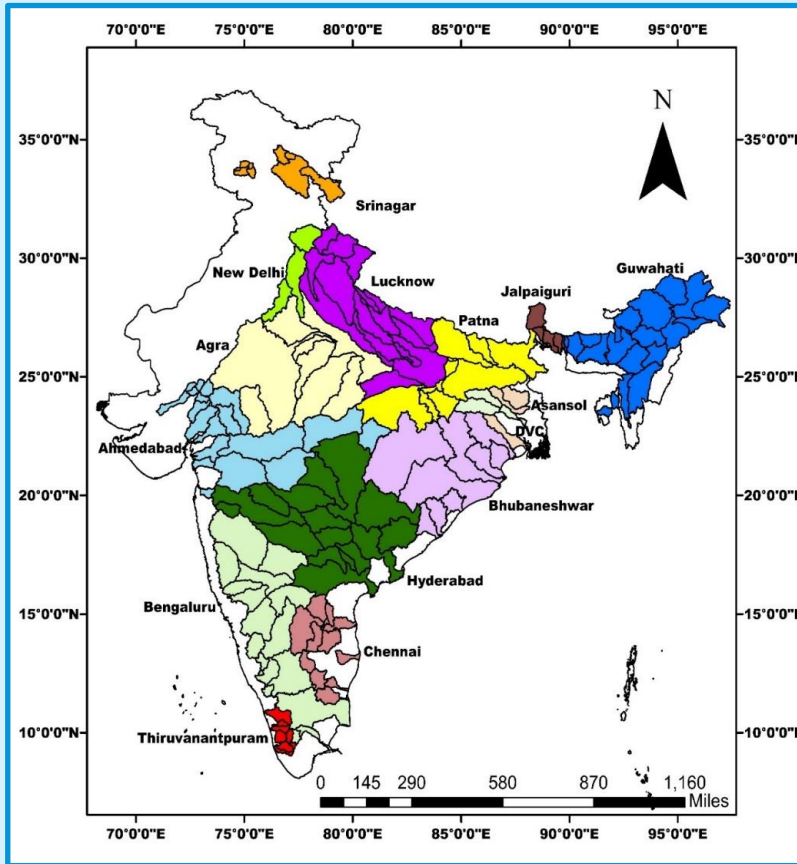


जल मौसम विज्ञान प्रभाग
भारत मौसम विज्ञान विभाग
पृथ्वी विज्ञान मंत्रालय

Hydromet Division
India Meteorological Department
Ministry of Earth Sciences

नदी उपबेसिन मात्रात्मक वर्षा पूर्वानुमान दक्षिण पश्चिमी मानसून 2022 का सत्यापन

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FOREWORD

Every year floods occur in one or another part of the country due to high variability of rainfall over time and space. In India, IMD provides the Hydromet services for flood forecast mainly in the form of Quantitative Precipitation Forecast (QPF), Heavy Rainfall warning, station wise significant rainfall etc. to CWC for their 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 betterment in its services.

It gives me immense pleasure that Hydromet Division has brought out the publication **“VERIFICATION OF RIVER SUB-BASIN-WISE QUANTITATIVE PRECIPITATION FORECAST DURING SW MONSOON 2022”** based on the Operational QPF and the Observed rainfall received in the different sub-basins under 14 FMOs along with DVC met unit Kolkata. 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 colleagues for improved forecast performance during 2022.

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 whereas 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 14 FMOs along with DVC met service stations located at different parts of flood prone areas of the country viz., Agra, Ahmedabad, Asansol, Bengaluru, Bhubaneswar, Chennai, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi, Srinagar, Thiruvananthapuram, Patna and Kolkata, cater this service which is shown in figure 1 and also their details are mentioned in Table 1.

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 these, four new Basins namely, Pennar, Sankosh, Jaldhaka and Torsa are included for issuance of operational QPF's for their flood forecast activities. Additional new river sub-basins of Kerala State are also included under FMO Bengaluru for this activity in 2019 after the Kerala flood in 2018. During this year (2021), a new FMO was commissioned at Thiruvananthapuram for issuing QPF of 8 river sub-basins of west flowing rivers situated in the state of Kerala, which were previously under FMO, Bengaluru. IMD also provides similar support to Damodar Valley Corporation (DVC) for the river Basins of Barakar and Damodar.

In recent years, it is observed that there is substantial improvement in the accuracy of QPF and availability of dynamical model-based weather forecast products on near realtime basis. Based on the evaluation of accuracy of operational as well as dynamic model based QPF and availability new tools and techniques, a DSS was implemented during SW monsoon 2021 vide which the validity of the operational daily sub-basin-wise QPF was increased from existing 1 to 3 days to 1 to 5 days. This meets the long pending demand from flood forecasting authority (CWC) as well as National Disaster Management Authority.

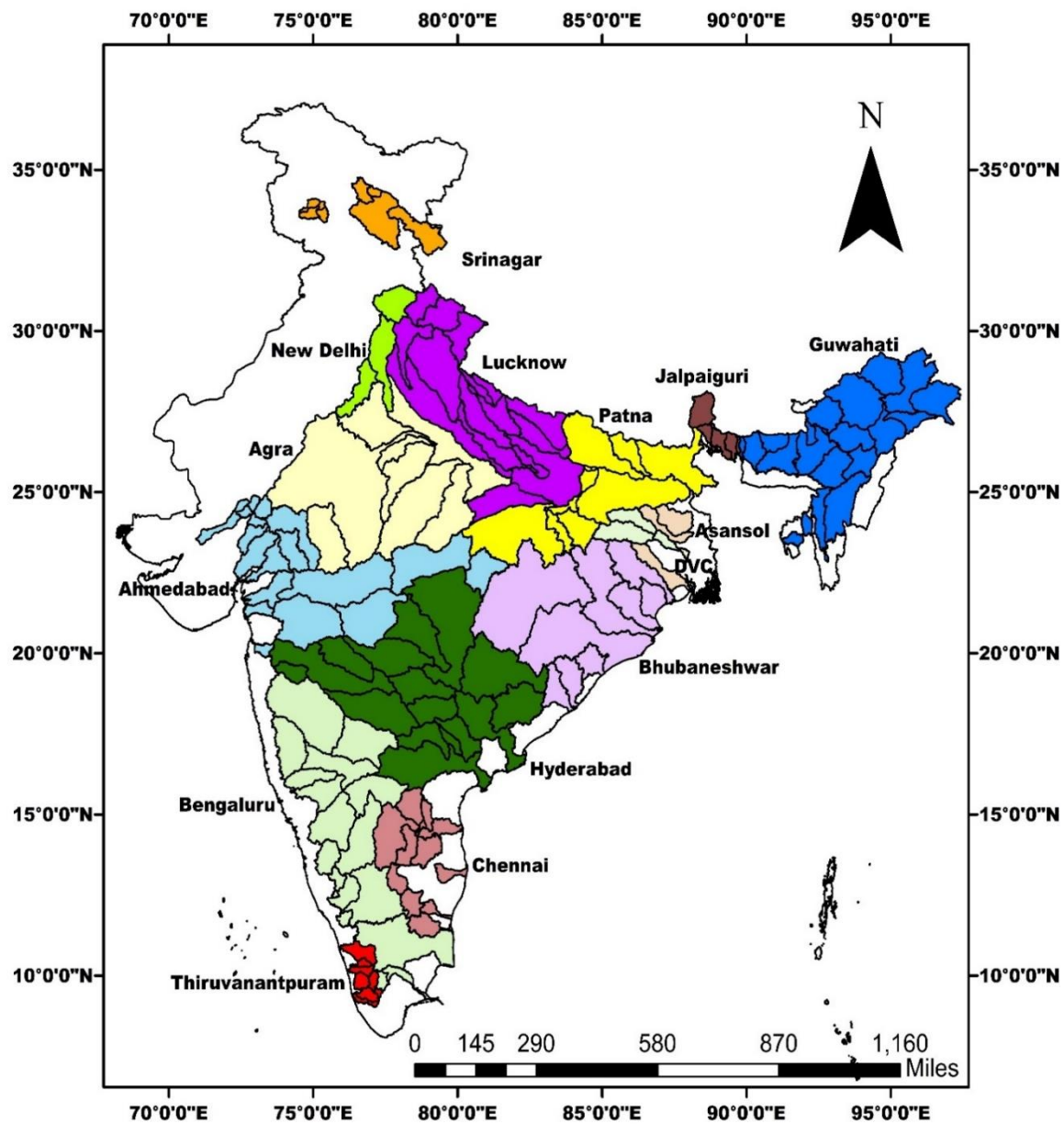


Figure 1: Map of Flood Meteorological offices with Sub-Basins in 2022

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

S. No.	FMOs	Main Basins/Sub-Basins	No of Sub-Basins	Area (Km ²)
1	Agra	Chambal, Betwa, Ken, Yamuna	8	2,92,492
2	Ahmedabad	Narmada, Tapi, Daman Ganga, Sabarmati, Banas, Mahi	19	2,20,946
3	Asansol	Ajoy, Mayurakshi, Kangsabati	3	23,669
4	Bhubaneswar	Subarnarekha, Baitarni, Burhabalang, Vamsadhara, Brahmani, Mahanadi, Rushikulya	9	2,44,670
5	DVC, Kolkata	Damodar	3	21,013
6	Guwahati	Brahmaputra, Barak, Dehung, Lohit, Buridihing, Subansiri, N. Dhansiri, S. Dhansiri, Jiabharali, Kapili, Manas/ Beki, Sankosh	20	1,82,195
7	Hyderabad	Godavari, Manjira, Wainganga, Penganga, Wardha, Indravati, Sabari	16	6,11,056
8	Jalpaiguri	Teesta, Jaldhaka, Raidak	5	16,151
9	Lucknow	Ghaghra, Rapti, Ramganga, Gomti, Sai, Sahibi, Chhatang, Bhagirathi, Alaknanda, Ganga, Sharda	14	2,20,465
10	New Delhi	Yamuna upto Mathura, Sahibi	3	36,670
11	Patna	Kosi, Mahananda, Adhwara, Bagmati, Gandak, Punpun, Sone, Kanhar, North Koel	8	1,71,698
12	Srinagar	Jhelum	8	4,788
13	Bengaluru	Upper Cauvery, Middle Cauvery, Lower Cauvery, Hemavathi, Kabini, Harangi, Upper Vaigai, Lower Vaigai, Upper Bhima, Upper Krishna, Middle Krishna, Lower Bhima, Upper Tungabhadra, Ghataprabha, Bennehalla, Hagari or Vedavati, Middle Tungabhadra, Lower Tungabhadra	18	2,85,157
14	Chennai	Gummanur, Upper South Pennar, Korttalaiyar, Vellar, Lower South Pennar, Kunderu, Sagileru, Upper Pennar, Lower Pennar, Papagni, Cheyyeru	11	6,05,708
15	Thiruvananthapuram	Achankoil, Meenachil, Pamba, Bharathapuzha, Chalakudi, Upper Periyar, Lower Periyar, Periyar	8	19,892
Total			153	29,56,570

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 their operational flood forecasting. QPF bulletin is issued at 0930 hrs IST and Hydromet Bulletin at 1230 hrs IST. Analysing the dynamical model past performances, this year the validity of sub-basin-wise QPF is increased from 3 days to 5 days. Categorical Sub-basin-wise QPF is issued for a lead-time of 7 days (forecast for 5 days and outlook for subsequent 2 days). If situation demands, QPF bulletins can be further updated in the evening.

SOP for Formulation of QPF & Hydromet Bulletin

Hydromet Bulletin contains the following information;

- Prevailing Synoptic situation over the jurisdiction area
- Daily sub-basin wise QPF for 5 days in different categories viz., 0, 0.1-10, 11-25, 26-50(26-37 & 38- 50), 51-100 (51-75 & 76-100) and >100 mm (Table - 2)
- Categorical Probabilistic QPF (Table - 3)
- Spatial & Intensity distribution of Rainfall (Tables - 4 & 5)
- Heavy Rainfall Warnings (HRW) for 5 days
- Outlook for subsequent two days
- Station-wise observed significant Rainfall (≥ 5 cm)
- Realized past 24-hour sub-basin-wise average areal rainfall at 0830 hrs IST.

Table - 2. QPF category and their colour codes

QPF Categories (mm)	Colour Code
0	
0.1-10	
11-25	
26-50	
51-100	
>100	

Table - 3. PQPF category and their colour codes

Probability of Occurrence (%)	Colour Code
0-5	
5-25	
25-50	
50-75	
75-100	

Table - 4. Rainfall Intensity and their colour codes

Intensity					
M.Dry	NIL	0 cm	VL	Very Light Rainfall	Trace
L	Light Rainfall	Upto 1 cm	M	Moderate Rainfall	2-6 cm
H	Heavy Rainfall	7-11 cm	VH	Very Heavy rainfall	12-20 cm
EH	Extremely Heavy Rainfall	21 cm or more			
ExH	Exceptionally Heavy Rainfall	When the amount is a value near about the highest recorded rainfall at or near the station for the month or season. However, this term will be used only when the actual rainfall amount exceeds 12 cm.			

Table - 5. Spatial distribution of Rainfall and their colour codes

Spatial Distribution		
DRY	Dry	No station reported rainfall
ISOL	One or two places	25% or less number of stations recorded rainfall 2.5 mm
SCT	At a few places	26%-50% number of stations recorded rainfall 2.5 mm
FWS	At many places	51%-75% number of stations recorded rainfall 2.5 mm
WS	At most places	76%-100% number of stations recorded rainfall 2.5 mm

FMOs issue operational QPF by analysing surface weather charts, Upper air charts, Rainfall Analysis, Synoptic analogue, NWP model forecast, Satellite products and Radar products (figure 2).

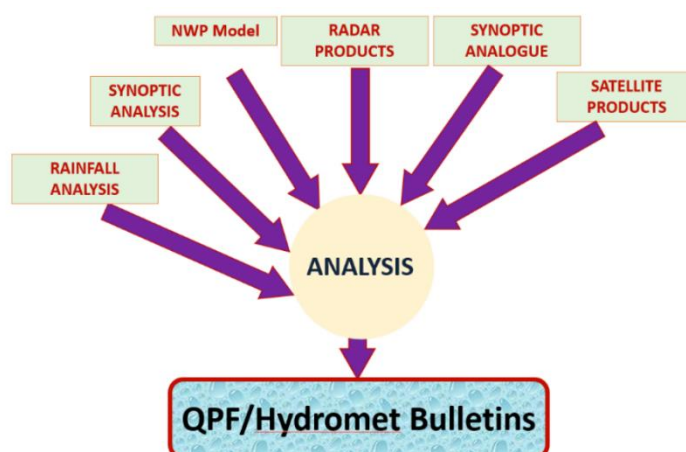


Figure 2. Input for issuing of QPF/Hydromet Bulletins

In addition to flood season, QPF Bulletin consisting of sub-basin-wise QPFs and heavy rainfall warning is issued by concerned FMOs during cyclone period or whenever 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 southwest monsoon season annually.

CHAPTER 2

Description of Different Flood Meteorological Offices

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 3).

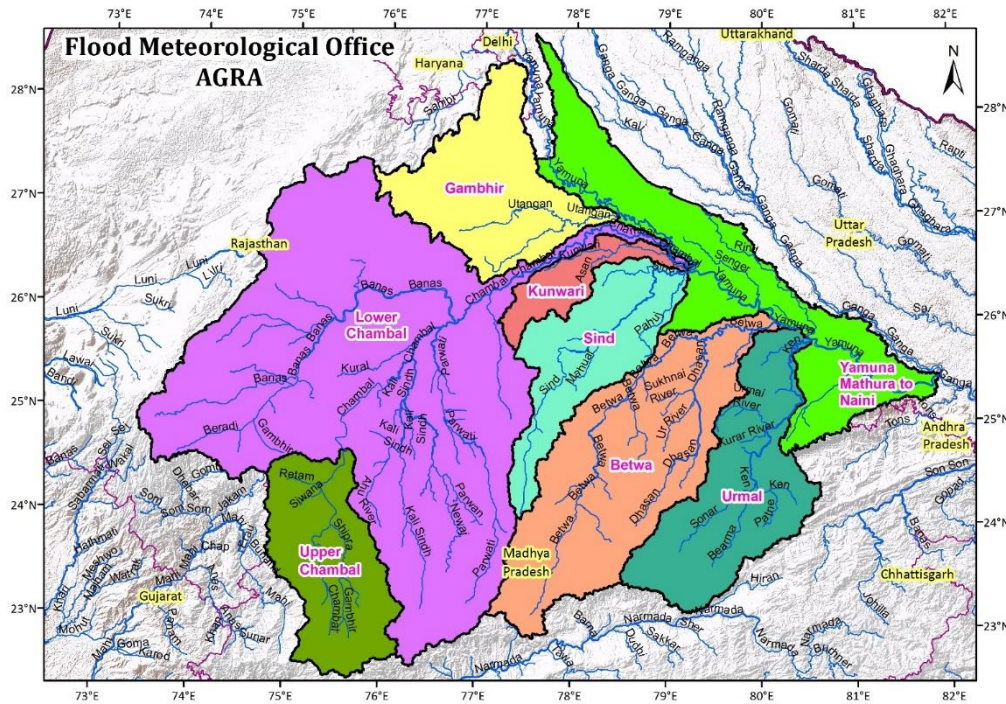


Figure 3: Map of FMO Agra with Sub-basins

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 6.

Table 6: 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

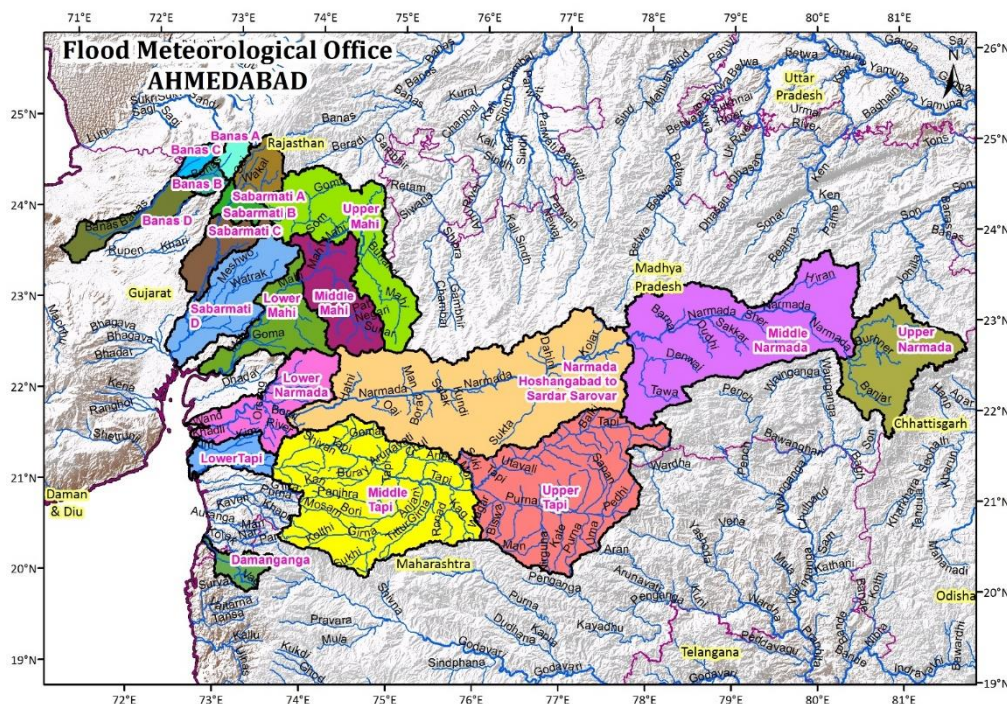


Figure 4: Map of FMO Ahmedabad with Sub-basins

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 (figure 4).

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 7.

Table 7: 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	40543.90
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	15721.00
9		Middle Mahi	9231.46
10		Lower Mahi	8123.46
11	Sabarmati	Sabarmati A	3259.47
12		Sabarmati B	1827.70
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 5).

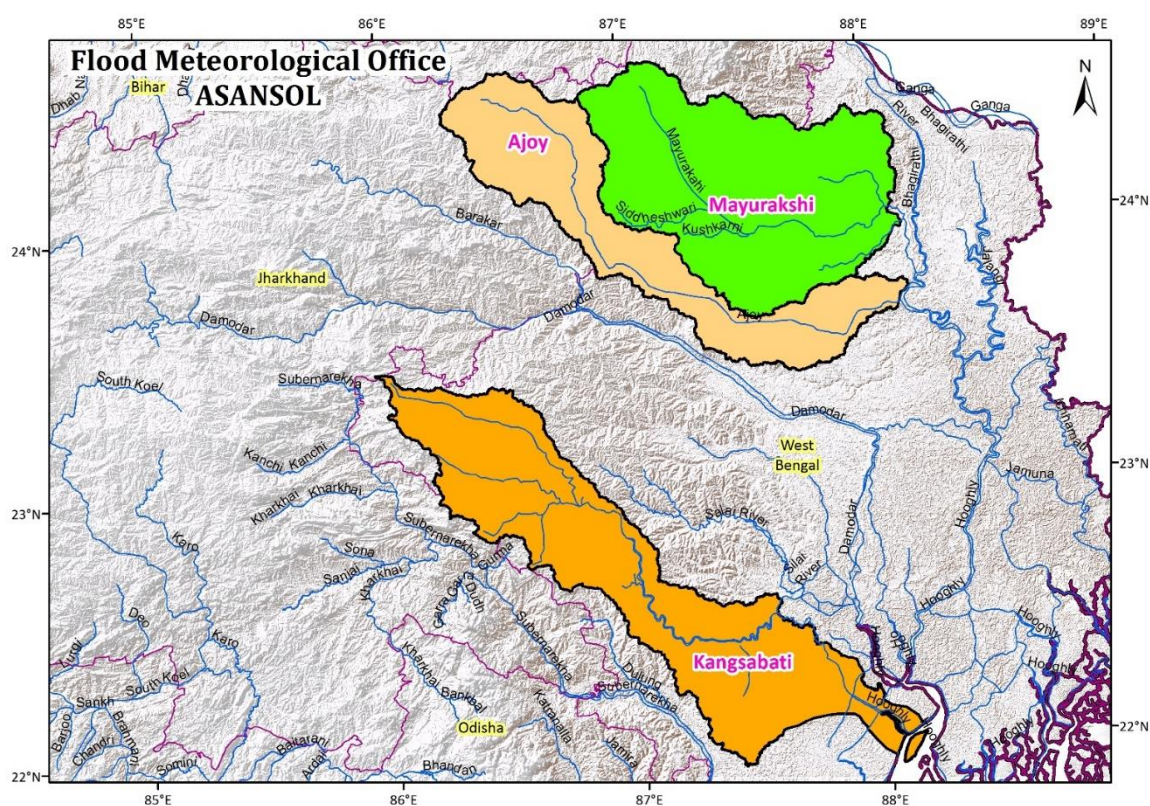


Figure 5: Map of FMO Asansol with Sub-basins

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 8.

Table 8: 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, Tamil Nadu and some parts of Andhra Pradesh (figure 6).

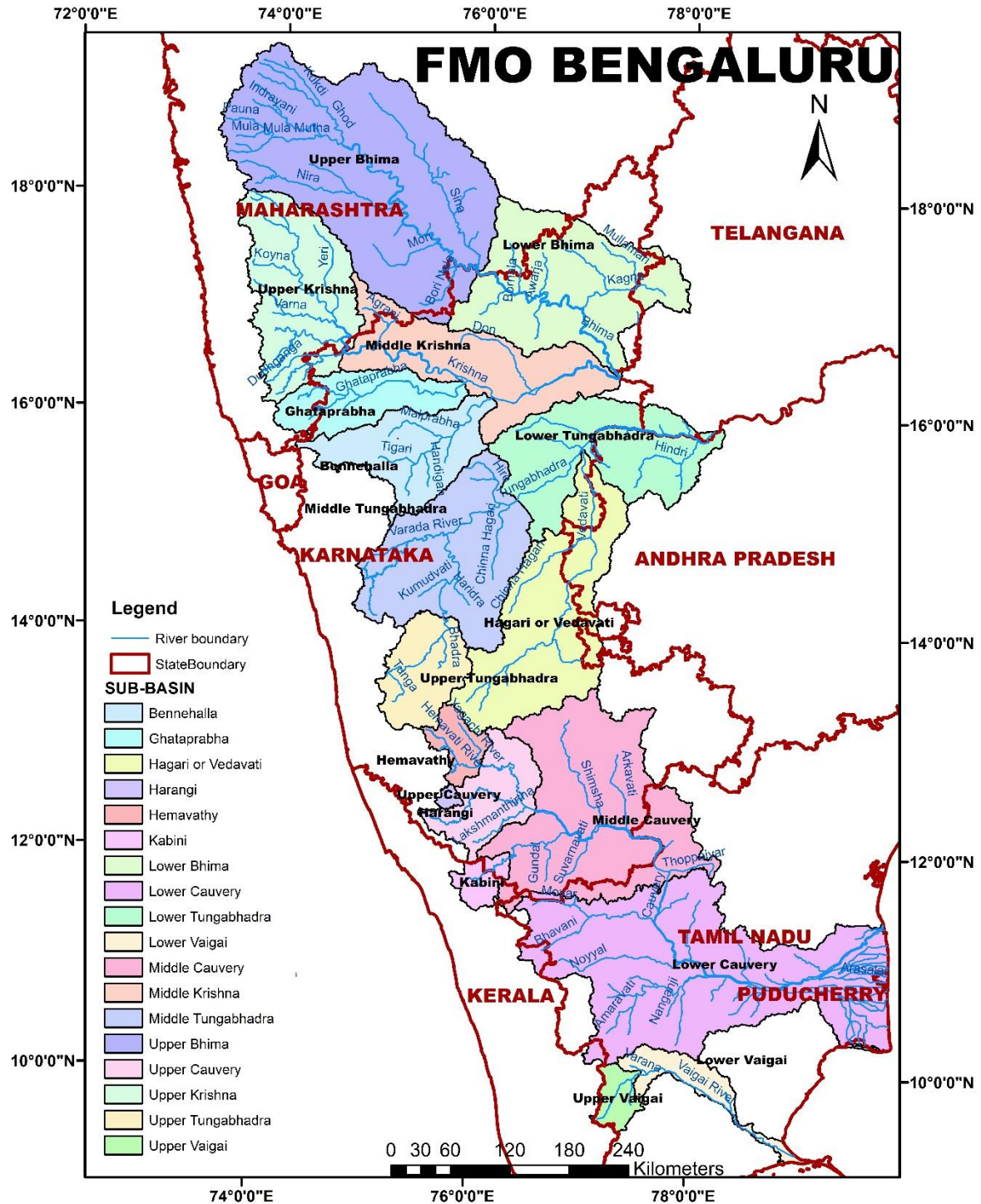


Figure 6: Map of FMO Bengaluru with Sub-basins

There are total of 18 sub-basins under the FMO Bengaluru. The name of basins, sub-basins with area (in Km²) are given in Table 9.

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	Krishna	Upper Krishna	17558.19
10	Krishna	Middle Krishna	17100.41
11	Krishna	Ghataprabha	8507.49
12	Krishna	Bennehalla	11338.67
13	Krishna	Upper Bhima	44793.32
14	Krishna	Lower Bhima	23652.70
15	Krishna	Hagari/Vedavati	23183.15
16	Krishna	Lower Tungabhadra	18481.57
17	Krishna	Upper Tungabhadra	7705.97
18	Krishna	Middle Tungabhadra	20813.44
Total			285156.90

Table 9: 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, Jharkhand and some parts of Andhra Pradesh (figure 7).

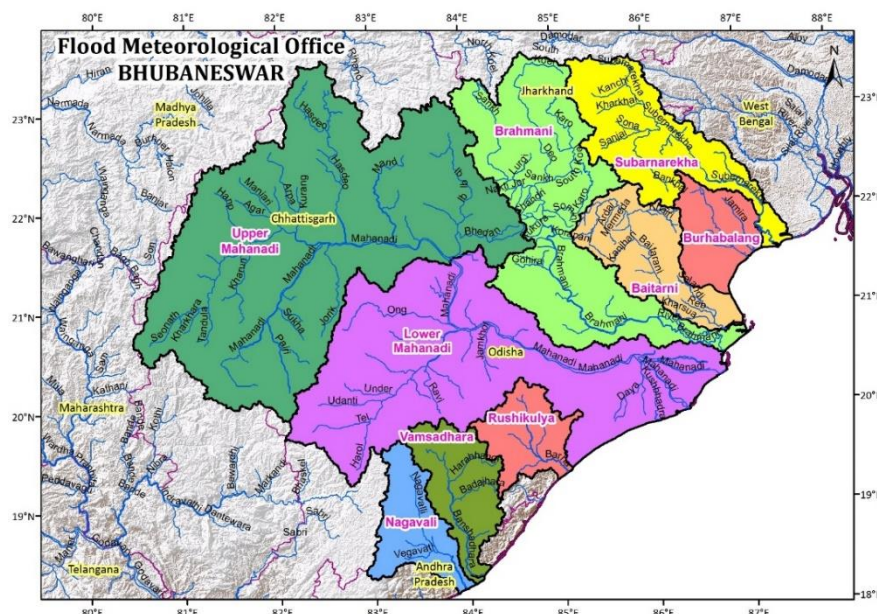


Figure 7: Map of FMO Bhubaneswar with Sub-basins

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 10.

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 10: 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 8).

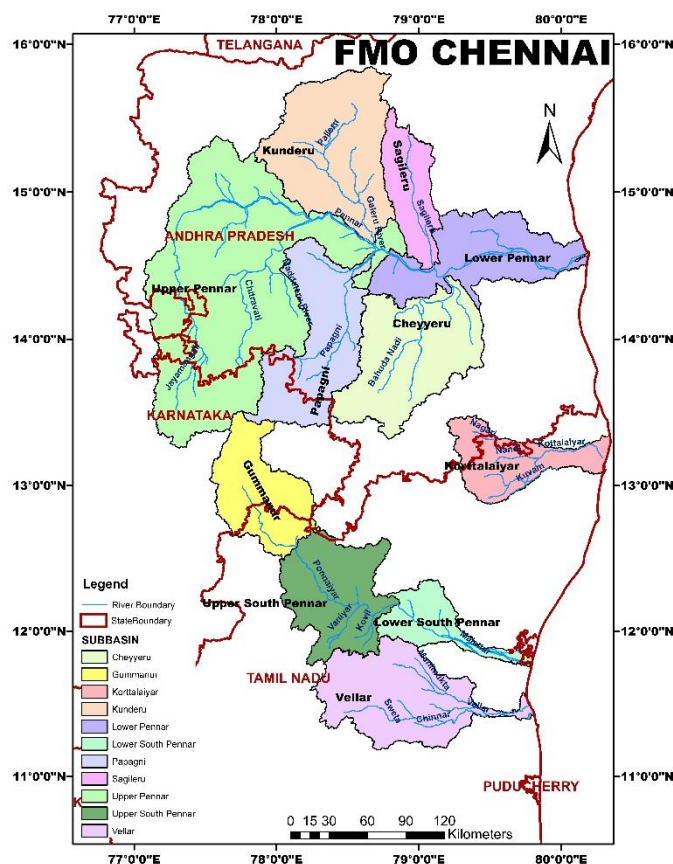


Figure 8: Map of FMO Chennai with Sub-basins

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 11.

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

FMO Chennai			
Sl.	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		Cheyzeru	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, Meghalaya, Tripura and few areas of West Bengal (figure 9).

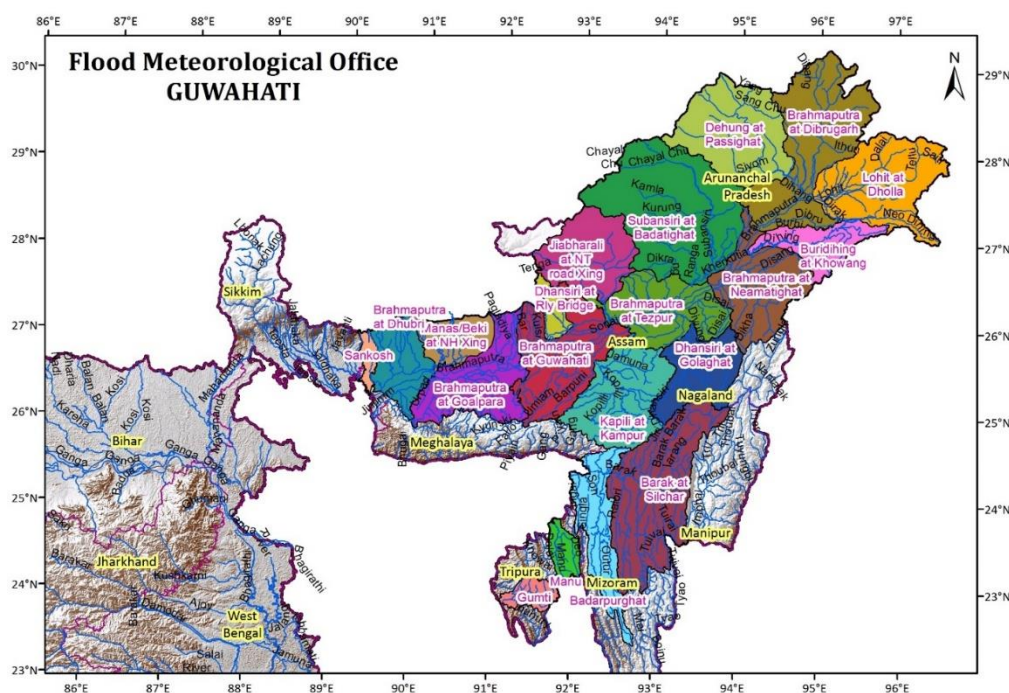


Figure 9: Map of FMO Guwahati with Sub-basins

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 12.

Table 12: 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

2.8 FMO Hyderabad

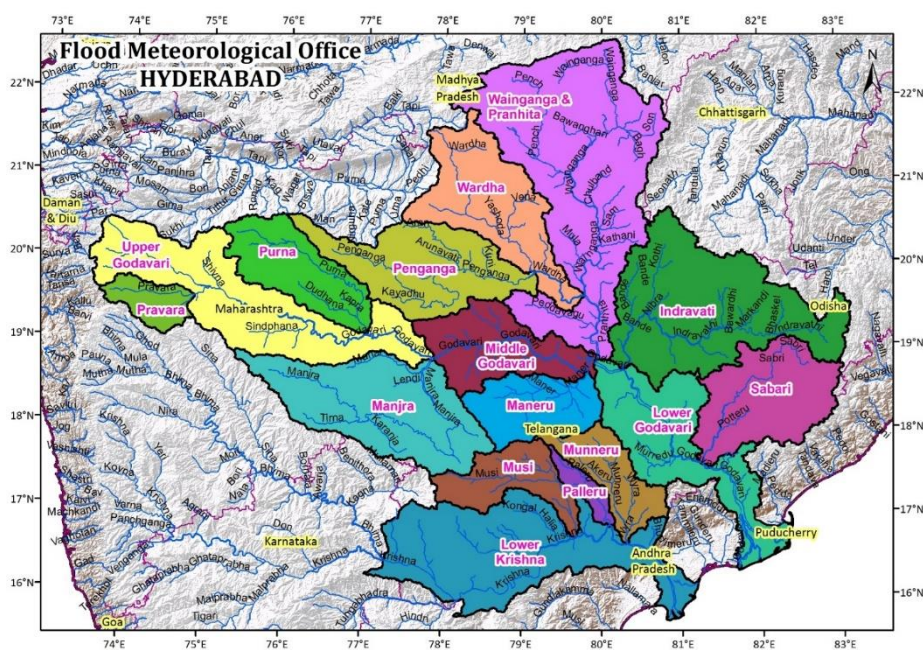


Figure 10: Map of FMO Hyderabad with Sub-basins

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, Karnataka , Madhya Pradesh, Chhattisgarh and UT Puducherry (figure 10).

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 13.

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

FMO Hyderabad			
Sl. 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	Krishna	Munneru	10127.33
14		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 & Raidak. It lies in the states of Sikkim & West Bengal (figure 11).

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 14.

Table 14: 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

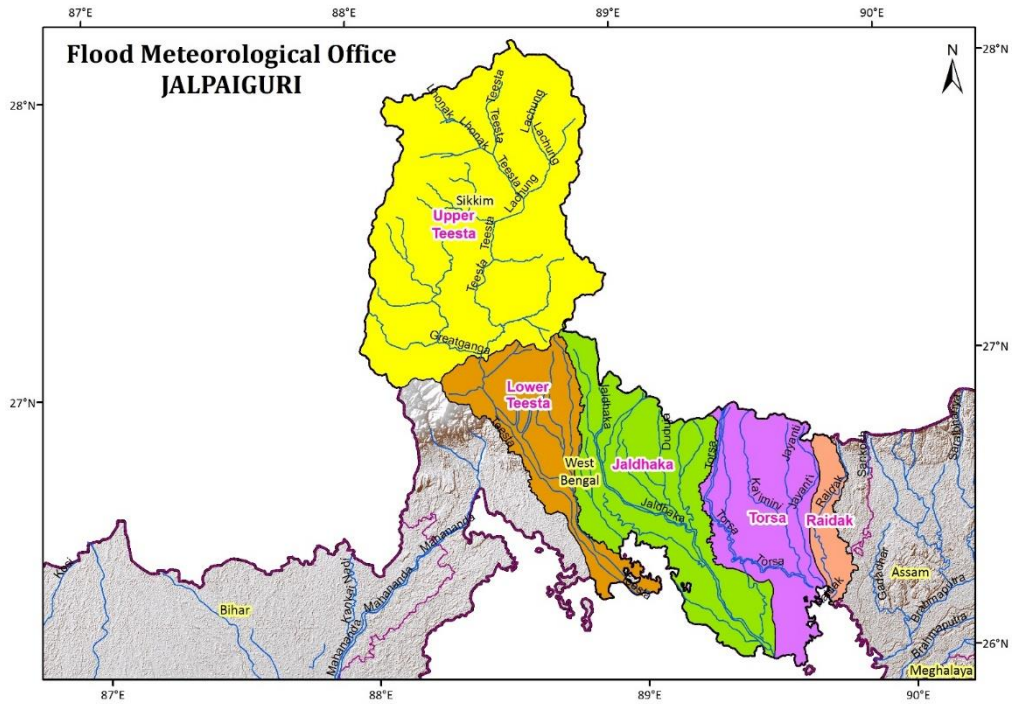


Figure 11: Map of FMO Jalpaiguri with Sub-basins

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, Uttar Pradesh and few areas of Madhya Pradesh and Bihar (figure 12).

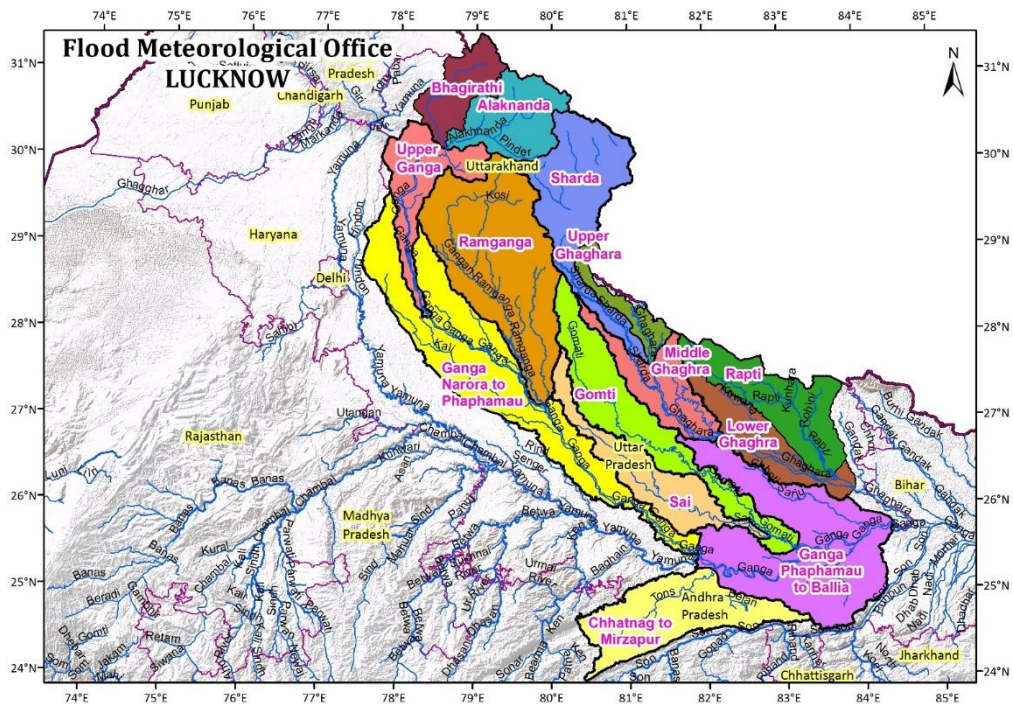


Figure 12: Map of FMO Lucknow with Sub-basins

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 15.

Table 15: 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 (figure 13).

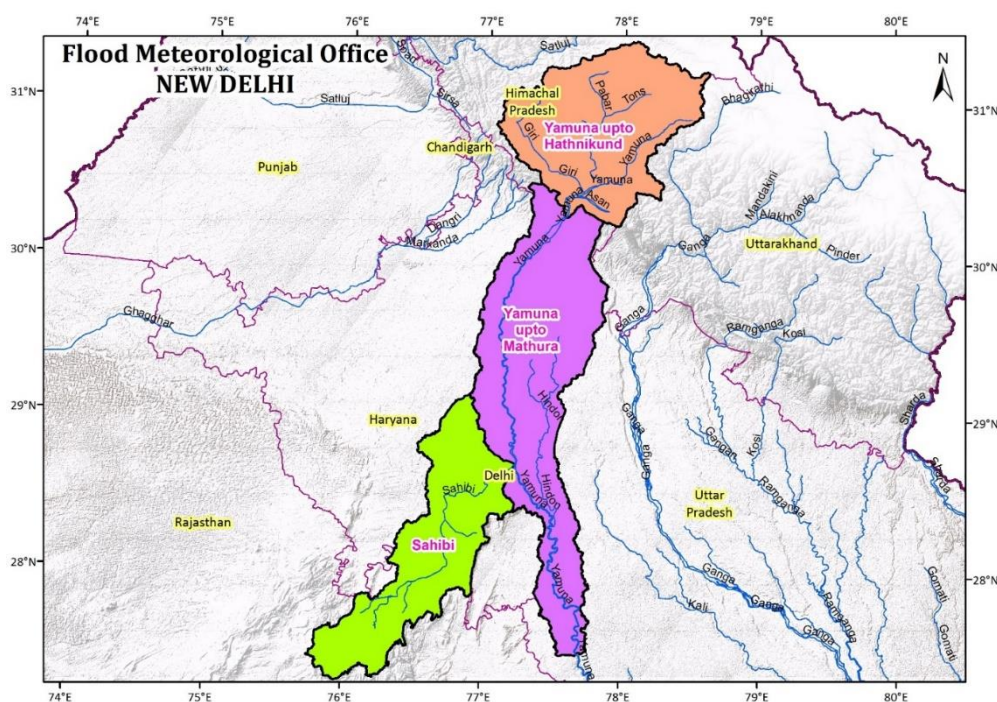


Figure 13: Map of FMO New Delhi with Sub-basins

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 16.

Table 16: 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

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, West Bengal and few areas of Uttar Pradesh (figure 14).

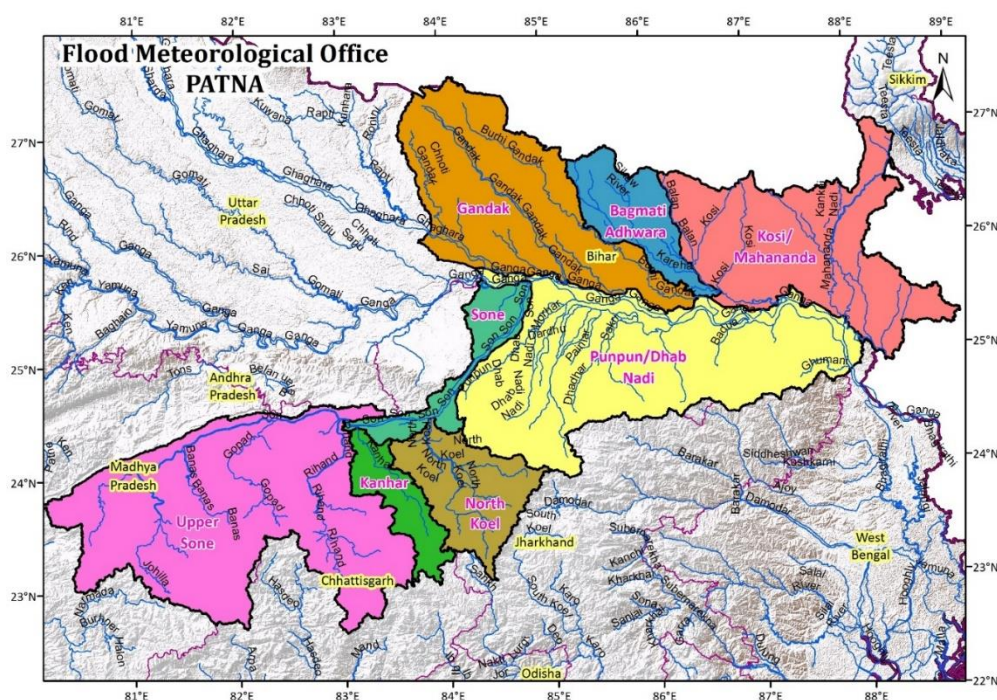


Figure 14: Map of FMO Patna with Sub-basins

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 17.

Table 17: 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	6144.30
5		Upper Sone	45069.53
6		Kanhar	5509.92
7		North Koel	10761.26
8		Zone VI	41035.31
		Total	171698.30

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 (figure 15).

Table 18: Area-wise Basins/Sub-basins under FMO Srinagar

FMO Srinagar			
Sl. 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	1244.90
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 18.

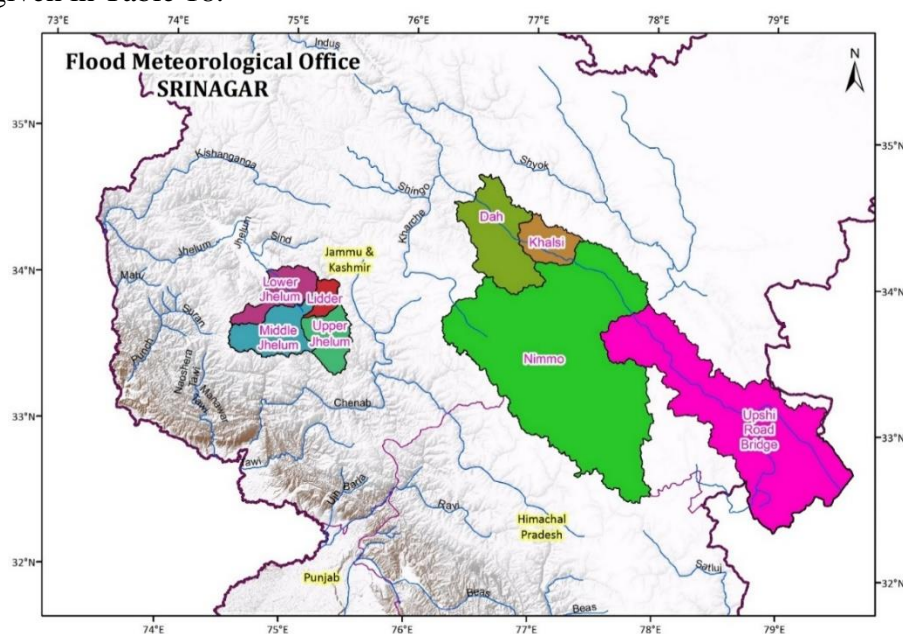


Figure 15: Map of FMO Srinagar with Sub-basins

2.14 FMO Thiruvananthapuram

The Flood Meteorological office, Thiruvananthapuram commissioned in the year 2021 to issue QPF for West Flowing River basins of Kerala State. There are total 8 sub-basins under FMO Thiruvananthapuram (figure 16). The name of basins, sub-basins with area (in Km²) are given in Table 19.

Table 19: Area-wise Basins/Sub-basins under FMO Thiruvananthapuram

FMO Thiruvananthapuram			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	West Flowing Rivers	Bharathapuzha	6001.33
2	West Flowing Rivers	Chalakudi	1361.68
3	West Flowing Rivers	Lower Periyar	2165.88
4	West Flowing Rivers	Upper Periyar	2604.03
5	West Flowing Rivers	Pamba	2818.47
6	West Flowing Rivers	Meenachil	2818.47
7	West Flowing Rivers	Achankoil	1488.07
8	West Flowing Rivers	Periyar	634.24
Total			19892.17



Figure 16: Map of FMO Srinagar with Sub-basins

2.15 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 (figure 17).

There are total of 3 sub-basins under the DVC. The name of basins, sub-basins with area (in Km²) are given in Table 20.

Table 20: 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

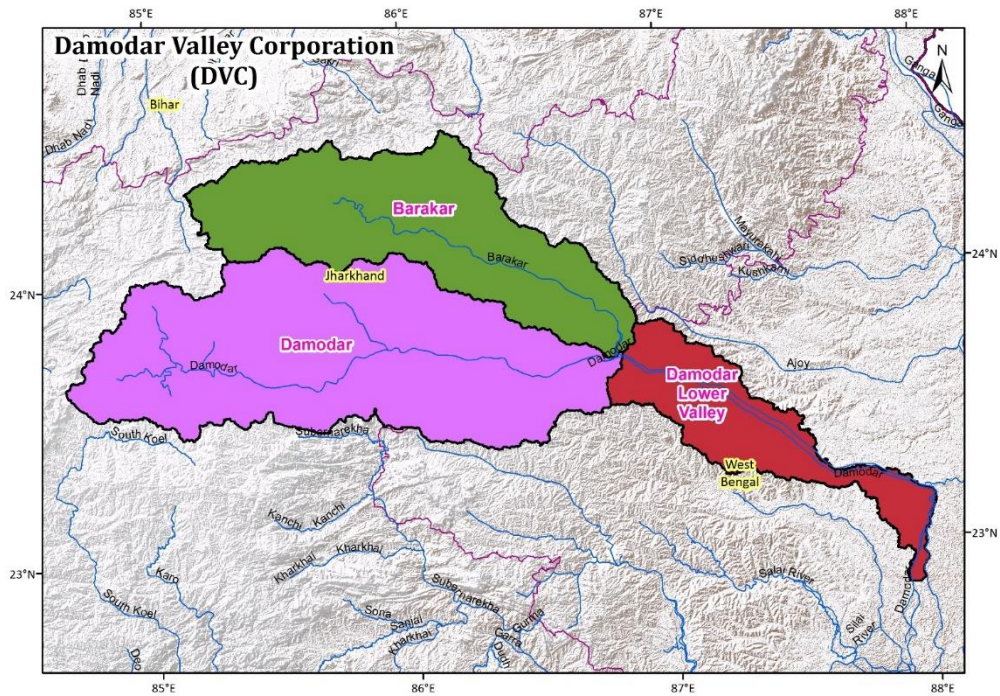


Figure 17: Map of DVC with Sub-basins

CHAPTER 3

Data Used and Methodology

3.1 Data Used

Operational QPF is issued sub-basin-wise as an average areal precipitation forecast by the FMOs daily during the 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 Average Areal Precipitation (AAP) during the southwest monsoon 2022. The daily river sub-basin-wise observed areal rainfall has been computed from the daily station-wise rainfall data by using isohyetal technique. The rainfall data of 3436 stations are used to compute sub-basin-wise AAP for all 153 river sub-basins.

The total number of QPF issued by 15 FMOs during the season 2022 is 18666 for each Day-1 to day-5 forecast.

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 21: 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 can be verified by computing Percentage Correct, Heidke Skill Score (HSS) and Critical Success Index (CSI), from 6X6 Contingency table which are as follows;

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

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

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

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

Table 22: 2 X 2 Contingency table

Observed	Forecast	
	Yes	No
Yes	A	B
No	C	D

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

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

Miss Rate (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) = $\frac{A}{A+B} + \frac{D}{C+D} - 1$

Percentage Correct (PC) = $\frac{A+D}{A+B+C+D} \times 100 = \text{Hit Rate} \times 100$

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

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

During season 2022, the skill scores for operational sub-basin-wise QPFs are computed for each FMO for day-1, day-2, day-3, day-4 and day-5. The final skill score individually is the average of all skill scores over all forecasting offices.

CHAPTER 4

QPF Verification

The river sub-basin-wise operational QPF verification statistics for different FMOs for Day-1, Day-2, Day-3, Day-4 and Day-5 forecast are computed and given in the subsequent sections. Hereafter wherever QPF will appear in this document, it will stand for river sub-basin-wise QPF.

4.1 Skill Scores of Day-1 QPF

The QPF verification skill scores for different FMOs for Day-1 are given in Table 23. All India percentage correct (PC) QPF within same category is 66% which is same as last year (2021) (figure 47). While FMO Asansol has the highest Percentage correct QPF of 75% and FMO Thiruvananthapuram has the lowest accuracy of 45%, four other FMOs viz., Ahmedabad, Agra, Bengaluru & Lucknow reported more than 70% accuracy of QPF for the Day-1 as seen in the figure 18. The percentage correct forecast for Day-1 QPF within ± 1 category shows a substantial improvement and was 93% & above for all FMOs except FMO Thiruvananthapuram where the accuracy was 89%. The performance of QPF within ± 2 , ± 3 , ± 4 category can also be seen in table 23.

Table 23: Performance of Day-1 QPF for the Flood Season 2022

FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one		Correct and ± 1	Out by two		Out by three		Out by four		Correct (%)	Usable Forecast Correct & ± 1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	704	132	116	952	15	8	1	0	0	0	72%	98%
Ahmedabad	2318	1665	442	154	2261	39	16	2	0	0	0	72%	98%
Asansol	366	273	76	16	365	0	1	0	0	0	0	75%	100%
Bengaluru	2196	1536	459	157	2152	33	11	0	0	0	0	70%	98%
Bhubaneswar	1220	794	320	93	1207	10	3	0	0	0	0	65%	99%
Chennai	1342	761	211	332	1304	8	24	0	6	0	0	57%	97%
DVC	732	503	166	54	723	3	6	0	0	0	0	69%	99%
Guwahati	2440	1575	700	65	2340	90	6	3	1	0	0	65%	96%
Hyderabad	1952	1321	380	192	1893	40	14	2	3	0	0	68%	97%
Jalpaiguri	610	331	176	63	570	24	15	0	1	0	0	54%	93%
Lucknow	1708	1244	170	273	1687	5	16	0	0	0	0	73%	99%
New Delhi	366	242	64	48	354	8	2	0	2	0	0	66%	97%
Patna	976	641	177	146	964	3	9	0	0	0	0	66%	99%
Srinagar	488	298	136	45	479	3	6	0	0	0	0	61%	98%
Thiruvananthapuram	976	442	277	148	867	50	44	8	6	1	0	45%	89%
All India Average	18666	12330	3886	1902	18118	331	181	16	19	1	0	66%	97%

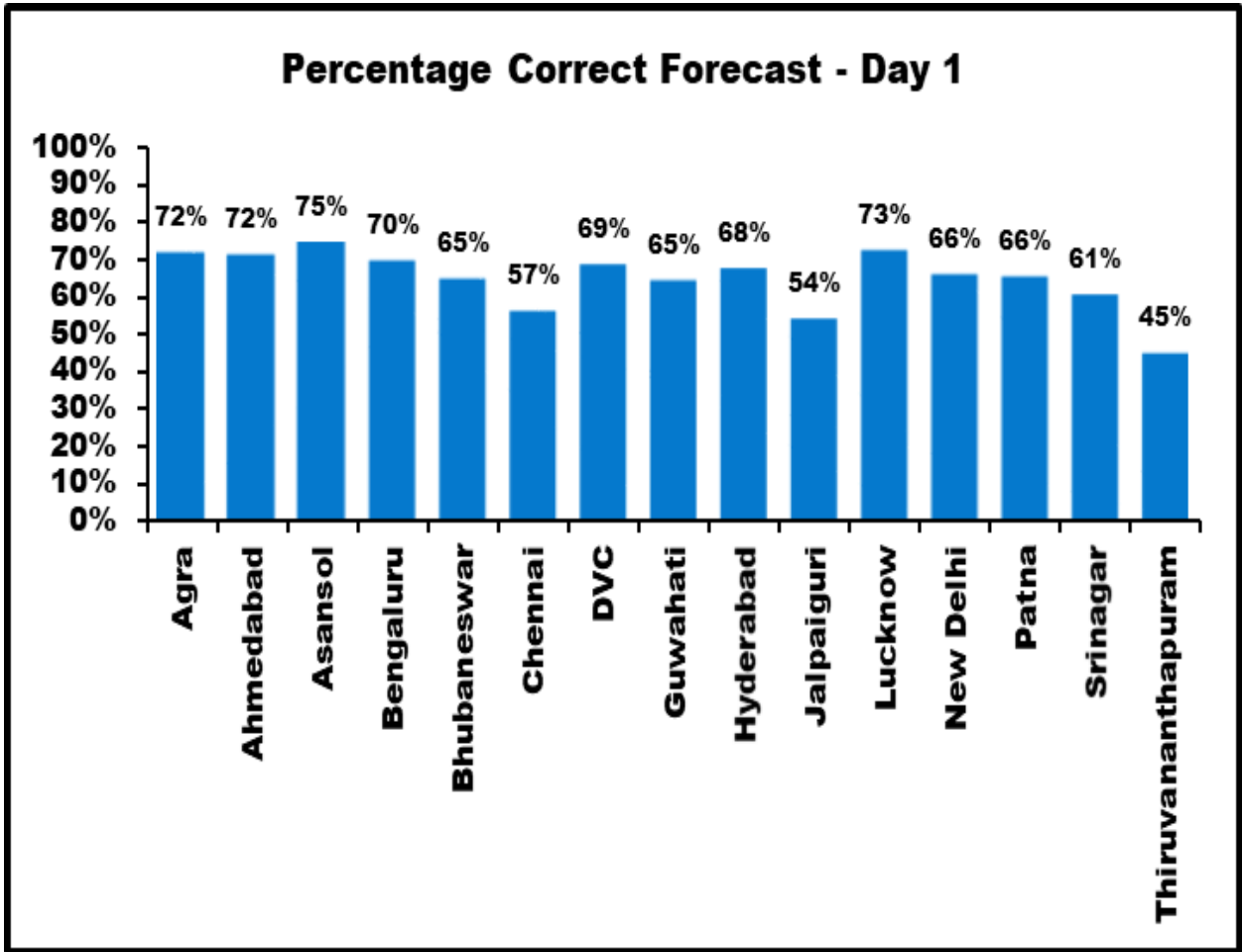


Figure 18: Percentage correct forecast Day-1 by different FMOs

All India skill scores viz, POD, FAR, MR, CSI, BIAS, PC, TSS and HSS computed from 2X2 contingency table are given in Table 24 and figures 19 - 21. While CSI and POD decreases with increase in the QPF category, an opposite trend is observed for False alarm rate and Missing rate.

Table 24: Skill Scores of Day-1 QPF

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.37	0.74	0.52	0.41	0.25	0.22
False Alarm Rate (FAR):	0.33	0.23	0.60	0.64	0.67	0.51
Missing Rate (MR):	0.63	0.26	0.48	0.59	0.75	0.78
Correct Non-Occurrence (C-NON):	0.95	0.65	0.83	0.96	0.99	1.00
Critical Success Index (CSI):	0.29	0.60	0.29	0.24	0.16	0.16
Bias for Occurrence (BIAS):	0.56	0.97	1.30	1.15	0.67	1.29
Hit Rate:	0.89	0.71	0.79	0.93	0.98	1.00
Percentage of Correct (PC):	0.89	0.71	0.79	0.93	0.98	1.00
True Skill Score (TSS):	0.32	0.39	0.35	0.36	0.25	0.21
Heidke Skill Score (HSS):	0.33	0.38	0.32	0.33	0.23	0.22

The category-wise percentage of correct forecast is given in Figure 22.

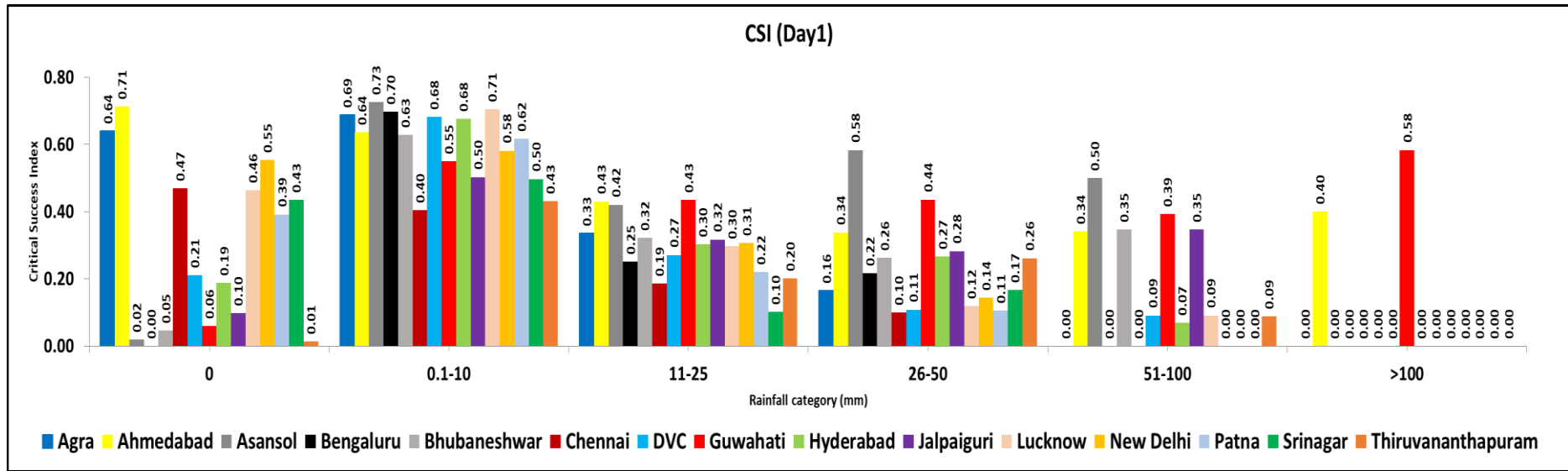


Figure 19: CSI for different categories of forecast for Day-1

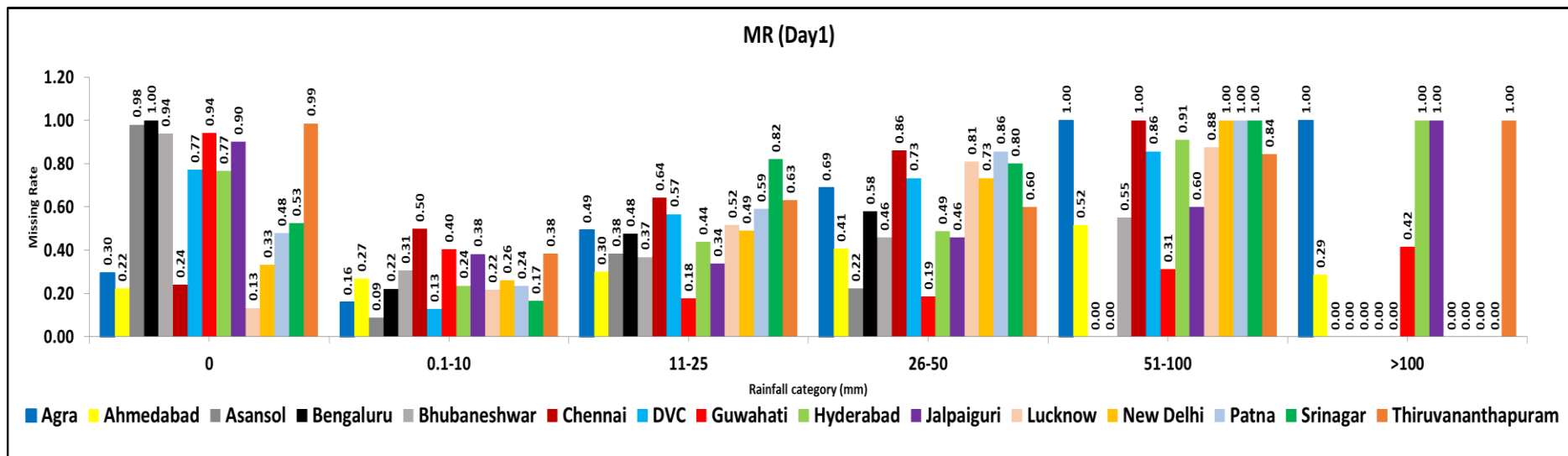


Figure 20: MR for different categories of forecast for Day-1

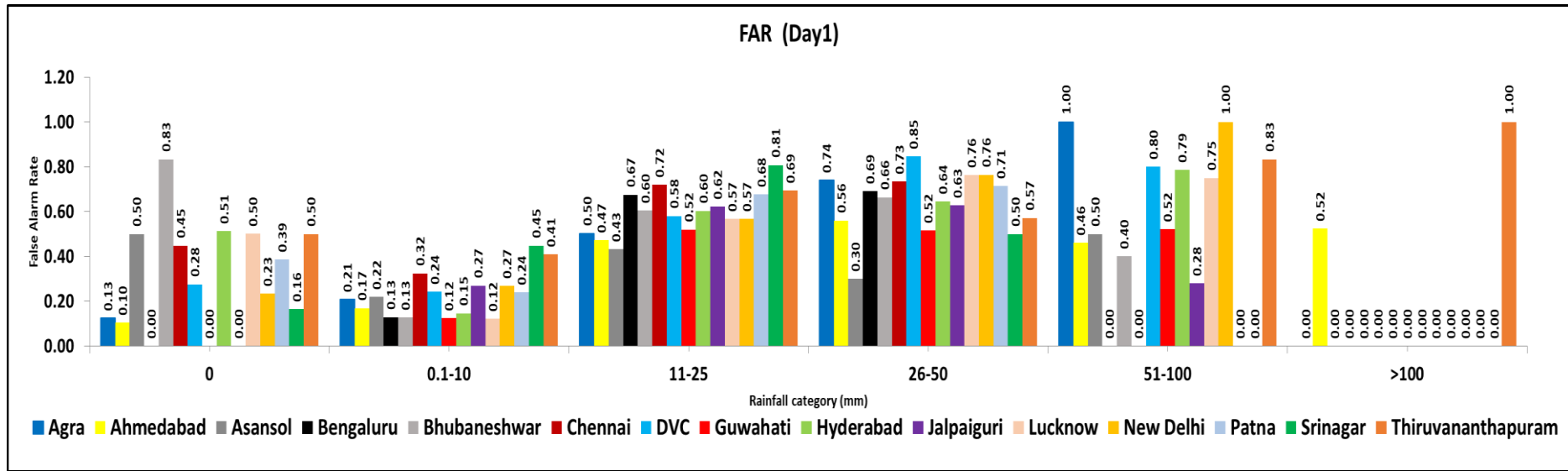


Figure 21: FAR for different categories of forecast for Day-1

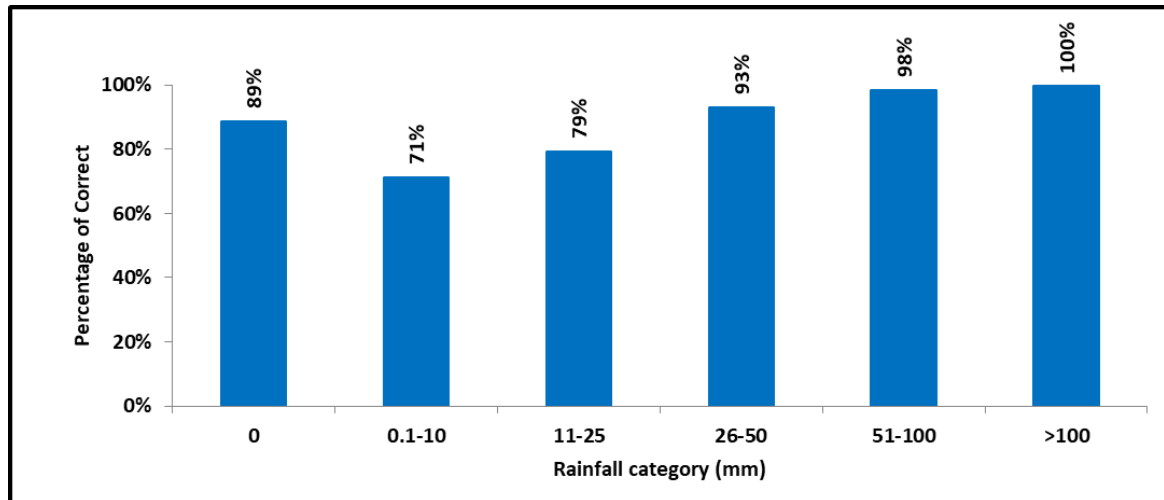


Figure 22: Category-wise Percentage Correct Forecast of Day-1

4.2 Skill Scores of Day-2 QPF

The QPF verification skill scores for different FMOs for Day-2 are given in Table 25. All India percentage correct QPF within same category is 63% which is an improvement by 1% (figure 47) as compared to last year (2021). While FMO Lucknow has the highest Percentage correct QPF of 71% and FMO Thiruvananthapuram has the lowest accuracy of 46%, ten other FMOs viz. Agra, Ahmedabad, Asansol, Bengaluru, Bhubaneswar, DVC, Hyderabad, New Delhi, Patna and Srinagar reported more than 60% accuracy of QPF for the Day-2 as seen in the figure 23. The percentage correct forecast for Day-2 QPF within ± 1 category shows a substantial improvement and was 95% & above for all FMOs except FMO Thiruvananthapuram where the accuracy was 87%. The performance of QPF within ± 2 , ± 3 , ± 4 category can also be seen in table 25.

Table 25: Performance of Day-2 QPF for the Flood Season 2022

FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one		Correct and ± 1	Out by two		Out by three		Out by four		Correct (%)	Usable Forecast Correct & ± 1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	685	129	135	949	6	17	4	0	0	0	70%	97%
Ahmedabad	2318	1442	382	403	2227	29	57	2	3	0	0	62%	96%
Asansol	366	256	88	21	365	0	1	0	0	0	0	70%	100%
Bengaluru	2196	1542	394	194	2130	48	18	0	0	0	0	70%	97%
Bhubaneswar	1220	780	300	128	1208	7	4	0	0	0	0	64%	99%
Chennai	1342	737	173	386	1296	17	24	0	5	0	0	55%	97%
DVC	732	492	163	66	721	0	11	0	0	0	0	67%	98%
Guwahati	2440	1385	786	158	2329	97	8	4	2	0	0	57%	95%
Hyderabad	1952	1257	380	232	1869	43	31	1	8	0	0	64%	96%
Jalpaiguri	610	319	155	83	557	34	16	2	1	0	0	52%	91%
Lucknow	1708	1209	200	267	1676	13	19	0	0	0	0	71%	98%
New Delhi	366	234	70	48	352	7	5	0	2	0	0	64%	96%
Patna	976	600	205	157	962	4	10	0	0	0	0	61%	99%
Srinagar	488	310	122	47	479	2	7	0	0	0	0	64%	98%
Thiruvananthapuram	976	448	229	175	852	55	57	2	10	0	0	46%	87%
Over All fct.	18666	11696	3776	2500	17972	362	285	15	31	0	0	63%	96%

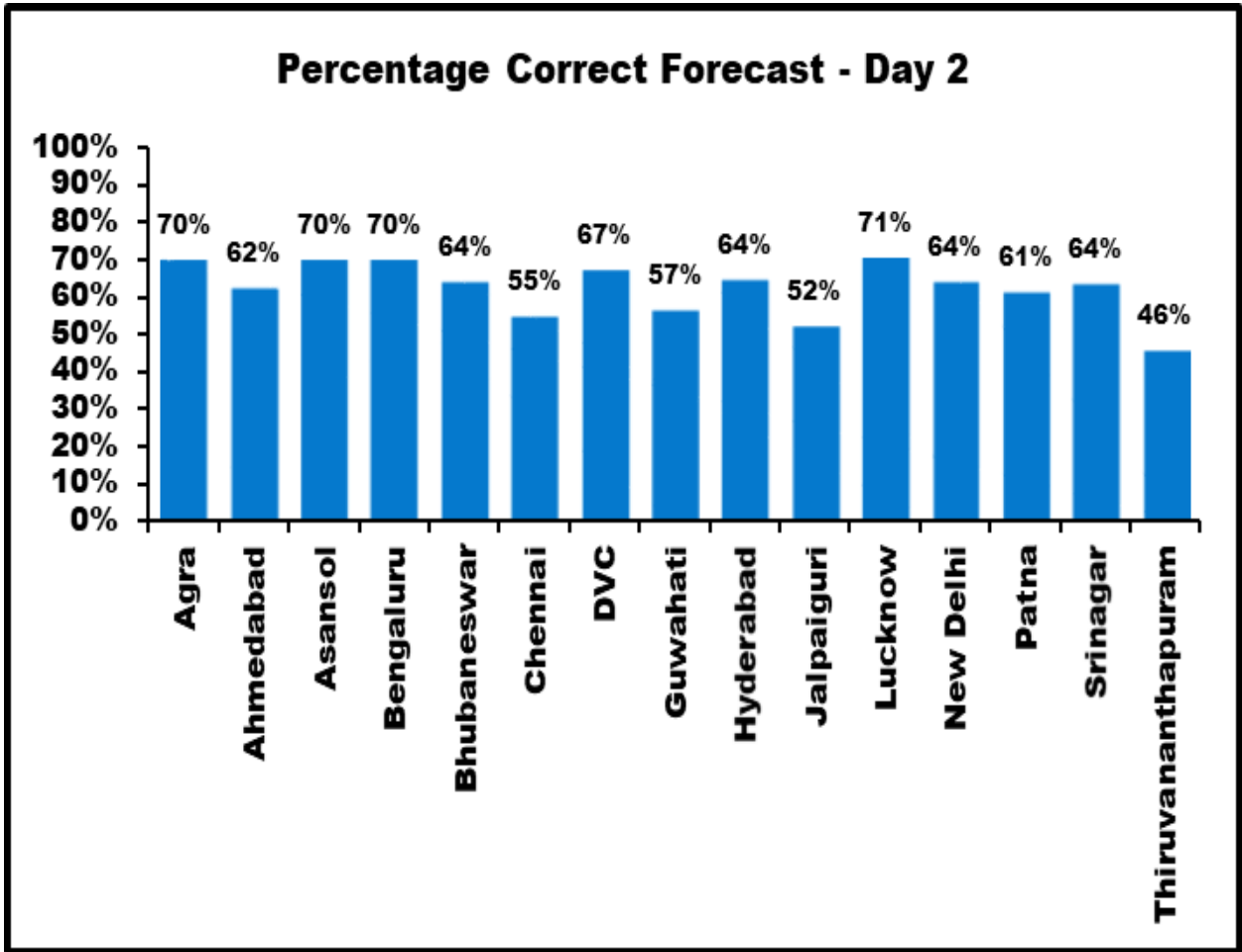


Figure 23. Percentage correct forecast Day-2 by different FMOs

All India skill scores viz, POD, FAR, MR, CSI, BIAS, PC, TSS and HSS computed from 2X2 contingency table are given in Table 26 and figures 24 - 26. While CSI and POD decreases with increase in the QPF category, an opposite trend is observed for False alarm rate and Missing rate.

Table 26: Skill Scores of Day-2 QPF

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.38	0.72	0.47	0.30	0.16	0.10
False Alarm Rate (FAR):	0.40	0.25	0.65	0.67	0.60	0.53
Missing Rate (MR):	0.62	0.28	0.53	0.70	0.84	0.90
Correct Non-Occurrence (C-NON):	0.94	0.62	0.82	0.96	0.99	1.00
Critical Success Index (CSI):	0.28	0.58	0.25	0.18	0.14	0.08
Bias for Occurrence (BIAS):	0.63	0.97	1.33	0.96	0.41	0.85
Hit Rate:	0.88	0.69	0.77	0.93	0.98	1.00
Percentage of Correct (PC):	0.88	0.69	0.77	0.93	0.98	1.00
True Skill Score (TSS):	0.32	0.34	0.29	0.26	0.16	0.10
Heidke Skill Score (HSS):	0.33	0.33	0.26	0.27	0.18	0.13

The category wise percentage of correct forecast is given in Figure 27.

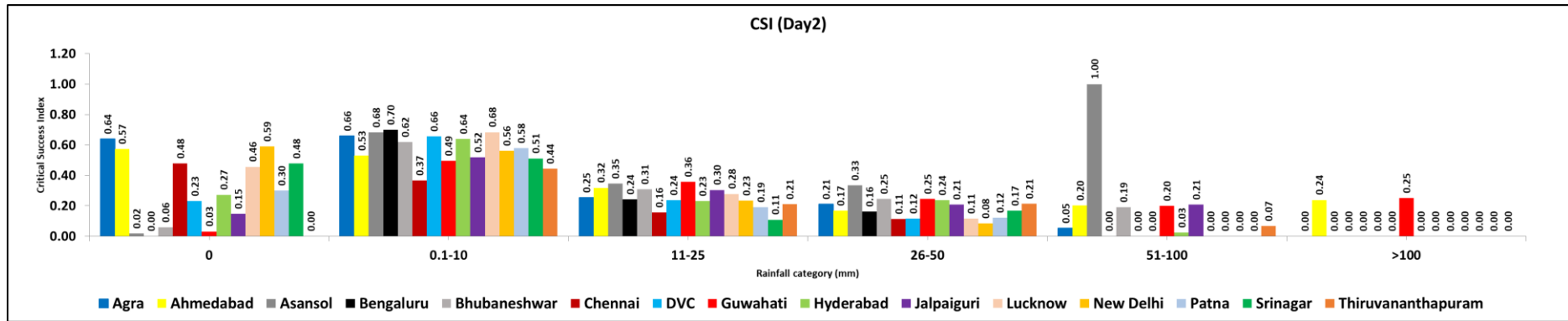


Figure 24: CSI for different categories of forecast for Day-2

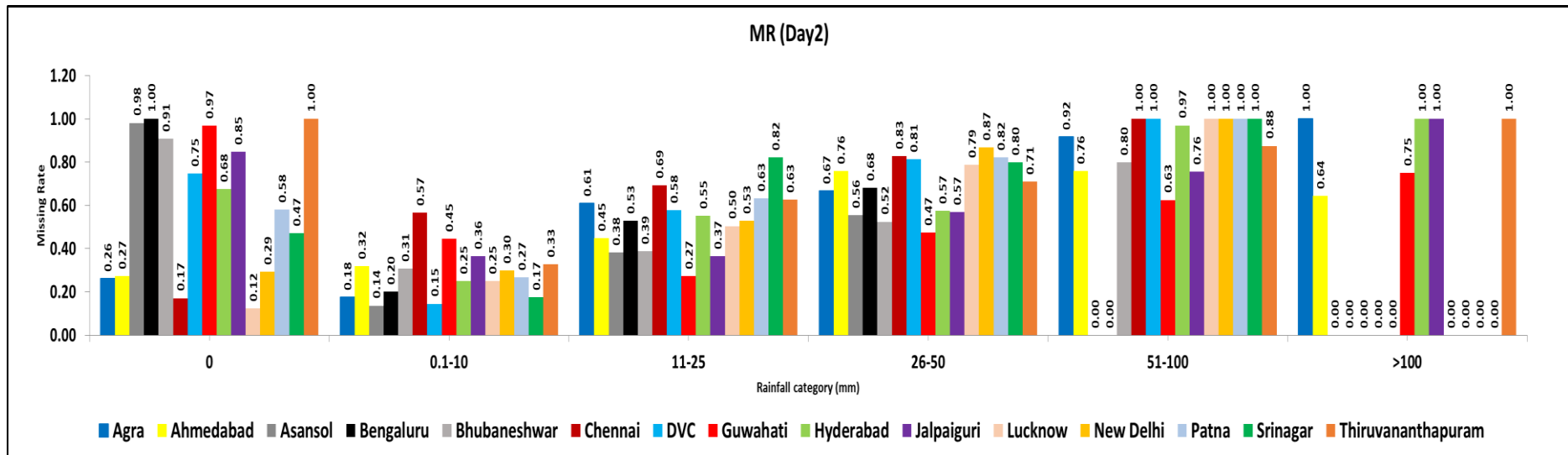


Figure 25: MR for different categories of forecast for Day-2

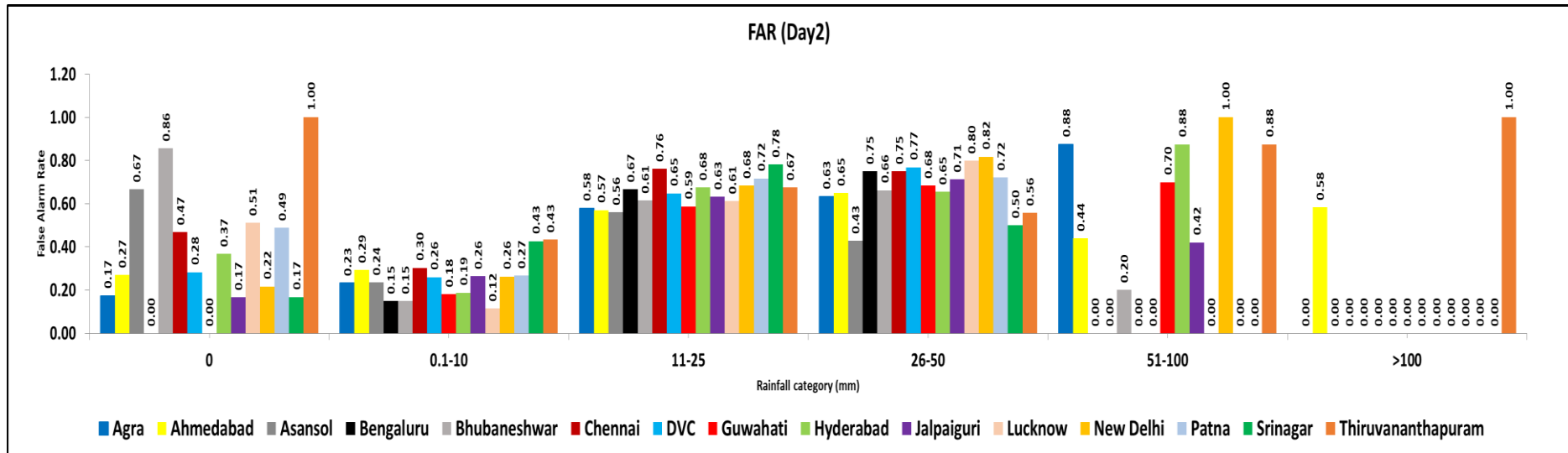


Figure 26: FAR for different categories of forecast for Day-2

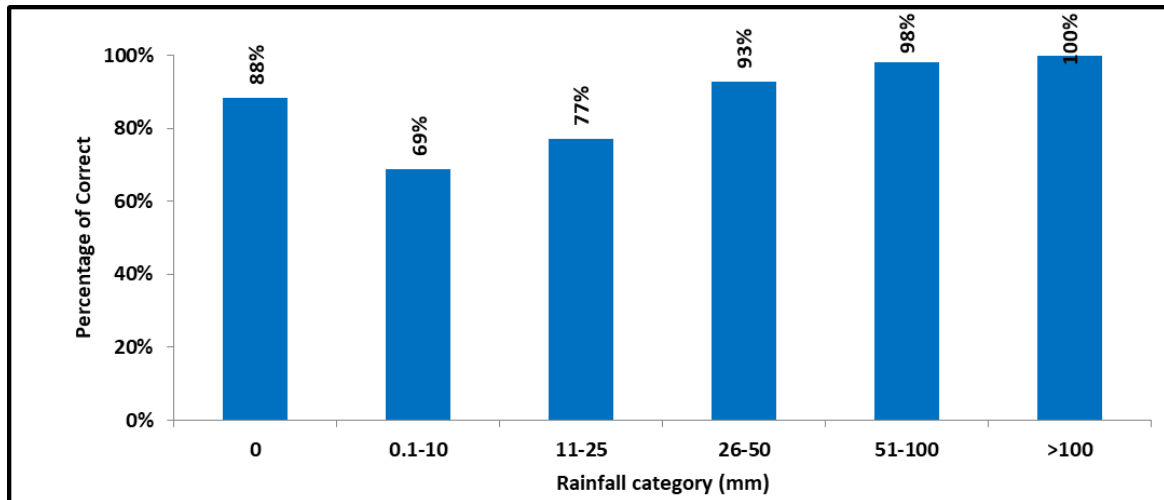


Figure 27: Category-wise Percentage Correct Forecast of Day-2

4.3 Skill Scores of Day-3 QPF

The QPF verification skill scores for different FMOs for Day-3 are given in Table 27. All India percentage correct QPF within same category is 61% which is same as last year (2021) (figure 47). While FMO Bengaluru has the highest Percentage correct QPF of 71% and FMO Thiruvananthapuram has the lowest accuracy of 43%, nine other FMOs viz. Agra, Asansol, Bhubaneswar, DVC, Hyderabad, Lucknow, New Delhi, Patna and Srinagar reported more than 60% Percentage correct QPF for the Day-3 as seen in the figure 28. The percentage correct forecast for Day-3 QPF within ± 1 category shows a substantial improvement and was 95% & above for all FMOs except FMO Thiruvananthapuram where the accuracy was 87%. The performance of QPF within ± 2 , ± 3 , ± 4 category can also be seen in table 27.

Table 27: Performance of Day-3 QPF for the Flood Season 2022

FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one		Correct and ± 1	Out by two		Out by three		Out by four		Correct (%)	Usable Forecast Correct & ± 1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	648	149	136	933	13	26	1	3	0	0	66%	96%
Ahmedabad	2318	1368	394	438	2200	42	65	2	9	0	0	59%	95%
Asansol	366	256	83	25	364	1	1	0	0	0	0	70%	99%
Bengaluru	2196	1556	352	220	2128	50	18	0	0	0	0	71%	97%
Bhubaneswar	1220	774	300	122	1196	13	11	0	0	0	0	63%	98%
Chennai	1342	686	180	415	1281	21	31	0	9	0	0	51%	95%
DVC	732	478	170	65	713	6	12	0	1	0	0	65%	97%
Guwahati	2440	1336	812	182	2330	91	14	3	2	0	0	55%	95%
Hyderabad	1952	1275	342	256	1873	42	27	0	10	0	0	65%	96%
Jalpaiguri	610	301	167	79	547	36	22	2	1	2	0	49%	90%
Lucknow	1708	1168	222	274	1664	22	21	1	0	0	0	68%	97%
New Delhi	366	231	70	48	349	9	7	0	1	0	0	63%	95%
Patna	976	610	216	127	953	6	17	0	0	0	0	63%	98%
Srinagar	488	325	113	43	481	2	5	0	0	0	0	67%	99%
Thiruvananthapuram	976	416	239	198	853	37	71	4	11	0	0	43%	87%
Over All fct.	18666	11428	3809	2628	17865	391	348	13	47	2	0	61%	96%

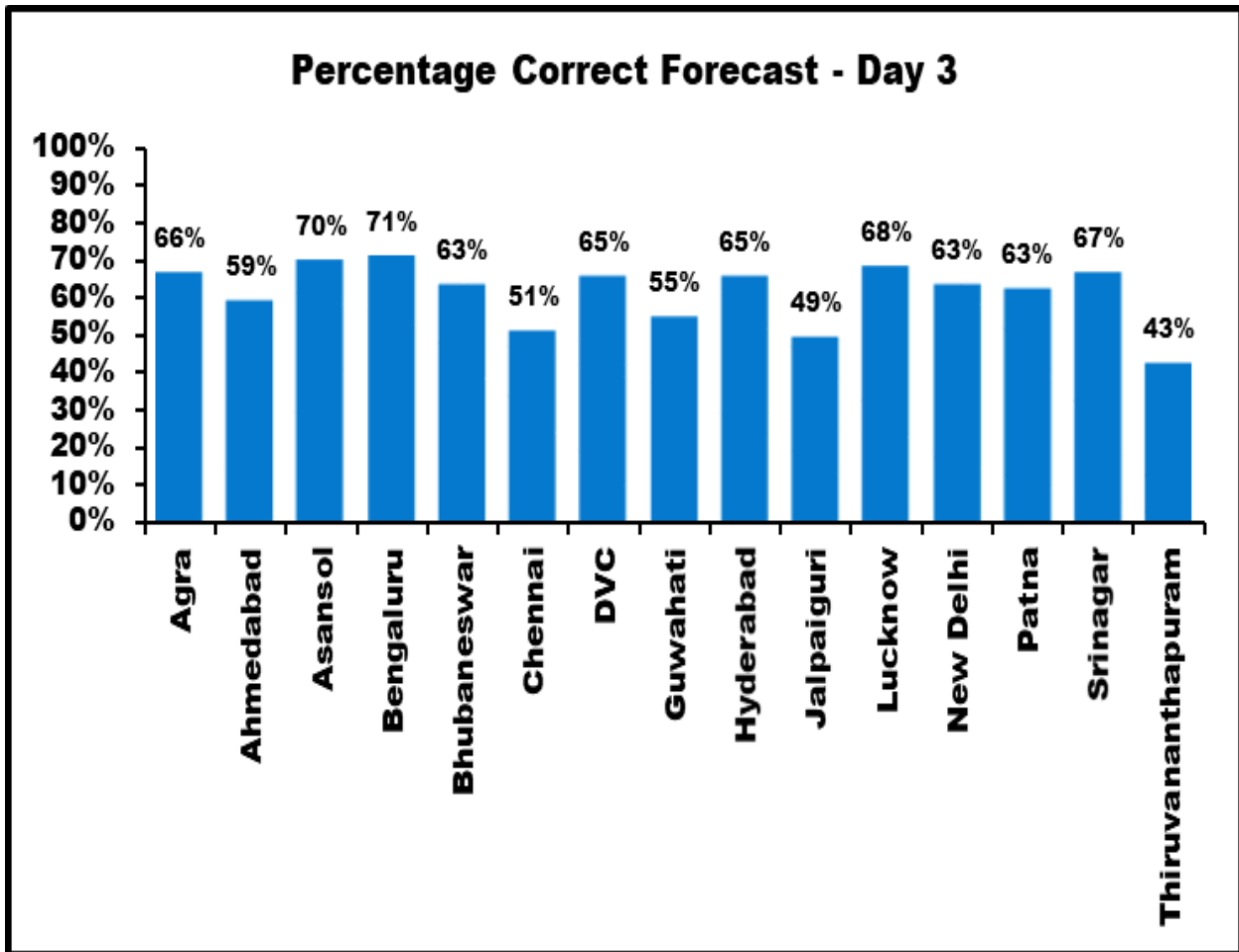


Figure 28. Percentage correct forecast Day-3 by different FMOs

All India skill scores viz, POD, FAR, MR, CSI, BIAS, PC, TSS and HSS computed from 2X2 contingency table are given in Table 28 and figures 29 - 31. While CSI and POD decreases with increase in the QPF category, an opposite trend is observed for False alarm rate and Missing rate.

Table 28: Skill Scores of Day-3 QPF

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.36	0.72	0.44	0.27	0.06	0.09
False Alarm Rate (FAR):	0.40	0.27	0.66	0.72	0.75	0.47
Missing Rate (MR):	0.64	0.28	0.56	0.73	0.94	0.91
Correct Non-Occurrence (C-NON):	0.94	0.60	0.82	0.96	1.00	1.00
Critical Success Index (CSI):	0.27	0.57	0.24	0.15	0.05	0.07
Bias for Occurrence (BIAS):	0.59	0.99	1.29	0.98	0.27	0.86
Hit Rate:	0.88	0.68	0.77	0.92	0.98	1.00
Percentage of Correct (PC):	0.88	0.68	0.77	0.92	0.98	1.00
True Skill Score (TSS):	0.30	0.31	0.26	0.22	0.06	0.08
Heidke Skill Score (HSS):	0.31	0.31	0.23	0.22	0.08	0.11

The category-wise percentage of correct forecast is given in Figure 32.

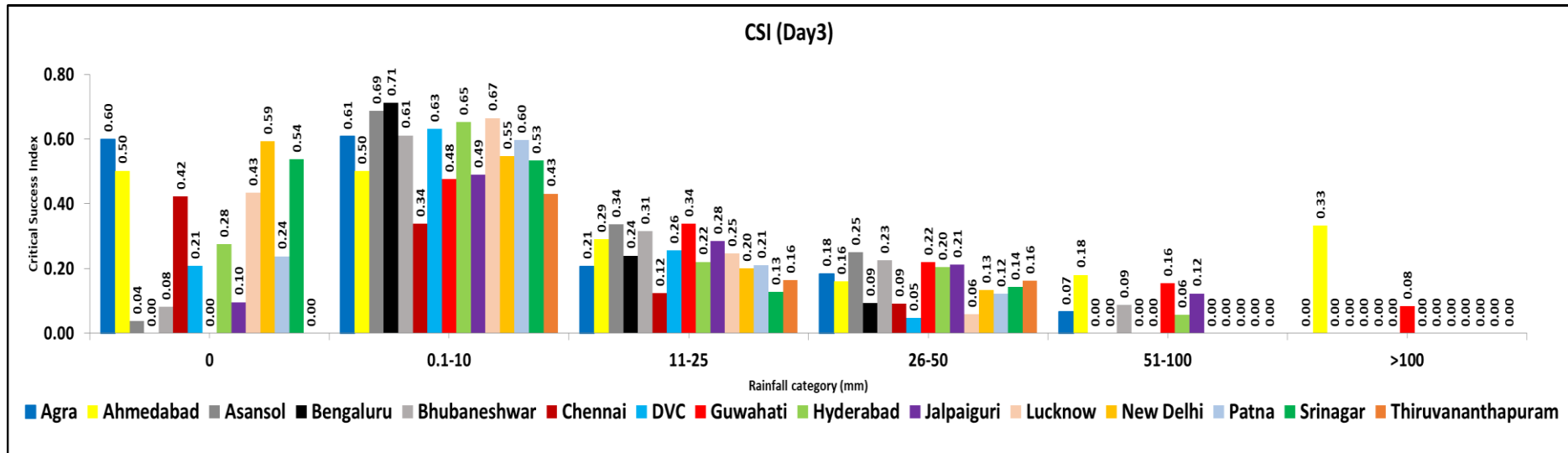


Figure 29: CSI for different categories of forecast for Day-3

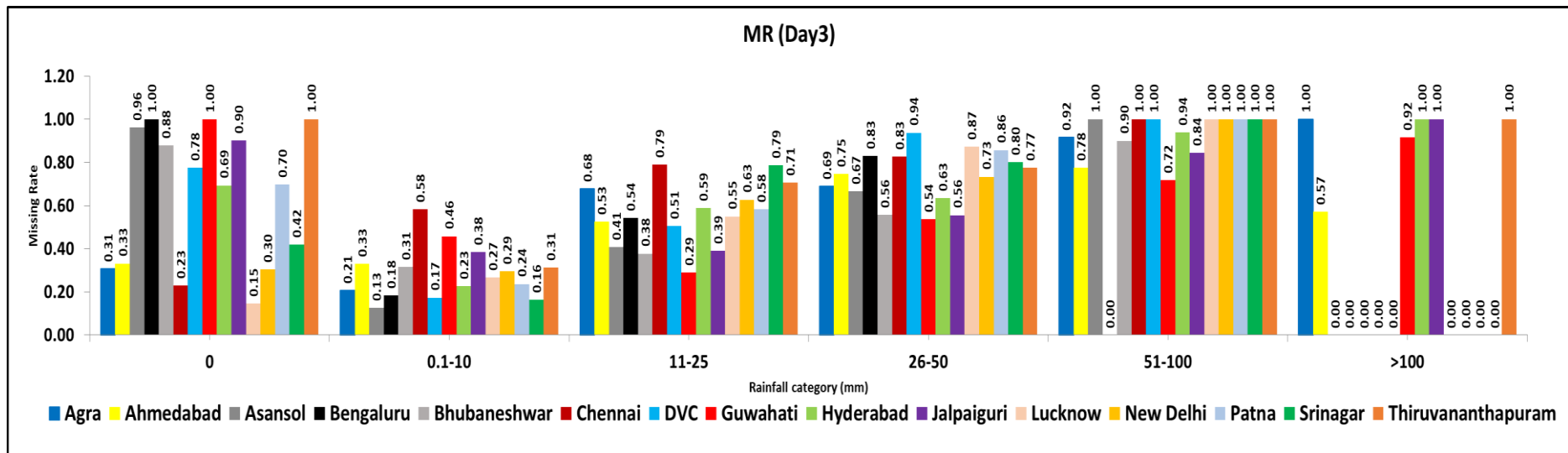


Figure 30: MR for different categories of forecast for Day-3

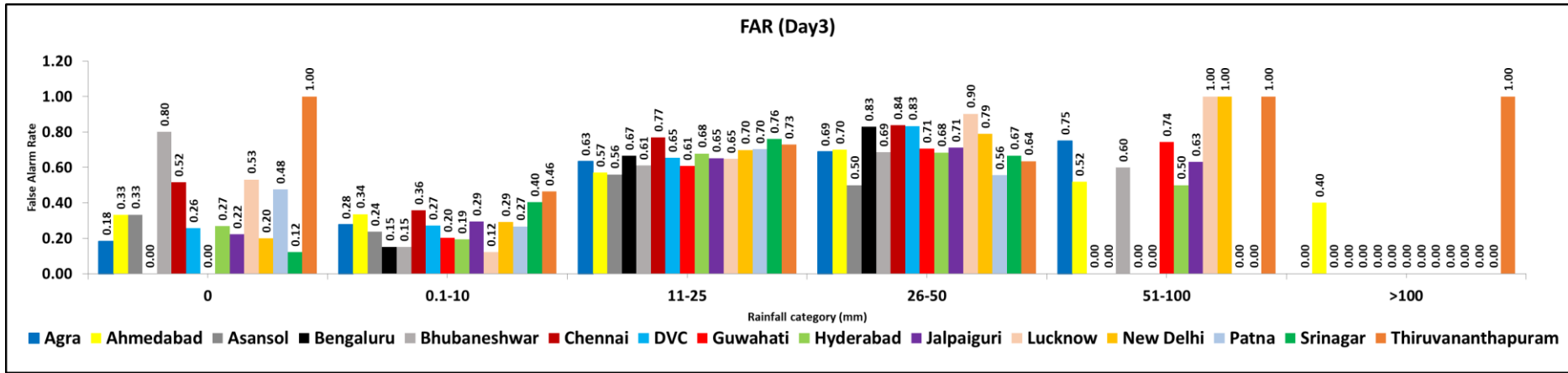


Figure 31: FAR for different categories of forecast for Day-3

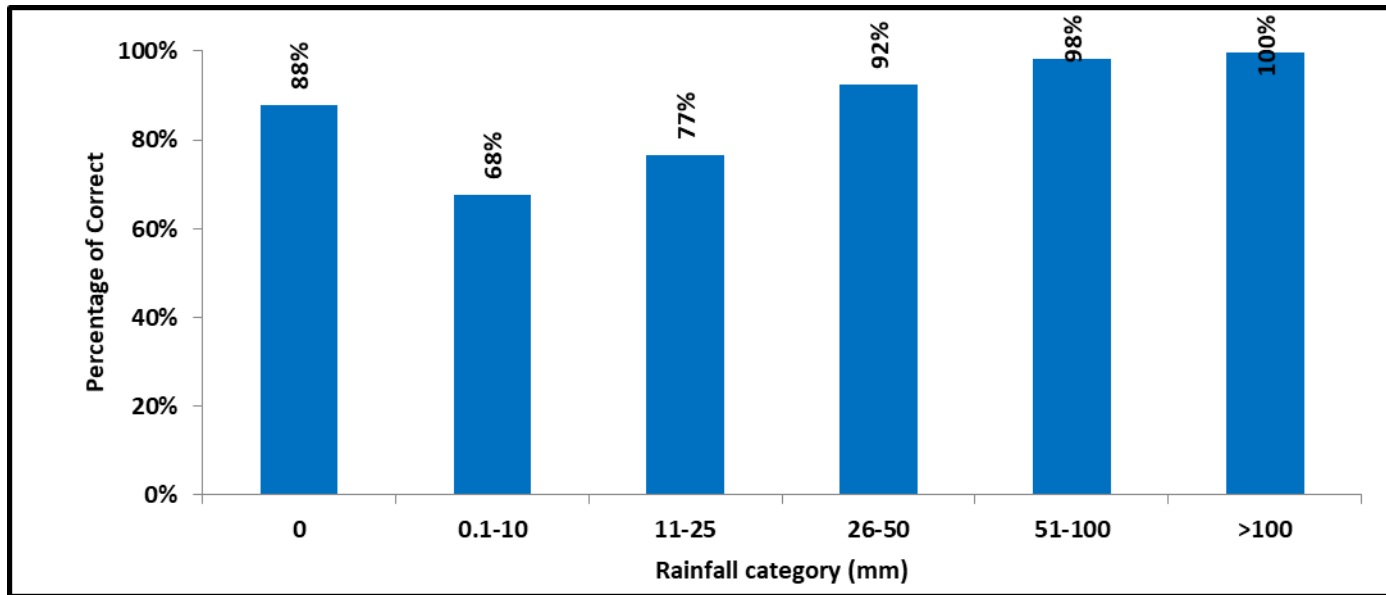


Figure 32: Category-wise Percentage Correct Forecast of Day-3

4.4 Skill Scores of Day-4 QPF

The QPF verification skill scores for different FMOs for Day-4 are given in Table 29. All India percentage correct QPF within same category is 61%. While FMO Asansol has the highest Percentage correct QPF of 72% and FMO Chennai has the lowest accuracy of 48%, nine other FMOs viz., Agra, Bengaluru, Bhubaneswar, DVC, Hyderabad, Lucknow, New Delhi, Patna and Srinagar reported more than 60% accuracy of QPF for the Day-4 as seen in the figure 33. The percentage correct forecast for Day-4 QPF within ± 1 category shows a substantial improvement and was 93% & above for all FMOs except newly commissioned FMO Thiruvananthapuram where the accuracy was 89%. The performance of QPF within ± 2 , ± 3 , ± 4 category can also be seen in table 29.

Table 29: Performance of Day-4 QPF for the Flood Season 2022

FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one		Correct and ± 1	Out by two		Out by three		Out by four		Correct (%)	Usable Forecast Correct & ± 1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	618	150	159	927	17	28	2	2	0	0	63%	95%
Ahmedabad	2318	1314	418	428	2160	47	93	5	13	0	0	57%	93%
Asansol	366	262	79	23	364	0	2	0	0	0	0	72%	99%
Bengaluru	2196	1544	334	253	2131	40	25	0	0	0	0	70%	97%
Bhubaneswar	1220	767	319	115	1201	9	10	0	0	0	0	63%	98%
Chennai	1342	645	157	469	1271	23	42	0	6	0	0	48%	95%
DVC	732	478	163	81	722	3	7	0	0	0	0	65%	99%
Guwahati	2440	1311	823	203	2337	84	15	2	2	0	0	54%	96%
Hyderabad	1952	1299	304	258	1861	40	40	2	9	0	0	67%	95%
Jalpaiguri	610	283	176	92	551	30	23	5	1	0	0	46%	90%
Lucknow	1708	1162	239	265	1666	14	24	2	2	0	0	68%	98%
New Delhi	366	228	65	48	341	9	15	0	1	0	0	62%	93%
Patna	976	616	224	112	952	10	14	0	0	0	0	63%	98%
Srinagar	488	306	119	54	479	2	7	0	0	0	0	63%	98%
Thiruvananthapuram	976	475	210	186	871	19	71	0	13	0	2	49%	89%
Over All fct.	18666	11308	3780	2746	17834	347	416	18	49	0	2	61%	96%

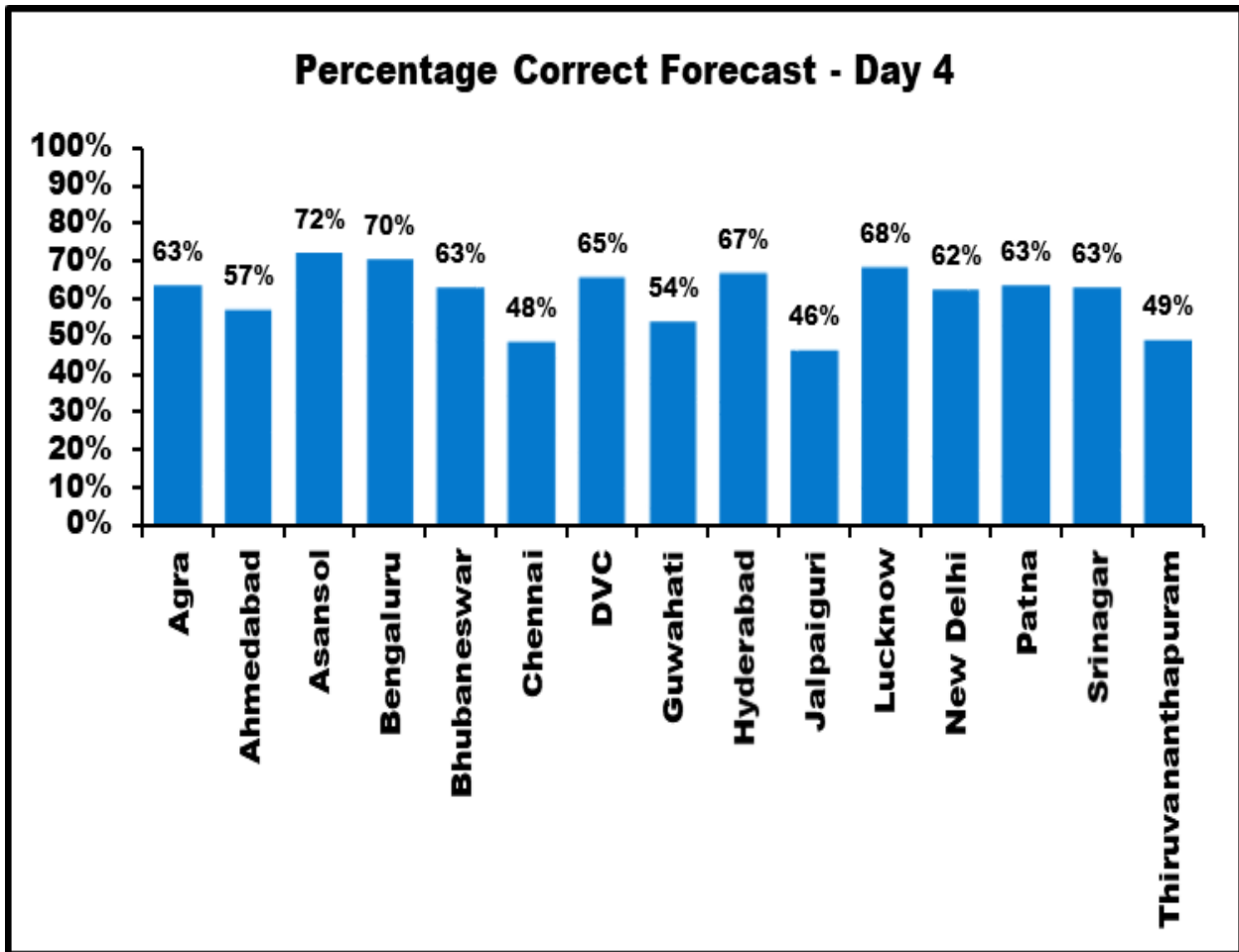


Figure 33. Percentage correct forecast Day-4 by different FMOs

All India skill scores viz, POD, FAR, MR, CSI, BIAS, PC, TSS and HSS computed from 2X2 contingency table are given in Table 30 and figures 34 - 36. While CSI and POD decreases with increase in the QPF category, an opposite trend is observed for False alarm rate and Missing rate.

Table 30: Skill Scores of Day-4 QPF

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.34	0.72	0.43	0.19	0.05	0.04
False Alarm Rate (FAR):	0.42	0.28	0.67	0.78	0.77	0.70
Missing Rate (MR):	0.66	0.28	0.57	0.81	0.95	0.96
Correct Non-Occurrence (C-NON):	0.94	0.57	0.82	0.96	1.00	1.00
Critical Success Index (CSI):	0.25	0.56	0.23	0.11	0.04	0.02
Bias for Occurrence (BIAS):	0.59	1.01	1.26	0.83	0.23	0.12
Hit Rate:	0.87	0.67	0.76	0.92	0.98	1.00
Percentage of Correct (PC):	0.87	0.67	0.76	0.92	0.98	1.00
True Skill Score (TSS):	0.28	0.29	0.25	0.15	0.05	0.04
Heidke Skill Score (HSS):	0.29	0.29	0.22	0.15	0.06	0.04

The category-wise percentage correct forecast is given in Figure 37.

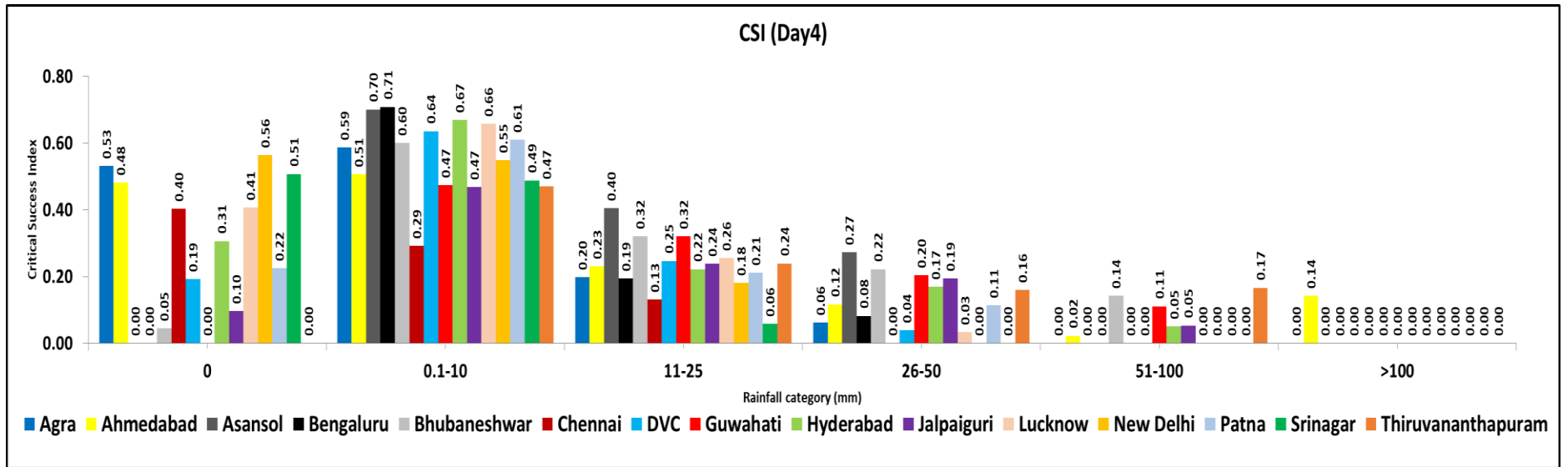


Figure 34: CSI for different categories of forecast for Day-4

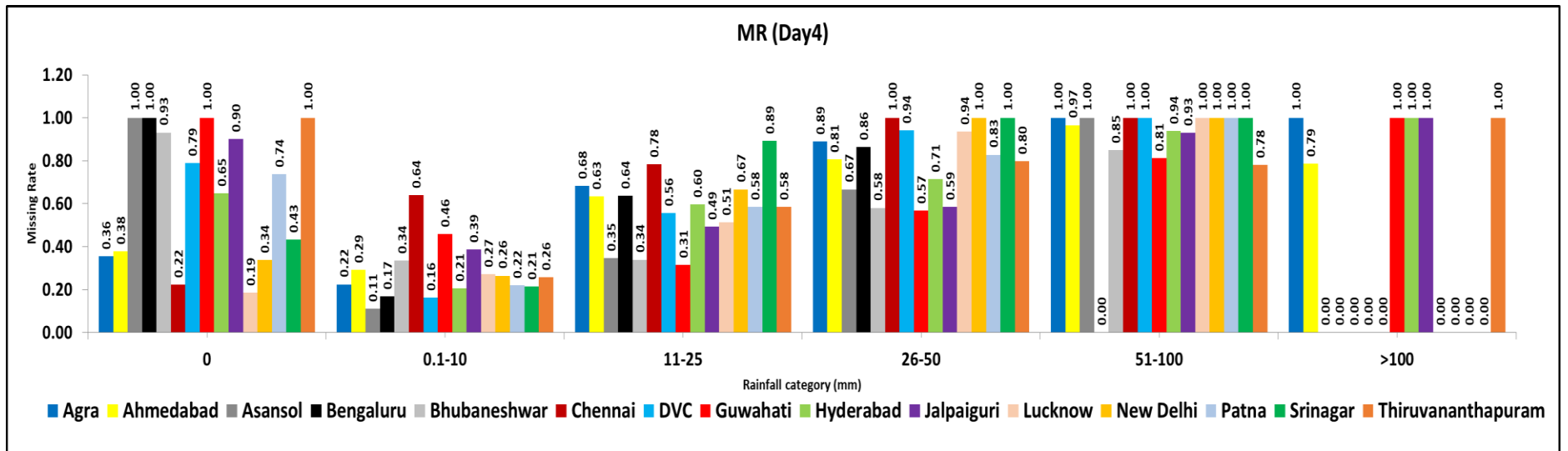


Figure 35: MR for different categories of forecast for Day-4

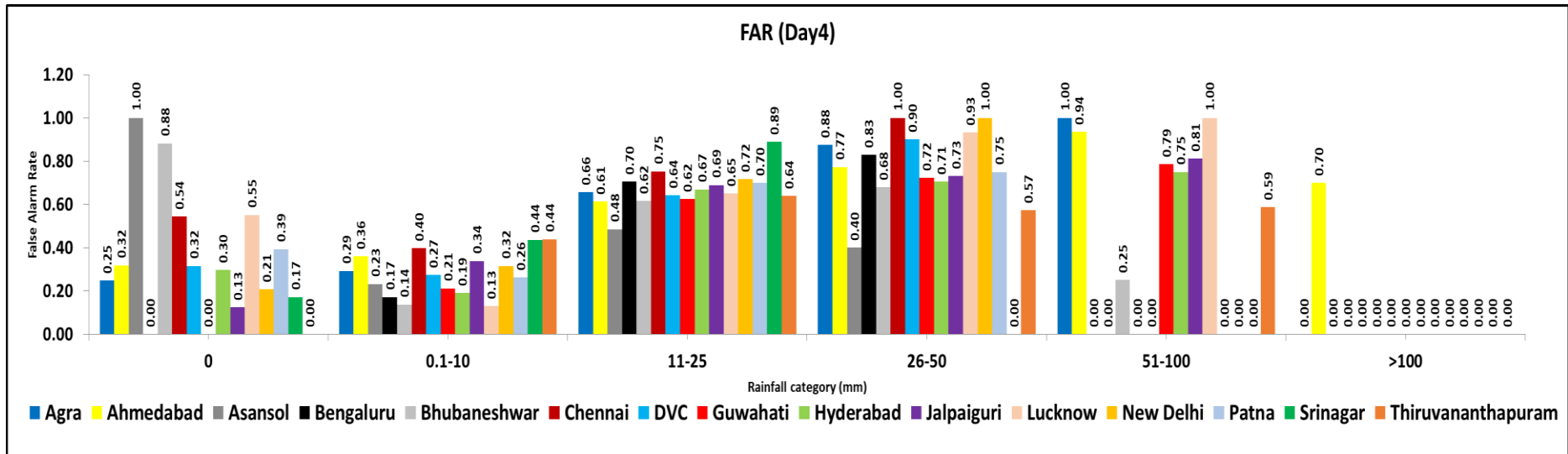


Figure 36: FAR for different categories of forecast for Day-4

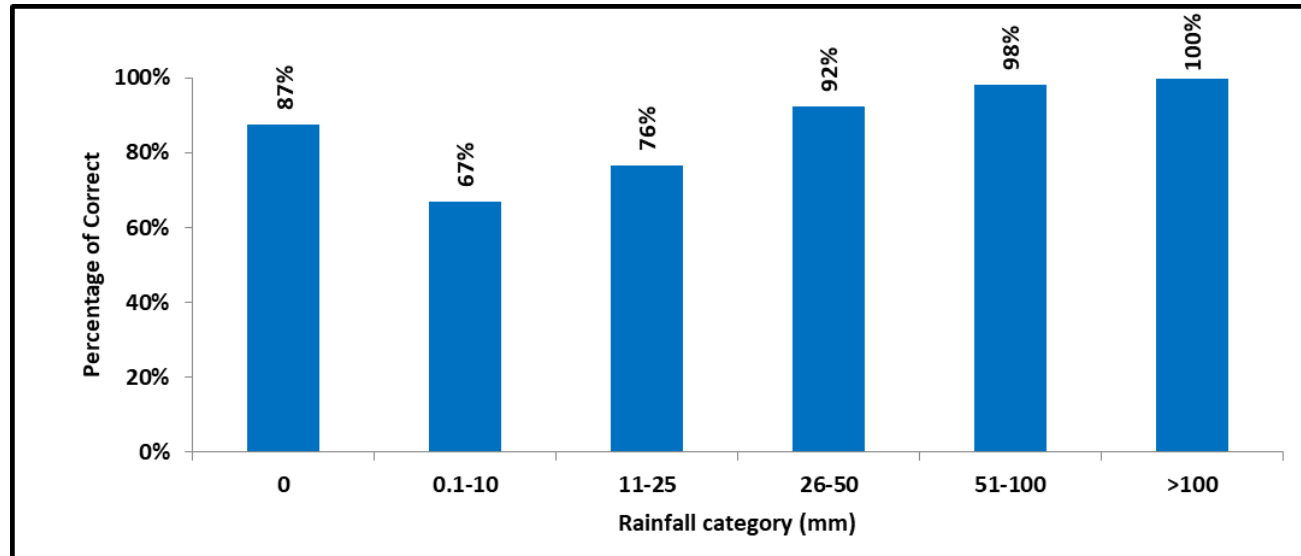


Figure 37: Category-wise Percentage Correct Forecast of Day-4

4.5 Skill Scores of Day-5 QPF

The QPF verification skill scores for different FMOs for Day-5 are given in Table 31. All India percentage correct QPF within same category is 59%. While FMO Bengaluru has the highest Percentage correct QPF of 70% and FMO Jalpaiguri has the lowest accuracy of 43%, eight other FMOs viz. Agra, Asansol, DVC, Hyderabad, Lucknow, New Delhi, Patna and Srinagar reported more than 60% Accuracy QPF for the Day-5 as seen in the figure 38. The percentage correct forecast for Day-5 QPF within ± 1 category shows a substantial improvement and was 92% & above for all FMOs except newly commissioned FMO Thiruvananthapuram where the accuracy was 88%. The performance of QPF within ± 2 , ± 3 , ± 4 category can also be seen in table 31.

Table 31: Performance of Day-5 QPF for the Flood Season 2022

FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one		Correct and ± 1	Out by two		Out by three		Out by four		Correct (%)	Usable Forecast Correct & ± 1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	607	153	153	913	21	33	4	5	0	0	62%	94%
Ahmedabad	2318	1301	420	401	2122	70	93	11	21	0	1	56%	92%
Asansol	366	244	87	32	363	2	1	0	0	0	0	67%	99%
Bengaluru	2196	1547	336	265	2148	20	28	0	0	0	0	70%	98%
Bhubaneswar	1220	713	368	105	1186	19	14	0	1	0	0	58%	97%
Chennai	1342	625	193	446	1264	28	40	0	10	0	0	47%	94%
DVC	732	479	163	77	719	6	7	0	0	0	0	65%	98%
Guwahati	2440	1281	845	197	2323	89	23	2	3	0	0	53%	95%
Hyderabad	1952	1278	281	287	1846	33	55	3	15	0	0	65%	95%
Jalpaiguri	610	260	190	96	546	31	27	3	3	0	0	43%	90%
Lucknow	1708	1149	250	258	1657	20	29	0	2	0	0	67%	97%
New Delhi	366	222	74	47	343	8	9	1	5	0	0	61%	94%
Patna	976	610	213	120	943	12	19	0	2	0	0	63%	97%
Srinagar	488	291	127	58	476	3	6	0	2	0	1	60%	98%
Thiruvananthapuram	976	473	188	196	857	18	82	0	16	0	3	48%	88%
Over All fct.	18666	11080	3888	2738	17706	380	466	24	85	0	5	59%	95%

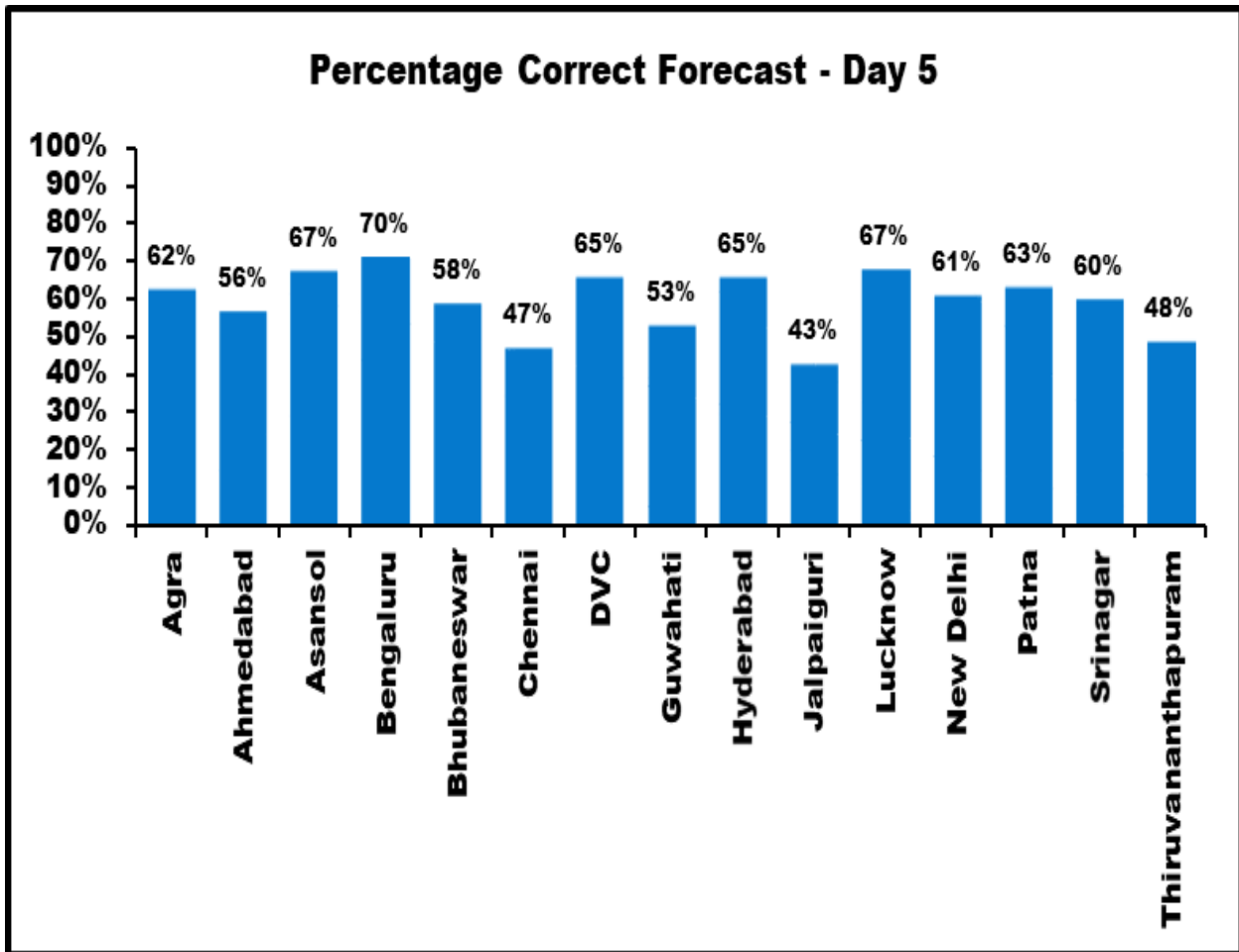


Figure 38. Percentage correct forecast Day-5 by different FMOs

All India skill scores viz, POD, FAR, MR, CSI, BIAS, PC, TSS and HSS computed from 2X2 contingency table are given in Table 32 and figures 39 - 41. While CSI and POD decreases with increase in the QPF category, an opposite trend is observed for False alarm rate and Missing rate.

Table 32: Skill Scores of Day-5 QPF

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.30	0.71	0.39	0.15	0.05	0.04
False Alarm Rate (FAR):	0.39	0.29	0.70	0.83	0.79	0.80
Missing Rate (MR):	0.70	0.29	0.61	0.85	0.95	0.96
Correct Non-Occurrence (C-NON):	0.94	0.55	0.81	0.96	1.00	1.00
Critical Success Index (CSI):	0.22	0.55	0.21	0.08	0.03	0.02
Bias for Occurrence (BIAS):	0.56	1.03	1.24	0.82	0.32	0.18
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):	0.24	0.26	0.21	0.11	0.04	0.03
Heidke Skill Score (HSS):	0.25	0.26	0.18	0.10	0.06	0.03

The category wise percentage correct forecast is given in Figure 42.

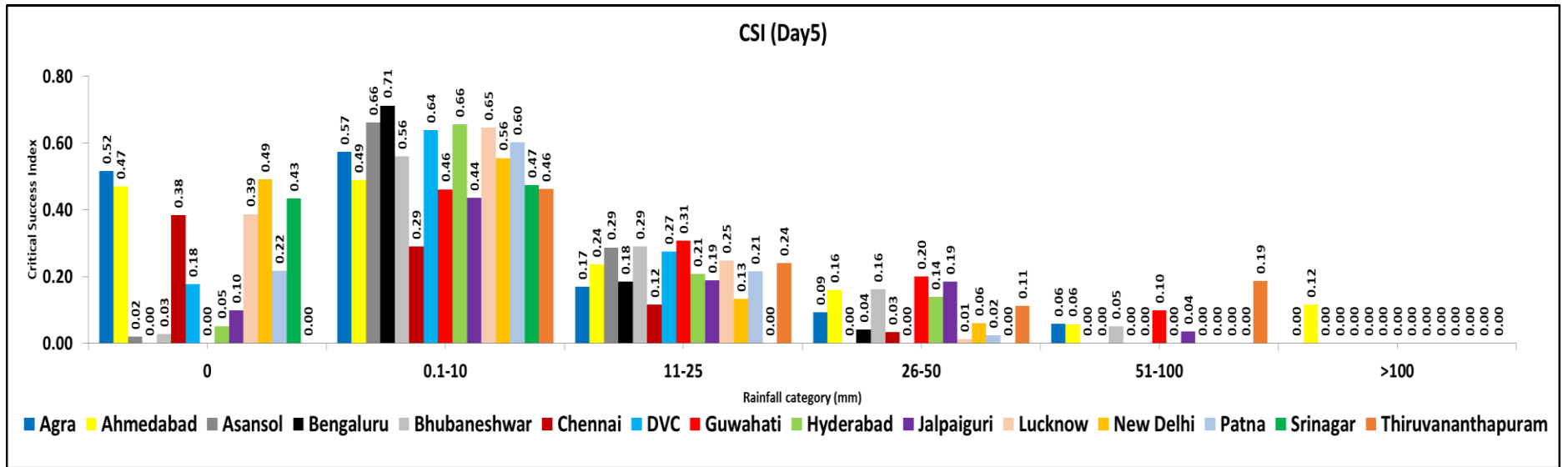


Figure 39: CSI for different categories of forecast for Day-5

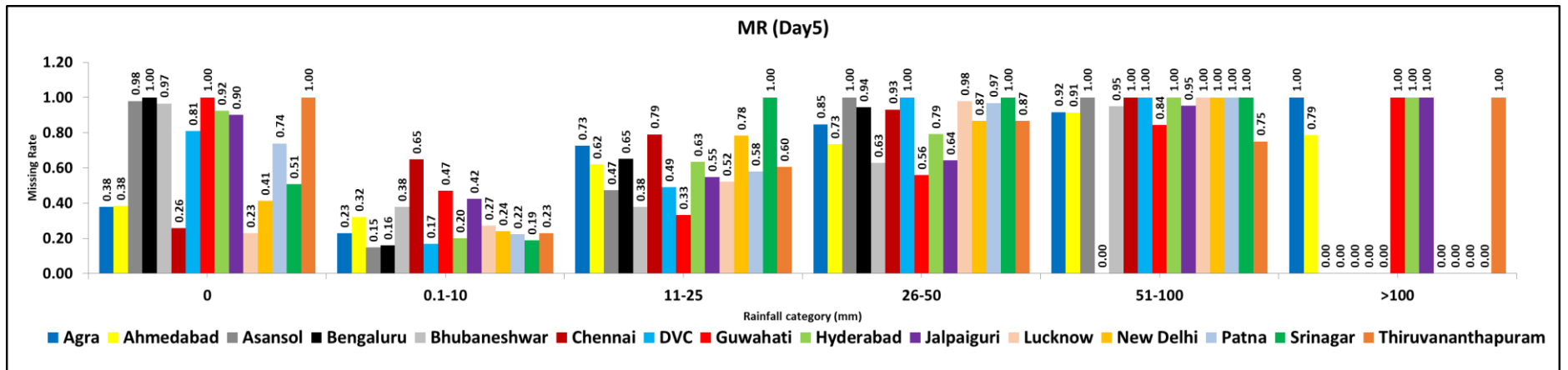


Figure 40: MR for different categories of forecast for Day-5

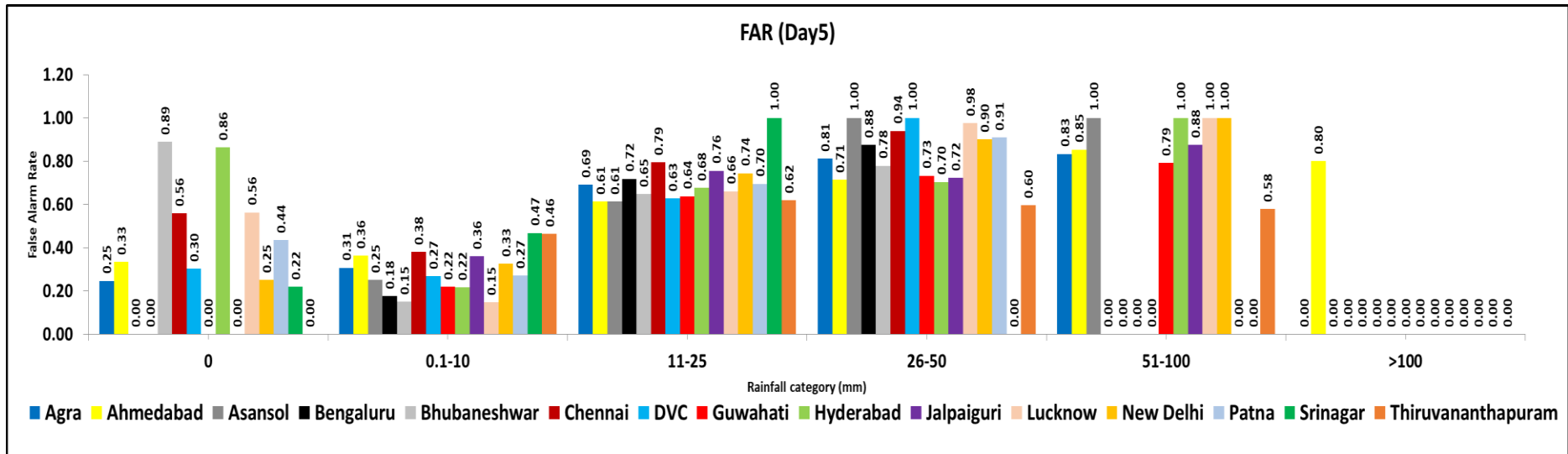


Figure 41: FAR for different categories of forecast for Day-5

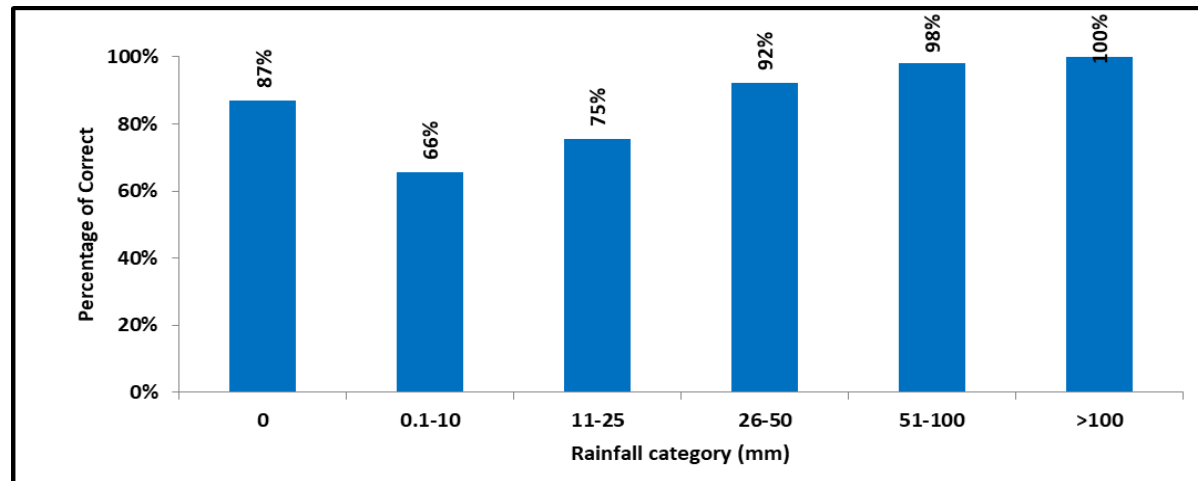


Figure 42: Category-wise Percentage Correct Forecast of Day-5

4.6 All India QPF Verification for Day-1, Day-2, Day-3, Day-4 and Day-5

The Day-1, Day-2, Day-3, Day-4 and Day-5 percentage correct forecast for all sub-basins under different FMOs for the years 2017-2022 are given in Figure 43. It is also observed during this year, the accuracy of forecast has improved by 1% in Day-2 and Day-4 as compared to last year.

The accuracy of QPF decreases with the increase in lead time from Day-1 to Day-5. It can be seen that the % accuracy decreases from 66% in Day-1 to 59% in Day-5 forecast. However, accuracy decreases sharply from Day-1 to Day-2 (by 3%), decreases from Day-2 to Day-3 (by 2%) but there is not much deterioration in the accuracy with increase in lead time from day-3 to day-5.

The category-wise average CSI in all sub-basins across the country for Day-1, Day-2, Day-3, Day-4 and Day-5 are given in figure 44. It is observed that CSI decreases as we move from lower to higher category of QPF and also with the increase in forecast lead time.

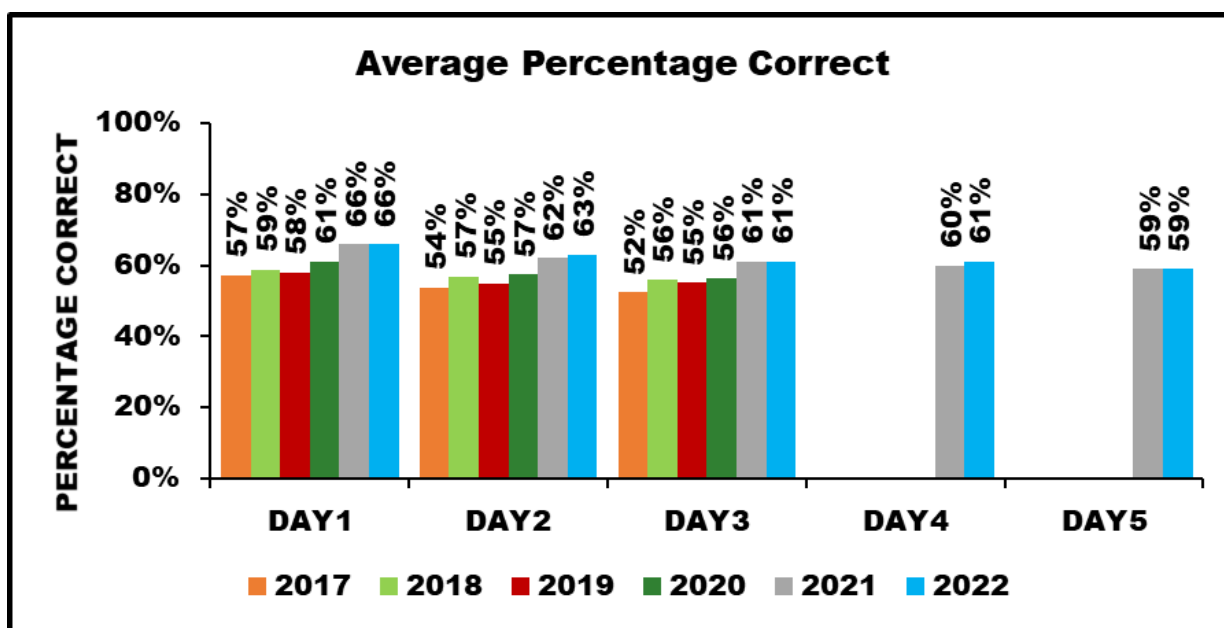


Figure 43: Day-1, Day-2, Day-3, Day-4 and Day-5 overall % correct forecast

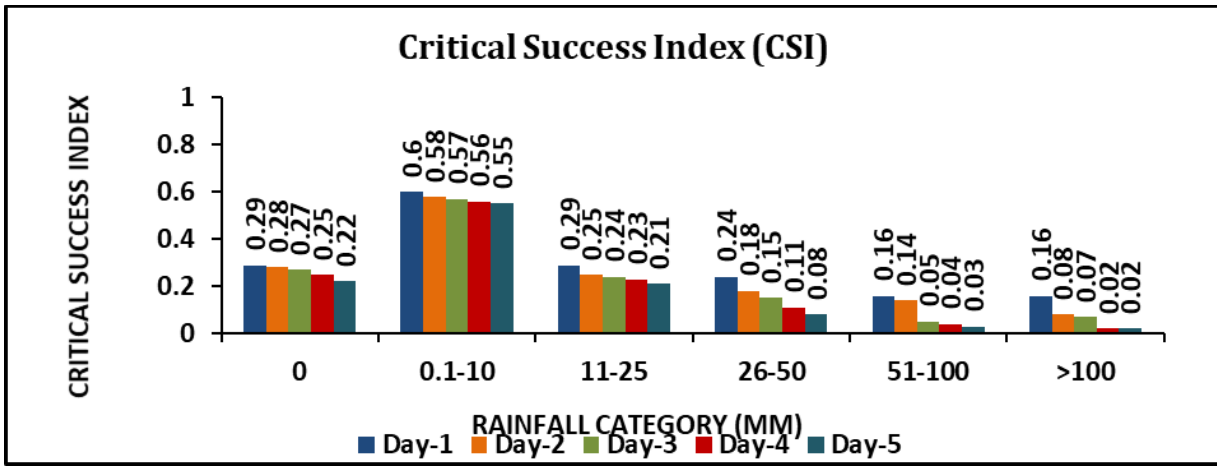


Figure 44: Category-wise Critical Success Index for Day-1, Day-2, Day-3, Day-4 and Day-5

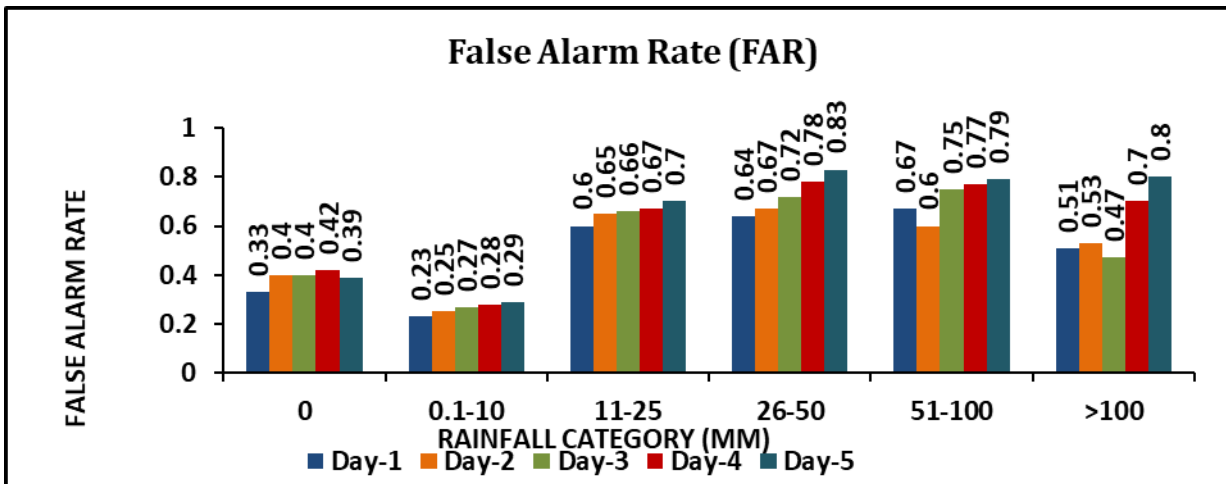


Figure 45: Category-wise False Alarm Rate for Day-1, Day-2, Day-3, Day-4 and Day-5

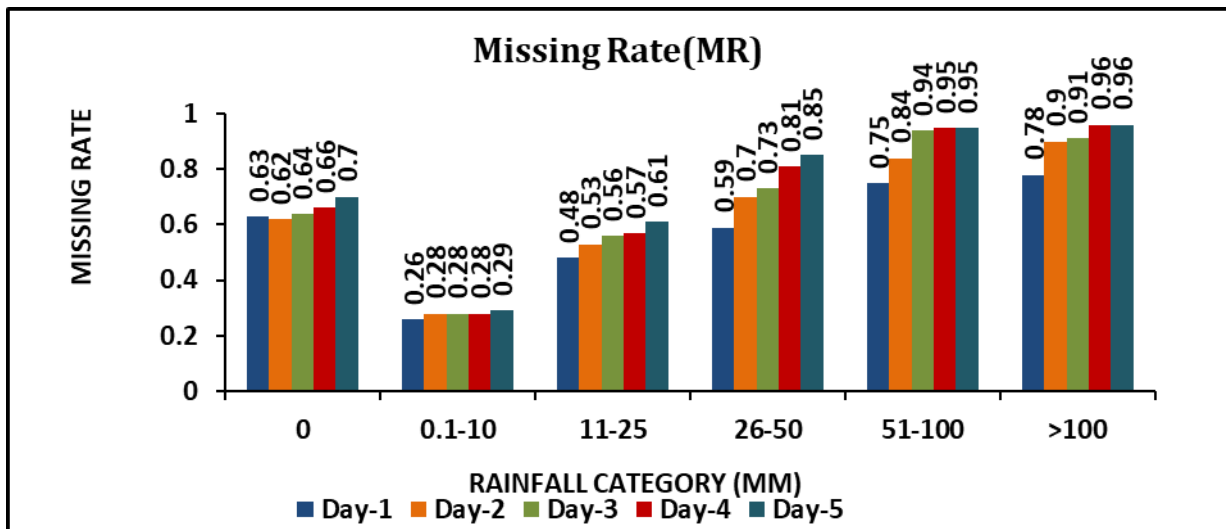


Figure 46: Category-wise Missing Rate for Day-1, Day-2, Day-3, Day-4 and Day-5

The category-wise average False Alarm rate (FAR) and Missing Rate(MR) for all sub-basins across the country for Day-1, Day-2, Day-3, Day-4 and Day-5 are given in figures 45 and 46 respectively.

It is observed that FAR & MR increased with the increase in forecast lead time for each category and also increased from lower to higher QPF category.

4.7. Improvement in operational QPF (2017 to 2022)

The FMO-wise Percentage correct QPF for Day-1 for the year 2017 to 2022 are given in Figure 47. The accuracy of Day-1 QPF when compared to previous years has improved in respect of FMOs Agra, Ahmedabad, Asansol, Chennai, Hyderabad and Thiruvananthapuram while it has deteriorated slightly in respect of FMOs Bengaluru, Bhubaneswar, DVC, Guwahati, Jalpaiguri, Lucknow, New Delhi, Patna and Srinagar.

The FMO-wise performance in operational QPF during 2022 as compared to average performance in the previous years (2017-2021) for Day-1, Day-2 and Day-3 are shown in Figure 48-50 respectively. Substantial improvement in the accuracy ($\geq 5\%$) is observed for the FMOs Agra, Bengaluru, Bhubaneswar, Chennai, Hyderabad, Lucknow and Patna.

FMO Thiruvananthapuram which got established in 2021 has shown 5% improvement in day-1, 7% in day-2 and 2% in day-3 percentage correct of QPF with compare previous sw monsoon season.

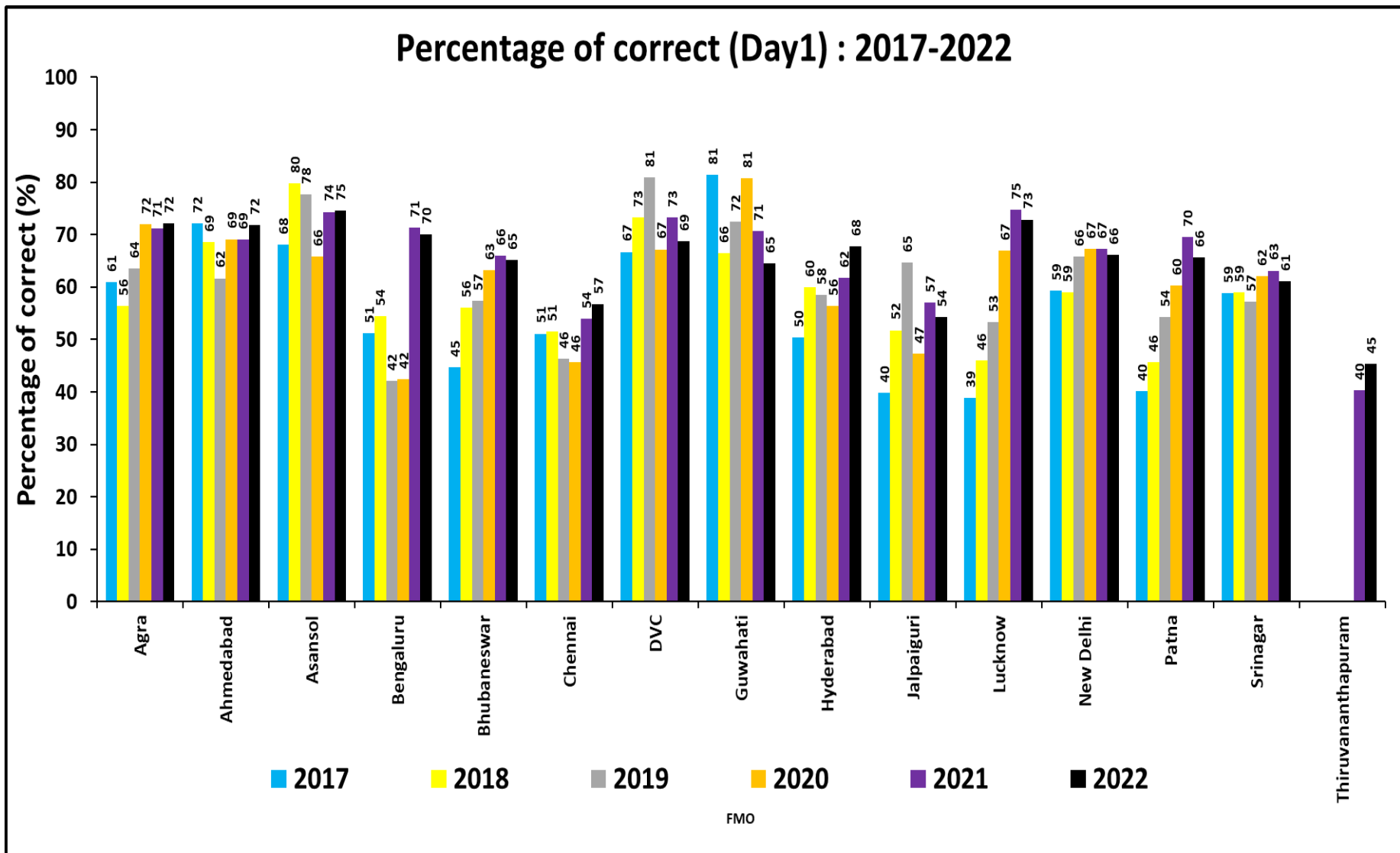


Figure 47: FMO-wise Percentage Correct QPF for Day-1 for the year 2017 to 2022

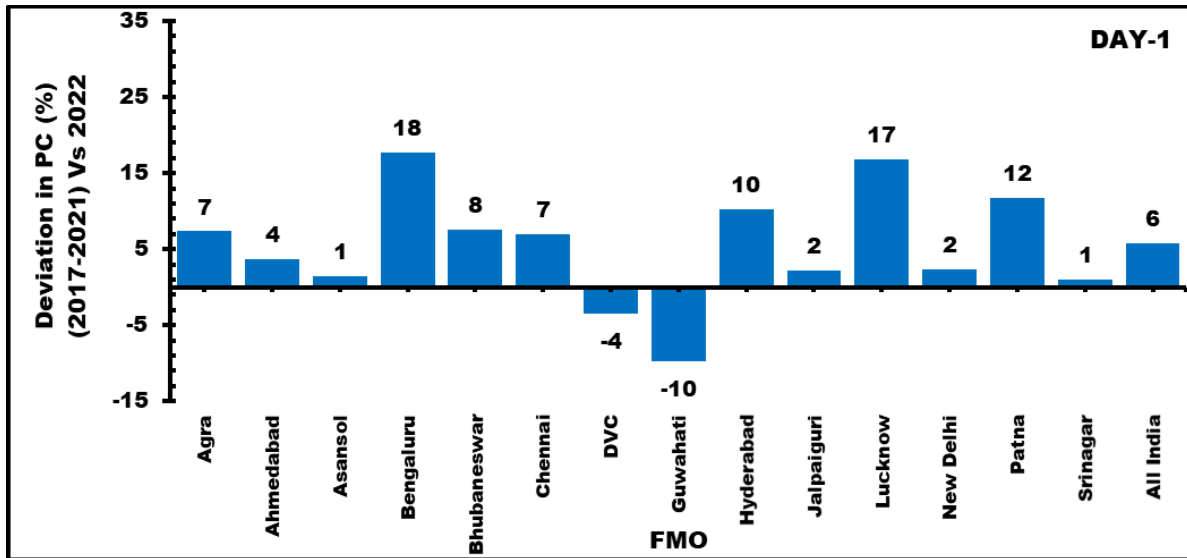


Figure 48. Day-1 performance of FMO-wise Operational QPF during 2022 Vs mean of 2017 - 2021

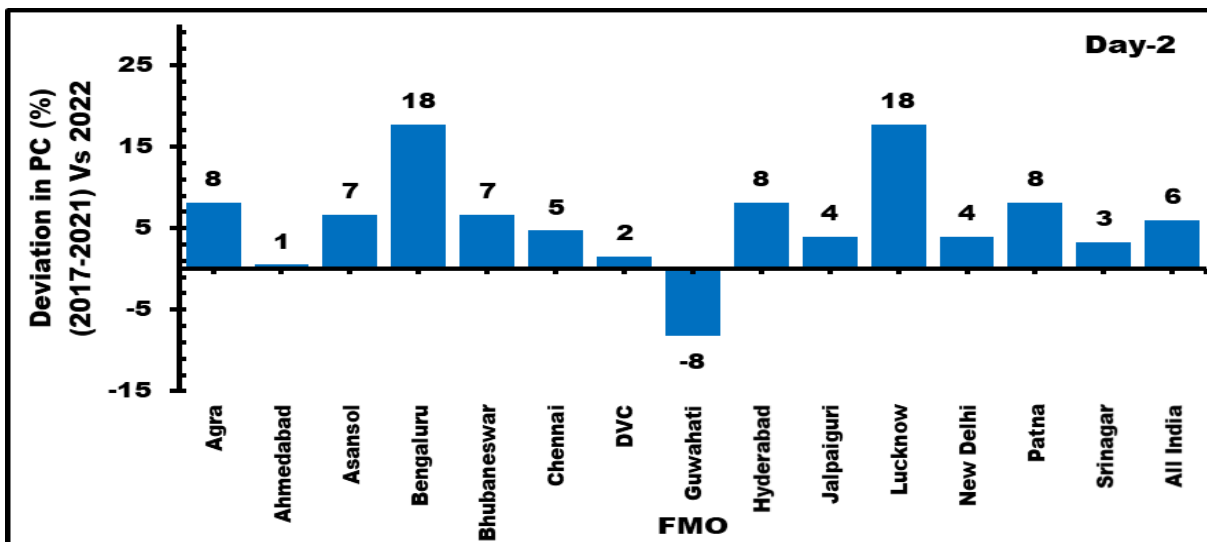


Figure 49. Day-2 performance of FMO-wise Operational QPF during 2022 Vs mean of 2017 - 2021

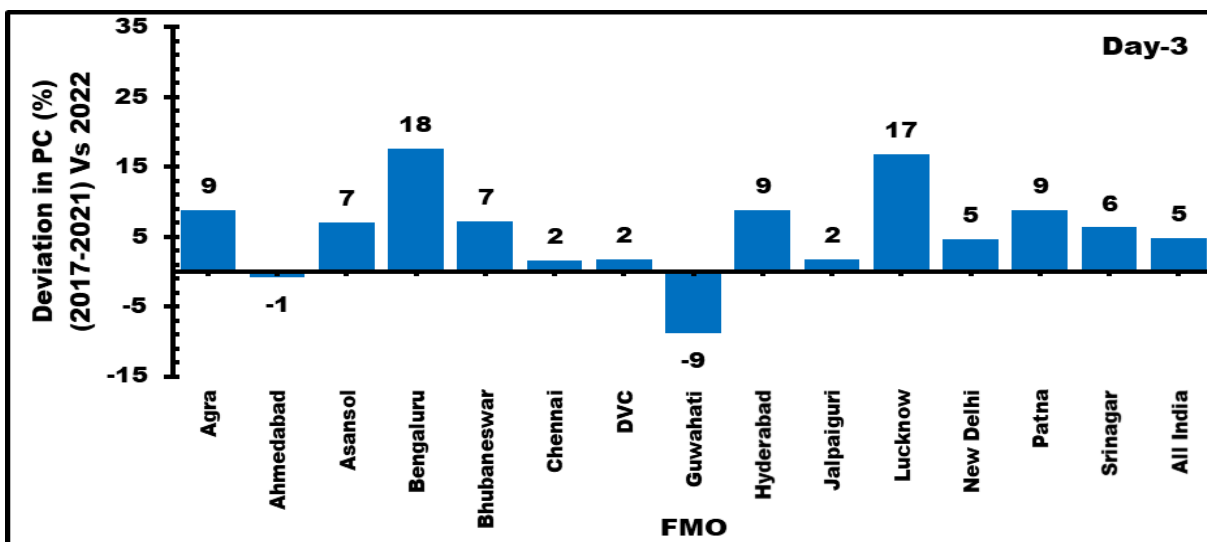


Figure 50. Day-3 performance of FMO-wise Operational QPF during 2022 Vs mean of 2017 - 2021

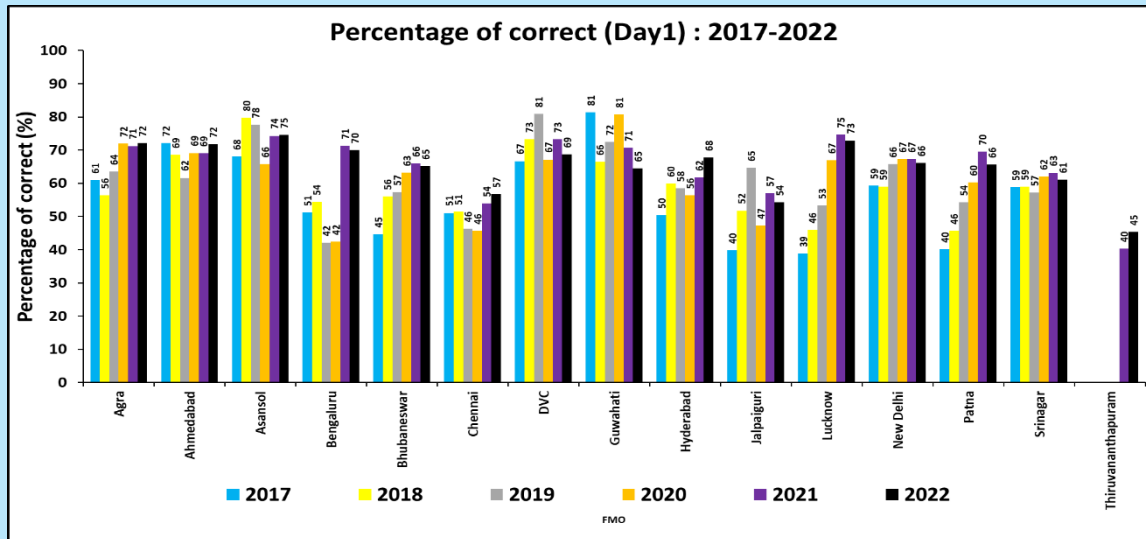
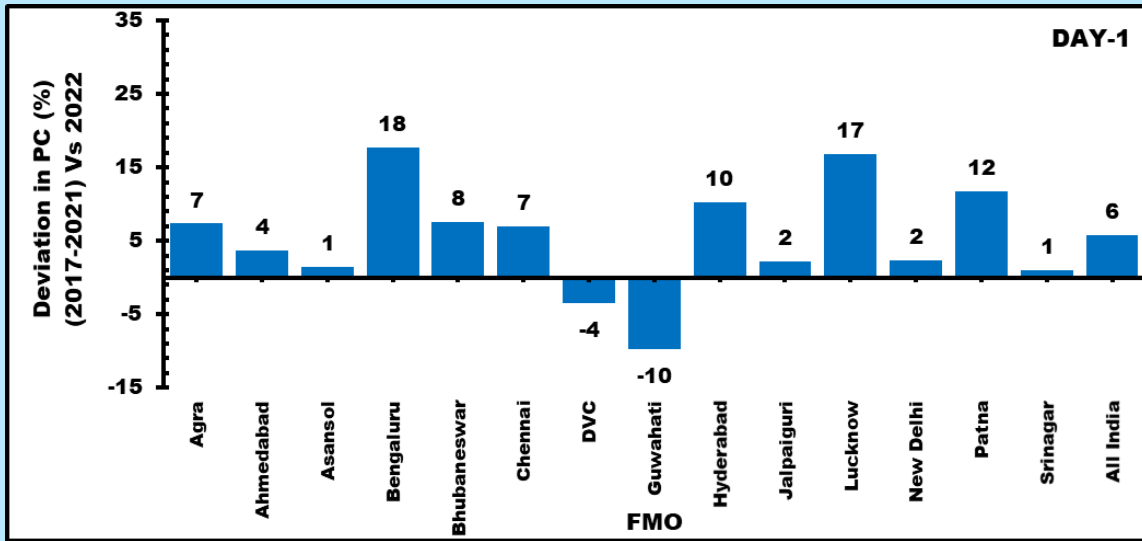
CHAPTER 5

Concluding Remarks

1. Percentage Correct of QPF within same category is 66% for Day-1, 63% for Day-2, 61% for Day-3, 61% for Day-4 and 59% for Day-5 for all 153 river sub-basins. However, accuracy of QPF within ± 1 category is more than 92% for all five days.
2. During this year, the accuracy within same category of river sub-basin-wise QPF has improved by 1% in Day-2 and Day-4 as compared to last year.
3. Substantial improvement in the accuracy ($\geq 5\%$) is observed for the FMOs Agra, Bengaluru, Bhubaneswar, Chennai, Hyderabad, Lucknow and Patna as compared to average performance in the previous five years (2017-2021) for Day-1.
4. The accuracy of Day-1 QPF when compared to previous five years (2017-2021) has improved in respect of FMOs Agra, Ahmedabad, Asansol, Chennai, Hyderabad and Thiruvananthapuram while it has deteriorated slightly in respect of FMOs Bengaluru, Bhubaneswar, DVC, Guwahati, Jalpaiguri, Lucknow, New Delhi, Patna and Srinagar.
5. The accuracy of QPF decreases with the increase in lead time from Day-1 to Day-5. Percent accuracy decreases from 66% in Day-1 to 59% in Day-5 forecast. Accuracy decreases sharply from Day-1 to Day-2 (by 3%), decreases from Day-2 to Day-3 (by 2%) but there is not much deterioration in the accuracy with increase in lead time from day-3 to day-5.
6. CSI & POD decrease whereas FAR & MR increase as we move from lower to higher rainfall categories of QPF.
7. CSI for the rainfall categories 0.1-10, 11-25, 26-50, 51-100 and >100 mm is 0.60, 0.29, 0.24, 0.16 and 0.16 respectively for Day-1 QPF for all 153 river sub-basins.

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