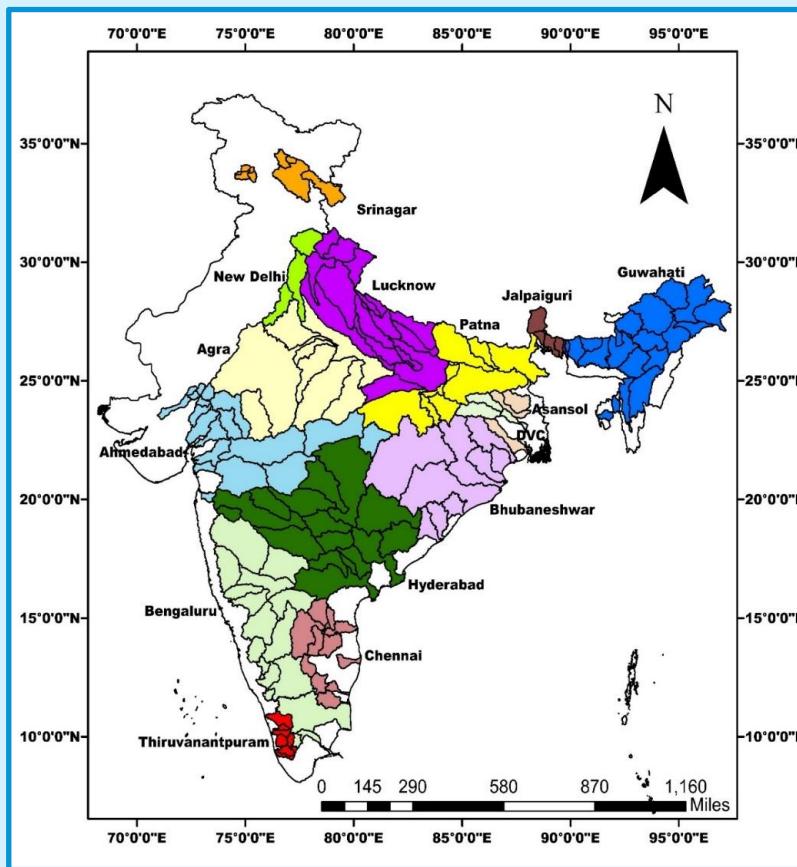


जल मौसम विज्ञान प्रभाग
भारत मौसम विज्ञान विभाग
पृथ्वी विज्ञान मंत्रालय

Hydromet Division
India Meteorological Department
Ministry of Earth Sciences

नदी उपबेसिन मात्रात्मक वर्षा पूर्वानुमान दक्षिण पश्चिमी मानसून 2022 का सत्यापन

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FOREWORD

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

It gives me immense pleasure that Hydromet Division has brought out the publication **“VERIFICATION OF RIVER SUB-BASIN-WISE QUANTITATIVE PRECIPITATION FORECAST DURING SW MONSOON 2022”** based on the Operational QPF and the Observed rainfall received in the different sub-basins under 14 FMOs along with DVC met unit Kolkata. I am sure this report will be useful to FMOs for taking measures for further improving the accuracy of QPF which will ultimately lead to improved flood forecasting. I appreciate the concerned FMO colleagues for improved forecast performance during 2022.

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

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

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CHAPTER 1

Introduction

Every year floods occurs in one or another part of the country. IMD is the nodal agency for issuing Quantitative Precipitation Forecast (QPF) for river Basins/ sub-Basins whereas CWC is the nodal agency for issuing Flood Forecast. The QPF is the main input in the Flood Forecasting models for issuing flood forecast by CWC. IMD through its field offices called ‘Flood Meteorological Offices’ (FMOs) issues QPF on operational basis during flood season. There are 14 FMOs along with DVC met service stations located at different parts of flood prone areas of the country viz., Agra, Ahmedabad, Asansol, Bengaluru, Bhubaneswar, Chennai, Guwahati, Hyderabad, Jalpaiguri, Lucknow, New Delhi, Srinagar, Thiruvananthapuram, Patna and Kolkata, cater this service which is shown in figure 1 and also their details are mentioned in Table 1.

After the disastrous floods in the state of Jammu & Kashmir in September 2014, the government decided to issue flood forecast for Jhelum Basin on operational basis from flood season 2015. FMO, Srinagar started issuing QPF operationally for Jhelum river sub Basins from the flood season 2015 and supplied to CWC to support their flood forecasting activities. In addition to these, four new Basins namely, Pennar, Sankosh, Jaldhaka and Torsa are included for issuance of operational QPF’s for their flood forecast activities. Additional new river sub-basins of Kerala State are also included under FMO Bengaluru for this activity in 2019 after the Kerala flood in 2018. During this year (2021), a new FMO was commissioned at Thiruvananthapuram for issuing QPF of 8 river sub-basins of west flowing rivers situated in the state of Kerala, which were previously under FMO, Bengaluru. IMD also provides similar support to Damodar Valley Corporation (DVC) for the river Basins of Barakar and Damodar.

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

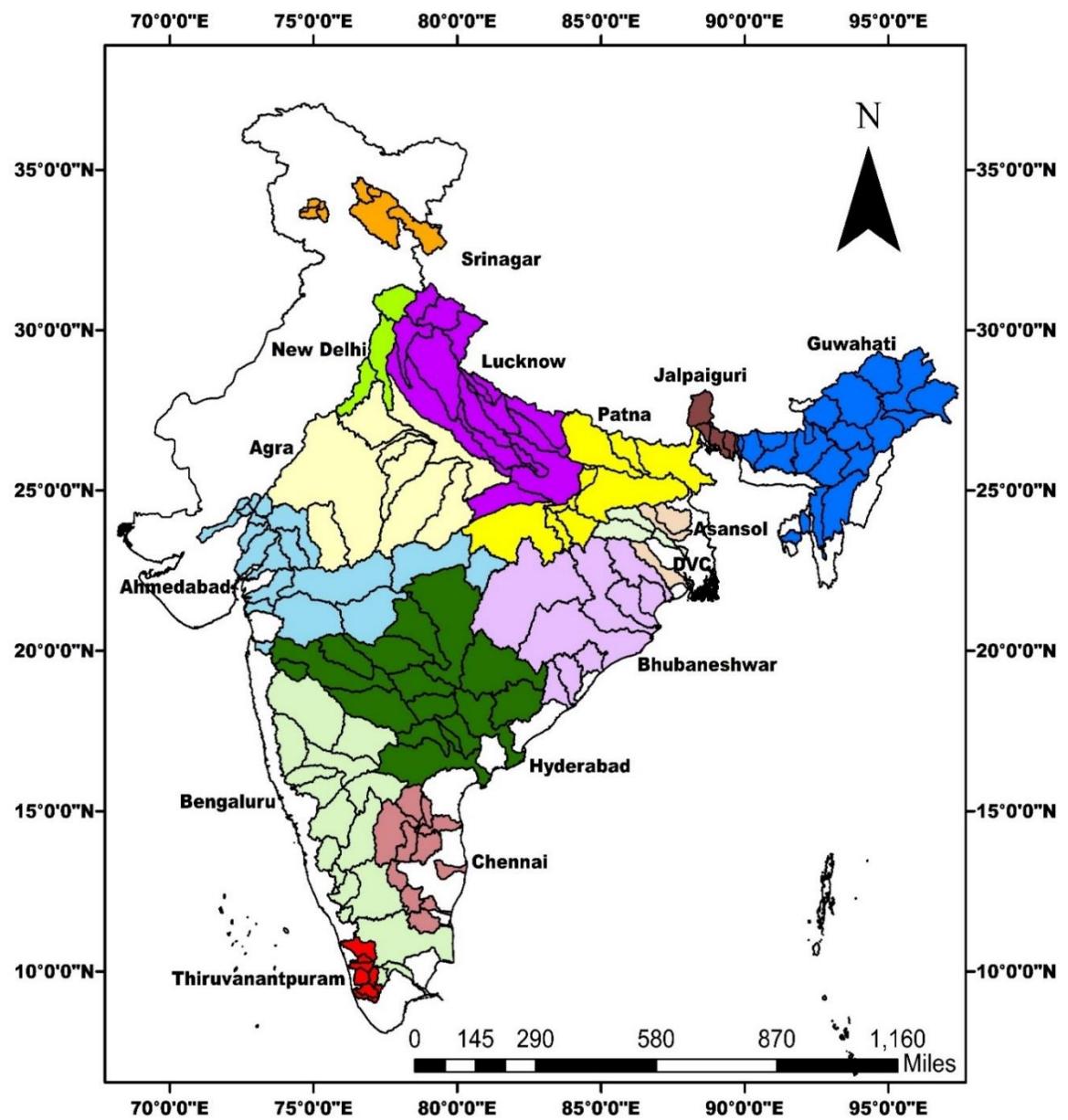


Figure 1: Map of Flood Meteorological offices with Sub-Basins in 2022

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

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

Flood Meteorological Service of IMD is provided through the FMOs. During flood season, daily QPF bulletin and Hydromet Bulletin are issued to Central Water Commission (CWC) for the purpose of their operational flood forecasting. QPF bulletin is issued at 0930 hrs IST and Hydromet Bulletin at 1230 hrs IST. Analysing the dynamical model past performances, this year the validity of sub-basin-wise QPF is increased from 3 days to 5 days. Categorical Sub-basin-wise QPF is issued for a lead-time of 7 days (forecast for 5 days and outlook for subsequent 2 days). If situation demands, QPF bulletins can be further updated in the evening.

SOP for Formulation of QPF & Hydromet Bulletin

Hydromet Bulletin contains the following information;

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

Table - 2. QPF category and their colour codes

| QPF Categories (mm) | Colour Code |
|------------------------|-------------|
| 0 | |
| 0.1-10 | Green |
| 11-25 | Blue |
| 26-50 | Yellow |
| 51-100 | Orange |
| >100 | Red |

Table - 3. PQPF category and their colour codes

| Probability of Occurrence (%) | Colour Code |
|----------------------------------|-------------|
| 0-5 | Grey |
| 5-25 | Light Blue |
| 25-50 | Light Green |
| 50-75 | Yellow |
| 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).

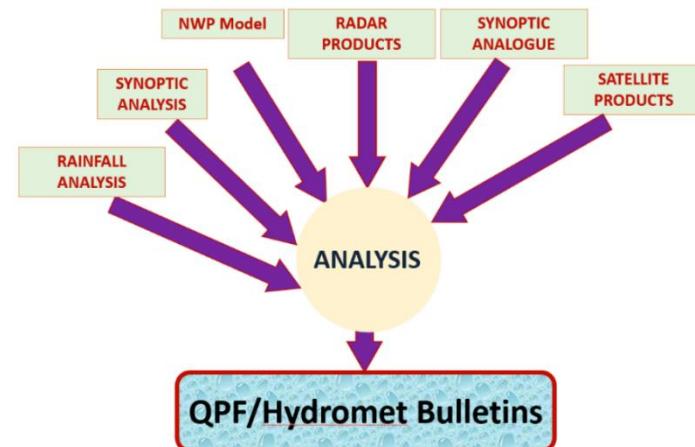


Figure 2. Input for issuing of QPF/Hydromet Bulletins

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).

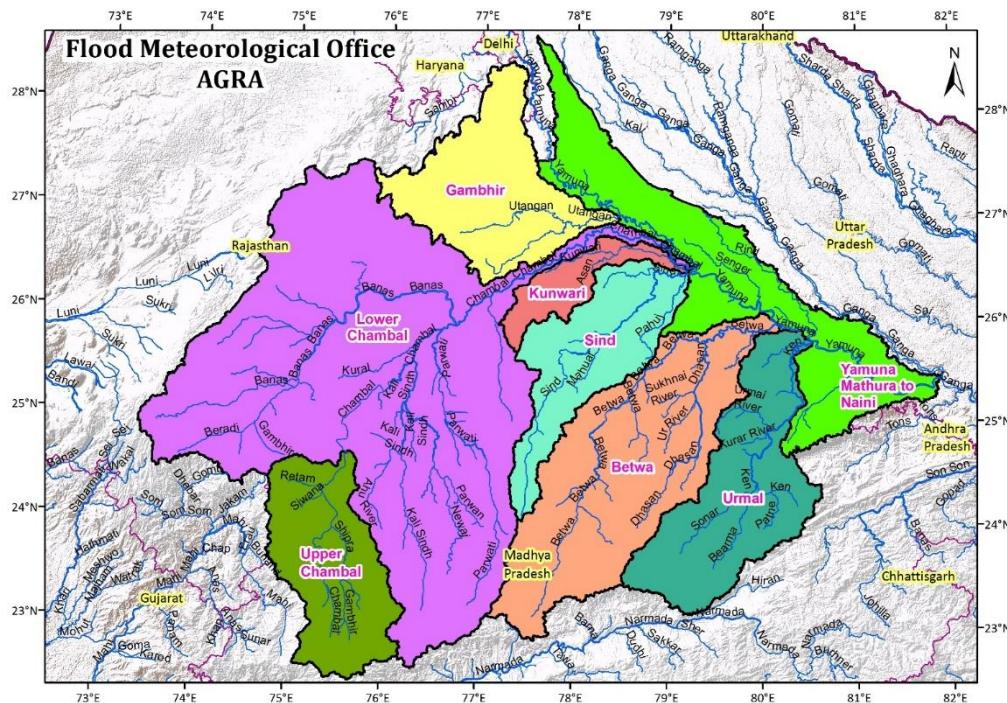


Figure 3: Map of FMO Agra with Sub-basins

There are total of 8 sub-basins under the FMO Agra. The name of basins, sub-basins with area (in Km²) are given in Table 6.

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

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

2.2 FMO Ahmedabad

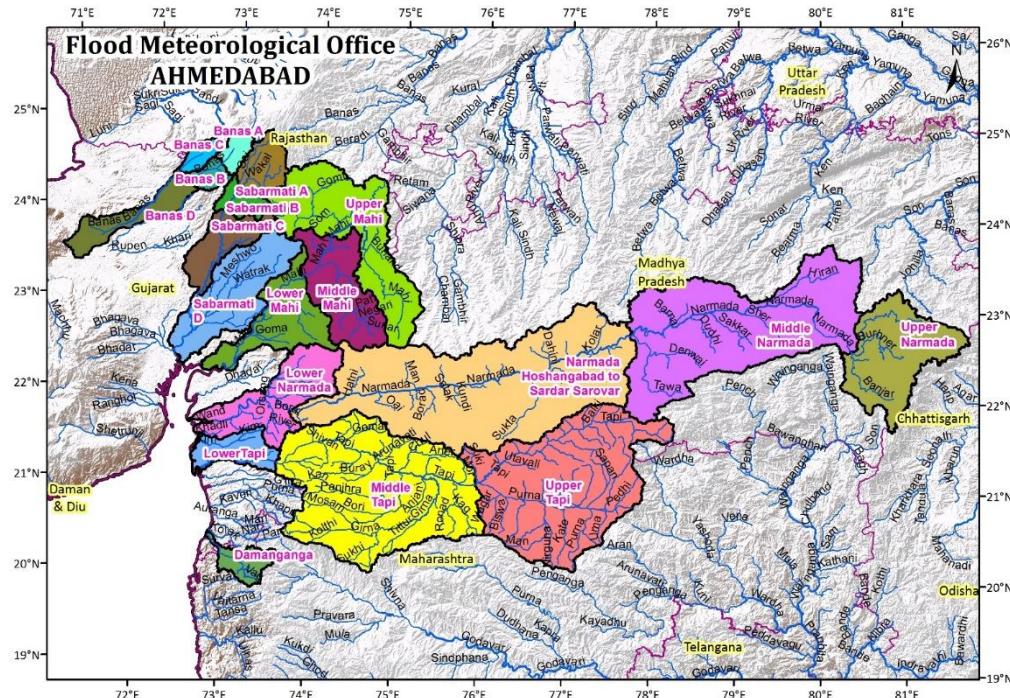


Figure 4: Map of FMO Ahmedabad with Sub-basins

The Flood Meteorological office, Ahmedabad was established in the year 1974 to issue QPF sub-basin-wise in rivers Narmada, Tapi, Mahi, Sabarmati, Banas and Damanganga. It lies in the states of Madhya Pradesh, Gujarat, Rajasthan, Maharashtra and UT of Daman & Diu (figure 4). There are total of 19 sub-basins under the FMO Ahmedabad. The name of basins, sub-basins with area (in Km²) are given in Table 7.

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

| FMO Ahmedabad | | | |
|---------------|-----------|---------------------------------------|----------------|
| S. No. | Basin | Sub-Basin | Area (Sq. Km.) |
| 1 | Narmada | Upper Narmada | 12441.93 |
| 2 | | Middle Narmada | 30782.56 |
| 3 | | Narmada Hoshangabad to Sardar Sarovar | 40543.90 |
| 4 | | Lower Narmada | 9715.95 |
| 5 | Tapi | Upper Tapi | 28592.98 |
| 6 | | Middle Tapi | 31221.03 |
| 7 | | Lower Tapi | 3598.13 |
| 8 | Mahi | Upper Mahi | 15721.00 |
| 9 | | Middle Mahi | 9231.46 |
| 10 | | Lower Mahi | 8123.46 |
| 11 | Sabarmati | Sabarmati A | 3259.47 |
| 12 | | Sabarmati B | 1827.70 |
| 13 | | Sabarmati C | 4626.83 |
| 14 | | Sabarmati D | 10697.66 |

| | | | |
|--------------|-------------------|-------------------|------------------|
| 15 | Banas | Banas A | 1376.87 |
| 16 | | Banas B | 1282.91 |
| 17 | | Banas C | 1205.89 |
| 18 | | Banas D | 4450.55 |
| 19 | Damanganga | Damanganga | 2245.69 |
| Total | | | 220945.97 |

2.3 FMO Asansol

The Flood Meteorological office, Asansol was established in the year 1980 to issue QPF sub-basin wise in rivers Mayurakshi, Ajoy and Kangsabati. It lies in the states of West Bengal and Jharkhand (figure 5).

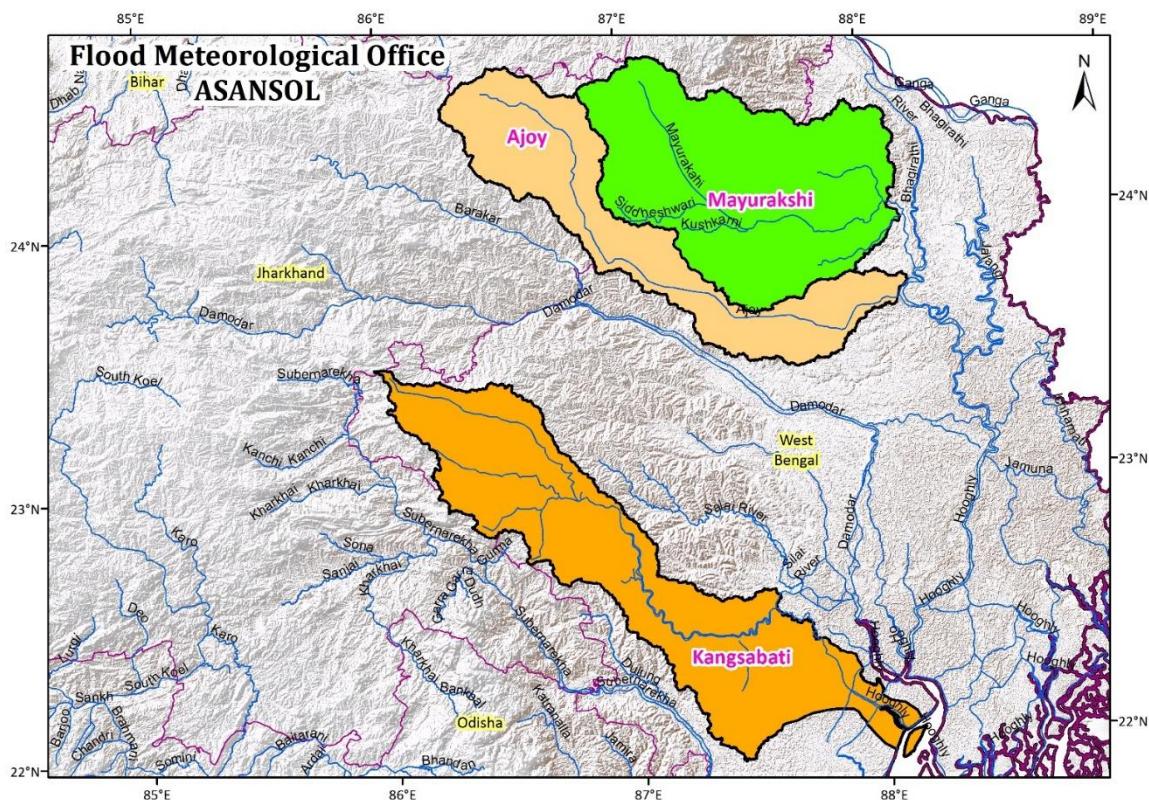


Figure 5: Map of FMO Asansol with Sub-basins

There are total of 3 sub-basins under the FMO Asansol. The name of basins, sub-basins with area (in Km²) are given in Table 8.

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

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

2.4 FMO Bengaluru

The Flood Meteorological office, Bengaluru is established in the year 2016 to issue QPF sub-basin wise in rivers Cauvery, Krishna, Tungabhadra, Kabini, Harangi, Hemavathi, Ghataprabha, Bennehalli. It lies in the states of Maharashtra, Karnataka, Tamil Nadu and some parts of Andhra Pradesh (figure 6).

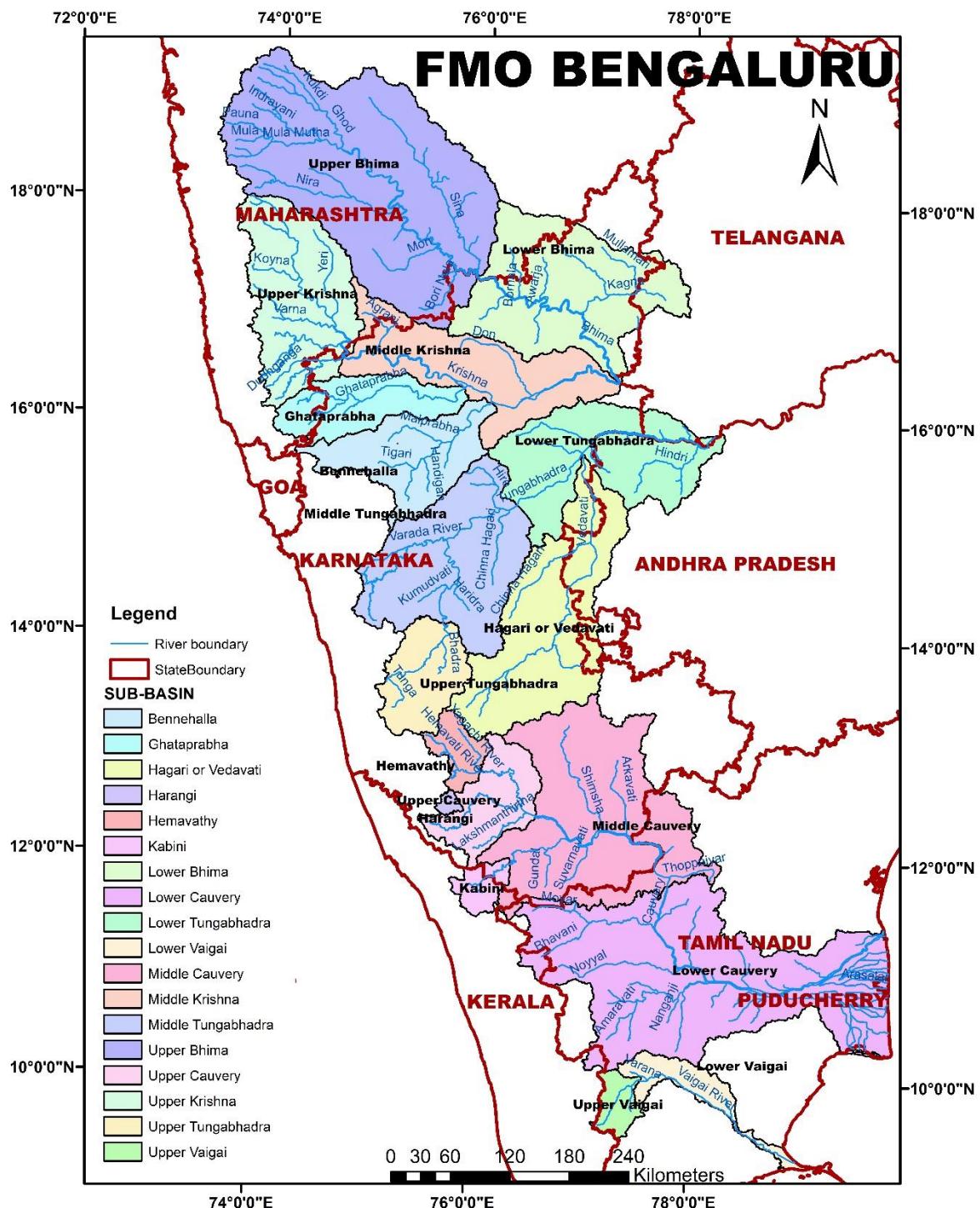


Figure 6: Map of FMO Bengaluru with Sub-basins

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

| FMO Bengaluru | | | |
|---------------|---------|--------------------|----------------|
| S. No. | Basin | Sub-Basin | Area (Sq. Km.) |
| 1 | Cauvery | Harangi | 421.96 |
| 2 | Cauvery | Hemavathy | 2897.23 |
| 3 | Cauvery | Kabini | 2176.75 |
| 4 | Cauvery | Middle Cauvery | 29808.80 |
| 5 | Cauvery | Upper Cauvery | 7639.61 |
| 6 | Cauvery | Lower Cauvery | 42681.88 |
| 7 | Cauvery | Upper Vaigai | 2273.47 |
| 8 | Cauvery | Lower Vaigai | 4122.33 |
| 9 | Krishna | Upper Krishna | 17558.19 |
| 10 | Krishna | Middle Krishna | 17100.41 |
| 11 | Krishna | Ghataprabha | 8507.49 |
| 12 | Krishna | Bennehalla | 11338.67 |
| 13 | Krishna | Upper Bhima | 44793.32 |
| 14 | Krishna | Lower Bhima | 23652.70 |
| 15 | Krishna | Hagari/Vedavati | 23183.15 |
| 16 | Krishna | Lower Tungabhadra | 18481.57 |
| 17 | Krishna | Upper Tungabhadra | 7705.97 |
| 18 | Krishna | Middle Tungabhadra | 20813.44 |
| Total | | | 285156.90 |

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

2.5 FMO Bhubaneswar

The Flood Meteorological office, Bhubaneswar was established in the year 1974 to issue QPF sub-basin-wise in rivers Subarnarekha, Brahmani, Burhabalang, Baitarni, Mahanadi, Vamsadhara, Rushikulya. It lies in the states of Odisha, Chhattisgarh, West Bengal, Jharkhand and some parts of Andhra Pradesh (figure 7).

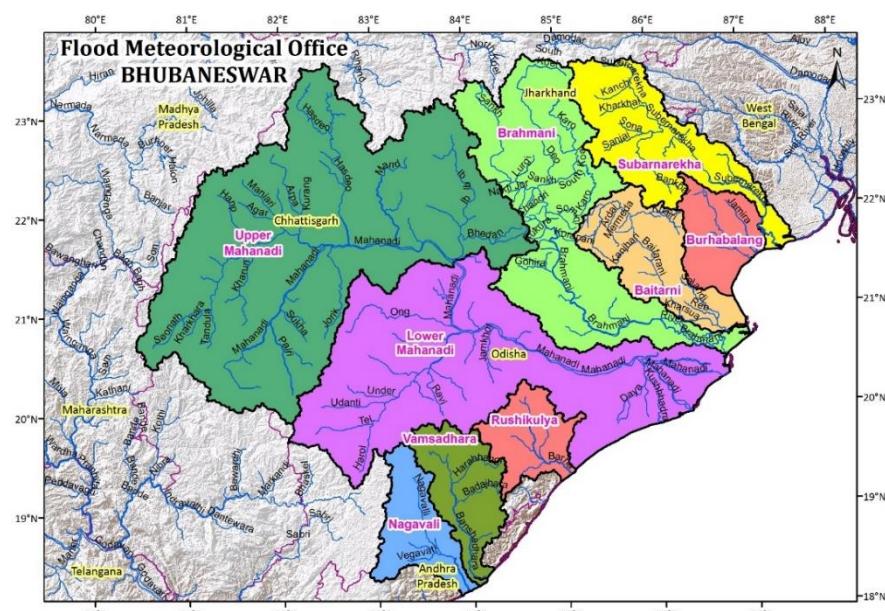


Figure 7: Map of FMO Bhubaneswar with Sub-basins

There are total of 9 sub-basins under the FMO Bhubaneswar. The name of basins, sub-basins with area (in Km²) are given in Table 10.

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

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

2.6 FMO Chennai

The Flood Meteorological office, Chennai is started from this year 2016 to issue QPF sub-basin-wise in rivers Pennar, Vaigai, Vellar, Kunderu, Gummanur, Cheyyeru, Papagni and Sagileru. It lies in the states of Andhra Pradesh, Karnataka, Tamil Nadu and UT Puducherry (figure 8).

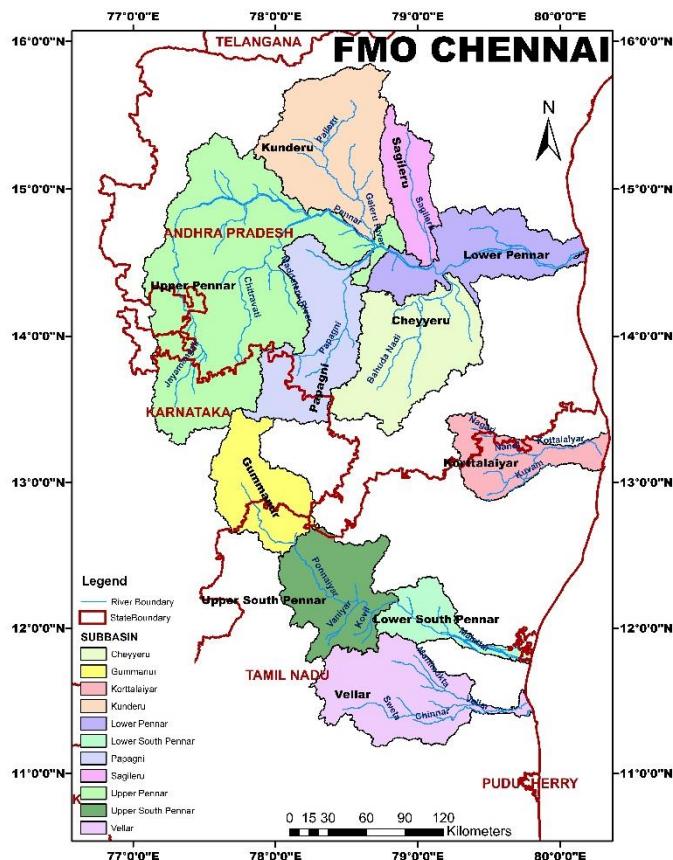


Figure 8: Map of FMO Chennai with Sub-basins

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

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

| FMO Chennai | | | |
|-------------|---------------------|--------------------|----------------|
| Sl. | BASIN | SUBBASIN | Area (Sq. Km.) |
| 1 | East Flowing Rivers | Gummanur | 5065.40 |
| 2 | | Upper South Pennar | 5866.20 |
| 3 | | Korttalaiyar | 3866.58 |
| 4 | | Vellar | 7440.81 |
| 5 | | Lower South Pennar | 2731.65 |
| 6 | Pennar | Kunderu | 8591.64 |
| 7 | | Sagileru | 3151.62 |
| 8 | | Upper Pennar | 21320.54 |
| 9 | | Lower Pennar | 6147.5 |
| 10 | | Papagni | 7047.79 |
| 11 | | 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).

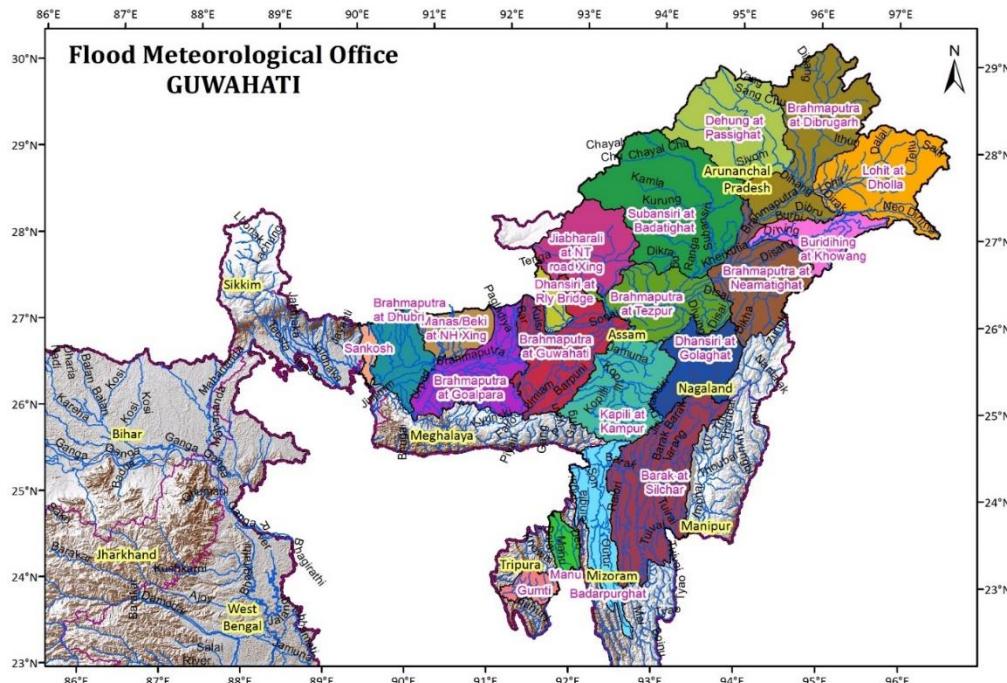


Figure 9: Map of FMO Guwahati with Sub-basins

There are total of 20 sub-basins under the FMO Guwahati. The name of basins, sub-basins with area (in Km²) are given in Table 12.

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

| FMO Guwahati | | | |
|--------------|--------------------|-------------------------------------|------------------|
| S. No. | Basin | Sub-Basin | Area (Sq. Km.) |
| 1 | Barak | Barak at Silchar | 18023.39 |
| 2 | | Badarpurghat | 7864.68 |
| 3 | Manu | Manu | 2137.63 |
| 4 | Gumti | Gumti | 2158.16 |
| 5 | Brahmaputra | Dehung at Passighat | 13920.42 |
| 6 | | Lohit at Dholla | 13855.87 |
| 7 | | Brahmaputra at Dibrugarh | 18046.84 |
| 8 | | Buridihing at Khowang | 5631.86 |
| 9 | | Subansiri at Badatighat | 23118.67 |
| 10 | | B-putra at Neamatighat | 11144.47 |
| 11 | | Dhansiri (S) at Golaghat | 7972.70 |
| 12 | | Brahmaputra at Tezpur | 10695.21 |
| 13 | | Jiabharali at NT road Xing | 9774.35 |
| 14 | | Dhansiri (N) at Rly Bridge | 2002.96 |
| 15 | | Kapili at Kampur | 11997.15 |
| 16 | | Brahmaputra at Guwahati | 13150.86 |
| 17 | | Manas/ Beki at N H Xing | 4754.78 |
| 18 | | Brahmaputra at Goalpara | 10781.00 |
| 19 | | Brahmaputra at Dhubri | 6198.57 |
| 20 | | Sankosh | 1125.52 |
| Total | | | 194355.09 |

2.8 FMO Hyderabad

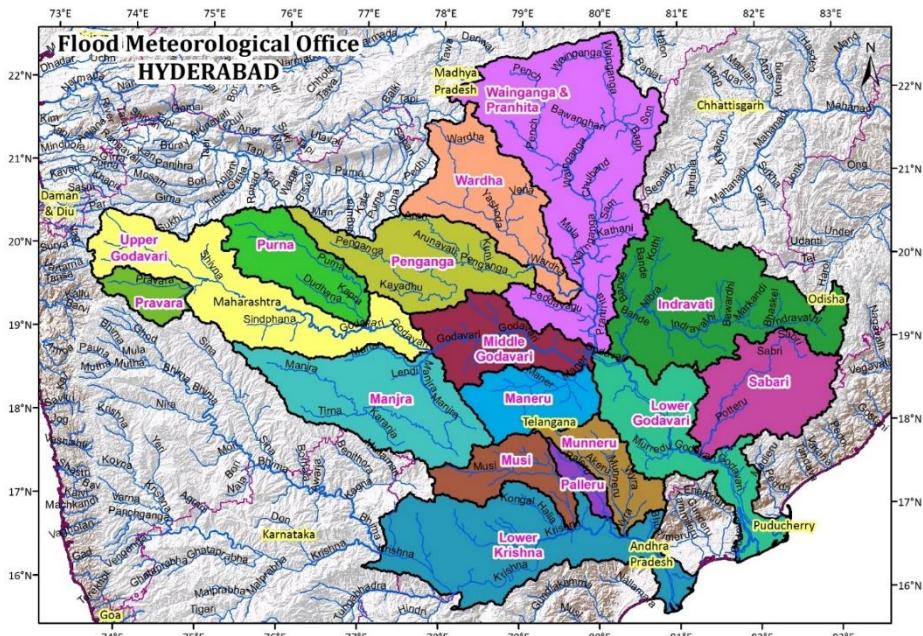


Figure 10: Map of FMO Hyderabad with Sub-basins

The Flood Meteorological office, Hyderabad was established in the year 1977 to issue QPF sub-basin-wise in rivers Krishna, Godavari and Pennar. It lies in the states of Andhra Pradesh, Telengana, Maharashtra, Karnataka , Madhya Pradesh, Chhattisgarh and UT Puducherry (figure 10).

There are total of 16 sub-basins under the FMO Hyderabad. The name of basins, sub-basins with area (in Km²) are given in Table 13.

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

| FMO Hyderabad | | | |
|---------------|----------|----------------------|----------------|
| Sl. No. | BASIN | SUBBASIN | Area (Sq. Km.) |
| 1 | Godavari | Wainganga & Pranhita | 58316.70 |
| 2 | | Wardha | 23113.06 |
| 3 | | Penganga | 23129.04 |
| 4 | | Purna | 15353.98 |
| 5 | | Indravati | 39265.57 |
| 6 | | Upper Godavari | 32843.49 |
| 7 | | Pravara | 5386.38 |
| 8 | | Middle Godavari | 16390.07 |
| 9 | | Sabari | 20868.03 |
| 10 | | Manjra | 30062.41 |
| 11 | | Maneru | 12764.00 |
| 12 | | Lower Godavari | 24569.99 |
| 13 | Krishna | Munneru | 10127.33 |
| 14 | | Musi | 11015.19 |
| 15 | | Palleru | 2976.77 |
| 16 | | Lower Krishna | 37495.95 |
| Total | | | 363677.94 |

2.9 FMO Jalpaiguri

The Flood Meteorological office, Jalpaiguri was established in the year 1974 to issue QPF sub-basin-wise in rivers Teesta, Jaldhaka, Torsa & Raidak. It lies in the states of Sikkim & West Bengal (figure 11).

There are total of 5 sub-basins under the FMO Jalpaiguri. The name of basins, sub-basins with area (in Km²) are given in Table 14.

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

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

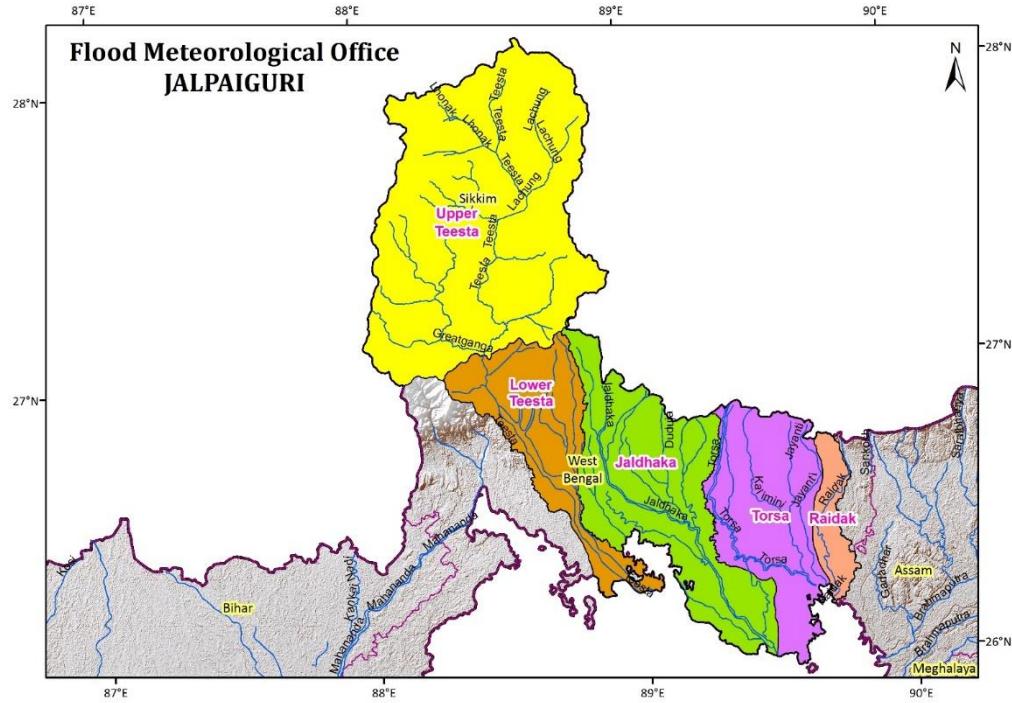


Figure 11: Map of FMO Jalpaiguri with Sub-basins

2.10 FMO Lucknow

The Flood Meteorological office, Lucknow was established in the year 1974 to issue QPF sub-basin-wise in rivers Alaknanda, Bhagirathi, Ganga, Ghaghra, Sharda and Rapti. It lies in the states of Uttarakhand, Uttar Pradesh and few areas of Madhya Pradesh and Bihar (figure 12).

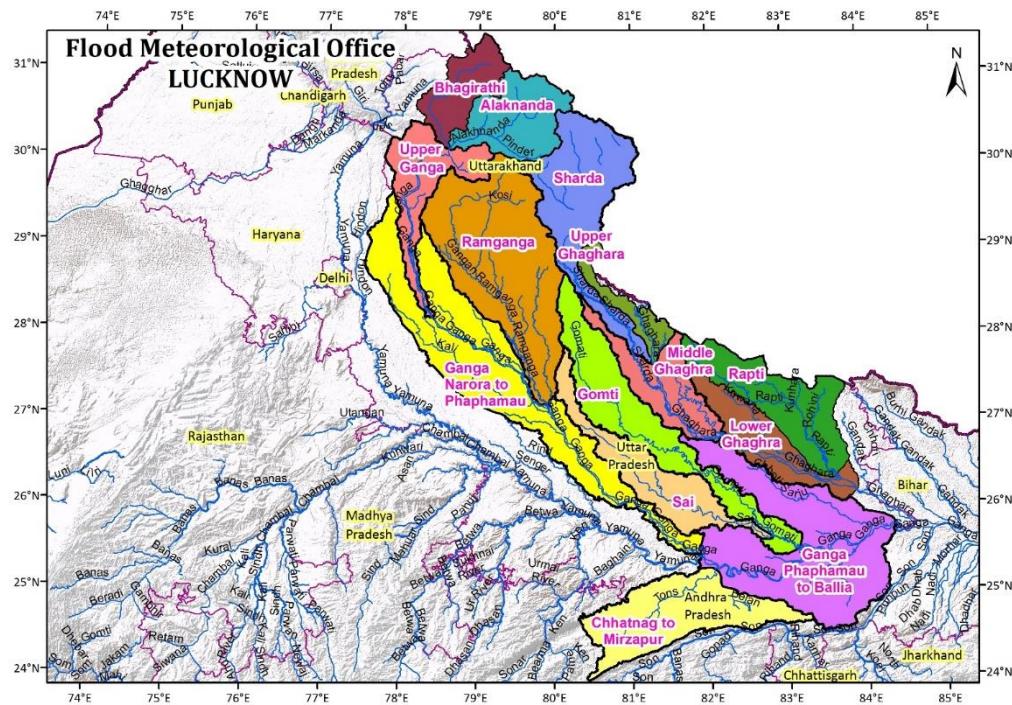


Figure 12: Map of FMO Lucknow with Sub-basins

There are total of 14 sub-basins under the FMO Lucknow. The name of basins, sub-basins with area (in Km²) are given in Table 15.

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

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

2.11 FMO New Delhi

The Flood Meteorological office, New Delhi was established in the year 1974 to issue QPF sub-basin wise in rivers Yamuna and Sahibi. It lies in the states of Himachal Pradesh, Haryana, Uttar Pradesh and Delhi (figure 13).

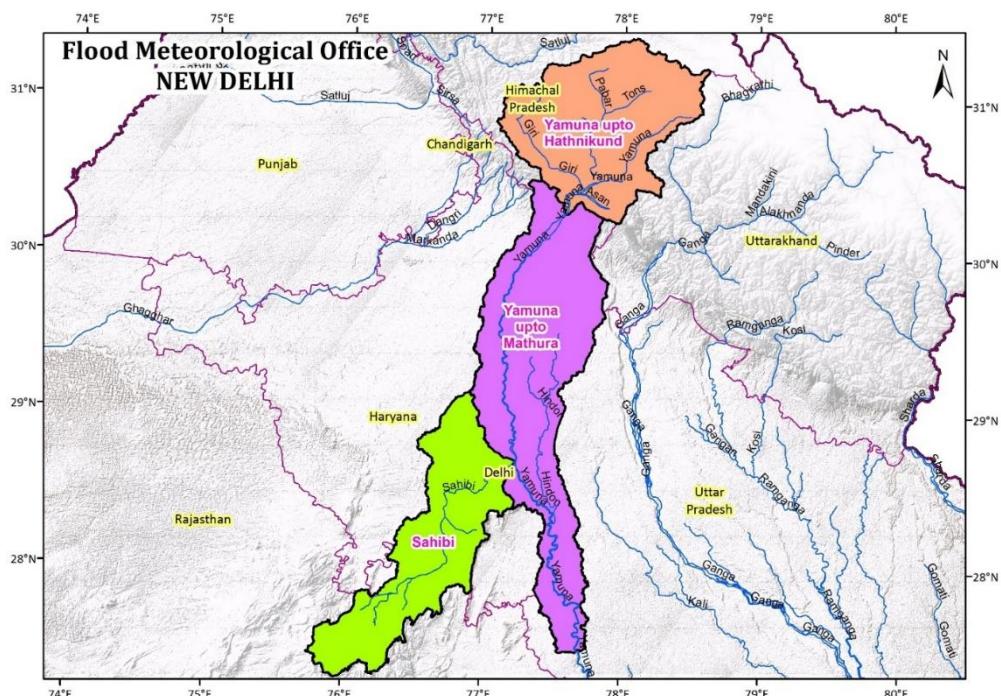


Figure 13: Map of FMO New Delhi with Sub-basins

There are total of 3 sub-basins under the FMO New Delhi. The name of basins, sub-basins with area (in Km²) are given in Table 16.

Table 16: Area-wise Basins/Sub-basins under FMO New Delhi

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

2.12 FMO Patna

The Flood Meteorological office, Patna was established in the year 1973 to issue QPF sub-basin-wise in rivers Kosi, Sone, Punpun, Bagmati, Gandak, North Koel and Kanhar. It lies in the states of Bihar, Chhattisgarh, Madhya Pradesh, Jharkhand, West Bengal and few areas of Uttar Pradesh (figure 14).

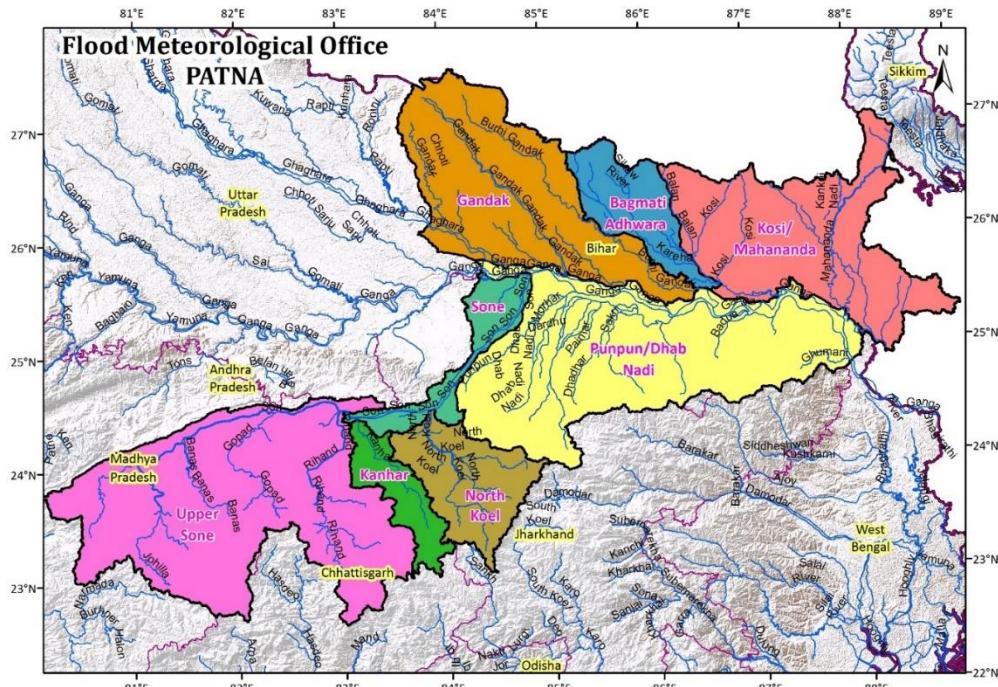


Figure 14: Map of FMO Patna with Sub-basins

There are total of 8 sub-basins under the FMO Patna. The name of basins, sub-basins with area (in Km²) are given in Table 17.

Table 17: Area-wise Basins/Sub-basins under FMO Patna

| FMO Patna | | | |
|-----------|-------|-----------------|----------------|
| S. No. | Basin | Sub-Basin | Area (Sq. Km.) |
| 1 | Ganga | Kosi/Mahananda | 27212.33 |
| 2 | | Bagmati Adhwara | 8256.36 |

| | | |
|--------------|-------------------|------------------|
| 3 | Gandak | 27709.29 |
| 4 | Sone | 6144.30 |
| 5 | Upper Sone | 45069.53 |
| 6 | Kanhar | 5509.92 |
| 7 | North Koel | 10761.26 |
| 8 | Zone VI | 41035.31 |
| Total | | 171698.30 |

2.13 FMO Srinagar

The Flood Meteorological office, Srinagar is started from this year 2015 to issue QPF sub-basin wise in Jhelum River for issuance of QPFs. It lies in the state of Jammu & Kashmir (figure 15).

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

| FMO Srinagar | | | |
|--------------|--------|-------------------|-----------------|
| Sl. No. | BASIN | SUBBASIN | Area (Sq. Km.) |
| 1 | Indus | Upshi Road Bridge | 11061.56 |
| 2 | | Nimmo | 17172.39 |
| 3 | | Khalsi | 1184.66 |
| 4 | | Dah | 3145.52 |
| 5 | Jhelum | Middle Jhelum | 1753.95 |
| 6 | | Upper Jhelum | 1244.90 |
| 7 | | Lidder | 479.96 |
| 8 | | Lower Jhelum | 1308.64 |
| Total | | | 37351.58 |

There are total of 8 sub-basins under the FMO, Srinagar. The name of basins, sub-basins with area (in Km²) are given in Table 18.

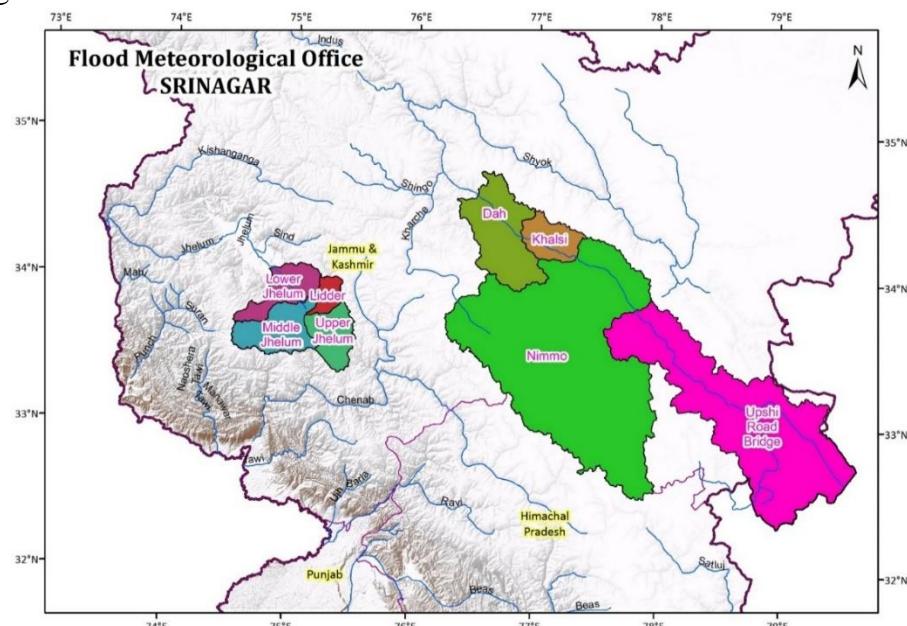


Figure 15: Map of FMO Srinagar with Sub-basins

2.14 FMO Thiruvananthapuram

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

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

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



Figure 16: Map of FMO Srinagar with Sub-basins

2.15 DVC Kolkata

The DVC, Kolkata was established in the year 1973 to issue QPF sub-basin-wise in rivers Barakar and Damodar. It lies in the states of Jharkhand and West Bengal (figure 17).

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

Table 20: Area-wise Basins/Sub-basins under DVC

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

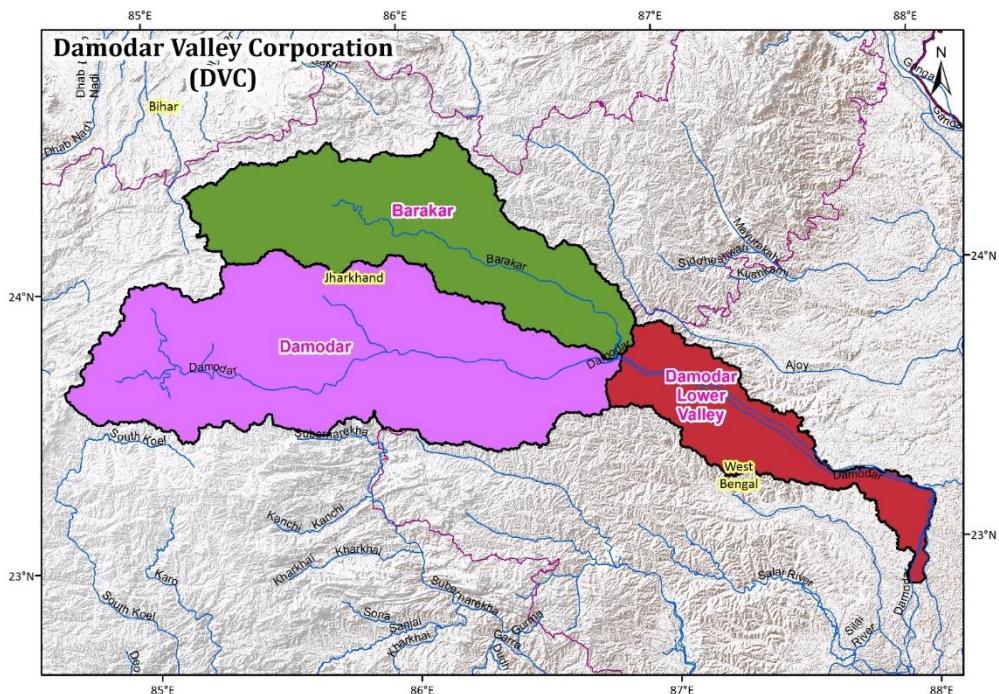


Figure 17: Map of DVC with Sub-basins

CHAPTER 3

Data Used and Methodology

3.1 Data Used

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

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

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

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

3.2 Methodology

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

Table 21: 6 X 6 Contingency table

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

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

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

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

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

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

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

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

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

CHAPTER 4

QPF Verification

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

4.1 Skill Scores of Day-1 QPF

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

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

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

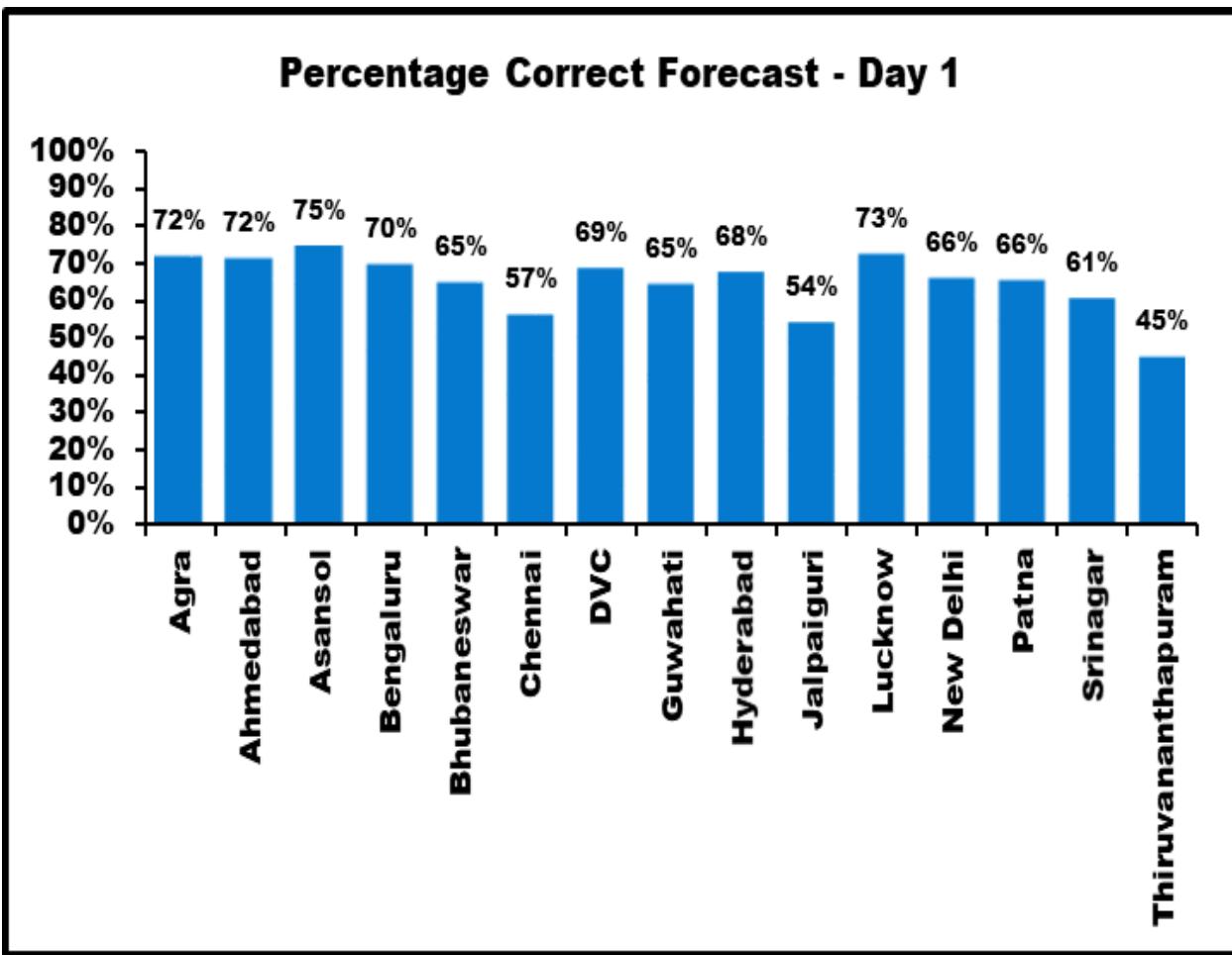


Figure 18: Percentage correct forecast Day-1 by different FMOs

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

Table 24: Skill Scores of Day-1 QPF

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

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

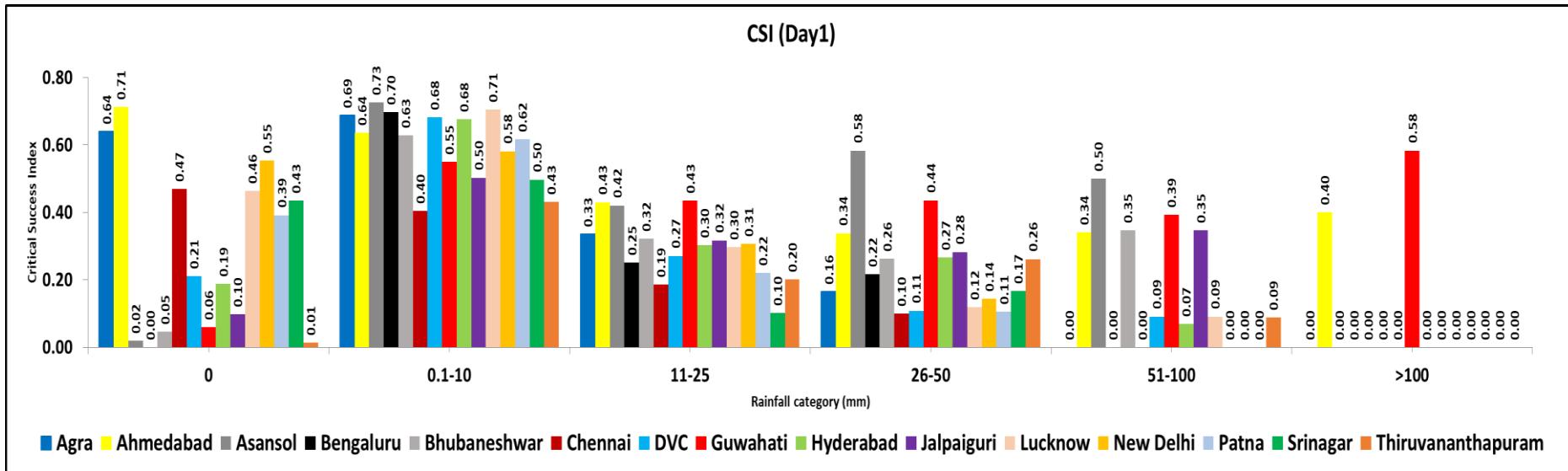


Figure 19: CSI for different categories of forecast for Day-1

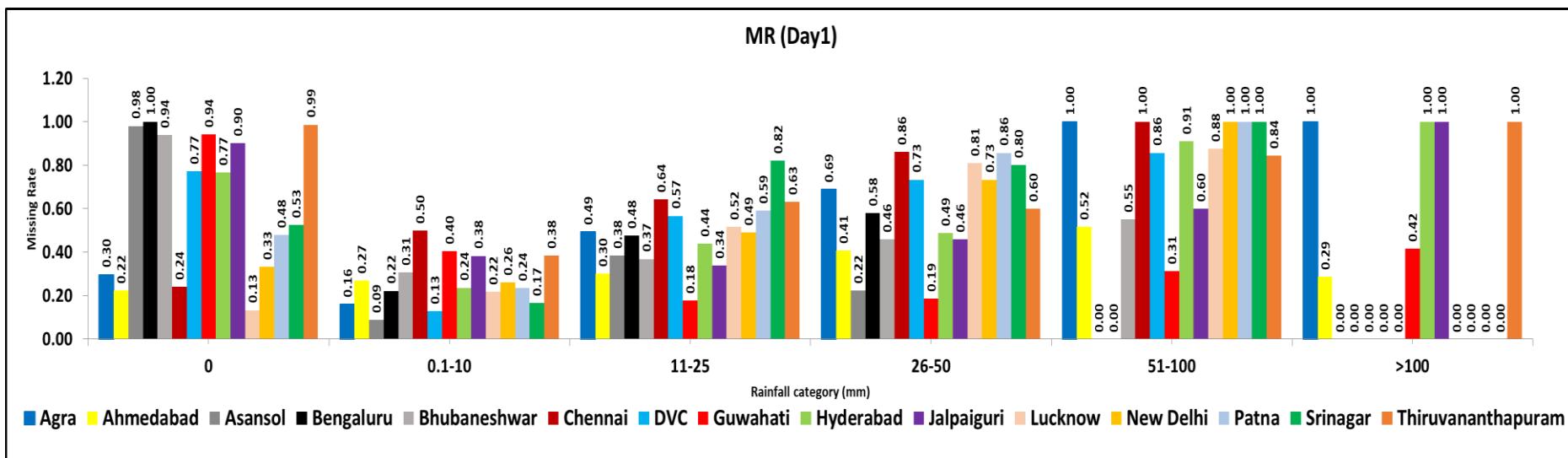


Figure 20: MR for different categories of forecast for Day-1

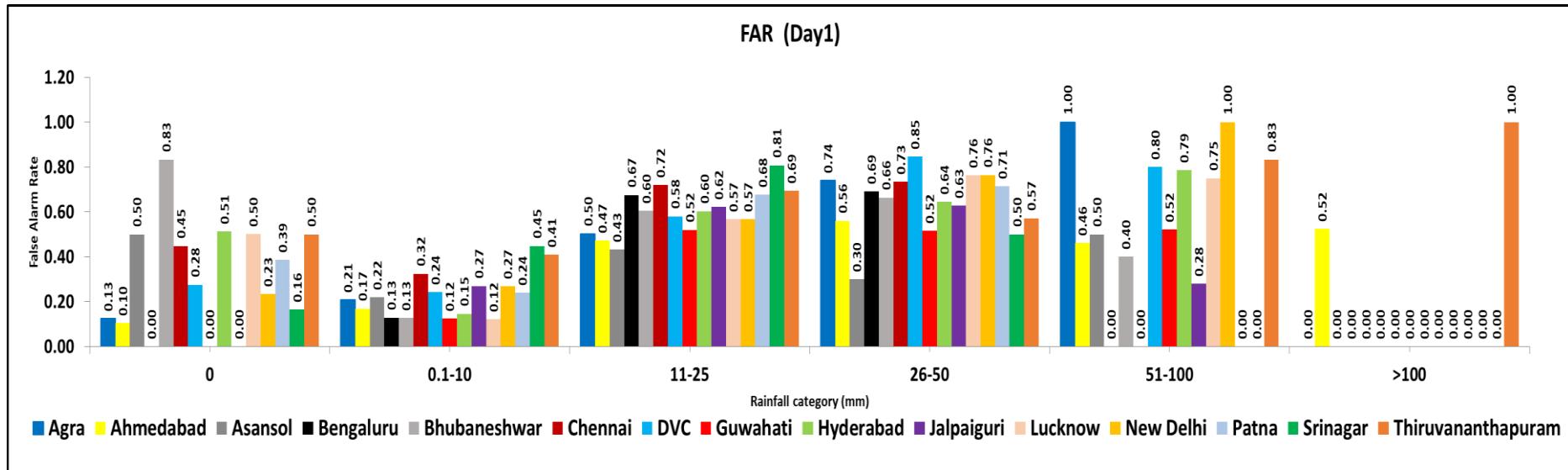


Figure 21: FAR for different categories of forecast for Day-1

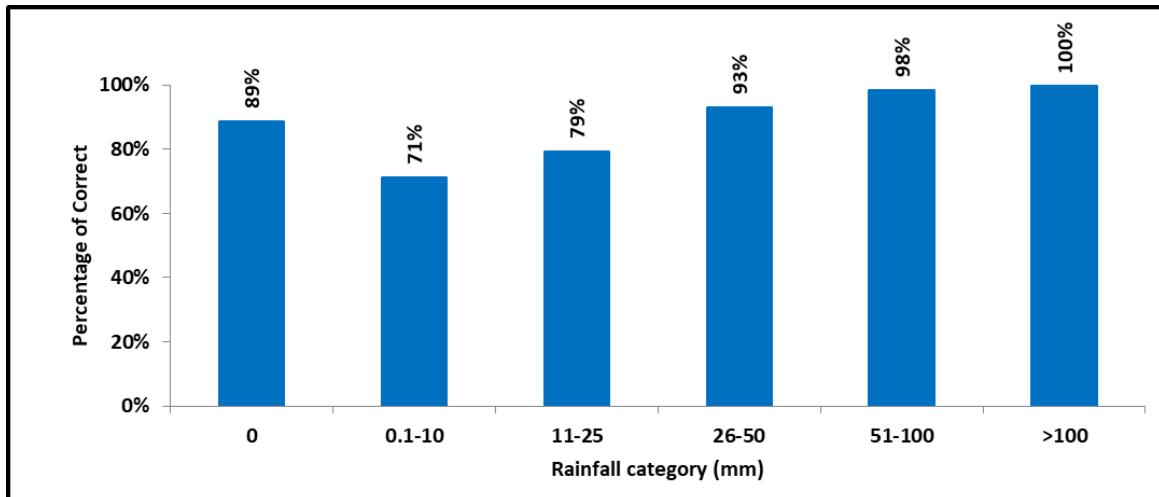


Figure 22: Category-wise Percentage Correct Forecast of Day-1

4.2 Skill Scores of Day-2 QPF

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

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

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

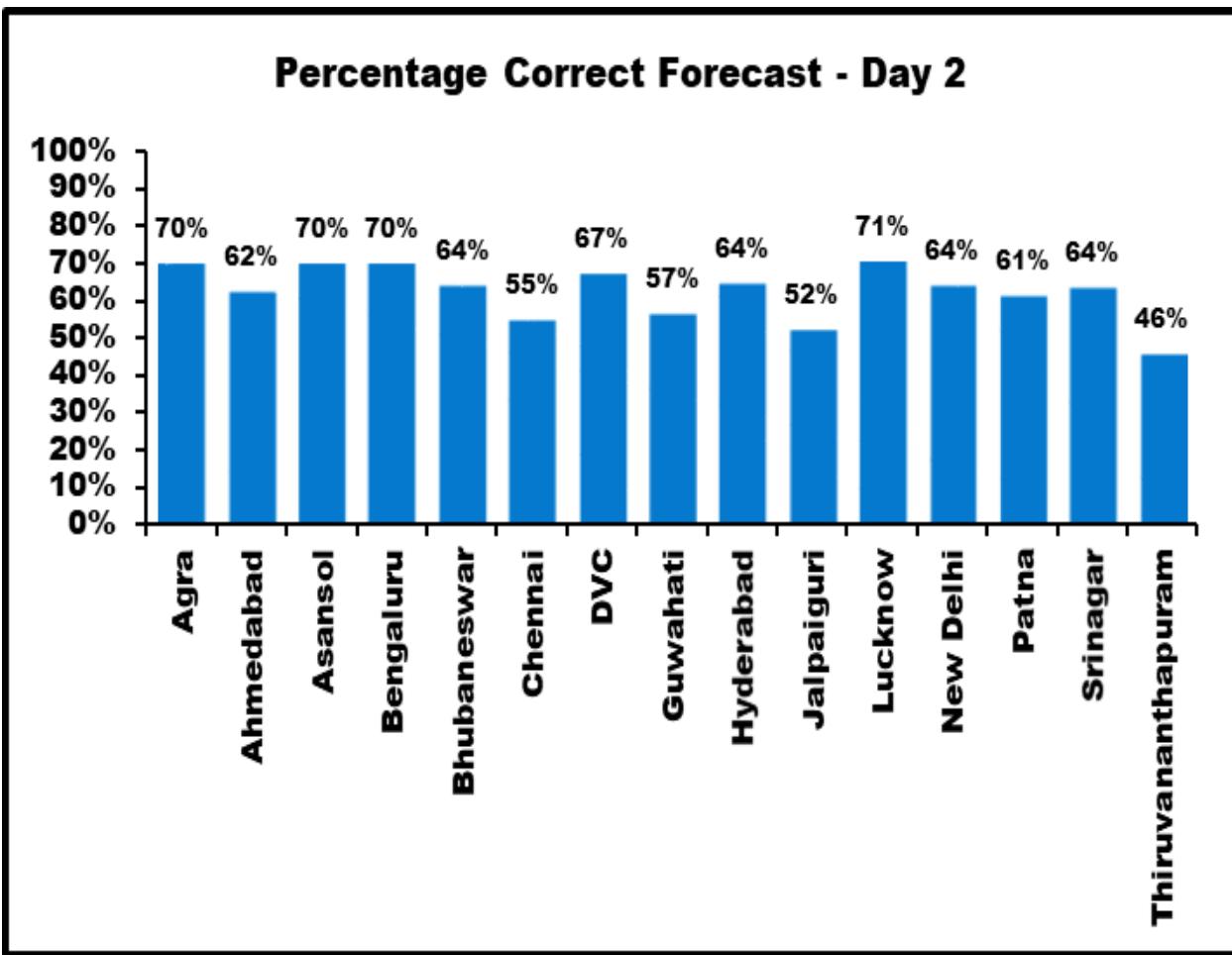


Figure 23. Percentage correct forecast Day-2 by different FMOs

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

Table 26: Skill Scores of Day-2 QPF

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

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

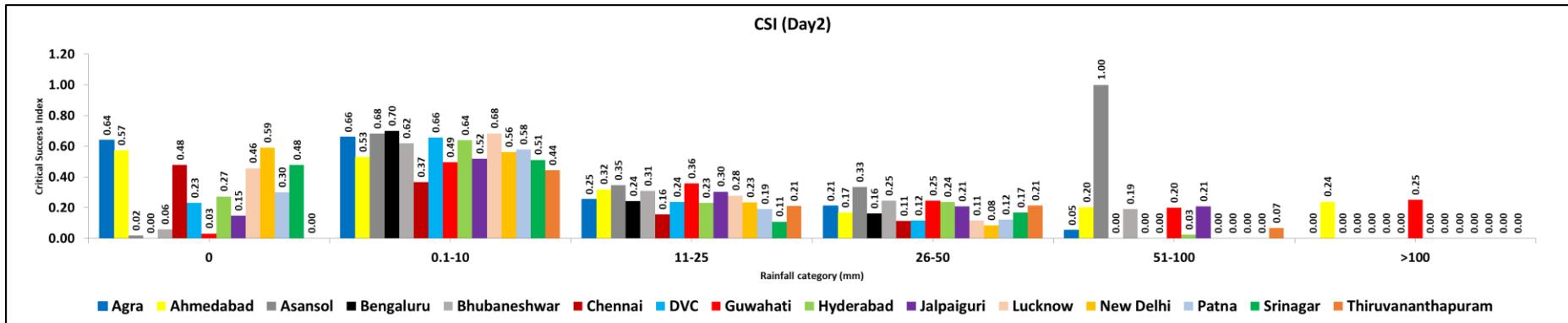


Figure 24: CSI for different categories of forecast for Day-2

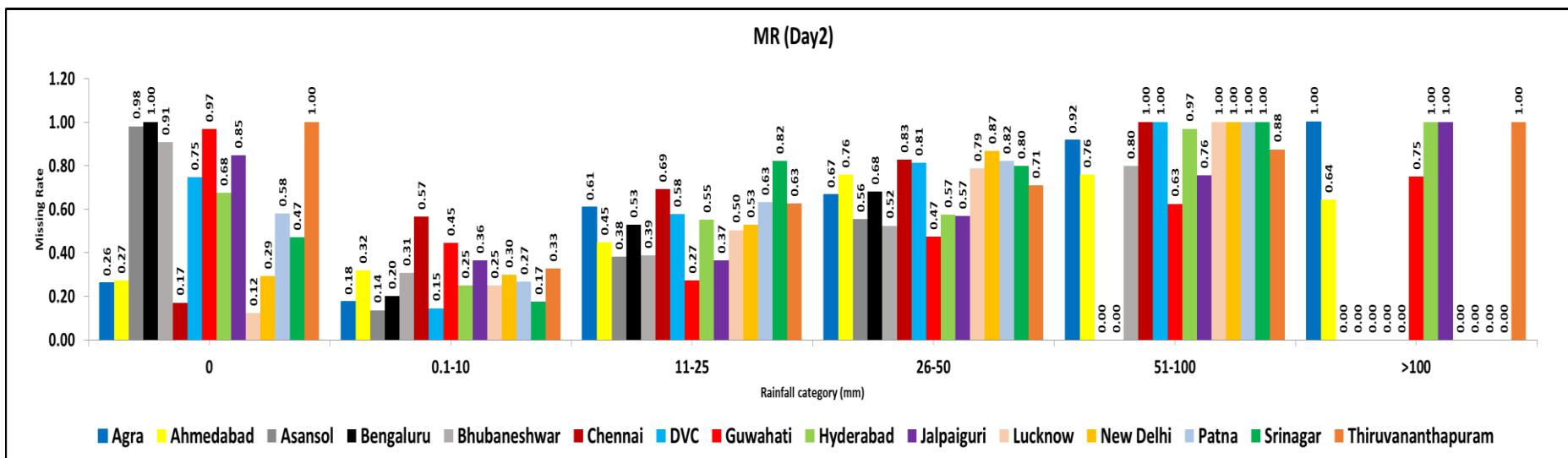


Figure 25: MR for different categories of forecast for Day-2

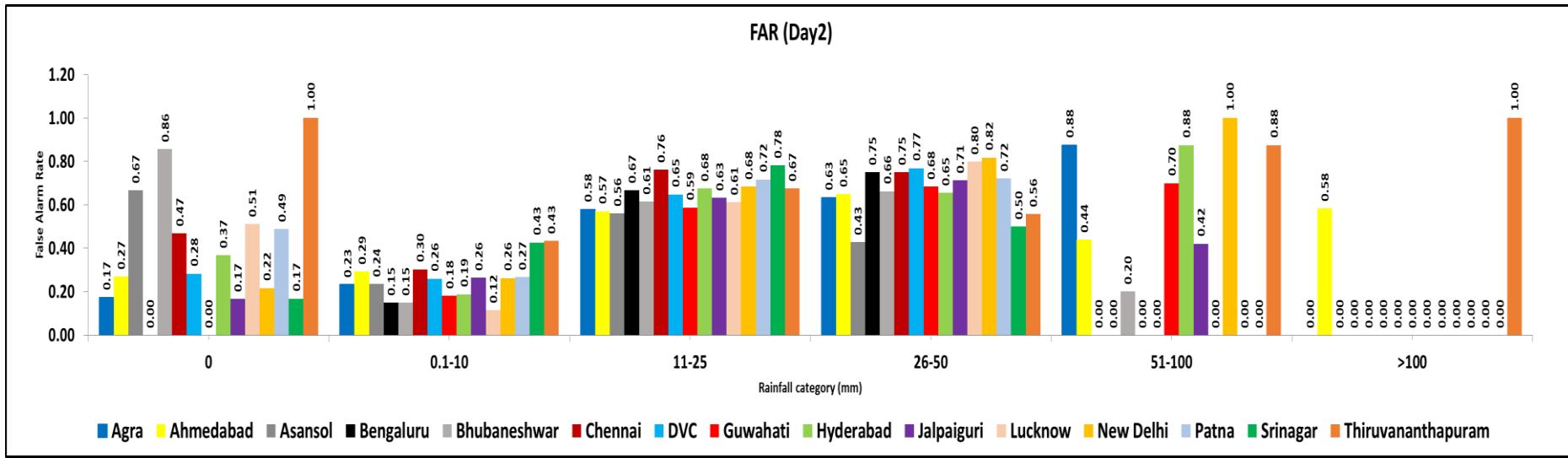


Figure 26: FAR for different categories of forecast for Day-2

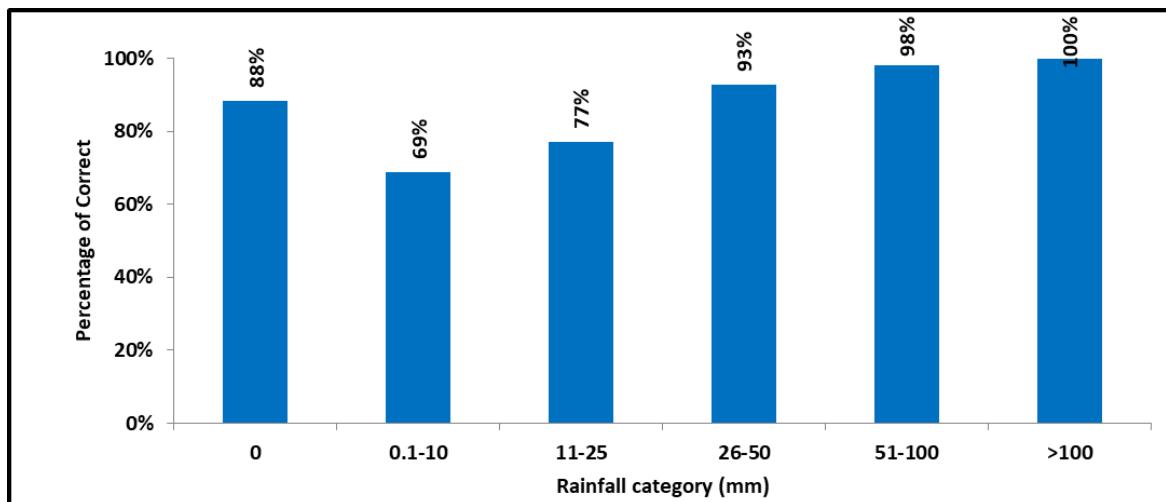


Figure 27: Category-wise Percentage Correct Forecast of Day-2

4.3 Skill Scores of Day-3 QPF

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

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

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

Percentage Correct Forecast - Day 3

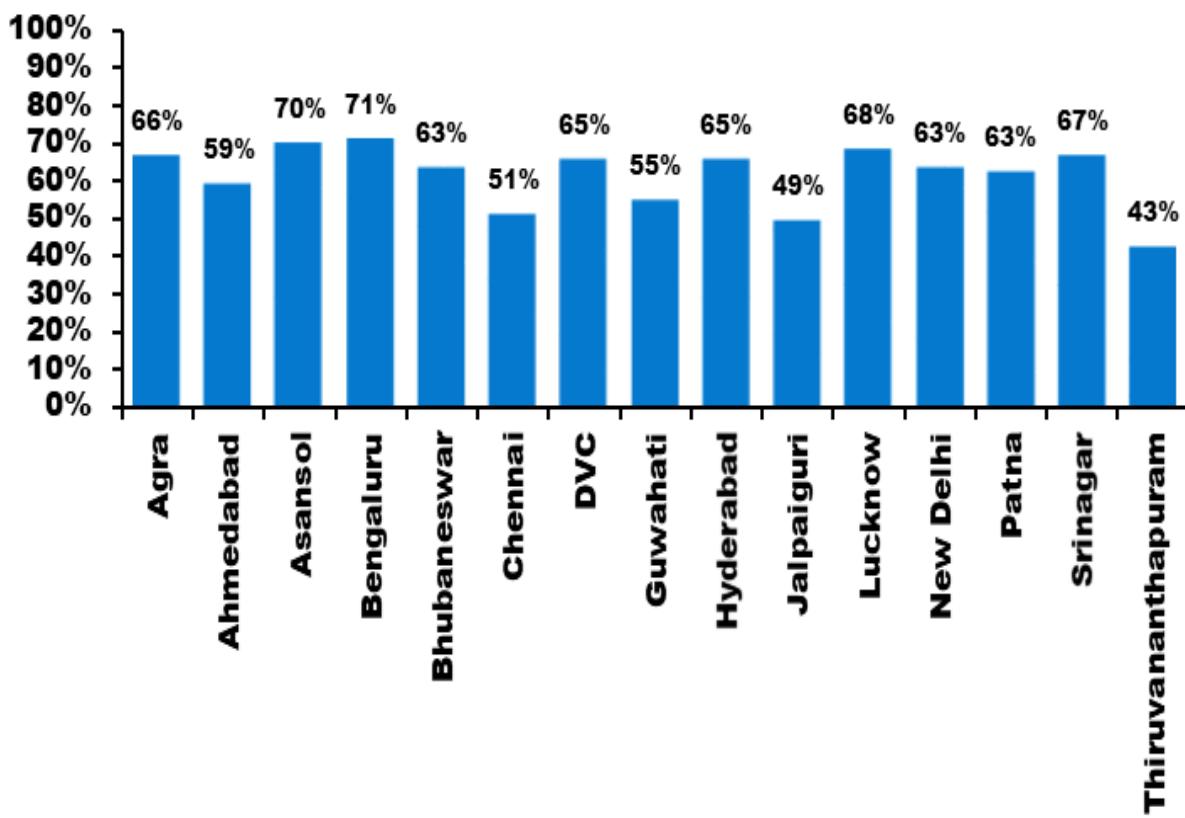


Figure 28. Percentage correct forecast Day-3 by different FMOs

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

Table 28: Skill Scores of Day-3 QPF

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

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

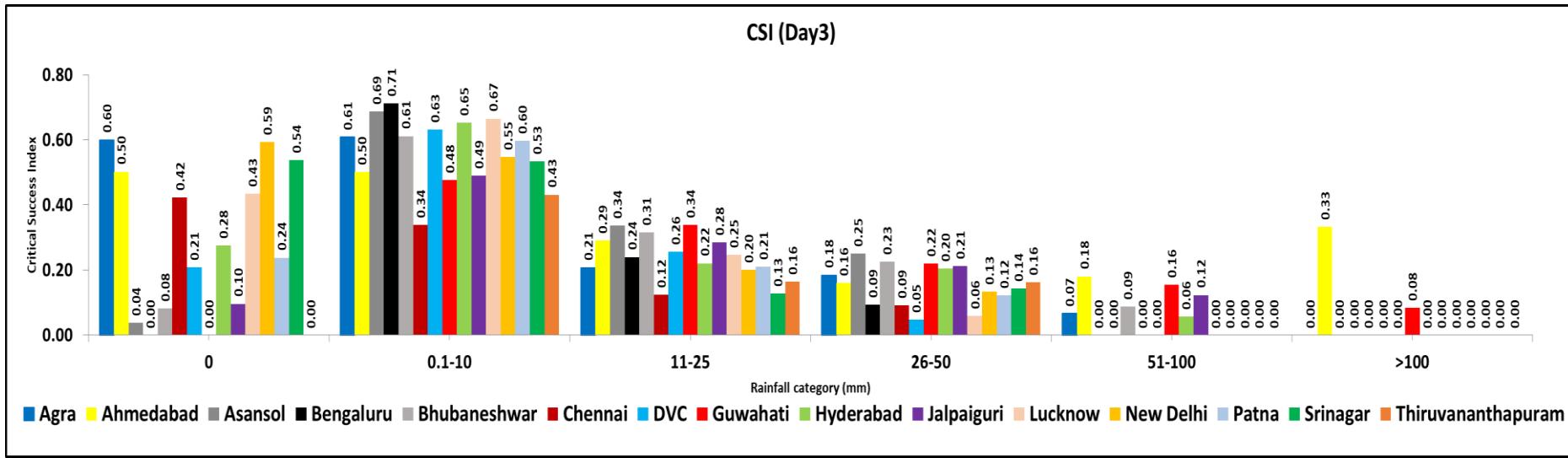


Figure 29: CSI for different categories of forecast for Day-3

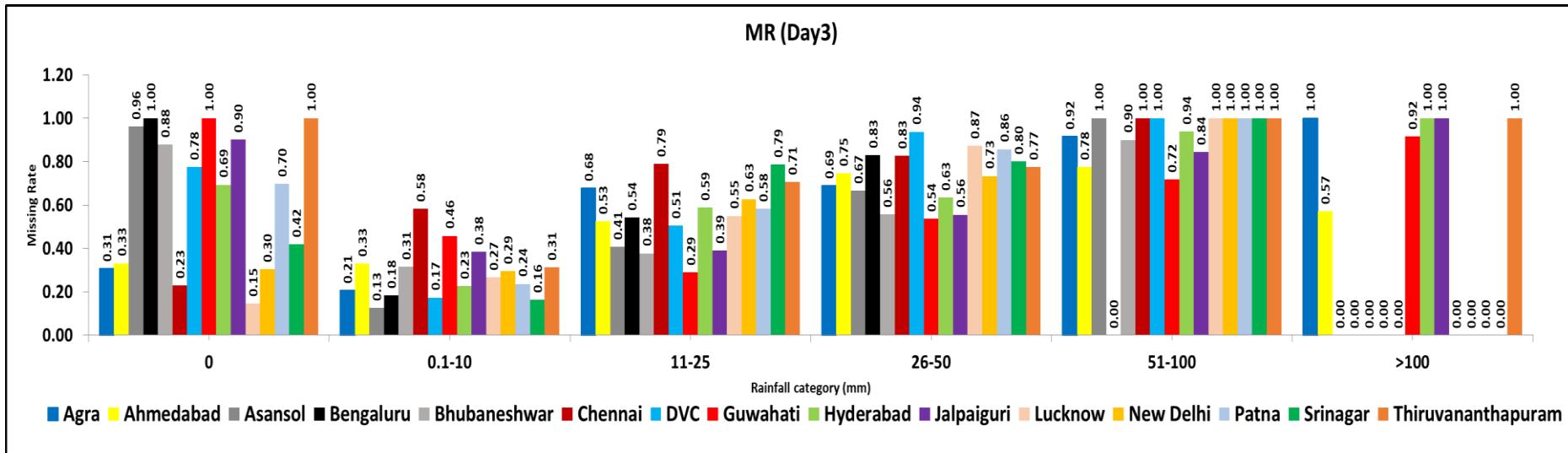


Figure 30: MR for different categories of forecast for Day-3

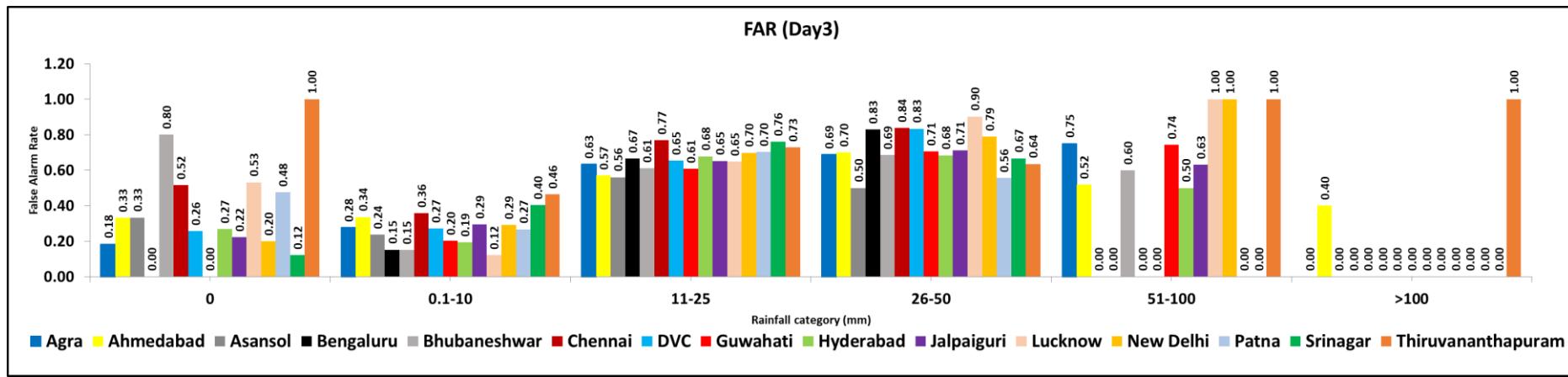


Figure 31: FAR for different categories of forecast for Day-3

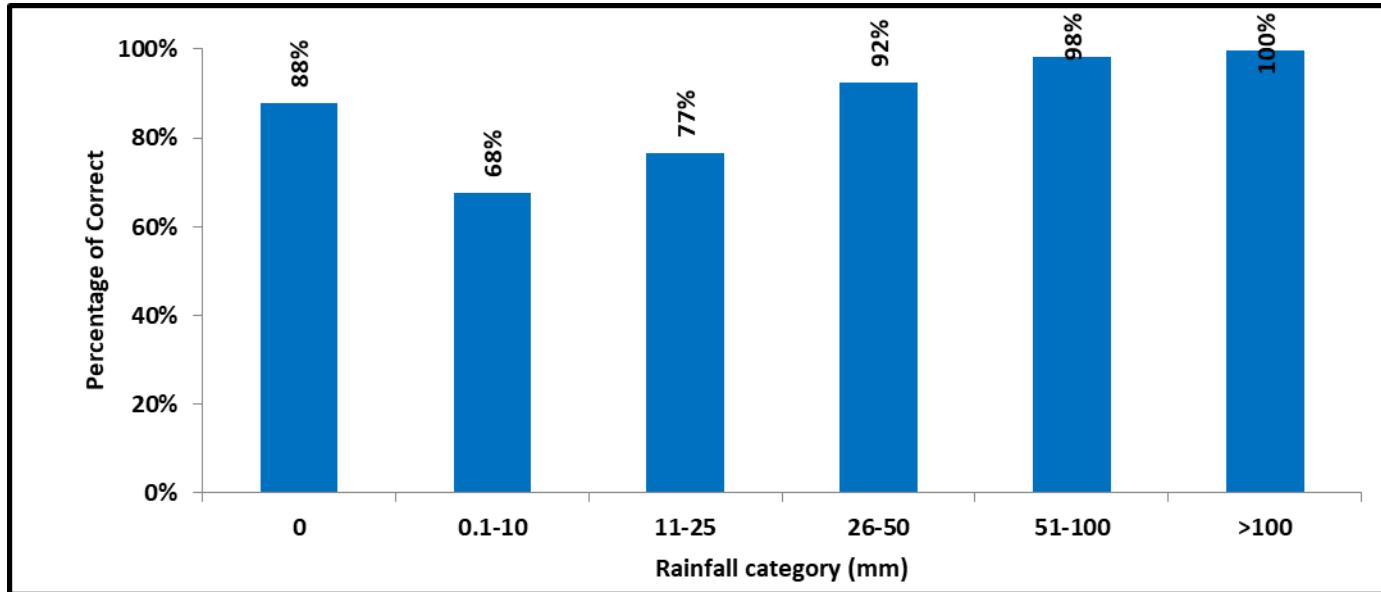


Figure 32: Category-wise Percentage Correct Forecast of Day-3

4.4 Skill Scores of Day-4 QPF

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

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

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

Percentage Correct Forecast - Day 4

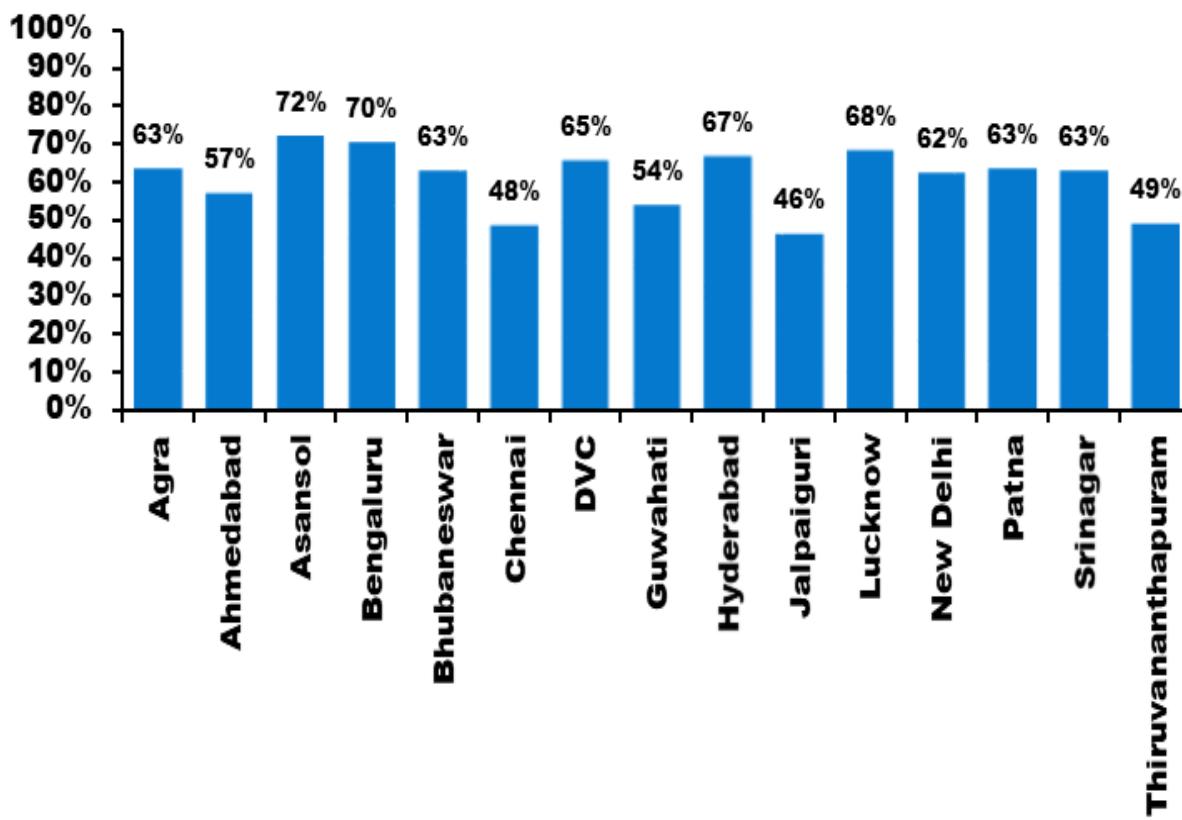


Figure 33. Percentage correct forecast Day-4 by different FMOs

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

Table 30: Skill Scores of Day-4 QPF

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

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

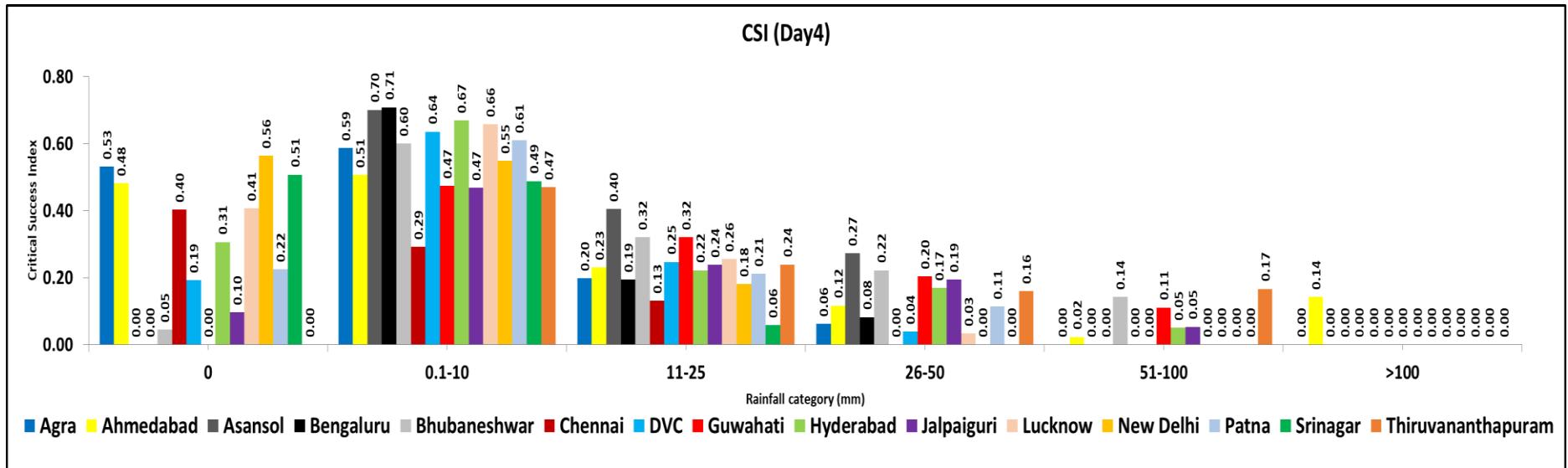


Figure 34: CSI for different categories of forecast for Day-4

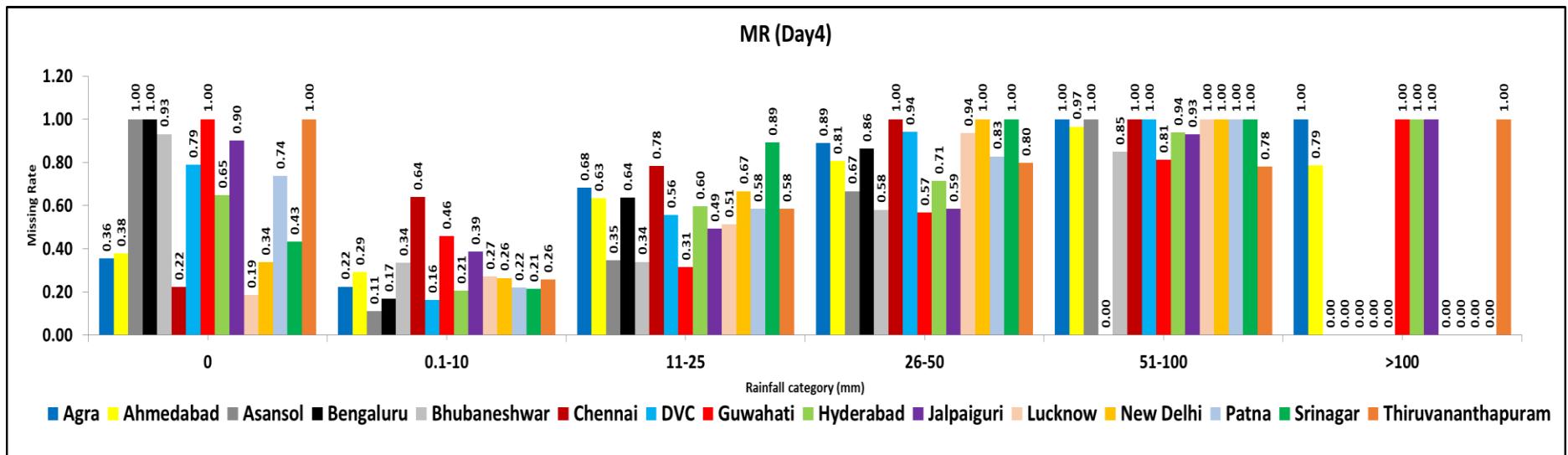


Figure 35: MR for different categories of forecast for Day-4

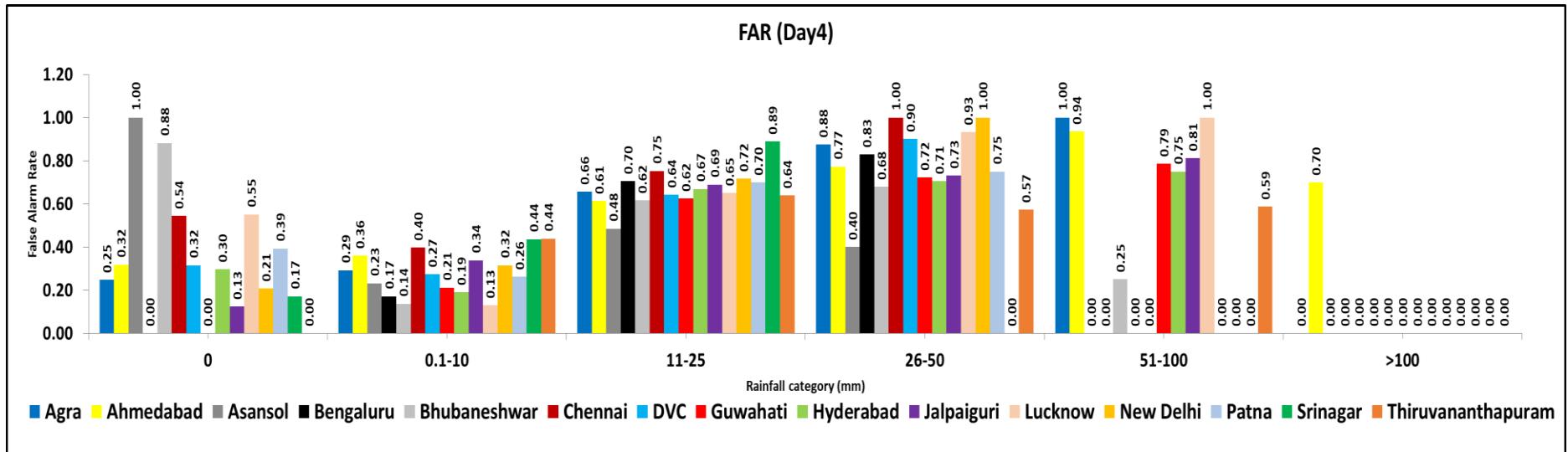


Figure 36: FAR for different categories of forecast for Day-4

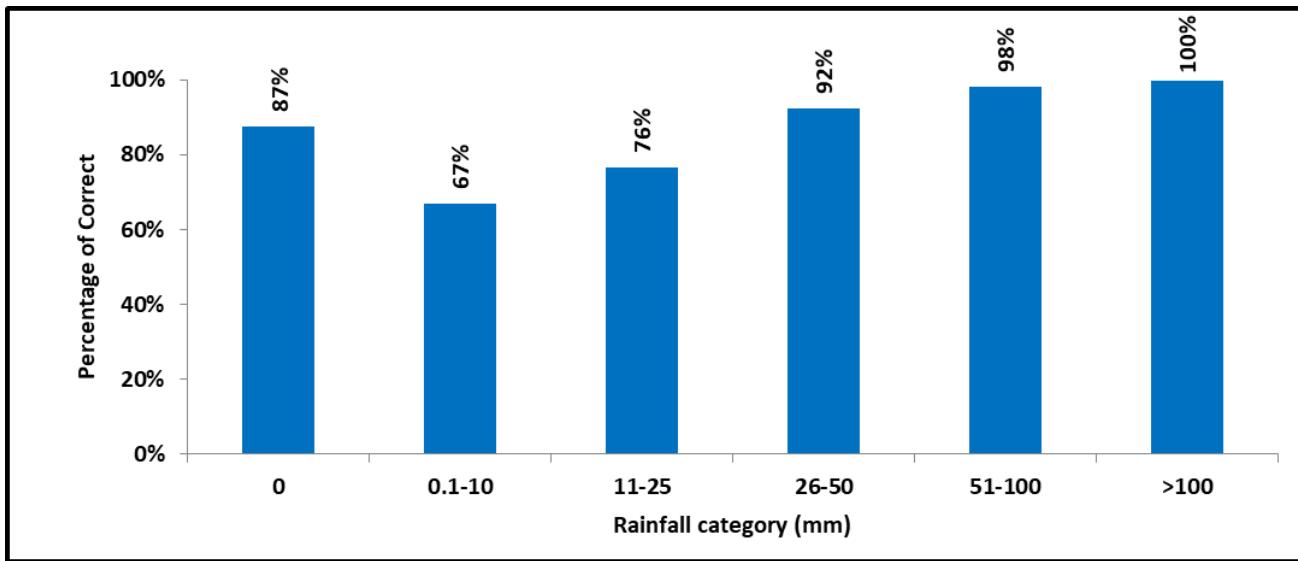


Figure 37: Category-wise Percentage Correct Forecast of Day-4

4.5 Skill Scores of Day-5 QPF

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

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

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

Percentage Correct Forecast - Day 5

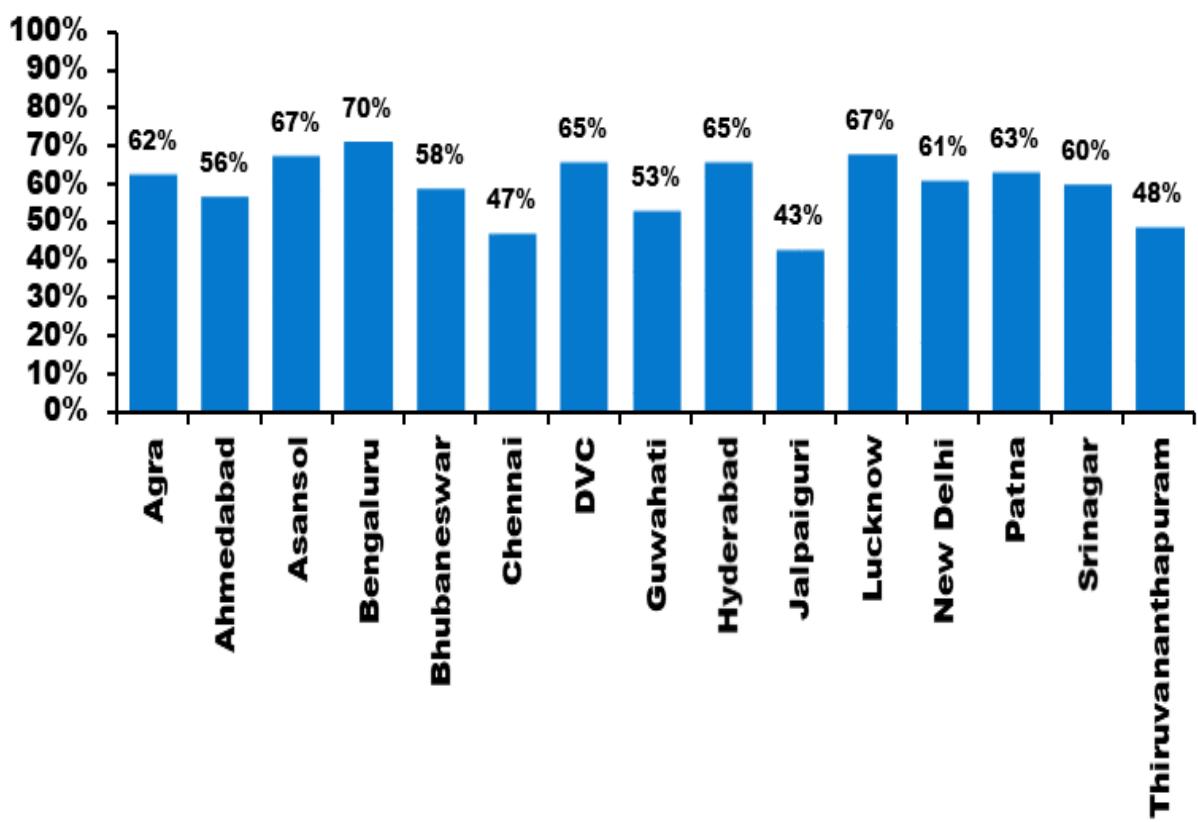


Figure 38. Percentage correct forecast Day-5 by different FMOs

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

Table 32: Skill Scores of Day-5 QPF

| SKILL SCORE | 0 | 0.1-10 | 11-25 | 26-50 | 51-100 | >100 |
|--|------|--------|-------|-------|--------|------|
| Probability of Detection (POD): | 0.30 | 0.71 | 0.39 | 0.15 | 0.05 | 0.04 |
| False Alarm Rate (FAR): | 0.39 | 0.29 | 0.70 | 0.83 | 0.79 | 0.80 |
| Missing Rate (MR): | 0.70 | 0.29 | 0.61 | 0.85 | 0.95 | 0.96 |
| Correct Non-Occurrence (C-NON): | 0.94 | 0.55 | 0.81 | 0.96 | 1.00 | 1.00 |
| Critical Success Index (CSI): | 0.22 | 0.55 | 0.21 | 0.08 | 0.03 | 0.02 |
| Bias for Occurrence (BIAS): | 0.56 | 1.03 | 1.24 | 0.82 | 0.32 | 0.18 |
| Hit Rate: | 0.87 | 0.66 | 0.75 | 0.92 | 0.98 | 1.00 |
| Percentage of Correct (PC): | 0.87 | 0.66 | 0.75 | 0.92 | 0.98 | 1.00 |
| True Skill Score (TSS): | 0.24 | 0.26 | 0.21 | 0.11 | 0.04 | 0.03 |
| Heidke Skill Score (HSS): | 0.25 | 0.26 | 0.18 | 0.10 | 0.06 | 0.03 |

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

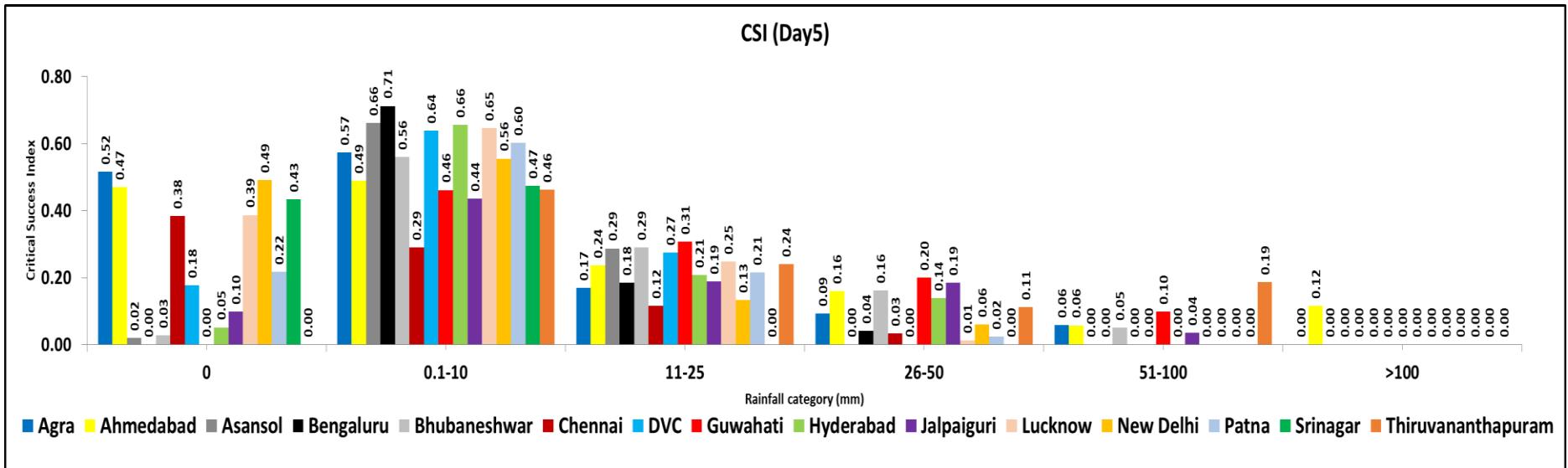


Figure 39: CSI for different categories of forecast for Day-5

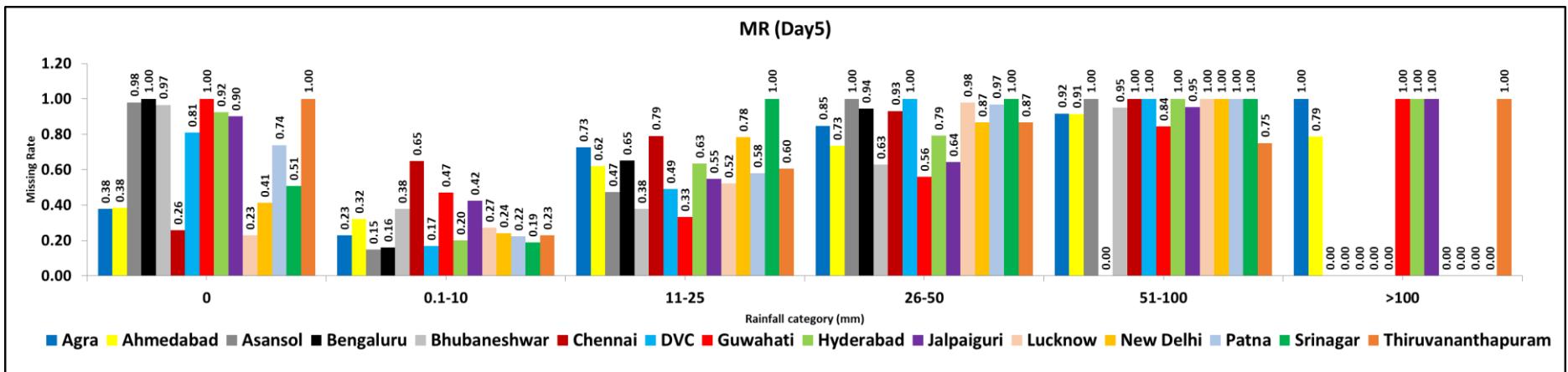


Figure 40: MR for different categories of forecast for Day-5

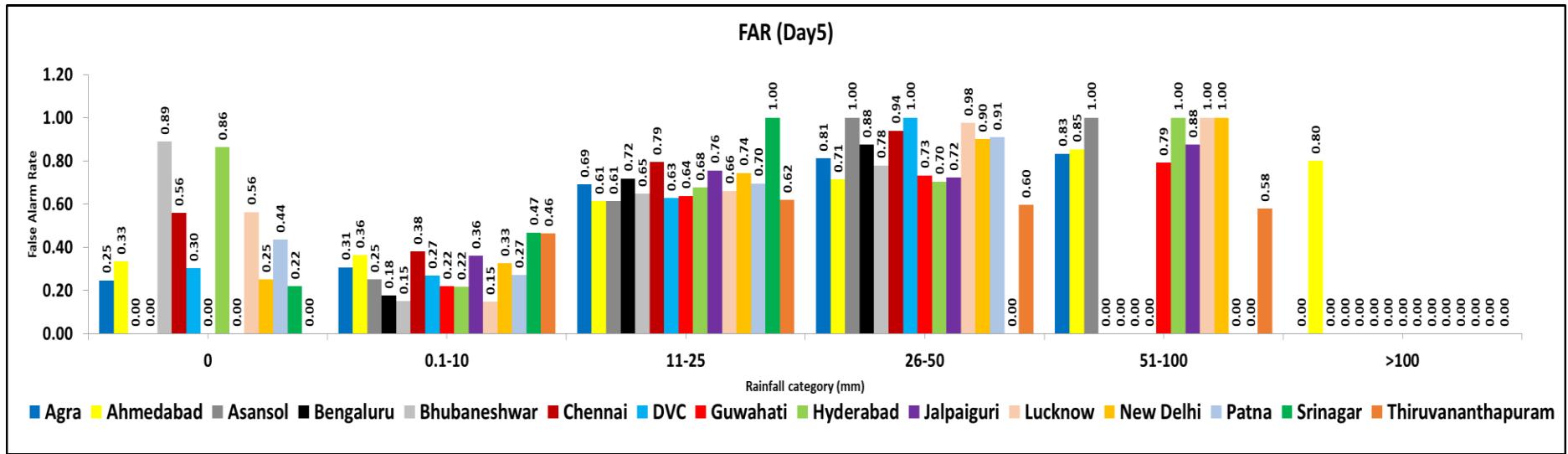


Figure 41: FAR for different categories of forecast for Day-5

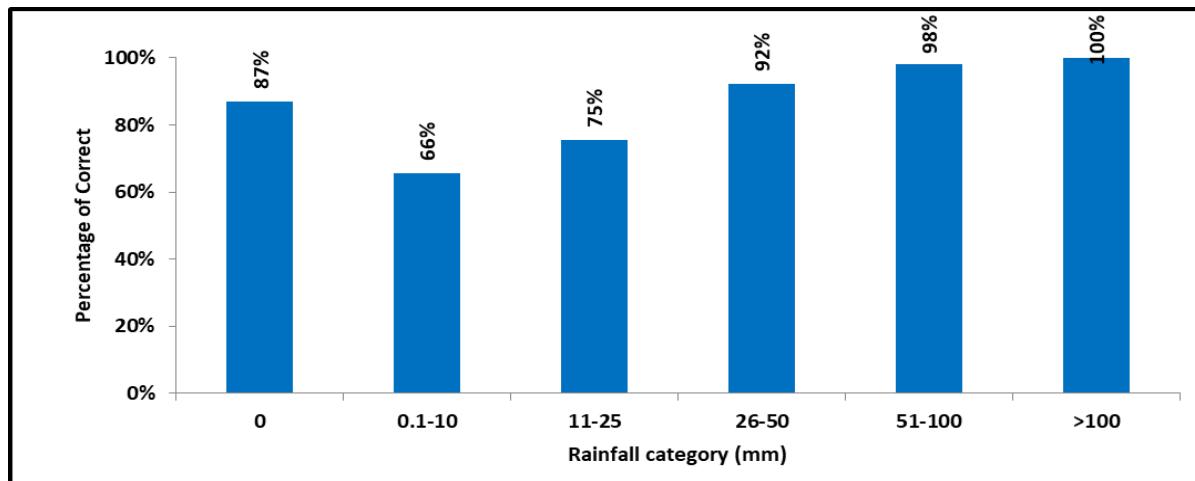


Figure 42: Category-wise Percentage Correct Forecast of Day-5

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

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

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

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

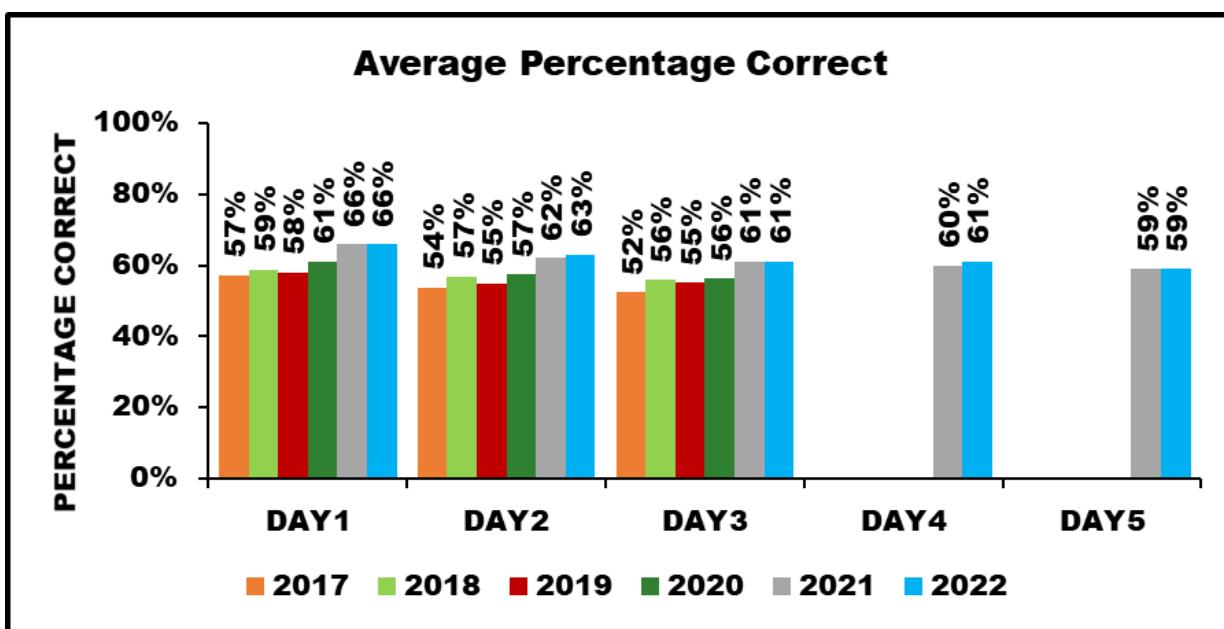


Figure 43: Day-1, Day-2, Day-3, Day-4 and Day-5 overall % correct forecast

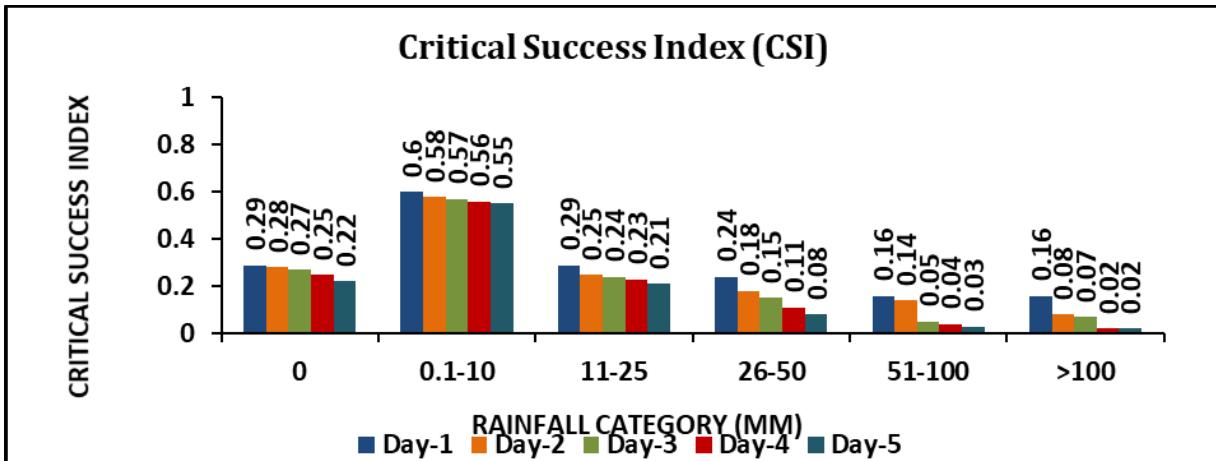


Figure 44: Category-wise Critical Success Index for Day-1, Day-2, Day-3, Day-4 and Day-5

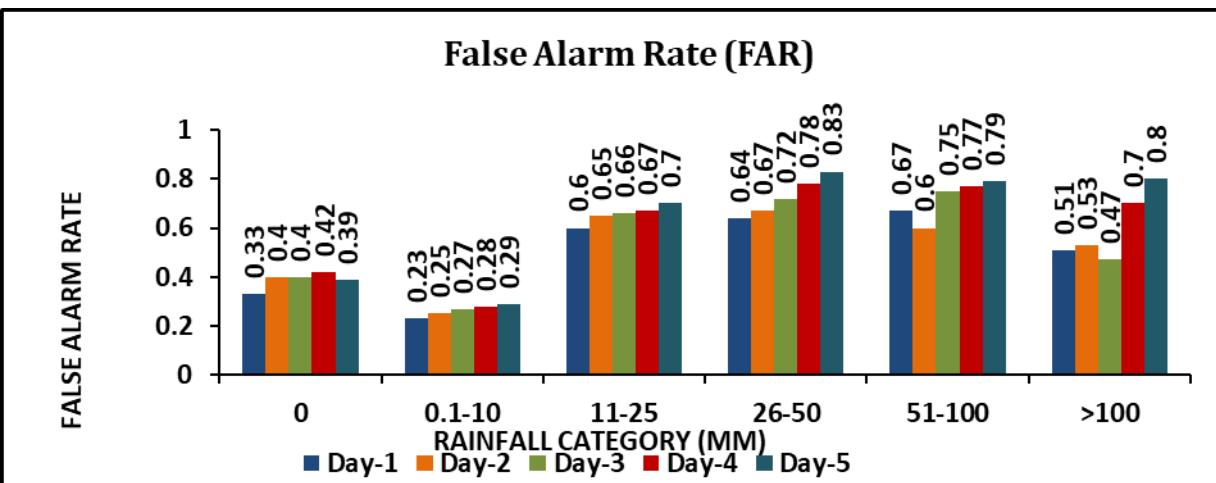


Figure 45: Category-wise False Alarm Rate for Day-1, Day-2, Day-3, Day-4 and Day-5

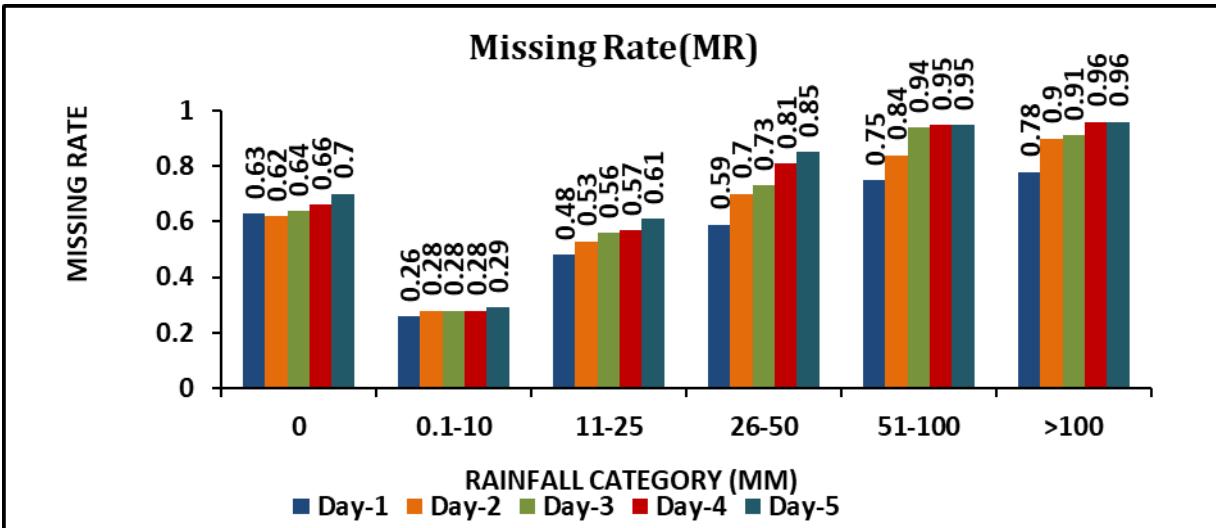


Figure 46: Category-wise Missing Rate for Day-1, Day-2, Day-3, Day-4 and Day-5

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

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

4.7. Improvement in operational QPF (2017 to 2022)

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

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

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

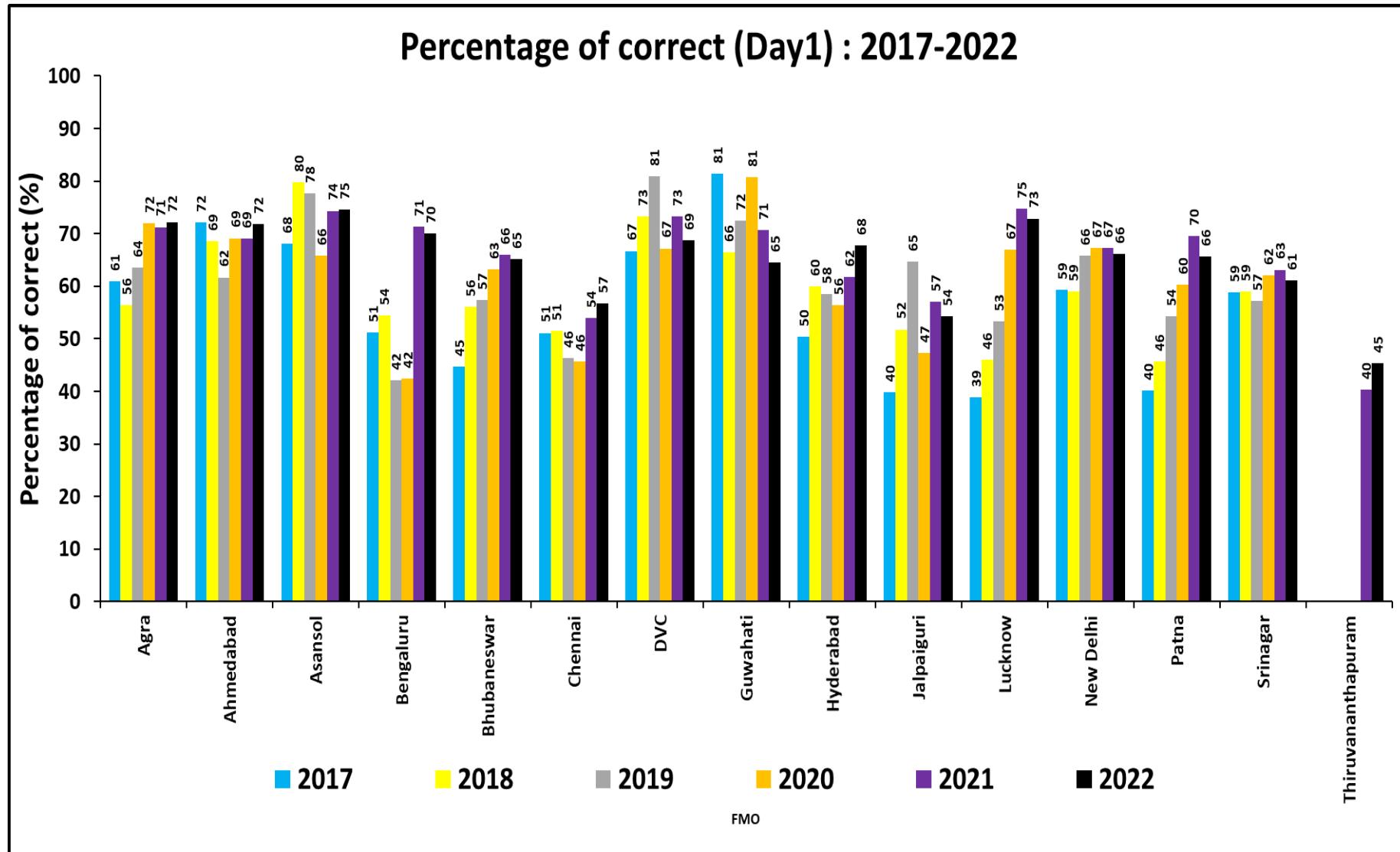


Figure 47: FMO-wise Percentage Correct QPF for Day-1 for the year 2017 to 2022

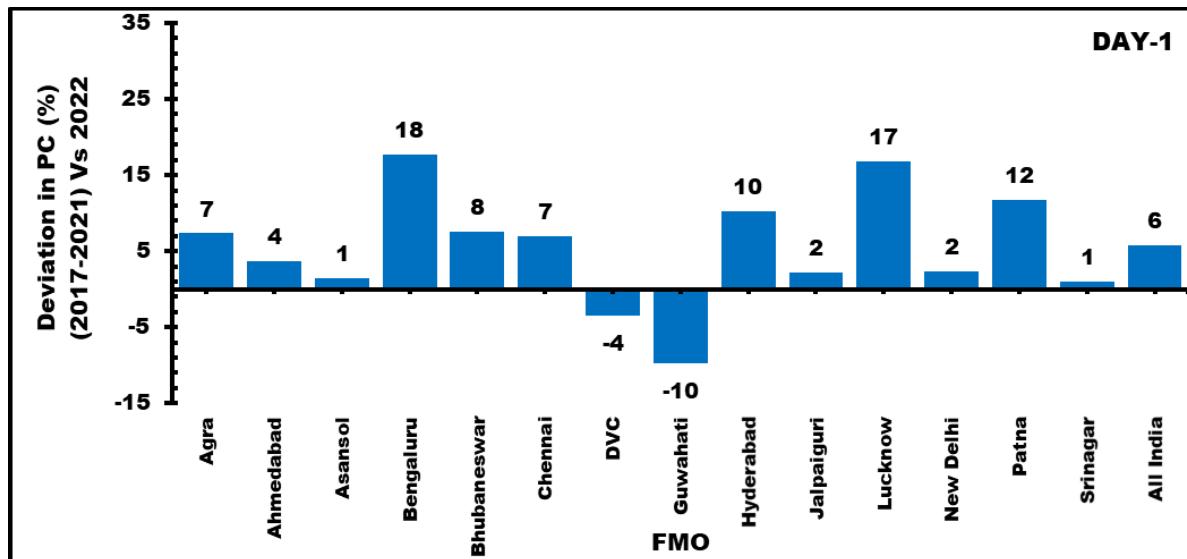


Figure 48. Day-1 performance of FMO-wise Operational QPF during 2022 Vs mean of 2017 - 2021

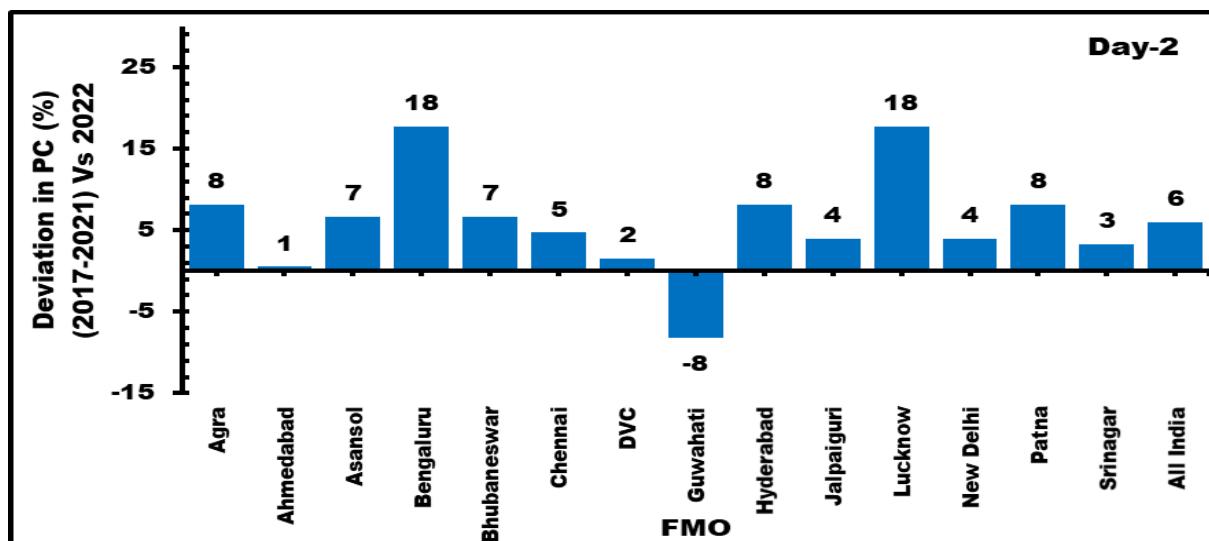


Figure 49. Day-2 performance of FMO-wise Operational QPF during 2022 Vs mean of 2017 - 2021

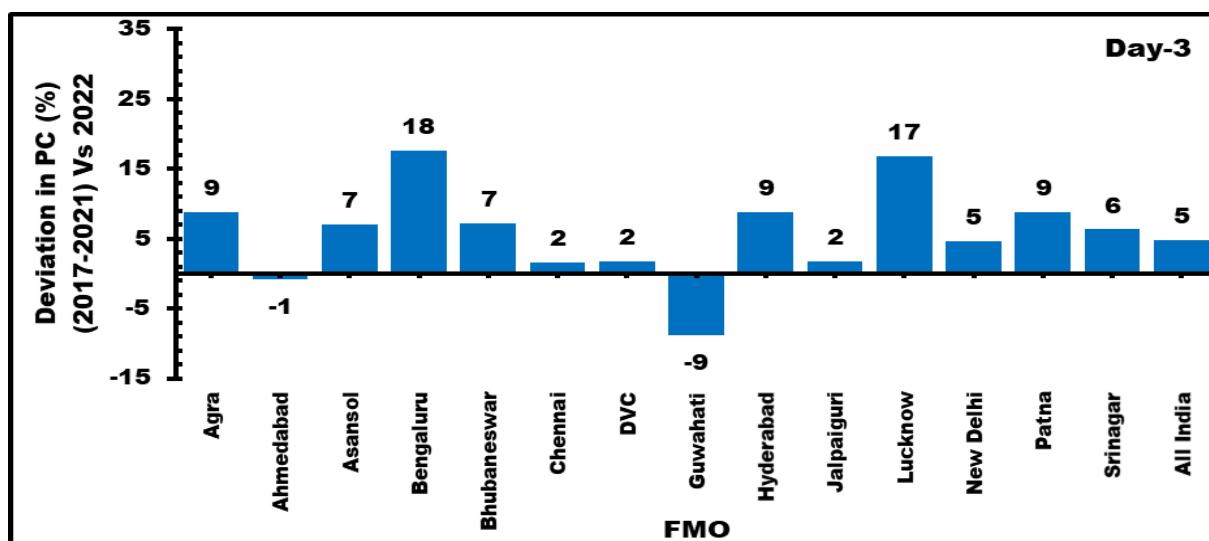


Figure 50. Day-3 performance of FMO-wise Operational QPF during 2022 Vs mean of 2017 – 2021

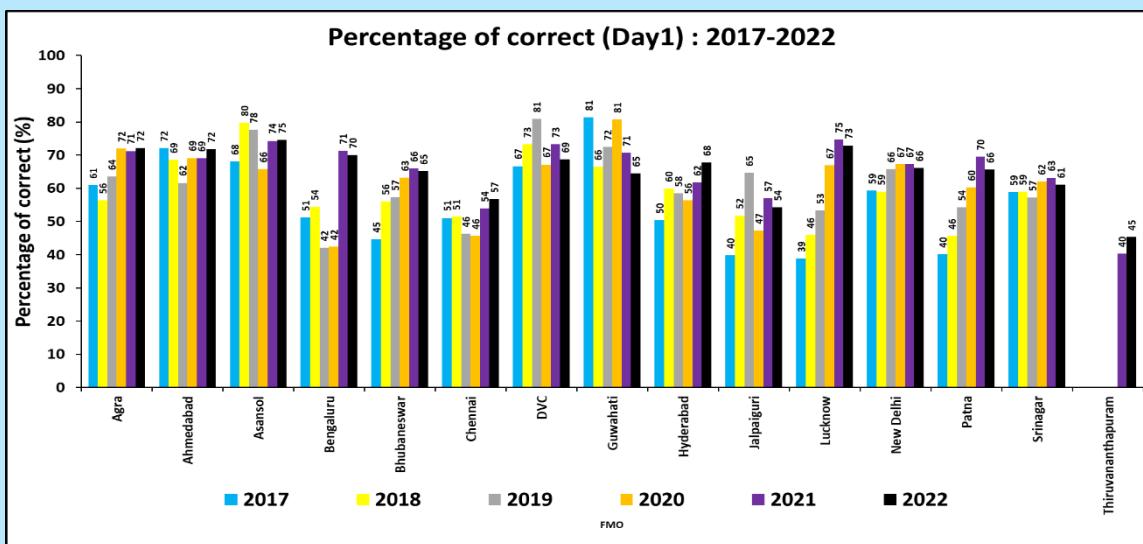
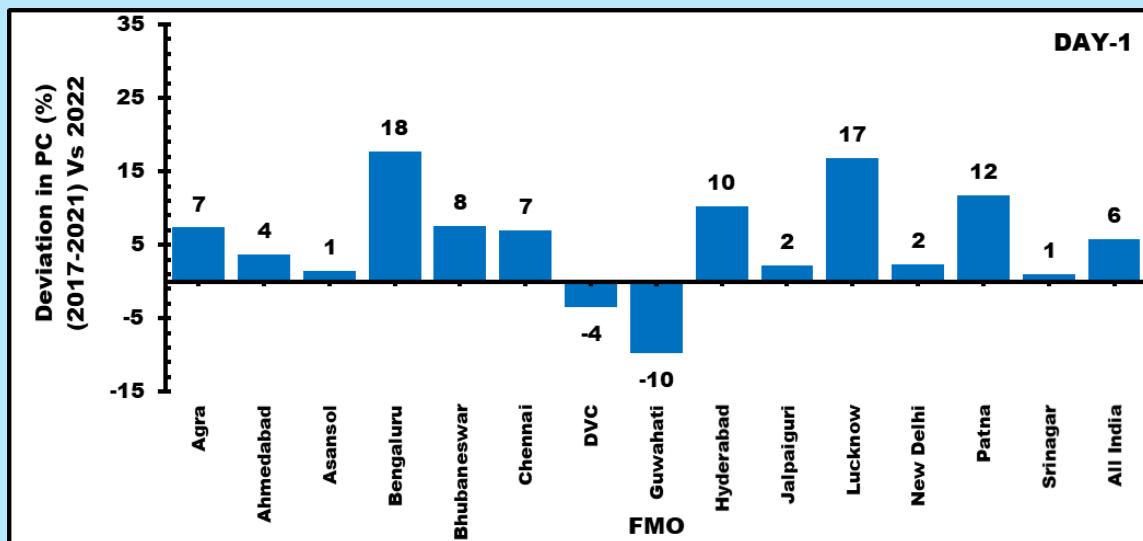
CHAPTER 5

Concluding Remarks

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

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