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Hydrometeorological services, an application of weather and climate services to water sector

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1. Introduction

Agro based economy of India is largely dependent on rainfall. The annual normal rainfall of the country is about 116 cm which is significantly higher than global average. However, 75% of rainfall (86.9 cm) occurs during limited period of four months that is during southwest Monsoon season, June to September. The number of rainy days in a year shows wide variation as less than 30 days in West Rajasthan to more than 150 days in sub Himalayan West Bengal and Sikkim. The spatial variation of rainfall is also erratic. It varies from wet NE India and western ghats to semi-arid region of Deccan platue, NW and Central India to Thar desert (Fig. 1).

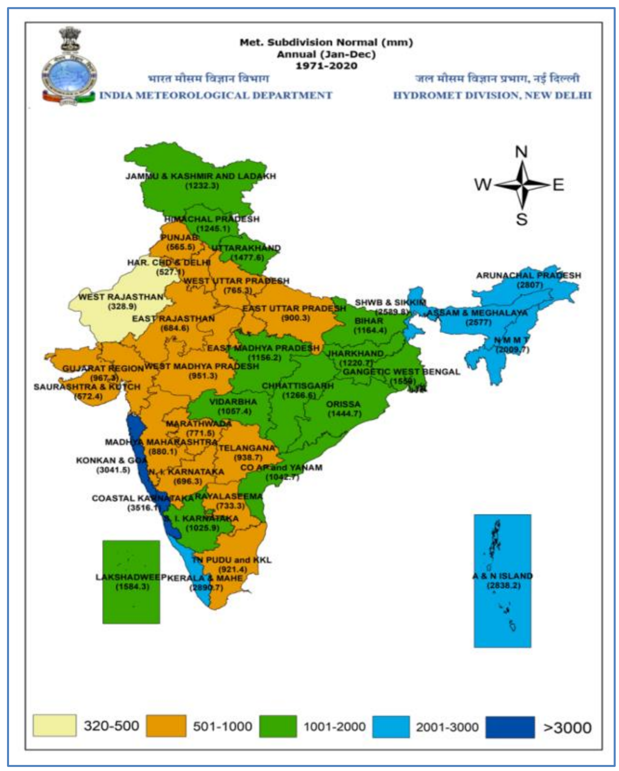

Fig. 1. Annual Spatial Variation of rainfall

Thus, though Indian rainfall is a good producer of water resources, is a bad distributor both in space and time. In order to meet water needs during 8 non monsoon months, it is essential to have storage structures like dams may be large, medium or small. There are more than 5254 large dams existing and 447 under construction in addition to innumerable medium and small structures. A large investment is made on these storage structures. The safety of these structures is of prime importance. Thus, inflow in dams particularly during heavy rainfall events needs to be adequately assessed. Similarly, storage capacity is to be decided with normal rainfall in the project catchment. Here hydro meteorological services of the country come into play. In course of time, the other activities like hydromet forecast for riverine flood forecast, rainfall monitoring and Flash Flood Guidance services get added.

2. Hydromet services in India, brief history.

After independence, large no. of irrigation, flood control and hydro power projects were planned. India Meteorological Department (IMD) was provided assistance for hydromet parameters and services for various river valley development schemes like for Damoder valley (Satcoppen, V. 1950). For the purpose Hydromet Unit was established at Alipore Kolkata in 1949 (which, afterwards, was named as Design Storm Unit, DSU). After heavy floods in 1954, and as per the recommendations of Khosla Committee of Engineers, Central Water Commission (CWC), India Meteorological Department (IMD), Research Development and Standards Organization (RDSO) of Indian Railways and Min of surface Transport

(Road Wing) to work in collaboration to estimate design floods. Accordingly, in Fist September 1966 Storm Analysis Unit (SAU) was formed in IMD. During 1970, country faced wrath of severe floods. Then Govt. of India constituted Ministerial Committee for flood and flood relief. Committee recommended two tier system for flood forecasting, IMD to provide Quantitative Precipitation Forecast (QPF) to CWC and CWC to issue flood forecast and warnings. Accordingly, in co-ordination with flood forecasting divisions of CWC, Flood Meteorological Unit (FMU) was established in 1972 and immediately first Flood Meteorological Office (FMO) was established in Patna in 1973. In 1974, Glaciology Unit was added and in 1979 Rainfall Monitoring Unit was established which prevailed under Districtwise Rainfall Monitoring Scheme (DRMS) since 1989.

In order to meet increasing demand in the field of hydro met services, IMD had integrated number of hydro meteorological schemes being operated on agency basis as SAU, DSU, FMU and FMOs into Hydromet Division in 1971. In course of time water balance unit, rainfall monitoring unit were part of the Division.

It is well established that due to climate change, the number of extreme rainfall events are increasing. As a result in a short period, the frequency of occurrence of very high intensity of rainfall is increased, consequently it enhances the risk of hydromet disasters like flash floods. There is more risk of flash floods in hilly areas. To mitigate this disaster, an early warning system of flash flood guidance system is established in 2020 at IMD namely, South Asia Flash Flood Guidance System (SAsiaFFGS) in cooperation with WMO & HRC USA.

This Division provides services in terms of inputs for hydrological planning, designing, forecasting and rainfall monitoring. The brief description of these activities is discussed here.

3. Inputs

The main input of hydromet services is rainfall data. The rainfall resolution of 1890 authorised India Meteorological Department (IMD) to collect rainfall records from State Govt.s and other agencies, its compilation and publication. The Climate Research and Services (CRS) wing of IMD at Pune has compiled and published daily station wise rainfall data since then. The other inputs require are weather parameters like temperature, dew point temperature, wind speed and directions, synoptic systems associated with heavy rainfall etc. which are available from daily weather reports. With these inputs, Hydro met services are provided particularly in the field of hydrological planning, designing, forecasting, monitoring, capacity building, snow melt modelling *etc*.

4. Hydro met planning

In order to decide the storage capacity of water storage structures, meteorological components like rainfall, evaporation, snowfall are required. The incorporation of these components in water balance equation will provide water availability for storage. The longterm average rainfall as well as assured rainfall at various degree of percentile is required for deciding the storage capacity. It is worth mentioning that in river dispute between states, the rainfall availability is one of the major point for consideration.

During 1965, United Nations Educational Scientific and Cultural Organisation (UNESCO) proposed programme of International Hydrological Decade (UNESCO - IHD). The aim is to enhance research in scientific hydrology. The Indian National Committee for International Hydrological Programme was established in IMD in collaboration with other national agencies. The water balance unit provided inputs for project report on Evolution of the Hydrologic Budget.

5. Hydro met design

Majority of storage structures are earthen dams which fail due to overtopping of stored water which could not be spilled out. Failure of dam will not only cause loss of large investment made thereon but also endanger life and property of downstream population. Even the over toppling of minor structure like bridges will cause traffic disruption. So in case of dams, spillway capacity and in case of culverts; bridges *etc*., water way capacity should be adequate. This capacity depends upon discharge data. Recording of discharge observations is costly and time consuming. The result is discharge records are inadequate for design purpose. The designers used to estimate design flood using empirical formula like $Q = c\ A^n$ where A is the area of upstream catchment and c and n are constants which were decided by designer with his experience and judgement.

With the development of rainfall – runoff models, rainfall found a place in hydrological design (Hathway, G. A. 1939). Rainfall observation is easy to record, less time consuming and less expensive. As a result, rainfall records of even 100 years are available. Another advantage is the rainstorm pattern of one area can be used for neighbouring area which is not possible in case of discharge data. Storm Analysis Unit estimates magnitude of rainfall of different Return Periods of 2, 5, 10, 25, 50,100 years and for various duration from 1 hr to 24 hr using data of Self Recording Rain gauge stations in the area.

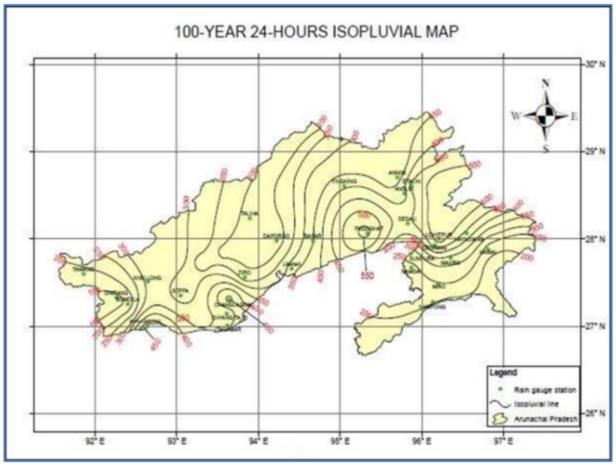

Fig. 2: 100-year 24-hour Isopluvial (Return Period) Map

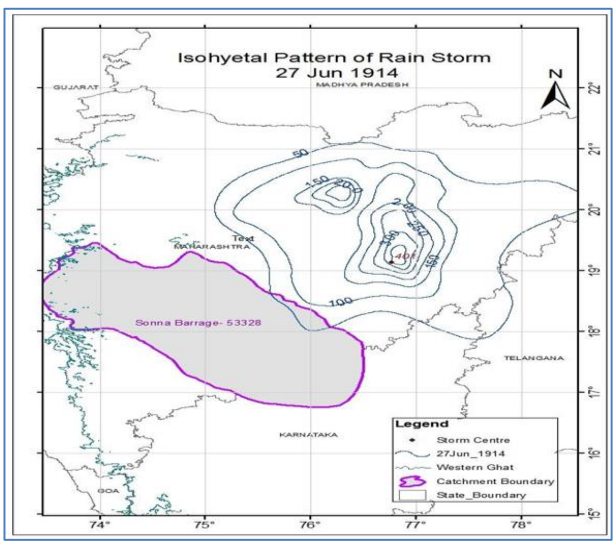

Fig. 3: Isohyetal pattern of rainstorm of 27 June, 1914 over state Madhya Pradesh

Return period is the average recurrence interval of occurrence or exceedance an event of particular magnitude. Return Period = 1/p where p is probability of occurrence or exceedance an event of particular magnitude. Return period of rainfall is estimated with annual extreme values series of rainfall and using Extreme Value Distributions as Gumbel Distribution. An isopluvial analysis of 24-hour rainfall for 100 year return period is illustrated (Fig. 2). From the rainfall of different return periods, Design flood magnitude for corresponding return period and duration is estimated.

The Design flood of particular return period is worked out by using rainfall magnitude of same return period in rainfall runoff model like unit hydrograph method. For the purpose India is divided into 7 meteorological homogeneous zones and 26 sub zones therein. CWC, IMD, RDSO and Min of Surface Transport brought out 22 Regional Flood Estimation report for 26 basins using return period analysis of rainfall and unit hydrograph method.

Design Storm unit undertakes the estimation of Design storm for medium and large storage structures where areal average rainfall is an input. The main steps are selection of rainstorms in and around project catchment, isohyetal analysis of these rainstorms to get rainstorm pattern and also to work out areal average rainstorm depth intercepted by project catchment (Fig. 3).

In order to enhance the data base, the rainstorm patterns of historical rainstorms from meteorological homogeneous region are transposed to project basin. The transposition of rainstorm is permissible only within meteorologically homogeneous regions. The homogeneity is decided from climatological parameters like distance from sea, prevailing winds, rain producing synoptic systems, same moisture source, temperature etc. It is worth mentioning that the storm transposition is not a meteorological concept but was suggested by a civil engineer (Bernard, M.1936).

The areal average rainfall intercepted by catchment after transposition is estimated for 1 day, 2 days, 3 days --- duration (cumulative rainfall values) as per requirement of the project. The highest rainfall depth over catchment area after transposition of heavy rainstorm in region to project catchment is known as Standard Project Storm (SPS). Even though it is the extreme rainstorm on record, there is some risk of its exceedance. Hence it is adopted for medium and small storage structures where failure of structure has minor risk of loss of property, crops *etc*. but no risk to human life. It is a compromise between risk and economy. The design of large storage structures requires risk free design. The failure of these structures causes loss to human life and livestock and loss to property, crops etc. The large investment made for construction of structure will go waste. In order to get risk free structure, the SPS value is further increased by applying Moisture Adjustment Factor (MAF). MAF is the ratio of Highest precipitable water in atmosphere ever recorded over project catchment to the precipitable water observed at or near to rainstorm centre during time of occurrence of historic rainstorm. It is derived from surface dew point temperature data. Generally, MAF is in between 1.25 to 1.5.

The design storm value so obtained is called as Probable Maximum Precipitation (PMP). It is physically upper limit of rain depth over the project catchment and there is virtually no risk of its exceedance.

The criteria of selection of type of Design storm estimation either return period value or SPS or PMP is decided according to IS: 11223, 1985.

The Design Storm value is used in rainfall runoff model to estimate Design Peak Flood discharge. The rainfall - runoff model requires temporal distribution of Design Storm in critical fashion so as to produce maximum discharge. The temporal distribution of design storm is worked out from self-recording rain gauge data available in and around project catchment.

The methodology of estimating design storm is elaborated in various publications (IMD 1972, WMO 1986, WMO 2009, BIS 1969, BIS 1985). The service is in demand from State Governments, Central Water Commission, Public Undertakings like NTPC, NHPC, WAPCOS, BBMB *etc*. and private consultants.

6. Hydro met forecasting

Flood is a natural calamity which causes maximum no. of deaths in the world. It also destroys standing crops, livestock, immovable property. After floods, epidemics occur due to polluted water and lack of sanitation. India suffers a loss of crores of rupees and hundreds of lives annually. It is estimated that about 400000 sq. km of country is flood prone. There were many expert committees to study the flood problem and suggest remedial measures. All the committees concluded that it is impossible to get total immunity from floods. However, with structural measures and flood warnings, loss of human lives and movable property can be reduced. In order to provide Quantitative Precipitation Forecast (QPF) to CWC for issuing flood forecast and warnings, initially 11 FMO were established at Agra, Ahmadabad, Asansol, Bhubaneswar, Guwahati, Hyderabad, Lucknow, Jalpaiguri, New Delhi, Patna and DVC Unit at Kolkata. Recently 4 FMOs at Chennai, Bengaluru, Srinagar and Thiruvananthapuram are added. Hydro met forecast is provided mainly to CWC and also to Disaster Management Authorities at district / state and national level. Presently, IMD provides this hydromet support for 157 river sub-basins through 15 FMOs (Fig. 4).

The challenging part of flood forecast is it should not be underestimated and at same time not overestimated. Underestimate forecast will endanger the life and property while overestimation will result into unnecessary displacement of population resulting into hardships.

Initially CWC was using lumped models to estimate discharge from QPF. For the purpose average areal rainfall of catchment/ sub catchment was to be forecasted. FMOs provide QPF in ranges 1-10 mm, 11-25 mm, 26-50 mm, 51 -100 mm and more than 100 mm with lead time of 24 hrs and outlook for next 48 hrs. Now they are using distributed type of models where QPF for grid points is expected with more lead time. For this purpose, IMD shares the gridded GFS (12km) and WRF (3km) model forecast rainfall shared with them on real-time basis.

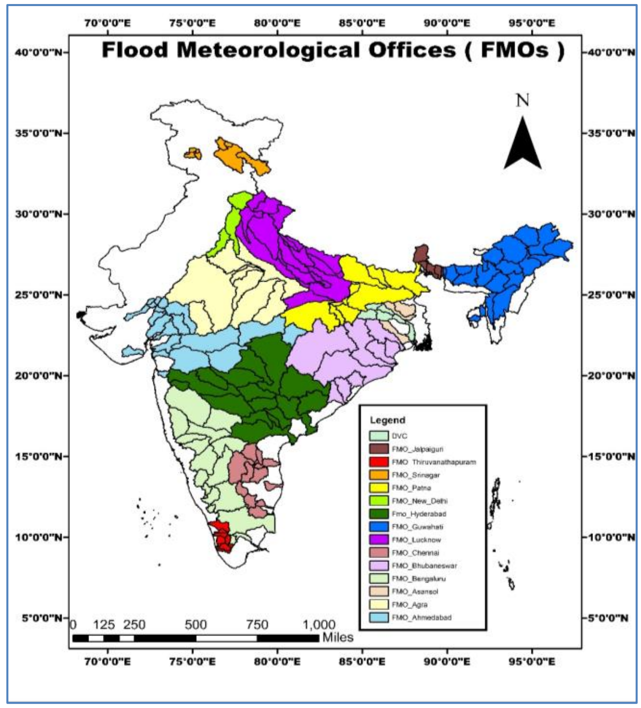

Fig. 4. Flood Meteorological Offices (FMOs)

Currently, the value added operational QPF and Hydromet bulletins for river sub-basins is provided to CWC which is valid from day-1 to day-7.

The bulletins contain the following inputs;

(*i*) River sub basin wise Quantitative Precipitation Forecast (QPF) in various categories viz., 0.1 -10 mm, 11 = 25mm, 26 – 50 mm, 51 -100 mm and > 100 mm for seven days.

(*ii*) Probabilistic QPF for each category for the next seven days.

(*iii*) Heavy rainfall warning for the next seven days.

(*iv*) Prevailing synoptic situations.

(*v*) Station-wise significant rainfall during the past 24-hours (≥ 5cm).

(*vi*) River sub basin wise Areal Average Precipitation (AAP) occurred during past 24-hours.

To accomplish this operational activity efficiently, various tools like Numerical Weather Prediction (NWP) model forecast, Synoptic analysis as well as statistical synoptic analogue model, Radar products, Satellite products etc. are used by the forecasters. In synoptic analogue method, the synoptic systems responsible for rainfall over catchment are identified. Contingency table

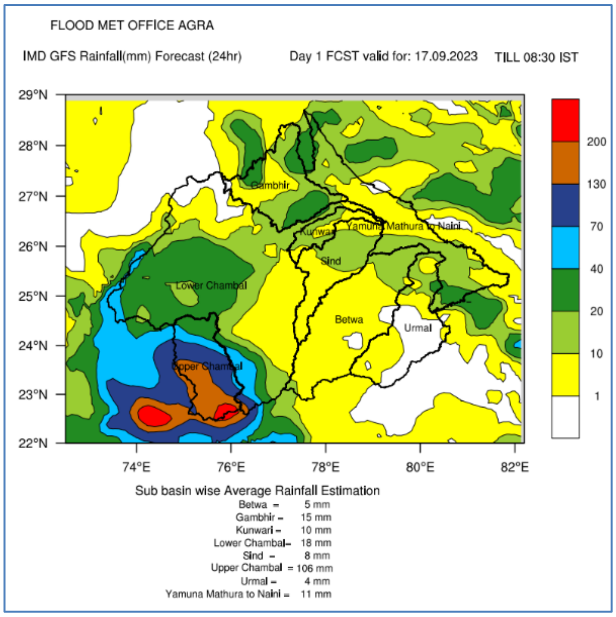

Fig. 5(a). River sub-basin-wise GFS average rainfall estimation

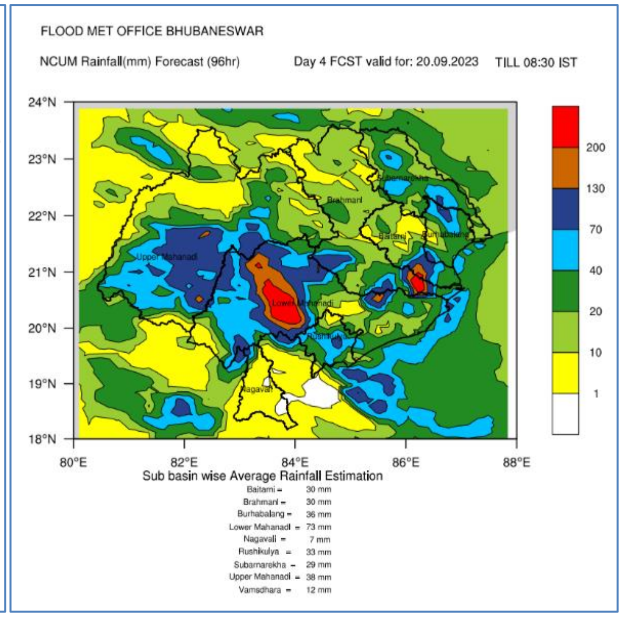

Fig. 5(b). River sub-basin-wise NCUM average rainfall estimation

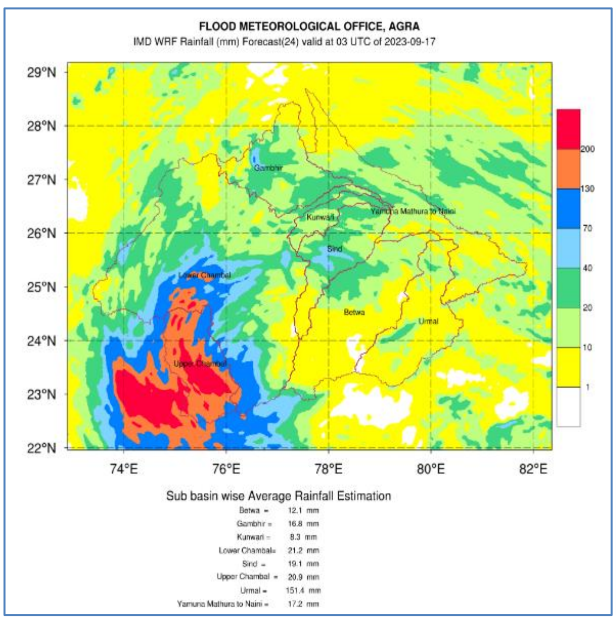

Fig. 5(c): River sub-basin-wise GFS average rainfall estimation

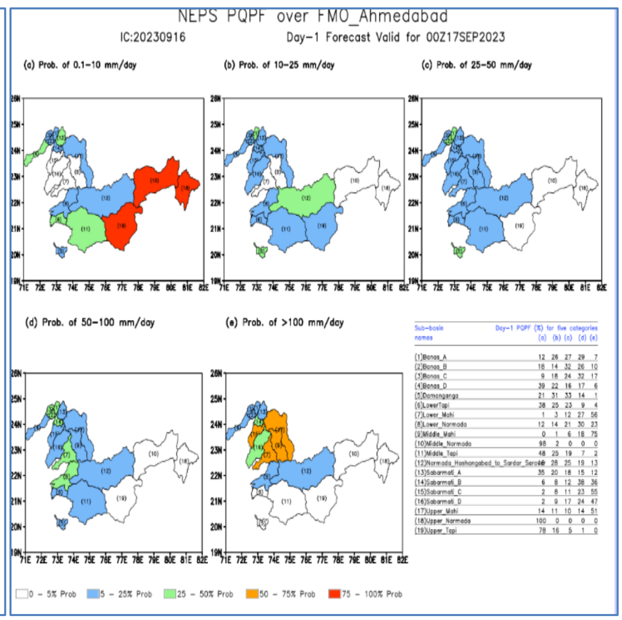

Fig. 6. : River sub-basin-wise Probabilistic QPF NEPS Model

of synoptic system and corresponding frequency of realised rain in different categories of QPF is prepared. While issuing QPF, forecaster refers the table and according to strength of system selects the QPF range.

In recent years, there is a rapid development in the NWP modelling system. The real time data assimilation into the model improves the forecast products. Also, availability of huge computing power in the HPC systems helps tremendously to generate very high resolution model products. With the help of various NWP models *viz*., WRF (3 km), NCUM-R(4 km), GFS (12 km), NCUM-G (12 km), river sub-basin wise rainfall forecast estimation products (Figs. 5(a, b & c) are generated and uploaded in the website. Also, two probabilistic NWP models *viz*., NEPS (21 members) (12 km) (Fig. 6) and GEFS (21 member) (12 km) for river sub-basins are also operational in the IMD hydromet website with help of IITM, Pune and NCMRWF, Noida to provide the technical support to forecasters at FMOs. These two models provide daily upto 7 days river sub-basin-wise Probabilistic QPF (PQPF) for each category of QPF. Both the deterministic and probabilistic river sub-basin-wise rainfall products are available on real time basin in the IMD website which is significantly useful for FMOs for their hydromet activities.

Other than flood season, if heavy rainfall is expected or in the event of formation of cyclone, concerned FMO will issue QPF/Hydromet bulletins. The bulletins are in colour coded format. The river sub-basin-wise QPF for all 157 river sub basins is also available on real-time in the public domain at https://mausam.imd.gov.in/responsive/quantPrecipForecast.php

With rise in urbanization clusters and inadequate drainage system, urban floods are disturbing traffic and endangering life in urban areas. Local administration demands rain forecast for issuing warnings and advisories to people. Hence rain forecast as very light to light rain (0.1 to 15.5 mm), moderate rain (15.6-64.4 mm), heavy rain (64.5-115.5 mm), very heavy rain (115.6-204.4 mm), exceptionally heavy rain (greater than 204.4 mm) is issued by local forecasting offices of IMD.

It is to understand that QPF is not the final product. From QPF, flood discharge is estimated and from flood discharge water level at gauging site is worked out using gauge discharge relation. The water level decides the flood fury and accordingly CWC issues flood warnings and forecasts to state authorities.

To keep updated the concerned departments/agencies for the flood status of the country and its mitigation, following two very important monitoring activities started in the year 2021 during the flood season;

(*i*) Daily Joint advisories by IMD, CWC and NDRF on Flood Status of the country

(*ii*) Bulletin for daily Real-time Monitoring of High QPF & riverine Floods status

7. Rainfall monitoring

The agriculture sector requires real time rainfall information to plan agricultural operations. In addition to agriculture, irrigation, fertilizer, drinking water, power demand *etc*. are dependent upon rainfall and accordingly operational strategies are planned. The authorities also use rainfall situation to anticipate drought situation and accordingly plan import export strategies of food grains, vegetables, sugar, onion *etc*. The rainfall situation also shows impact on stock market. The rainfall monitoring is a decision making tool and high in demand from various quarters.

In order to monitor rainfall in district, met sub division, state and country as a whole, Rainfall Monitoring Unit (RMU) was established in 1979. Initially RMU was functioning during SW monsoon season. During 1989 District wise Rainfall Monitoring Scheme (DRMS) was framed to incorporate rainfall data from properly installed rain gauge stations, ensuring the reception of data in time with quality checks, prepare the rainfall summary both in tabular and pictorial form and disseminate same to govt. authorities and registered users. Now it is in public domain.

In recent years, large number of raingauge stations were added in the DRMS scheme and also increased the number districts. At present there are 6495 rain gauge stations under DRMS (Fig. 7) catering need of 729 districts, 36 states and Union Territories and 36 met sub divisions (Figs. 8(a)-(b)). Depending upon % departure of Actual Rainfall from Normal Rainfall, rainfall situation is categorized as Large Excess (>59%), Excess (20-59%), Normal (-19 to 19%), Deficient (-20 to -59%), Large Deficient (-60 to -99%) and No Rain (-100%). Climate Research and Services, Pune workout long term average rainfall from 50 years' rainfall observation record for districts, met sub divisions, states, four homogeneous regions and country as whole and daily accumulated, seasonal, monthly & annual. It is revised at every 10 years. Currently normal of 1971-2020 are in use. For the computation purpose software mkRAIN was developed in house which substantially reduced the time of preparation of rainfall summary. Further in 2015, a GIS based Customized Rainfall Information System (CRIS) was operationalized for automation of hydromet activities. After implementation of CRIS, there is significant improvement in efficiency for preparation more number of real time rainfall products and also semi automation was introduced in design storm studies activities. In addition to this, it is reduced the requirement of manpower for accomplishment of these services. Now rainfall summary is prepared on daily as well weekly basis during all 4 seasons of the year. Presently, more than 130 near real-time daily rainfall products in the form of table, maps and graphs are prepared and made available in the IMD hydromet website at https://hydro.imd.gov.in/hydrometweb/.

The rainfall monitoring bulletin provides Actual Rainfall, Long period average or Normal rainfall for same period and Departure of actual rainfall from Normal rainfall in terms of % and then the category of situation. The simple arithmetical average is used to work out District Rainfall situation. The Rain situation in met sub division and state is worked out from area weightage average of District rainfall. The rainfall situation for country as a whole is estimated from area weightage average of met sub divisional rainfall (Table 1).

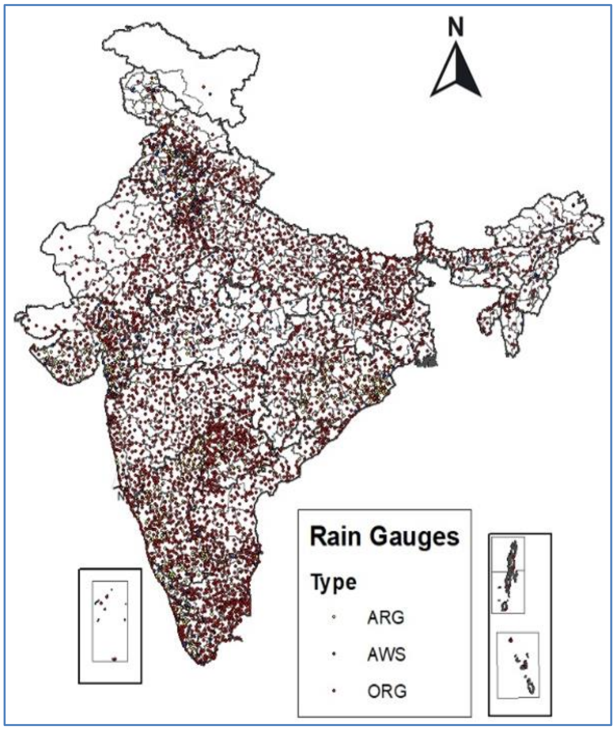

Fig. 7: Raingauge station Network under DRMS

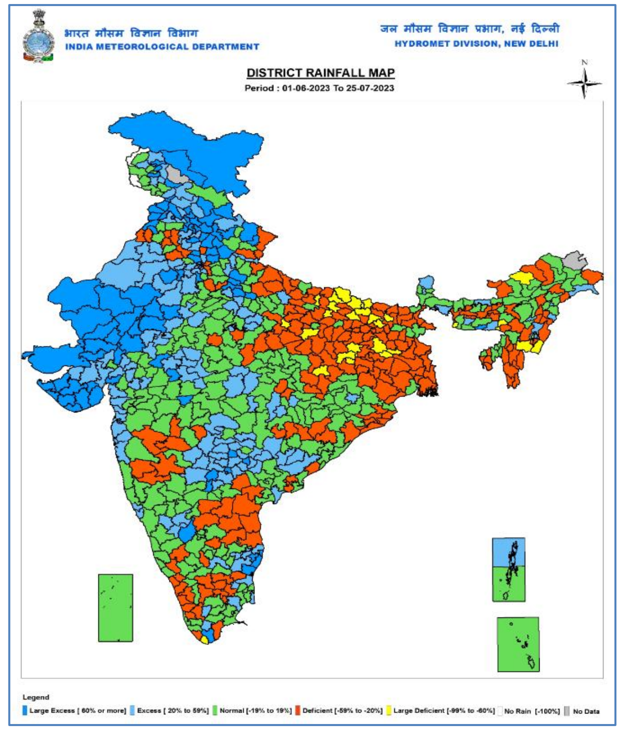

Fig. 8(a): District-wise map for rainfall

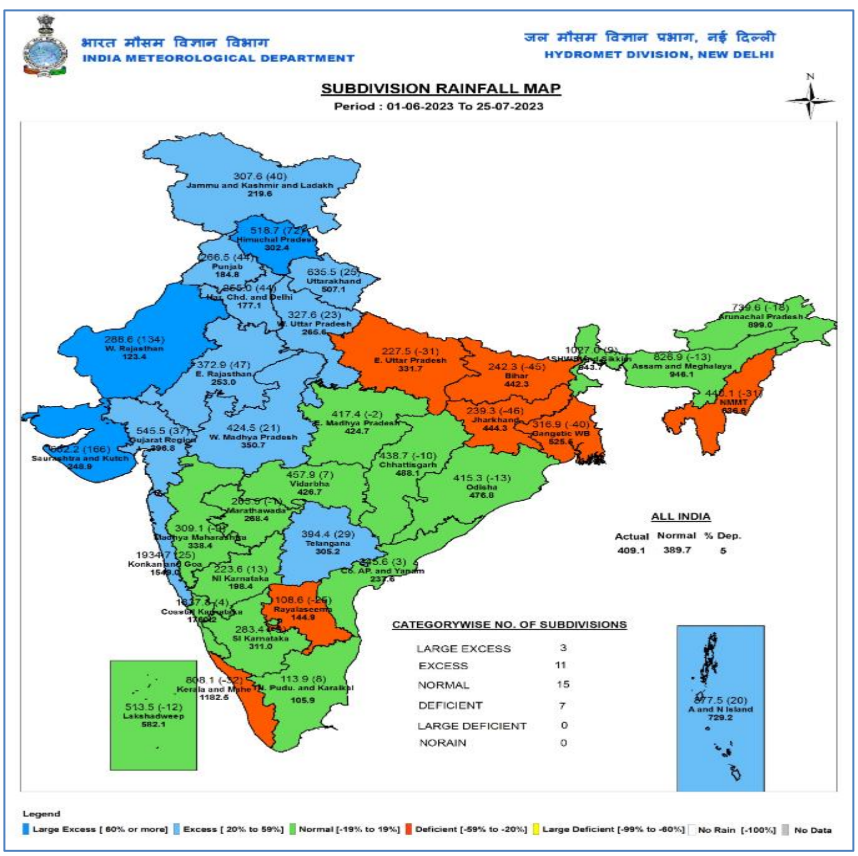

Fig. 8(a): District-wise map for rainfall

TABLE-1

Met-sub-division-wise rainfall Statistics

S. NO.	METEOROLOGICAL SUBDIVISIONS	DAY : 02.12.2024 TO 02.12.2024				PERIOD: 01.10.2024 TO 02.12.2024			
		ACTUAL	NORMAL	% DEP.	CAT.	ACTUAL	NORMAL	% DEP.	CAT.
EAST & NORTH EAST INDIA		0.0	0.3	-95%		149.2	146.6	2%	
1	ARUNACHAL PRADESH	0.0	1.0	-100%	NR	271.7	213.6	27%	E
2	ASSAM & MEGHALAYA	0.0	0.3	-100%	NR	209.6	180.5	16%	N
3	N M M T	0.0	0.0	-100%	NR	127.7	189.1	-32%	D
4	SHWB & SIKKIM	0.0	0.3	-100%	NR	173.2	158.2	9%	N
5	GANGETIC WEST BENGAL	0.1	0.1	14%	N	204.5	156.6	31%	E
6	JHARKHAND	0.0	0.2	-100%	NR	61.4	82.7	-26%	D
7	BIHAR	0.0	0.2	-100%	NR	19.7	62.3	-68%	LD
NORTH WEST INDIA		0.0	0.1	-98%		7.7	34.0	-77%	
1	EAST U.P.	0.0	0.1	-100%	NR	3.1	37.1	-92%	LD
2	WEST U.P.	0.0	0.2	-100%	NR	0.3	24.4	-99%	LD
3	UTTARAKHAND	0.0	0.0	-100%	NR	3.5	37.7	-91%	LD
4	HAR. CHD & DELHI	0.0	0.0	-100%	NR	0.5	13.4	-97%	LD
5	PUNJAB	0.0	0.1	-100%	NR	2.5	13.3	-81%	LD
6	HIMACHAL PRADESH	0.0	0.4	-100%	NR	0.9	45.8	-98%	LD
7	J & K AND LADAKH	0.0	0.4	-97%	LD	19.8	69.3	-71%	LD
8	WEST RAJASTHAN	0.0	0.0	-100%	NR	4.5	10.6	-58%	D
9	EAST RAJASTHAN	0.0	0.1	-100%	NR	11.4	22.8	-50%	D
CENTRAL INDIA		0.2	0.2	-6%		56.1	71.5	-22%	
1	ODISHA	1.2	0.0	11981%	LE	78.5	134.4	-42%	D
2	WEST MADHYA PRADESH	0.0	0.1	-100%	NR	34.9	40.6	-14%	N
3	EAST MADHYA PRADESH	0.0	0.4	-100%	NR	16.8	48.5	-65%	LD
4	GUJARAT REGION	0.0	0.0	-100%	NR	41.1	31.4	31%	E
5	SAURASHTRA & KUTCH	0.0	0.0	-100%	NR	49.8	28.0	78%	LE
6	KONKAN & GOA	0.0	0.0	-100%	NR	239.6	137.5	74%	LE
7	MADHYA MAHARASHTRA	0.0	0.1	-100%	NR	102.8	99.5	3%	N
8	MARATHWADA	0.0	0.1	-100%	NR	71.9	92.2	-22%	D
9	VIDARBHA	0.0	0.3	-100%	NR	41.7	71.4	-42%	D
10	CHHATTISGARH	0.1	0.2	-29%	D	27.9	70.8	-61%	LD
SOUTH PENINSULA		12.9	1.6	705%		251.7	245.1	3%	
1	A & N ISLAND	1.3	5.2	-76%	LD	518.3	534.4	-3%	N
2	COASTAL A. P.& YANAM	8.5	1.4	506%	LE	219.6	297.7	-26%	D
3	TELANGANA	1.9	0.1	1784%	LE	68.3	119.0	-43%	D
4	RAYALASEEMA	11.9	1.7	600%	LE	273.4	213.2	28%	E
5	TAMIL., PUDU. & KARAIKAL	35.4	5.0	608%	LE	429.6	362.9	18%	N
6	COASTAL KARNATAKA	0.0	0.3	-90%	LD	284.0	255.2	11%	N
7	N. I. KARNATAKA	0.0	0.0	-72%	LD	128.3	126.6	1%	N
8	S. I. KARNATAKA	6.2	0.5	1145%	LE	259.8	189.3	37%	E
9	KERALA & MAHE	33.0	1.8	1734%	LE	395.7	463.6	-15%	N
10	LAKSHADWEEP	0.0	4.9	-100%	NR	268.0	280.4	-4%	N
COUNTRY AS A WHOLE		2.6	0.5	420%		94.5	106.1	-11%	

From percentage departure of actual realized data many other products are derived as state wise distribution of districts in different categories, District / state/ met subdivision wise rainfall distribution (Daily and cumulative), District / met subdivision wise week by week rainfall departures (both weekly and cumulative), All India (as well as over homogeneous regions) time series of daily and cumulative rainfall and corresponding departures.

8. Snow hydrology

Snow is a natural water reservoir. During winter months, snowfall occurs at higher altitudes. Snow stays on ground when water demand is less and start melting during summer when water demand goes on rising. So it is a self-regulatory reservoir. Adverse part of snowfall is disruption to traffic during heavy snowfall and avalanches. The rivers in Northern India get water both from rain and snowmelt while rivers in peninsular India dried up during summer. So snow and snow melt estimation is very important to tourism, agriculture, hydro power sector *etc*.

Hydrometeorological Services provides snowfall observations. In addition, Hydromel service provided assistance in development of snow melt modelling by participating in various inter departmental glacier expeditions. Garo glacier (1975), Gangotri glacier (1975), Snow Survey Beas Catchment(1981), Chhota Sigri glacier (1986, 1987, 1988, 1989), Shaune Garang Glacier (1982, 1983, 1985), Dokriyani Bamak Glacier(1991) expeditions were some of these expeditions. During expeditions in addition to meteorological parameters, solar radiation data was collected so as to estimate snow melt both by Degree Day method and Energy Balance approach.

During 1996 then Hon President of India, Dr. A. P. J. Abdul Kalam, suggested that Snow and Avalanche Study Establishment (SASE), IMD, Indian Army to jointly make project for avalanche forecast in western Himalaya. Accordingly, Project Paravat was initiated. IMD component of procurement, training, installation of observatories etc. was conceptualize in hydromet division. The operational part is taken care of by Mountain Meteorological Division in National Weather Forecasting Centre of IMD

9. Flash flood guidance

The hydro- meteorological disasters and heavy rainfall associated hazards in a short period of time that produce immediate runoff creating a short duration flood within few hours during or after the rainfall is referred as Flash Flood. These short duration floods with a relatively high peak discharge usually less than 6 hours between the occurrence of rainfall and the peak flood. The South Asia Flash Flood Guidance System (SAsiaFFGS) was made operational in cooperation with WMO & HRC USA in 2020, covering Bangladesh, Bhutan, India, Nepal and Sri Lanka for providing the flash guidance service in the south Asian region. The India Meteorological Department (IMD) was selected as the Regional Center to provide forecast products to the participating countries and also to provide IT infrastructure, Issue flash flood guidance bulletins for each member country

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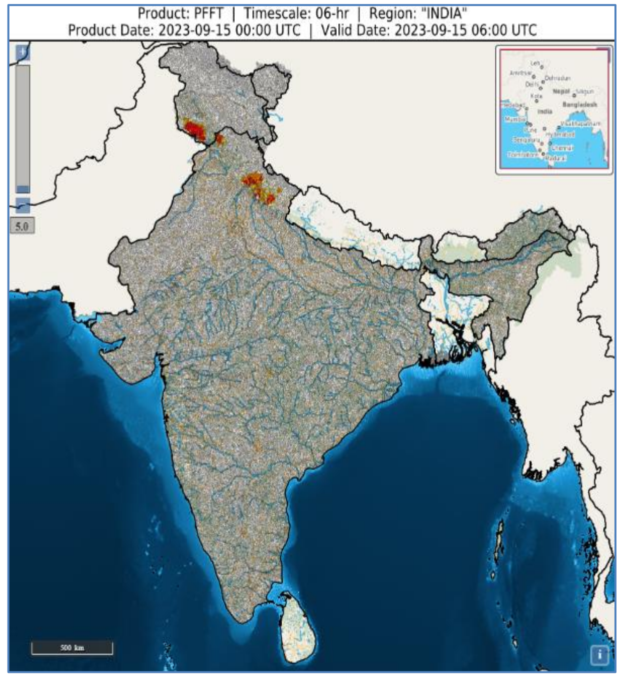

Fig. 9: Flash Flood Threat (PFFT) product

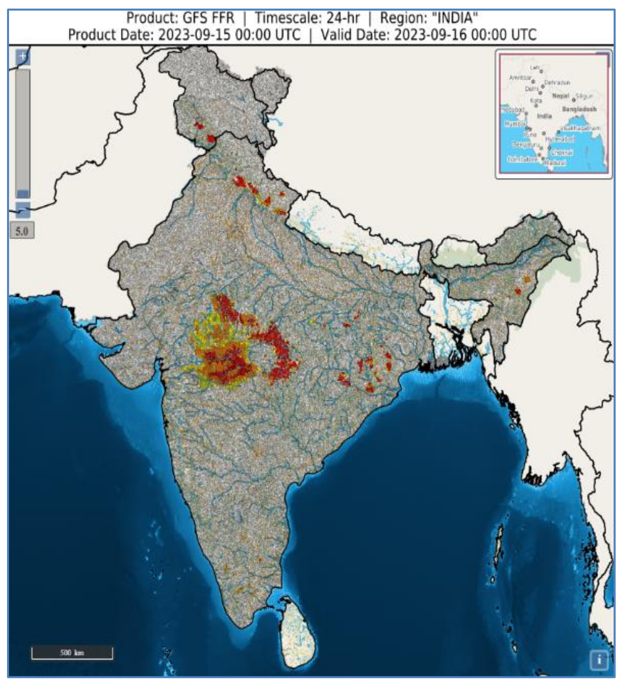

Fig. 10: Flash Flood Risk (FFR) product

was selected as the Regional Center to provide forecast products to the participating countries and also to provide IT infrastructure, Issue flash flood guidance bulletins for each member country.

With the use of satellite imaginaries, Raingauge data, radar products, and NWP model outputs, flash flood guidance bulletins are issued. The bulletins are issued based on 00, 06, 12 and 18 UTC data operationally and send through Email, WhatsApp and IMD website to MHA, NDMA, NDRF, MoJS, CWC, MoT & H, Prasar Bharati, state and district disaster management authorities, *etc*. The Guidance is issued in terms of Flash Flood Threat for next 06 hours (Fig. 9) and Flash Flood Risk for next 12, 24 and 36 hours (Fig. 10) which emerges as a very useful service for impact based forecast and its mitigation purposes.

10. Capacity building.

Ministry of Water Resources with four other central agencies including IMD and nine peninsular states implemented World Bank Aided Hydrology Project- I during 1996 -2006. The aim of the project was to generate quality hydrological and hydro meteorological data base for water resources development planning. IMD component was to assist state governments in procurement of meteorological instruments, installation of met observatories / raingauge stations, validation of data and capacity building.

Hydromet Division prepared training modules for observers, supervisors and executives. State Govt. deputed their persons for training. Observers were trained in procedures of taking observations as per norms and dissemination of same. Supervisors were trained in inspection of instruments and maintenance. Executives were trained in development of hydromet products from data, utilization of same in planning and designing of development projects and hydro met services of IMD available to them.

IMD officers were invited to deliver lectures on hydrometeorology for post graduate course at Department of Hydrology of IIT Roorkee.

In house capacity building is also a continuous routine activity for enhancement as well as improvement of the services. There is a close coordination with Officers/Staffs at Flood Meteorological Offices, Meteorological Centres and Regional Met Centres and provides training in respect of the Design Storm Studies, Rainfall monitoring, Hydromet Support for Flood Forecast and Flash Flood Guidance Activity services both in online and offline mode.

11. Publications

In order to have quick appraisal of hydroment components in project preparation, number of publications in form of manuals, monographs and atlases were brought out. They serve the purpose of ready reckoner. Some of them are listed here. The list is indicative and not exhaustive.

11.1. *Manuals*

(*i*) India Meteorological Department (1972): Manual of Hydrometeorology Part I.

(*ii*) India Meteorological Department (2009): Manual of Hydrometeorology (Revised).

(*iii*) India Meteorological Department (2021): Standard Operating Procedure Hydrometeorological Services in India.

11.2. *Monographs*

(*i*) India Meteorological Department (1971): Rainfall And Variability of Mahanadi Basins Monograph No. Basin Hydrology No. 6/ 1971.

(*ii*) India Meteorological Department (1972): A study of storm rainfall over North Bengal river basins, Meteorological Monograph No. Hydrology/No.4.

(*iii*) India Meteorological Department (1973): One day rainfall of India for different return periods, Meteorological Monograph No. Hydrology/No.5/1973.

(*iv*) India Meteorological Department (1973): Rainfall and Variability Bangla Desh Basins, Monograph No. Basin Hydrology No.7/1973.

(*v*) India Meteorological Department (1977): Rainfall and Variability TapiBasin, Basin Hydrology Monograph No. Basin Hydrology No.8/1977.

(*vi*) India Meteorological Department (1981): A Study on Trends And Periodicities Of Rainfall Over Brahmaputra Catchment, Basin Hydrology Monograph No.9/ 1981.

(*vii*) India Meteorological Department (1987): Meteorological aspects of severe floods in India 1923-1979, Meteorological Monograph No. Hydrology/No. 10/1987.

(*viii*) India Meteorological Department (1988): Generalized maps of 1 day point probable maximum

Precipitation, Meteorological Monograph No. Hydrology/No.11/1988.

11.3. *Atlas*

(*i*) India Meteorological Department (2007): Atlas of State wise Generalized ISOPLUVIAL Maps of the Southern India (Part I), Document No ALT/07/01.

(*ii*) India Meteorological Department (2008): Atlas of State wise Generalized ISOPLUVIAL Maps of the Eastern India (Part II), Document No ALT/08/01.

(*iii*) India Meteorological Department (2008): Atlas of State wise Generalized ISOPLUVIAL Maps of the Central India (Part III), Document No ALT/08/02.

(*iv*) India Meteorological Department (2009): Atlas of State wise Generalized ISOPLUVIAL Maps of the Northern India (Part III), Document No ALT/09/01.

(*v*) India Meteorological Department (2017): Probable Maximum Precipitation Atlas of Krishna Basin, Part I Atlas No ESSO/IMD/Hydrology/ATL/01(2017)/06.

(*vi*) India Meteorological Department (2020): Probable Maximum Precipitation Atlas of Indus Basin, Part I Atlas No ESSO/IMD/Hydrology/ATL/01(2097)/07.

(*vii*) Central Water Commission and India Meteorological Department (2014): PMP Atlas for Godavari River Basin.

(*viii*) Central Water Commission and India Meteorological Department (2015): PMP Atlas for Brahmaputra River Basin.

(*ix*) Central Water Commission and India Meteorological Department (2015): PMP Atlas for Narmada, Tapi, Sabarmati and Luni River Systems and rivers of Saurashtra and Kutch Region including Mahi.

(*x*) Central Water Commission and India Meteorological Department (2015): PMP Atlas for Mahanadi and adjourning river basins.

(*xi*) Central Water Commission and India Meteorological Department (2015): PMP Atlas for West flowing rivers of Western Ghats.

(*xii*) Central Water Commission and India Meteorological Department (2015): PMP Atlas for Ganga river basin including Yamuna.

(*xiii*) Central Water Commission and India Meteorological Department (2015): PMP Atlas for Cauvery and other East flowing river.

11.4. *Book*

Upadhyay, D.S., Ex- Director, Hydromet Division, IMD, Cold Climate Hydrometeorology, New International (P) Limited, Publishers (formerly Wiley Eastern Limited), 1995.

In addition to these publications, many research papers covering various aspects of Hydro met services are published in national and international journals, presented in various symposiums and workshops. Also, annual service reports on Design Storm, River sub-basin-wise QPF verification, Rainfall Monitoring etc. and data products are available in the IMD hydromet web site at https://hydro.imd.gov.in/hydrometweb/.

12. National and international cooperation.

IMD is a member of national and state level committees related to water. To name few are Ministry of Jal Shakti (Department of Water Resources), Central Board of Irrigation and Power, Flood Control Commissions of various rivers, Central Water Commission, Central Ground Water Board, National Disaster Management Authority, Bureau of Indian Standards, National Institute of Hydrology, Brahmaputra Board *etc*.

At International level IMD has representation on Commission of Hydrology of World Meteorological Organization and on working group of RA II (Asia) on hydrology, International Centre for Integrated Mountain Development, Indian National Committee for International Hydrological Programme (INC-IHP, previously known as UNESCO-IHD). It is already mentioned that in cooperation with WMO & HRC USA since 2020, the South Asia Flash Flood Guidance System (SAsiaFFGS) is operational since 2020, covering Bangladesh, Bhutan, India, Nepal and Sri Lanka for providing the flash flood guidance. India Meteorological Department (IMD) is selected as the regional Center to provide forecast products and flash flood guidance bulletins to the participating countries.

13. Conclusion

From the above discussion, one may conclude that hydro met service is a value addition to climatological data and meteorological forecasts so as to convert same into tailor made user friendly output as per users' requirements. The planning, designing and monitoring of water resources projects become more scientific, logical and economically viable with inclusion of climatological and meteorological inputs in runoff estimation. Hydromet output is important even for construction of public utility structures *e.g.*, bridges, highways, railways, airports *etc*.

However, hydromet outputs provide intermittent parameter as same needs to be used as inputs in estimation of final component that is design discharge or flood water level. Near real time rainfall monitoring, hydromet support for flood forecast, Flash Flood guidance services are also become important services for planning of agricultural activities, support for flood forecast monitoring and its mitigation in the country. There is a continuous enhancement and improvements in the hydromet services as per requirement, demand and wellbeing of the society. The hydromet products so derived from weather and climate services are unbiased as IMD is not a beneficiary of any of them.

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