नदी उपबेसिन मात्रात्मक वर्षा पूर्वानुमान दक्षिण पश्चिमी मानसून 2023 का सत्यापन

VERIFICATION OF RIVER SUB-BASIN-WISE QUANTITATIVE PRECIPITATION FORECAST DURING SW MONSOON 2023

S. C. Bhan, Ashok Kr. Das, A. Madhulatha, S. K. Manik, Charu, M. C. Papnai, Dhara Singh, Rajesh Maurya, A. Sravani, Dwaraka Nath Maji, H. R. Biswas, K. R. Beena, Kuldeep Srivastava, Manorama Mohanty, Mohammed Danish, P. S. Kannan, Rajavel Manickam, Ranendra Sarkar, Ravindra Kumar, Sonam Lotus, Sourish Bondyopadhyay, Sunit Das
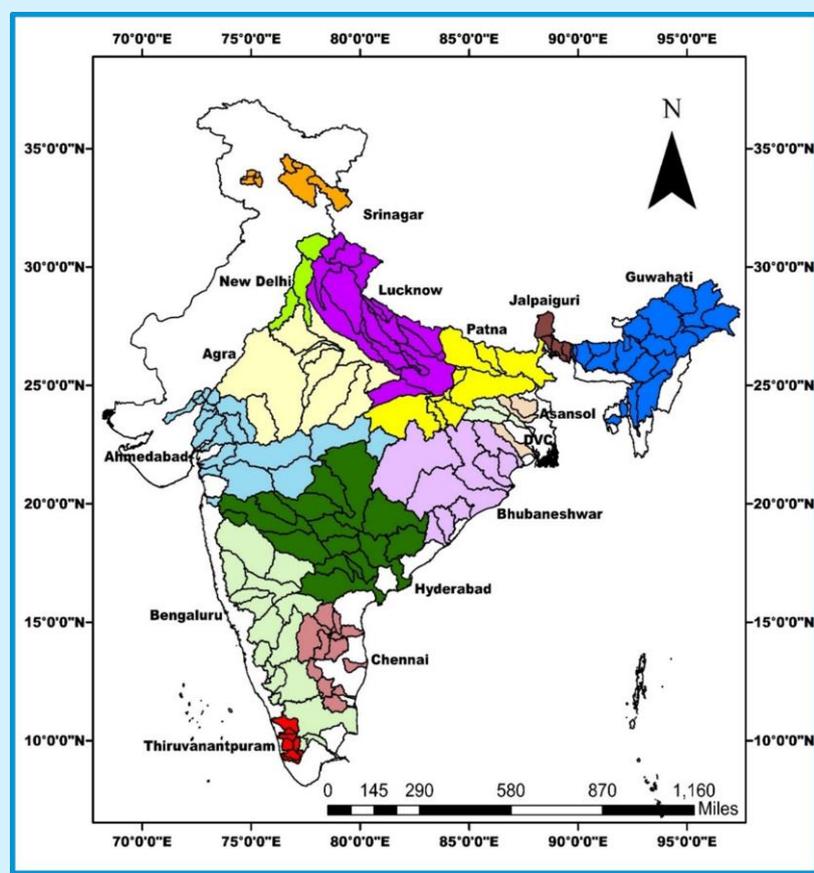
भारत मौसम विज्ञान विभाग

(पृथ्वी विज्ञान मंत्रालय)

India Meteorological Department

(Ministry of Earth Sciences)

Report No. MoES/IMD/H.S/Basin Hydrology/01(2024)/16

नदी उपबेसिन मात्रात्मक वर्षा पूर्वानुमान दक्षिण पश्चिमी मानसून 2023 का सत्यापन

VERIFICATION OF RIVER SUB-BASIN-WISE QUANTITATIVE PRECIPITATION FORECAST DURING SW MONSOON 2023

S. C. Bhan, Ashok Kr. Das, A. Madhulatha, S. K. Manik, Charu, M. C. Papnai, Dhara Singh, Rajesh Maurya, A. Sravani, Dwaraka Nath Maji, H. R. Biswas, K. R. Beena, Kuldeep Srivastava, Manorama Mohanty, Mohammed Danish, P. S. Kannan, Rajavel Manickam, Ranendra Sarkar, Ravindra Kumar, Sonam Lotus, Sourish Bondyopadhyay, Sunit Das

डॉ. एम. रविचंद्रन
Dr. M. Ravichandran

सचिव
भारत सरकार
पृथ्वी विज्ञान मंत्रालय
पृथ्वी भवन, लोदी रोड, नई दिल्ली—110003

SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
PRITHVI BHAWAN, LODHI ROAD, NEW DELHI-110003

Foreword

It gives me immense pleasure to know that Hydrometeorology Division of India Meteorological Department (IMD) has prepared an annual report entitled 'Verification of River Sub-Basin-Wise Quantitative Precipitation (QPF) forecast during the SW Monsoon 2023' based on Operational QPF and the Observed rainfall received in the different sub-basins under 14 FMOs along with DVC met unit Kolkata.

River sub-basin wise QPF (both deterministic and probabilistic) and heavy rainfall warnings are important inputs provided by IMD to support riverine flood forecasting by Central Water Commission is a determinant for effective flood forecast in the country. Therefore, the verification is essential and may be mandatory to analyze its performance for further improvement in the services as well as to take correction measures for these activities, if any. Tabular and graphical formats in the report in addition to thematic maps provide a lucid description for easy comprehension. This publication is very important for the Research Scholars, flood forecasters, Agriculturists, Policy Makers, Planners and many more.

This report is an outcome of sincere and consistent effort of all the team members of Hydrometeorology Division, IMD. I take this opportunity to express my appreciation to Dr. M. Mohapatra, DGM, IMD, Shri S. C. Bhan, Head, Hydrometeorology Division and their team of scientists and staff for putting their best efforts in brings out this valuable publication successfully.

(M. RAVICHANDRAN)

Tel. : +91-11-24629771, 24629772 ❑ Fax : +81-11-24629777 ❑ E-mail : secretary@moes.gov.in

डॉ. मृत्युंजय महापात्र

मौसम विज्ञान विभाग के महानिदेशक,
विश्व मौसम विज्ञान संगठन में भारत के स्थाई प्रतिनिधि
विश्व मौसम विज्ञान संगठन के तीसरे उपाध्यक्ष

Dr. Mrutyunjay Mohapatra

Director General of Meteorology,
Permanent Representative of India to WMO
Third Vice President of WMO

भारत सरकार
पृथ्वी विज्ञान मंत्रालय
भारत मौसम विज्ञान विभाग
मौसम भवन, लोदी रोड
नई दिल्ली—110003
Government of India
Ministry of Earth Sciences
India Meteorological Department
Mausam Bhawan, Lodi Road
New Delhi - 110003

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 Central Water Commission (CWC) for their Flood Forecasting services. QPF is the crucial 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 the SW Monsoon 2023' 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 2023.

I thank and appreciate my colleagues in Hydrometeorology Division of IMD, New Delhi for their whole-hearted efforts in bringing out this publication.

(MRUTYUNJAY MOHAPATRA)

Phone : 91-11-24611842, Fax : 91-11-24611792
E-mail : directorgeneral.imd@imd.gov.in / dgmmet@gmail.com / m.mohapatra@imd.gov.in

Preface

India Meteorological Department through Flood Meteorological Offices (FMOS) provides hydrometeorological support services for flood forecast activities of Central Water Commission. FMOs located at different flood prone areas of the country issue the QPF and Hydromet Bulletin to field offices of CWC. Presently, there are 14 FMOs and DVC Met. Unit Kolkata and provide the services for total 156 river sub-basins. The main input in the bulletin is the river sub-basin wise QPF which is valid for day 1 to day 7. This QPF is the main input for flood forecast model of CWC and determines its success for their flood forecast in the country. Therefore, the verification is very much essential and may be mandatory to analyze its performance for further improvement in the services as well as to take correction measures for these activities, if any.

It is a very challenging task for issuing river sub-basin wise QPF. To accomplish this activity, daily prepared numerical weather prediction model-based river sub-basin-wise QPF using WRF, NCUM-R, GFS, NCUM, MME and for Probabilistic QPF (PQPF) using GEFS & NEPS which are valid for 7 days which are made available in the IMD website (https://hydro.imd.gov.in/hydrometweb/).

This report provides the detailed performance of River-sub-basin-wise QPF for JJAS 2023 based on Operational QPF and Observed river sub-basin wise Average Areal Precipitation (AAP) based on rainfall data if total 4118 stations over the river sub-basins. We hope, this publication containing analysis of the performance of operational river sub-basin-wise QPF for the year 2023 would be useful for specially for FMOs including the various stakeholders

We are grateful to all 14 FMOs and DVC Met. Unit Kolkata for sharing the observed and operational forecast data and also thankful to staff of Flood Monitoring Unit (FMU), Hydrometeorology Division, New Delhi for their whole-hearted contribution in bringing out this publication.

CONTENTS

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. All the activities of FMO Agra is operational at RMC New Delhi.

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 sub-basins of west flowing rivers in Kerala State are also included under FMO Bengaluru for this activity in 2019 after the Kerala flood in 2018. During the 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 Kerala, which were previously under FMO, Bengaluru. IMD also provides similar support to Damodar Valley Corporation (DVC) for the six river sub-basins of Barakar and Damodar rivers.

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 real-time basis. Based on the evaluation of accuracy of operational as well as dynamic model based QPF and availability new tools and techniques, the validity of the operational daily sub-basin-wise QPF was increased from existing 1 to 3 days to 1 to 5 days during SW monsoon 2021 which was further increased during the flood season 2023 to 1 to 7 days. This meets the long pending demand from flood forecasting authority (CWC) as well as National Disaster Management Authority.
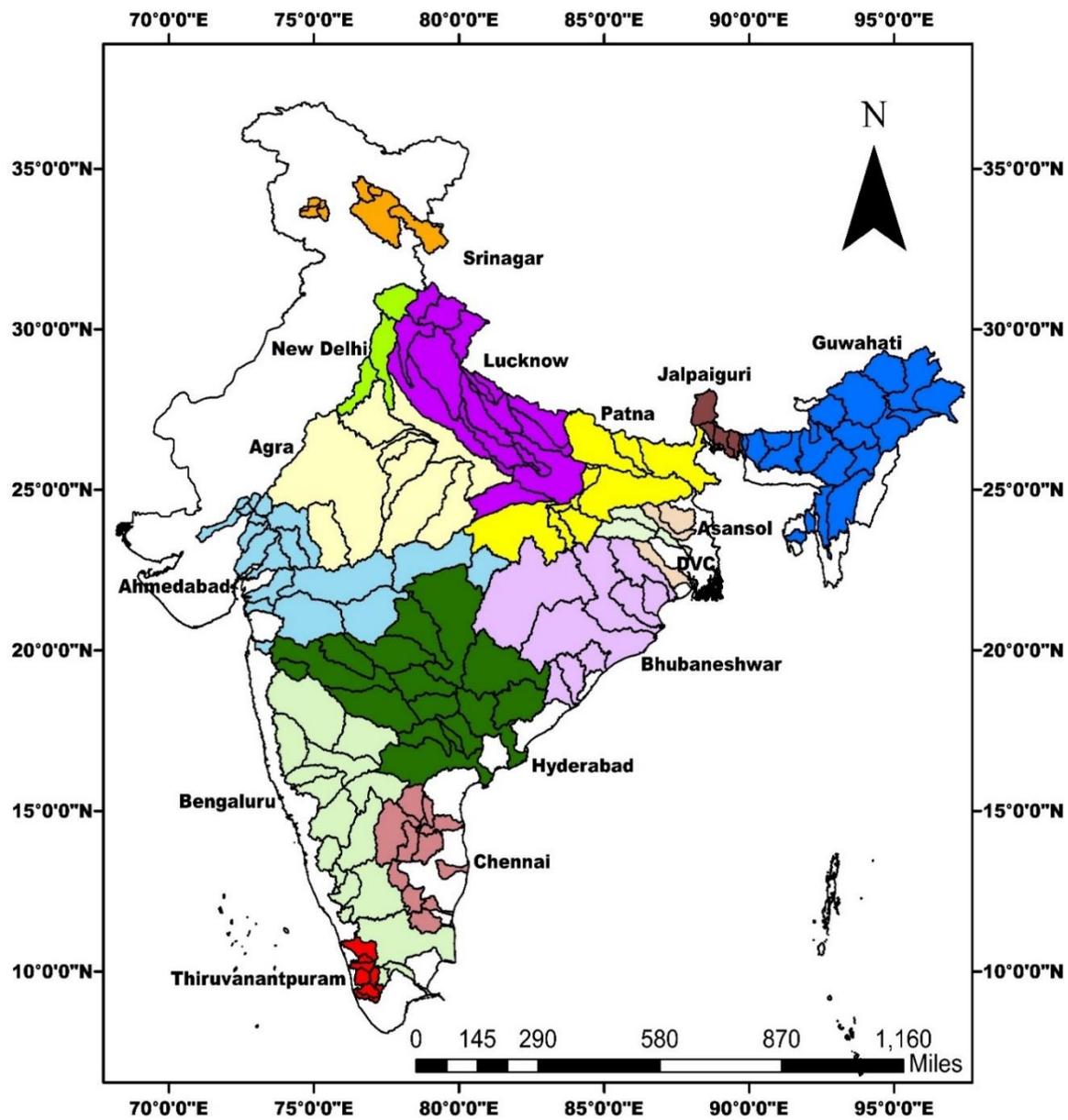
Figure 1: Map of Flood Meteorological offices with Sub-Basins in 2023

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	6	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			156	29,56,570

Hydrometeorological Services of IMD for riverine flood forecasting 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. Categorical Sub-basin-wise QPF is issued for a lead-time of 7 days. Also, if situation demands, QPF bulletins can be further updated in the evening. The flood season may vary depending upon location of basin and onset/withdrawal of S-W monsoon. As per the guidelines from CWC vide notification no 3/120/2019-FFM/ dated 22nd April, 2019, the flood season is as follows;

- Brahmaputra & Barak (including Teesta, Rivers flowing in States of Tripura, Manipur, Mizoram, Nagaland, Meghalaya, North Bengal, Sikkim) Basins and Jhelum Sub-Basin of Indus Basin from 1st May to 31st October
- All other basins upto Krishna basin from 1st June to 31st October and
- Basins south of Krishna basin (Pennar, Cauvery and southern rivers) from 1st June to 31st December.

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 day 1 to day 7 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 7 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   Table - 3. PQPF category and their colour codes

QPF Categories (mm)	Colour Code	Probability of Occurrence (%)	Colour Code
0			
0.1-10	(green)	0-5	(grey)
11-25	(blue)	5-25	(light blue)
26-50	(yellow)	25-50	(light green)
51-100	(orange)	50-75	(orange)
>100	(red)	75-100	(red)

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).
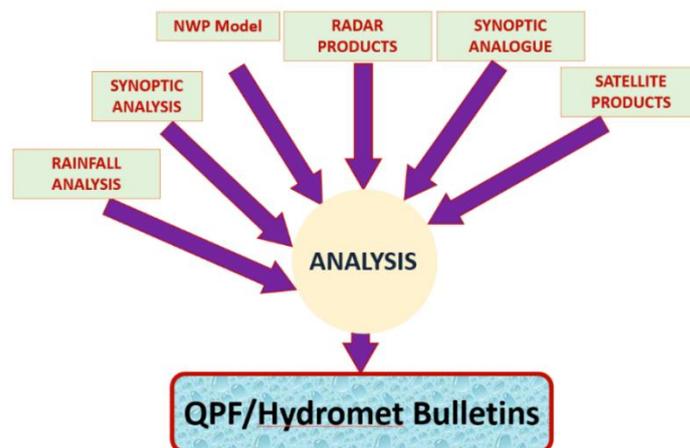
Figure 2. Input for issuing of QPF/Hydromet Bulletins

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).
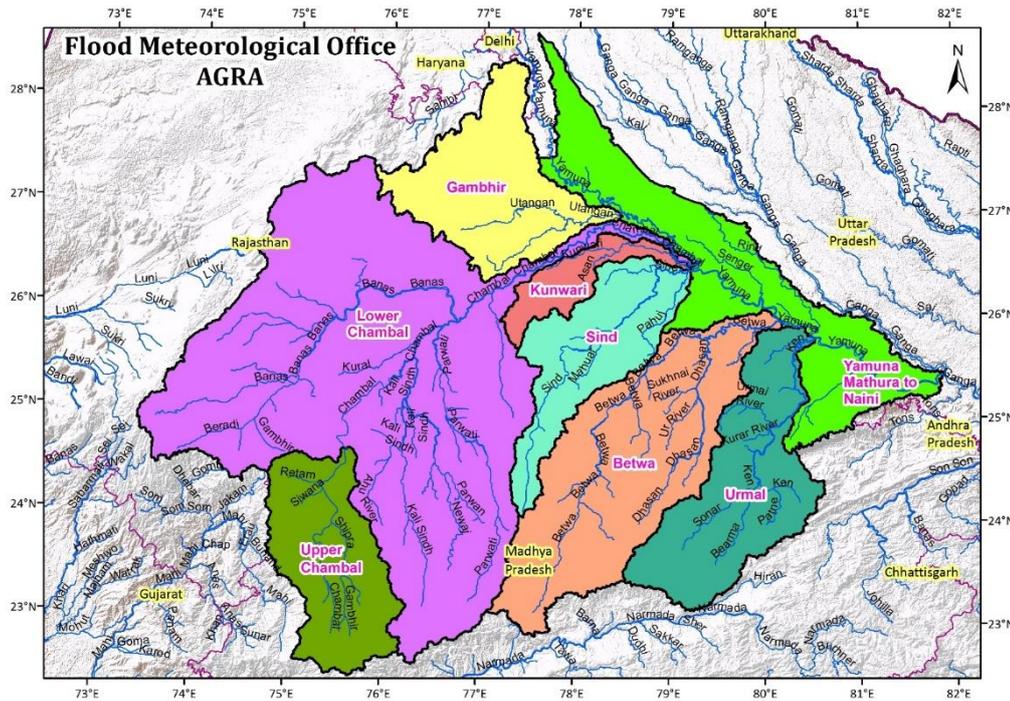
Figure 3: Map of FMO Agra with Sub-basins

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).
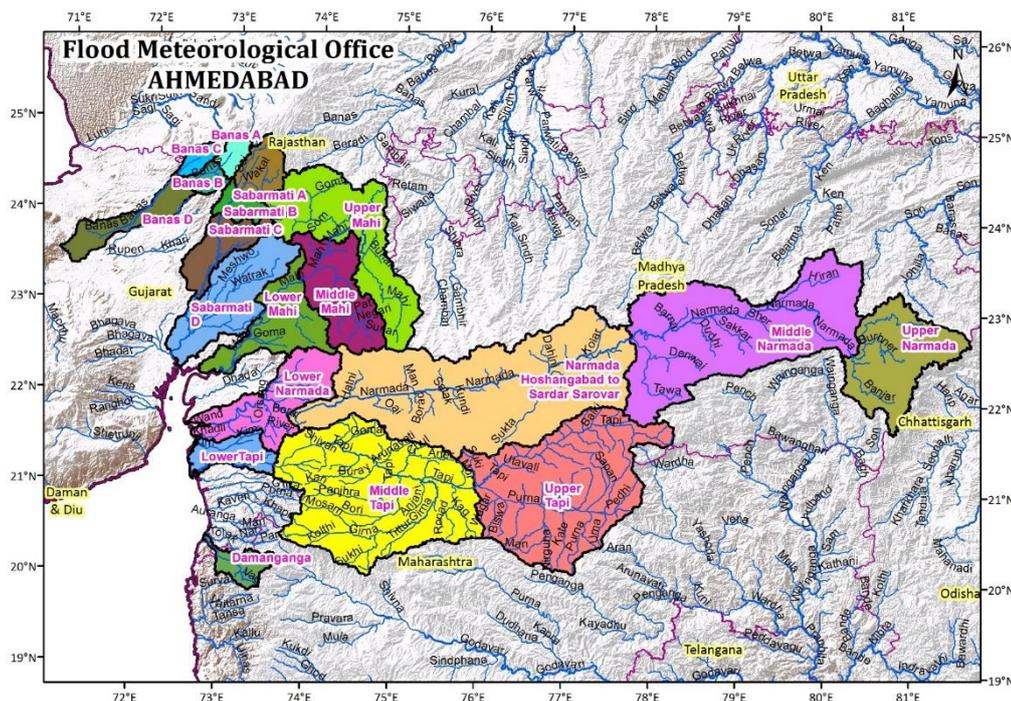
There are total of 19 sub-basins under the FMO Ahmedabad. The name of basins, sub-basins with area (in Km^2) are given in Table 7.

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 was 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).
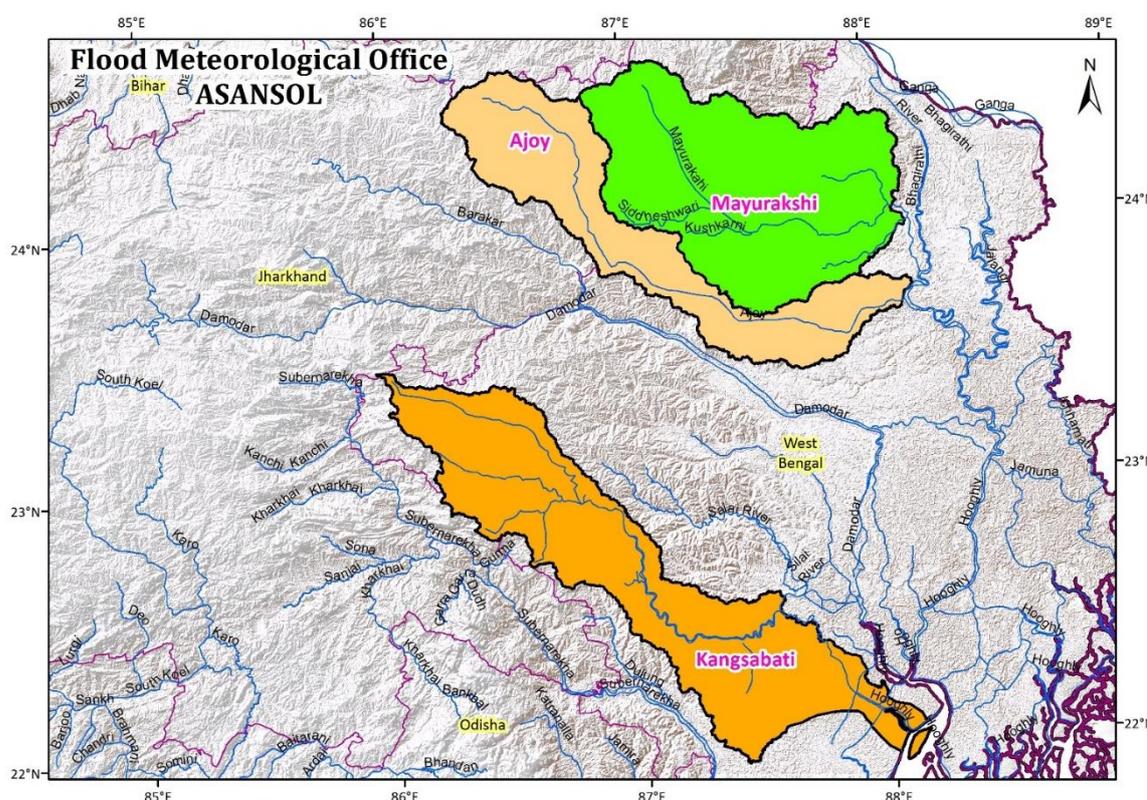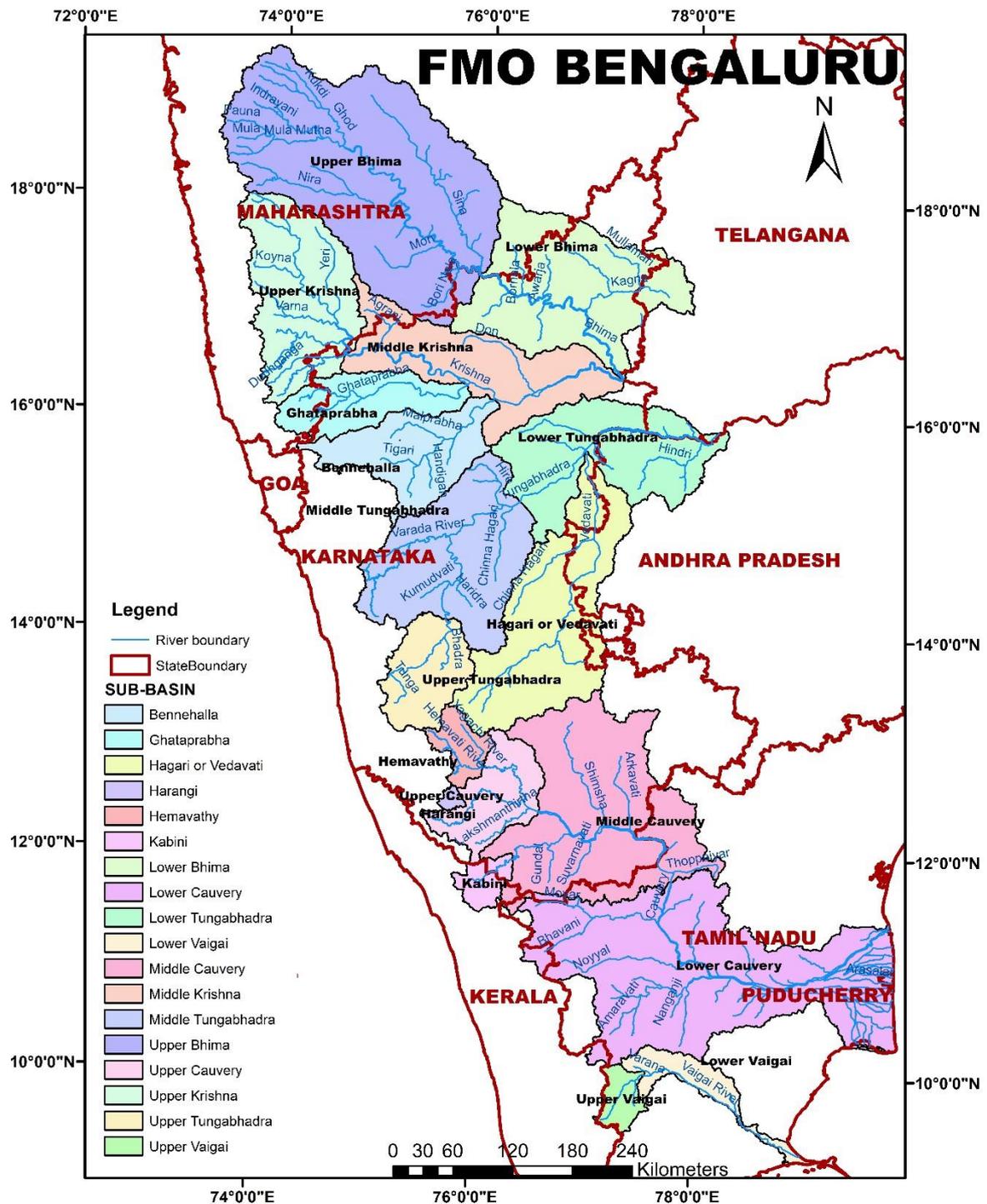

Figure 6: Map of FMO Bengaluru with Sub-basins

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.

S. No.	Basin	Sub-Basin	Area (Sq. Km.)
		FMO Bengaluru	
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).
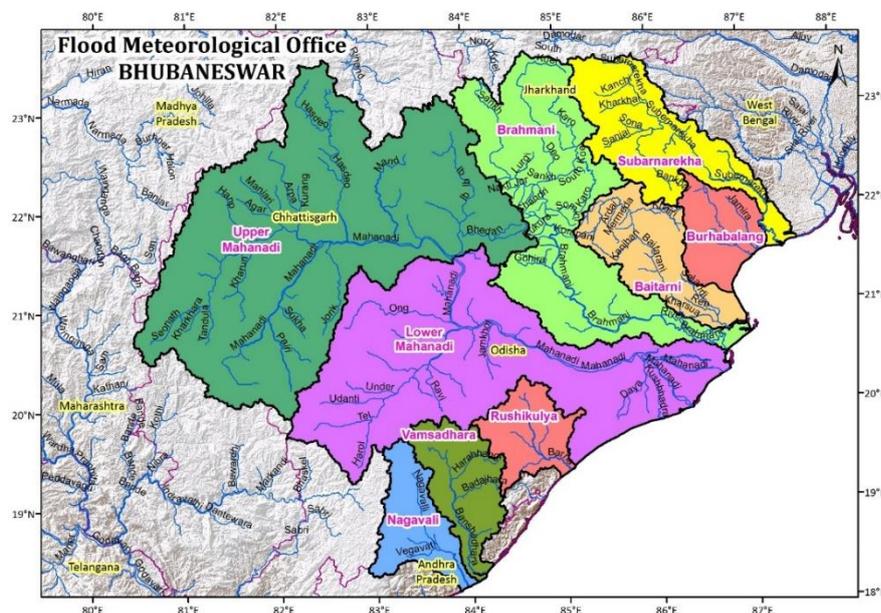

Figure 7: Map of FMO Bhubaneswar with Sub-basins

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.

S. No.	Basin	Sub-Basin	Area (Sq. Km.)
FMO Bhubaneswar
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 was established in the 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).
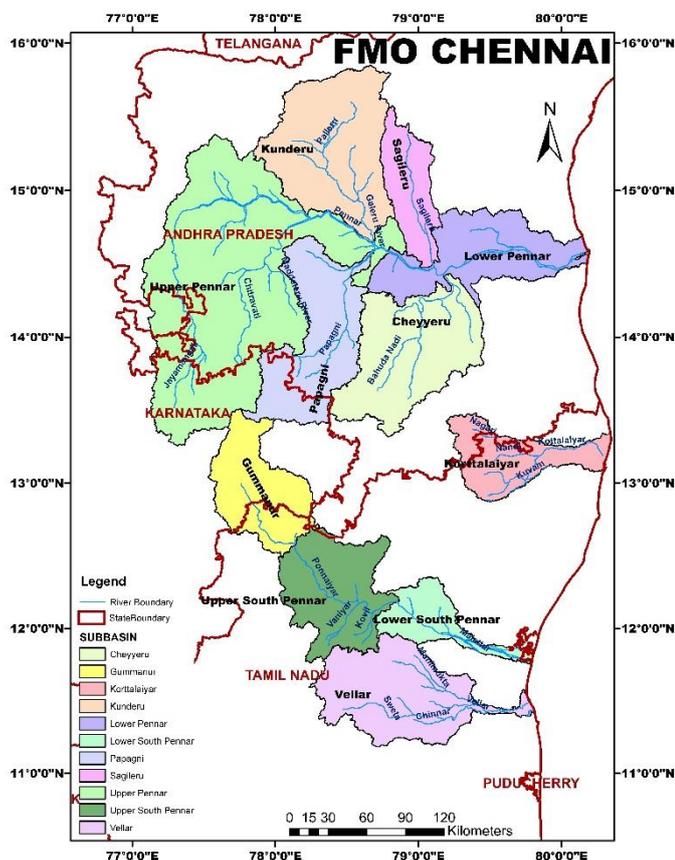

Figure 8: Map of FMO Chennai with Sub-basins

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 Chenna			
Sl. N	**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

| S. No.	Basin	Sub-Basin	Area (Sq. Km.)
FMO Guwahati		
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
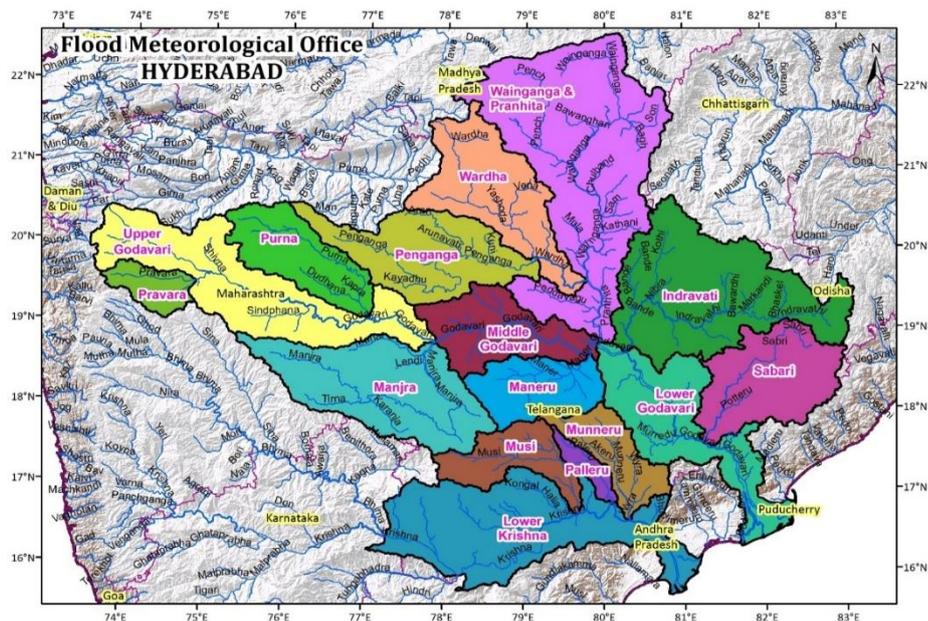
Figure 10: Map of FMO Hyderabad with Sub-basins

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

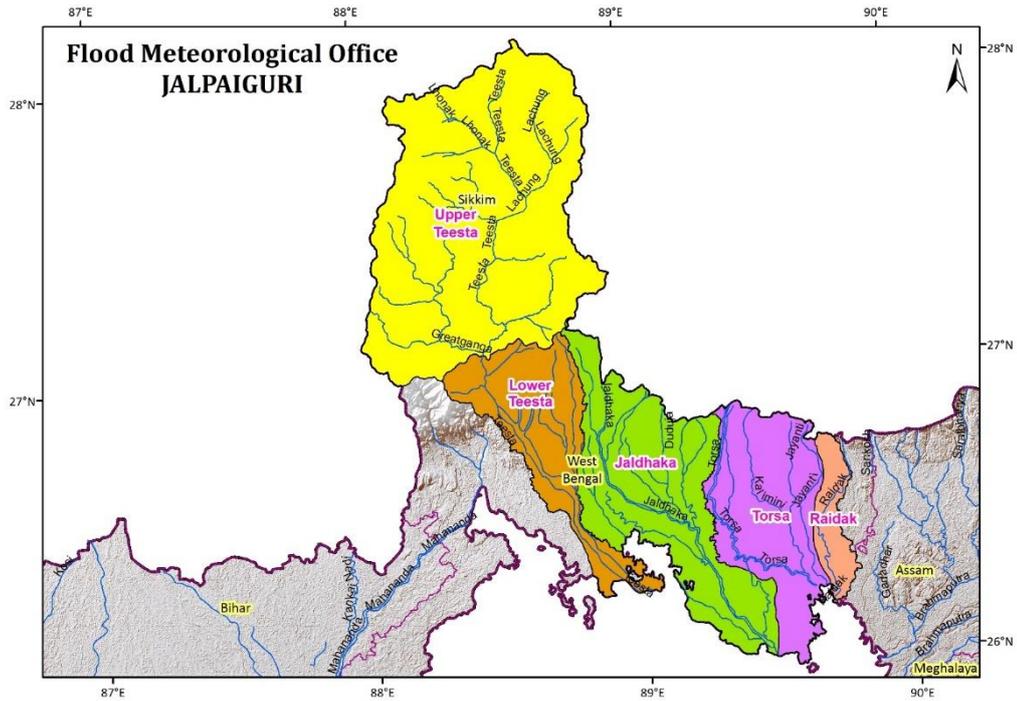| FMO Jalpaiguri			
S. No.	Basin	Sub-Basin	Area (Sq. Km.)
1	Brahmaputra	Upper Teesta	7569.27
2		Lower Teesta	2205.45
3		Jaldhaka	3705.50
4		Torsa	2643.04
5		Raidak	590.26
Total			16713.52

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).
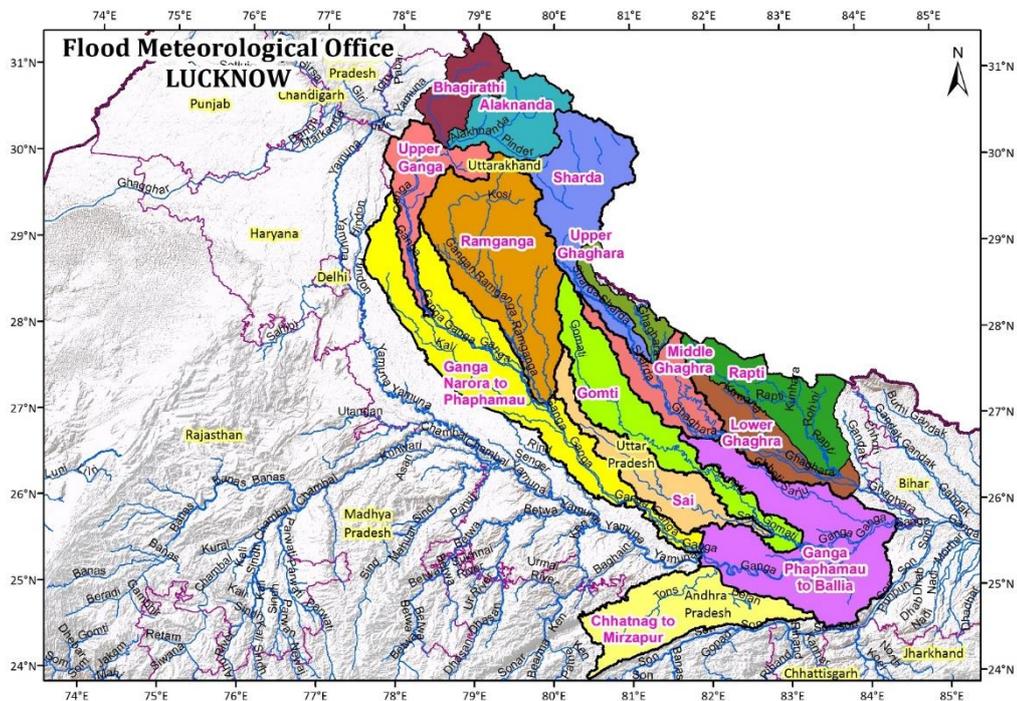

Figure 12: Map of FMO Lucknow with Sub-basins

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.

16

Table 15: Area-wise Basins/Sub-basins under FMO Lucknow

S. No.	Basin	Sub-Basin	Area (Sq. Km.)
	FMO Lucknow		
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).
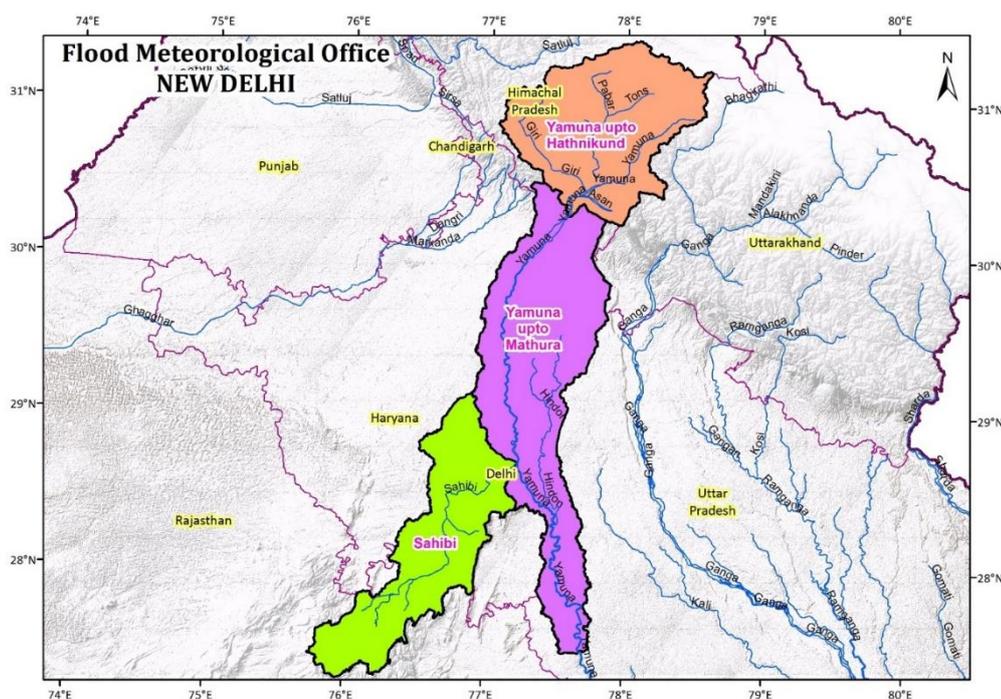

Figure 13: Map of FMO New Delhi with Sub-basins

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

S. No.	Basin	Sub-Basin	Area (Sq. Km.)
	FMO New Delhi		
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).
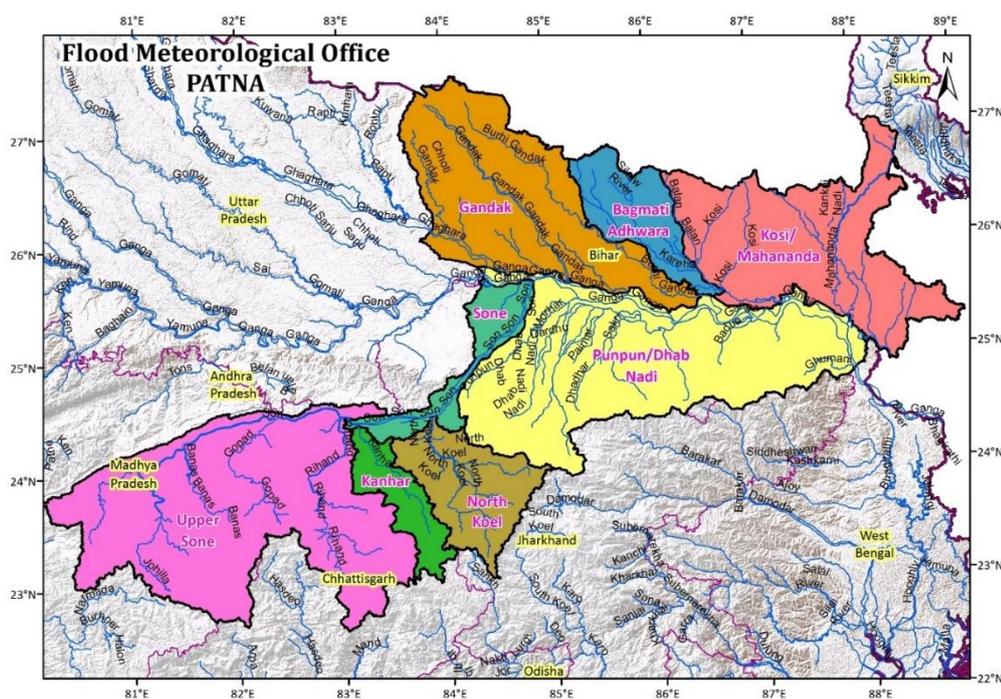

Figure 14: Map of FMO Patna with Sub-basins

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

S. No.	Basin	Sub-Basin	Area (Sq. Km.)
FMO Patna			
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 was established in the 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

Sl. No.	BASIN	SUBBASIN	Area (Sq. Km.)
FMO Srinagar			
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.
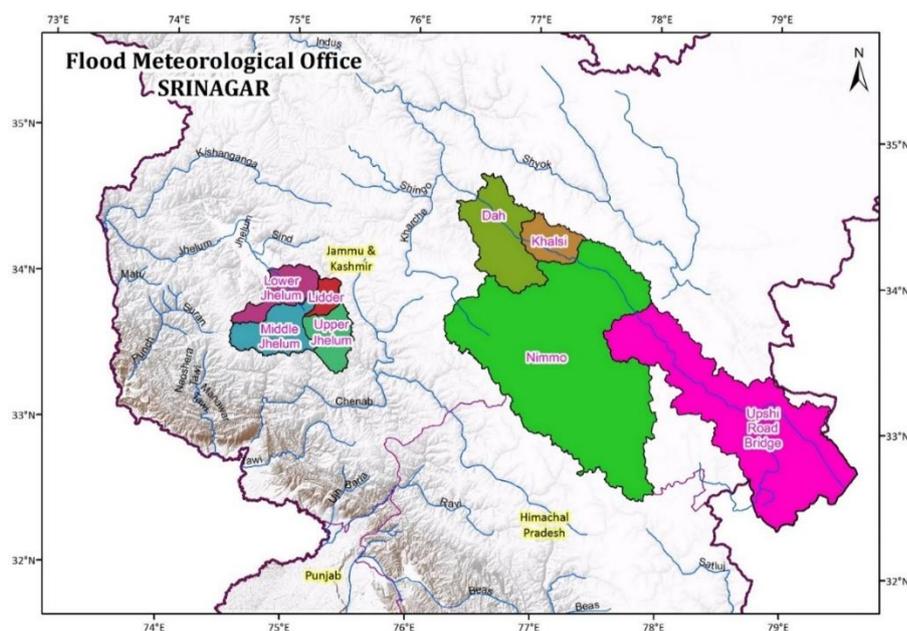
Figure 15: Map of FMO Srinagar with Sub-basins

2.14 FMO Thiruvananthapuram

The Flood Meteorological office, Thiruvananthapuram was established 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

| S. No.	Basin	Sub-Basin	Area (Sq. Km.)
FMO Thiruvananthapuram			
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
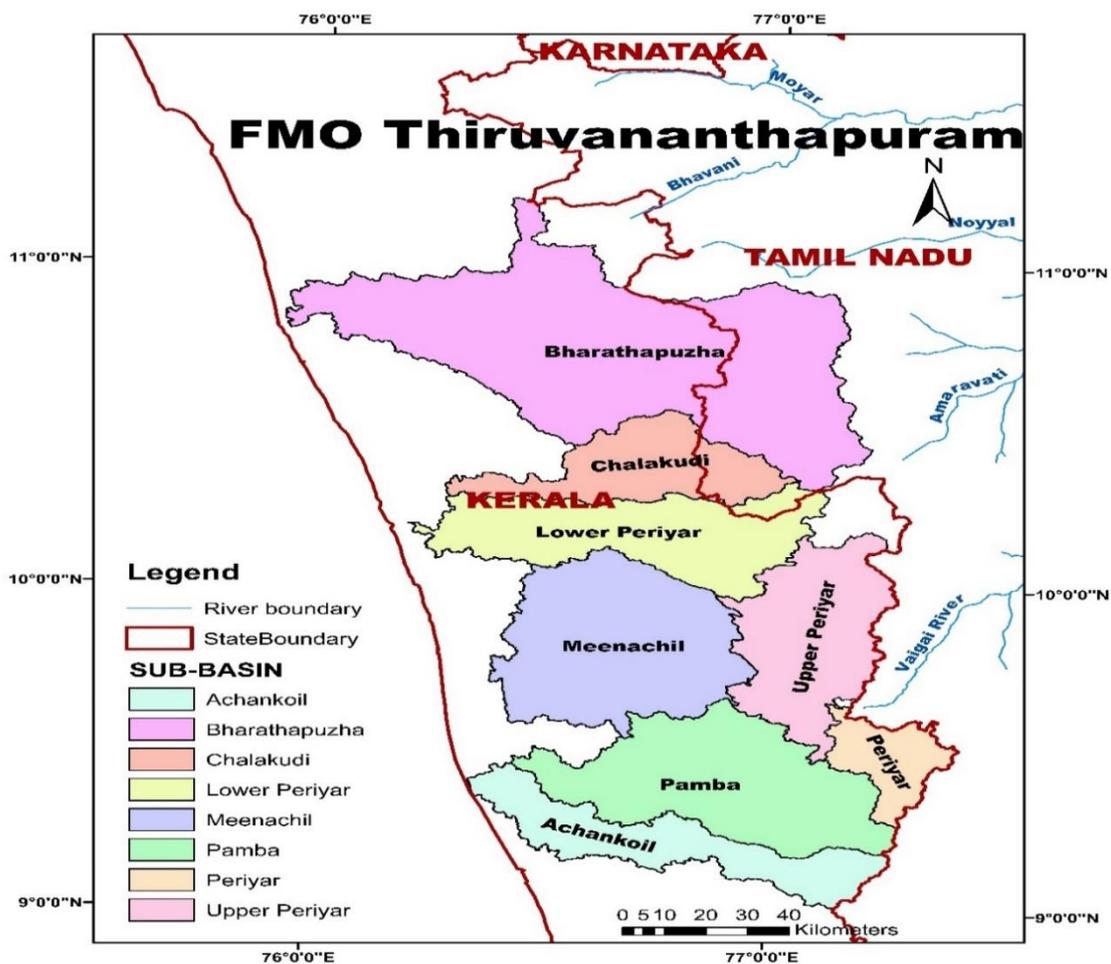
Figure 16: Map of FMO Srinagar with Sub-basins

2.15 DVC Kolkata (PLZ update the map table)

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). The jurisdiction area of the DVC river sub basins updated and also no. of sub-basins increased from 3 to 6.

There are total of 6 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

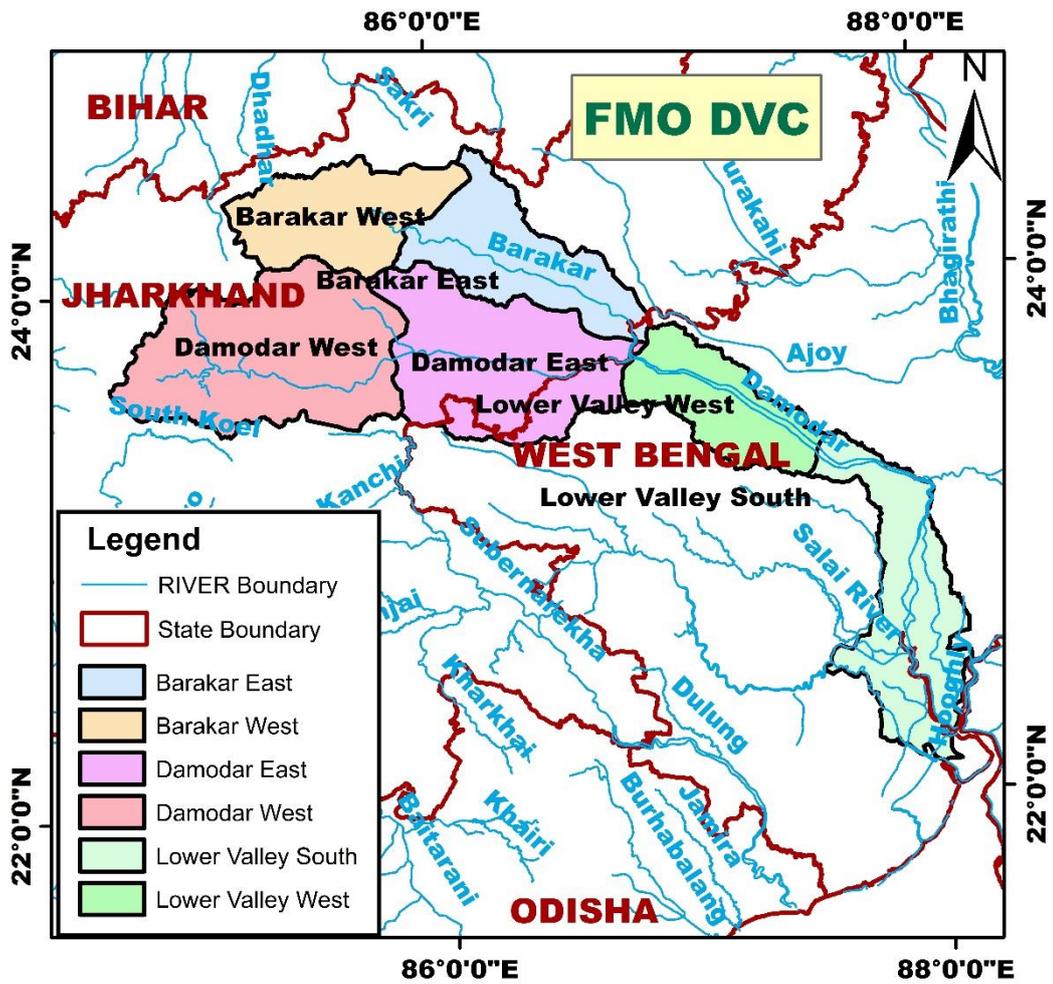| S. No.	Basin	Sub-Basin	Area (Sq. Km.)
DVC Kolkata			
1	Barakar	Barakar West	3200.75
		Barakar East	3461.48
2	Damodar	Damodar West	6361.15
		Damodar East	5363.80
3	Lower Valley	Lower Valley West	2644.42
		Lower Valley South	4313.22
Total			25344.82

Figure 17: Map of DVC with Sub-basins

CHAPTER 3

Data Used and Methodology

3.1 Data Used

River sub-basin-wise Operational QPF is issued 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 (JJAS) 2023 as major riverine flood events were generally occurred during the period. 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 4118 stations are used to compute sub-basin-wise AAP for all 156 river sub-basins.

The total number of QPF issued by 15 FMOs during the season 2023 (1st June to 30th September) is 18666 each for Day-1 to Day-5 forecast. Day-6 and Day-7 forecast started on 10th July 2023 so the total number of QPF issued by 15 FMOs for each Day-6 and Day-7 during the season 2023 (10th July to 30th September) is 12699.

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 the season 2023, the skill scores for operational sub-basin-wise QPFs are computed for each FMO for day-1, day-2, day-3, day-4, day-5, day-6 and day-7. 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, Day-5, Day-6 and Day-7 forecasts 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) of QPF within same category is 70% which is an improvement by 4% as compared to last year (2022) (figure 53). While FMO Bengaluru has the highest Percentage correct QPF of 83% and FMO Chennai has the lowest accuracy of 56%, eight other FMOs viz., Agra, Ahmedabad, Asansol, DVC, Guwahati, New Delhi, Patna and Srinagar 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 its all India PC score was 98% (Table 23). The performance of QPF within ±2, ±3, ±4 category can also be seen in table 23. Very few cases are observed for out by 2 and out by 3 category and no case is observed for out by 4 category for Day-1 forecast.

Table 23: Performance of Day-1 QPF for the JJAS 2023

| FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one Stage (±1)		Correct and ±1	Out by two Stage (±2)		Out by three Stage (±3)		Out by four Stage (±4)		Correct (%)	Usable Forecast Correct & ±1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	700	129	119	948	15	11	0	2	0	0	72%	97%
Ahmedabad	2318	1646	458	161	2265	38	13	1	1	0	0	71%	98%
Asansol	366	255	90	20	365	1	0	0	0	0	0	70%	100%
Bengaluru	2196	1826	237	125	2188	5	3	0	0	0	0	83%	100%
Bhubaneswar	1220	812	301	87	1200	18	2	0	0	0	0	67%	98%
Chennai	1342	751	266	304	1321	10	10	0	1	0	0	56%	98%
DVC	732	539	125	63	727	4	1	0	0	0	0	74%	99%
Guwahati	2440	1736	549	110	2395	24	20	0	1	0	0	71%	98%
Hyderabad	1952	1325	343	209	1877	54	19	2	0	0	0	68%	96%
Jalpaiguri	610	346	177	55	578	22	6	3	1	0	0	57%	95%
Lucknow	1708	1112	361	203	1676	19	13	0	0	0	0	65%	98%
New Delhi	366	264	61	28	353	1	12	0	0	0	0	72%	96%
Patna	976	689	163	109	961	7	8	0	0	0	0	71%	98%
Srinagar	488	345	100	38	483	0	4	0	1	0	0	71%	99%
Thiruvananthapuram	976	650	145	138	933	9	34	0	0	0	0	67%	96%
All India Average	18666	12996	3505	1769	18270	227	156	6	7	0	0	70%	98%
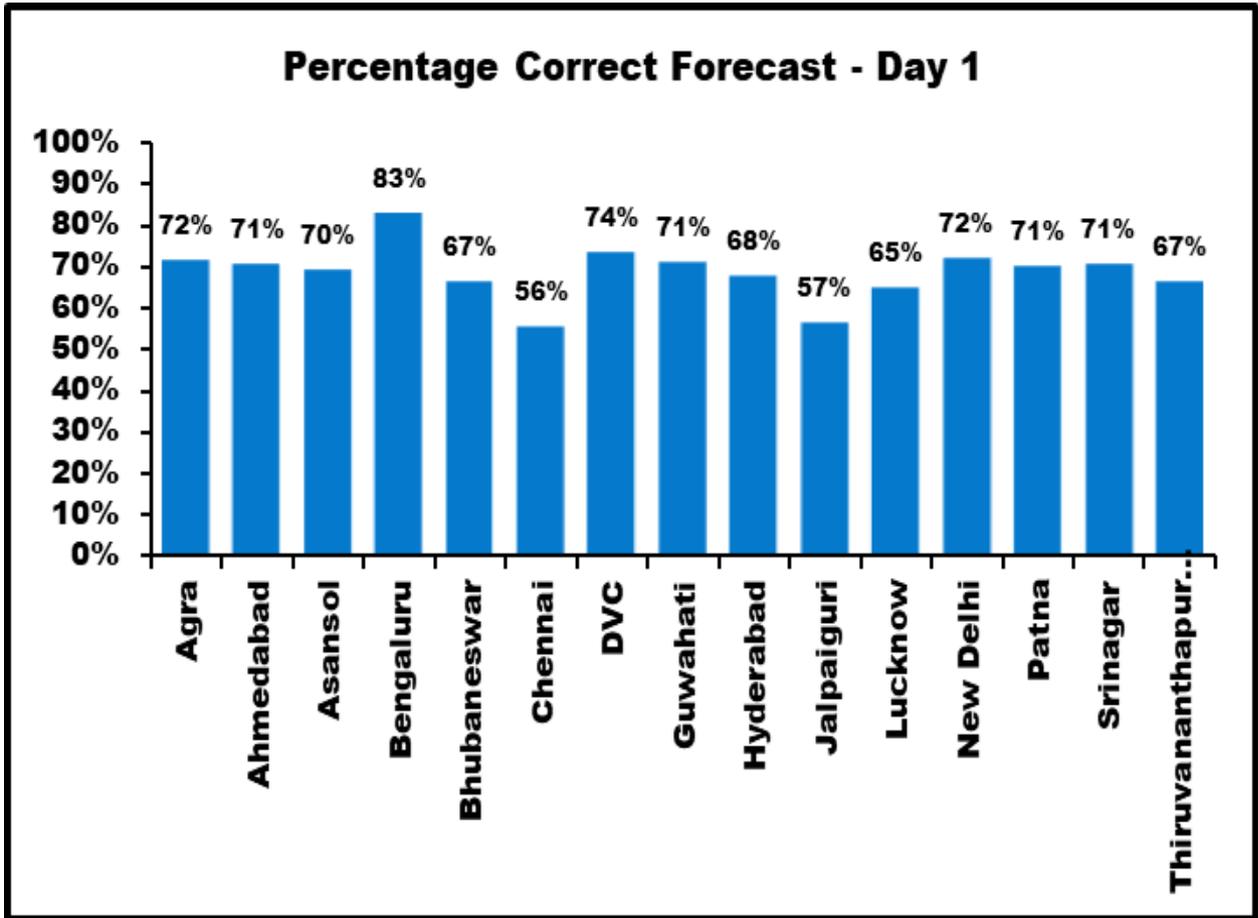
Figure 18: Percentage correct forecast Day-1 by different FMOs for JJAS 2023

Forecast is provided by FMOs based on different numerical models. All India skill scores viz, POD, FAR, MR, CSI, BIAS, PC, TSS and HSS computed from 2X2 contingency table are given in Table 24 (average of all FMO's) and figures 19 – 21 for different FMO's. 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) except 0 mm rainfall category

Table 24: Skill Scores of Day-1 QPF for JJAS 2023

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.49	0.76	0.56	0.38	0.29	0.28
False Alarm Rate (FAR):	0.33	0.21	0.58	0.66	0.42	0.50
Missing Rate (MR):	0.51	0.24	0.44	0.62	0.71	0.72
Correct Non-Occurrence (C-NON):	0.95	0.67	0.86	0.97	1.00	1.00
Critical Success Index (CSI):	0.40	0.63	0.33	0.22	0.20	0.16
Bias for Occurrence (BIAS):	0.72	0.97	1.35	1.11	0.60	0.58
Hit Rate:	0.89	0.74	0.83	0.95	0.99	1.00
Percentage of Correct (PC):	0.89	0.74	0.83	0.95	0.99	1.00
True Skill Score (TSS):	0.43	0.43	0.42	0.35	0.29	0.27
Heidke Skill Score (HSS):	0.47	0.42	0.37	0.32	0.30	0.22

The category-wise percentage of correct forecast (Table 24) is also given in Figure 22.
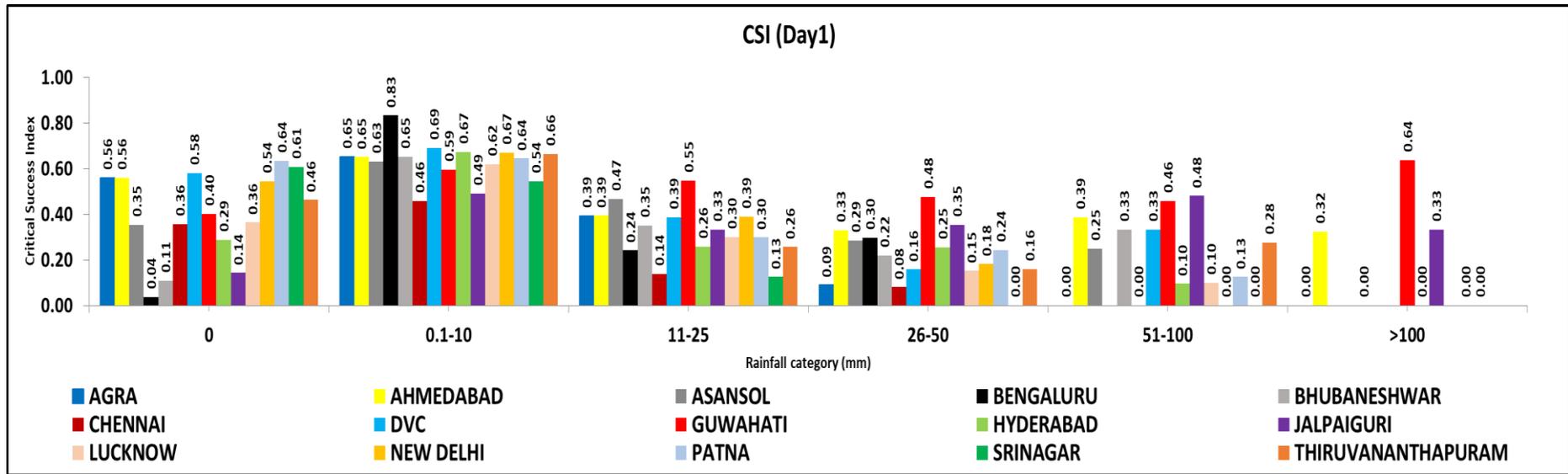
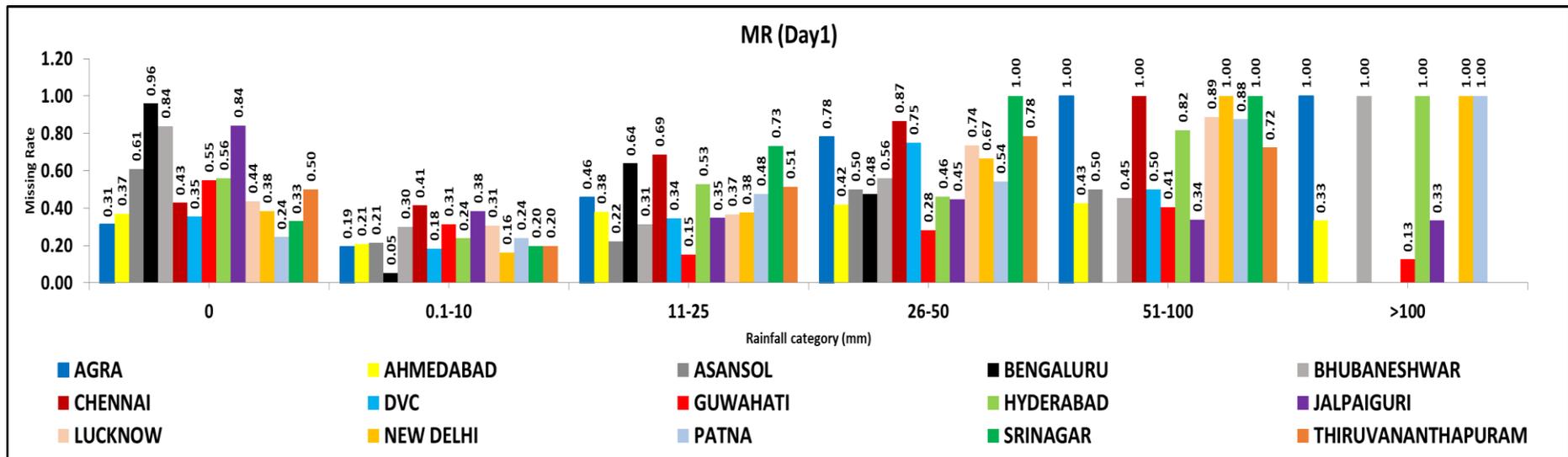**Figure 19: CSI for different categories of forecast for Day-1 for JJAS 2023**

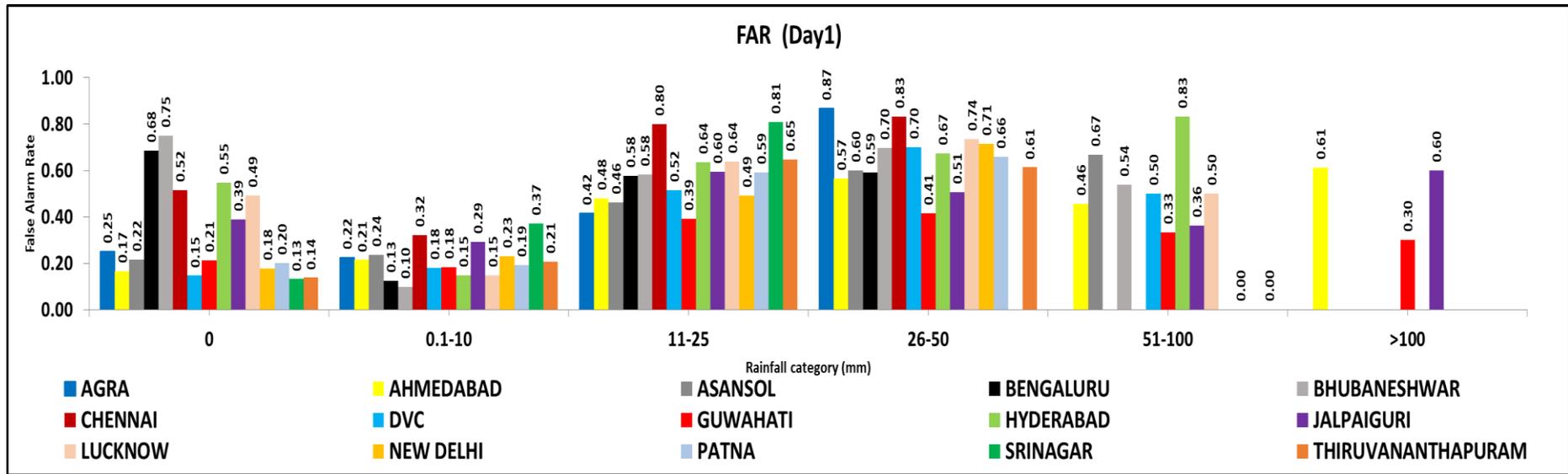**Figure 20: MR for different categories of forecast for Day-1 for JJAS 2023**

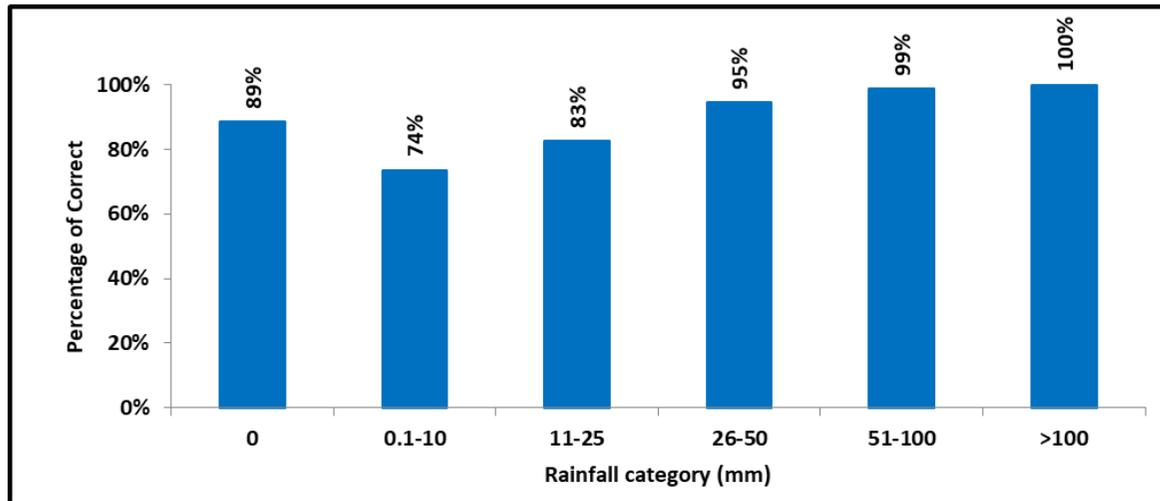**Figure 21: FAR for different categories of forecast for Day-1 for JJAS 2023**

Figure 22: Category-wise Percentage Correct Forecast of Day-1 for JJAS 2023

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 66% which is an improvement by 3% (figure 53) as compared to last year (2022). While FMO Bengaluru has the highest Percentage correct QPF of 83% and FMO Jalpaiguri has the lowest accuracy of 48%, twelve other FMOs viz. Agra, Ahmedabad, Asansol, Bhubaneshwar, DVC, Guwahati, Hyderabad, Lucknow, New Delhi, Patna, Srinagar and Thiruvananthapuram 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 its all India PC score was 97%. The performance of QPF within ±2, ±3, ±4 category can also be seen in Table 25. Very few cases are observed for out by 2 and out by 3 category and no case is observed for out by 4 category for Day-2 forecast.

Table 25: Performance of Day-2 QPF for the JJAS 2023

| FMO/MC | Total No. of QPF issued | Correct Forecast | Out by one Stage (±1) | | Correct and ±1 | Out by two Stage (±2) | | Out by three Stage (±3) | | Out by four Stage (±4) | | Correct (%) | Usable Forecast Correct & ±1 Stage |
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	670	131	147	948	12	12	0	4	0	0	69%	97%
Ahmedabad	2318	1468	370	397	2235	27	48	2	6	0	0	63%	96%
Asansol	366	234	91	37	362	3	1	0	0	0	0	64%	99%
Bengaluru	2196	1817	198	172	2187	2	7	0	0	0	0	83%	100%
Bhubaneswar	1220	775	296	134	1205	8	7	0	0	0	0	64%	99%
Chennai	1342	782	208	326	1316	6	17	0	3	0	0	58%	98%
DVC	732	492	135	92	719	10	2	0	1	0	0	67%	98%
Guwahati	2440	1494	597	289	2380	20	37	0	3	0	0	61%	98%
Hyderabad	1952	1332	281	253	1866	45	38	0	3	0	0	68%	96%
Jalpaiguri	610	294	203	78	575	17	15	3	0	0	0	48%	94%
Lucknow	1708	1090	385	201	1676	12	18	0	2	0	0	64%	98%
New Delhi	366	223	93	38	354	1	10	0	1	0	0	61%	97%
Patna	976	648	162	145	955	8	13	0	0	0	0	66%	98%
Srinagar	488	339	81	59	479	3	5	0	1	0	0	69%	98%
Thiruvananthapuram	976	606	118	182	906	12	54	0	4	0	0	62%	93%
Over All fct.	18666	12264	3349	2550	18163	186	284	5	28	0	0	66%	97%
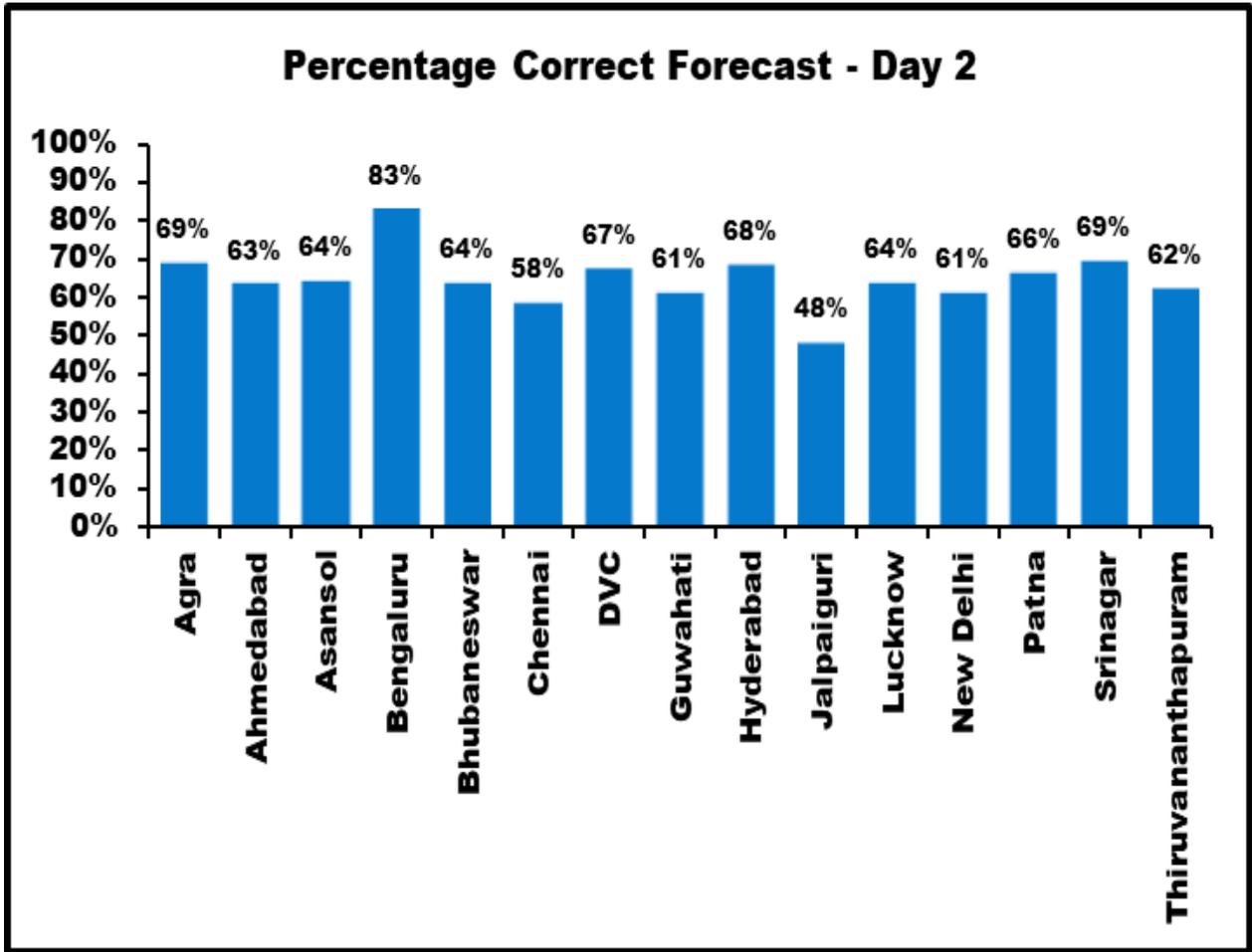
Figure 23. Percentage correct forecast Day-2 by different FMOs for JJAS 2023

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 for JJAS 2023

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.46	0.74	0.44	0.23	0.15	0.09
False Alarm Rate (FAR):	0.43	0.25	0.65	0.71	0.52	0.80
Missing Rate (MR):	0.54	0.26	0.56	0.77	0.85	0.91
Correct Non-Occurrence (C-NON):	0.93	0.60	0.85	0.97	1.00	1.00
Critical Success Index (CSI):	0.35	0.59	0.25	0.14	0.12	0.05
Bias for Occurrence (BIAS):	0.79	0.99	1.24	0.83	0.34	0.36
Hit Rate:	0.87	0.70	0.80	0.94	0.99	1.00
Percentage of Correct (PC):	0.87	0.70	0.80	0.94	0.99	1.00
True Skill Score (TSS):	0.38	0.33	0.29	0.20	0.15	0.09
Heidke Skill Score (HSS):	0.41	0.33	0.26	0.21	0.17	0.08

The category wise percentage of correct forecast is given in Figure 27.
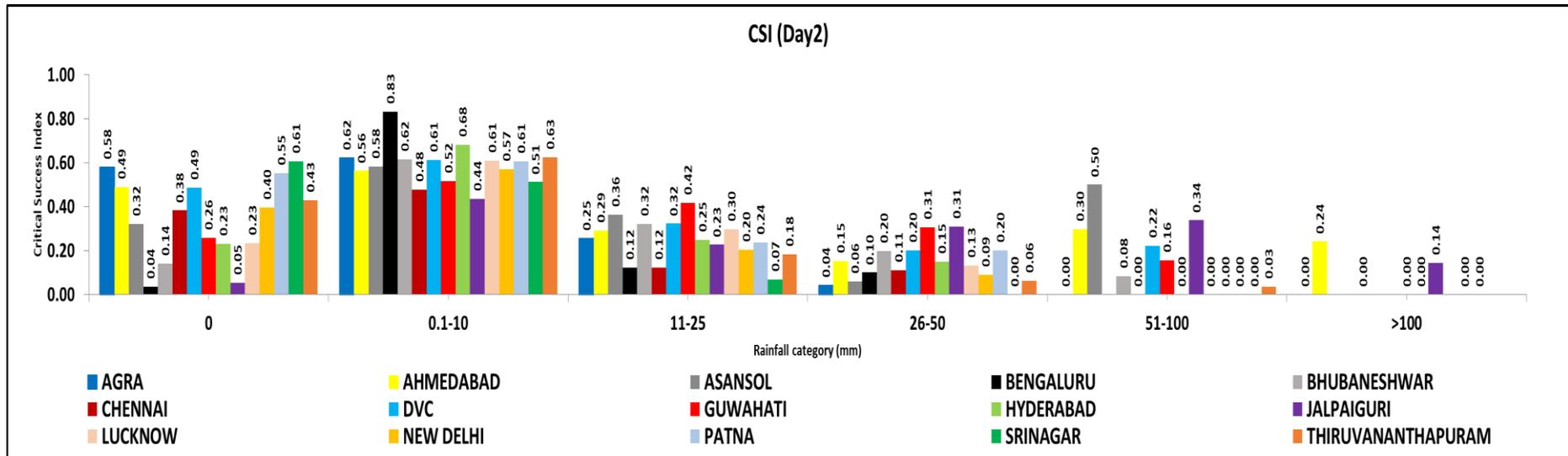
Figure 24: CSI for different categories of forecast for Day-2 for JJAS 2023
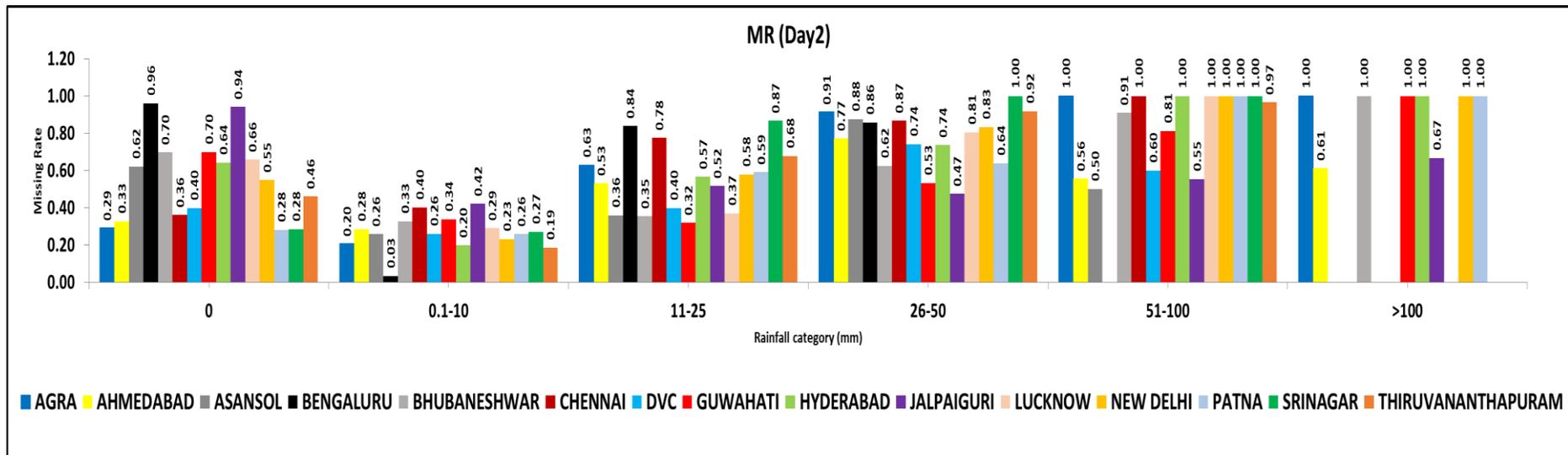
Figure 25: MR for different categories of forecast for Day-2 for JJAS 2023
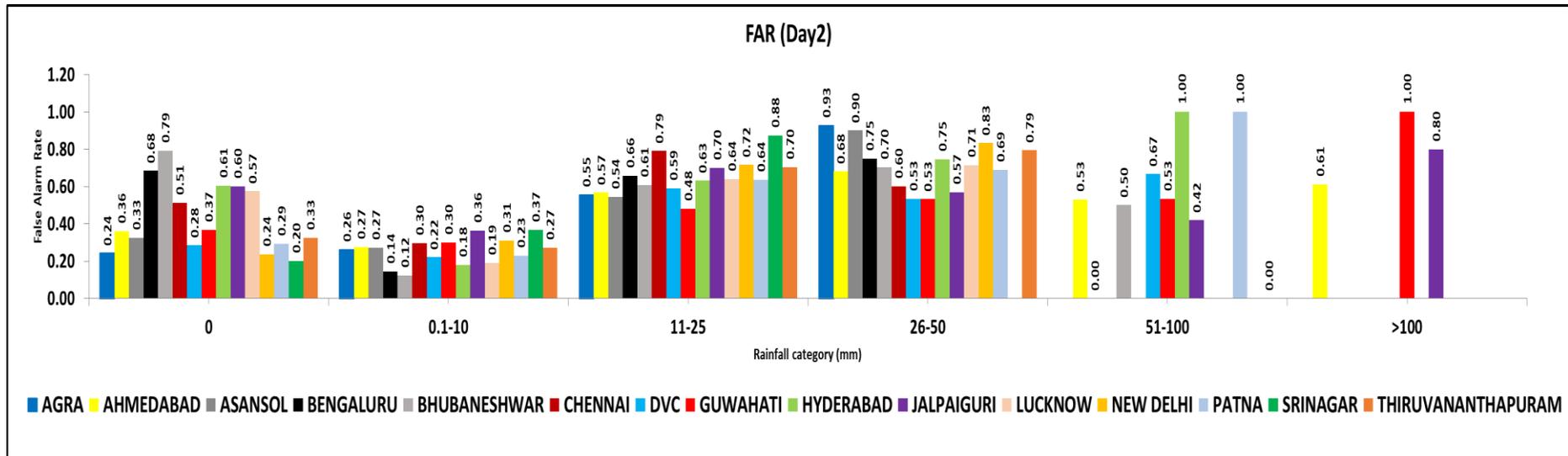
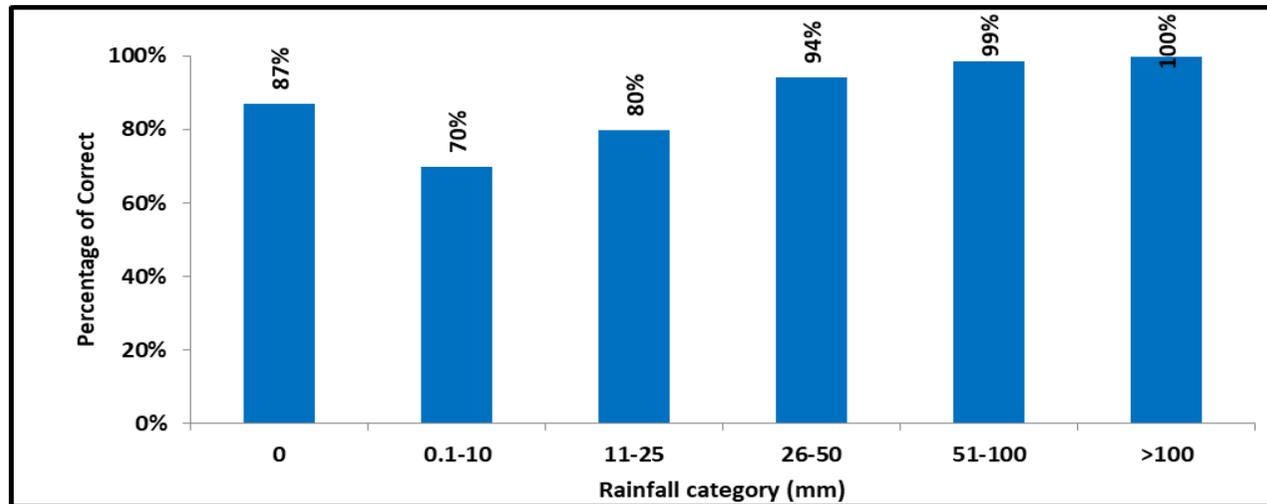**Figure 26: FAR for different categories of forecast for Day-2 for JJAS 2023**

Figure 27: Category-wise Percentage Correct Forecast of Day-2 for JJAS 2023

33

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 64% which is an improvement by 3% (figure 53) as compared to last year (2022). While FMO Bengaluru has the highest Percentage correct QPF of 84% and FMO Jalpaiguri has the lowest accuracy of 46%, eight other FMOs viz. Agra, Bhubaneshwar, DVC, Hyderabad, Lucknow, Patna, Srinagar and Thiruvananthapuram 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 its overall India PC score was 97%. The performance of QPF within ±2, ±3, ±4 category can also be seen in table 27. Very few cases are observed for out by 2, out by 3 and out by 4 category for Day-3 forecast.

Table 27: Performance of Day-3 QPF for the JJAS 2023

| FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one Stage (±1)		Correct and ±1	Out by two Stage (±2)		Out by three Stage (±3)		Out by four Stage (±4)		Correct (%)	Usable Forecast Correct & ±1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	635	155	155	945	9	18	0	4	0	0	65%	97%
Ahmedabad	2318	1376	337	489	2202	20	77	4	12	1	2	59%	95%
Asansol	366	216	89	48	353	10	3	0	0	0	0	59%	96%
Bengaluru	2196	1841	189	156	2186	1	9	0	0	0	0	84%	100%
Bhubaneswar	1220	808	265	123	1196	14	10	0	0	0	0	66%	98%
Chennai	1342	783	199	331	1313	4	23	0	2	0	0	58%	98%
DVC	732	472	121	118	711	13	5	2	1	0	0	64%	97%
Guwahati	2440	1426	655	293	2374	25	35	0	6	0	0	58%	97%
Hyderabad	1952	1303	295	274	1872	32	47	0	1	0	0	67%	96%
Jalpaiguri	610	279	199	88	566	21	19	2	2	0	0	46%	93%
Lucknow	1708	1079	386	199	1664	18	23	0	3	0	0	63%	97%
New Delhi	366	213	86	50	349	5	10	0	1	0	1	58%	95%
Patna	976	635	165	145	945	10	18	0	3	0	0	65%	97%
Srinagar	488	346	62	72	480	2	5	0	1	0	0	71%	98%
Thiruvananthapuram	976	598	89	223	910	10	53	0	3	0	0	61%	93%
Over All fct.	**18666**	**12010**	**3292**	**2764**	**18066**	**194**	**355**	**8**	**39**	**1**	**3**	**64%**	**97%**
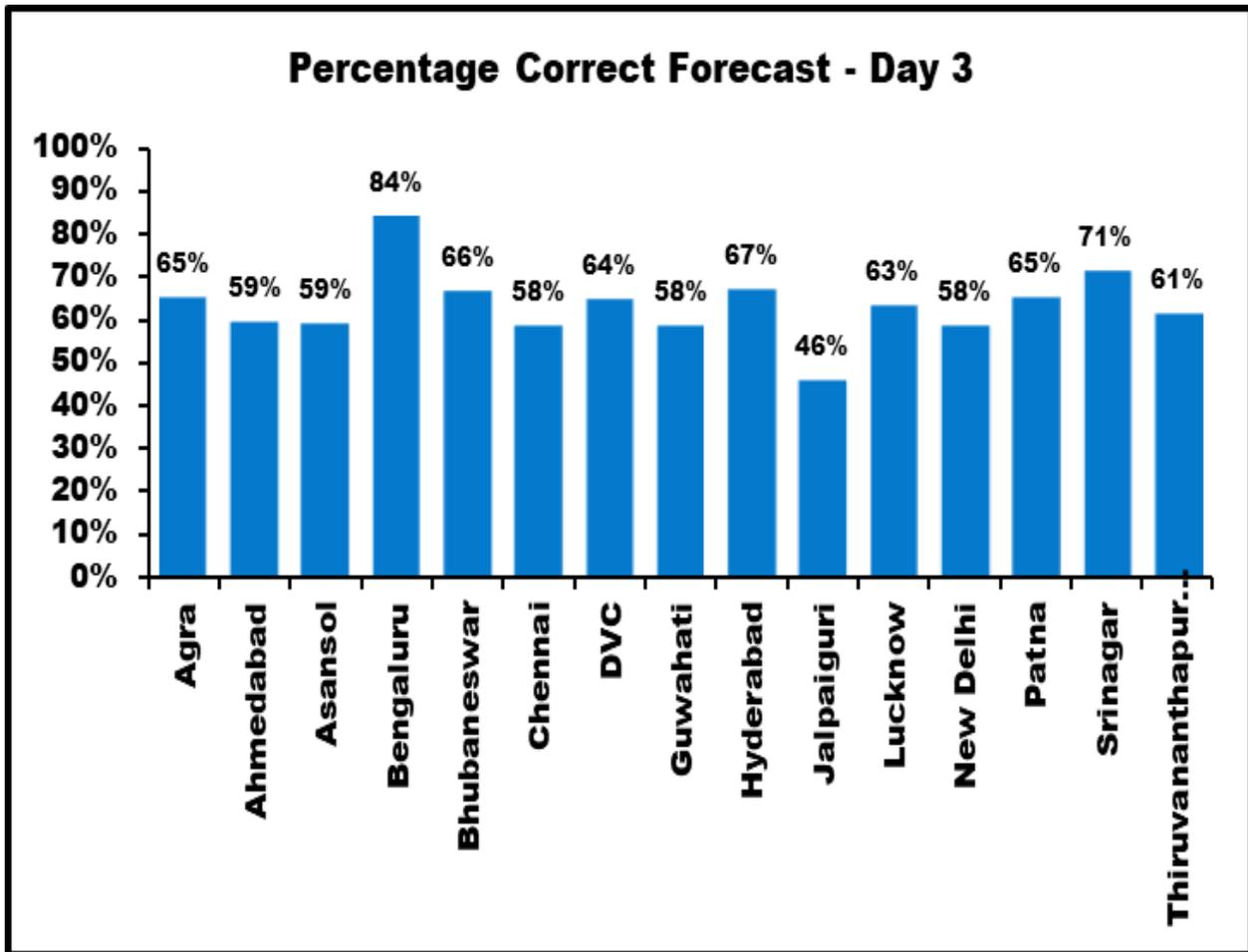
Figure 28. Percentage correct forecast Day-3 by different FMOs for JJAS 2023

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 for the JJAS 2023

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.41	0.73	0.41	0.14	0.06	0.08
False Alarm Rate (FAR):	0.44	0.27	0.66	0.82	0.59	0.50
Missing Rate (MR):	0.59	0.27	0.59	0.86	0.94	0.92
Correct Non-Occurrence (C-NON):	0.92	0.57	0.85	0.97	1.00	1.00
Critical Success Index (CSI):	0.31	0.58	0.23	0.08	0.05	0.08
Bias for Occurrence (BIAS):	0.74	1.00	1.17	0.69	0.22	0.13
Hit Rate:	0.86	0.68	0.79	0.94	0.98	1.00
Percentage of Correct (PC):	0.86	0.68	0.79	0.94	0.98	1.00
True Skill Score (TSS):	0.33	0.30	0.26	0.11	0.06	0.08
Heidke Skill Score (HSS):	0.35	0.30	0.24	0.11	0.08	0.10

The category-wise percentage of correct forecast is given in Figure 32.
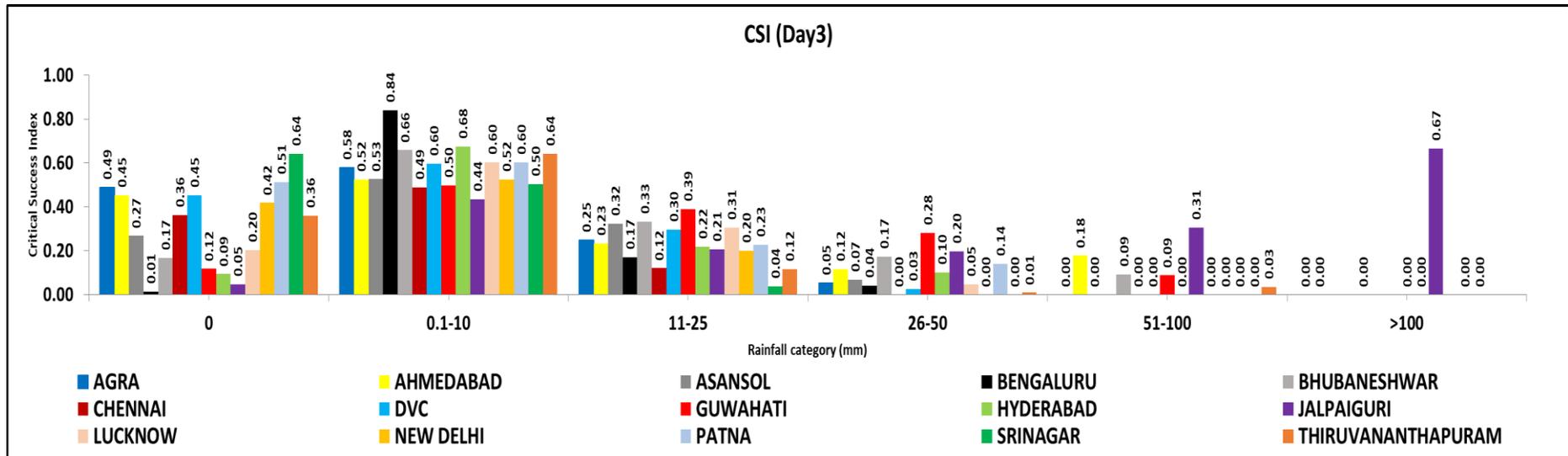
Figure 29: CSI for different categories of forecast for Day-3 for JJAS 2023
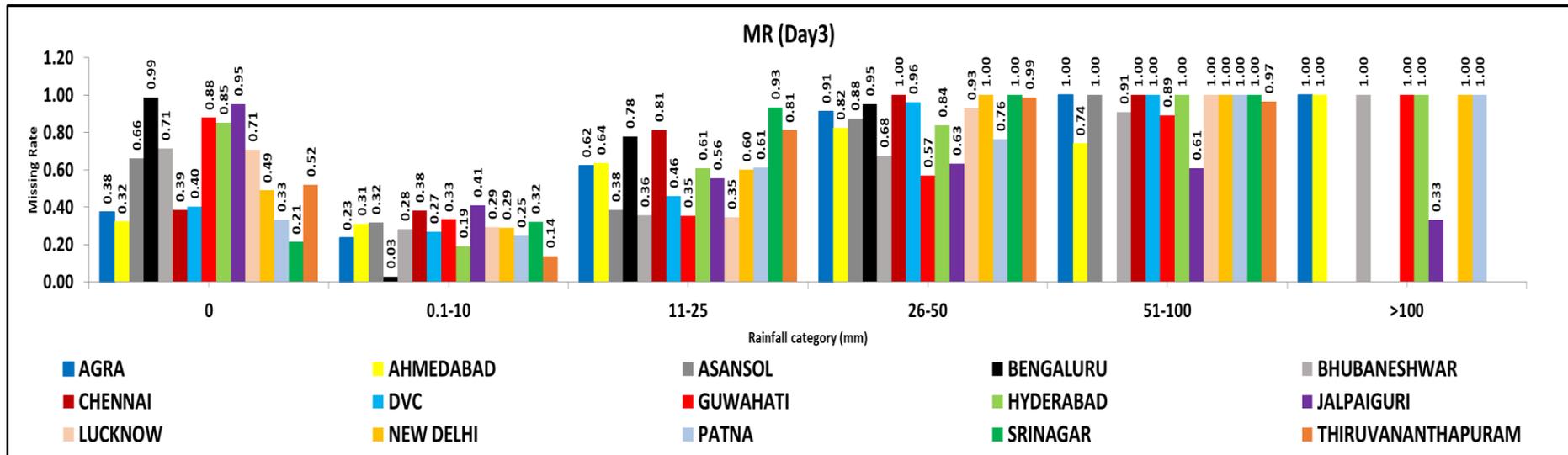
Figure 30: MR for different categories of forecast for Day-3 for JJAS 2023
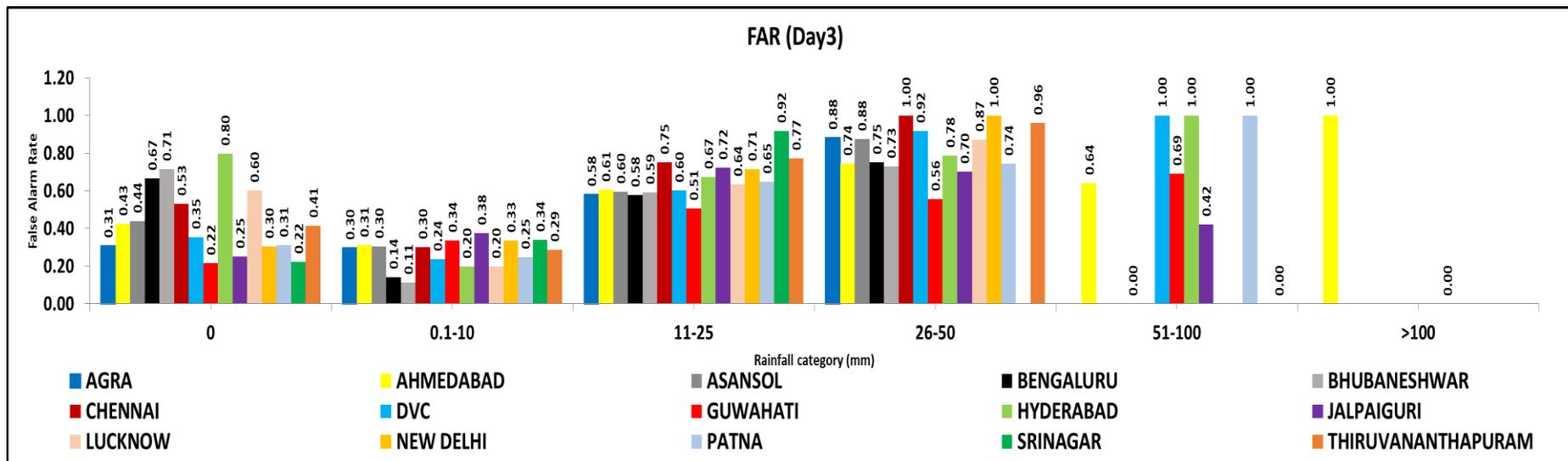
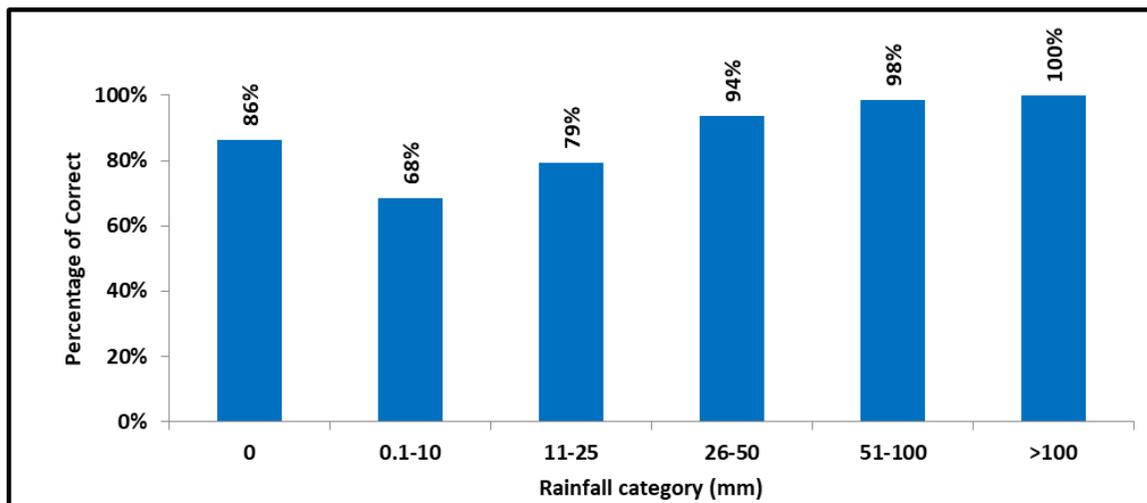**Figure 31: FAR for different categories of forecast for Day-3 for JJAS 2023**

Figure 32: Category-wise Percentage Correct Forecast of Day-3 for JJAS 2023

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 63% which is an improvement by 2% (figure 53) as compared to last year (2022). While FMO Bengaluru has the highest Percentage correct QPF of 83% and FMO Jalpaiguri has the lowest accuracy of 47%, eight other FMOs viz., Agra, Bhubaneshwar, DVC, Hyderabad, Lucknow, Patna, Srinagar and Thiruvananthapuram 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 its all India PC score was 96%. The performance of QPF within ±2, ±3, ±4 category can also be seen in Table 29. Very few cases are observed for out by 2, out by 3 and out by 4 category for Day-4 forecast.

Table 29: Performance of Day-4 QPF for the JJAS 2023

| FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one Stage (±1)		Correct and ±1	Out by two Stage (±2)		Out by three Stage (±3)		Out by four Stage (±4)		Correct (%)	Usable Forecast Correct & ±1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	616	171	160	947	7	17	0	4	0	1	63%	97%
Ahmedabad	2318	1358	332	488	2178	21	98	1	17	0	3	59%	94%
Asansol	366	214	82	62	358	2	6	0	0	0	0	58%	98%
Bengaluru	2196	1824	192	163	2179	1	16	0	0	0	0	83%	99%
Bhubaneswar	1220	790	284	118	1192	19	9	0	0	0	0	65%	98%
Chennai	1342	705	234	375	1314	5	17	0	6	0	0	53%	98%
DVC	732	472	108	130	710	3	18	0	1	0	0	64%	97%
Guwahati	2440	1347	696	309	2352	40	43	0	5	0	0	55%	96%
Hyderabad	1952	1297	312	258	1867	22	60	2	1	0	0	66%	96%
Jalpaiguri	610	284	179	97	560	21	26	3	0	0	0	47%	92%
Lucknow	1708	1032	423	195	1650	24	29	0	5	0	0	60%	97%
New Delhi	366	214	90	42	346	4	14	0	1	0	1	58%	95%
Patna	976	603	170	157	930	15	27	0	4	0	0	62%	95%
Srinagar	488	333	74	75	482	0	5	0	1	0	0	68%	99%
Thiruvananthapuram	976	592	97	186	875	19	74	0	8	0	0	61%	90%
Over All fct.	**18666**	**11681**	**3444**	**2815**	**17940**	**203**	**459**	**6**	**53**	**0**	**5**	**63%**	**96%**
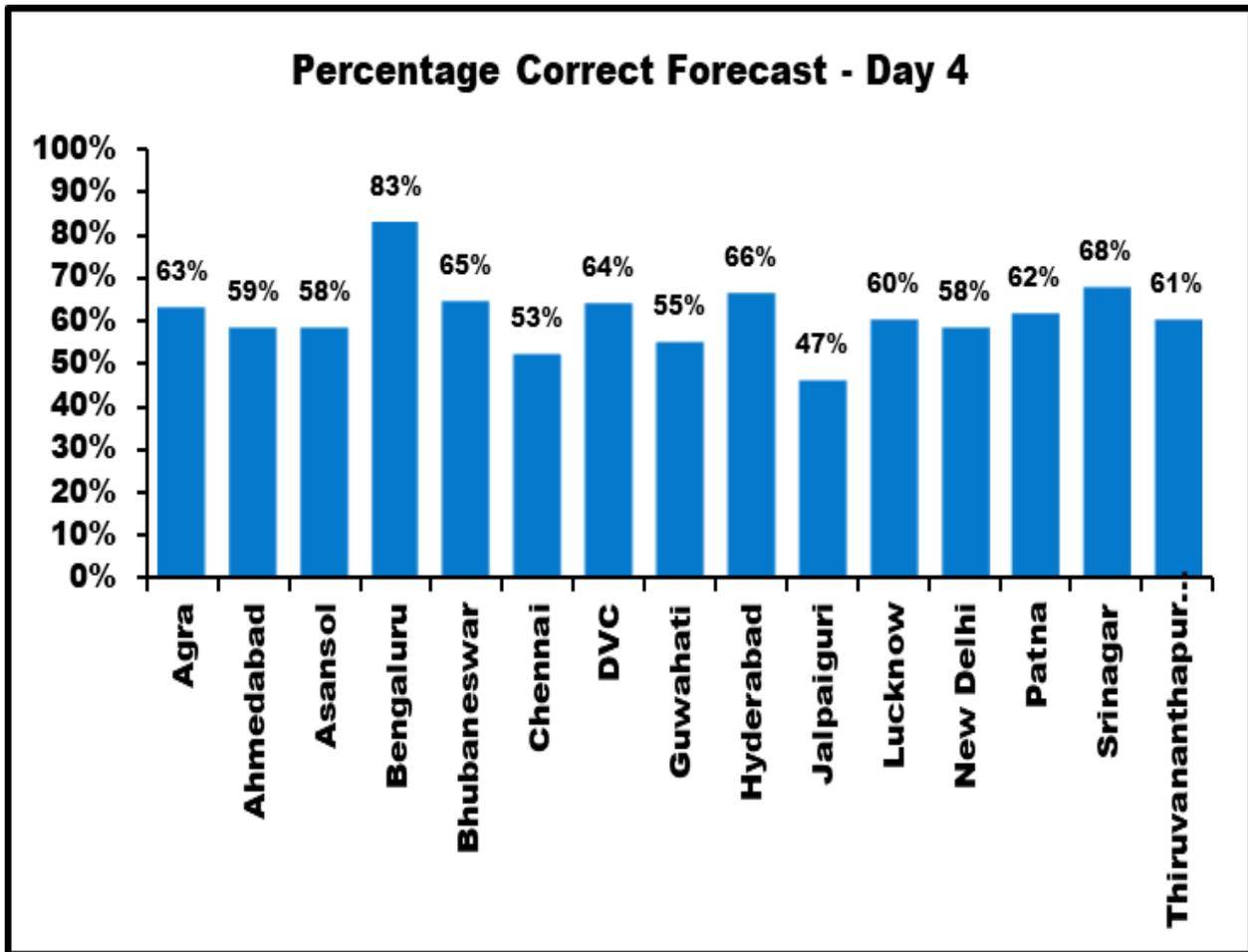
Figure 33. Percentage correct forecast Day-4 by different FMOs for JJAS 2023

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 for JJAS 2023

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.38	0.73	0.36	0.13	0.03	0.00
False Alarm Rate (FAR):	0.50	0.29	0.69	0.79	0.77	1.00
Missing Rate (MR):	0.62	0.27	0.64	0.87	0.97	1.00
Correct Non-Occurrence (C-NON):	0.92	0.52	0.85	0.97	1.00	1.00
Critical Success Index (CSI):	0.29	0.56	0.20	0.08	0.03	0.00
Bias for Occurrence (BIAS):	0.71	1.03	1.12	0.59	0.12	0.03
Hit Rate:	0.86	0.67	0.78	0.94	0.98	1.00
Percentage of Correct (PC):	0.86	0.67	0.78	0.94	0.98	1.00
True Skill Score (TSS):	0.31	0.25	0.21	0.10	0.03	0.00
Heidke Skill Score (HSS):	0.32	0.25	0.19	0.10	0.04	0.00

The category-wise percentage correct forecast is given in Figure 37.
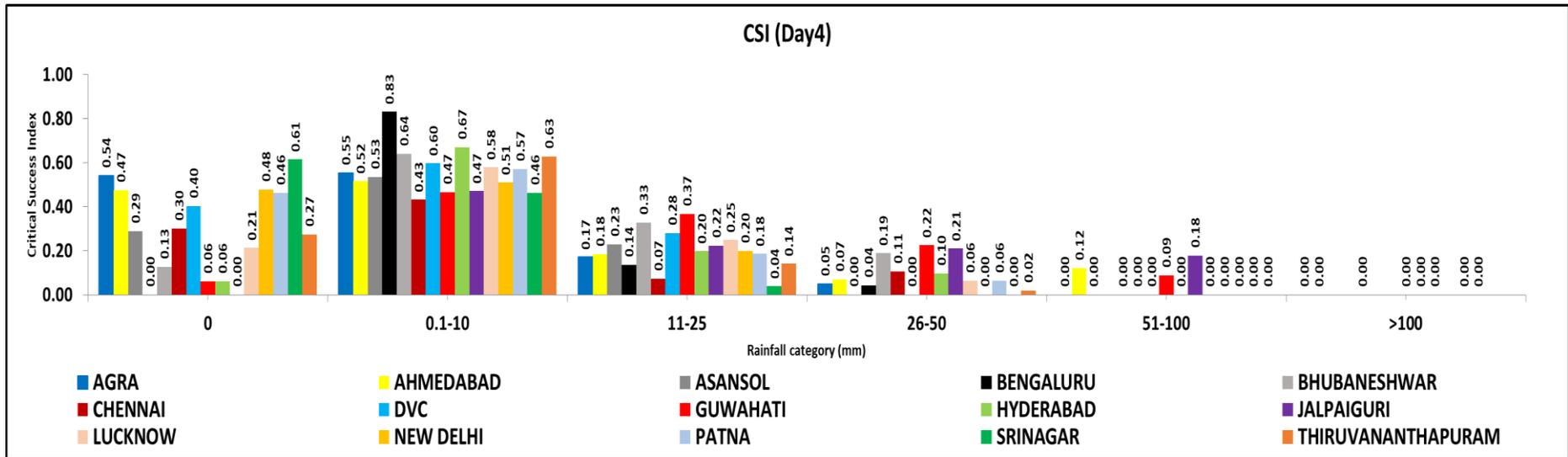
Figure 34: CSI for different categories of forecast for Day-4 for JJAS 2023
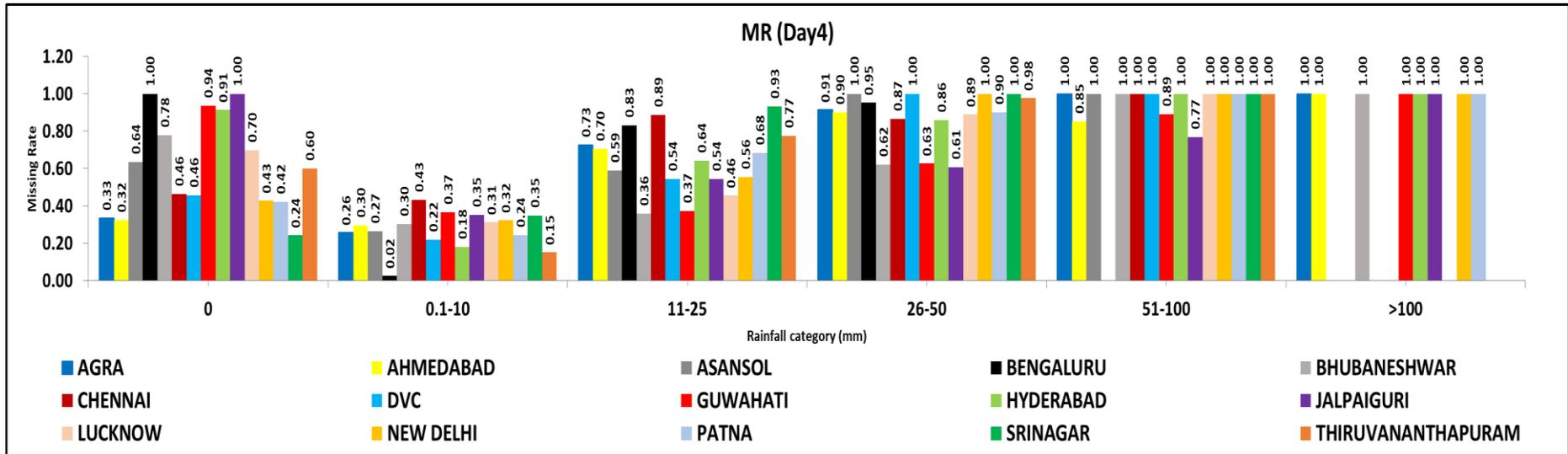
Figure 35: MR for different categories of forecast for Day-4 for JJAS 2023
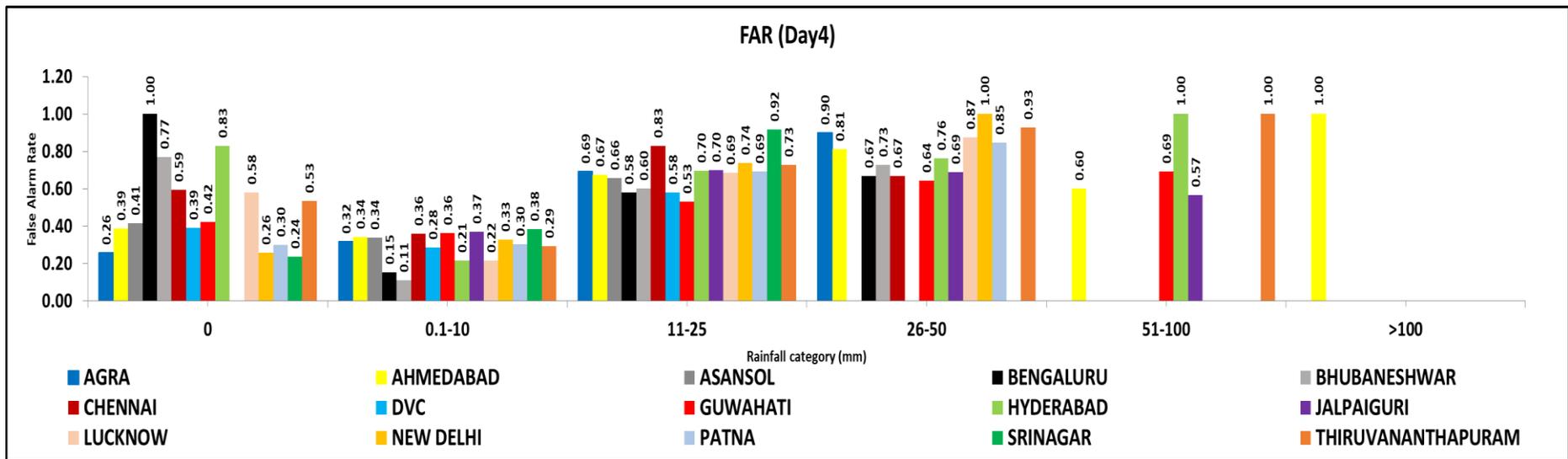
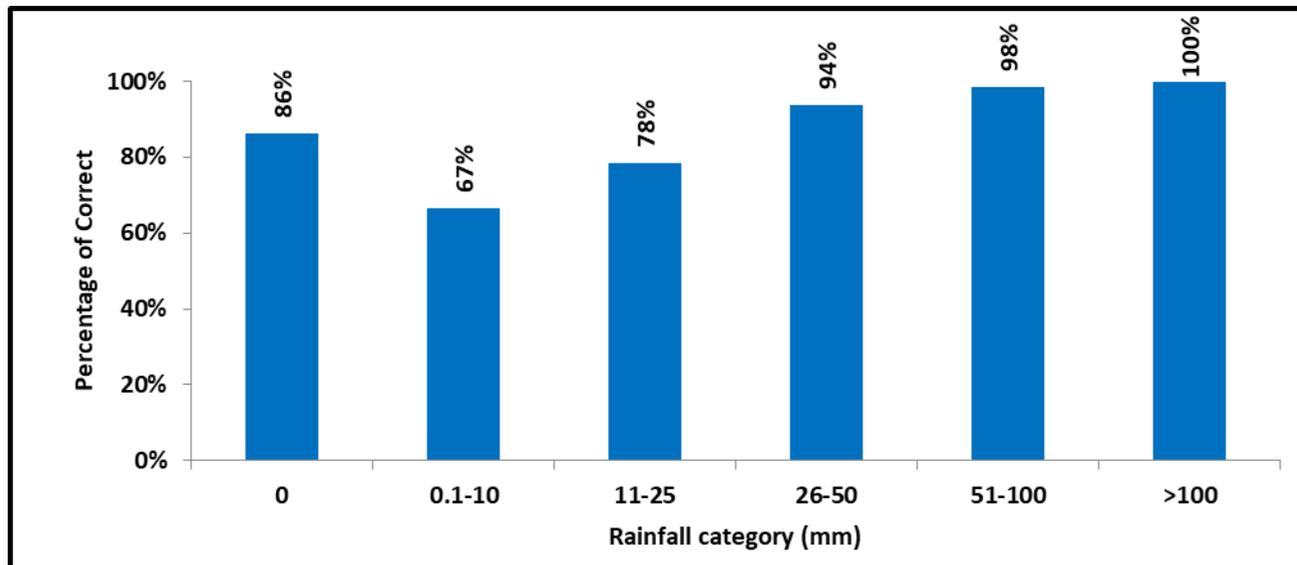**Figure 36: FAR for different categories of forecast for Day-4 for JJAS 2023**

Figure 37: Category-wise Percentage Correct Forecast of Day-4 for JJAS 2023

41

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 62% which is an improvement by 3% (figure 53) as compared to last year (2022). While FMO Bengaluru has the highest Percentage correct QPF of 82% and FMO Jalpaiguri has the lowest accuracy of 48%, eight other FMOs viz. Agra, Ahmedabad, Bhubaneshwar, DVC, Hyderabad, Patna, Srinagar and Thiruvananthapuram 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 its all India PC score was 96%. The performance of QPF within ±2, ±3, ±4 category can also be seen in table 31. Very few cases are observed for out by 2, out by 3 and out by 4 category for Day-5 forecast.

Table 31: Performance of Day-5 QPF for the JJAS 2023

| FMO/MC | Total No. of QPF issued | Correct Forecast | Out by one Stage (±1) | | Correct and ±1 | Out by two Stage (±2) | | Out by three Stage (±3) | | Out by four Stage (±4) | | Correct (%) | Usable Forecast Correct & ±1 Stage |
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	976	588	174	168	930	19	23	1	2	0	1	60%	95%
Ahmedabad	2318	1396	291	494	2181	14	91	1	26	0	5	60%	94%
Asansol	366	213	79	66	358	0	8	0	0	0	0	58%	98%
Bengaluru	2196	1800	201	176	2177	1	18	0	0	0	0	82%	99%
Bhubaneswar	1220	782	281	113	1176	33	11	0	0	0	0	64%	96%
Chennai	1342	735	233	345	1313	8	18	0	3	0	0	55%	98%
DVC	732	468	102	139	709	2	18	0	3	0	0	64%	97%
Guwahati	2440	1300	703	353	2356	36	42	0	6	0	0	53%	97%
Hyderabad	1952	1258	333	246	1837	45	65	0	5	0	0	64%	94%
Jalpaiguri	610	295	168	104	567	13	28	2	0	0	0	48%	93%
Lucknow	1708	1011	450	193	1654	25	25	0	4	0	0	59%	97%
New Delhi	366	201	95	47	343	8	12	0	1	0	2	55%	94%
Patna	976	594	192	146	932	11	29	1	3	0	0	61%	95%
Srinagar	488	333	62	85	480	0	7	0	1	0	0	68%	98%
Thiruvananthapuram	976	583	111	188	882	26	58	0	10	0	0	60%	90%
Over All fct.	18666	11557	3475	2863	17895	241	453	5	64	0	8	62%	96%
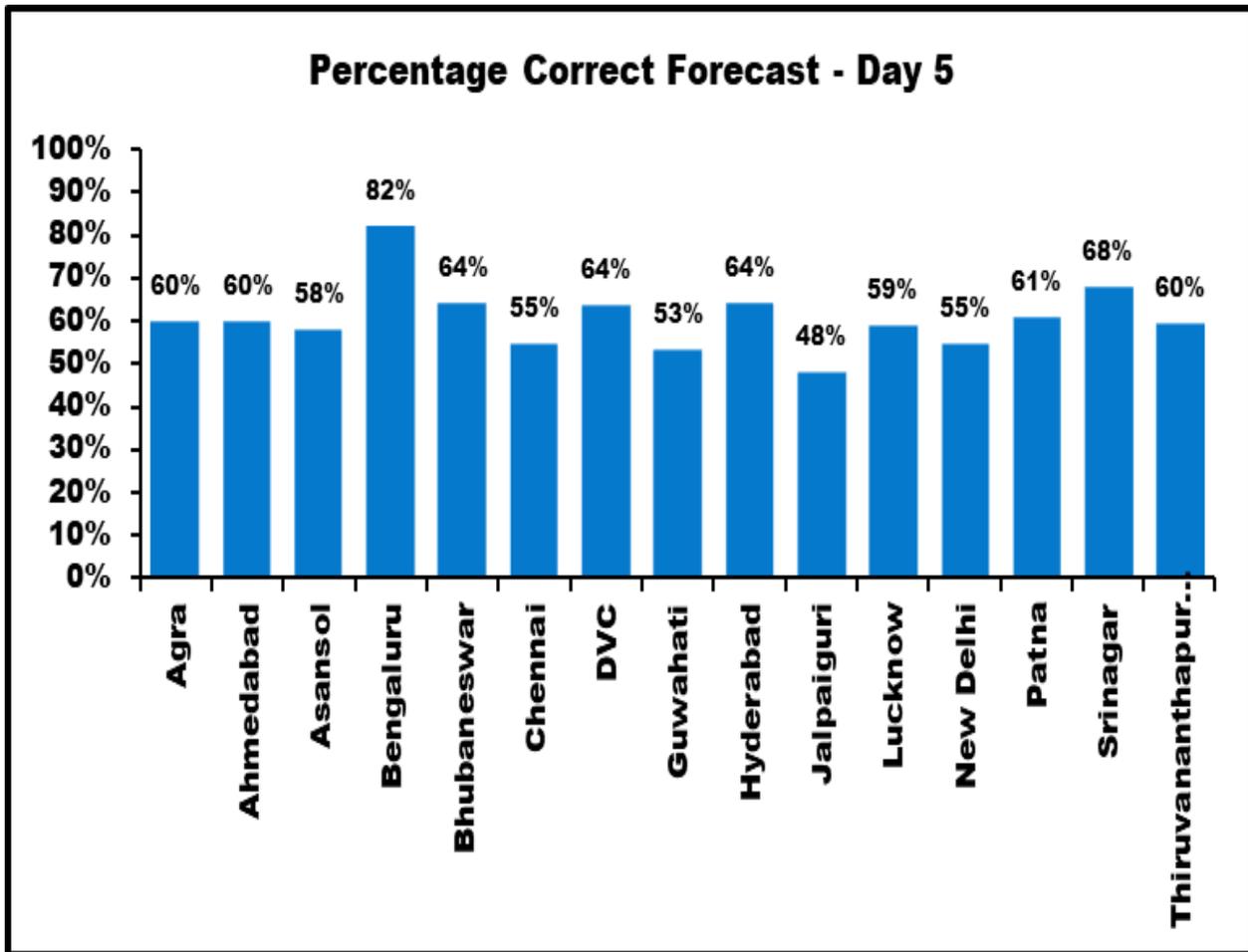
Figure 38. Percentage correct forecast Day-5 by different FMOs for JJAS 2023

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 for JJAS 2023

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.35	0.73	0.35	0.12	0.03	0.02
False Alarm Rate (FAR):	0.53	0.30	0.69	0.71	0.69	0.00
Missing Rate (MR):	0.65	0.27	0.65	0.88	0.97	0.98
Correct Non-Occurrence (C-NON):	0.92	0.50	0.85	0.97	1.00	1.00
Critical Success Index (CSI):	0.26	0.56	0.19	0.07	0.02	0.02
Bias for Occurrence (BIAS):	0.64	1.05	1.08	0.61	0.08	0.02
Hit Rate:	0.86	0.66	0.78	0.93	0.98	1.00
Percentage of Correct (PC):	0.86	0.66	0.78	0.93	0.98	1.00
True Skill Score (TSS):	0.27	0.24	0.20	0.09	0.02	0.02
Heidke Skill Score (HSS):	0.29	0.24	0.19	0.10	0.04	0.04

The category wise percentage correct forecast is given in Figure 42.
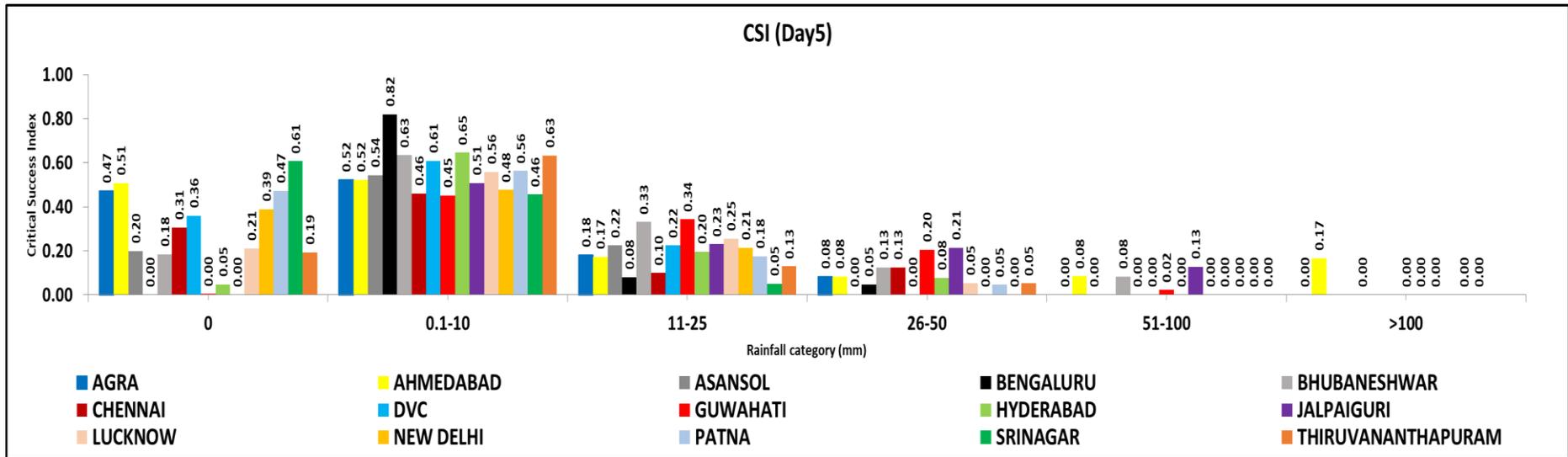
Figure 39: CSI for different categories of forecast for Day-5 for JJAS 2023
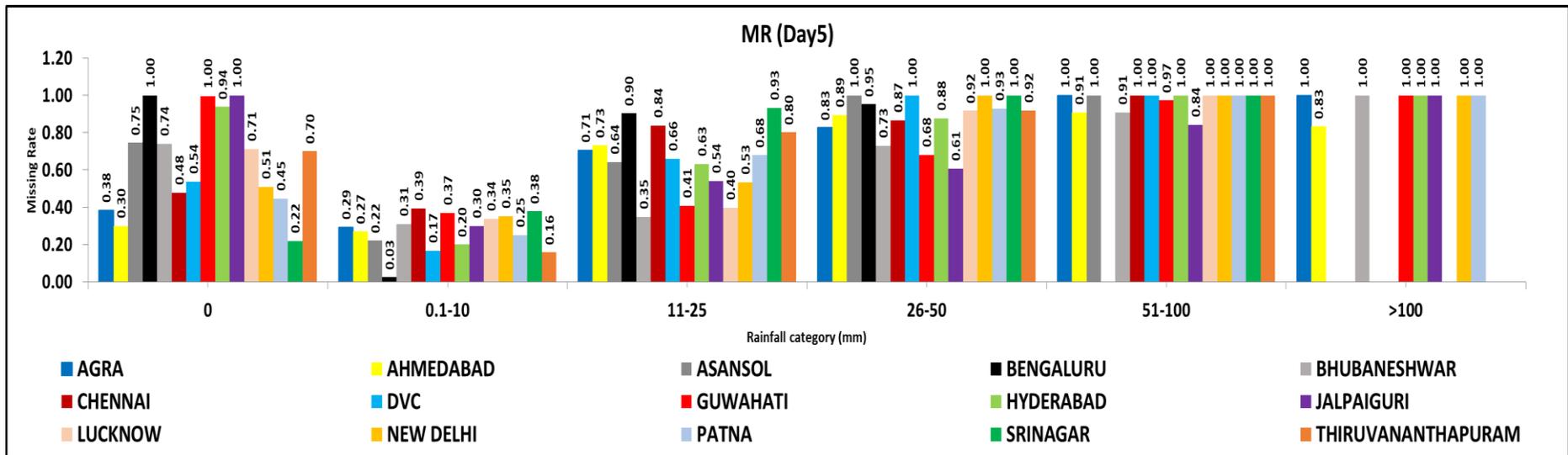
Figure 40: MR for different categories of forecast for Day-5 for JJAS 2023
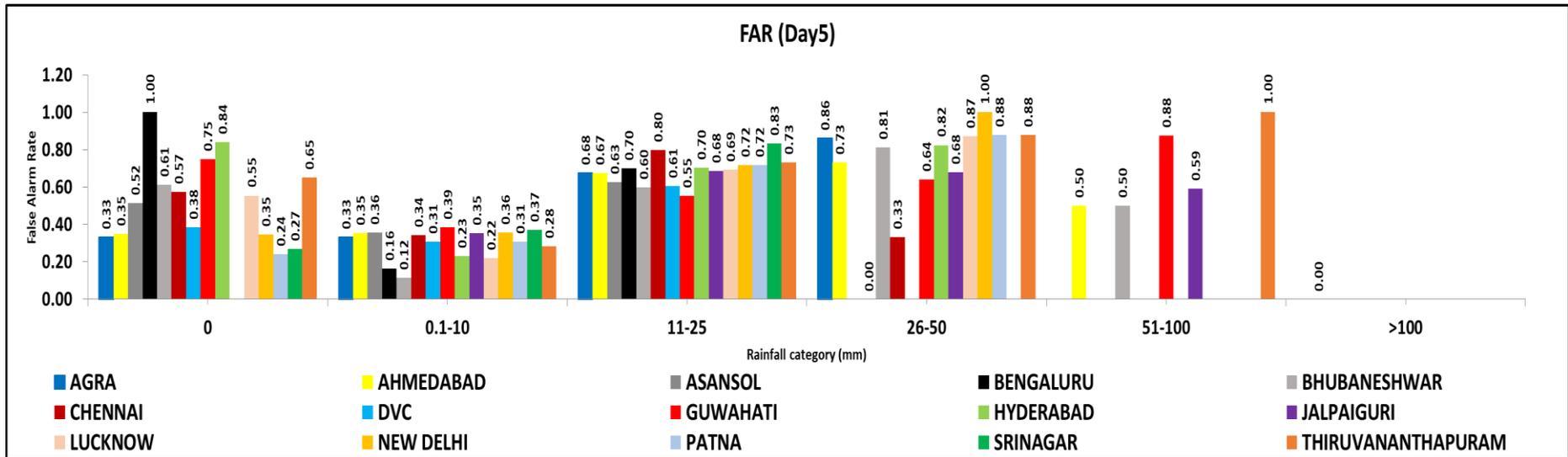
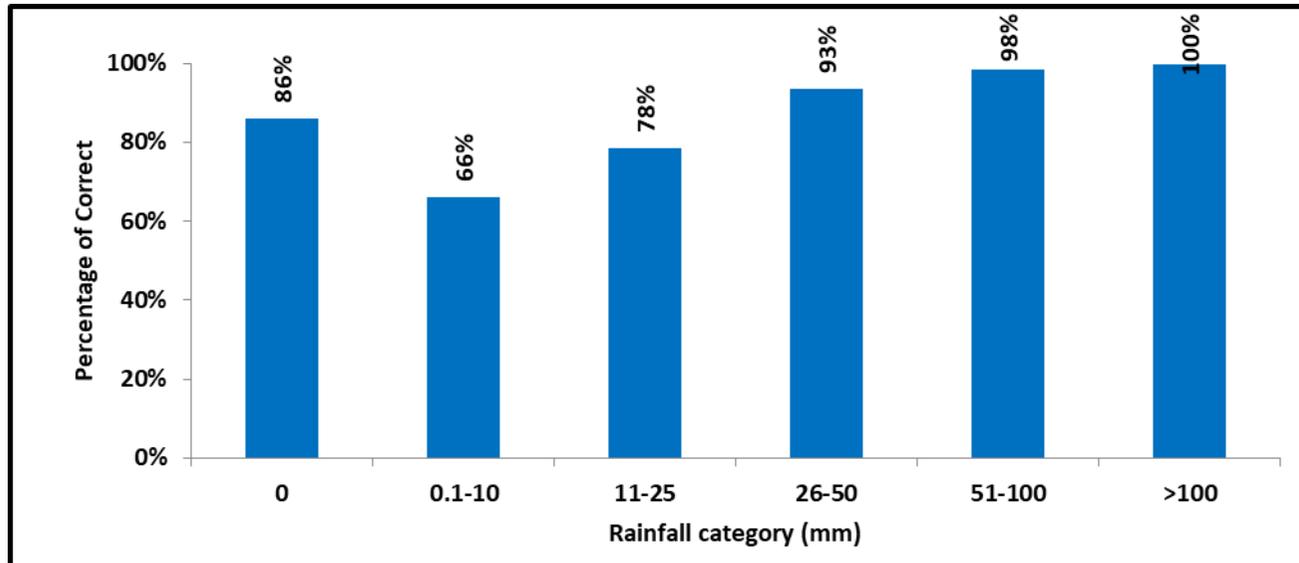**Figure 41: FAR for different categories of forecast for Day-5 for JJAS 2023**

Figure 42: Category-wise Percentage Correct Forecast of Day-5 for JJAS 2023

4.6 Skill Scores of Day-6 QPF

The QPF verification skill scores for different FMOs for Day-6 are given in Table 33. All India percentage correct QPF within same category is 62%. While FMO Bengaluru has the highest Percentage correct QPF of 78% and FMO Jalpaiguri has the lowest accuracy of 50%, six other FMOs viz. Ahmedabad, DVC, Hyderabad, Lucknow, Srinagar and Thiruvananthapuram reported more than 60% accuracy QPF for the Day-6 as seen in the figure 43. The percentage correct forecast for Day-6 QPF within ±1 category shows a substantial improvement and its overall India PC score was 96%. The performance of QPF within ±2, ±3, ±4 category can also be seen in Table 33. Very few cases are observed for out by 2, out by 3 and out by 4 category for Day-6 forecast.

Table 33: Performance of Day-6 QPF for the JJAS 2023

| FMO/MC | Total No. of QPF issued | Correct Forecast | Out by one Stage (±1) | | Correct and ±1 | Out by two Stage (±2) | | Out by three Stage (±3) | | Out by four Stage (±4) | | Correct (%) | Usable Forecast Correct & ±1 Stage |
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	664	383	142	114	639	7	15	0	2	0	1	58%	96%
Ahmedabad	1577	1043	113	323	1479	6	62	0	18	0	12	66%	94%
Asansol	249	140	57	42	239	0	10	0	0	0	0	56%	96%
Bengaluru	1494	1171	179	124	1474	0	20	0	0	0	0	78%	99%
Bhubaneswar	830	481	203	111	795	21	14	0	0	0	0	58%	96%
Chennai	913	479	165	239	883	6	21	0	3	0	0	52%	97%
DVC	498	306	65	103	474	0	21	0	3	0	0	61%	95%
Guwahati	1660	927	443	242	1612	17	26	0	5	0	0	56%	97%
Hyderabad	1328	878	166	173	1217	47	60	0	4	0	0	66%	92%
Jalpaiguri	415	208	105	68	381	10	21	1	2	0	0	50%	92%
Lucknow	1162	702	309	117	1128	7	23	0	4	0	0	60%	97%
New Delhi	249	142	54	42	238	3	7	0	1	0	0	57%	96%
Patna	664	387	145	102	634	8	15	0	7	0	0	58%	95%
Srinagar	340	237	36	66	339	0	1	0	0	0	0	70%	100%
Thiruvananthapuram	656	405	53	142	600	2	50	0	4	0	0	62%	91%
Over All fct.	12699	7889	2235	2008	12132	134	366	1	53	0	13	62%	96%
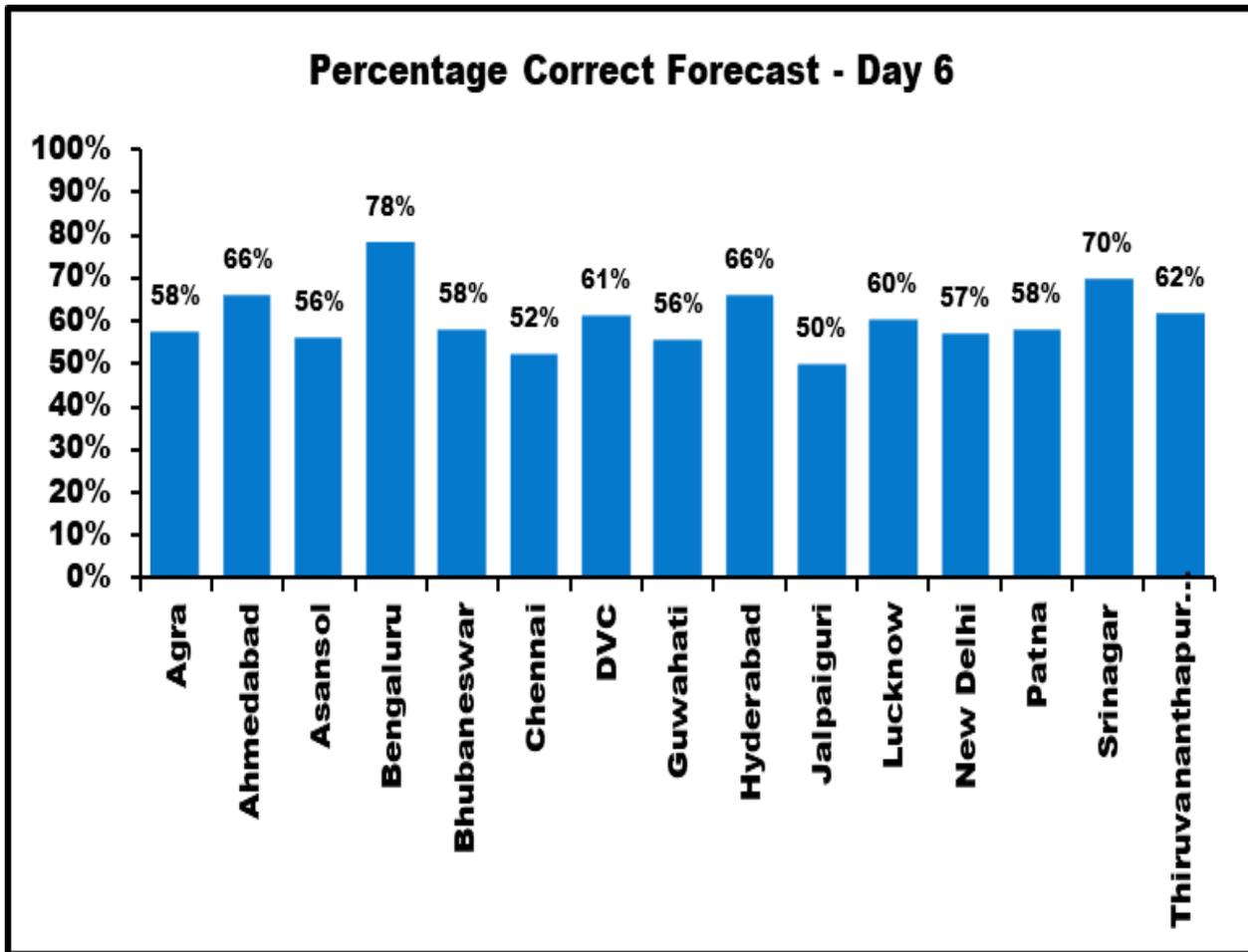
Figure 43. Percentage correct forecast Day-6 by different FMOs for JJAS 2023

All India skill scores viz, POD, FAR, MR, CSI, BIAS, PC, TSS and HSS computed from 2X2 contingency table are given in Table 34 and figures 44 - 46. While CSI and POD decreases with increase in the QPF category, an opposite trend is observed for False alarm rate and Missing rate.

Table 34: Skill Scores of Day-6 QPF for JJAS 2023

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.27	0.76	0.27	0.07	0.00	0.00
False Alarm Rate (FAR):	0.60	0.31	0.73	0.76	1.00	
Missing Rate (MR):	0.73	0.24	0.73	0.93	1.00	1.00
Correct Non-Occurrence (C-NON):	0.92	0.42	0.86	0.98	1.00	1.00
Critical Success Index (CSI):	0.20	0.56	0.15	0.05	0.00	0.00
Bias for Occurrence (BIAS):	0.51	1.11	0.95	0.33	0.01	0.00
Hit Rate:	0.85	0.65	0.78	0.94	0.99	1.00
Percentage of Correct (PC):	0.85	0.65	0.78	0.94	0.99	1.00
True Skill Score (TSS):	0.19	0.18	0.13	0.05	0.00	0.00
Heidke Skill Score (HSS):	0.20	0.18	0.12	0.07	0.00	0.00

The category wise percentage correct forecast is given in Figure 47.
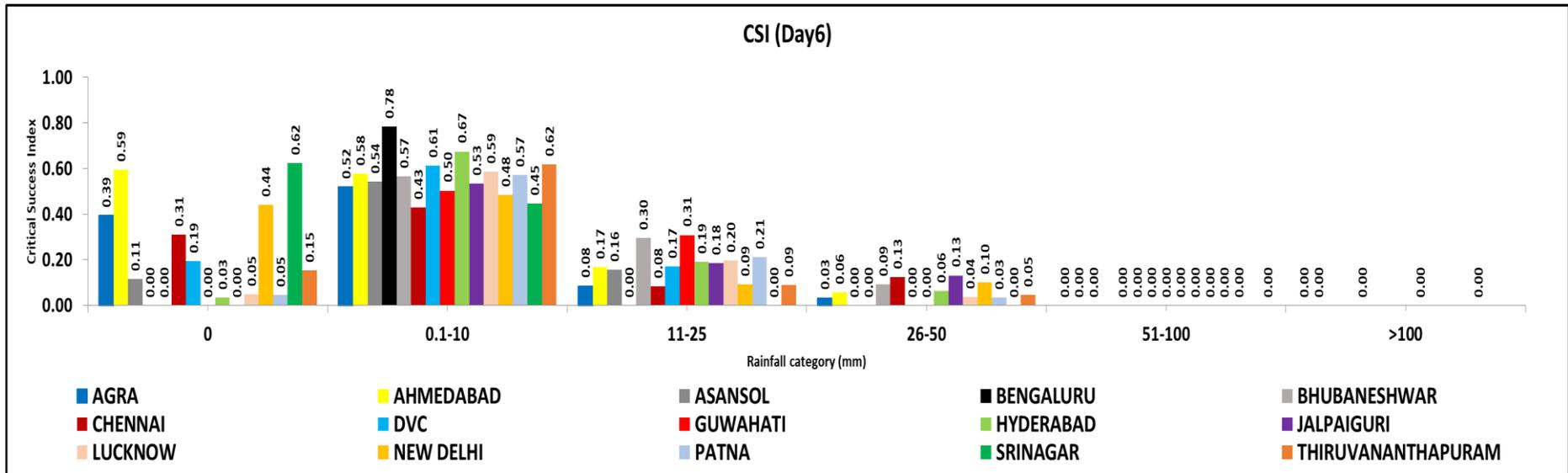
Figure 44: CSI for different categories of forecast for Day-6 for JJAS 2023
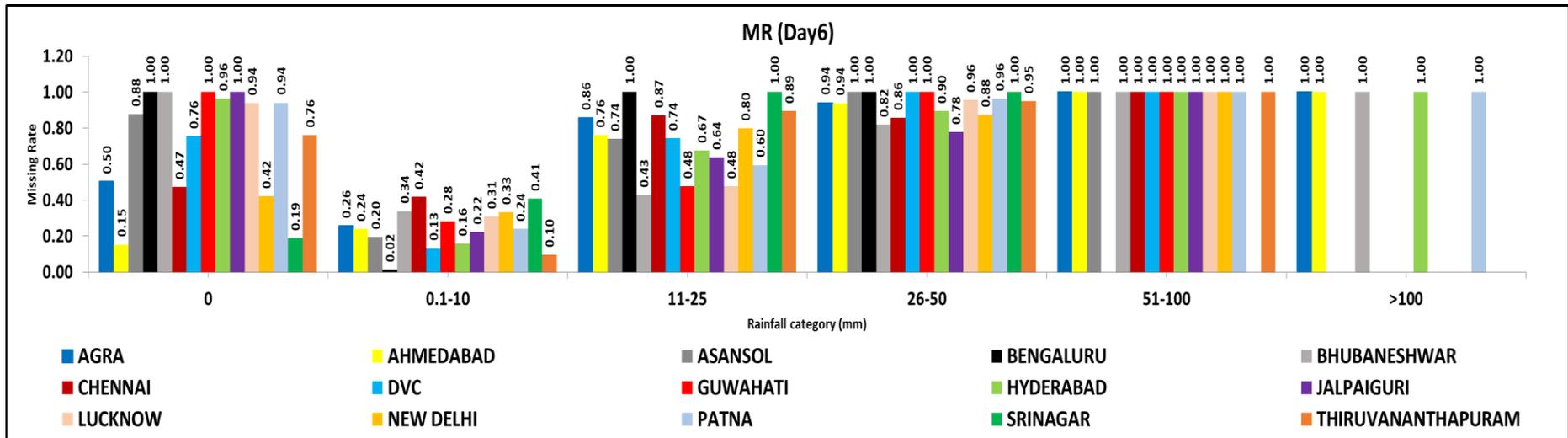
Figure 45: MR for different categories of forecast for Day-6 for JJAS 2023
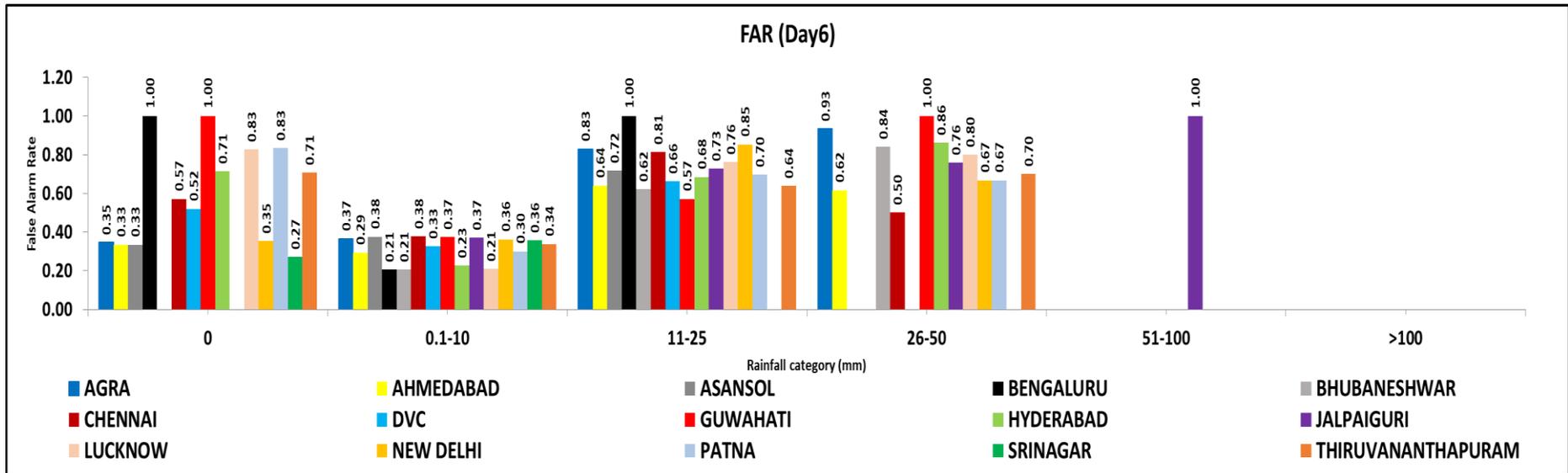
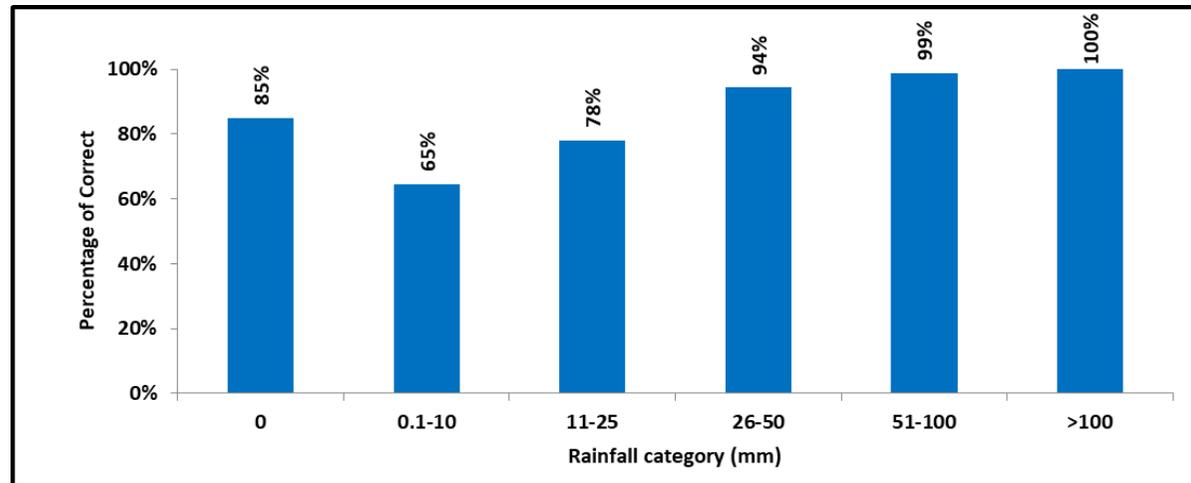**Figure 46: FAR for different categories of forecast for Day-6 for Flood Season JJAS 2023**

Figure 47: Category-wise Percentage Correct Forecast of Day-6 for JJAS 2023

4.7 Skill Scores of Day-7 QPF

The QPF verification skill scores for different FMOs for Day-7 are given in Table 35. All India percentage correct QPF within same category is 62%. While FMO Bengaluru has the highest Percentage correct QPF of 78% and FMO Jalpaiguri has the lowest accuracy of 50%, seven other FMOs viz. Agra, Ahmedabad, DVC, Hyderabad, Lucknow, Patna and Srinagar reported more than 60% Accuracy QPF for the Day-7 as seen in the figure 48. The percentage correct forecast for Day-7 QPF within ±1 category shows a substantial improvement and its all India PC score was 95%. The performance of QPF within ±2, ±3, ±4 category can also be seen in table 35. Very few cases are observed for out by 2, out by 3 and out by 4 category for Day-7 forecast.

Table 35: Performance of Day-7 QPF for the JJAS 2023

| FMO/MC	Total No. of QPF issued	Correct Forecast	Out by one Stage (±1)		Correct and ±1	Out by two Stage (±2)		Out by three Stage (±3)		Out by four Stage (±4)		Correct (%)	Usable Forecast Correct & ±1 Stage
			Over fct.	Under fct.		Over fct.	Under fct.	Over fct.	Under fct.	Over fct.	Under fct.		
Agra	664	416	127	101	644	2	14	0	3	0	1	63%	97%
Ahmedabad	1577	996	157	305	1458	11	67	0	28	0	13	63%	92%
Asansol	249	142	59	39	240	2	7	0	0	0	0	57%	96%
Bengaluru	1494	1167	186	120	1473	0	21	0	0	0	0	78%	99%
Bhubaneswar	830	493	206	91	790	27	12	0	1	0	0	59%	95%
Chennai	913	489	156	237	882	8	17	0	5	0	1	54%	97%
DVC	498	299	77	100	476	0	21	0	1	0	0	60%	96%
Guwahati	1660	897	461	242	1600	25	28	0	7	0	0	54%	96%
Hyderabad	1328	852	177	196	1225	35	58	0	10	0	0	64%	92%
Jalpaiguri	415	207	104	67	378	7	23	0	7	0	0	50%	91%
Lucknow	1162	751	266	118	1135	4	19	0	4	0	0	65%	98%
New Delhi	249	148	53	33	234	7	8	0	0	0	0	59%	94%
Patna	664	412	128	92	632	7	19	0	6	0	0	62%	95%
Srinagar	340	242	20	76	338	0	1	0	1	0	0	71%	99%
Thiruvananthapuram	656	387	61	135	583	4	59	0	10	0	0	59%	89%
Over All fct.	12699	7898	2238	1952	12088	139	374	0	83	0	15	62%	95%
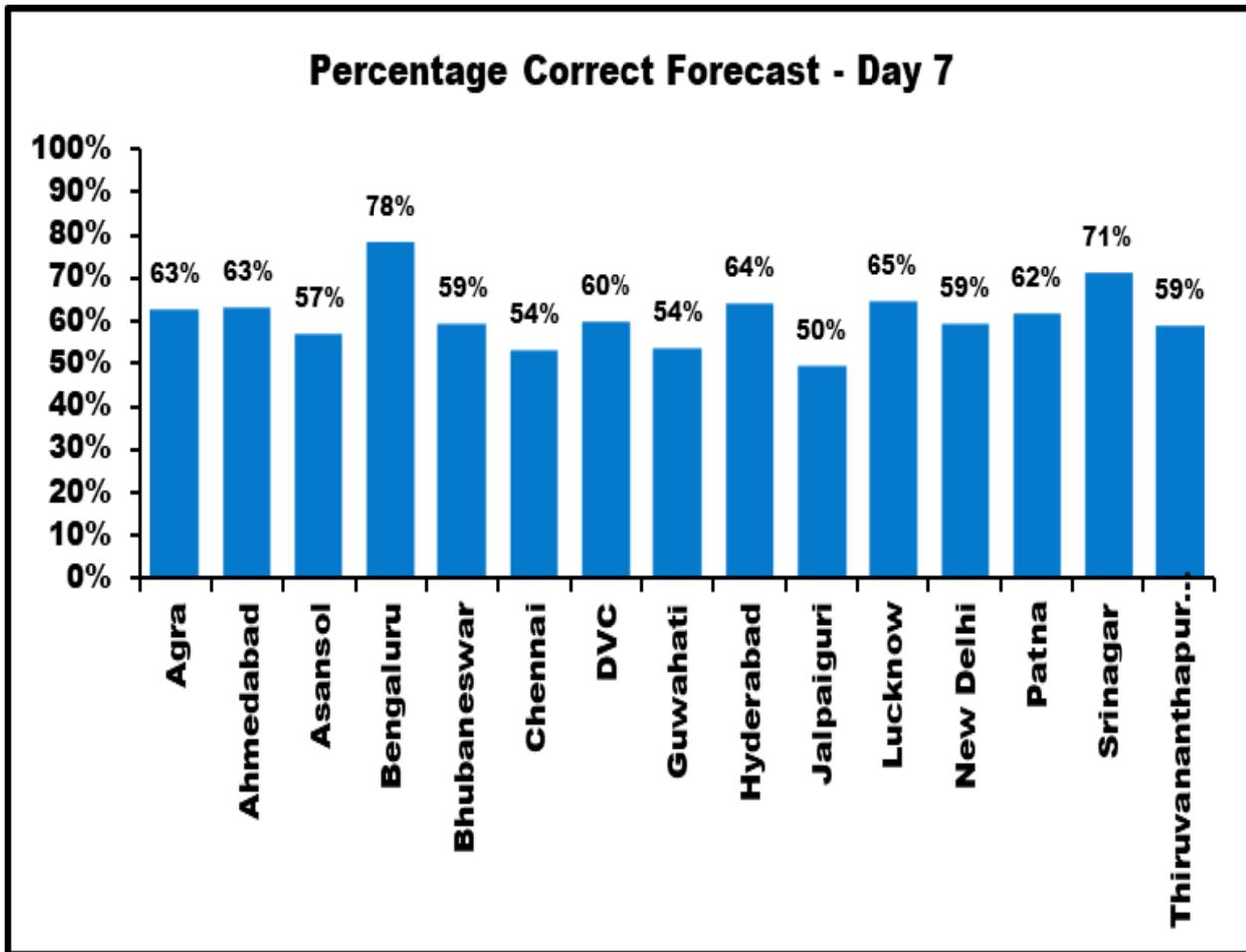
Figure 48. Percentage correct forecast Day-7 by different FMOs for JJAS 2023

All India skill scores viz, POD, FAR, MR, CSI, BIAS, PC, TSS and HSS computed from 2X2 contingency table are given in Table 36 and figures 49 - 51. While CSI and POD decreases with increase in the QPF category, an opposite trend is observed for False alarm rate and Missing rate.

Table 36: Skill Scores of Day-7 QPF for JJAS 2023

SKILL SCORE	0	0.1-10	11-25	26-50	51-100	>100
Probability of Detection (POD):	0.25	0.77	0.28	0.05	0.00	0.00
False Alarm Rate (FAR):	0.63	0.31	0.71	0.89	1.00	
Missing Rate (MR):	0.75	0.23	0.72	0.95	1.00	1.00
Correct Non-Occurrence (C-NON):	0.92	0.42	0.87	0.99	1.00	1.00
Critical Success Index (CSI):	0.18	0.57	0.15	0.03	0.00	0.00
Bias for Occurrence (BIAS):	0.47	1.12	0.93	0.29	0.01	0.00
Hit Rate:	0.85	0.65	0.79	0.95	0.99	1.00
Percentage of Correct (PC):	0.85	0.65	0.79	0.95	0.99	1.00
True Skill Score (TSS):	0.17	0.18	0.14	0.03	0.00	0.00
Heidke Skill Score (HSS):	0.17	0.18	0.13	0.04	0.00	0.00
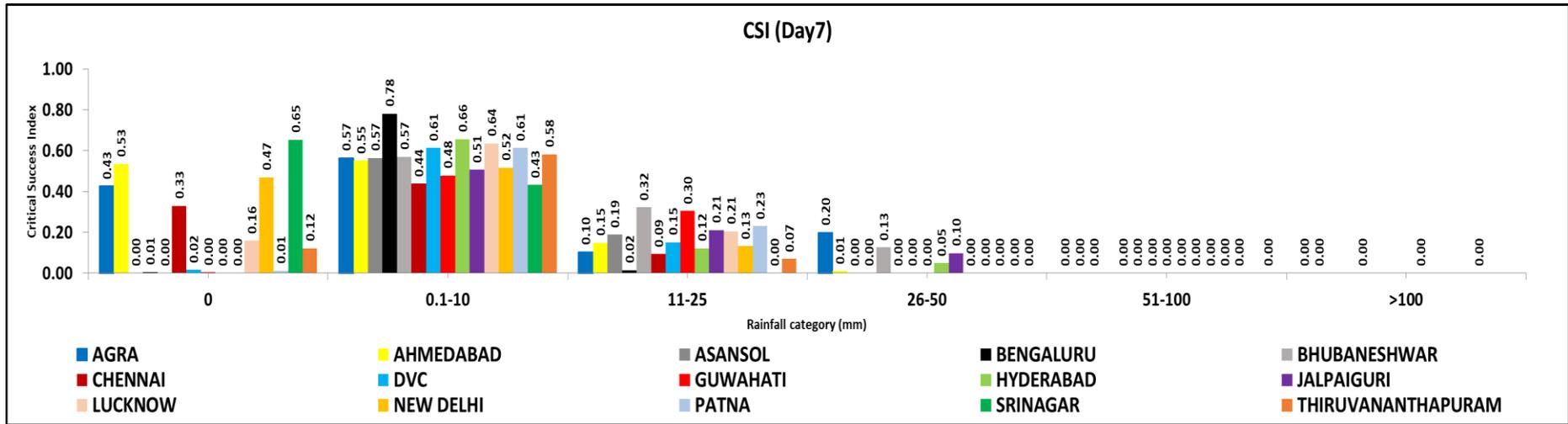
Figure 49: CSI for different categories of forecast for Day-7 for JJAS 2023
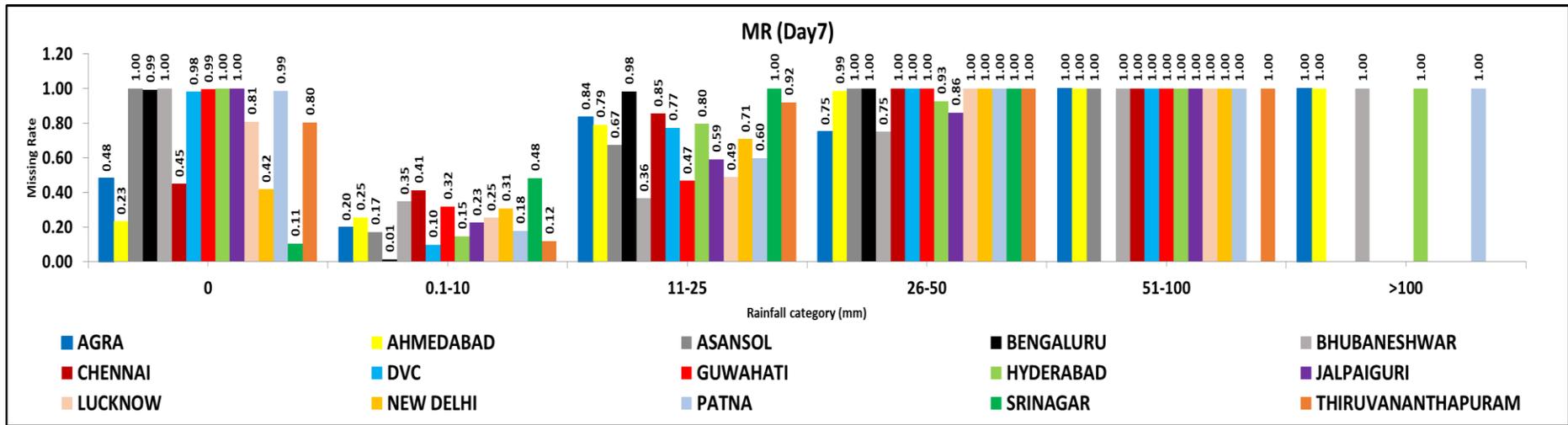
Figure 50: MR for different categories of forecast for Day-7 for JJAS 2023
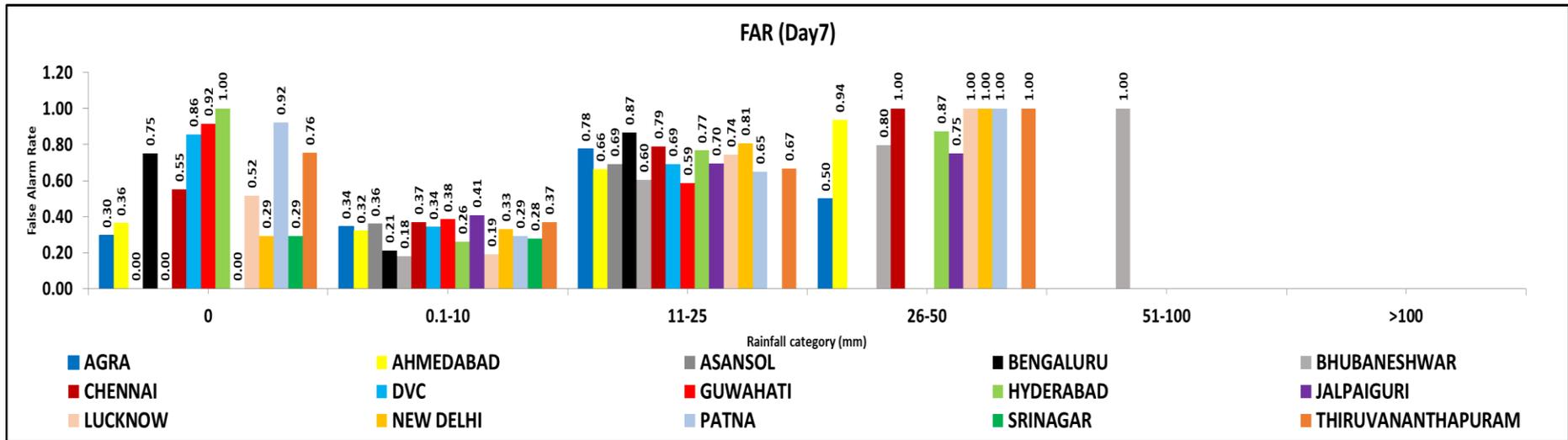
Figure 51: FAR for different categories of forecast for Day-7 for JJAS 2023
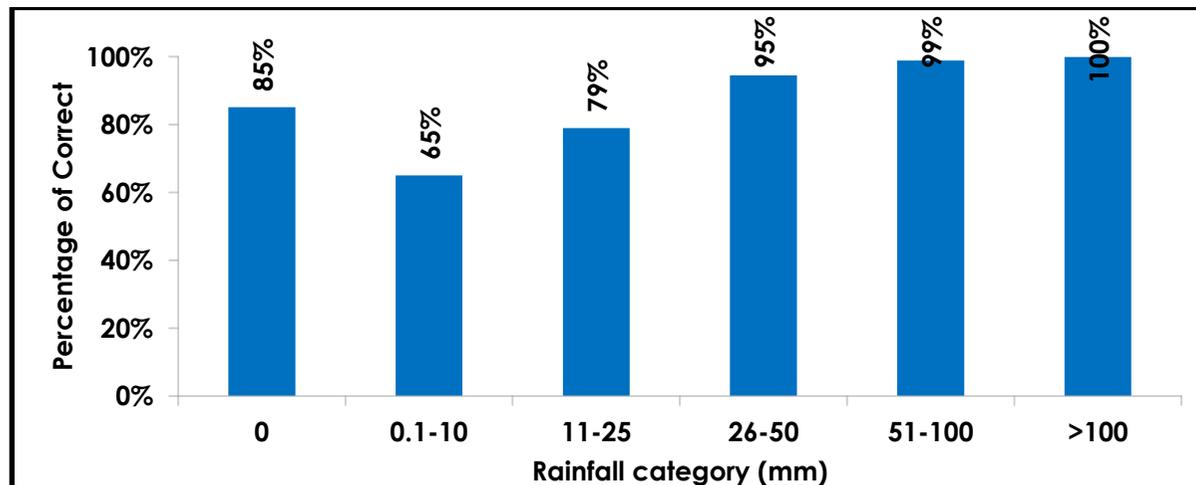
Figure 52: Category-wise Percentage Correct Forecast of Day-7 for JJAS 2023

4.8 All India QPF Verification for Day-1, Day-2, Day-3, Day-4, Day-5, Day-6 and Day-7

The Day-1, Day-2**,** Day-3, Day-4, Day-5, Day-6 and Day-7 percentage correct forecast for all sub-basins under different FMOs for the years 2018-2023 are given in Figure 53 It is observed during this year, the accuracy of forecast has improved by 4% in Day-1, 3% in Day-2, 3% in Day-3, 2% in Day-4 and 3% in Day-5 as compared to last year.

The accuracy of QPF decreases with the increase in lead time from Day-1 to Day-7. It can be seen that the % accuracy decreases from 70% in Day-1 to 62% in Day-7 forecast. However, accuracy decreases sharply from Day-1 to Day-2 (by 4%), decreases from Day-2 to Day-3 (by 3%) but there is not much deterioration in the accuracy with increase in lead time from Day-3 to Day-7 (Figure 53).

The category-wise average CSI in all sub-basins across the country for Day-1, Day-2**,** Day-3, Day-4, Day-5, Day-6 and Day-7 are given in figure 54. 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.
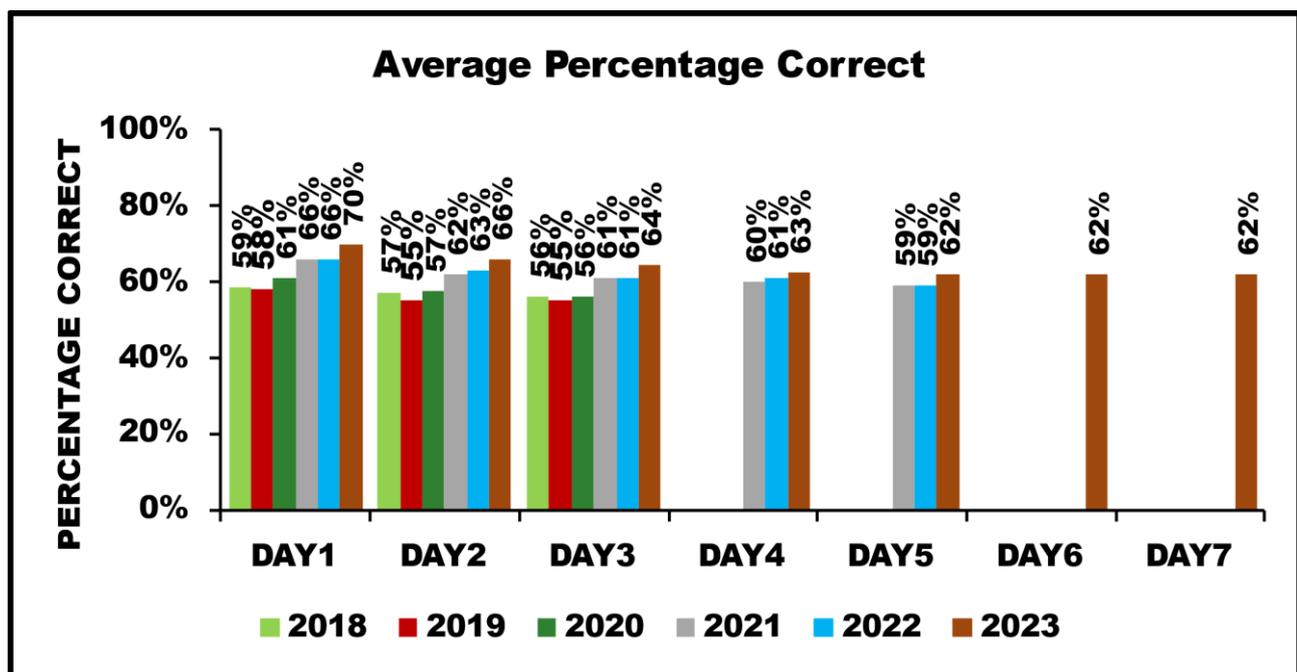
Figure 53: Day-1, Day-2, Day-3, Day-4, Day-5, Day-6 and Day-7 overall % correct forecast for JJAS 2018 to 2023
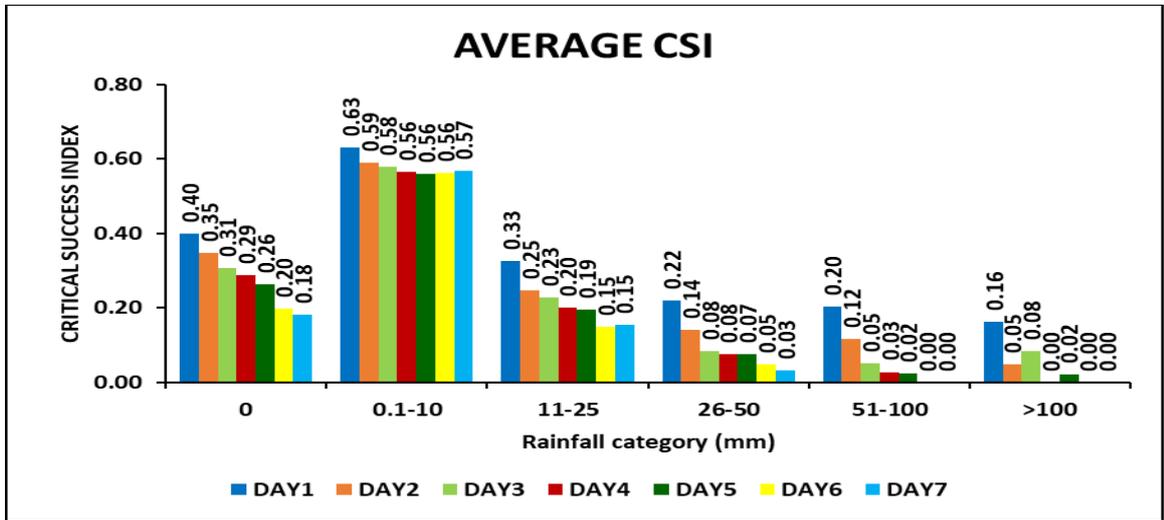
Figure 54: Category-wise Critical Success Index for Day-1, Day-2, Day-3, Day-4, Day-5, Day-6 and Day-7 for JJAS 2023
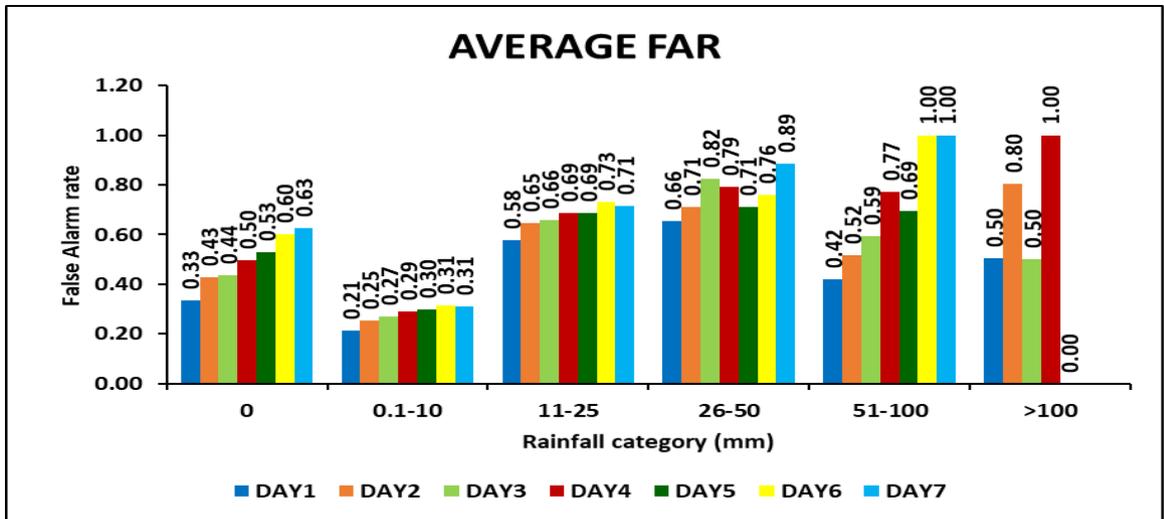

Figure 55: Category-wise False Alarm Rate for Day-1, Day-2, Day-3, Day-4, Day-5, Day-6 and Day-7 for JJAS 2023
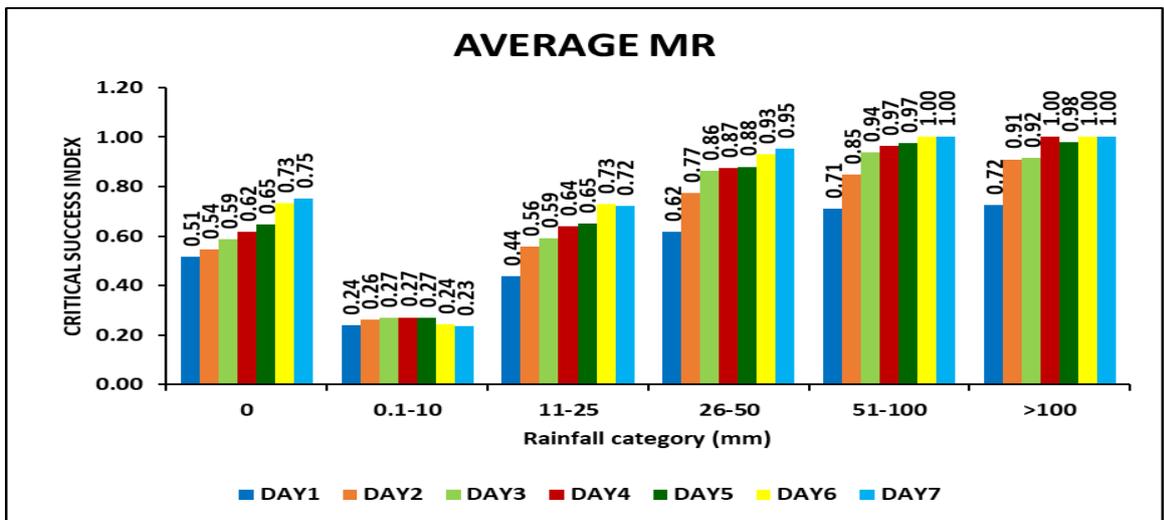

Figure 56: Category-wise Missing Rate for Day-1, Day-2, Day-3, Day-4, Day-5, Day-6 and Day-7 for JJAS 2023

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, Day-5, Day-6 and Day-7 are given in figures 55 and 56 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.

4.9. Improvement in operational QPF (2018 to 2023)

The FMO-wise Percentage correct QPF for Day-1 for the year 2018 to 2023 are given in Figure 57. The accuracy of Day-1 QPF when compared to previous years has improved in respect of FMOs Bengaluru, Bhubaneshwar, DVC, Guwahati, Jalpaiguri, New Delhi, Patna, Srinagar and Thiruvananthapuram while it has deteriorated slightly in respect of FMOs Ahmedabad, Asansol, Chennai and Lucknow.

The FMO-wise performance in operational QPF during 2023 as compared to average performance in the previous years during 2018 to -2022 for Day-1, Day-2 and Day-3 are shown in Figure 58-60 respectively. Substantial improvement in the accuracy (≥5%) is observed for Day1 for the FMOs Agra (5%), Bengaluru (27%), Bhubaneswar(5%), Chennai(5%), Hyderabad(7%), New Delhi(7%), Patna(12%), Srinagar(10%) and Thiruvananthapuram(24%). Substantial improvement in the accuracy (≥5%) for Day-2 forecast is observed for the FMOs Agra (5%), Bengaluru(26%), Chennai(7%), Hyderabad(9%), Patna(9%), Srinagar(8%) and Thiruvananthapuram(20%) as shown in Fig.59. Substantial improvement in the accuracy (≥5%) for Day-3 forecast is observed for the FMOs Agra(6%), Bengaluru(27%), Bhubaneswar(6%), Chennai(8%), Hyderabad(7%), Lucknow(5%), Patna(7%), Srinagar(8%) and Thiruvananthapuram(19%) as shown in Fig.60.

The improvement in all India PC score with compare to average of 2018 to 2022 were 8%, 6% and 5% respectively (figs. 58-60).
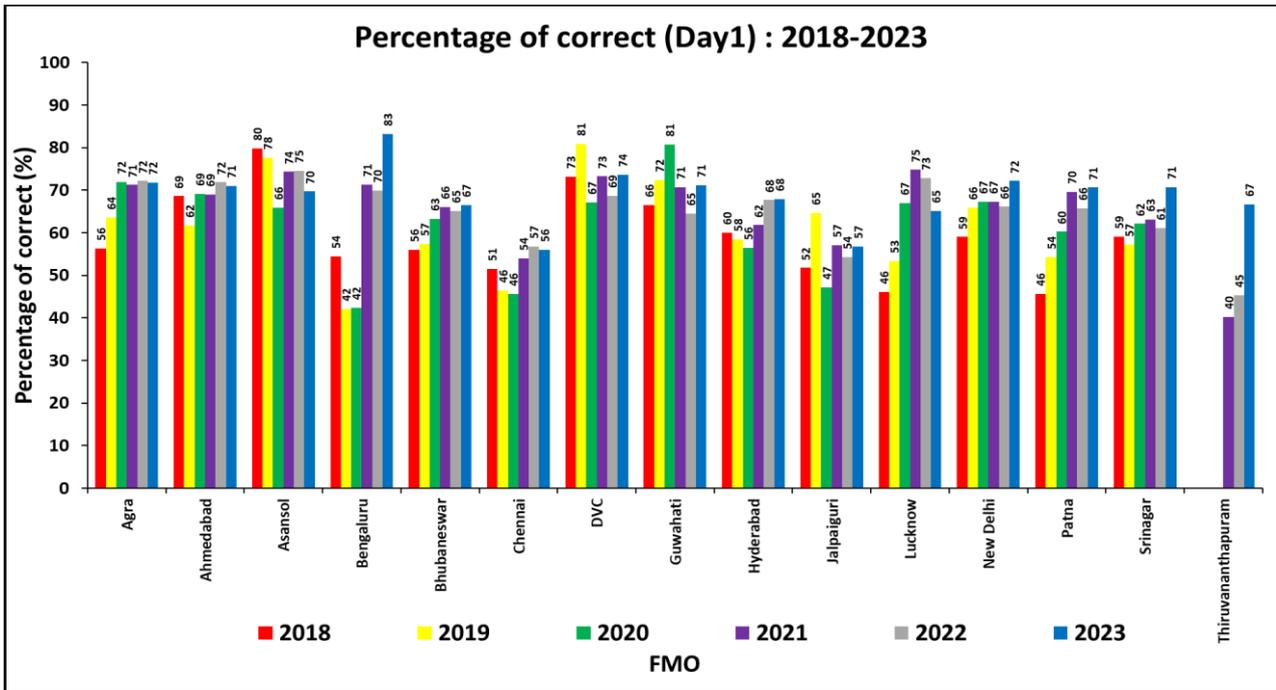
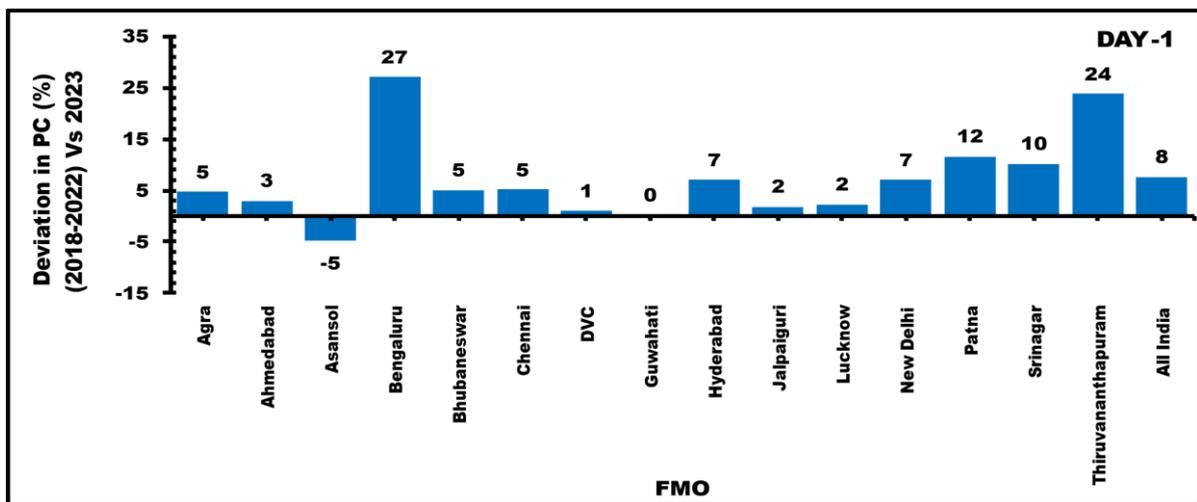**Figure 57: FMO-wise Percentage Correct QPF for Day-1 for the year 2018 to 2023**

Figure 58. Day-1 performance of FMO-wise Operational QPF during 2023 Vs mean of 2018 - 2022
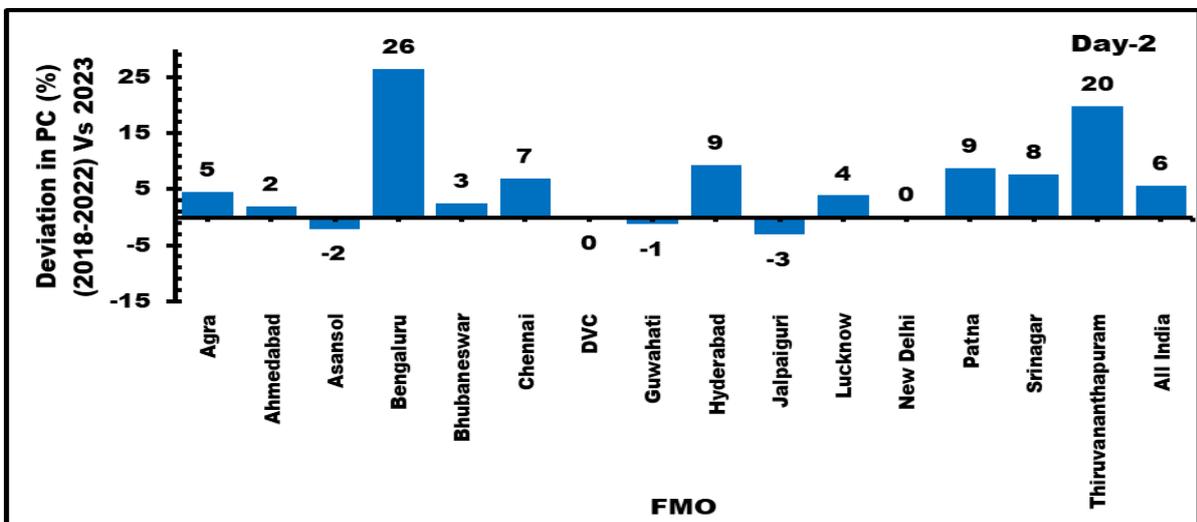

Figure 59. Day-2 performance of FMO-wise Operational QPF during 2023 Vs mean of 2018 – 2022
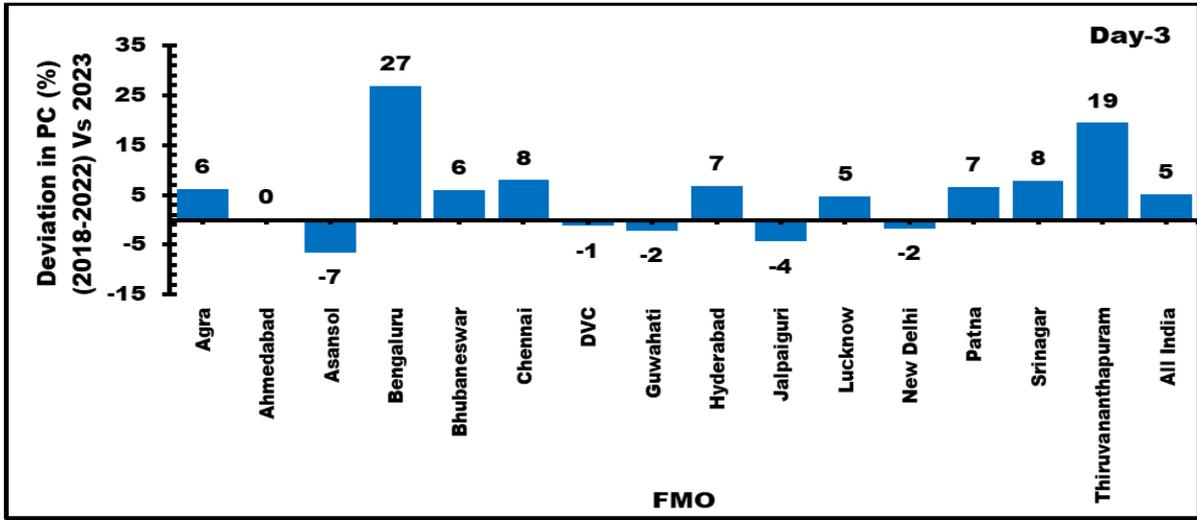
Figure 60. Day-3 performance of FMO-wise Operational QPF during 2023 Vs mean of 2018 – 2022

CHAPTER 5

Concluding Remarks

1. Percentage Correct of QPF within same category is 70% for Day-1, 66% for Day-2, 64% for Day-3, 63% for Day-4, 62% for Day-5, 62% for Day-6 and 62% for Day-7 for all 156 river sub- basins. However, accuracy of QPF within ±1 category is more than 95% for all five days.

2. During this year, the accuracy within same category of river sub-basin-wise QPF 4% in Day-1, 3% in Day-2, 3% in Day-3, 2% in Day-4 and 3% in Day-5 as compared to last year.

3. Substantial improvement in the accuracy (≥5%) is observed for the FMOs Agra, Bengaluru, Bhubaneswar, Chennai, Hyderabad, New Delhi, Patna, Srinagar and Thiruvananthapuram as compared to average performance in the previous five years (2018-2022) for Day-1.

4. The accuracy of Day-1 QPF when compared to previous five years (2018-2022) has improved in respect of FMOs Bengaluru, Bhubaneshwar, DVC, Guwahati, Jalpaiguri, New Delhi, Patna, Srinagar and Thiruvananthapuram while it has deteriorated slightly in respect of FMOs Ahmedabad, Asansol, Chennai and Lucknow.

5. The accuracy of QPF decreases with the increase in lead time from Day-1 to Day-7. Percent accuracy decreases from 70% in Day-1 to 62% in Day-7 forecast. Accuracy decreases sharply from Day-1 to Day-2 (by 4%), decreases from Day-2 to Day-3 (by 3%) but there is not much deterioration in the accuracy with increase in lead time from Day-3 to Day-4 and onwards.

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 0.63, 0.33, 0.24, 0.16 and 0.16 respectively for Day-1 QPF for all 156 river sub-basins.

8. FAR for the rainfall categories 0.1-10, 11-25, 26-50, 51-100 and >100 mm is 0.21, 0.58, 0.66, 0.42 and 0.50 respectively for Day-1 QPF for all 156 river sub-basins.

9. Improvement in river sub-basin-wise operational QPF by 8%, 6% and 5% for the forecast of day1, day2 and day3 respectively in 2023 with compare to recent 5 years.

References:

1. Ashok Kr. Das, B. P. Yadav, Charu and J. Dhingra, published a paper entitled "Evaluation of performance of WRF (ARW) and GFS for Quantitative Precipitation Forecast and its value addition over India river sub-basins during recent years", Mausam, **73**, 2 (April 2022), 315-340.

2. B. P. Yadav, Naresh Kumar and L. S. Rathore published paper entitled "Skill of operational forecast of heavy rainfall events during southwest monsoon season over India", **66**, 3 (2015), 579- 584.

3. Ashok Kumar Das and Surinder Kaur published paper entitled "Performance of IMD Multi-model Ensemble (MME) and WRF ARW based sub-basin wise rainfall forecast for Mahanadi basin during Flood Season 2009, 2010", Mausam, **64**, 4(Oct 2013), 625-644.

4. Ashok Kr. Das and Surinder Kaur published paper entitled "Performance of IMD Multi-Model Ensemble and WRF (ARW) model for sub-basin wise rainfall forecast during Monsoon 2012", Mausam **67**, 2 (April 2016), 323-332.

5. B. P. Yadav, Ashok Kr. Das et. al., published Met. Monograph No. MoES/IMD/H.S./Basin Hydrology/01(2023)/15 titled "Verification of River Sub-basin-wise Quantitative Precipitation Forecast during SW Monsoon 2022".

6. B. P. Yadav, Ashok Kr. Das et. al., published Met. Monograph No. MoES/IMD/HS/Basin Hydrology/01(2022)/14 titled "Verification of sub-basin-wise Quantitative Precipitation Forecast during SW Monsoon 2021".

7. B. P. Yadav, Ashok Kr. Das et. al., published Met. Monograph No. MOES/IMD/HS/Basin Hydrology/ 01(2021)/13 titled "Verification of Quantitative Precipitation Forecast (QPF) 2020 over river basins of India".

8. B. P. Yadav, Ashok Kr. Das, Charu and Jyotsana Dhingra published SW Monsoon Report 2019 in IMD Met. Monograph No. ESSO/IMD/Synoptic Met/02(2019)/24 titled "Verification of Quantitative Precipitation Forecast (QPF) 2019 during SW Monsoon over River Sub-basins of India" , Chapter - 15, pg. 221-236.

9. B. P. Yadav and Ashok Kr. Das published SW Monsoon Report 2018 titled "Verification of Quantitative Precipitation Forecast (QPF) 2018 during SW Monsoon over River Sub-basins of India", Chapter -17.

10. B. P. Yadav and Ashok Kr. Das published SW Monsoon Report 2017 titled "Verification of Quantitative Precipitation Forecast (QPF) 2017 during SW Monsoon over River Sub-basins of India", Chapter -21.

11. B. P. Yadav, Ashok Kr. Das, Charu and Jyotsana Dhingra published SW Monsoon Report 2020 in IMD Met. Monograph No.: ESSO/IMD/Synoptic Met/01(2021)/25) titled "Verification of Quantitative Precipitation Forecast (QPF) 2020 during SW Monsoon over River Sub-basins of India", Chapter - 11, pg. 183-201.

12. S. Kaur, S. K. Diwakar and Ashok Kr. Das published Met. Monograph Report No. ESSO/IMD/HS/Basin Hydrology/12/2017(1) titled 'Verification of Quantitative Precipitation Forecast (QPF) 2015 over river basins of India'.

Percentage of correct (Day1) : 2018-2023
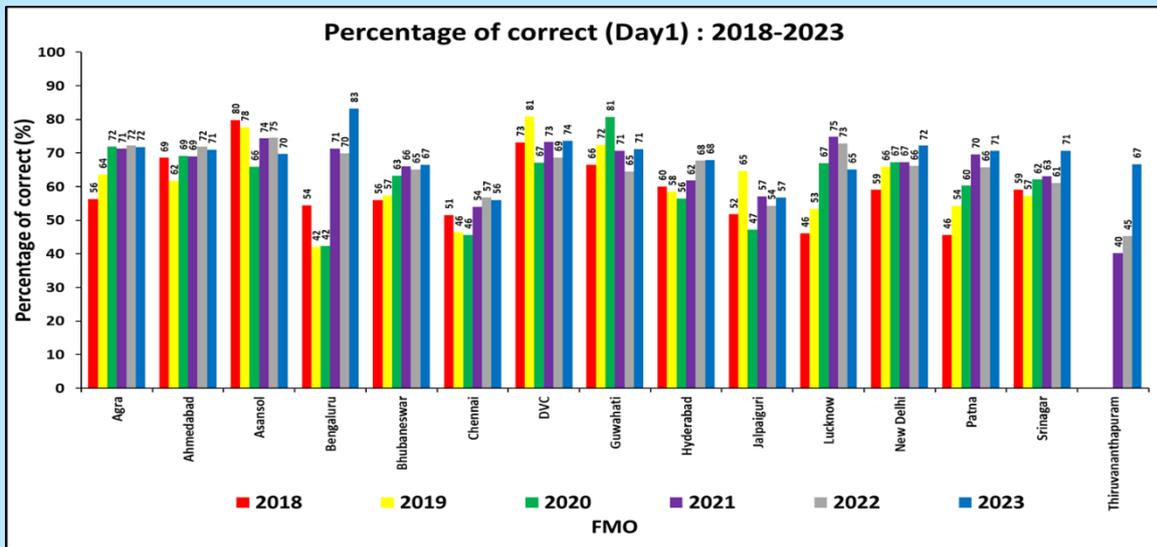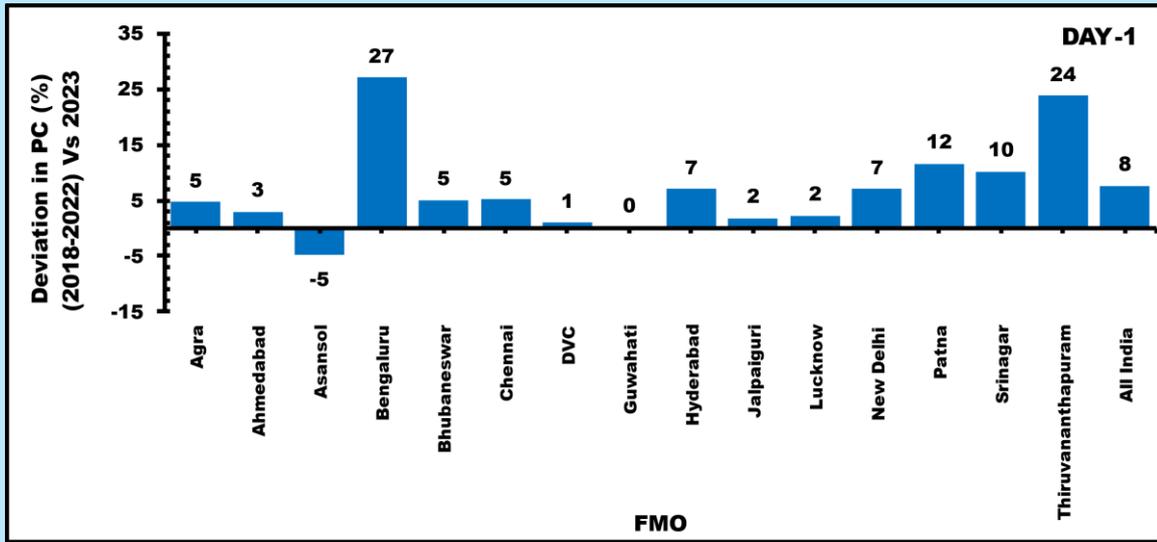
जल मौसम विज्ञान प्रभाग, भारत मौसम विज्ञान विभाग
(पृथ्वी विज्ञान मंत्रालय)
Hydromet Division, India Meteorological Department
(Ministry of Earth Sciences)
मौसम भवन, लोदी रोड, नई दिल्ली- 110003
Mausam Bhavan, Lodi Road, New Delhi- 110003