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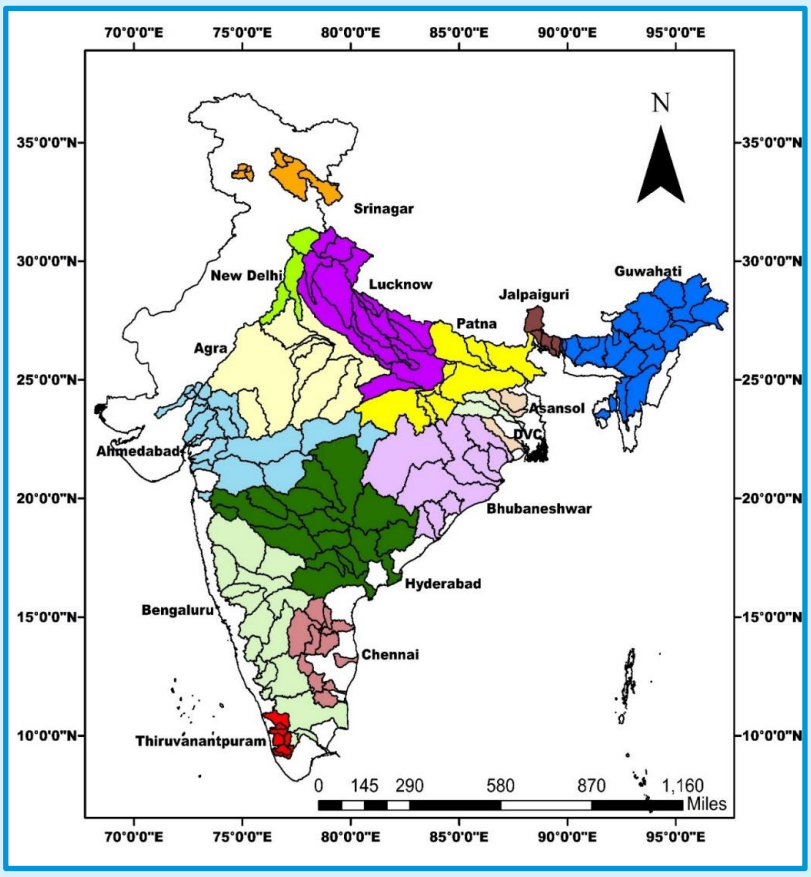
जल मौसम विज्ञान प्रभाग
भारत मौसम विज्ञान विभाग
पृथ्वी विज्ञान मंत्रालय

Hydromet Division
India Meteorological Department
Ministry of Earth Sciences

उपबेसिन मात्रात्मक वर्षा पूर्वानुमान दक्षिण पश्चिमी मानसून 2021 का सत्यापन

VERIFICATION OF SUB-BASIN-WISE QUANTITATIVE PRECIPITATION FORECAST DURING SW MONSOON 2021



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डॉ. मृत्युंजय महापात्र
मौसम विज्ञान विभाग के महानिदेशक,
विश्व मौसम विज्ञान संगठन में भारत के स्थाई प्रतिनिधि
एवं कार्यकारी परिषद के सदस्य

Dr. Mrutyunjay Mohapatra
Director General of Meteorology,
Permanent Representative of India with WMO,
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भारत सरकार
पृथ्वी विज्ञान मंत्रालय
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FOREWORD

Every year floods occur in some parts of the country due to high variability of rainfall over time and space. In India, IMD provides the Hydrometeorological services mainly in the form of Quantitative Precipitation Forecast (QPF), Heavy Rainfall warning, station-wise significant rainfall etc. to Central Water Commission (CWC) for their Flood Forecasting services. QPF is one of the important inputs for issuing flood forecast. It is necessary to analyse the performance of operational QPF for its betterment in operational services.

It gives me immense pleasure that Hydrometeorological Division has brought out the publication "VERIFICATION OF SUB-BASIN-WISE QUANTITATIVE PRECIPITATION FORECAST DURING SOUTHWEST MONSOON 2021" based on the Operational QPF and the Observed rainfall received in the different sub-basins under 14 Flood Meteorological Offices (FMOs) along with Damodar Valley Corporation (DVC) Meteorological Unit, Kolkata. This report will certainly 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 2021.

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

(Mrutyunjay Mohapatra)

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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.

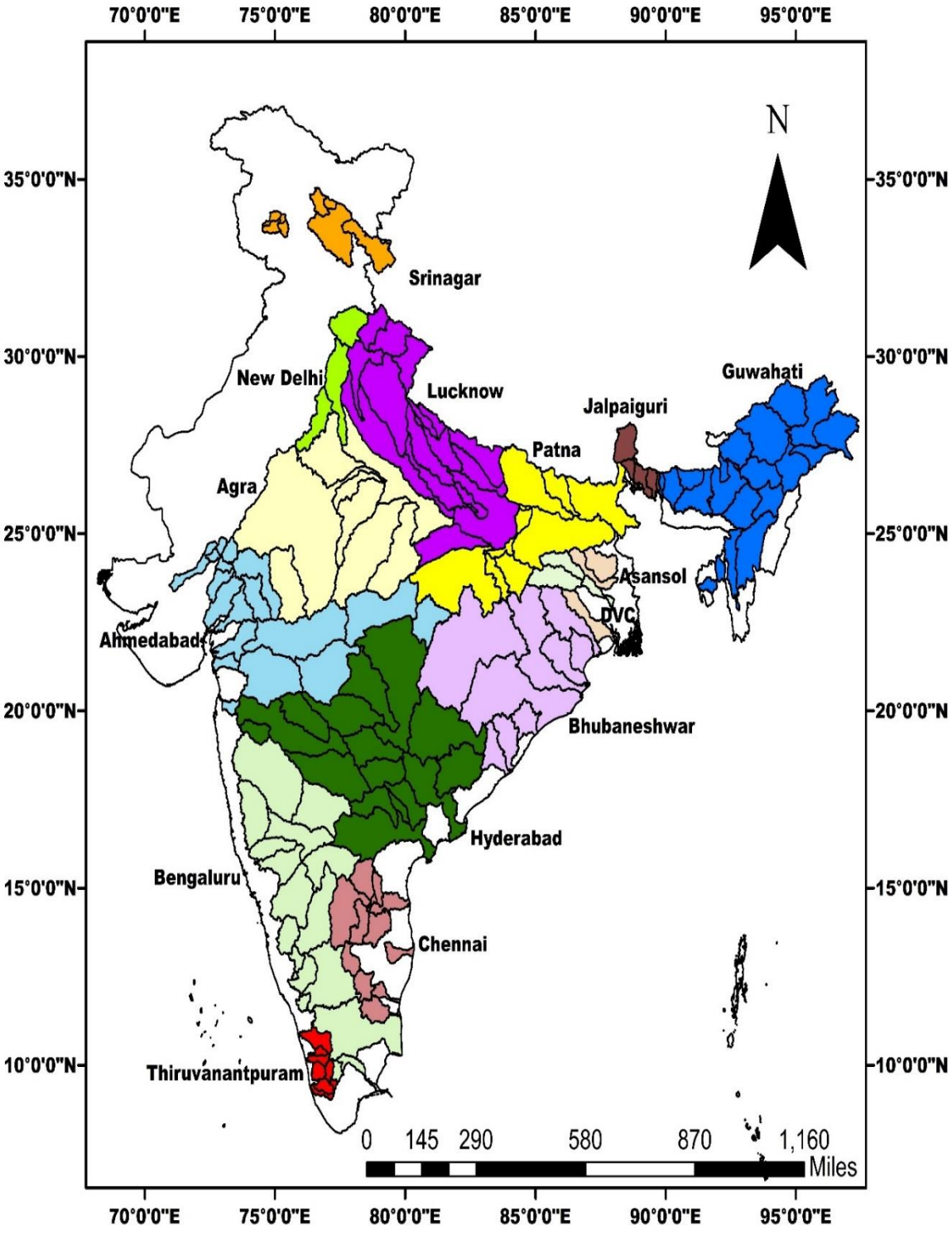

Figure 1: Map of Flood Meteorological offices with Sub-Basins in 2021

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 (≥5cm)
- 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).

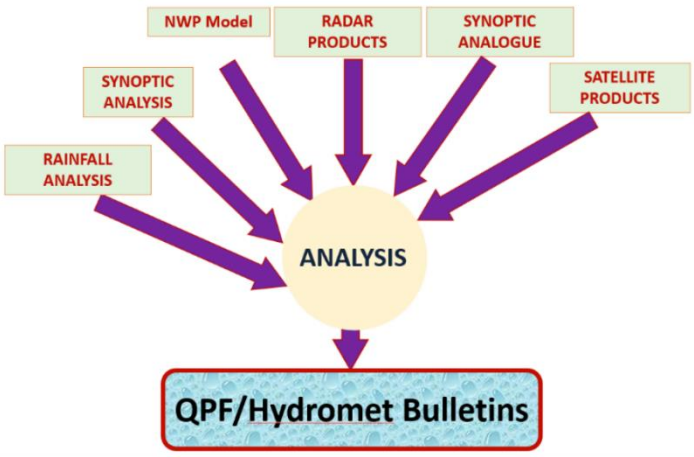

Figure 2. Input for issuing of QPF/Hydromet Bulletins

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).

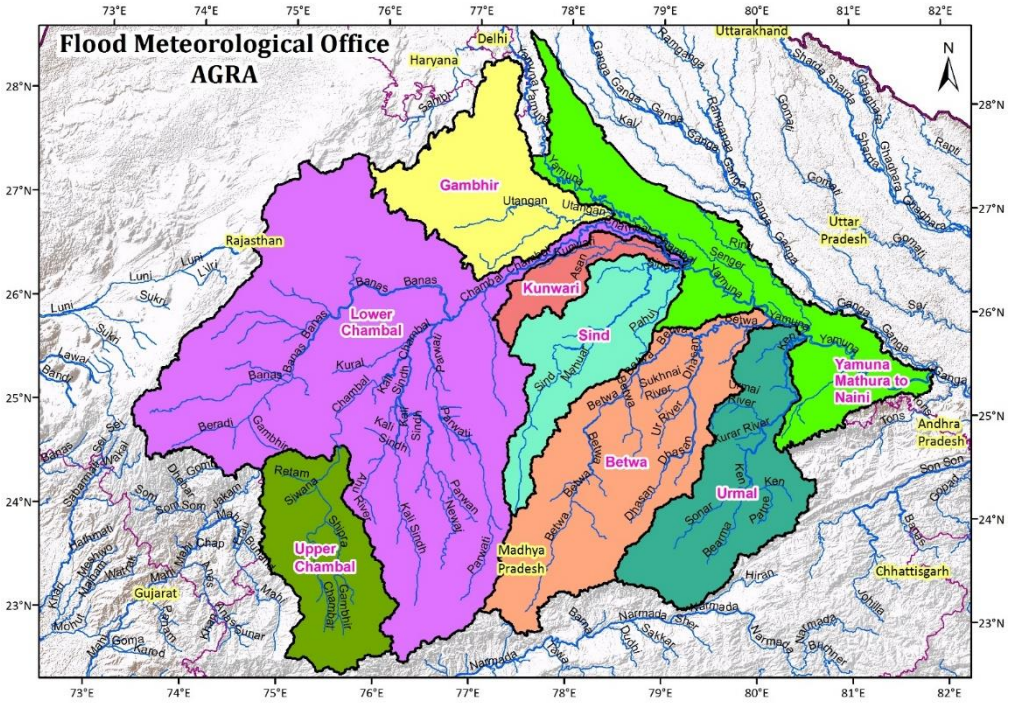

Figure 3: Map of FMO Agra with Sub-basins

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

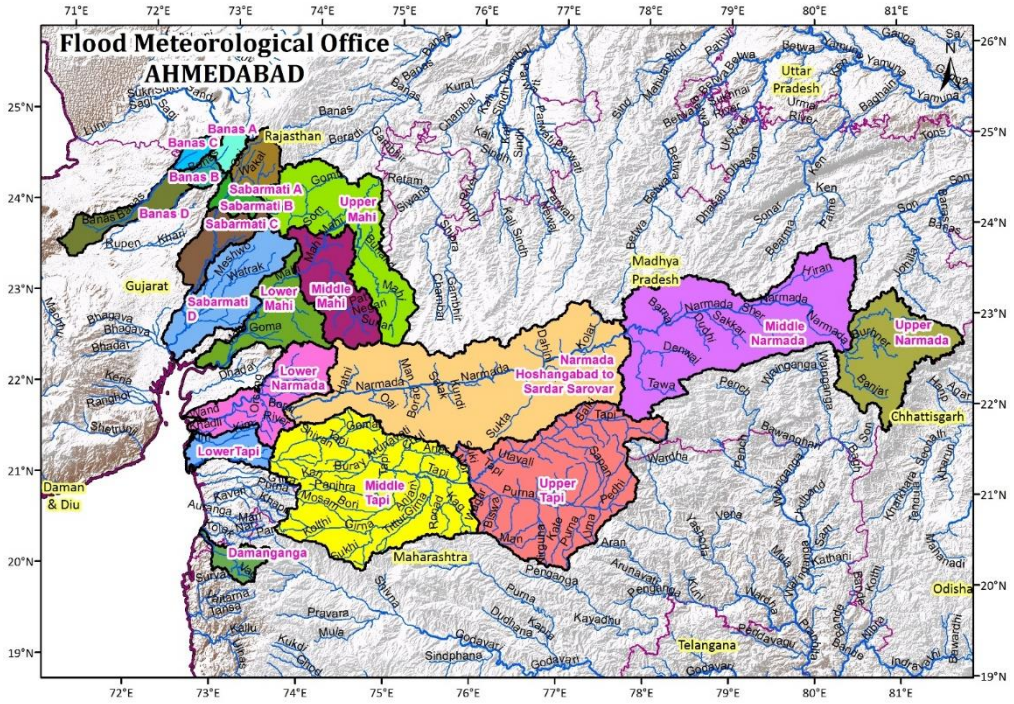

Figure 4: Map of FMO Ahmedabad with Sub-basins

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 Km^2) 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).

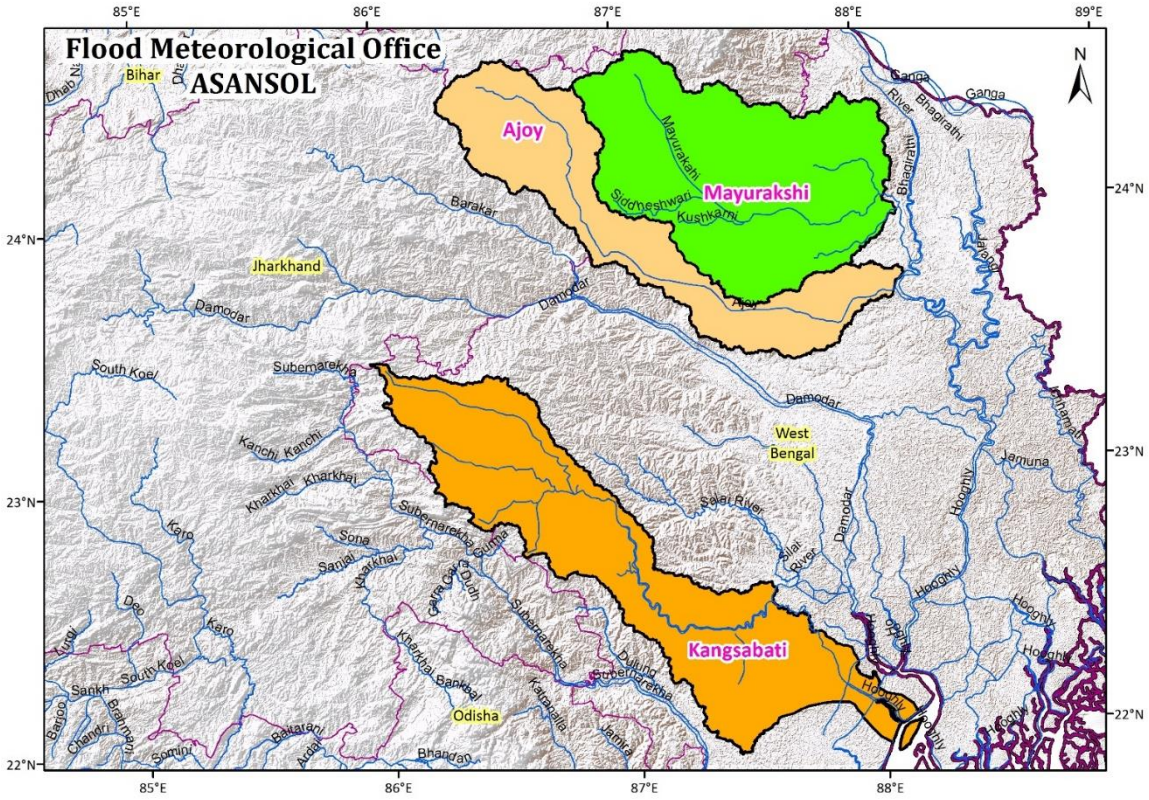

Figure 5: Map of FMO Asansol with Sub-basins

There are total of 3 sub-basins under the FMO Asansol. The name of basins, sub-basins with area (in Km^2) 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).

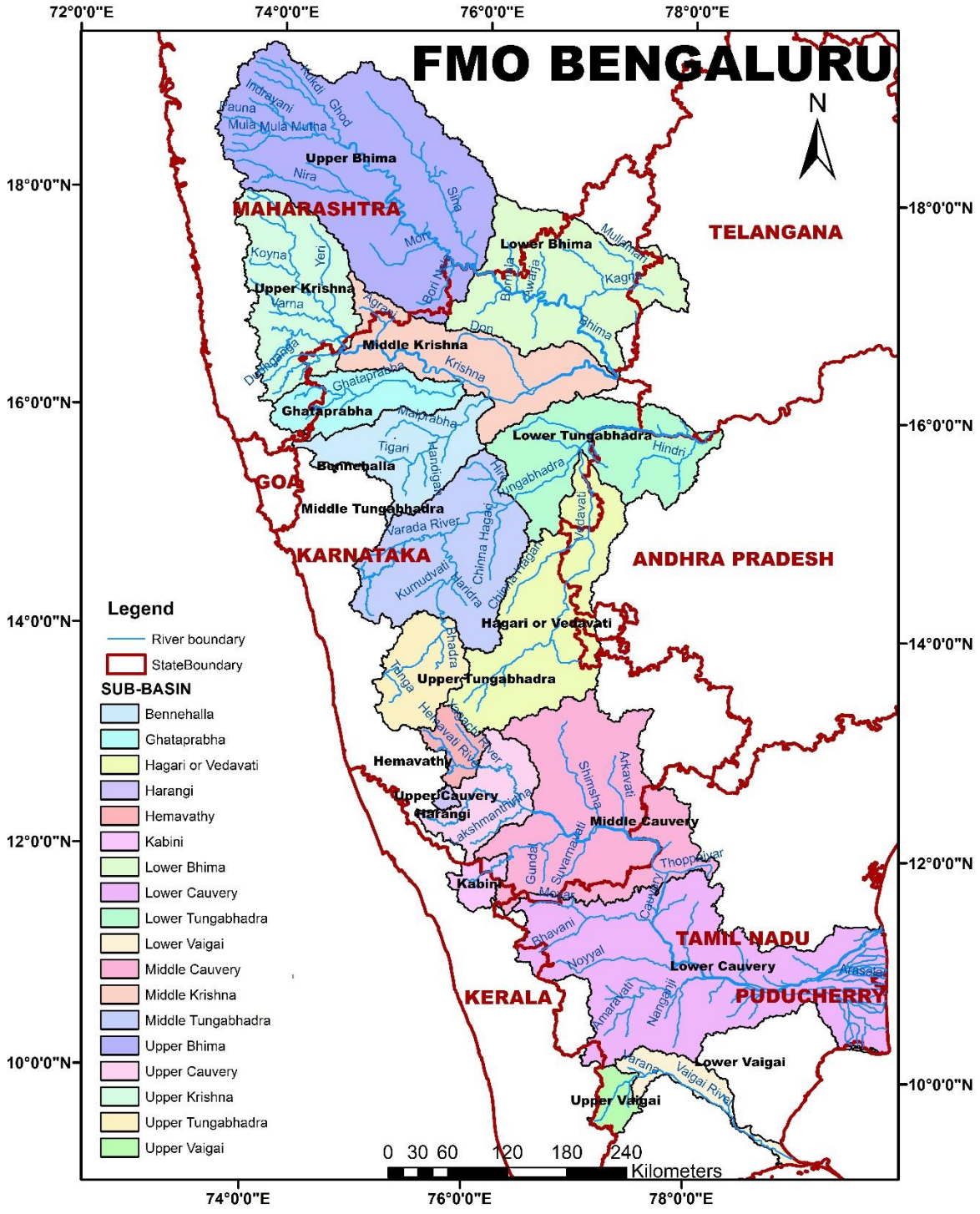

Figure 6: Map of FMO Bengaluru with Sub-basins

There are total of 18 sub-basins under the FMO Bengaluru. The name of basins, sub-basins with area (in Km^2) 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).

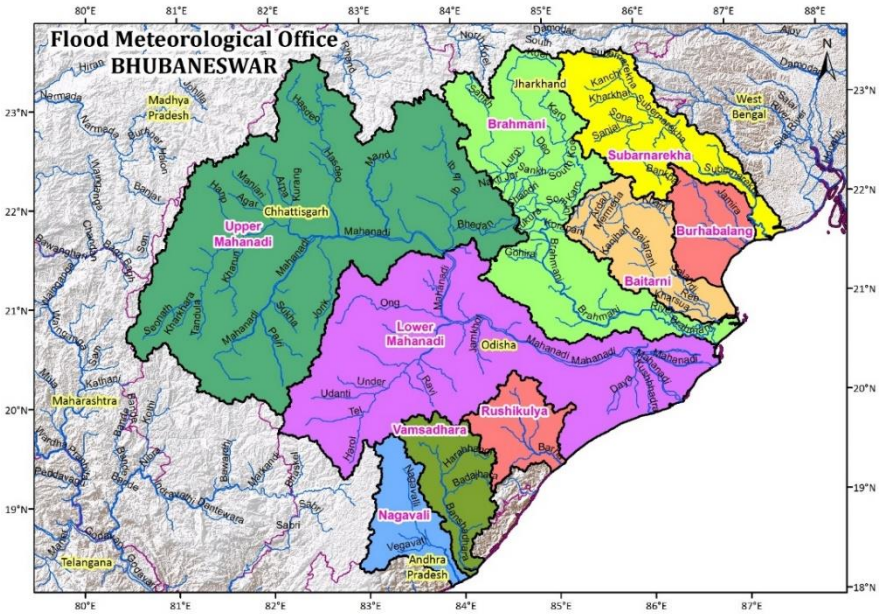

Figure 7: Map of FMO Bhubaneswar with Sub-basins

There are total of 9 sub-basins under the FMO Bhubaneswar. The name of basins, sub-basins with area (in Km^2) 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).

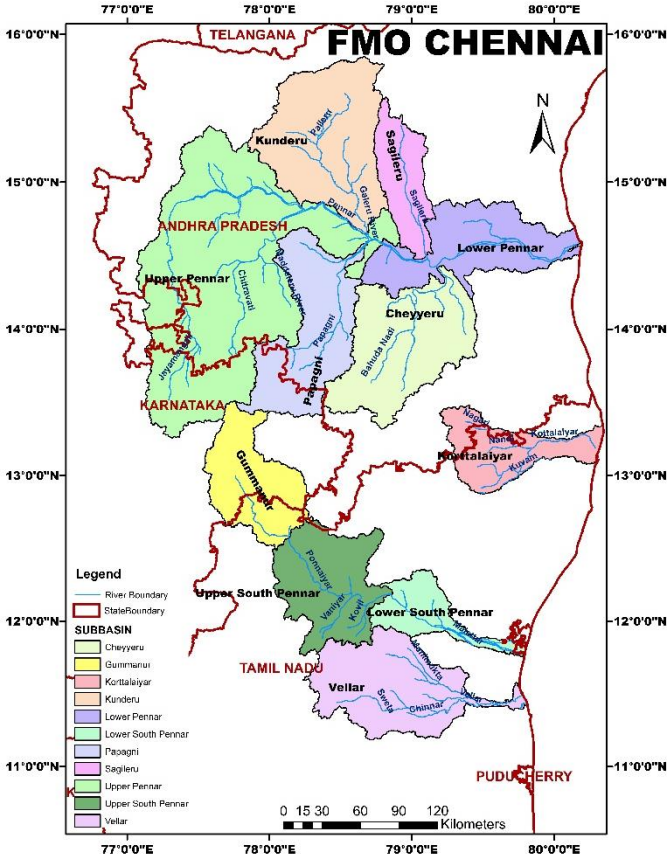

Figure 8: Map of FMO Chennai with Sub-basins

There are total of 11 sub-basins under the FMO Chennai. The name of basins, sub-basins with area (in Km^2) 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		**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, Meghalaya, Tripura and few areas of West Bengal (figure 9).

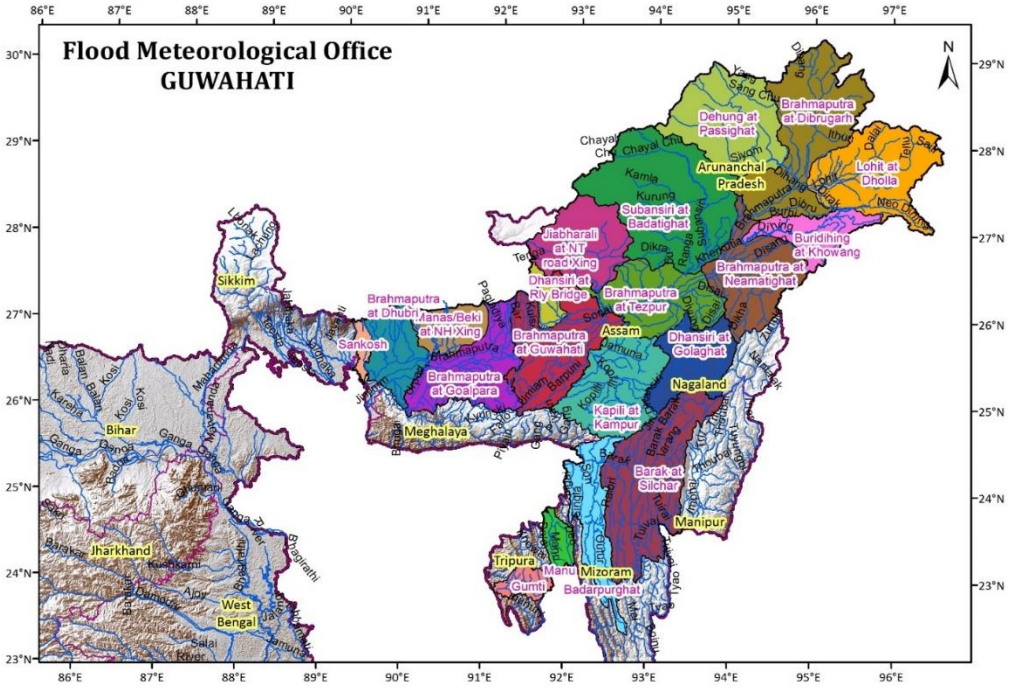

Figure 9: Map of FMO Guwahati with Sub-basins

There are total of 20 sub-basins under the FMO Guwahati. The name of basins, sub-basins with area (in Km^2) 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

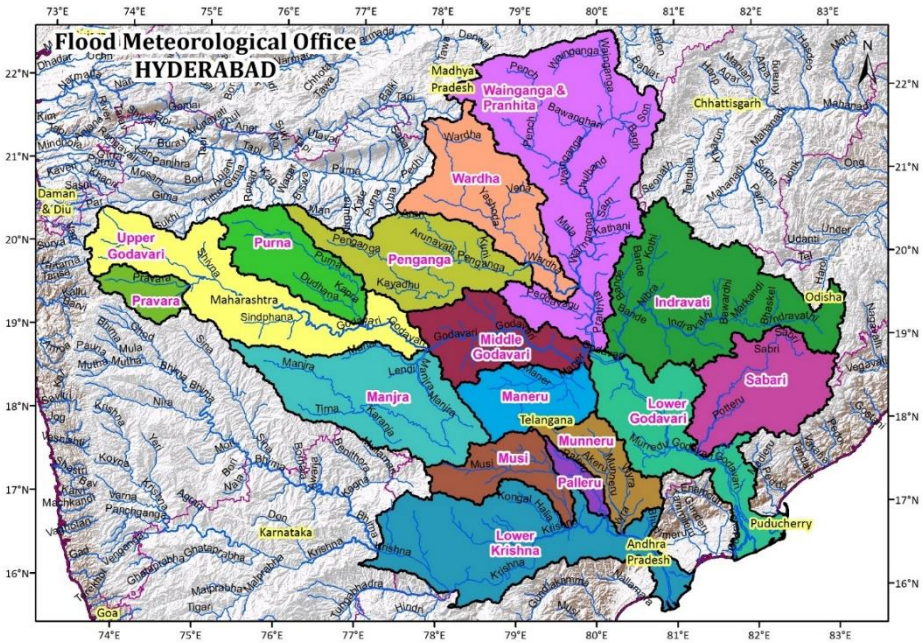

Figure 10: Map of FMO Hyderabad with Sub-basins

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 Km^2) 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 Km^2) 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**

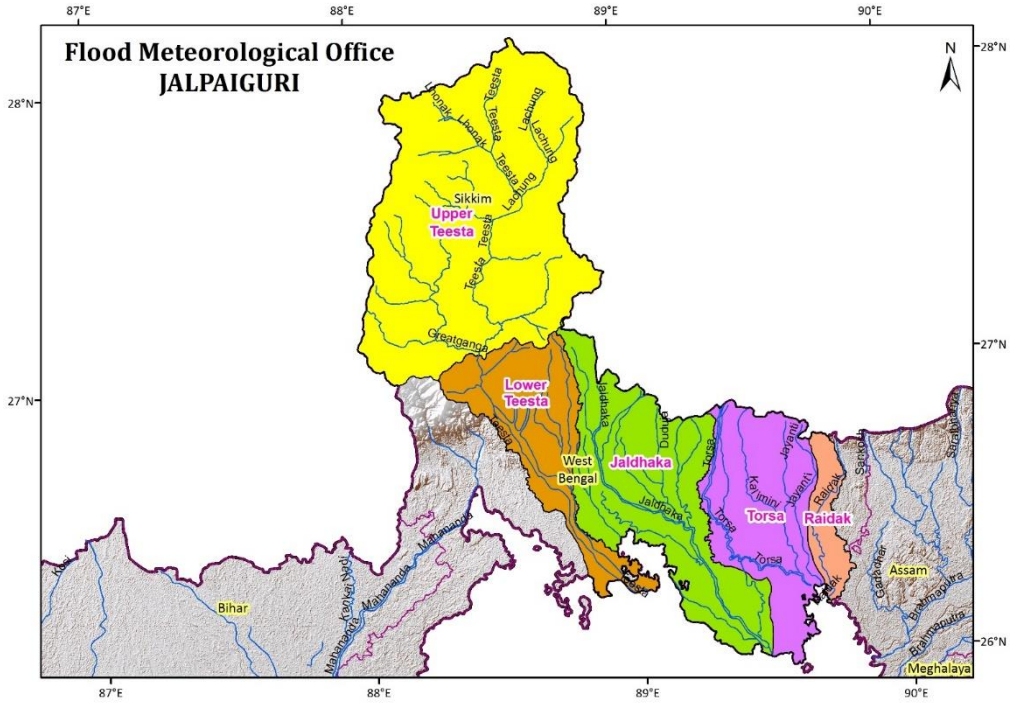

Figure 11: Map of FMO Jalpaiguri with Sub-basins

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).

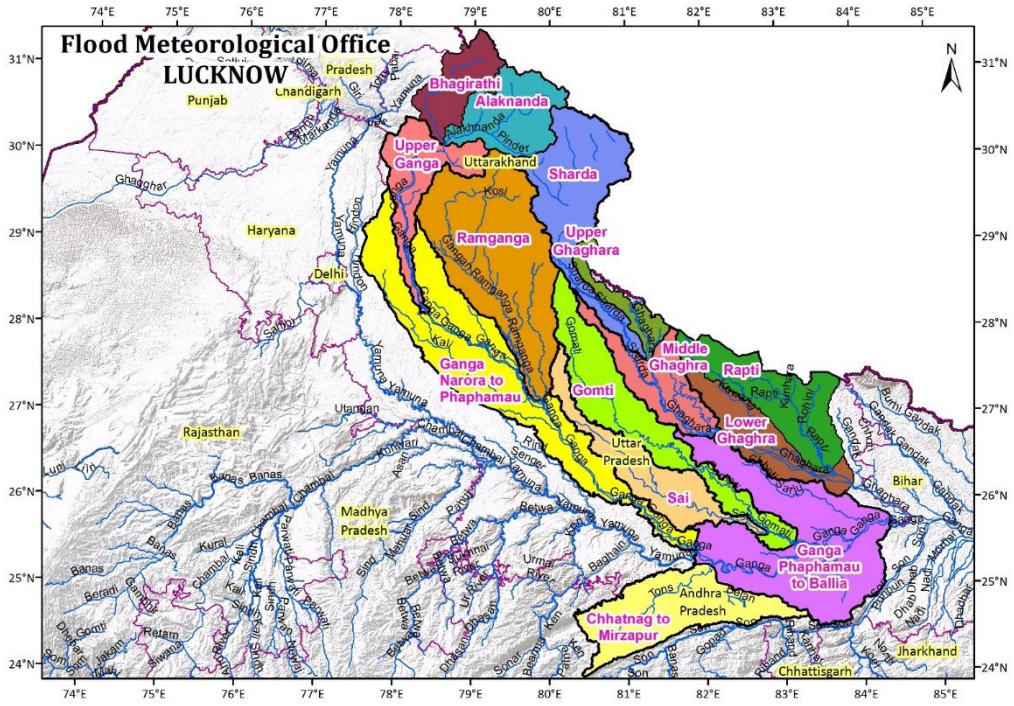

Figure 12: Map of FMO Lucknow with Sub-basins

There are total of 14 sub-basins under the FMO Lucknow. The name of basins, sub-basins with area (in Km^2) 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).

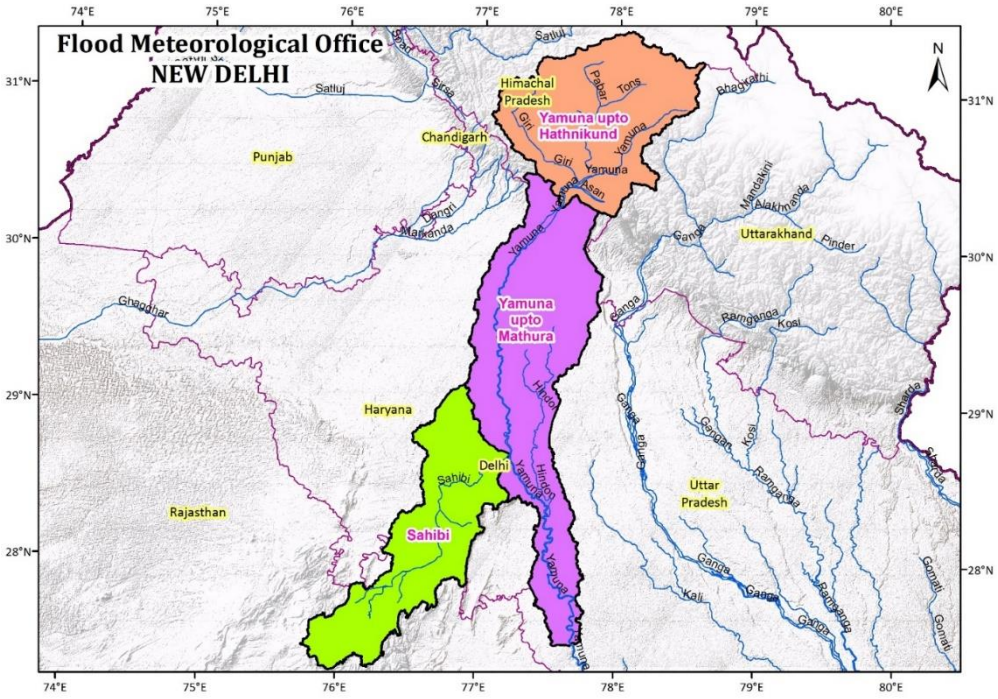

Figure 13: Map of FMO New Delhi with Sub-basins

There are total of 3 sub-basins under the FMO New Delhi. The name of basins, sub-basins with area (in Km^2) 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).

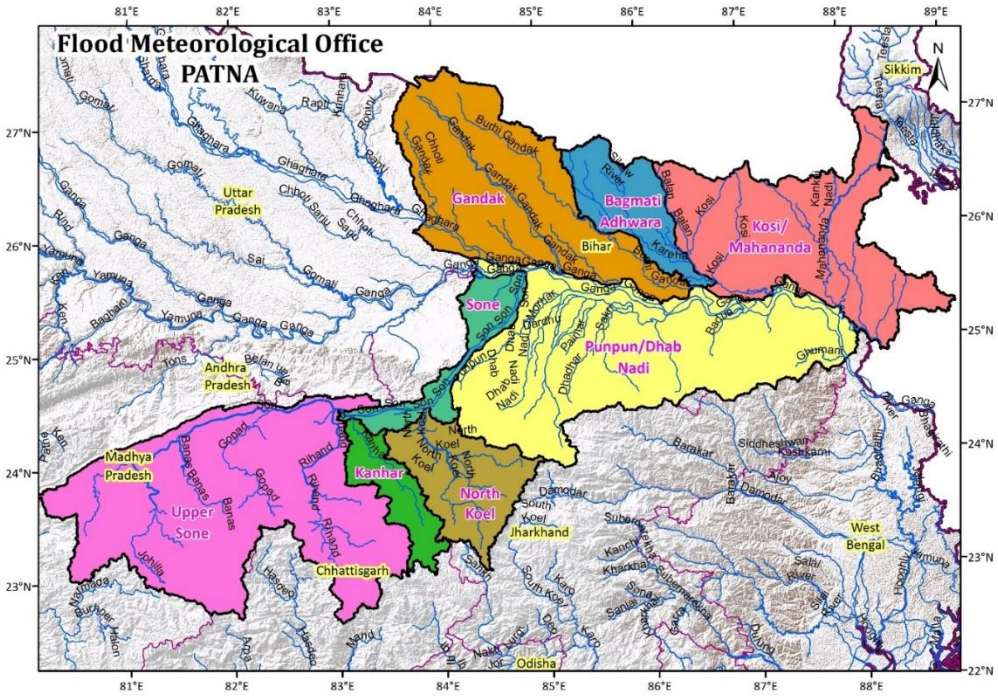

Figure 14: Map of FMO Patna with Sub-basins

There are total of 8 sub-basins under the FMO Patna. The name of basins, sub-basins with area (in Km^2) 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 Km^2) are given in Table 18.

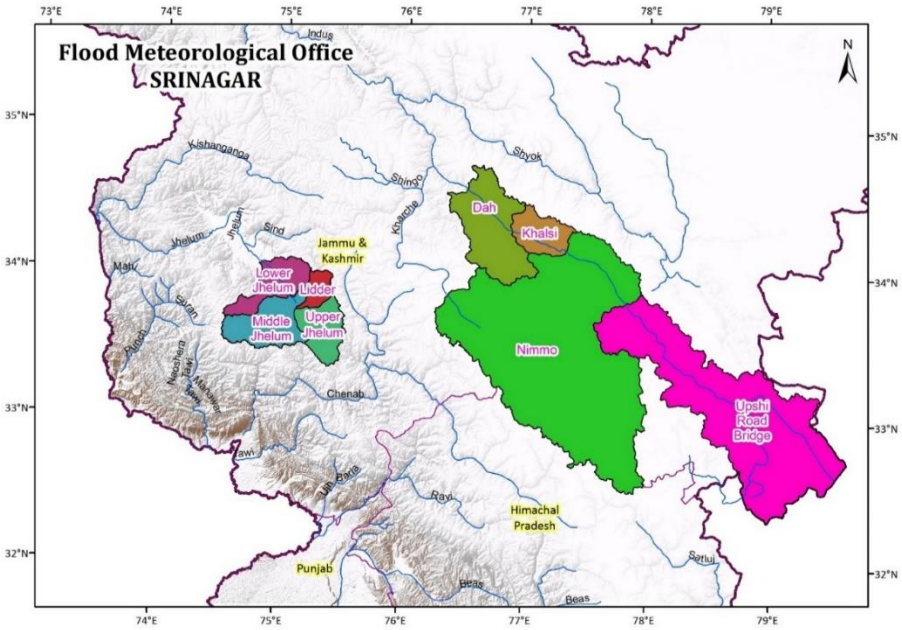

Figure 15: Map of FMO Srinagar with Sub-basins

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 Km^2) 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**

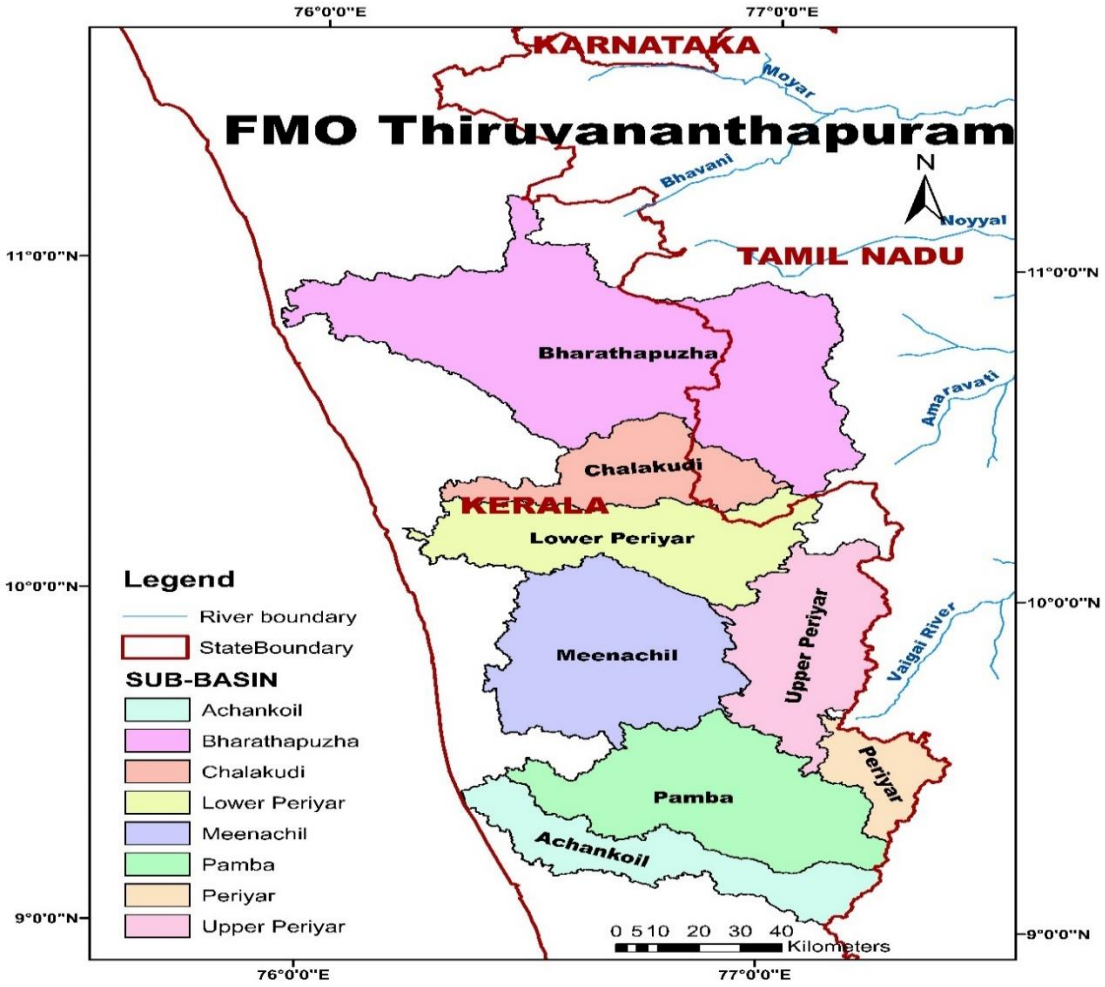

Figure 16: Map of FMO Srinagar with Sub-basins

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 Km^2) 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**

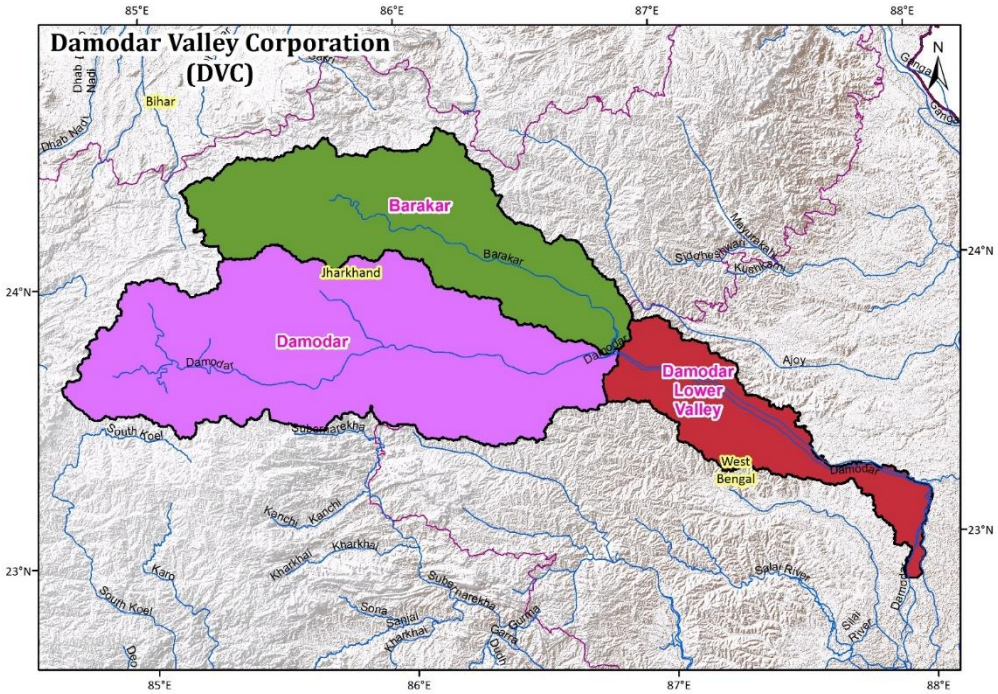

Figure 17: Map of DVC with Sub-basins

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 2021. The sub-basin-wise observed areal rainfall has been computed from the daily station-wise rainfall data by using isohyetal technique. The rainfall data of 2871 stations are used to compute sub-basin-wise AAP.

The total number of QPF issued by 15 FMOs during the season 2021 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)**						
	0	0.1-10	11-25	26-50	51-100	>100	**Total**
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=$\frac{a+h+o+v+ac+aj}{T}$X 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 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)=($\frac{A}{A+B}$) , Range: 0 to ∞, Perfect score = 1

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

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)=$\frac{A+D}{A+B+C+D}X100$=Hit Rate X 100

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

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

During season 2021, 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 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.

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 QPF within same category is 66% which is an improvement by 5% (figure 47) as compared to last year (2020). While FMO Lucknow has the highest Percentage correct QPF of 75% and FMO Thiruvananthapuram has the lowest accuracy of 40%, six other FMOs reported more than 70% Percentage correct 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 95% and above for all FMOs except newly commissioned FMO Thiruvananthapuram where the accuracy was 88%.

Table 23: Performance of Day-1 QPF for the Flood Season 2021

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	695	142	121	958	6	12	0	0	0	0	71%	98%
Ahmedabad	2318	1600	498	162	2260	33	22	2	1	0	0	69%	97%
Asansol	366	272	77	13	362	1	3	0	0	0	0	74%	99%
Bengaluru	2196	1563	420	144	2127	46	20	0	0	0	0	71%	97%
Bhubaneswar	1220	805	286	98	1189	29	1	1	0	0	0	66%	97%
Chennai	1342	724	248	313	1285	17	38	0	2	0	0	54%	96%
DVC	732	536	128	56	720	5	6	0	1	0	0	73%	98%
Guwahati	2440	1723	540	120	2383	45	11	0	1	0	0	71%	98%
Hyderabad	1952	1206	476	213	1895	37	20	0	0	0	0	62%	97%
Jalpaiguri	610	348	166	63	577	15	13	1	4	0	0	57%	95%
Lucknow	1708	1277	211	191	1679	8	21	0	0	0	0	75%	98%
New Delhi	366	246	66	40	352	3	11	0	0	0	0	67%	96%
Patna	976	679	128	136	943	12	21	0	0	0	0	70%	97%
Srinagar	488	308	121	54	483	2	3	0	0	0	0	63%	99%
Thiruvanantpuram	976	393	361	100	854	96	19	4	3	0	0	40%	88%
Over All fct.	**18666**	**12375**	**3868**	**1824**	**18067**	**355**	**221**	**8**	**12**	**0**	**0**	66%	97%

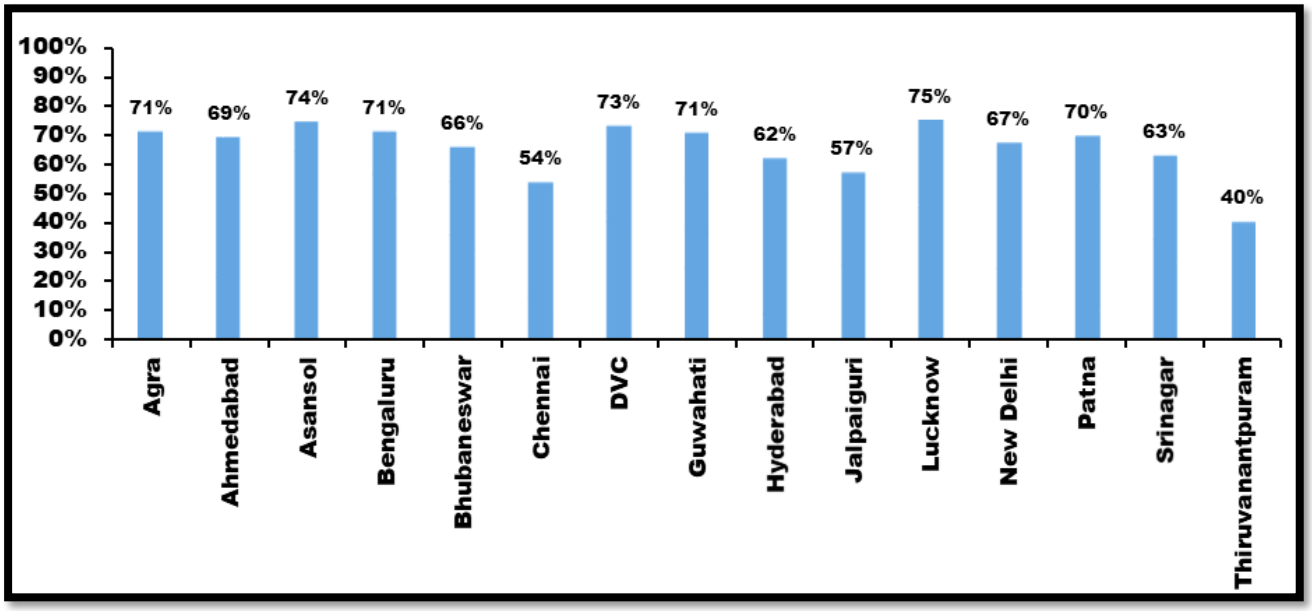

Figure 18: Percentage correct forecast Day-1 by different FMOs

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):	0.32	0.73	0.52	0.39	0.29	0.08
False Alarm Rate (FAR):	0.48	0.21	0.60	0.70	0.56	0.67
Missing Rate (MR):	0.68	0.27	0.48	0.61	0.71	0.92
Correct Non-Occurrence (C-NON):	0.96	0.67	0.82	0.95	0.99	1.00
Critical Success Index (CSI):	0.25	0.61	0.29	0.21	0.21	0.06
Bias for Occurrence (BIAS):	0.60	0.94	1.33	1.36	0.68	0.27
Hit Rate:	0.91	0.71	0.78	0.93	0.98	1.00
Percentage of Correct (PC):	0.91	0.71	0.78	0.93	0.98	1.00
True Skill Score (TSS):	0.28	0.40	0.34	0.34	0.29	0.08
Heidke Skill Score (HSS):	0.30	0.38	0.31	0.29	0.31	0.09

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

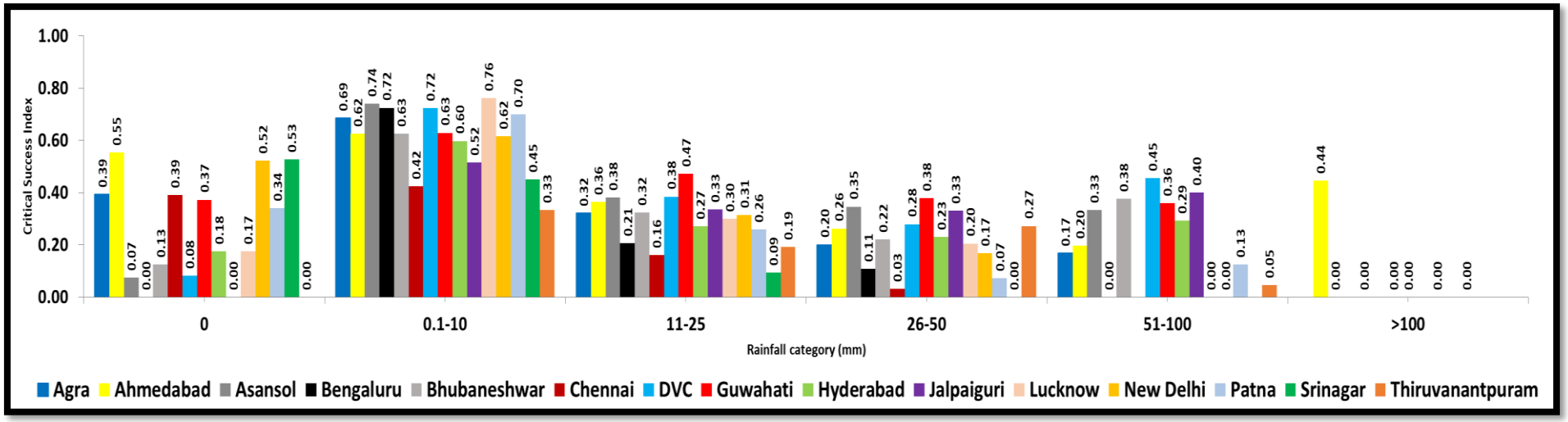

Figure 19: CSI for different categories of forecast for Day-1

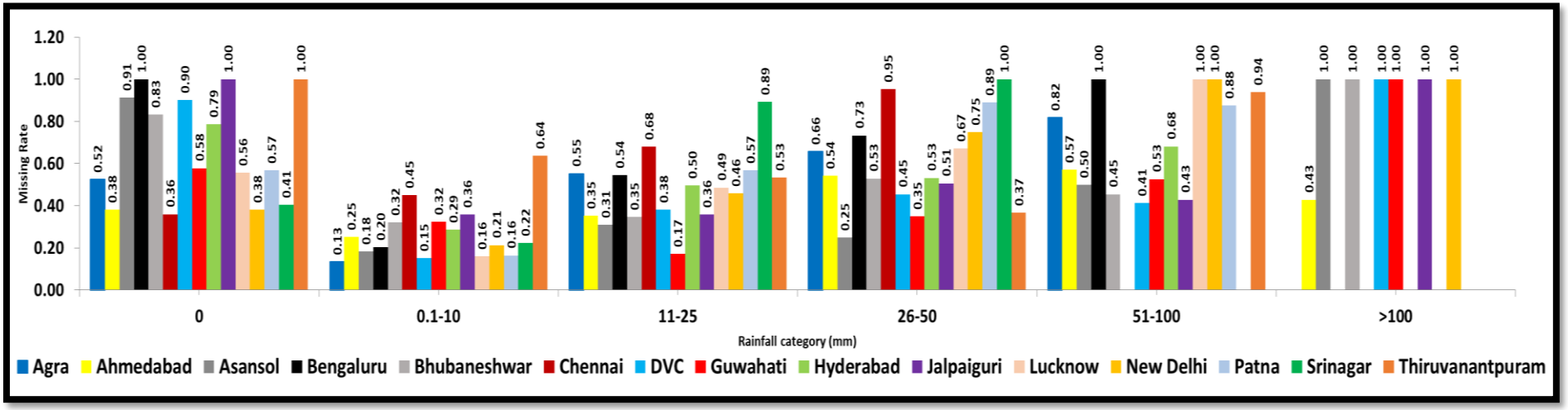

Figure 20: MR for different categories of forecast for Day-1

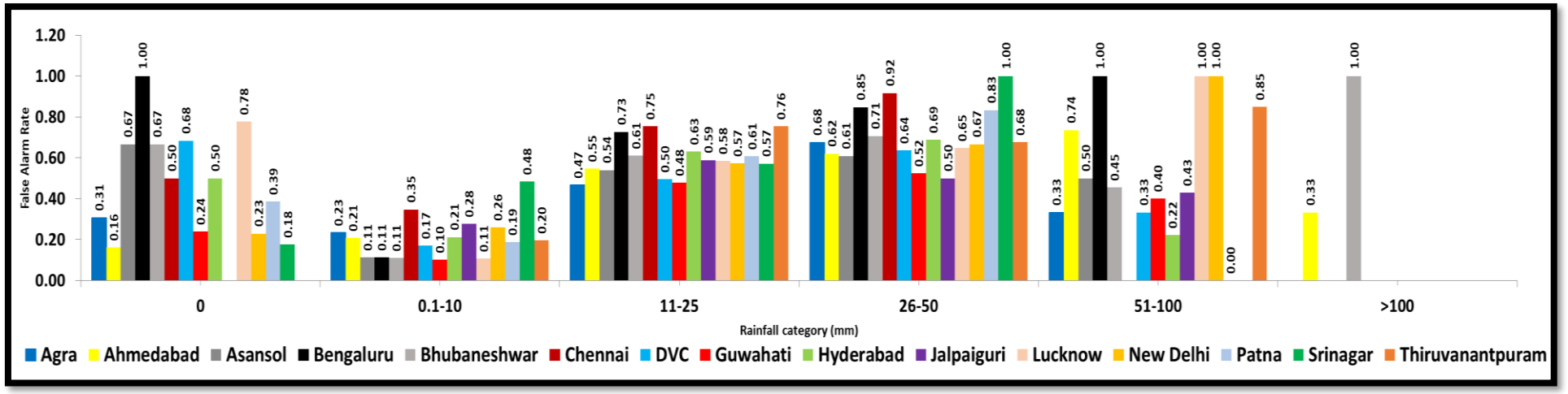

Figure 21: FAR for different categories of forecast for Day-1

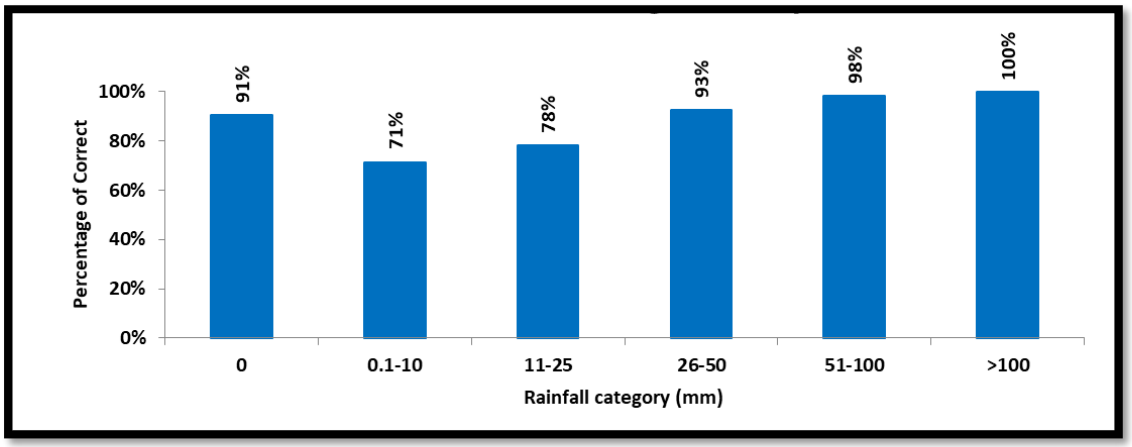

Figure 22: Category-wise Percentage Correct Forecast of Day-1

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 62% which is an improvement by 5% (figure 47) as compared to last year (2020). While FMO Bengaluru has the highest Percentage correct QPF of 72% and FMO Thiruvananthapuram has the lowest accuracy of 38%, eleven other FMOs reported more than 60% Percentage correct 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 94% and above for all FMOs except newly commissioned FMO Thiruvananthapuram where the accuracy was 88%.

Table 25: Performance of Day-2 QPF for the Flood Season 2021

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	658	139	147	944	10	19	0	3	0	0	67%	97%
Ahmedabad	2318	1487	433	323	2243	29	38	3	2	1	2	64%	97%
Asansol	366	253	78	30	361	1	2	0	2	0	0	69%	99%
Bengaluru	2196	1573	372	173	2118	47	26	0	2	0	0	72%	96%
Bhubaneswar	1220	790	276	131	1197	19	2	2	0	0	0	65%	98%
Chennai	1342	677	181	410	1268	17	47	0	10	0	0	50%	94%
DVC	732	500	152	59	711	4	13	0	4	0	0	68%	97%
Guwahati	2440	1481	663	233	2377	43	15	2	2	0	1	61%	97%
Hyderabad	1952	1196	438	242	1876	41	33	0	2	0	0	61%	96%
Jalpaiguri	610	317	174	83	574	20	8	4	4	0	0	52%	94%
Lucknow	1708	1154	274	229	1657	18	29	0	4	0	0	68%	97%
New Delhi	366	228	74	48	350	1	12	0	3	0	0	62%	96%
Patna	976	649	143	143	935	9	29	0	3	0	0	66%	96%
Srinagar	488	311	128	42	481	2	3	2	0	0	0	64%	99%
Thiruvanantpuram	976	375	331	148	854	98	19	0	5	0	0	38%	88%
Over All fct.	**18666**	**11649**	**3856**	**2441**	**17946**	**359**	**295**	**13**	**46**	**1**	**3**	**62%**	**96%**

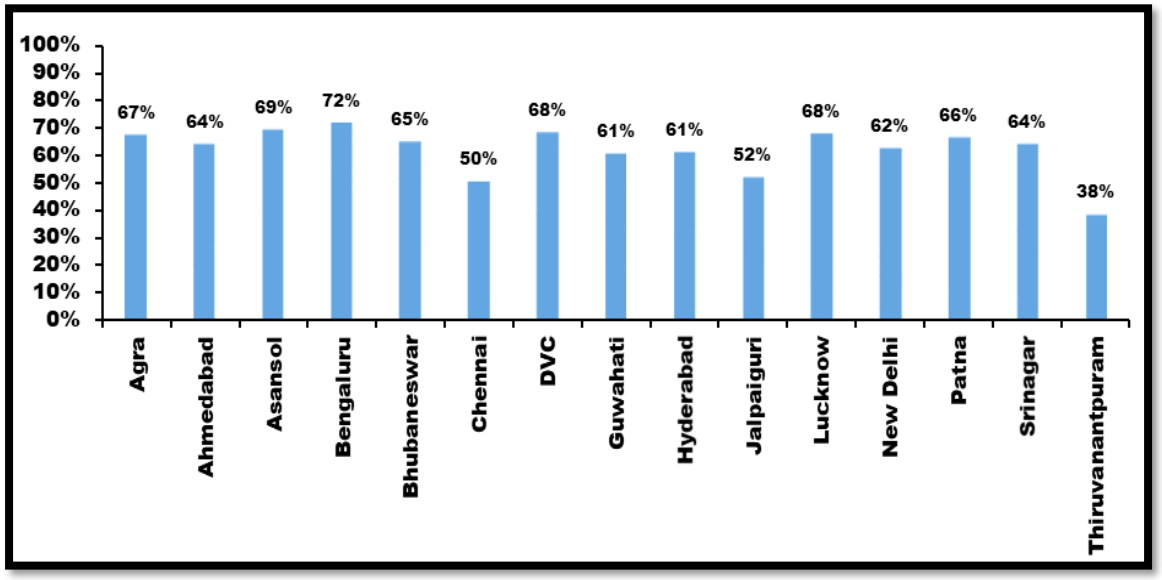

Figure 23. Percentage correct forecast Day-2 by different FMOs

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):	0.30	0.70	0.46	0.26	0.17	0.02
False Alarm Rate (FAR):	0.53	0.24	0.65	0.76	0.66	0.88
Missing Rate (MR):	0.70	0.30	0.54	0.74	0.83	0.98
Correct Non-Occurrence (C-NON):	0.94	0.62	0.80	0.96	1.00	1.00
Critical Success Index (CSI):	0.21	0.57	0.25	0.15	0.11	0.01
Bias for Occurrence (BIAS):	0.73	0.94	1.34	1.04	0.45	0.16
Hit Rate:	0.90	0.68	0.75	0.92	0.98	1.00
Percentage of Correct (PC):	0.90	0.68	0.75	0.92	0.98	1.00
True Skill Score (TSS):	0.25	0.32	0.26	0.21	0.17	0.02
Heidke Skill Score (HSS):	0.25	0.31	0.24	0.20	0.17	0.02

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

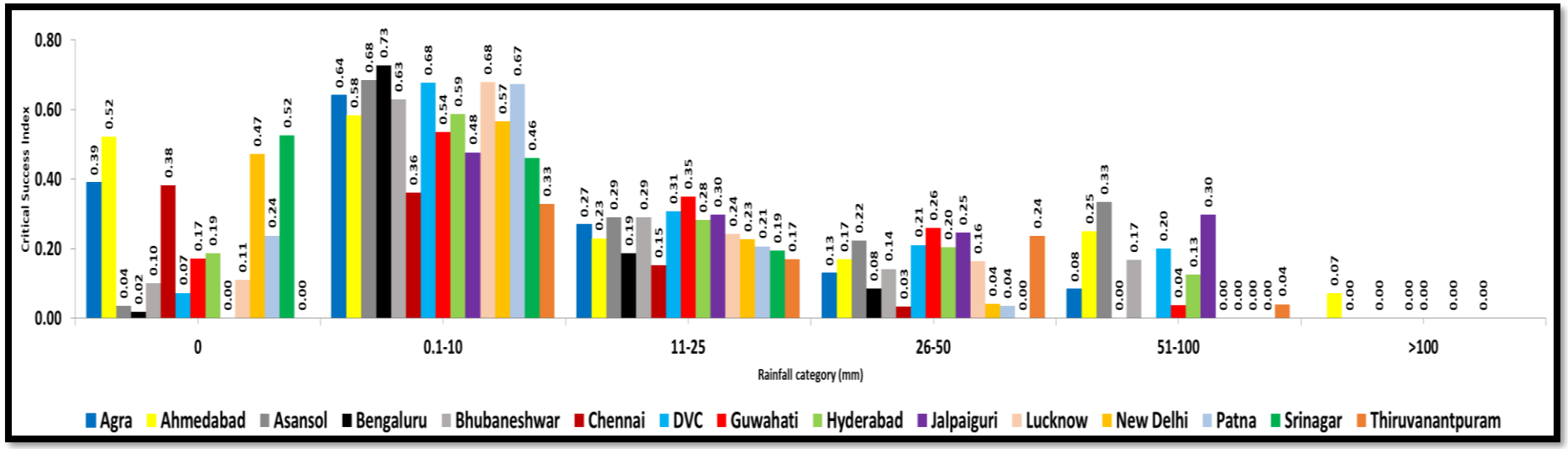

Figure 24: CSI for different categories of forecast for Day-2

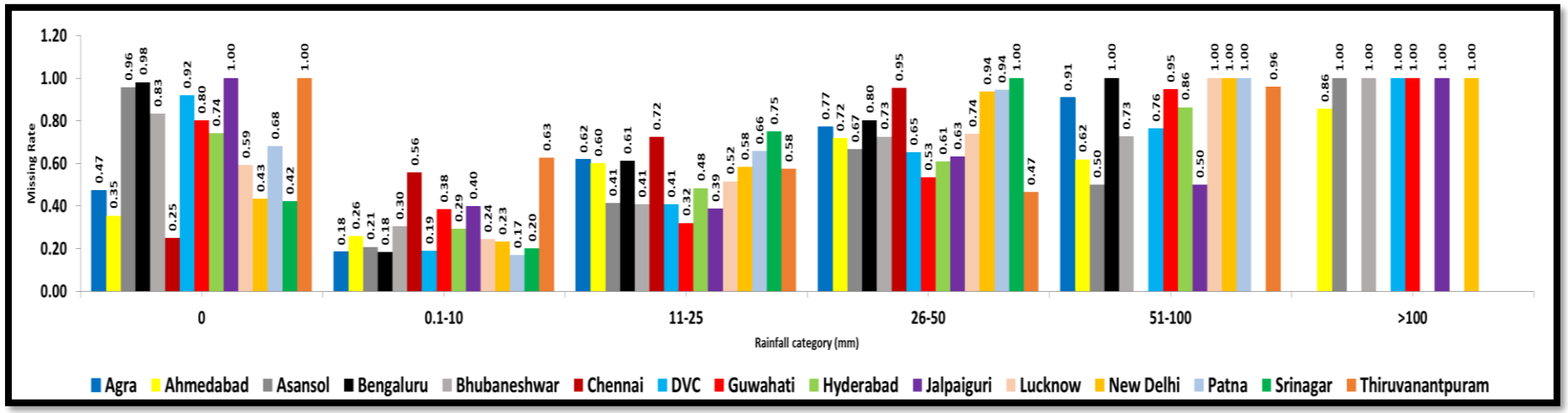

Figure 25: MR for different categories of forecast for Day-2

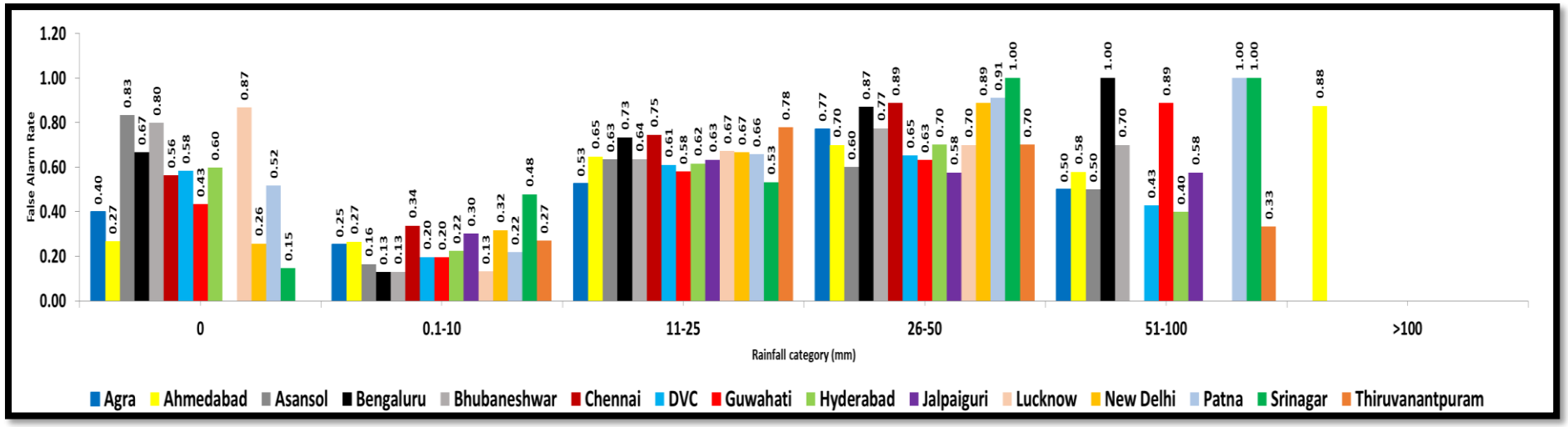

Figure 26: FAR for different categories of forecast for Day-2

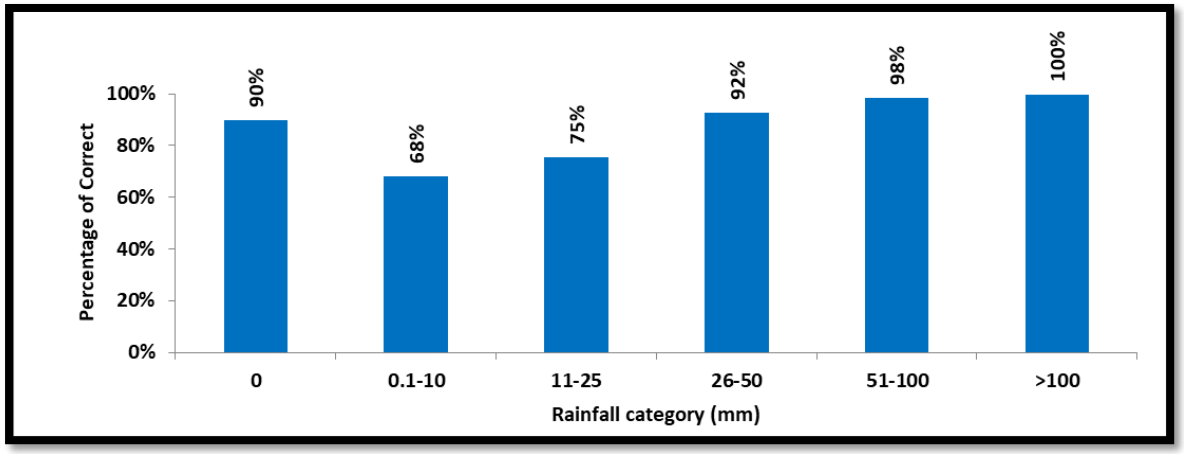

Figure 27: Category-wise Percentage Correct Forecast of Day-2

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 an improvement by 5% (figure 47) as compared to last year (2020). While FMO Bengaluru has the highest Percentage correct QPF of 73% and FMO Thiruvananthapuram has the lowest accuracy of 41%, ten other FMOs 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 94% and above for all FMOs except newly commissioned FMO Thiruvananthapuram where the accuracy was 88%.

Table 27: Performance of Day-3 QPF for the Flood Season 2021

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	604	170	160	934	17	21	0	4	0	0	62%	96%
Ahmedabad	2318	1424	436	363	2223	40	47	2	2	1	3	61%	96%
Asansol	366	237	87	35	359	2	3	0	2	0	0	65%	98%
Bengaluru	2196	1610	320	209	2139	26	25	3	1	0	0	73%	97%
Bhubaneswar	1220	771	284	126	1181	28	9	2	0	0	0	63%	97%
Chennai	1342	714	159	404	1277	11	41	1	12	0	0	53%	95%
DVC	732	492	142	73	707	6	12	0	7	0	0	67%	97%
Guwahati	2440	1365	714	273	2352	63	21	1	3	0	0	56%	96%
Hyderabad	1952	1201	388	297	1886	20	43	0	3	0	0	62%	97%
Jalpaiguri	610	312	176	83	571	18	17	0	4	0	0	51%	94%
Lucknow	1708	1124	258	244	1626	33	39	0	10	0	0	66%	95%
New Delhi	366	222	78	45	345	2	14	0	5	0	0	61%	94%
Patna	976	667	122	147	936	8	29	1	2	0	0	68%	96%
Srinagar	488	313	119	49	481	2	3	2	0	0	0	64%	99%
Thiruvanantpuram	976	401	307	154	862	87	22	1	4	0	0	41%	88%
Over All fct.	18666	11457	3760	2662	17879	363	346	13	59	1	3	61%	96%

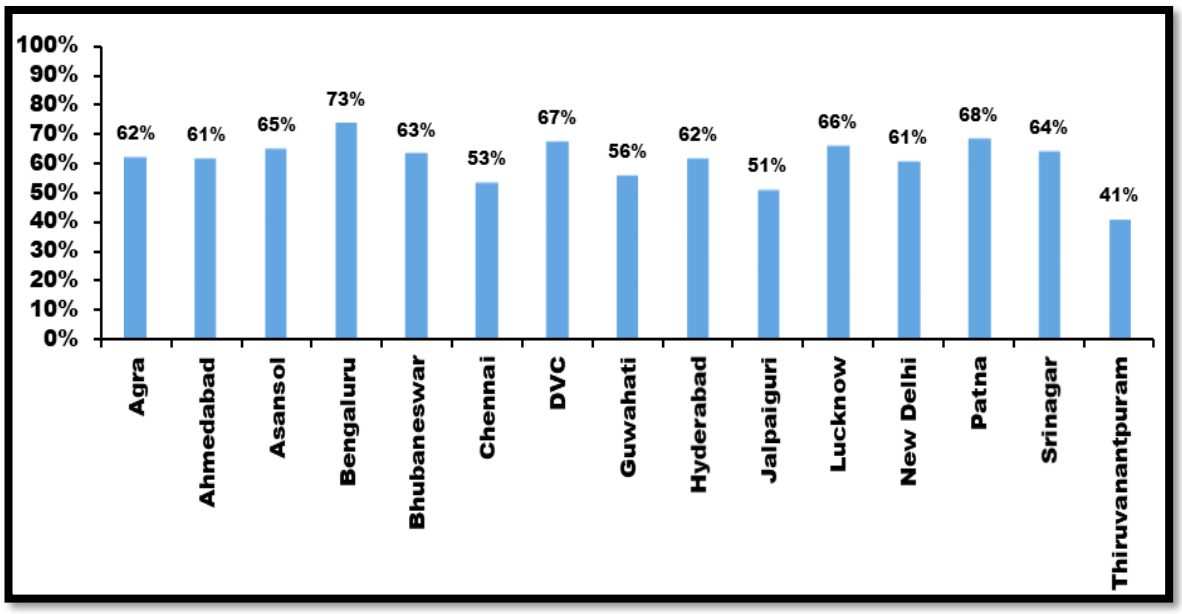

Figure 28. Percentage correct forecast Day-3 by different FMOs

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):	0.29	0.71	0.42	0.21	0.13	0.00
False Alarm Rate (FAR):	0.55	0.25	0.67	0.78	0.59	1.00
Missing Rate (MR):	0.71	0.29	0.58	0.79	0.87	1.00
Correct Non-Occurrence (C-NON):	0.94	0.58	0.80	0.96	1.00	1.00
Critical Success Index (CSI):	0.20	0.57	0.22	0.12	0.11	0.00
Bias for Occurrence (BIAS):	0.81	0.96	1.29	0.92	0.39	0.06
Hit Rate:	0.89	0.67	0.75	0.93	0.98	1.00
Percentage of Correct (PC):	0.89	0.67	0.75	0.93	0.98	1.00
True Skill Score (TSS):	0.24	0.29	0.22	0.17	0.13	0.00
Heidke Skill Score (HSS):	0.24	0.27	0.20	0.17	0.16	0.00

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

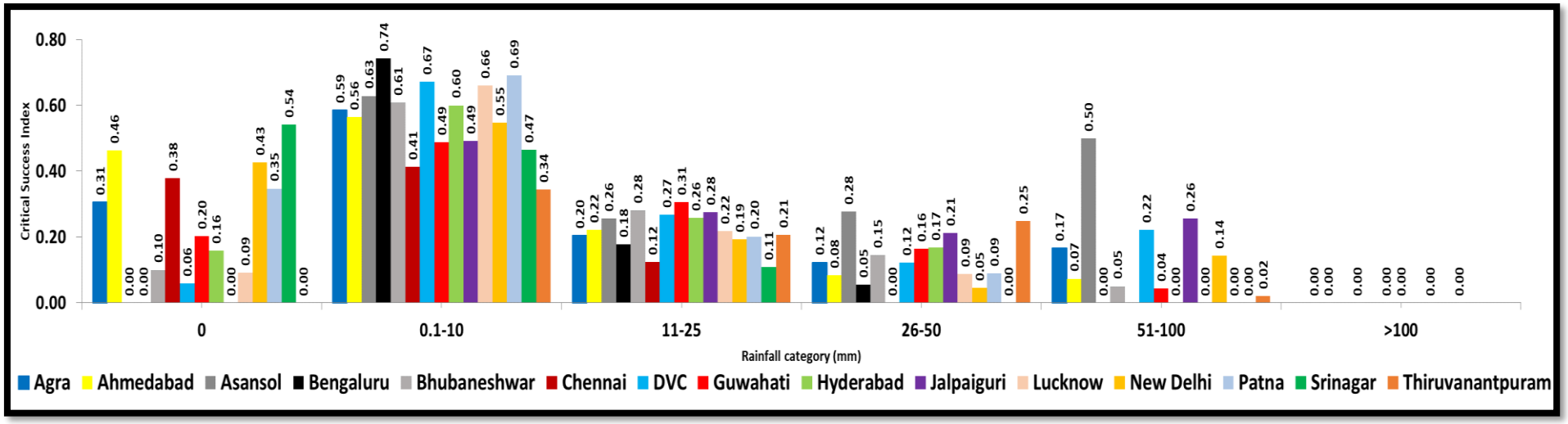

Figure 29: CSI for different categories of forecast for Day-3

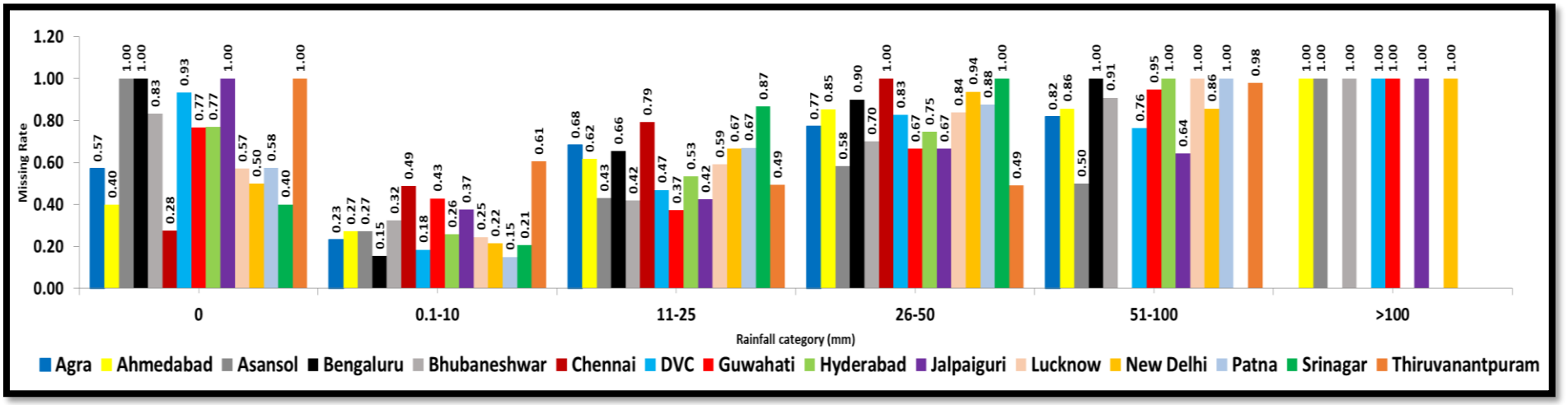

Figure 30: MR for different categories of forecast for Day-3

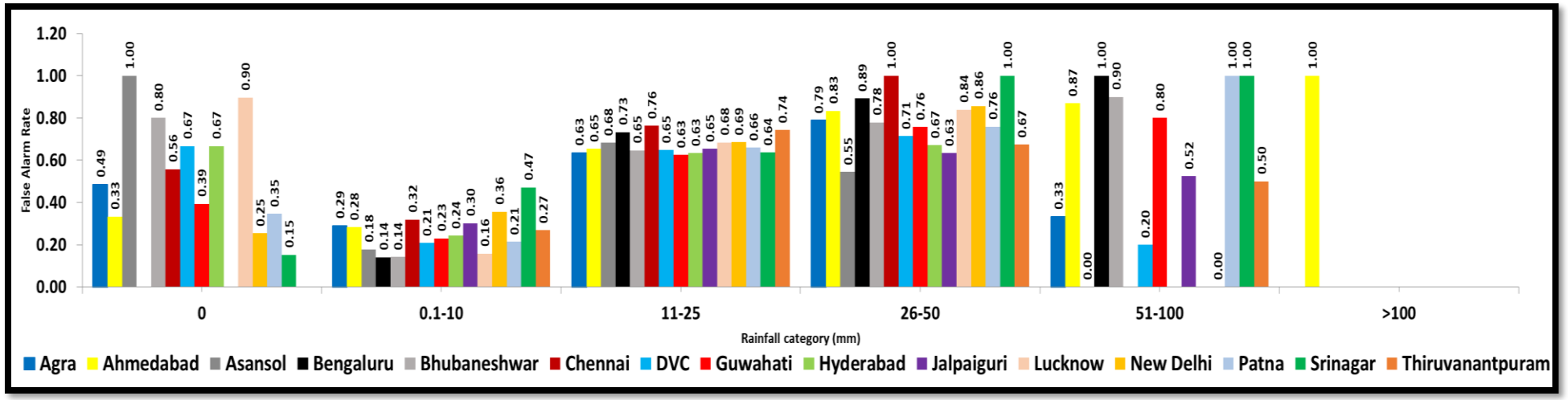

Figure 31: FAR for different categories of forecast for Day-3

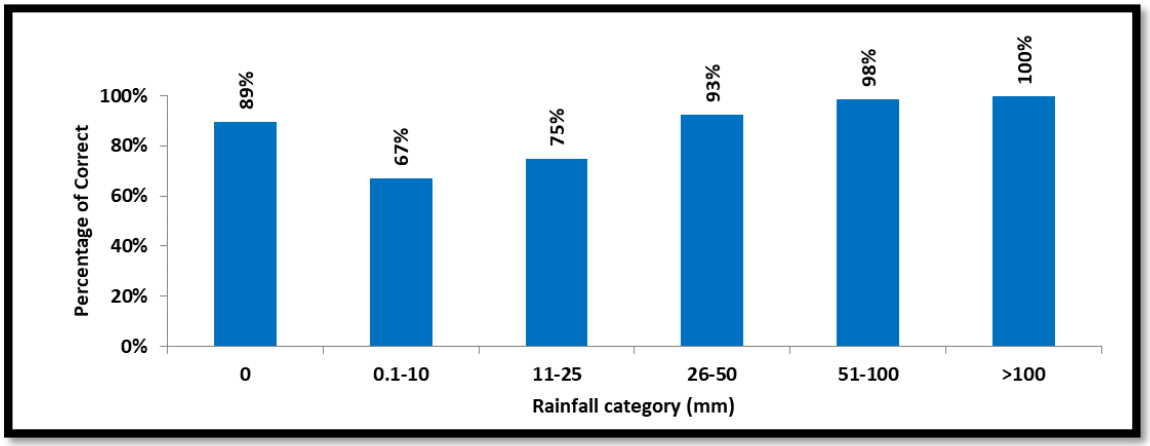

Figure 32: Category-wise Percentage Correct Forecast of Day-3

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 60%. While FMO Bengaluru has the highest Percentage correct QPF of 73% and FMO Thiruvananthapuram has the lowest accuracy of 42%, seven other FMOs reported more than 60% Percentage correct 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% and above for all FMOs except newly commissioned FMO Thiruvananthapuram where the accuracy was 87%.

Table 29: Performance of Day-4 QPF for the Flood Season 2021

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	577	180	164	921	18	27	1	9	0	0	59%	94%
Ahmedabad	2318	1404	423	367	2194	44	67	2	8	1	2	61%	95%
Asansol	366	220	94	41	355	5	3	0	2	0	1	60%	97%
Bengaluru	2196	1603	339	199	2141	25	26	2	1	0	0	73%	97%
Bhubaneswar	1220	737	294	147	1178	29	10	3	0	0	0	60%	97%
Chennai	1342	689	169	413	1271	7	47	0	17	0	0	51%	95%
DVC	732	479	142	86	707	4	15	0	5	0	1	65%	97%
Guwahati	2440	1337	734	293	2364	50	23	0	3	0	0	55%	97%
Hyderabad	1952	1142	383	333	1858	31	57	2	3	0	0	59%	95%
Jalpaiguri	610	307	180	79	566	18	18	3	5	0	0	50%	93%
Lucknow	1708	1111	285	234	1630	31	37	0	10	0	0	65%	95%
New Delhi	366	215	87	37	339	5	16	2	3	0	1	59%	93%
Patna	976	675	119	138	932	4	36	2	3	0	0	69%	95%
Srinagar	488	322	105	54	481	2	3	2	0	0	0	66%	99%
Thiruvanantpuram	976	407	285	153	845	93	30	6	2	0	0	42%	87%
Over All fct.	**18666**	**11225**	**3819**	**2738**	**17782**	**366**	**415**	**25**	**71**	**1**	**5**	60%	95%

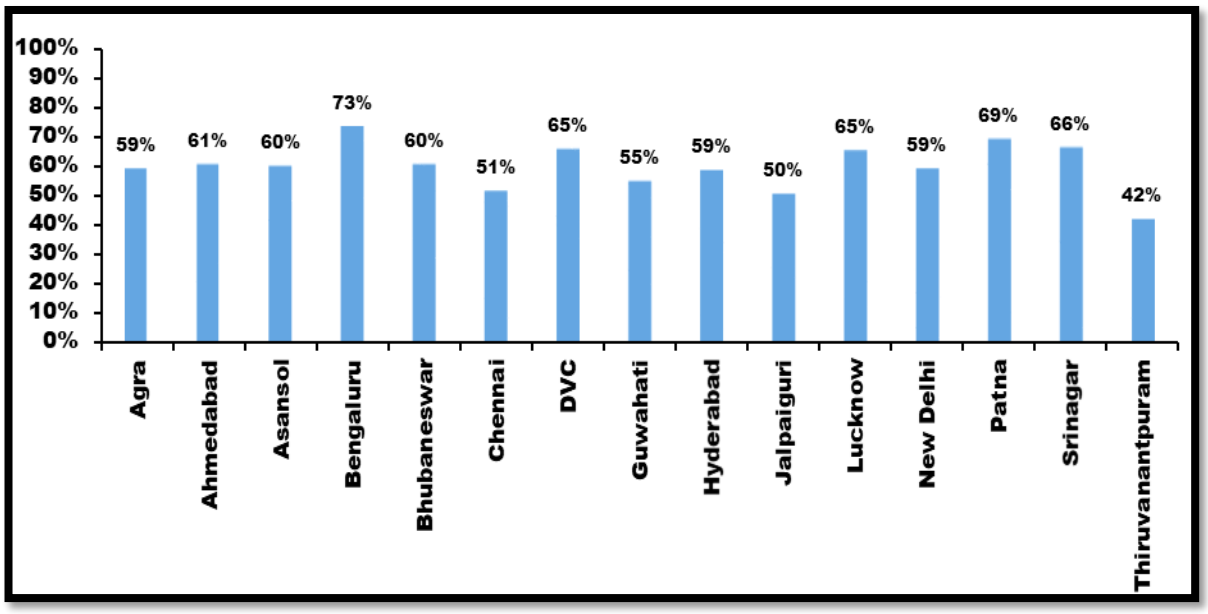

Figure 33. Percentage correct forecast Day-4 by different FMOs

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):	0.28	0.69	0.43	0.17	0.08	0.00
False Alarm Rate (FAR):	0.59	0.26	0.67	0.81	0.83	1.00
Missing Rate (MR):	0.72	0.31	0.57	0.83	0.92	1.00
Correct Non-Occurrence (C-NON):	0.94	0.57	0.79	0.96	0.99	1.00
Critical Success Index (CSI):	0.19	0.55	0.22	0.10	0.06	0.00
Bias for Occurrence (BIAS):	0.90	0.94	1.35	0.76	0.36	0.02
Hit Rate:	0.89	0.66	0.74	0.93	0.98	1.00
Percentage of Correct (PC):	0.89	0.66	0.74	0.93	0.98	1.00
True Skill Score (TSS):	0.22	0.26	0.21	0.13	0.08	0.00
Heidke Skill Score (HSS):	0.21	0.25	0.20	0.13	0.09	0.00

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

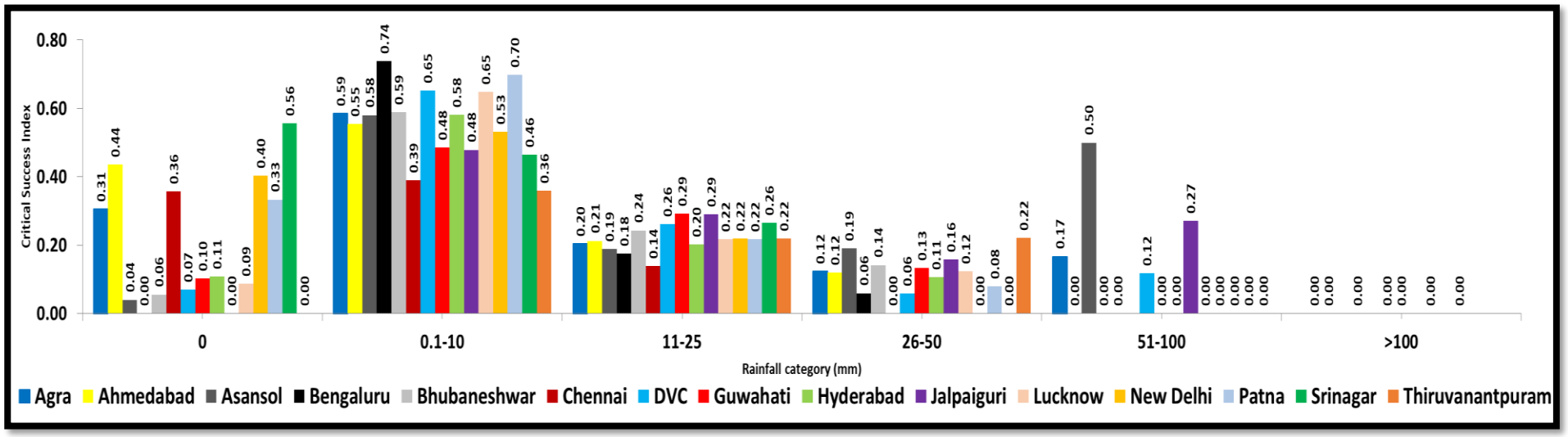

Figure 34: CSI for different categories of forecast for Day-4

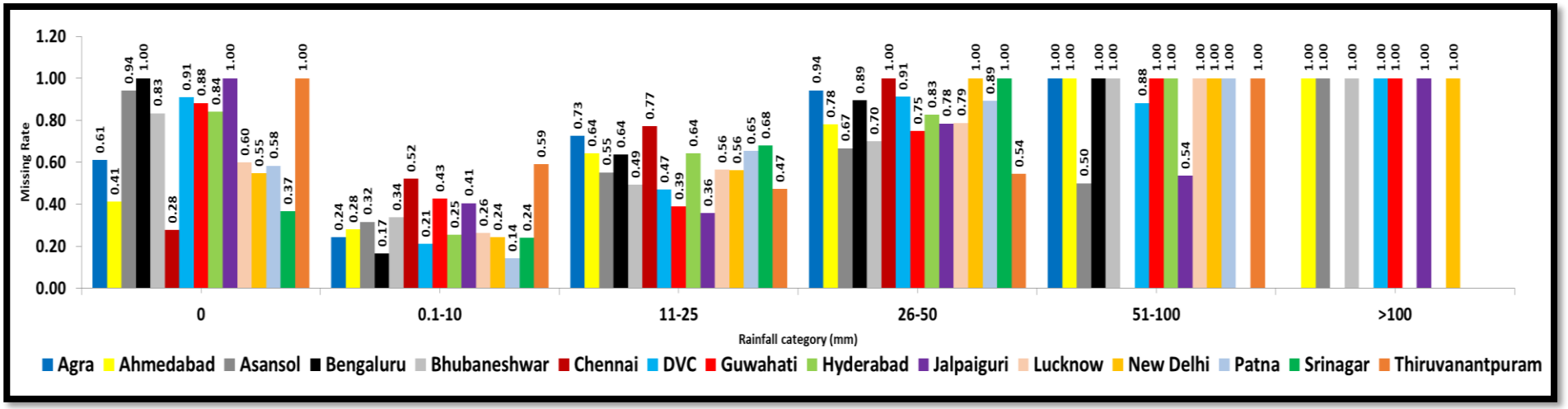

Figure 35: MR for different categories of forecast for Day-4

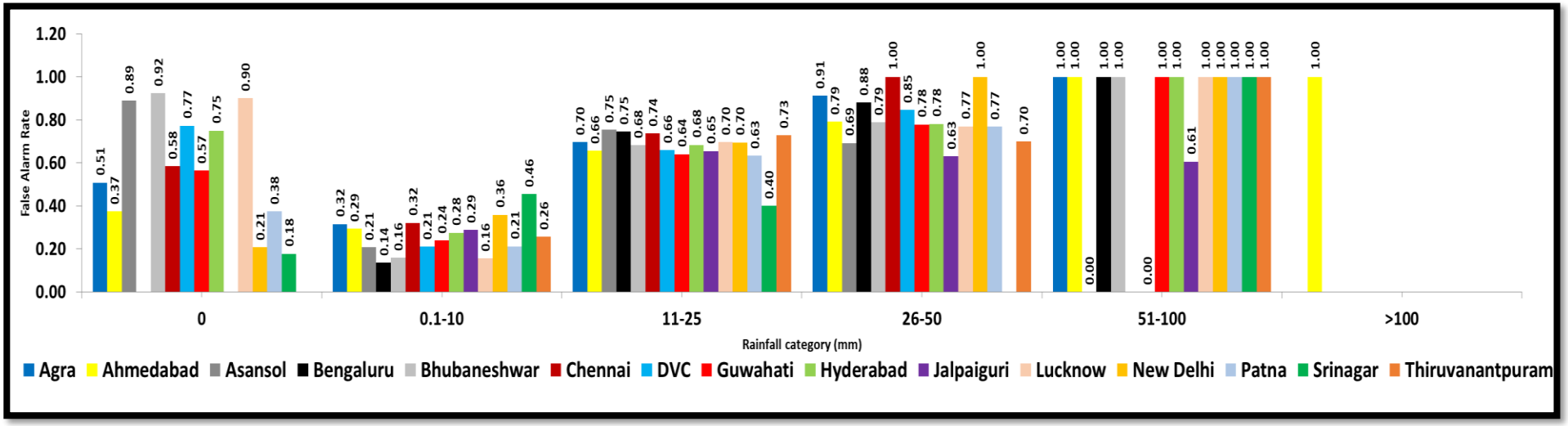

Figure 36: FAR for different categories of forecast for Day-4

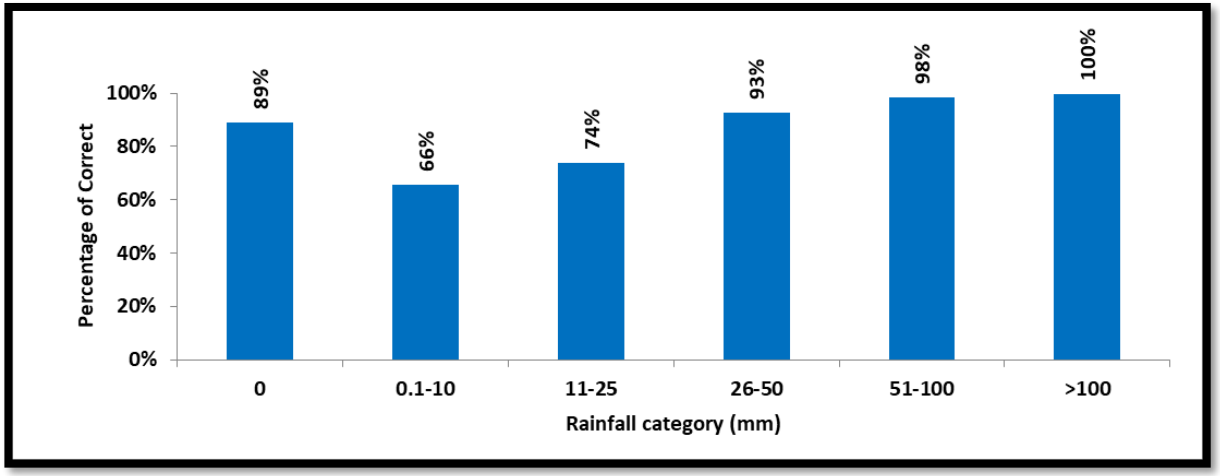

Figure 37: Category-wise Percentage Correct Forecast of Day-4

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 72% and FMO Thiruvananthapuram has the lowest accuracy of 40%, six other FMOs reported more than 60% Percentage correct 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 93% and above for all FMOs except newly commissioned FMO Thiruvananthapuram where the accuracy was 86%.

Table 31: Performance of Day-5 QPF for the Flood Season 2021

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	542	212	166	920	19	27	0	10	0	0	56%	94%
Ahmedabad	2318	1337	465	382	2184	40	79	1	12	0	2	58%	94%
Asansol	366	224	94	35	353	3	9	0	1	0	0	61%	96%
Bengaluru	2196	1590	332	208	2130	39	22	1	4	0	0	72%	97%
Bhubaneswar	1220	750	290	135	1175	28	15	2	0	0	0	61%	96%
Chennai	1342	682	174	416	1272	16	45	1	8	0	0	51%	95%
DVC	732	485	136	86	707	1	15	0	7	0	2	66%	97%
Guwahati	2440	1274	752	328	2354	53	28	0	5	0	0	52%	96%
Hyderabad	1952	1158	354	330	1842	31	59	2	18	0	0	59%	94%
Jalpaiguri	610	280	201	90	571	16	15	2	6	0	0	46%	94%
Lucknow	1708	1070	331	229	1630	22	44	0	12	0	0	63%	95%
New Delhi	366	212	87	41	340	7	13	1	5	0	0	58%	93%
Patna	976	662	130	139	931	4	39	0	2	0	0	68%	95%
Srinagar	488	308	109	65	482	2	4	0	0	0	0	63%	99%
Thiruvanantpuram	976	393	306	142	841	81	42	4	8	0	0	40%	86%
Over All fct.	18666	10967	3973	2792	17732	362	456	14	98	0	4	59%	95%

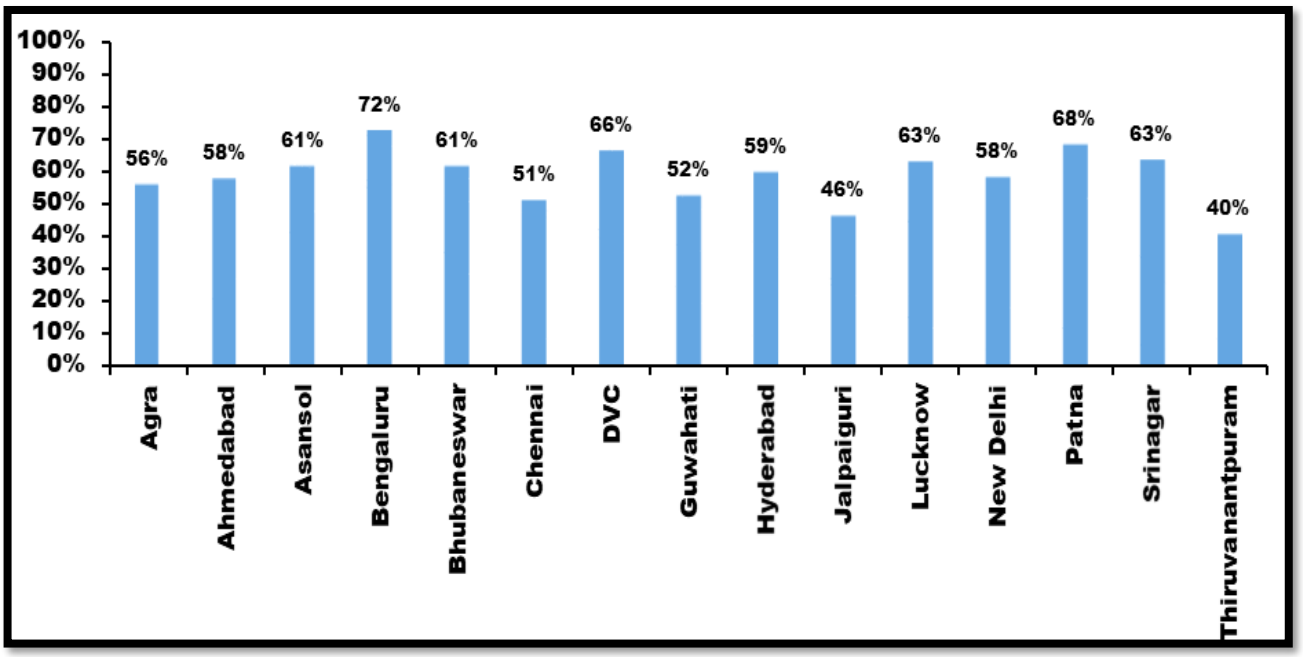

Figure 38. Percentage correct forecast Day-5 by different FMOs

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):	0.25	0.68	0.39	0.14	0.05	0.00
False Alarm Rate (FAR):	0.63	0.28	0.70	0.82	0.85	
Missing Rate (MR):	0.75	0.32	0.61	0.86	0.95	1.00
Correct Non-Occurrence (C-NON):	0.94	0.52	0.78	0.97	1.00	1.00
Critical Success Index (CSI):	0.16	0.54	0.20	0.08	0.03	0.00
Bias for Occurrence (BIAS):	0.76	0.96	1.34	0.75	0.25	0.00
Hit Rate:	0.89	0.64	0.73	0.93	0.98	1.00
Percentage of Correct (PC):	0.89	0.64	0.73	0.93	0.98	1.00
True Skill Score (TSS):	0.19	0.21	0.18	0.10	0.05	0.00
Heidke Skill Score (HSS):	0.18	0.20	0.16	0.11	0.05	0.00

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

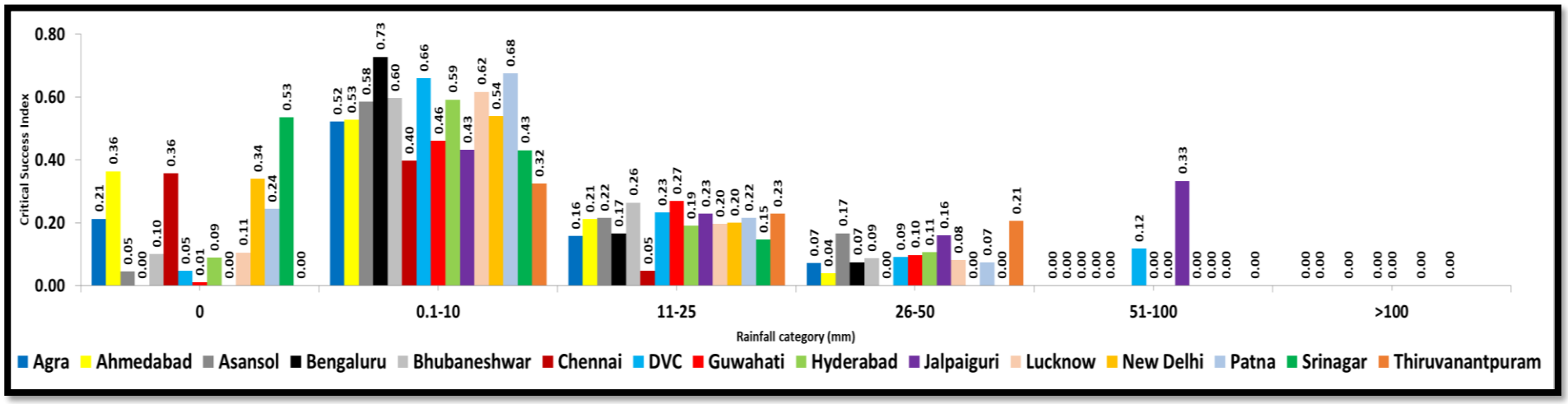

Figure 39: CSI for different categories of forecast for Day-5

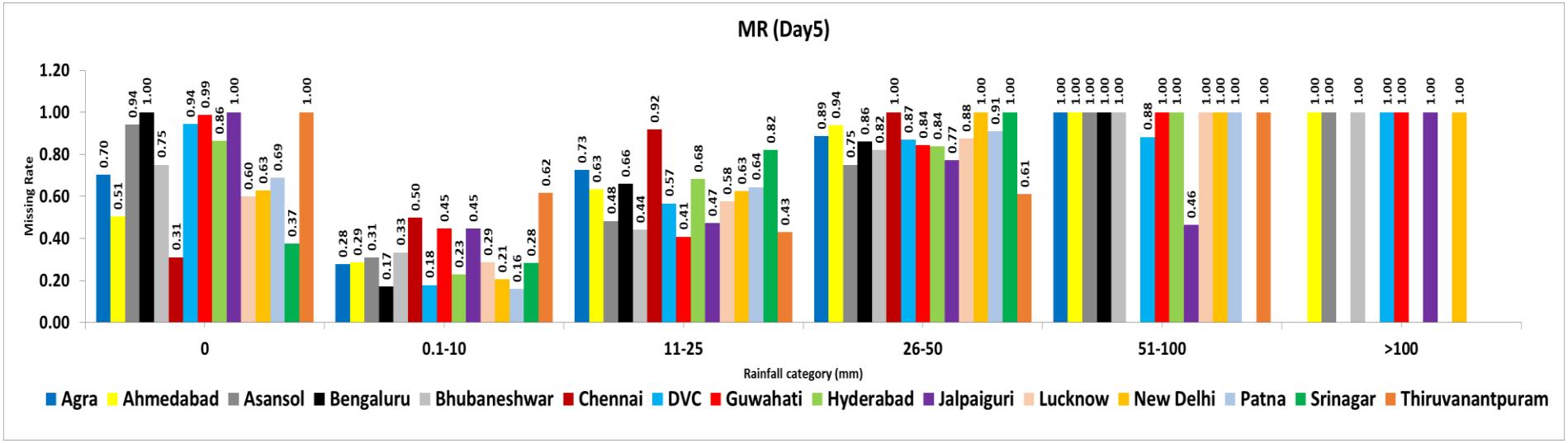

Figure 40: MR for different categories of forecast for Day-5

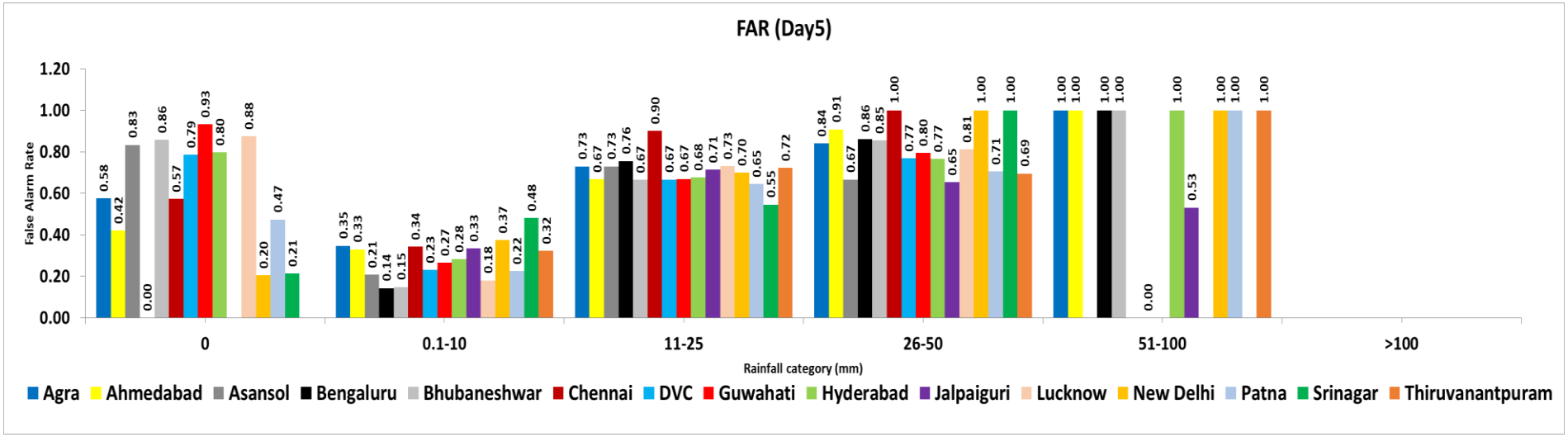

Figure 41: FAR for different categories of forecast for Day-5

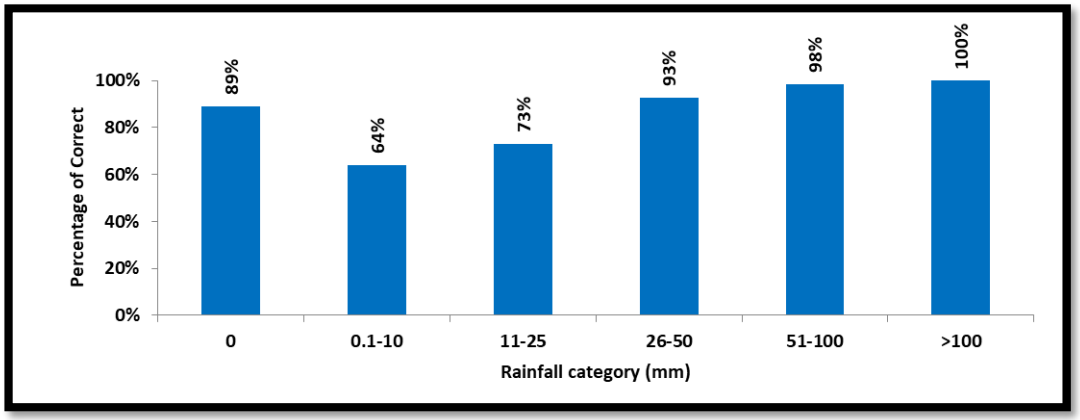

Figure 42: Category-wise Percentage Correct Forecast of Day-5

4.6 Analysis of Heavy Rainfall Cases

Flood occurs when the Basin receives heavy rainfall, however, it depends on antecedent conditions of the soil moisture and other topographical features. Moderate amount of rainfall may also lead to flood when the soil is fully saturated. Forecasters try to minimize both false alarms and missed cases. While false alarms result into unnecessary displacement, missed rate results into unexpected inundation.

Considering that the prediction of heavy rainfall cases (QPF categories above 26mm) are very important for the flood events. Statistics for total number of inaccurate forecast issued (out by ≥ 1 category) in context of false alarm and missed category for QPF range 26-50, 51-100, and > 100mm issued by FMOs are summarized in Table 33. During the period of evaluation, there were total 18666 number of QPF issued for day-1. The table indicates that the number of inaccurate Day-1 forecast is 1313 in the category 26-50 mm, 243 in category 51-100 mm and 22 in the category of >100 mm. Most inaccurate forecasts were noticed in case of FMO Thiruvananthapuram followed by FMO Hyderabad for the categories 26-50 mm & 51-100 mm and FMO Jalpaiguri in the category of >100 mm. All India percentage frequency of False Alarm (FA) cases (QPF given in higher category, but observed in lower category) and Missing Cases (MC) (QPF given for lower category but higher category observed) accumulated under “Inaccurate Forecast (IF)” are given in figure 43.

Table 33: 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	48	25	23	10	1	9	0	0	0
AHMEDABAD	124	72	52	37	25	12	5	2	3
Asansol	17	14	3	2	1	1	2	0	2
Bengaluru	133	89	44	14	5	9	0	0	0
Bhubaneswar	85	58	27	10	5	5	2	1	1
Chennai	63	22	41	0	0	0	0	0	0
DVC	31	21	10	12	5	7	4	0	4
Guwahati	113	76	37	16	6	10	2	0	2
Hyderabad	171	113	58	17	2	15	0	0	0
Jalpaiguri	77	38	39	24	12	12	6	0	6
Lucknow	101	48	53	20	4	16	0	0	0
New Delhi	20	8	12	11	4	7	1	0	1
Patna	78	30	48	7	0	7	0	0	0
Srinagar	11	8	3	0	0	0	0	0	0
Thiruvananthapura	241	189	52	63	17	46	0	0	0
TOTAL	1313	811	502	243	87	156	22	3	19

The rainfall category 26-50 mm has False Alarm (FA) cases more than Missed Cases (MC) whereas for higher rainfall categories 51-100 mm and >100 mm, Missed Cases (MC) are much more than False Alarm (FA) cases.

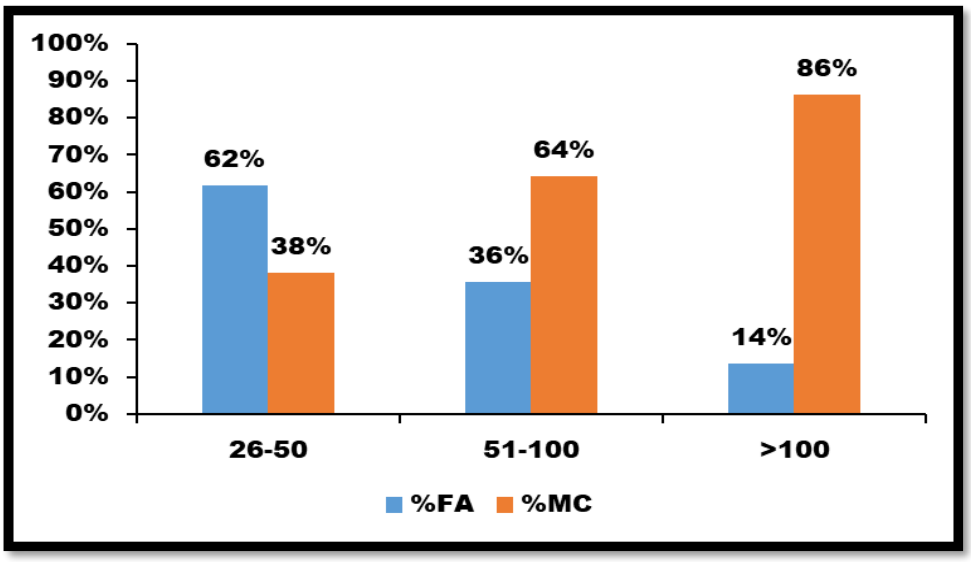

Figure 43: % of FA cases & MC for higher rainfall categories

4.7 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 2016-2021 are given in Figure 44. It is also observed during this year, the accuracy of forecast has improved by 5% in Day-1, Day-2 and Day-3 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 5%), but there is not much deterioration in the accuracy with increase in lead time from day-2 to day-5 (by 1%).

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 45. 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.

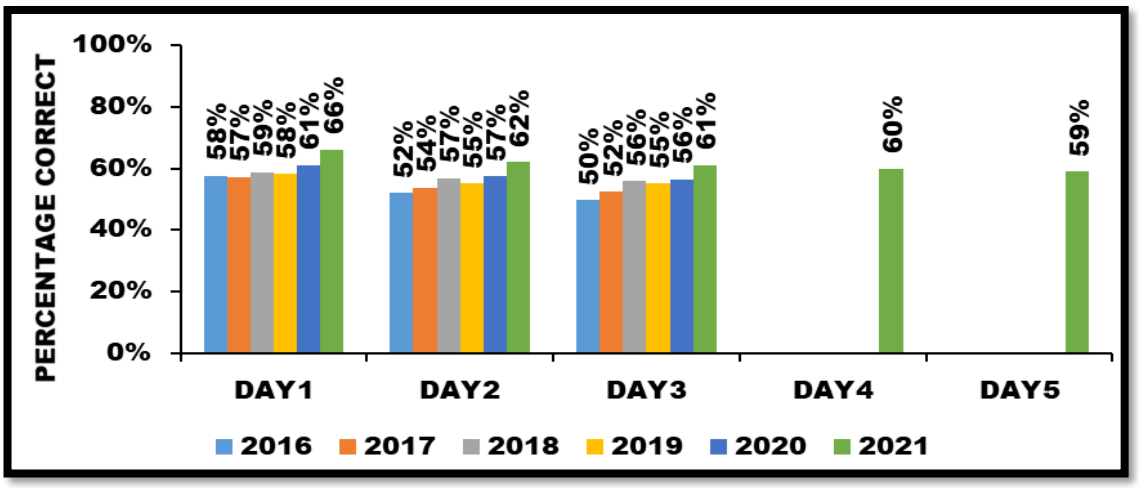

Figure 44: Day-1, Day-2, Day-3, Day-4 and Day-5 overall % correct forecast

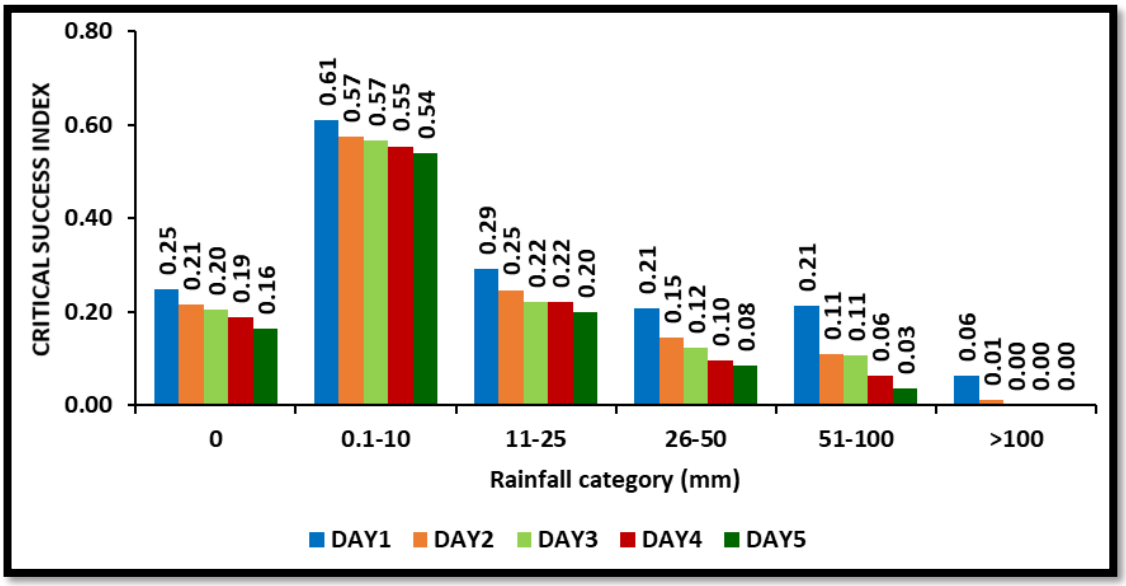

Figure 45: Category-wise Critical Success Index for Day-1, Day-2, Day-3, Day-4 and Day-5

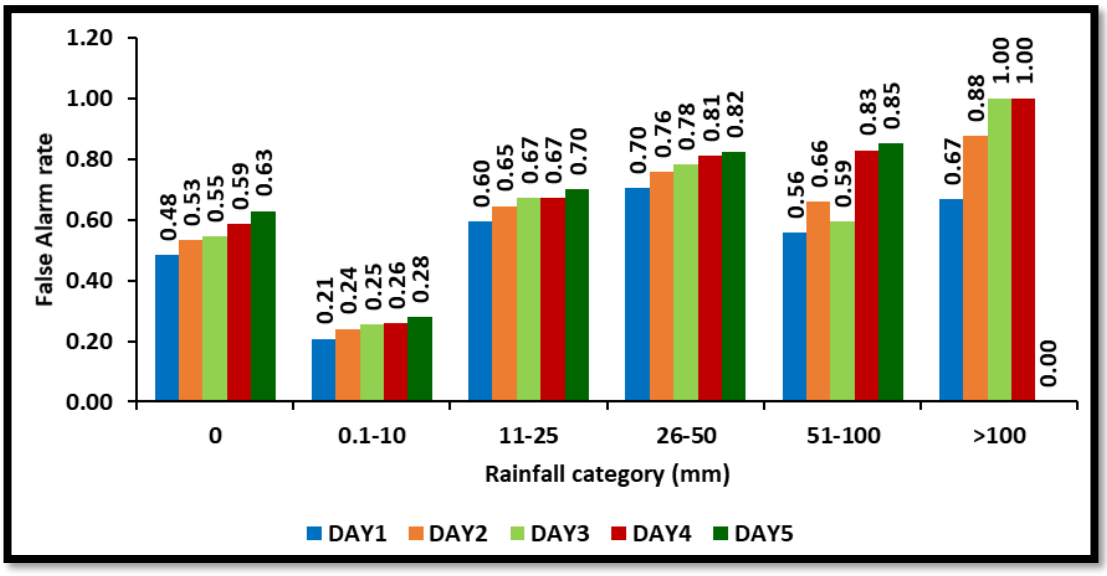

Figure 46: Category-wise False Alarm Rate for Day-1, Day-2, Day-3, Day-4 and Day-5

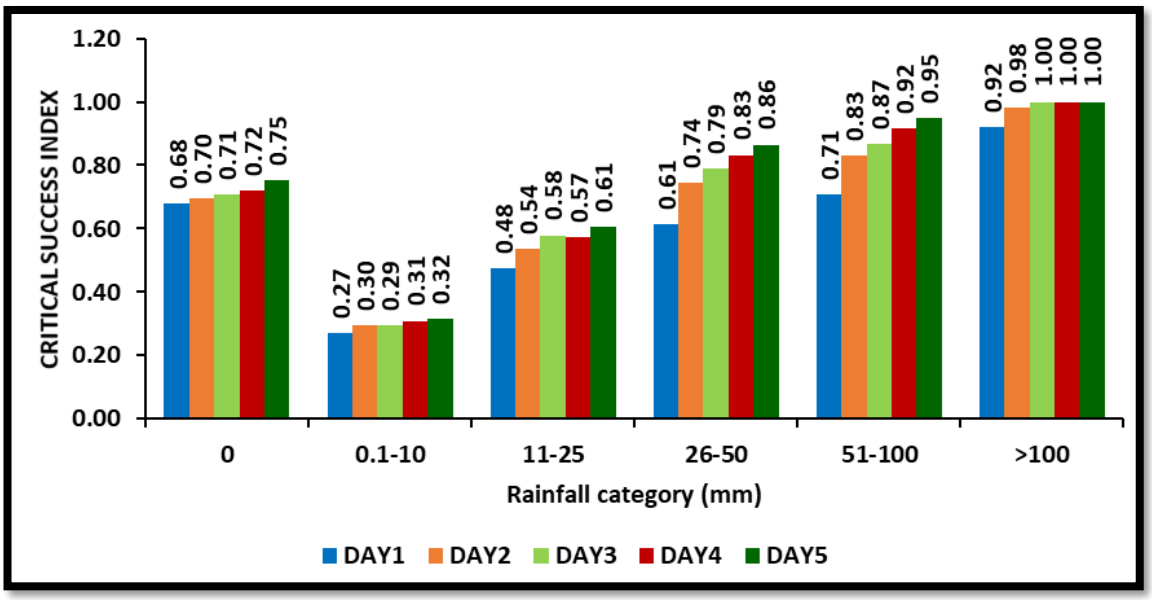

Figure 47: Category-wise Missing Rate for Day-1, Day-2, Day-3, Day-4 and Day-5

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 46 and 47 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.

4.8. Improvement in operational QPF (2013 to 2021)

The FMO-wise Percentage correct QPF for Day-1 for the year 2013 to 2021 are given in Figure 48. The accuracy of Day-1 QPF when compared to previous years has improved significantly in respect of FMOs Asansol, Bengaluru, Bhubaneshwar, Chennai, DVC, Hyderabad, Jalpaiguri, Lucknow and Patna while it has deteriorated slightly in respect of FMOs namely, Agra, Guwahati and Srinagar.

The FMO-wise performance in operational QPF during 2021 as compared to average performance in the previous years (2013-2020) for Day-1 and (2016 to 2020) for Day-2 and Day-3 are shown in Figure 49-51 respectively. Substantial improvement in the accuracy (≥5%) is observed for the FMOs Agra, Bengaluru, Bhubaneswar, Chennai, DVC, Hyderabad, Jalpaiguri, Lucknow, New Delhi and Patna.

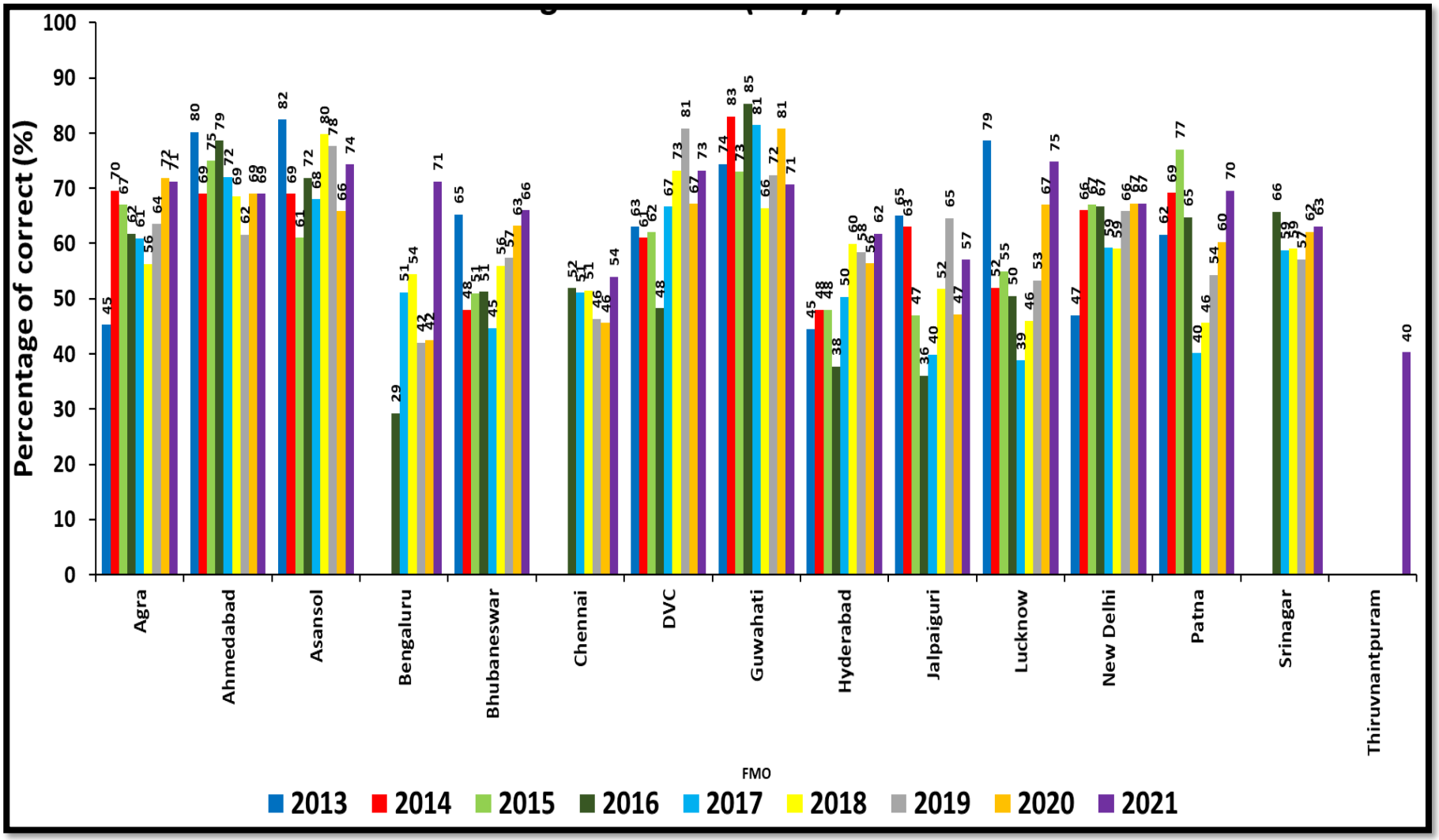

Figure 48: FMO-wise Percentage Correct QPF for Day-1 for the year 2013 to 2021

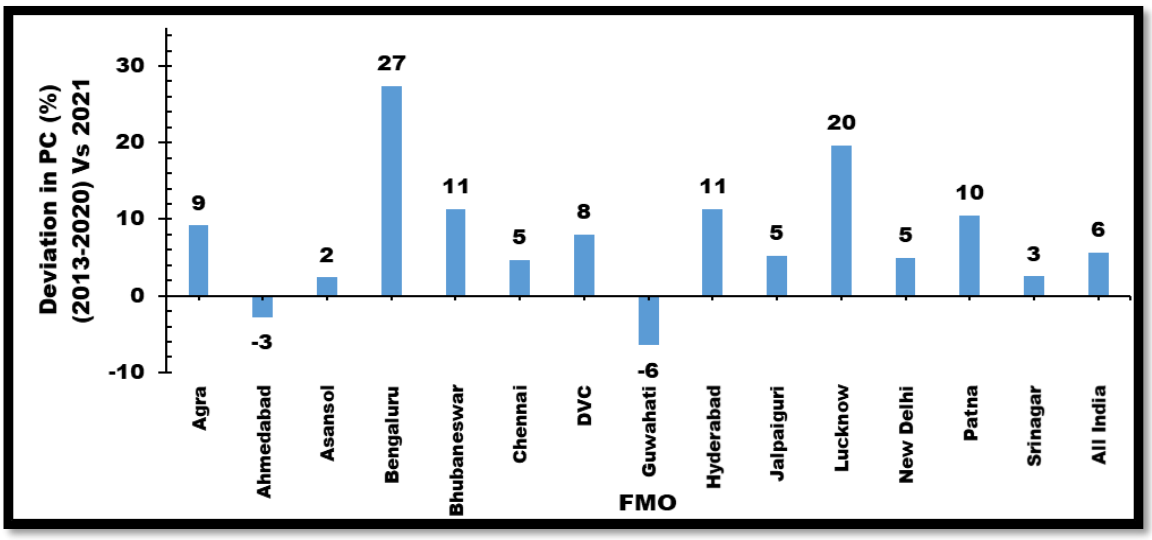

Figure 49. Day-1 performance of FMO-wise Operational QPF during 2021 Vs mean of 2013 - 2020

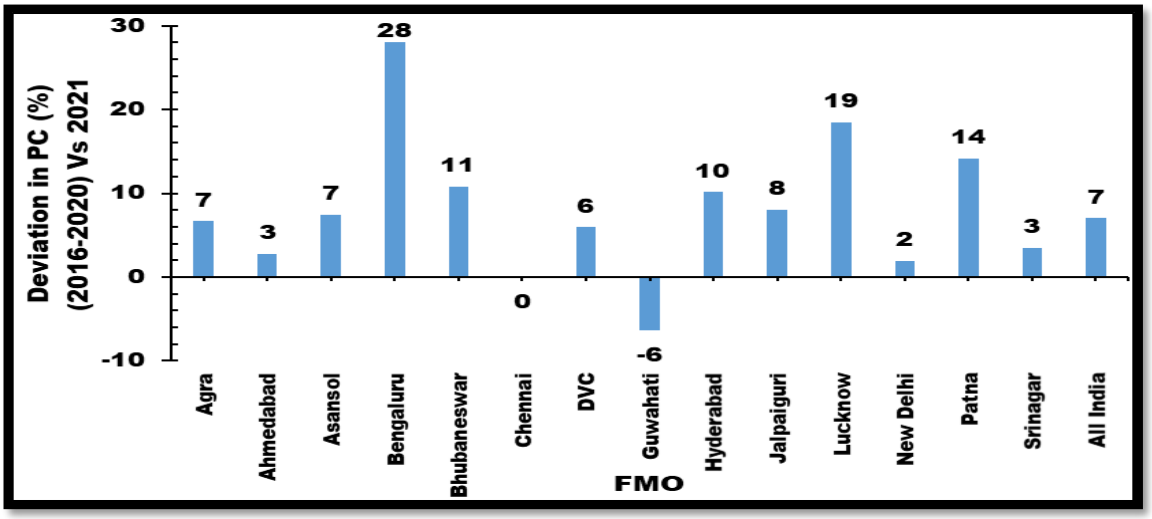

Figure 50. Day-2 performance of FMO-wise Operational QPF during 2021 Vs mean of 2016 - 2020

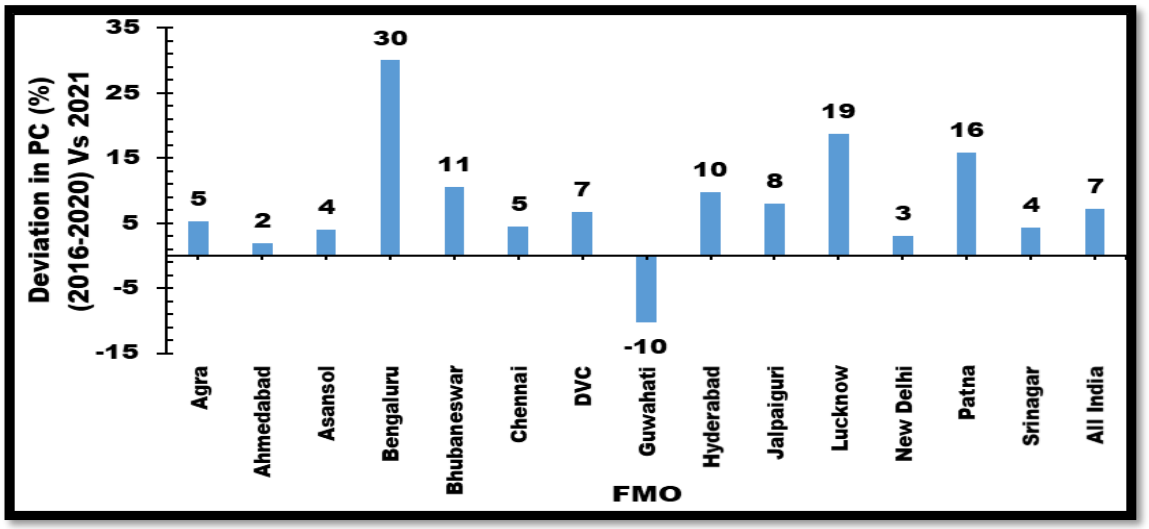

Figure 51. Day-3 performance of FMO-wise Operational QPF during 2021 Vs mean of 2016 – 2020

CHAPTER 5

Concluding Remarks

1. During this year, the accuracy within same category of river sub-basin-wise QPF has improved by 5% in Day-1, Day-2 and Day-3 as compared to 2020.
2. Substantial improvement in the accuracy (≥5%) during 2021 is observed for the FMOs Agra, Bengaluru, Bhubaneswar, Chennai, DVC, Hyderabad, Jalpaiguri, Lucknow, New Delhi and Patna as compared to average performance in the previous years (2013-2020) for Day-1.
3. The accuracy of Day-1 QPF when compared to previous years (2013-2020) has improved significantly in respect of FMOs Agra, Asansol, Bengaluru, Bhubaneshwar, Chennai, DVC, Hyderabad, Jalpaiguri, Lucknow, Patna and Srinagar while it has deteriorated slightly for FMOs Guwahati and Ahmedabad.
4. PC of QPF within same category is 66% for Day-1, 62% for Day-2, 61% for Day-3, 60% for Day-4 and 59% for Day-5 for all 153 river sub- basins. However, accuracy of QPF within ±1 category is more than 95% for all five days.
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 5%), but there is not much deterioration in the accuracy with increase in lead time from day-2 to day-5 (by 1%).
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 0.61, 0.29, 0.21, 0.21 and 0.06 respectively for Day-1 QPF for all 153 river sub-basins.

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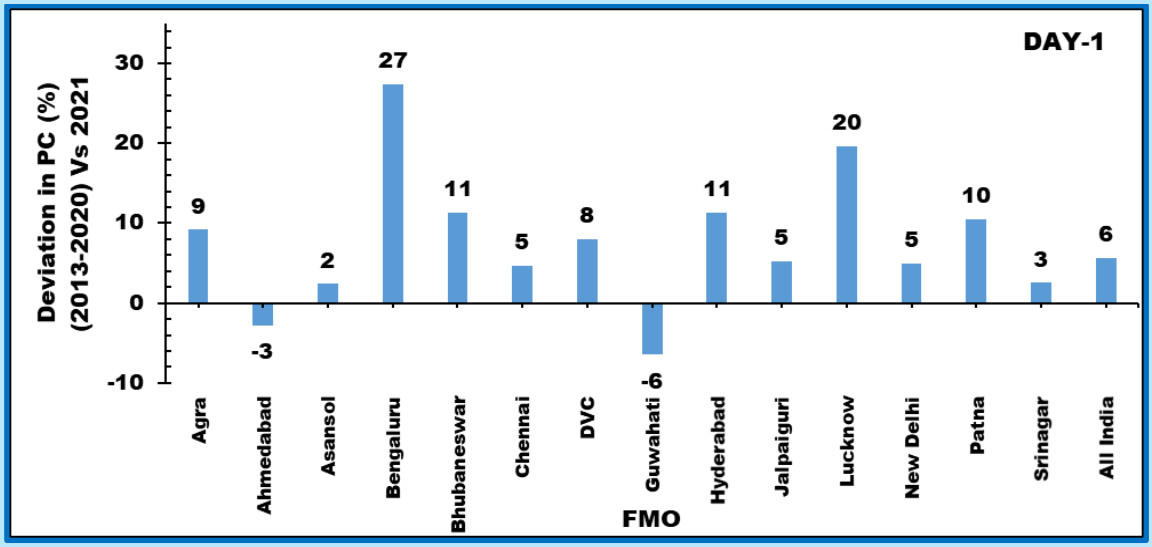

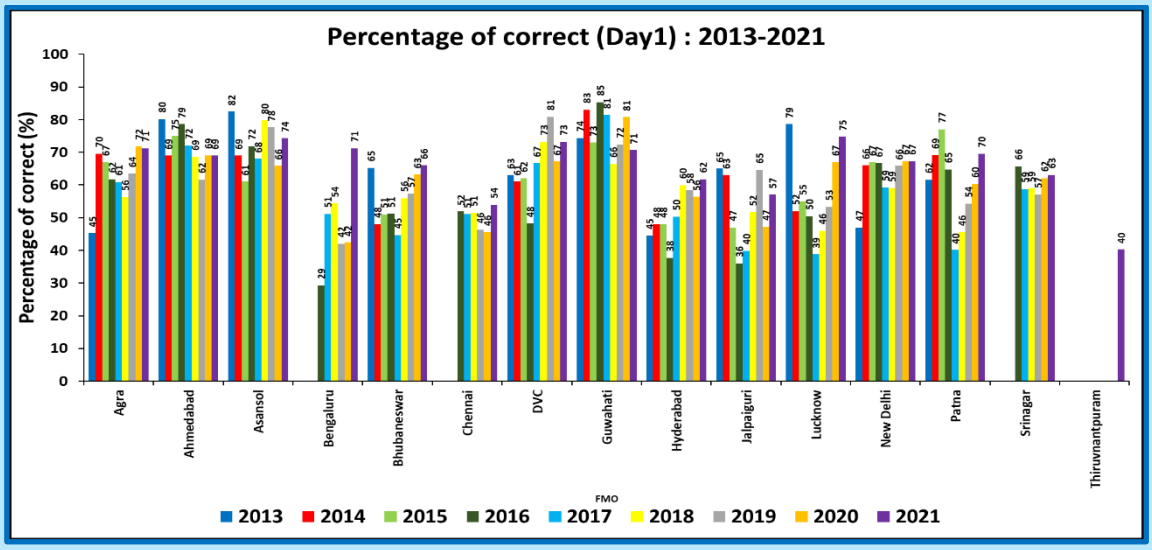

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