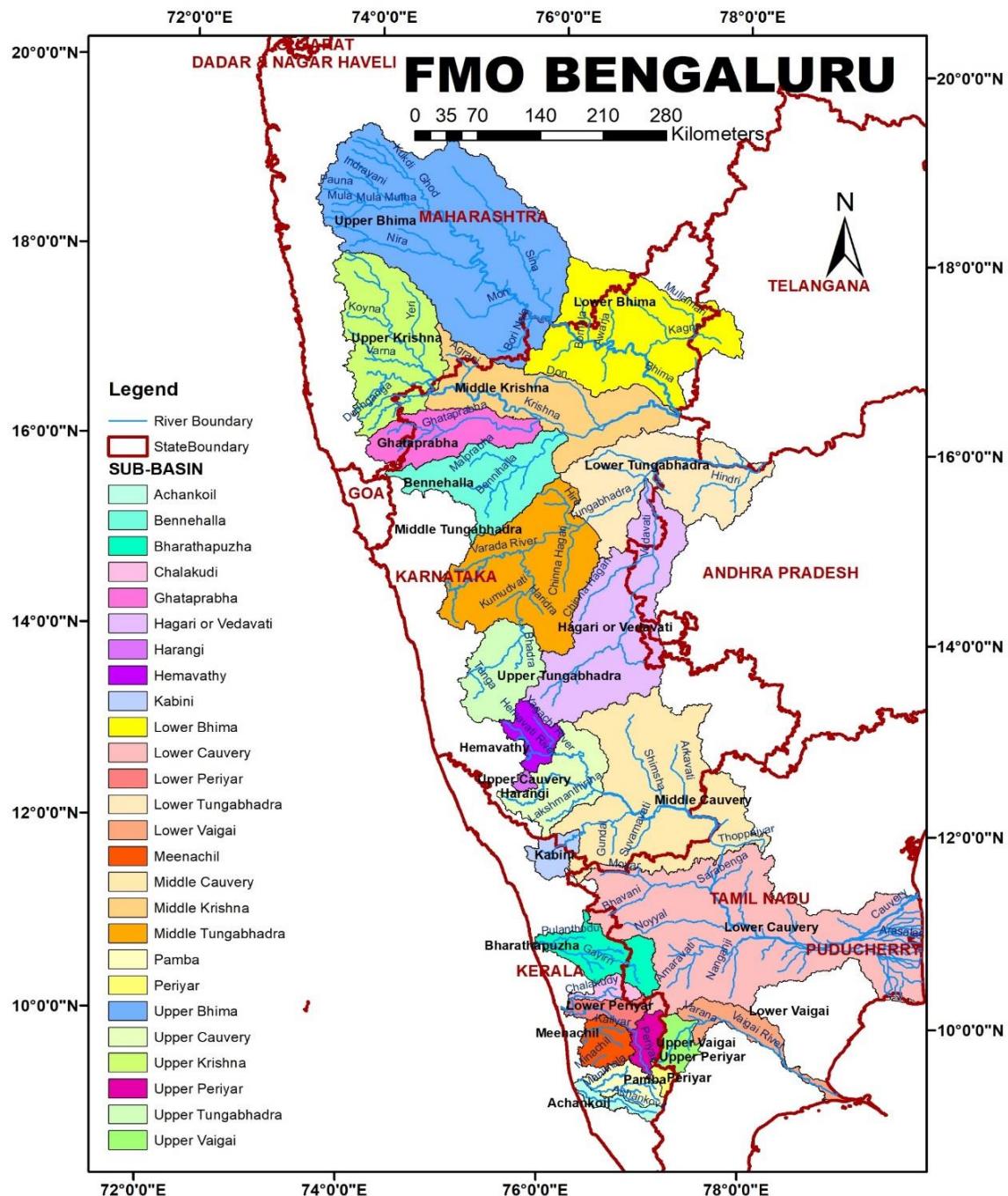


Figure 5: Map of FMO Bengaluru with Sub-basins

There are total of 26 sub-basins under the FMO Bengaluru. The name of basins, sub-basins with area (in Km²) are given in Table 5.

FMO Bengaluru			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Cauvery	Harangi	421.96
2	Cauvery	Hemavathy	2897.23
3	Cauvery	Kabini	2176.75
4	Cauvery	Middle Cauvery	29808.80
5	Cauvery	Upper Cauvery	7639.61
6	Cauvery	Lower Cauvery	42681.88
7	Cauvery	Upper Vaigai	2273.47
8	Cauvery	Lower Vaigai	4122.33
9	Cauvery	Periyar	634.24
10	Krishna	Upper Krishna	17558.19
11	Krishna	Middle Krishna	17100.41
12	Krishna	Ghataprabha	8507.49
13	Krishna	Bennehalla	11338.67
14	Krishna	Upper Bhima	44793.32
15	Krishna	Lower Bhima	23652.70
16	Krishna	Hagari/Vedavati	23183.15
17	Krishna	Lower Tungabhadra	18481.57
18	Krishna	Upper Tungabhadra	7705.97
19	Krishna	Middle Tungabhadra	20813.44
20	West Flowing Rivers	Bharathapuzha	6001.33
21	West Flowing Rivers	Chalakudi	1361.68
22	West Flowing Rivers	Lower Periyar	2165.88
23	West Flowing Rivers	Upper Periyar	2604.03
24	West Flowing Rivers	Pamba	2818.47
25	West Flowing Rivers	Meenachil	2818.47
26	West Flowing Rivers	Achankoil	1488.07
Total			305049.11

Table 5: Area-wise Basins/Sub-basins under FMO Bengaluru

2.5 FMO Bhubaneswar

The Flood Meteorological office, Bhubaneswar was established in the year 1974 to issue QPF sub-basin wise in rivers Subarnarekha, Brahmani, Burhabalang, Baitarni, Mahanadi, Vamsadhara, Rushikulya. It lies in the states of Odisha, Chhattisgarh, West Bengal and Jharkhand.

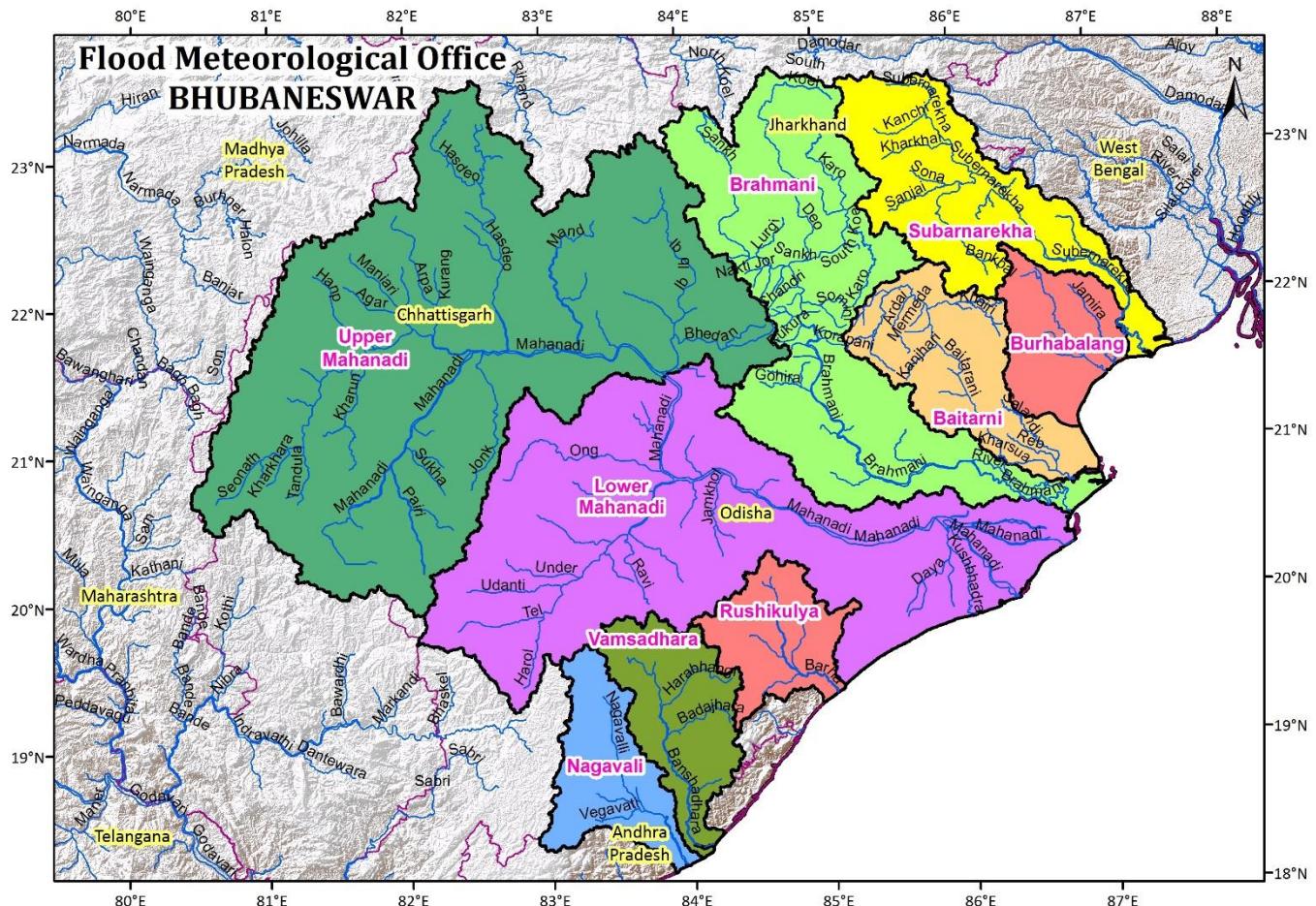


Figure 6: Map of FMO Bhubaneswar with Sub-basins

There are total of 9 sub-basins under the FMO Bhubaneswar. The name of basins, sub-basins with area (in Km²) are given in Table 6.

FMO Bhubaneswar			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Subarnarekha	Subarnarekha	18609.88
2	Burhabalang	Burhabalang	8333.36
3	Baitarani	Baitarani	13200.15
4	Brahmani	Brahmani	37545.83
5	Mahanadi	Upper Mahanadi	81692.55
6		Lower Mahanadi	57958.88
7	Rushikulya	Rushikulya	7934.86
8	Vamsadhara	Vamsadhara	10396.55
9	Nagavali	Nagavali	8997.68
Total			244669.74

Table 6: Area-wise Basins/Sub-basins under FMO Bhubaneswar

2.6 FMO Chennai

The Flood Meteorological office, Chennai is started from this year 2016 to issue QPF sub-basin wise in rivers Pennar, Vaigai, Vellar, Kunderu, Gummanur, Cheyyeru, Papagni and Sagileru. It lies in the states of Andhra Pradesh, Karnataka, Tamil Nadu and UT Puducherry.

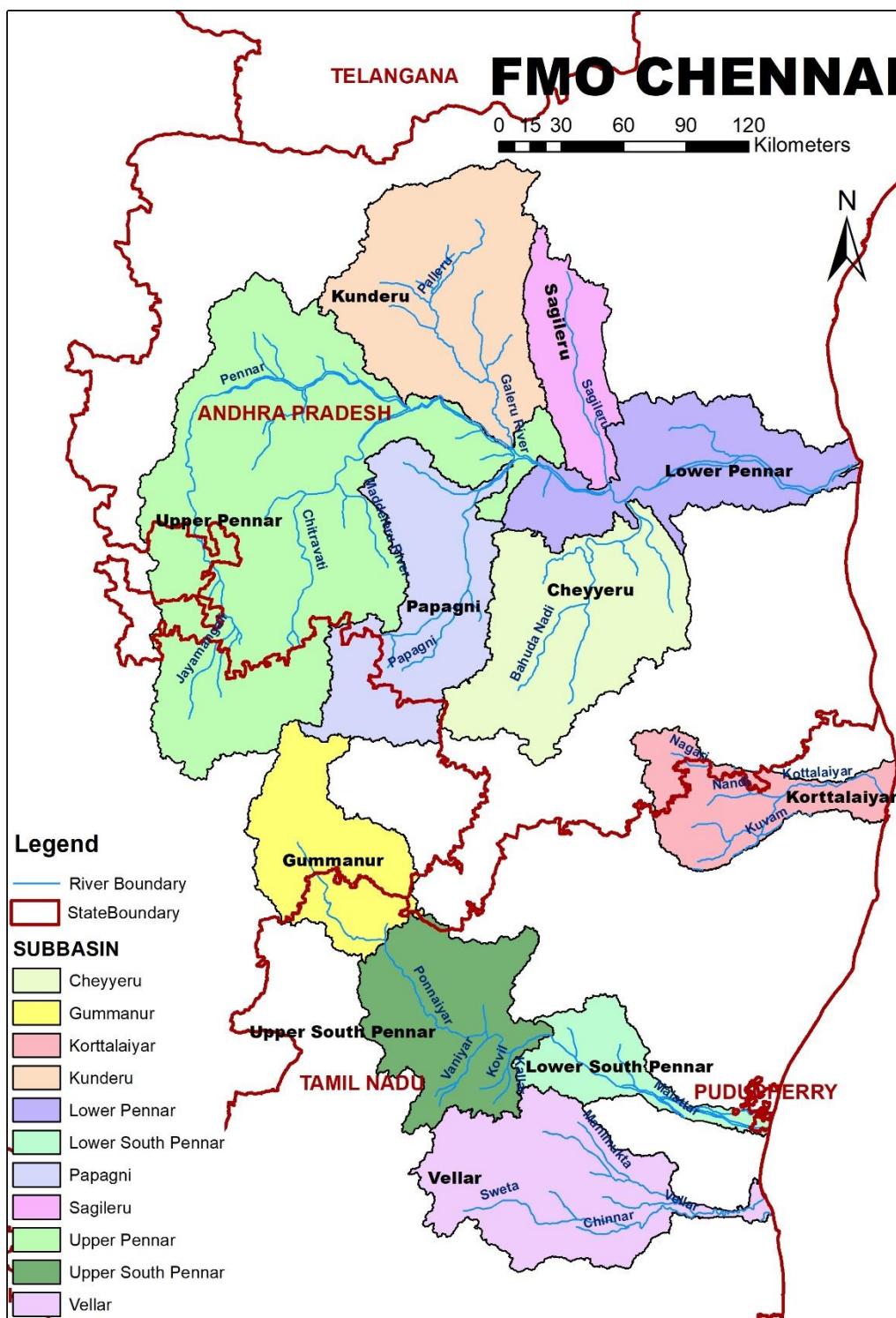


Figure 7: Map of FMO Chennai with Sub-basins

There are total of 11 sub-basins under the FMO Chennai. The name of basins, sub-basins with area (in Km²) are given in Table 7.

Table 7: Area-wise Basins/Sub-basins under FMO Chennai

FMO Chennai			
Sl. No.	BASIN	SUBBASIN	Area (Sq. Km.)
1	East Flowing Rivers	Gummanur	5065.40
2		Upper South Pennar	5866.20
3		Korttalaiyar	3866.58
4		Vellar	7440.81
5		Lower South Pennar	2731.65
6	Pennar	Kunderu	8591.64
7		Sagileru	3151.62
8		Upper Pennar	21320.54
9		Lower Pennar	6147.5
10		Papagni	7047.79
11		Cheyyeru	7984.34
Total			685993.11

2.7 FMO Guwahati

The Flood Meteorological office, Guwahati was established in the year 1975 to issue QPF sub-basin wise in rivers Brahmaputra and Barak. It lies in the states of Assam, Arunachal Pradesh, Nagaland, Manipur, Mizoram and Meghalaya.

There are total of 20 sub-basins under the FMO Guwahati. The name of basins, sub-basins with area (in Km²) are given in Table 8.

Table 8: Area-wise Basins/Sub-basins under FMO Guwahati

FMO Guwahati			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Barak	Barak at Silchar	18023.39
2		Badarpurghat	7864.68
3	Manu	Manu	2137.63
4	Gumti	Gumti	2158.16
5	Brahmaputra	Dehung at Passighat	13920.42

6	Lohit at Dholla	13855.87
7	Brahmaputra at Dibrugarh	18046.84
8	Buridihing at Khowang	5631.86
9	Subansiri at Badatighat	23118.67
10	B-putra at Neamatighat	11144.47
11	Dhansiri (S) at Golaghat	7972.70
12	Brahmaputra at Tezpur	10695.21
13	Jiabharali at NT road Xing	9774.35
14	Dhansiri (N) at Rly Bridge	2002.96
15	Kapili at Kampur	11997.15
16	Brahmaputra at Guwahati	13150.86
17	Manas/ Beki at N H Xing	4754.78
18	Brahmaputra at Goalpara	10781.00
19	Brahmaputra at Dhubri	6198.57
20	Sankosh	1125.52
Total		194355.09

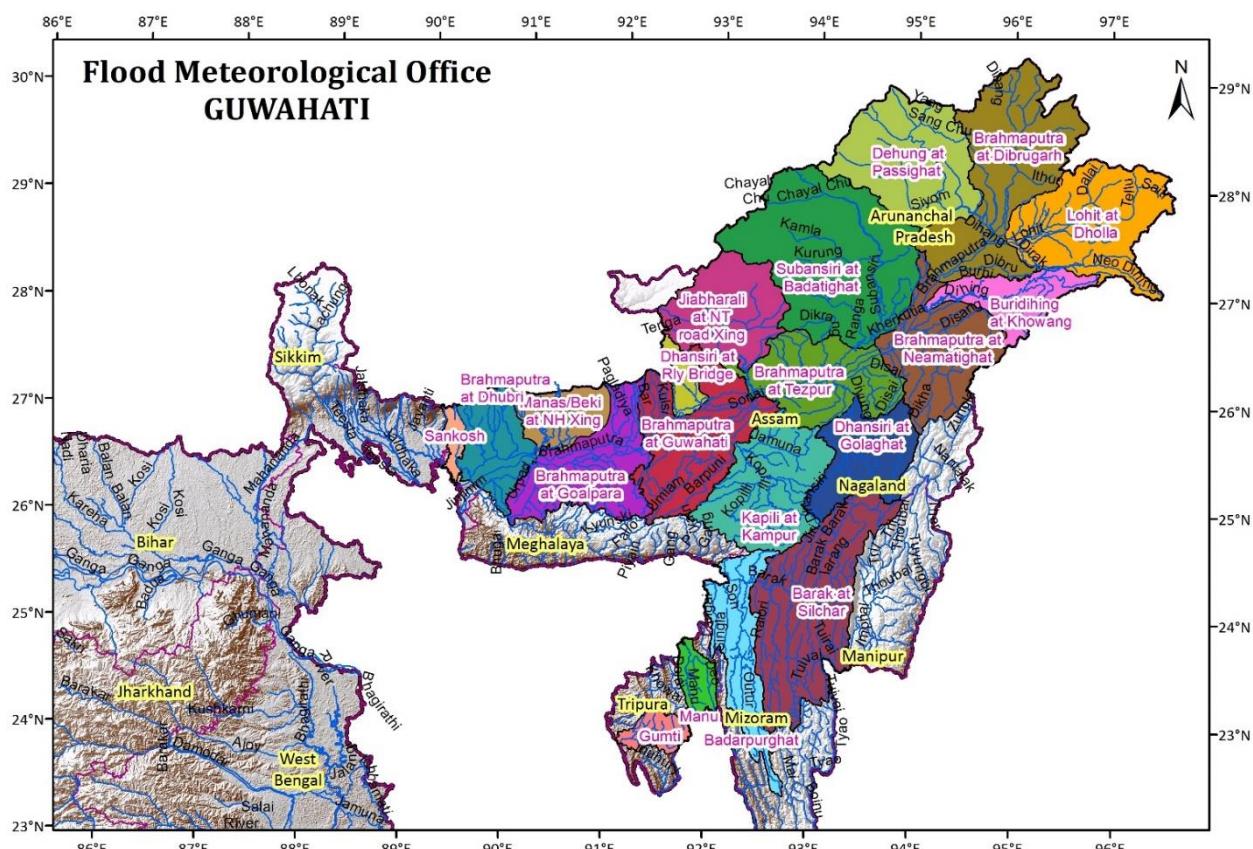


Figure 8: Map of FMO Guwahati with Sub-basins

2.8 FMO Hyderabad

The Flood Meteorological office, Hyderabad was established in the year 1977 to issue QPF sub-basin wise in rivers Krishna, Godavari and Pennar. It lies in the states of Andhra Pradesh, Telengana, Maharashtra and UT Puducherry.

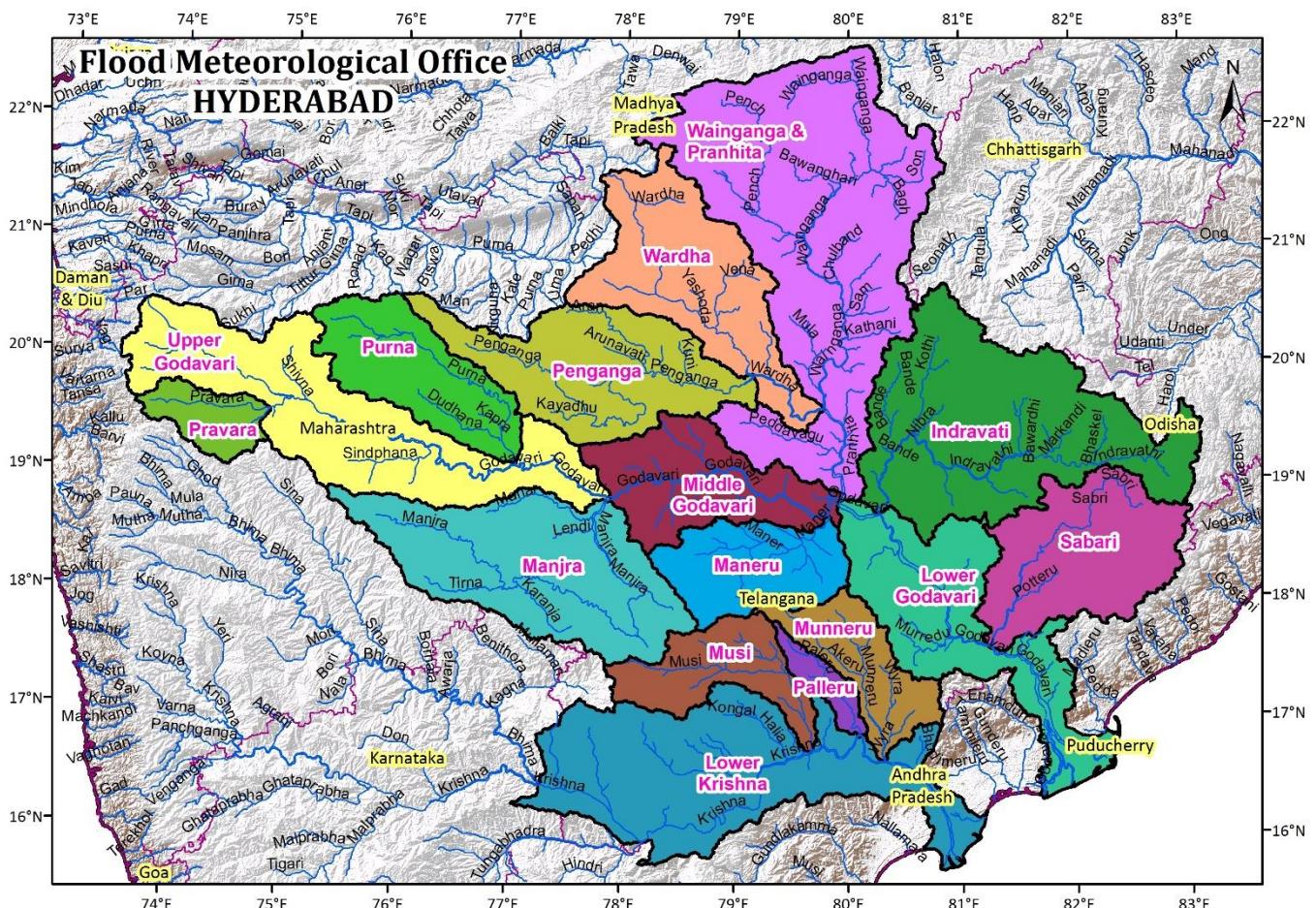


Figure 9: Map of FMO Hyderabad with Sub-basins

There are total of 16 sub-basins under the FMO Hyderabad. The name of basins, sub-basins with area (in Km²) are given in Table 9.

Table 9: Area-wise Basins/Sub-basins under FMO Hyderabad

FMO Hyderabad			
SI. No.	BASIN	SUBBASIN	Area (Sq. Km.)
1	Godavari	Wainganga & Pranhita	58316.70
2		Wardha	23113.06
3		Penganga	23129.04
4		Purna	15353.98
5		Indravati	39265.57
6		Upper Godavari	32843.49
7		Pravara	5386.38

8		Middle Godavari	16390.07
9		Sabari	20868.03
10		Manjra	30062.41
11		Maneru	12764.00
12		Lower Godavari	24569.99
13		Munneru	10127.33
14	Krishna	Musi	11015.19
15		Palleru	2976.77
16		Lower Krishna	37495.95
		Total	363677.94

2.9 FMO Jalpaiguri

The Flood Meteorological office, Jalpaiguri was established in the year 1974 to issue QPF sub-basin wise in rivers Teesta, Jaldhaka, Torsa and Raidak. It lies in the states of Sikkim and West Bengal.

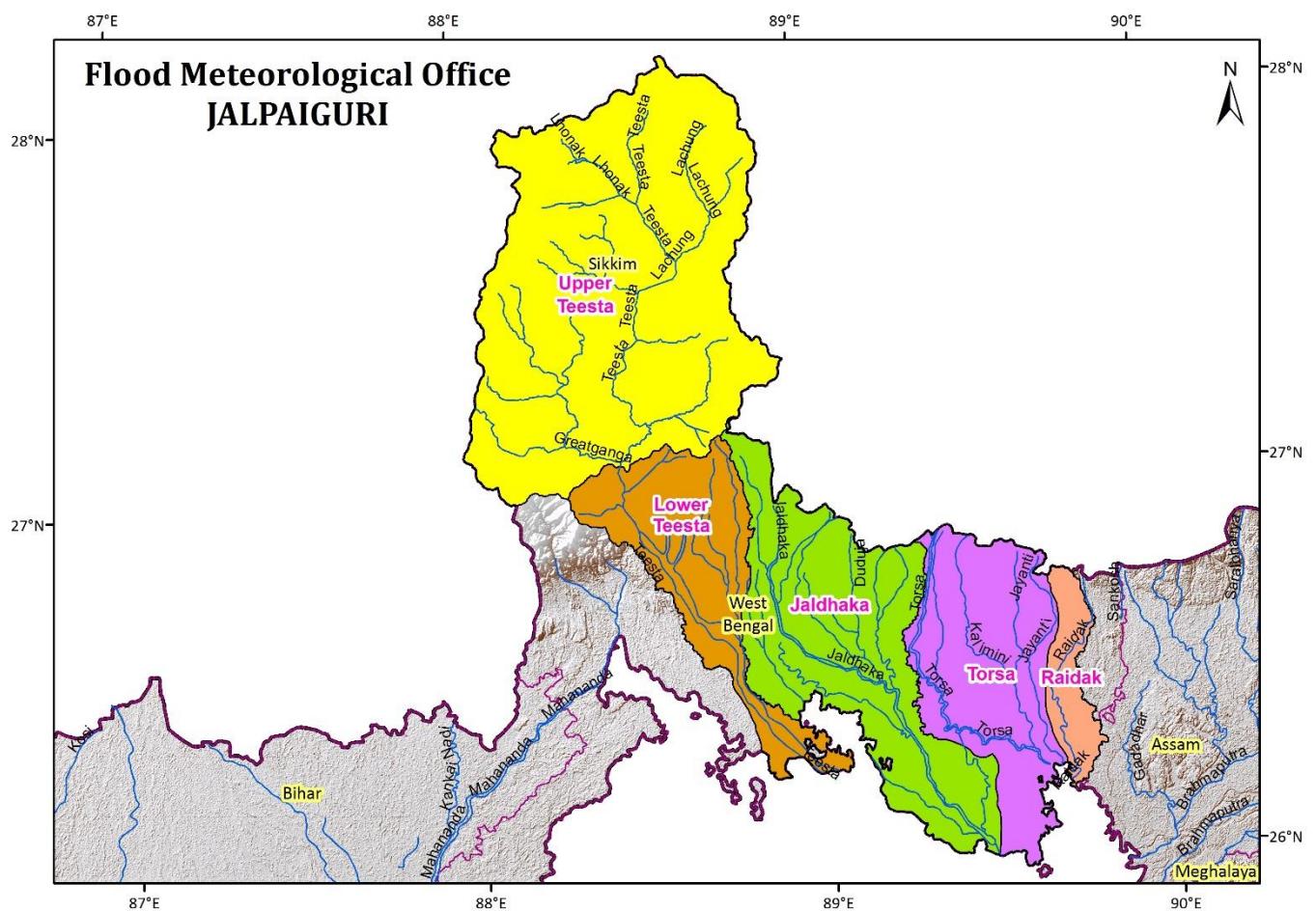


Figure 10: Map of FMO Jalpaiguri with Sub-basins

There are total of 5 sub-basins under the FMO Jalpaiguri. The name of basins, sub-basins with area (in Km²) are given in Table 10.

Table 10: Area-wise Basins/Sub-basins under FMO Jalpaiguri

FMO Jalpaiguri			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Brahmaputra	Upper Teesta	7569.27
2		Lower Teesta	2205.45
3		Jaldhaka	3705.50
4		Torsa	2643.04
5		Raidak	590.26
Total			16713.52

2.10 FMO Lucknow

The Flood Meteorological office, Lucknow was established in the year 1974 to issue QPF sub-basin wise in rivers Alaknanda, Bhagirathi, Ganga, Ghaghra, Sharda and Rapti. It lies in the states of Uttarakhand and Uttar Pradesh.

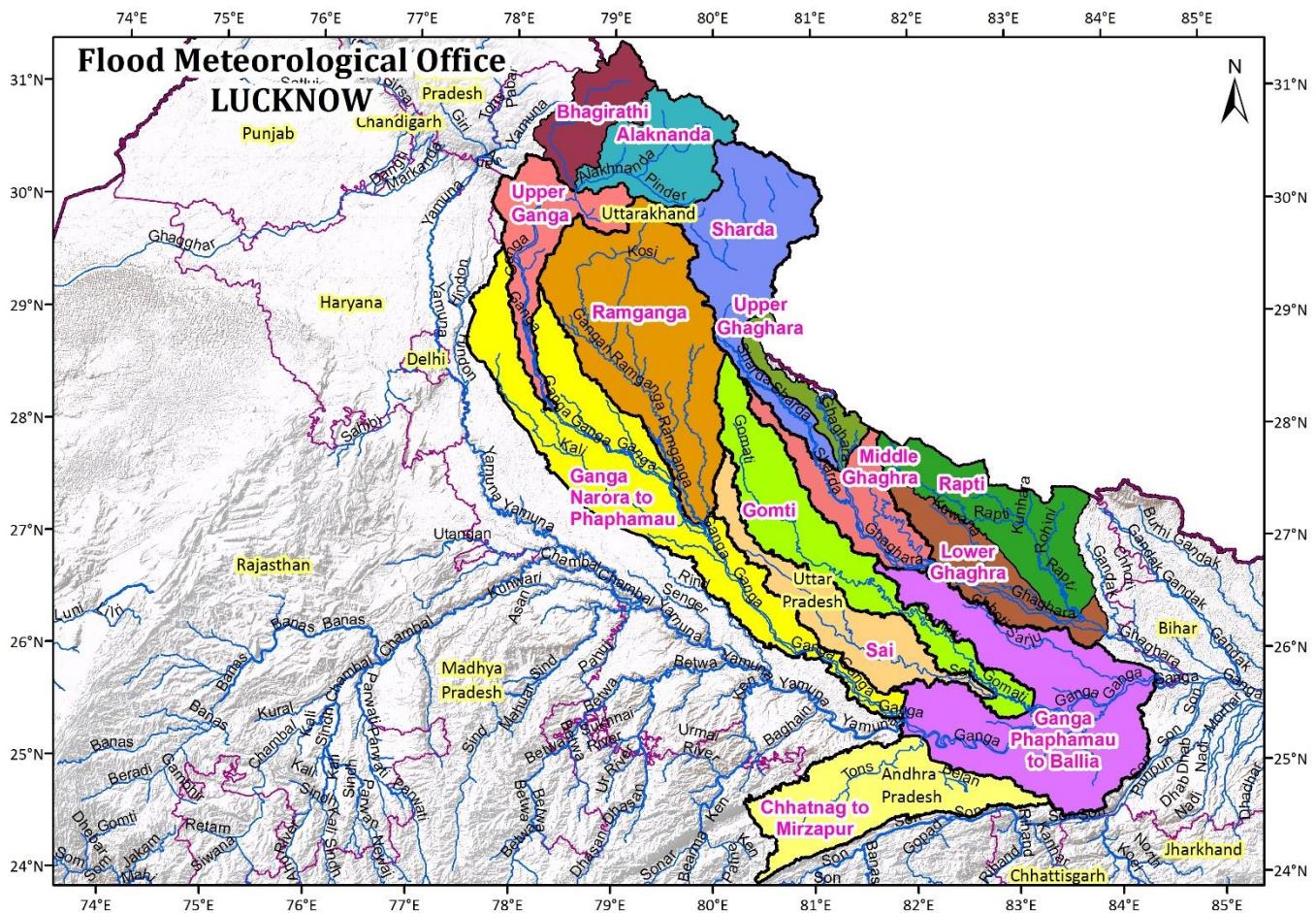


Figure 11: Map of FMO Lucknow with Sub-basins

There are total of 14 sub-basins under the FMO Lucknow. The name of basins, sub-basins with area (in Km²) are given in Table 11.

Table 11: Area-wise Basins/Sub-basins under FMO Lucknow

FMO Lucknow			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Ganga	Upper Ganga	10604.45
2		Ganga Narora to Phaphamau	31679.87
3		Ganga Phaphamau to Ballia	31437.24
4		Gomti	18317.22
5		Sai	11943.15
6		Chhatang to Mirzapur	16871.70
7	Bhagirathi	Bhagirathi	7440.94
8	Alaknanda	Alaknanda	10811.73
9	Ramganga	Ramganga	30728.17
10	Ghaghra	Upper Ghaghra	3397.16
11		Middle Ghaghra	9705.21
12		Lower Ghaghra	9766.68
13	Sharda	Sharda	13694.38
14	Rapti	Rapti	14067.04
Total			220464.94

2.11 FMO New Delhi

The Flood Meteorological office, New Delhi was established in the year 1974 to issue QPF sub-basin wise in rivers Yamuna and Sahibi. It lies in the states of Himachal Pradesh, Haryana, Uttar Pradesh and Delhi.

There are total of 3 sub-basins under the FMO New Delhi. The name of basins, sub-basins with area (in Km²) are given in Table 12.

Table 12: Area-wise Basins/Sub-basins under FMO New Delhi

FMO New Delhi			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Yamuna	Yamuna upto Hathnikund	11109.34
2		Yamuna upto Mathura	15784.68
3	Sahibi	Sahibi	9775.71
Total			36669.73

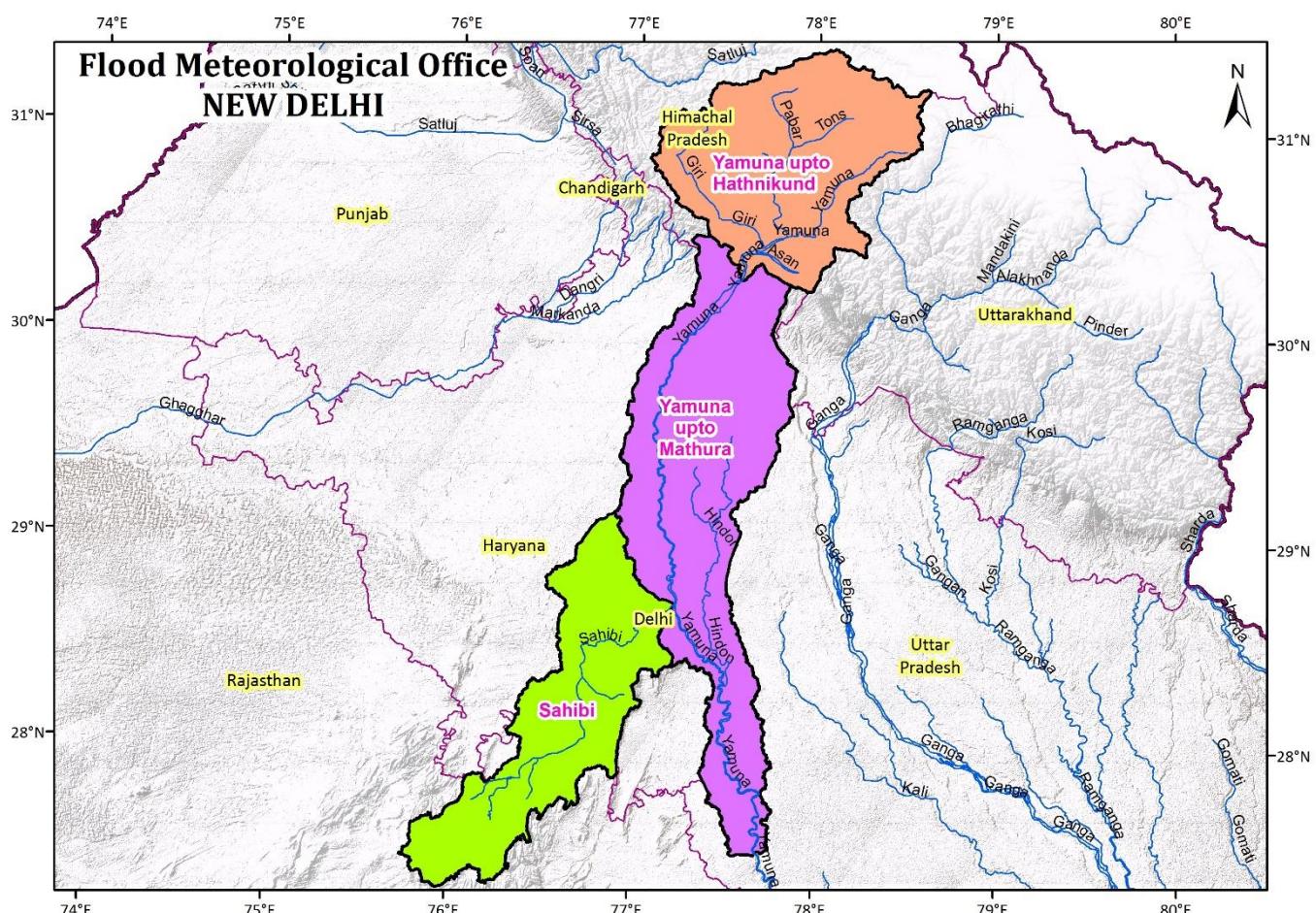


Figure 12: Map of FMO New Delhi with Sub-basins

2.12 FMO Patna

The Flood Meteorological office, Patna was established in the year 1973 to issue QPF sub-basin wise in rivers Kosi, Sone, Punpun, Bagmati, Gandak, North Koel and Kanhar. It lies in the states of Bihar, Chhattisgarh, Madhya Pradesh, Jharkhand and West Bengal.

Table 13: Area-wise Basins/Sub-basins under FMO Patna

FMO Patna			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Ganga	Kosi/Mahananda	27212.33
2		Bagmati Adhwara	8256.36
3		Gandak	27709.29
4		Sone	6144.3
5		Upper Sone	45069.53
6		Kanhar	5509.92
7		North Koel	10761.26
8		Zone VI	41035.31
Total			171698.3

There are total of 8 sub-basins under the FMO Patna. The name of basins, sub-basins with area (in Km²) are given in Table 13.

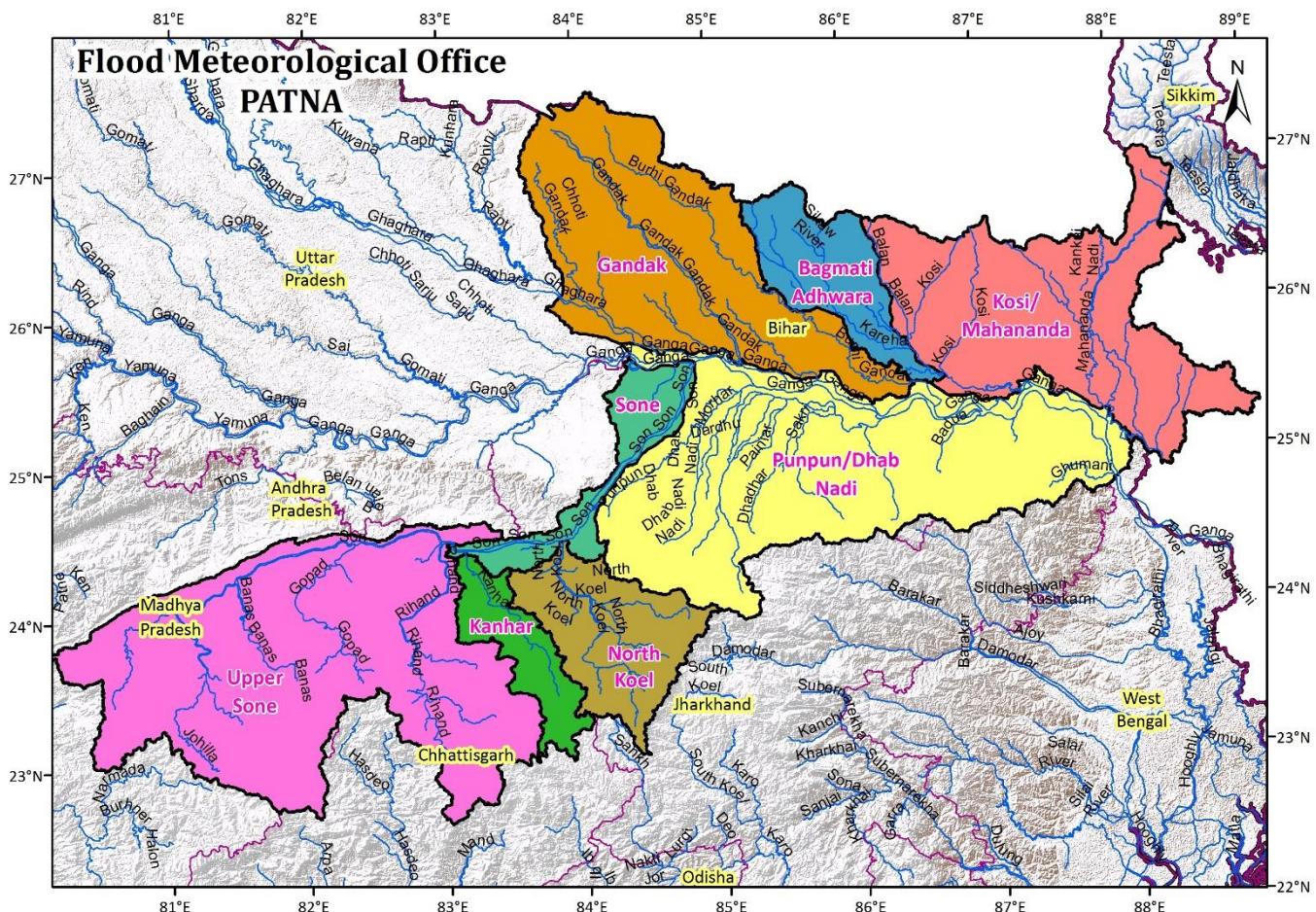


Figure 13: Map of FMO Patna with Sub-basins

2.13 FMO Srinagar

The Flood Meteorological office, Srinagar is started from this year 2015 to issue QPF sub-basin wise in Jhelum River for issuance of QPFs. It lies in the state of Jammu & Kashmir.

Table 14: Area-wise Basins/Sub-basins under FMO Srinagar

FMO Srinagar			
SI. No.	BASIN	SUBBASIN	Area (Sq. Km.)
1	Indus	Upshi Road Bridge	11061.56
2		Nimmo	17172.39
3		Khalsi	1184.66
4		Dah	3145.52
5	Jhelum	Middle Jhelum	1753.95
6		Upper Jhelum	1244.9
7		Lidder	479.96
8		Lower Jhelum	1308.64
Total			37351.58

There are total of 8 sub-basins under the FMO, Srinagar. The name of basins, sub-basins with area (in Km²) are given in Table 14.

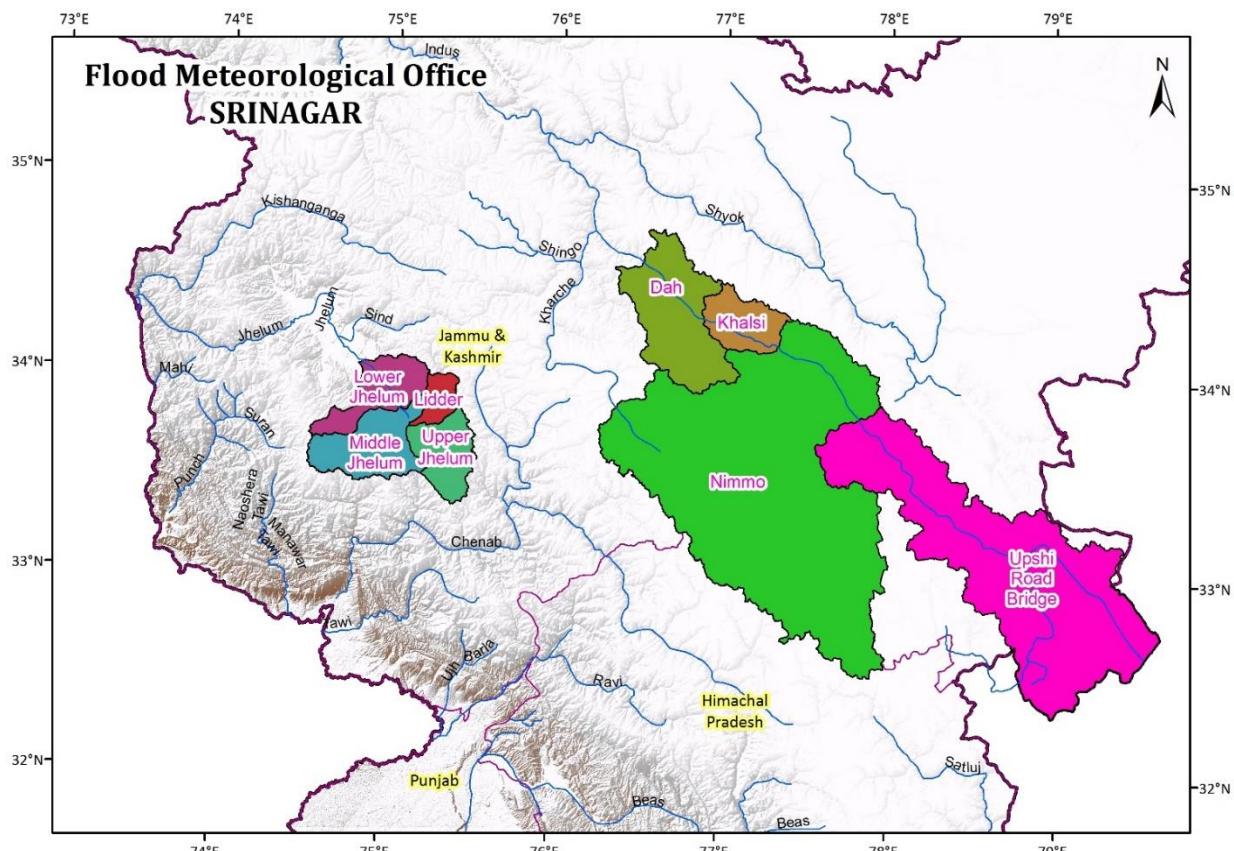


Figure 14: Map of FMO Srinagar with Sub-basins

2.14 DVC, Kolkata

The DVC, Kolkata was established in the year 1973 to issue QPF sub-basin wise in rivers Barakar and Damodar. It lies in the states of Jharkhand and West Bengal

There are total of 3 sub-basins under the DVC. The name of basins, sub-basins with area (in Km²) are given in Table 15.

Table 15: Area-wise Basins/Sub-basins under DVC

DVC Kolkata			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Barakar	Barakar West	6805.78
		Barakar East	
2	Damodar	Damodar West	10900.31
		Damodar East	
3	Lower Valley	Lower Valley West	3307.26
Total			21013.35

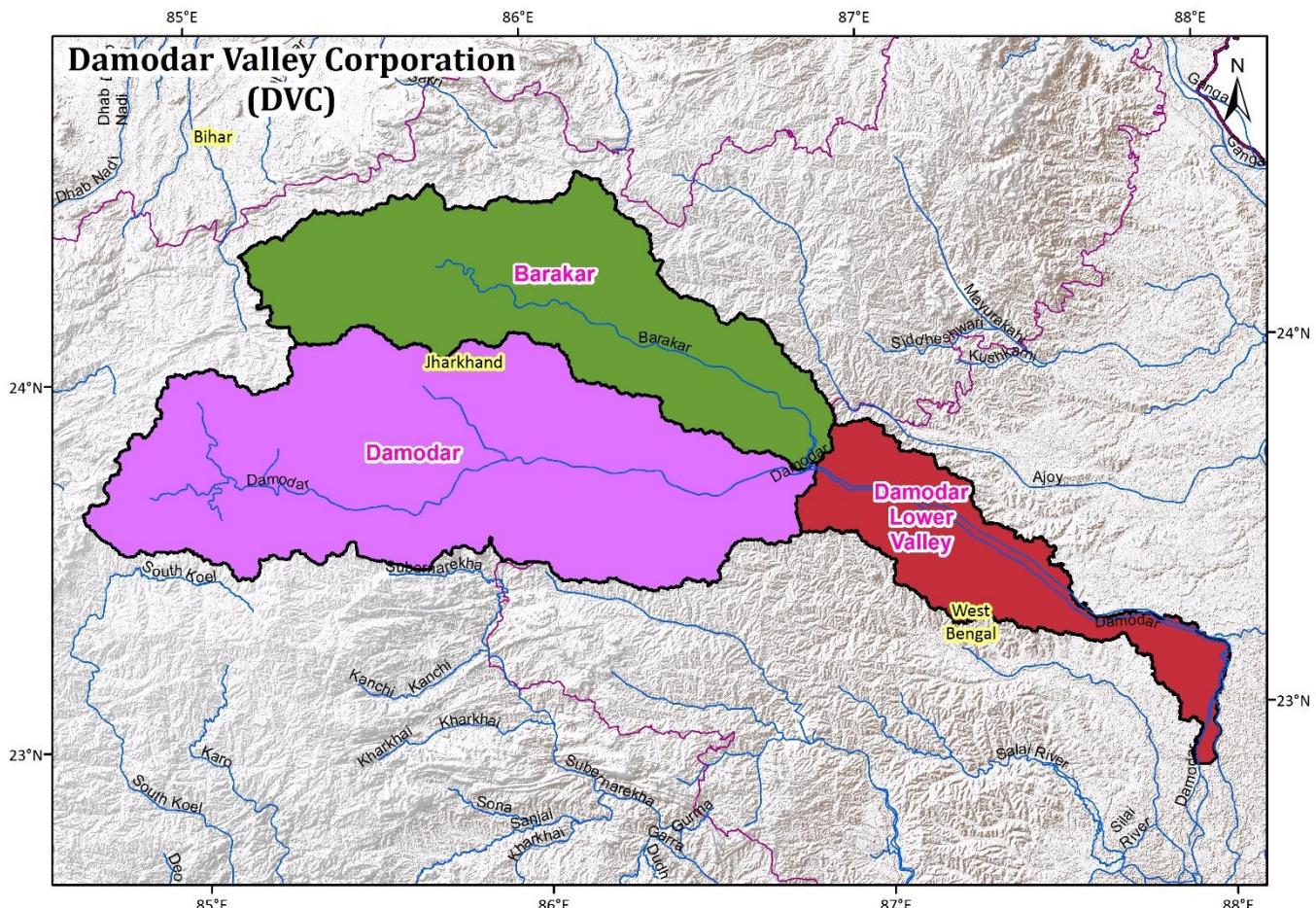


Figure 15: Map of DVC with Sub-basins

CHAPTER 3

Data Used and Methodology

3.1 Data Used

Operational QPF is issued sub-basin wise as an areal precipitation forecast by the FMOs and DVC daily during the flood season in the following categories.

- i. **0 (No Rain)**
- ii. **0.1 – 10 mm**
- iii. **11 – 25mm**
- iv. **26 – 50 mm**
- v. **51 – 100 mm**
- vi. **> 100mm**

The sub-basin wise QPF are verified with the observed sub basin wise Areal Average Rainfall (AAP) during the southwest monsoon 2020. The sub-basin observed areal rainfall has been computed by averaging the observed rainfall of stations in the area. The rainfall data of 2871 stations are used to compute sub-basin wise average observed rainfall.

The overall QPF issued for Day-1 by 13 FMOs and DVC Kolkata during the flood season 2020 is 18666, for Day-2 are 18666 and for Day-3 are 18666.

3.2 Methodology

For all the precipitation categories mentioned in section 2 above, 6 X 6 contingency table for observed and forecast precipitation category wise is prepared.

Table 16: 6 X 6 Contingency table

Observed category (mm)	Forecast Precipitation category (mm)						Total
	0	0.1-10	11-25	26-50	51-100	>100	
0	a	b	c	d	e	f	A
0.1-10	G	h	i	j	k	l	B
11-25	M	n	o	p	q	r	C
26-50	S	t	u	v	w	x	D
51-100	Y	z	aa	ab	ac	ad	E
>100	Ae	af	ag	ah	ai	aj	F
Total	G	H	I	J	K	L	T

The performance of categorical QPF issued for different river sub-Basins is verified from 6X6 contingency table. The QPF issued for different river Basins be verified by computing Percentage Correct, Heidke Skill Score(HSS) and Critical Success Index (CSI), from 6X6 Contingency table which are as follows;

$$PC = \frac{a+h+o+v+ac+aj}{T} \times 100$$

$$CSI = \frac{a}{A+G-a}, \frac{h}{B+H-h}, \frac{o}{C+I-o}, \frac{v}{D+J-v}, \frac{ac}{E+K-ac}, \frac{aj}{F+L-aj}$$

$$HSS = \frac{\frac{T(a+h+o+v+ac+aj)-(AG+BH+CI+DJ+EK+FL)}{T}}{\frac{T*(T-(AG+BH+CI+DJ+EK+FL))}{T}}$$

The POD, FAR, MR, CSI, BIAS, PC, TSS and HSS for each category be computed by reducing the above 6X6 contingency table into 2X2 contingency table for YES/NO forecast.

Table 17: 2 X 2 Contingency table

		Forecast	
		Yes	No
Yes	A	B	
	C	D	

Probability of detection (POD)= $\frac{A}{A+B}$, Range: 0 to ∞ , Perfect score = 1

False Alarm Rate (FAR)= $\frac{C}{C+A}$, Range: 0 to 1, Perfect score = 0

MissRate (MR)= $\frac{B}{B+A}$, Range: 0 to 1, Perfect score = 0

Correct Non-Occurrence (C-NON)= $\frac{D}{C+D}$, Range: 0 to 1, Perfect score = 1

Critical Success Index (CSI)=Threat Score= $\frac{A}{A+B+C}$, Range: 0 to 1, Perfect score = 1

Bias for occurrence (BIAS)= $\frac{A+C}{A+B}$, Range: 0 to ∞ , Perfect score = 1

True Skill Score (TSS)= $\frac{A}{A+B} + \frac{D}{C+D} - 1$

Heidke skill score (HSS)= $2\left\{\frac{AD-BC}{B*B+C*C+2AD+(B+C)(A+D)}\right\}$, Range: $-\infty$ to 1, Perfect score = 1

FOR BEST/PERFECT FORECAST, POD=1, FAR=0, MR=0

The final skill score is the average of this verification over all forecasting offices. In addition to percentage of correct forecast within the same category, the percentages of QPFs that are within ± 1 category and out by two or more categories are computed. During flood season 2020, the skill scores for operational sub-basin wise QPFs are computed for all FMOs and DVC for day-1, day-2 and day-3.

CHAPTER 4

QPF Verification based on Skill Scores

The QPF verification statistics for different FMOs and DVC for Day-1, Day-2 and Day-3 forecast are computed and given in the subsequent sections.

4.1 Skill Scores of Day-1 QPF

The QPF verification statistics for different FMOs and DVC for Day-1 are given in Table 18. All India percentage correct QPF within category is 61% and within ± 1 category is 95%. The maximum percentage correct QPF issued by FMO Guwahati is 81% and minimum by FMO Bengaluru as 42% as seen from Figure 16. The percentage correct forecast within ± 1 category for all the forecasting offices is more than 80% and the maximum 99% is for FMO DVC.

Table 18: Performance of Day-1 QPF for the Flood Season 2020

FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one Stage		Correct and ± 1	Out by two Stage		Out by three Stage		Out by four Stage		Correct (%)	Usable Forecast Correct & ± 1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	702	169	91	962	10	4	0	0	0	0	72%	99%
Ahmedabad	2318	1602	517	123	2242	50	16	10	0	0	0	69%	97%
Asansol	366	241	105	15	361	5	0	0	0	0	0	66%	99%
Bengaluru	3156	1339	1183	276	2798	287	48	14	6	2	1	42%	89%
Bhubaneswar	1220	771	316	110	1197	16	7	0	0	0	0	63%	98%
Chennai	1342	612	441	153	1206	108	17	5	6	0	0	46%	90%
DVC	731	491	187	46	724	2	3	0	2	0	0	67%	99%
Guwahati	2440	1970	269	121	2360	47	21	8	1	2	0	81%	97%
Hyderabad	1952	1101	546	207	1854	65	26	4	3	0	0	56%	95%
Jalpaiguri	610	288	161	82	531	52	21	5	1	0	0	47%	87%
Lucknow	1708	1144	275	234	1653	28	25	0	2	0	0	67%	97%
New Delhi	366	246	73	36	355	5	4	0	2	0	0	67%	97%
Patna	976	588	260	87	935	24	15	2	0	0	0	60%	96%
Srinagar	488	303	128	48	479	3	6	0	0	0	0	62%	98%
Over All fct.	18649	11398	4630	1629	17657	702	213	48	23	4	1	61%	95%

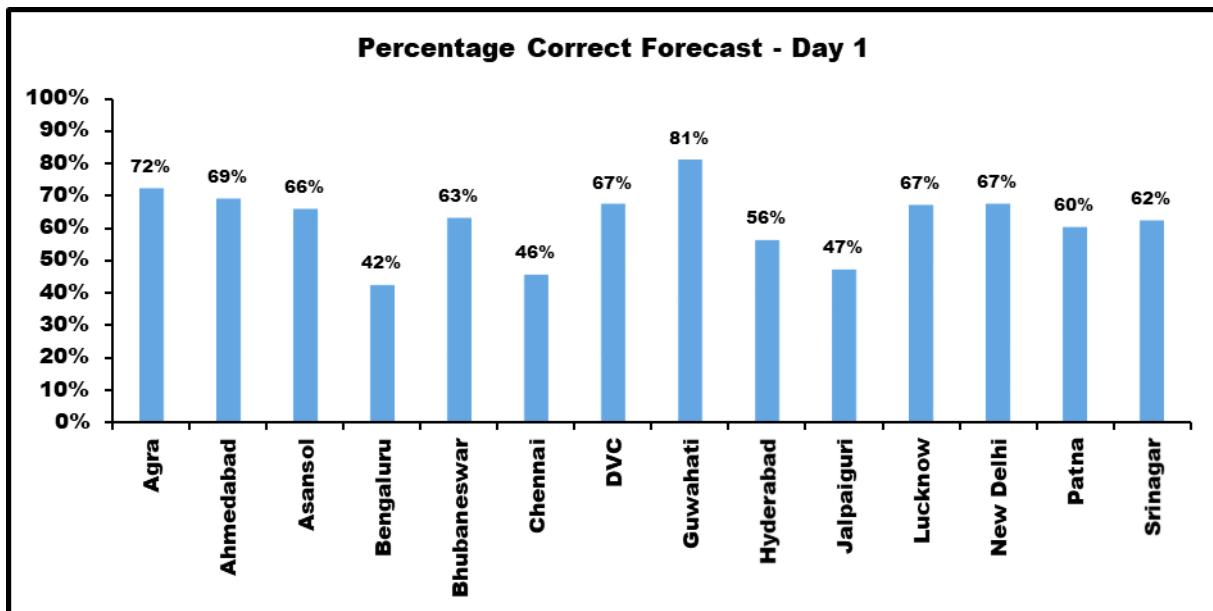


Figure 16: Percentage correct forecast Day-1 by different FMOs & DVC.

All India skill scores viz, POD, FAR, MR, CSI, BIAS, PC, TSS and HSS have been computed from 2X2 contingency table and are given in Table 19.

Table 19: Skill Scores of Day-1 QPF

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.29	0.70	0.55	0.38	0.31	0.15
False Alarm Rate (FAR):	0.30	0.28	0.62	0.68	0.55	0.85
Missing Rate (MR):	0.71	0.30	0.45	0.62	0.69	0.85
Correct Non-Occurrence (C-NON):	0.96	0.65	0.81	0.95	0.99	1.00
Critical Success Index (CSI):	0.25	0.56	0.30	0.21	0.22	0.05
Bias for Occurrence (BIAS):	0.41	1.00	1.48	1.25	0.68	1.01
Hit Rate:	0.87	0.69	0.78	0.93	0.98	1.00
Percentage of Correct (PC):	0.87	0.69	0.78	0.93	0.98	1.00
True Skill Score (TSS):	0.25	0.35	0.36	0.33	0.30	0.14
Heidke Skill Score (HSS):	0.29	0.34	0.31	0.29	0.31	0.09

All India false alarm rate increases for higher categories. The maximum false alarm rate is for >100 category and maximum missing rate is also for >100 category.

FMO wise CSI, MR, and FAR for different categories of rainfall for Day1 is given in Figures 17 to 19. Critical Success Index (CSI) decreases towards higher categories of QPF for all FMOs.

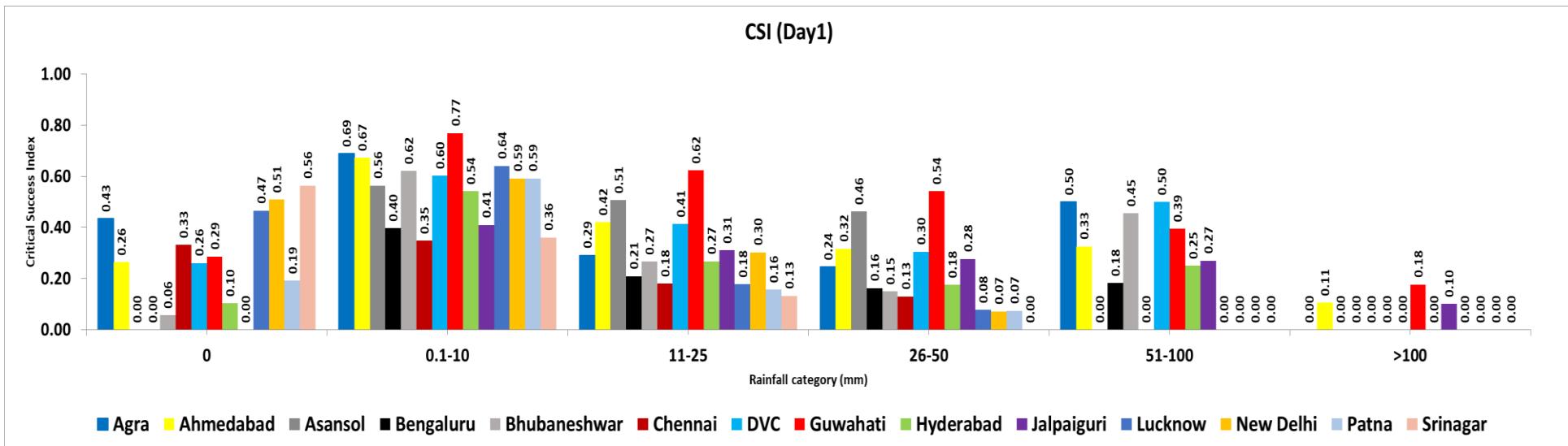


Figure 17: CSI for different categories of forecast for Day1

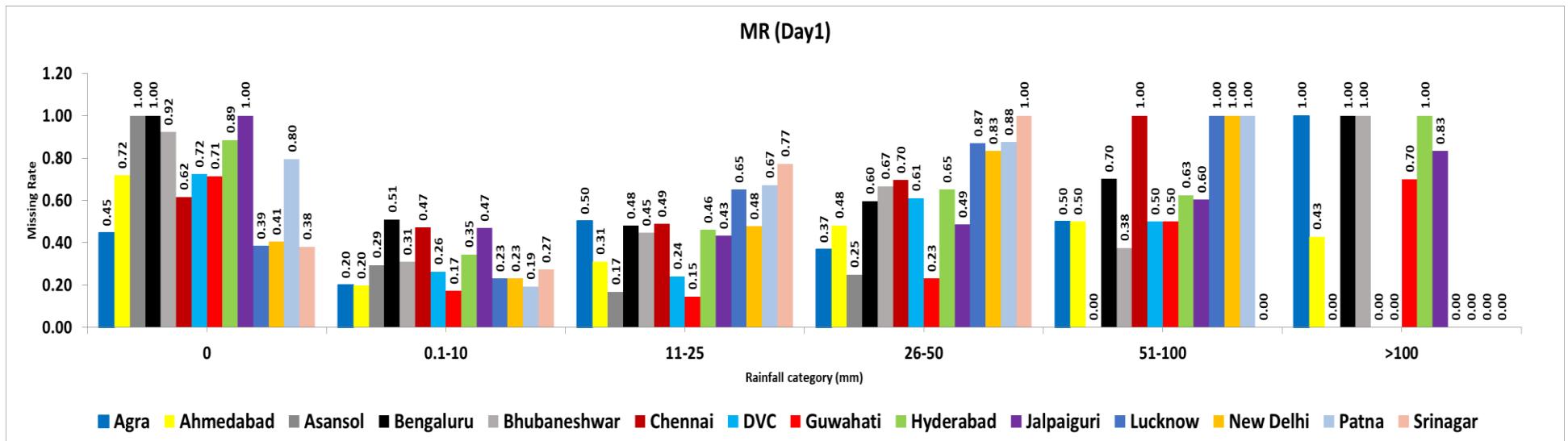


Figure 18: MR for different categories of forecast for Day-1

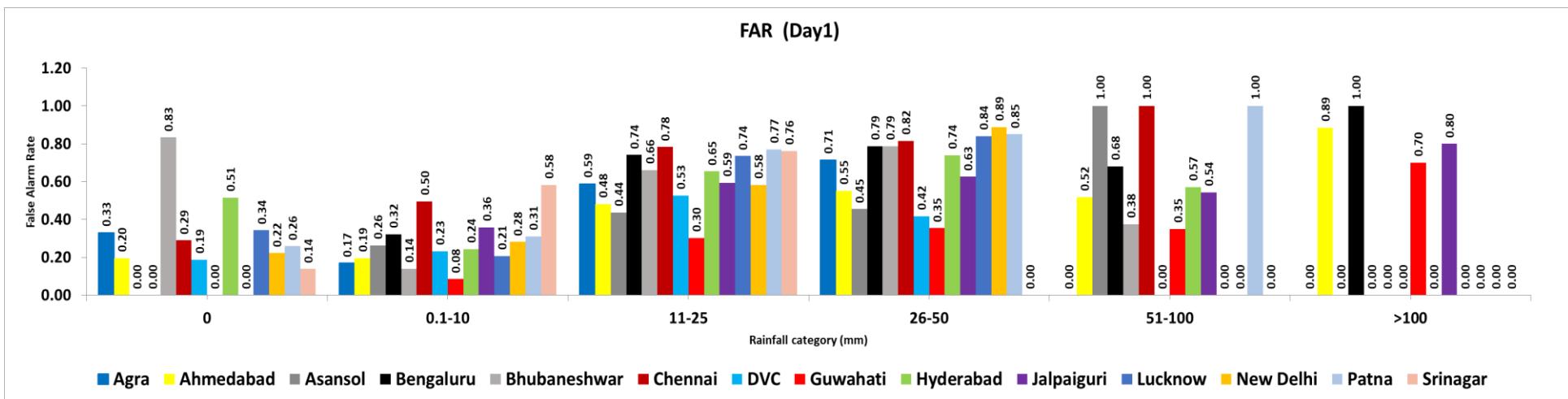


Figure 19: FAR for different categories of forecast for Day-1

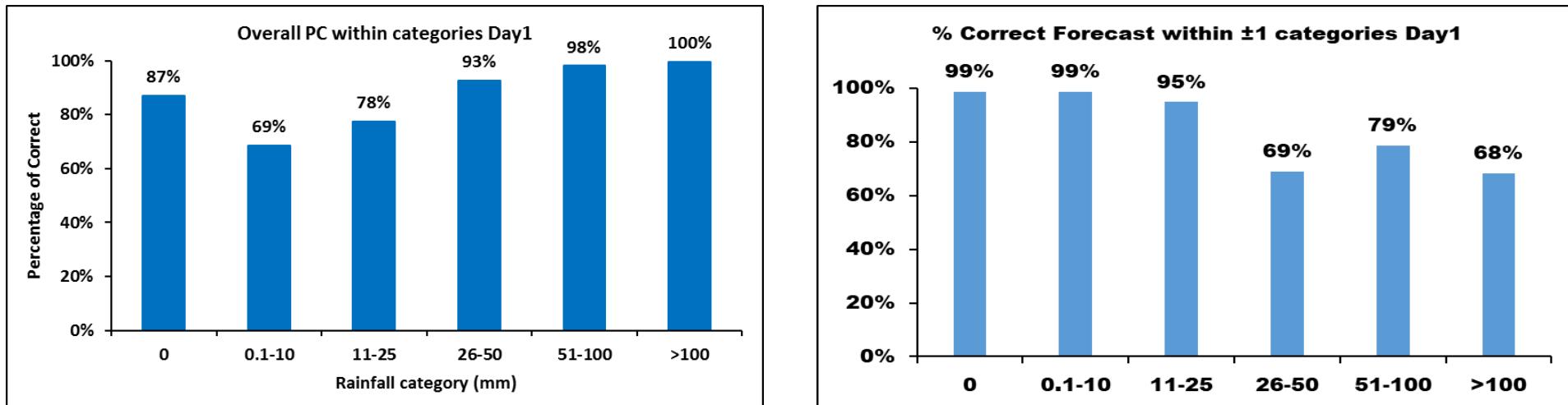


Figure 20: % Correct Forecast within Category and within ±1 categories of Day-1 QPF

The category wise QPF verification for correct forecast and correct forecast within ± 1 are given in Figure 20 .

4.2 Skill Scores of Day-2 QPF

The QPF verification statistics for different FMOs and DVC for Day-2 are computed and presented in Table 20. All India percentage correct QPF within category is 57% and within ± 1 category is 94%. The maximum percentage correct QPF issued by FMO Agra is 68% and minimum is 44% by FMO Bengaluru. The percentage correct forecast within ± 1 category for all the forecasting offices is more than 80% and the maximum 99% is for FMO Asansol.

FMO wise skill scores viz, POD, FAR, MR, CSI, BIAS, PC, TSS and HSS have been computed from 2X2 contingency table and are given in Table 21. All India false alarm rate increases for higher categories. The maximum false alarm rate and missing rate are for the category >100 mm.

The category wise QPF verification for correct forecast and correct forecast within ± 1 are given in Figure 25 and it showed that the forecast efficiency decreases for higher categories. It can also be seen that the percentage correct forecast within ± 1 category for higher rainfall categories 26-50 and 51-100 mm are 64% and 69% respectively.

Table 20: Performance of Day-2 QPF for the Flood Season 2020

FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one Stage		Correct and ± 1	Out by two Stage		Out by three Stage		Out by four Stage		Correct (%)	Usable Forecast Correct & ± 1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	661	176	95	932	41	2	0	1	0	0	68%	95%
Ahmedabad	2318	1404	450	361	2215	34	58	6	5	0	0	61%	96%
Asansol	366	217	107	38	362	4	0	0	0	0	0	59%	99%
Bengaluru	3156	1404	1089	341	2834	223	66	24	7	1	1	44%	90%
Bhubaneswar	1220	781	281	128	1190	16	14	0	0	0	0	64%	98%
Chennai	1342	649	342	228	1219	65	46	8	3	0	1	48%	91%
DVC	731	463	175	77	715	6	8	0	2	0	0	63%	98%
Guwahati	2440	1572	387	388	2347	45	37	5	5	1	0	64%	96%
Hyderabad	1952	1046	521	256	1823	66	52	5	5	1	0	54%	93%
Jalpaiguri	610	273	144	103	520	54	23	9	4	0	0	45%	85%
Lucknow	1708	1122	346	182	1650	38	20	0	0	0	0	66%	97%
New Delhi	366	224	89	37	350	10	4	1	1	0	0	61%	96%
Patna	976	563	286	73	922	34	15	3	2	0	0	58%	94%
Srinagar	488	319	108	51	478	1	9	0	0	0	0	65%	98%
Over All fct.	18649	10698	4501	2358	17557	637	354	61	35	3	2	57%	94%

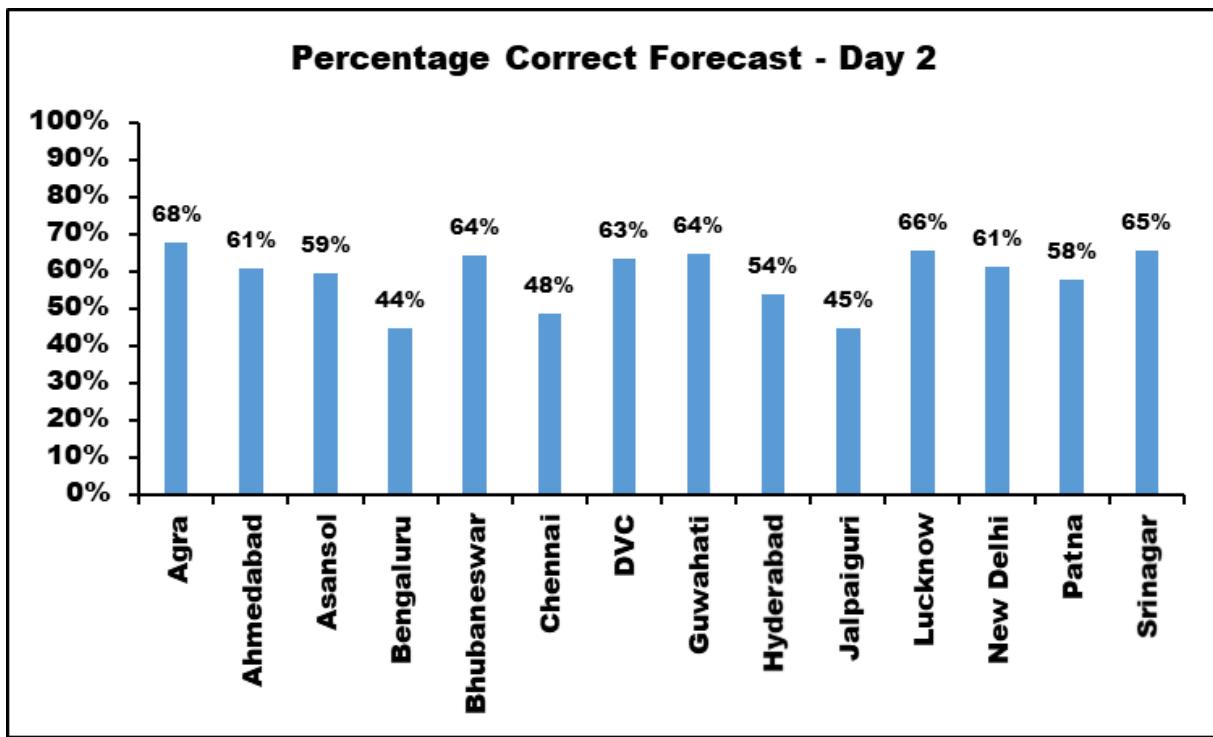


Figure 21. Percentage correct forecast Day-2 by different FMOs & DVC.

Table 21: Skill Scores of Day-2 QPF

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.28	0.69	0.46	0.19	0.19	0.10
False Alarm Rate (FAR):	0.39	0.31	0.67	0.82	0.73	0.83
Missing Rate (MR):	0.72	0.31	0.54	0.81	0.81	0.90
Correct Non-Occurrence (C-NON):	0.95	0.60	0.80	0.95	0.99	1.00
Critical Success Index (CSI):	0.23	0.53	0.24	0.10	0.10	0.06
Bias for Occurrence (BIAS):	0.44	1.02	1.41	1.28	0.74	0.49
Hit Rate:	0.87	0.66	0.75	0.92	0.98	1.00
Percentage of Correct (PC):	0.87	0.66	0.75	0.92	0.98	1.00
True Skill Score (TSS):	0.23	0.29	0.25	0.14	0.19	0.10
Heidke Skill Score (HSS):	0.27	0.28	0.22	0.13	0.15	0.10

CSI, MR, and FAR for different categories of rainfall for Day2 is given in Figures 22 to 24. Critical Success Index (CSI) decreases towards higher categories of QPF.

All India false alarm rate increases for higher categories. The maximum false alarm rate is for >100 category and maximum missing rate is also for >100 category.

FMO wise CSI, MR, and FAR for different categories of rainfall for Day 2 is given in Figures 22 to 24. Critical Success Index (CSI) decreases towards higher categories of QPF for all FMOs.

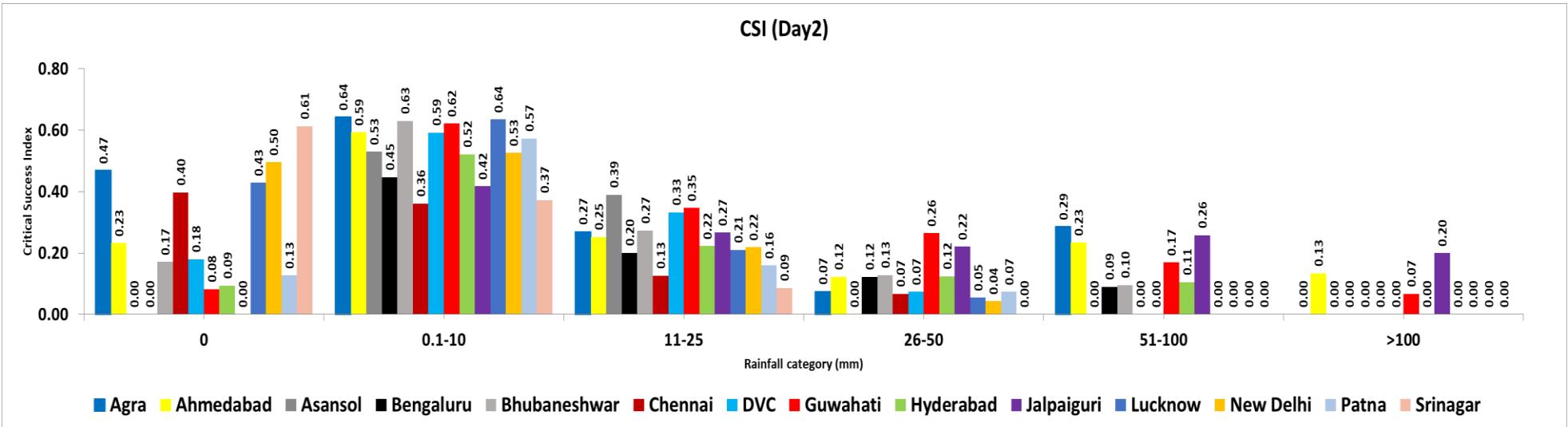


Figure 22. : CSI for different categories of forecast for Day2

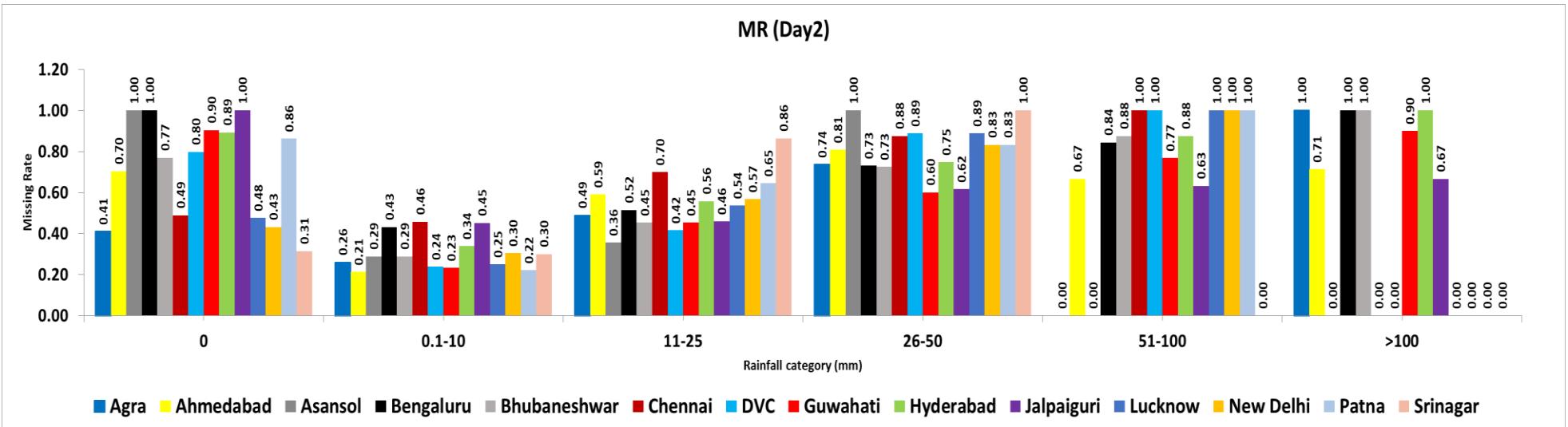


Figure 23. : MR for different categories of forecast for Day2

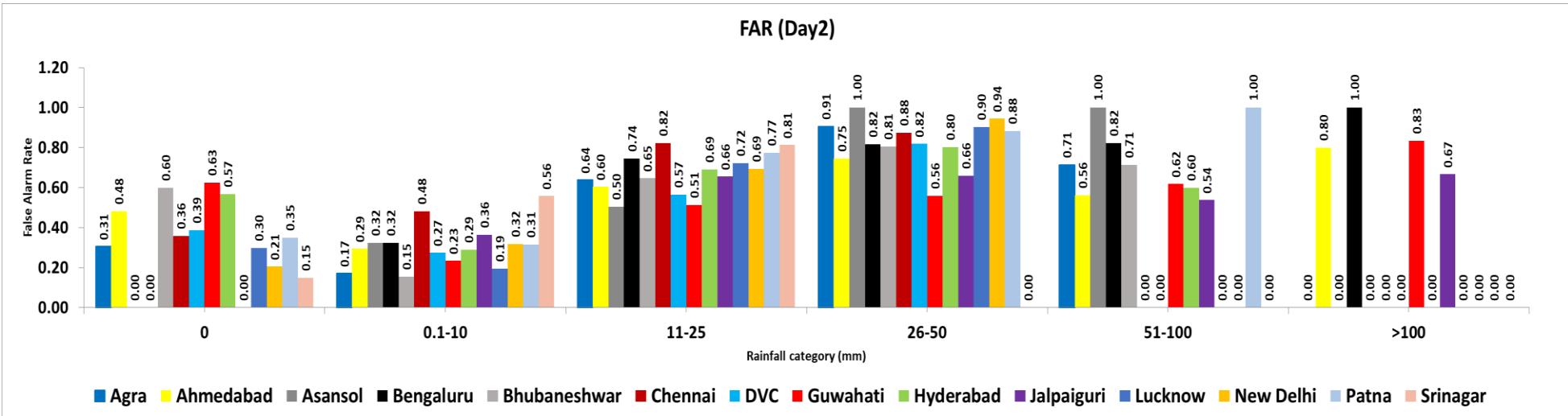


Figure 24. : FAR for different categories of forecast for Day2

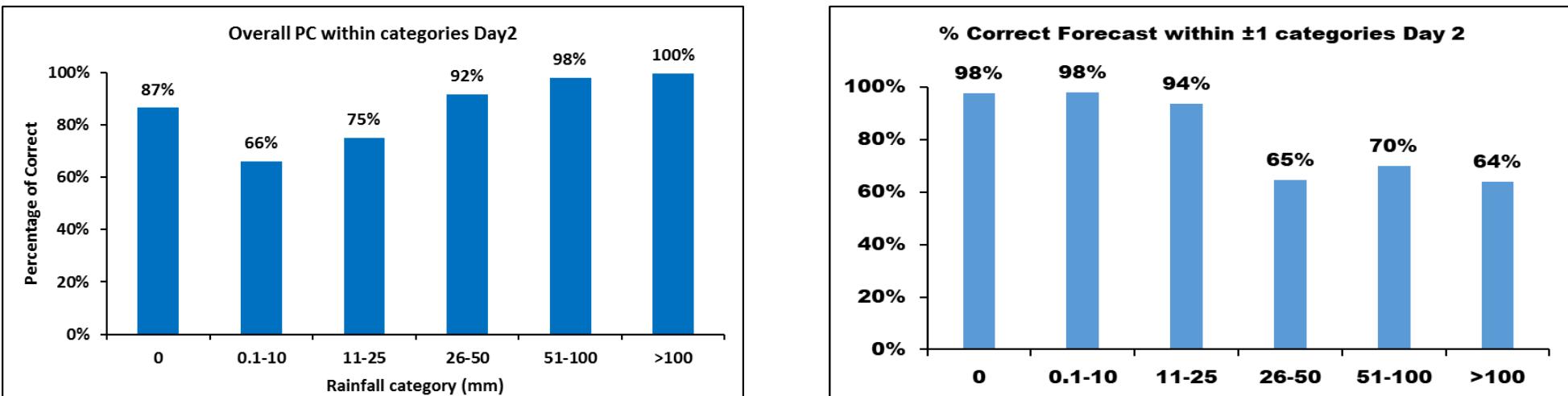


Figure 25: % Correct Forecast within Category and within ±1 categories of Day-2 QPF

The category wise QPF verification for correct forecast and correct forecast within ± 1 category are given in Figure 25.

4.3 Skill Scores of Day-3 QPF

The QPF verification statistics for different FMOs, MC Srinagar and DVC for Day-3 are given in Table 22. It can be seen from this table that the all India percentage correct QPF within category is 56% and within ± 1 category is 94%. The maximum percentage correct QPF issued by FMO Guwahati is 63% and minimum is 46% by FMO Jalpaiguri. The percentage correct forecast within ± 1 category for all the forecasting offices is more than 80% and the maximum 99% is for FMO Asansol.

The skill scores viz, POD, FAR, MR, CSI, BIAS, PC, TSS and HSS have been computed from 2X2 contingency table and are given in Table 23. All India false alarm rate increases for higher categories. The maximum false alarm rate and missing rate is for >100 mm category. Numbers of forecasts issued are decreasing for higher categories because there is less no. of heavy rainfall cases.

The category wise QPF verification for correct forecast and correct forecast within ± 1 category are given in Figure 30 and it showed that the forecast efficiency decreases for higher categories.

Table 22: Performance of Day-3 QPF for the Flood Season 2020

FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one		Correct and ± 1	Out by two Stage		Out by three Stage		Out by four Stage		Correct (%)	Usable Forecast Correct & ± 1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	591	232	100	923	46	6	1	0	0	0	61%	95%
Ahmedabad	2318	1373	384	439	2196	33	79	2	8	0	0	59%	95%
Asansol	366	211	103	49	363	2	1	0	0	0	0	58%	99%
Bengaluru	3156	1462	1028	361	2851	188	71	27	14	4	1	46%	90%
Bhubaneswar	1220	770	277	141	1188	13	19	0	0	0	0	63%	97%
Chennai	1342	616	344	261	1221	58	44	8	7	0	4	46%	91%
DVC	731	437	179	97	713	8	8	0	2	0	0	60%	98%
Guwahati	2440	1547	331	455	2333	37	56	3	11	0	0	63%	96%
Hyderabad	1952	1086	441	271	1798	64	75	4	11	0	0	56%	92%
Jalpaiguri	610	278	131	130	539	37	26	3	5	0	0	46%	88%
Lucknow	1708	1068	451	127	1646	47	14	0	1	0	0	63%	96%
New Delhi	366	211	98	33	342	19	3	2	0	0	0	58%	93%
Patna	976	555	273	85	913	36	16	11	0	0	0	57%	94%
Srinagar	488	298	122	56	476	0	12	0	0	0	0	61%	98%
Over All fct.	18649	10503	4394	2605	17502	588	430	61	59	4	5	56%	94%

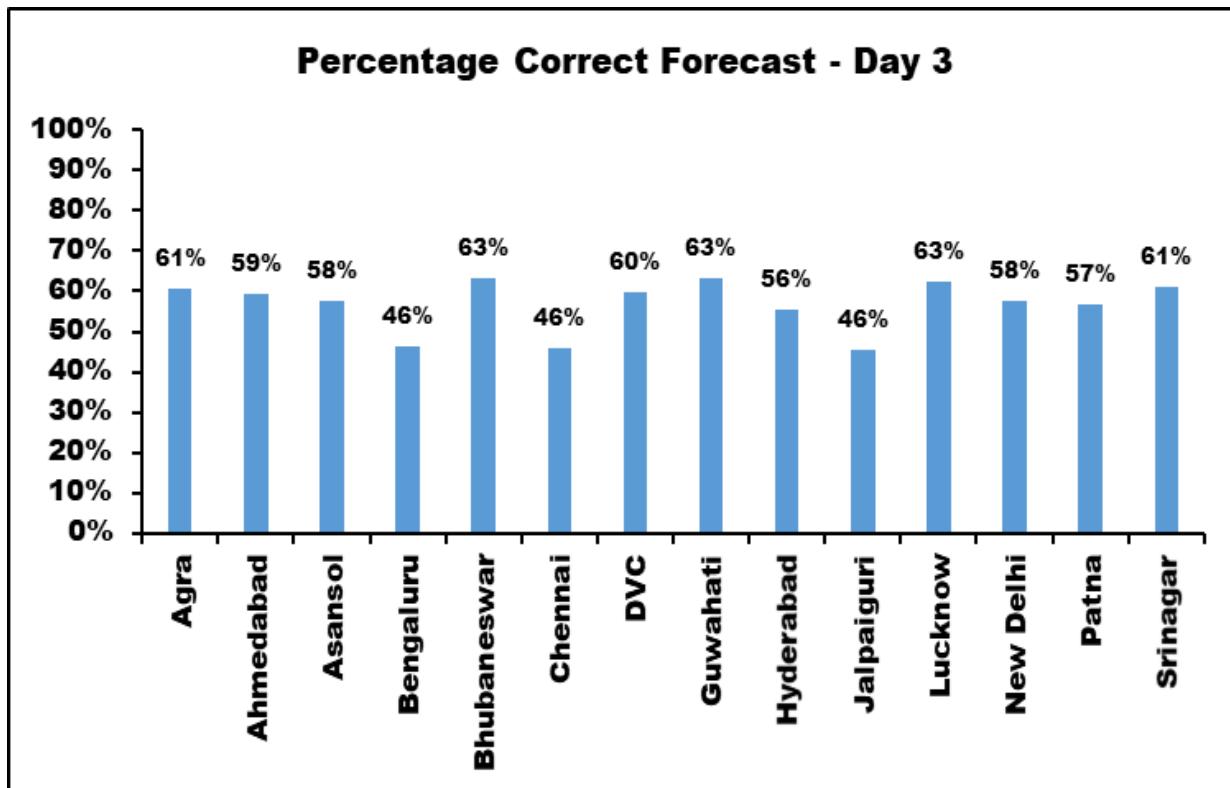


Figure 26. Percentage correct forecast Day-3 by different FMOs & DVC.

Table 23: Skill Scores of Day-3 QPF

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.26	0.69	0.41	0.23	0.06	0.04
False Alarm Rate (FAR):	0.47	0.33	0.69	0.81	0.76	0.89
Missing Rate (MR):	0.74	0.31	0.59	0.77	0.94	0.96
Correct Non-Occurrence (C-NON):	0.94	0.56	0.80	0.95	1.00	1.00
Critical Success Index (CSI):	0.22	0.52	0.21	0.11	0.05	0.03
Bias for Occurrence (BIAS):	0.45	1.05	1.37	1.51	0.59	0.54
Hit Rate:	0.86	0.64	0.74	0.92	0.98	1.00
Percentage of Correct (PC):	0.86	0.64	0.74	0.92	0.98	1.00
True Skill Score (TSS):	0.21	0.25	0.21	0.18	0.06	0.04
Heidke Skill Score (HSS):	0.23	0.24	0.19	0.15	0.09	0.04

CSI, MR, and FAR for different categories of rainfall for Day3 is given in Figures 27 to 29. Critical Success Index (CSI) decreases towards higher categories of QPF.

All India false alarm rate increases for higher categories. The maximum false alarm rate is for >100 category and maximum missing rate is also for >100 category.

FMO wise CSI, MR, and FAR for different categories of rainfall for Day 3 is given in Figures 27 to 29. Critical Success Index (CSI) decreases towards higher categories of QPF for all FMOs.

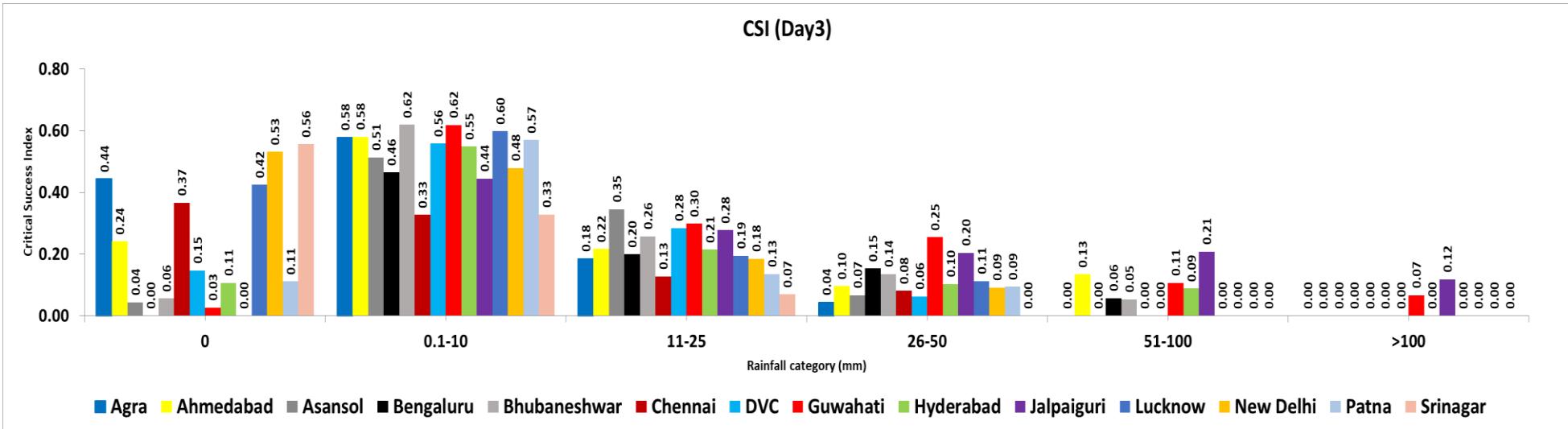


Figure 27: CSI for different categories of forecast for Day3

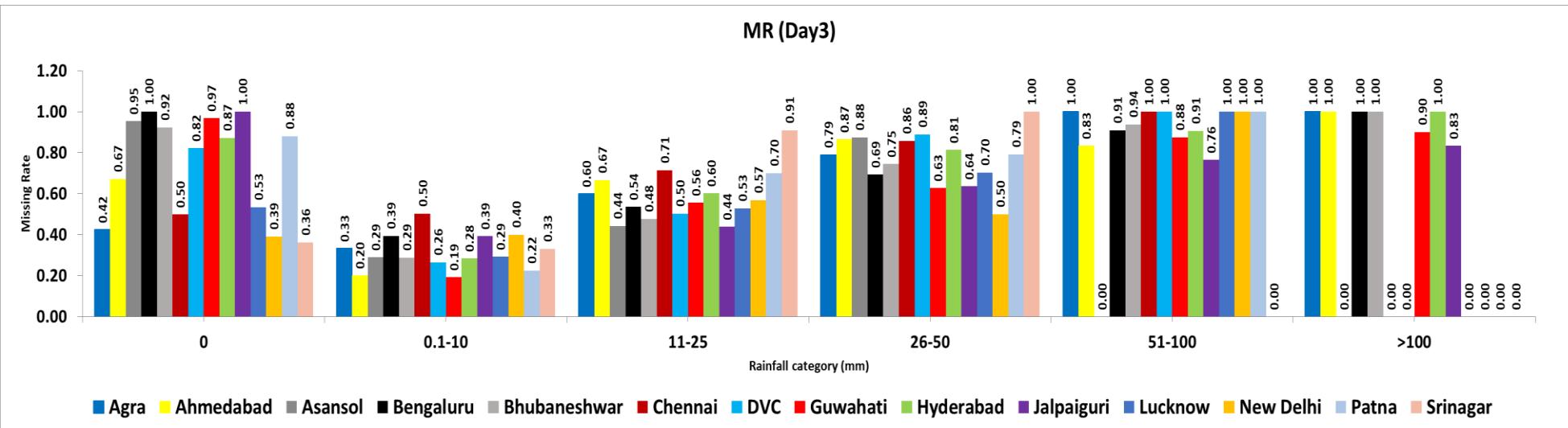


Figure 28: MR for different categories of forecast for Day3

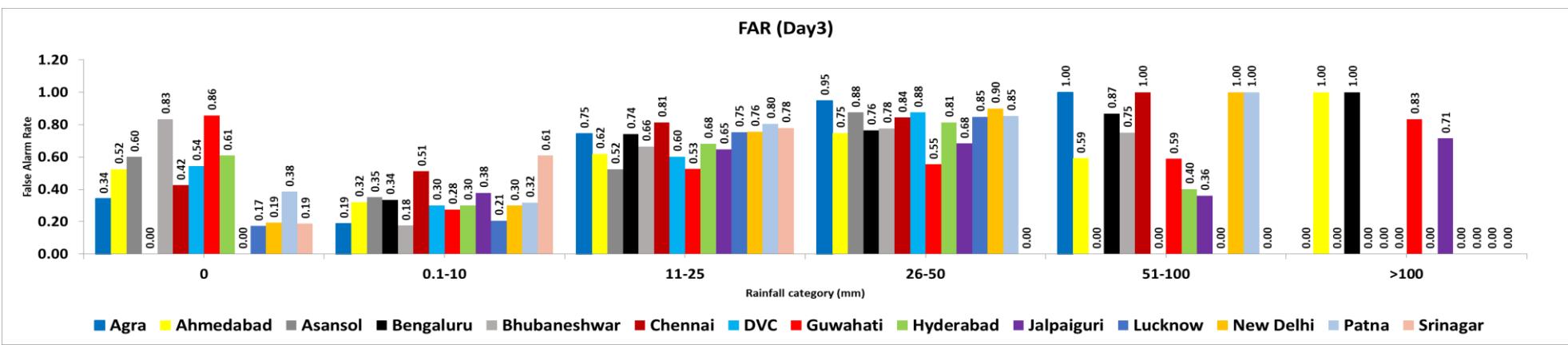


Figure 29: FAR for different categories of forecast for Day3

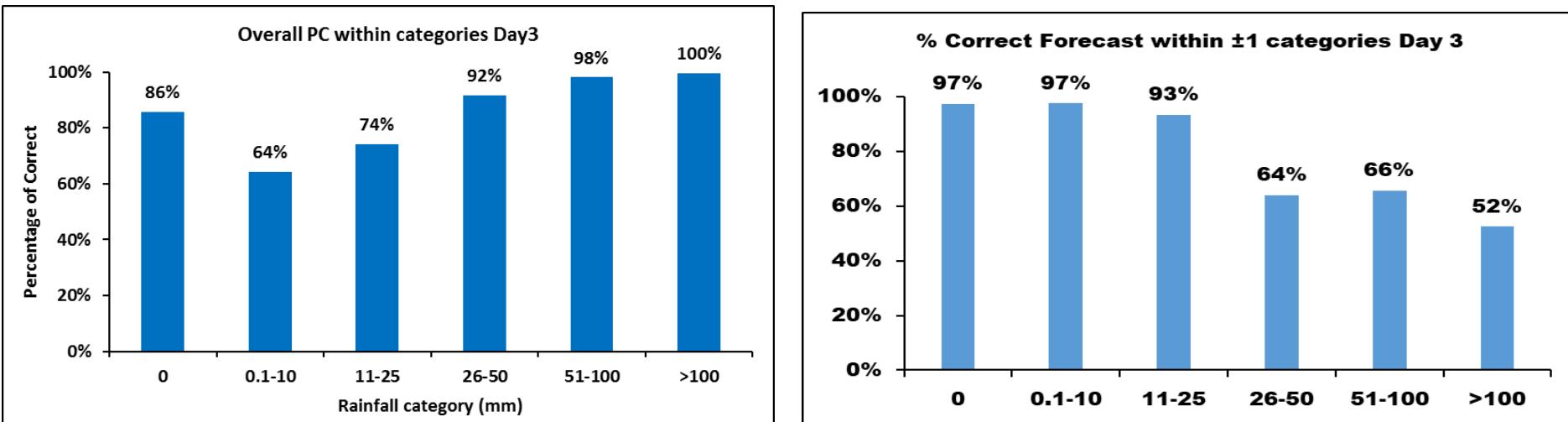


Figure 30: % Correct Forecast within Category and within ±1 categories of Day-3 QPF

The category wise QPF verification for correct forecast and correct forecast within ± 1 are given in Figure 30. It can also be seen that the percentage correct forecast within ± 1 category for higher rainfall categories 51-100 mm and >100 mm varies between 52 to 66%.

4.4 Analysis of Heavy rainfall Cases

Generally, the flood occurs when the Basin receives heavy rainfall and it depends on antecedent conditions of the soil. When the soil is fully saturated then the small amount of rainfall may also lead to flood. While giving QPF forecast, forecasters try to minimize both false alarm and missed cases; false alarm results into unnecessary displacement and missed rate results into unexpected inundation. The prediction of heavy rainfall cases (rainfall categories above 26mm) are very important for the flood events and the statistics for total number of inaccurate forecast (out by ≥ 1 category), either false alarm or missed category, in respect of rainfall categories 26-50, 51-100, and > 100 mm for all FMOs and DVC Kolkata are given in Table 24. This Table indicates that the total numbers of Inaccurate forecast (Day-1) are 1607 for category 26-50, 361 for category 51-100 and 95 for category > 100 mm. The maximum numbers of these for FMO Bengaluru (Operational from year 2016) followed by FMO Hyderabad for category 26-50 mm & 51-100 mm and FMO Ahmedabad for category > 100 . All India percentage frequency of False Alarm (FA) cases (no. of QPF issued in higher category, but observed in lower category) and Missing Cases (MC) (no. lower category QPF issued but higher category observed) for the Inaccurate Forecast (IF) in the categories 26-50, 51-100, and > 100 mm are given in Figure 23. For the category 26-50 mm and >100 mm, FA cases are more than MC whereas for 51-100 mm category missed cases are much more than FA.

Table 24: Total Nos. of Inaccurate Forecast (IF), False Alarm (FA) cases & Missed Cases (MC)

FMO	HIGH RAINFALL CATEGORY								
	26-50 mm			51-100 mm			>100 mm		
	No. of inaccurate forecast (IF)	False Alarm Cases (FA)	Missed Case (MC)	No. of inaccurate forecast (IF)	False Alarm Cases (FA)	Missed Case (MC)	No. of inaccurate forecast (IF)	False Alarm Cases (FA)	Missed Case (MC)
AGRA	37	30	7	1	0	1	1	0	1
Ahmedabad	158	90	68	56	29	27	34	31	3
Asansol	7	5	2	1	1	0	0	0	0
Bengaluru	578	412	166	103	49	54	24	5	19
Bhubaneswar	97	63	34	12	6	6	2	0	2
Chennai	114	75	39	15	3	12	0	0	0
DVC	16	5	11	2	0	2	0	0	0
Guwahati	118	76	42	43	15	28	14	7	7
Hyderabad	202	122	80	36	16	20	1	0	1
Jalpaiguri	144	92	52	73	32	41	18	8	10
Lucknow	84	37	47	8	0	8	0	0	0
New Delhi	13	8	5	3	0	3	0	0	0
Patna	38	17	21	12	7	5	0	0	0
Srinagar	8	0	8	0	0	0	0	0	0
TOTAL	1614	1032	582	365	158	207	94	51	43

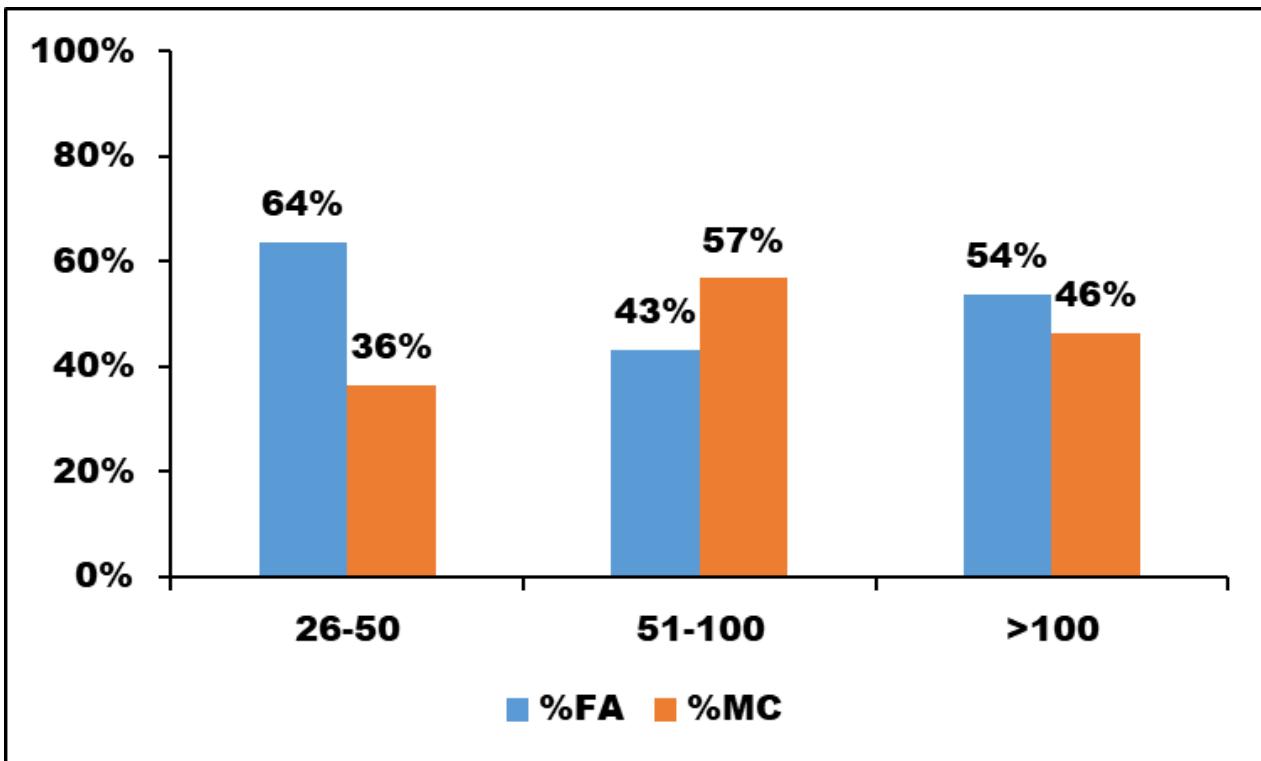


Figure 31: % of FA cases & MC for higher rainfall categories

4.5 All India overall QPF Verification for Day-1, Day-2 and Day-3

The Day-1, Day-2 and Day-3 percentage correct forecast for overall sub-Basins under different FMOs are given in Figure 32. It can be seen that the % accuracy decreases from day-1 as 61% to day-3 as 56%. It can be also observed that there is increment in Day-1 and Day-2 from previous years.

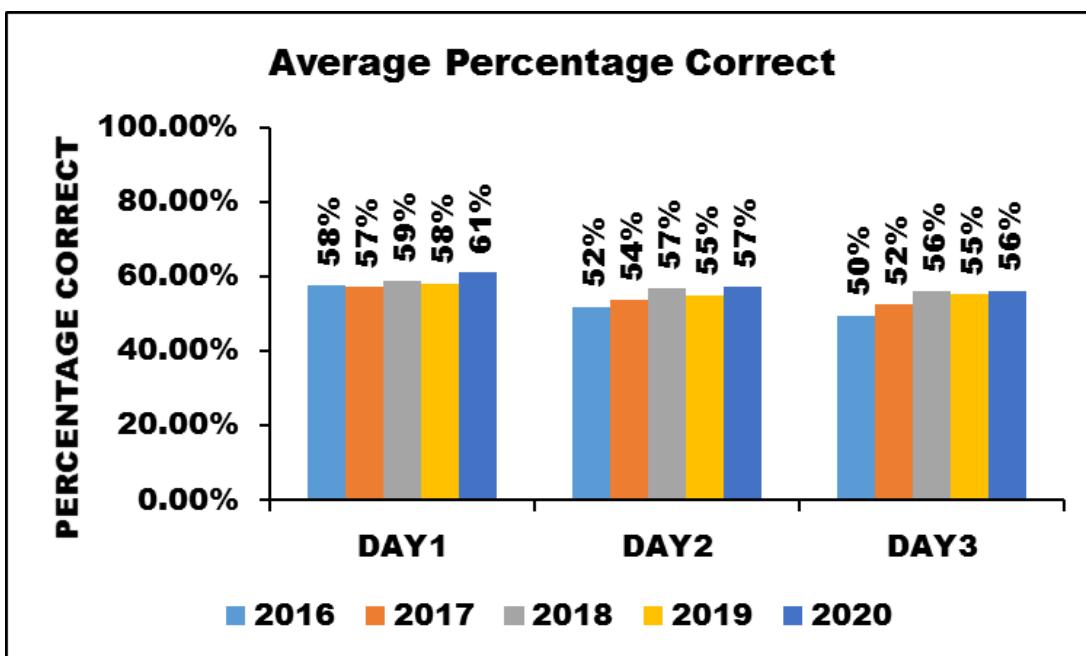


Figure 32: Day-1, Day-2 and Day-3 overall % correct forecast

The category-wise overall critical success index average over all sub-Basins under different FMOs and DVC for Day-1, Day-2 and Day-3 are given in Figure 33. It is observed that there is an improvement of Day-1 forecast over Day-2 & Day-3.

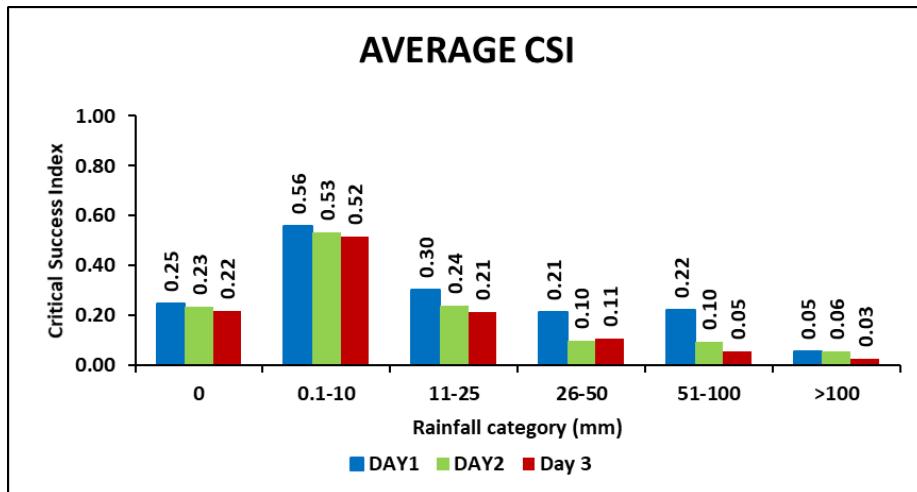


Figure 33: Category-wise Critical Success Index for Day1, Day2 and Day3

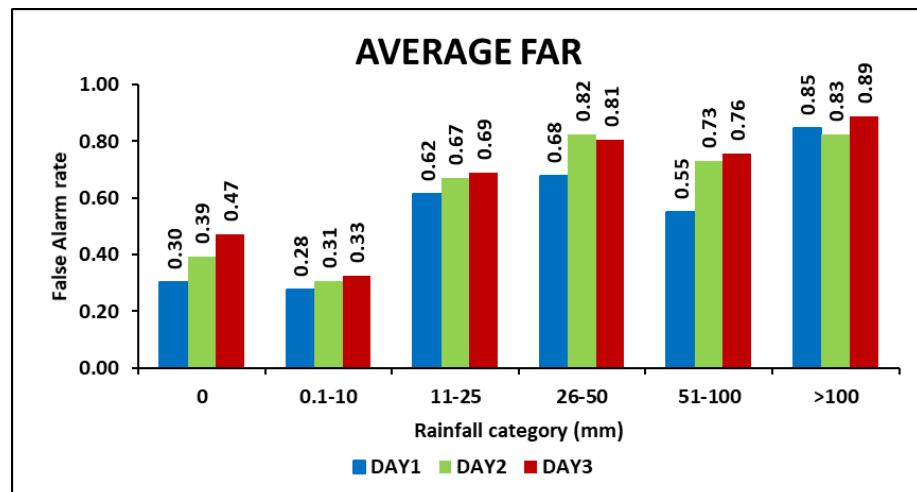


Figure 34: Category-wise False Alarm Rate for Day1, Day2 and Day3

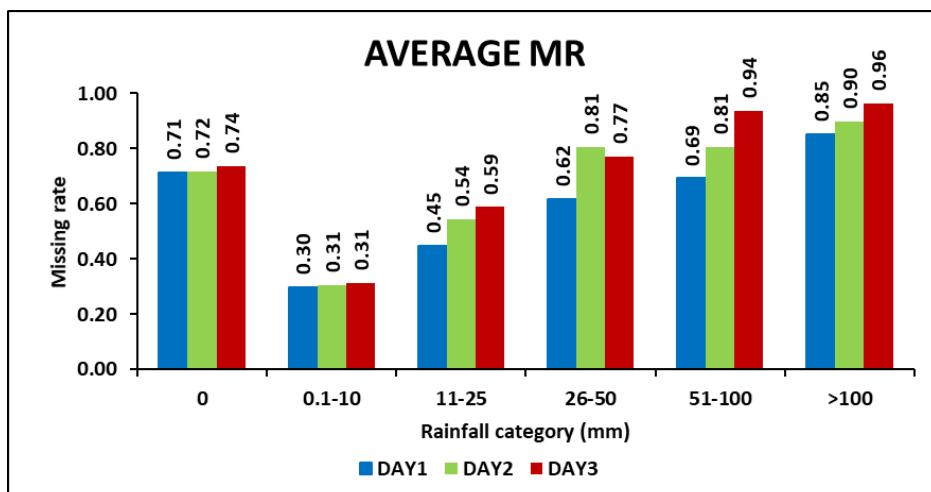


Figure 35: Category-wise Missing Rate for Day1, Day2 and Day3

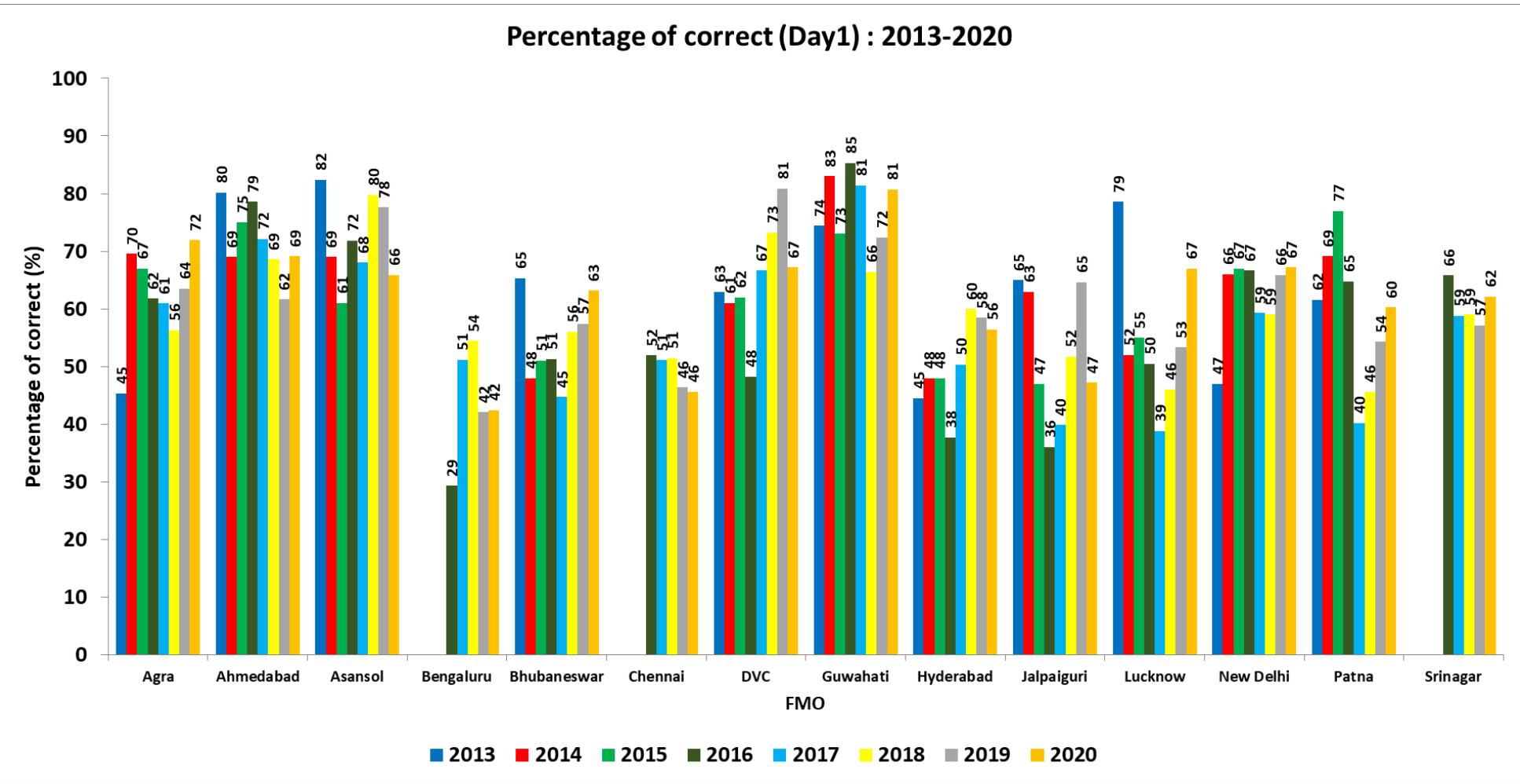


Figure 36: The FMO-wise Percentage correct QPF for Day-1 are plotted for the year 2013 to 2020

The FMO-wise Percentage correct QPF for Day-1 are plotted for the year 2013 to 2020 (Fig.- 36). The accuracy of Day-1 QPF of FMOs namely, Agra, Ahmedabad, Guwahati, Lucknow, Srinagar and Patna have improved (5% or more) during the last years while it has deteriorated in respect of FMOs namely, Asansol, DVC, Chennai, Hyderabad and Jalpaiguri.

CHAPTER 5

Conclusion

- a) All India percentage correct QPF within category for FMOs are 61% for Day-1, 57% for Day-2, and 56% for Day-3. However, the accuracy of correct QPF within ± 1 category is 95% for Day-1, 94% for Day-2, and 94% for Day-3.
- b) The highest percentage correct QPF issued by FMO Guwahati is 81% and lowest by FMO Bengaluru as 42% for Day-1; it is the highest for FMO Agra as 68%, and lowest 44% by FMO Bengaluru for Day2; it is highest by FMO Guwahati as 63% and lowest 46% by FMO Jalpaiguri for Day3.
- c) All India Critical Success Index (CSI) for the rainfall categories 0.1-10, 11-25, 26-50, 51-100 and >100 mm varies from 0.56 to 0.05 for Day-1, 0.53 to 0.06 for Day-2, 0.52 to 0.03 for Day-3. CSI decreases as we move to the higher rainfall categories. Probability of Detection (POD) also varies in similar manner.
- d) All India False Alarm Rate (FAR) for the rainfall categories 0.1-10, 11-25, 26-50, 51-100 and >100 mm varies from 0.28 to 0.85 for Day-1, 0.31 to 0.83 for Day-2, 0.33 to 0.89 for Day-3. FAR increases as we move to the higher rainfall categories.
- e) The higher rainfall categories 26-50 mm and >100 mm, shows that the False Alarm (FA) cases are more than Missed Cases (MC) whereas for 51-100 mm category MC are much more than FA.
- f) The category wise overall performance of percentage correct forecast within category under different FMOs and DVC for Day-1, Day-2 and Day-3, shows that the performance of Day-1 forecast for the higher rainfall categories 26-50 mm, 51-100 mm and >100 mm has significant improvement over Day-2 & Day-3.
- g) The accuracy of Day-1 QPF of FMOs namely, Agra, Ahmedabad, Guwahati, Lucknow, Srinagar and Patna have improved (5% or more) during the last years while it has deteriorated in respect of FMOs namely, Asansol, DVC, Chennai, Hyderabad and Jalpaiguri.

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जल मौसम विज्ञान प्रभाग, भारत मौसम विज्ञान विभाग
(पृथ्वी विज्ञान मंत्रालय)

Hydromet Division, India Meteorological Department
(Ministry of Earth Sciences)
मौसम भवन, लोदी रोड, नई दिल्ली- 110003
Mausam Bhavan, Lodi Road, New Delhi- 110003