Chapter 34
RAINFALL

Rain in Indian Tradition

34.1 In ancient India, it was believed that the sun causes rainfall (Adityat Jayate Vrishti) and that good rainfall in the rainy season is the key to bountiful agriculture and food for the people. Kautilya's Arthashastra contains records of scientific measurements of rainfall and its application to the country's revenue and relief work. Kalidasa in his epic, 'Meghdootam' written around the seventh century, even mentioned the date of onset of the monsoon over central India and traces the path of the monsoon clouds. Indian Classical music system celebrates monsoon with several ragas.

Measuring Rain

34.2 Rain gauges are used to measure rain and they are usually placed at places where eddies of air will not interfere with the normal fall of the raindrops are used for measuring the levels of rainfall. Rain gauge gives relatively accurate point measurement of rainfall but observations are not available over most remote land areas and over oceanic areas. Land rain gauge observations give sampling error if the network is not adequately dense.

34.3 Rainfall data are used for a variety of purposes and are required at a range of time scales. Real time rainfall data are required for flood forecasting and hydropower and reservoir operation. Summaries of storm rainfall event data are required for assessment of the severity of events at weekly or monthly time scales. Rainfall bulletins for agricultural and irrigation operations are needed at different time scales. The frequency of occurrence of rainfall of various magnitudes is also important in the application of mathematical models for synthesizing hydrological data.

34.4 When the rainfall for the monsoon season of June to September for the country as a whole is within 10% of its long period average, it is categorized as a “Normal” monsoon. It is categorized as “Excess” monsoon, if it is above 110 % of long period average and “Deficient”, if it is below 90% of long period average. The performance of monsoon rainfall over smaller areas of the country is monitored by evaluating the departures from the normal for each meteorological sub-division and district. The rainfall is classified as excess, normal deficient or scanty as per the following criteria. Excess : +20% of normal or more, 'Normal: + 19% to -19% of normal, Deficient -20% to -59% of normal, Scanty: -60 % of normal or less.

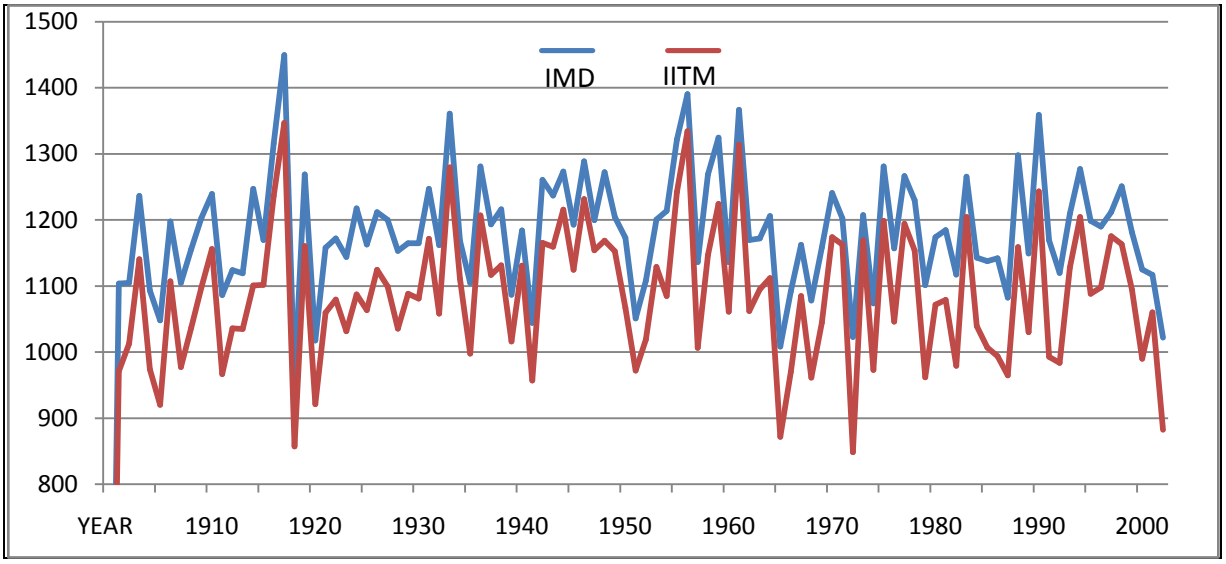
Sources of Rainfall Data

34.5 In India, two time series data on rainfall are available and popularly used . The All-India area-weighted mean summer monsoon rainfall, based on a homogeneous rainfall data set of 306 rain gauges in India, developed by the Indian Institute of Tropical Meteorology (IITM), Pune (www.tropmet.res.in) is widely considered as a reliable index

of summer monsoon activity over the Indian region. Long time series of this index since 1871 have revealed several interesting aspects of the interannual and decadal-scale variations in the monsoon as well as its regional and global teleconnections.

34.6 Rainfall time series of 36 meteorological sub Divisions of India using 1476 rain gauge stations has also been constructed by India Meteorological Department, IMD Pune since 1901. This series includes hilly regions also.

34.7 Comparison Between The Two Series: A comparative picture of the two series (annual all India rainfall in mm 1901-2003 from **India Meteorological department, IMD series & Indian Institute of Tropical Metrology, IITM Series**) indicates that both the series show identical movement with the rainfall figures of IMD (average 1183 mm) moving above the IITM figures (average 1086 mm) because of larger coverage including hilly region with higher rainfall. As expected , the IMD series with increased number of rain gauge stations shows an improvement in terms of dispersion with coefficient of variation of about 7% vis a vis about 9% coeff of variation in case of IITM series although both the series are strongly correlated with correlation coefficient more than 0.96.

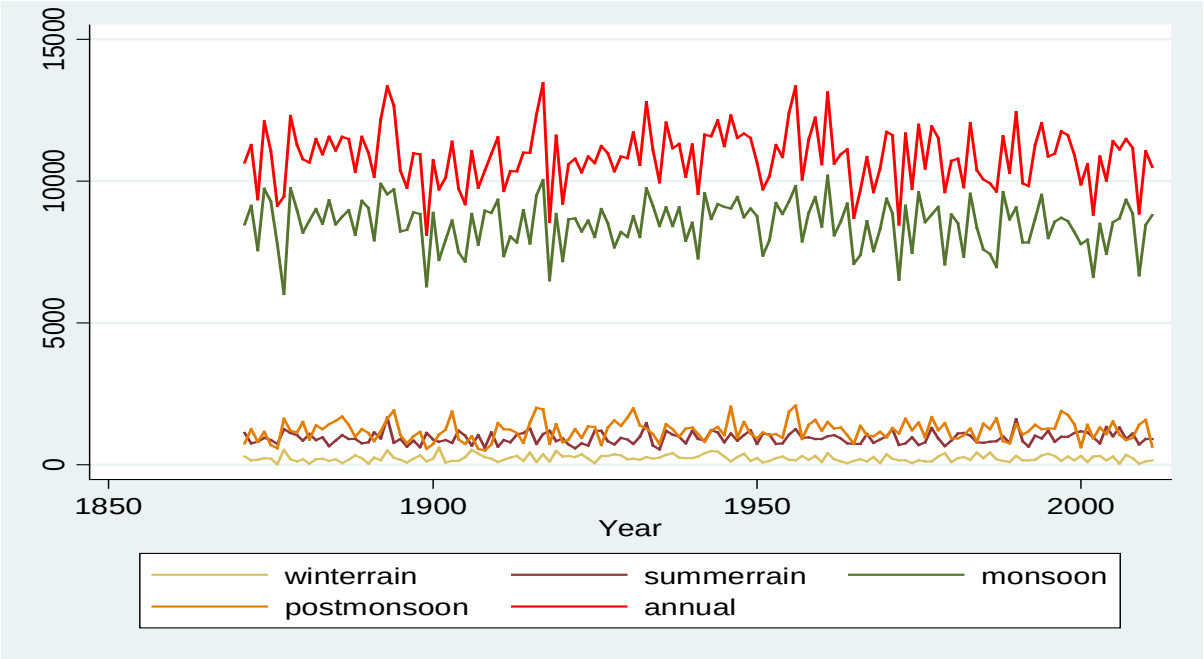


Spatio Temporal Variation In Rainfall:

34.8 During any given year, much variation is observed in the distribution of rainfall both across the geographic spread of India and across various months. Out of an average of about 125 cm rainfall , more than 75% of the annual rainfall is received in the four rainy months of June to September. The seasonality in the rainfall data based on the IITM series is summarized below:

Seasonality : Rainfall (In 1/10 mm) As Per IITM Series

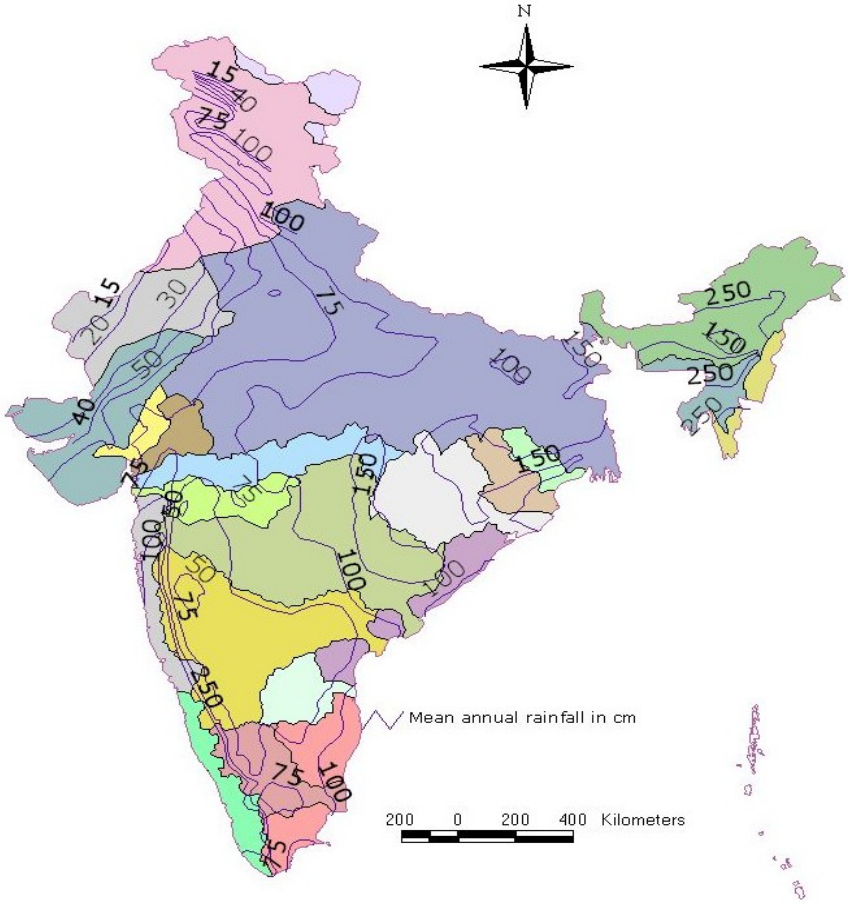
Jan-Feb : Winter rain, Mar-May :Summer rain, June-Sep: Monsoon, Oct-Dec : Post Monsoon



Variable	Obs	Mean	Std. Dev.	Coeff of Var	Min	Max	Range
Jan	141	106.9433	76.42987	71%	9	405	396
Feb	141	127.5532	89.81715	70%	6	410	404
Mar	141	151.4043	92.63199	61%	28	527	499
Apr	141	265.383	89.74875	34%	80	605	525
May	141	529.0071	160.8206	30%	205	1077	872
June	141	1640.794	365.3379	22%	782	2416	1634
July	141	2719.369	379.9893	14%	1176	3460	2284
Aug	141	2420.362	378.3641	16%	1441	3393	1952
Sep	141	1703.518	370.1472	22%	772	2678	1906
Oct	141	775.7163	283.821	37%	147	1595	1448
Nov	141	313.3475	183.4626	59%	18	883	865
Dec	141	117.695	94.64301	80%	3	565	562
winter rain	141	234.4965	117.902	50%	30	609	579
summer rain	141	945.7943	204.569	22%	552	1665	1113
monsoon	141	8484.043	834.4583	10%	6039	10201	4162
post monsoon	141	1206.759	344.6311	29%	501	2097	1596
annual	141	10871.09	1015.173	9%	8110	13468	5358

34.9 Spatial Variations In The Rainfall

a. Areas of Heavy Rainfall (Over 200cm) : The highest rainfall occurs in west coast, on the western Ghats as well as the Sub-Himalayan areas in North East and Meghalaya Hills, Assam, West Bengal, and Southern slopes of eastern Himalayas.
b. Areas of Moderately Heavy Rainfall (100-200 cm) : Moderate rainfall occurs in Southern parts of Gujarat, East Tamil Nadu, North-eastern Peninsular, Western Ghats, eastern Maharashtra, Madhya Pradesh, Orrisa and the middle Ganga valley.
c. Areas of Less Rainfall (50-100 cm) : Upper Ganga valley, eastern Rajasthan, Punjab, Southern Plateau of Karnataka, Andhra Pradesh and Tamil Nadu experience less rain.
d. Areas of Scanty Rainfall (Less than 50 cm):Northern part of Kashmir, Western Rajasthan, Punjab and Deccan Plateau get scanty rainfall.
Two significant features of India's rainfall are in the north India, rainfall decreases westwards and in Peninsular India, except Tamil Nadu, it decreases eastward.

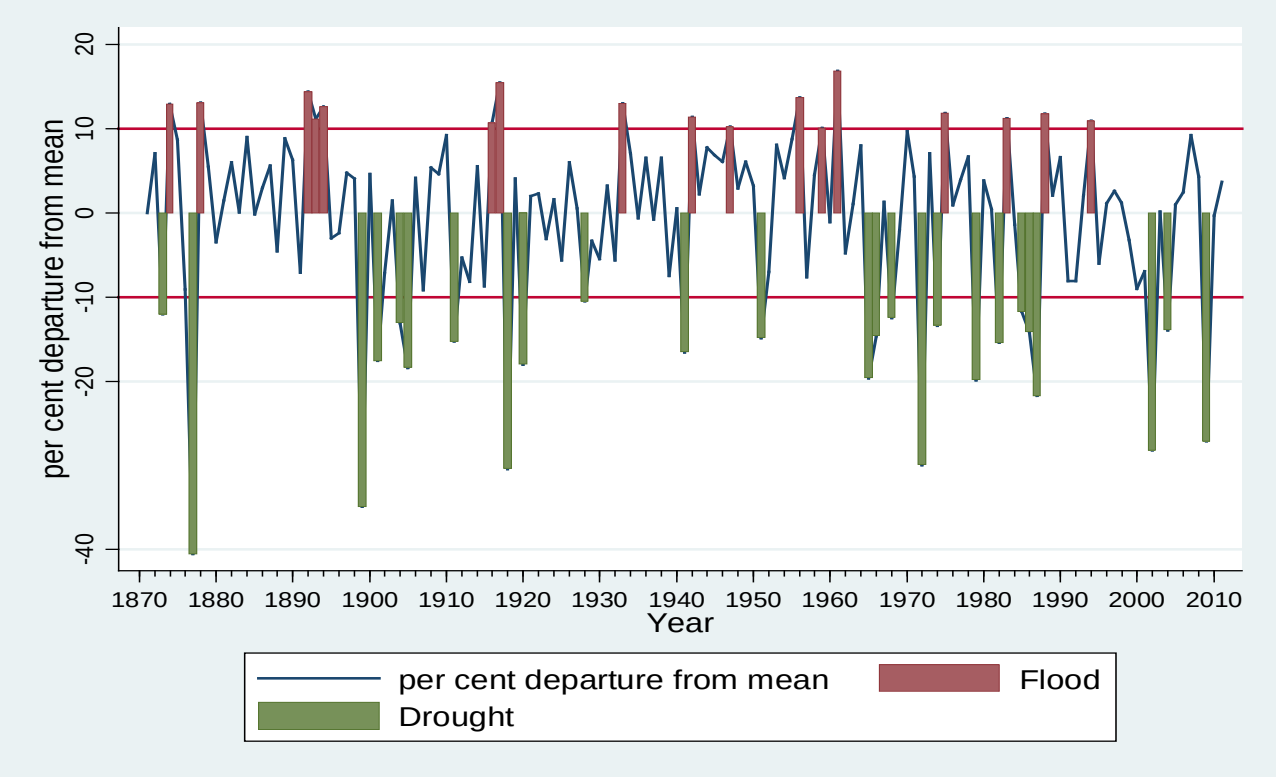


Distribution of Area According to Annual Rainfall

Category	Rainfall (mm)	Area (%)
Dry	0–750	30
Medium	750–1 50	42
	1 150–2 000	20
High	> 2 000	8

Summary of Rainfall Since 1871

34.10 All-India Summer Monsoon (June-September) Rainfall (AISMR) Anomalies (expressed as percent departures from its long-term mean , based on All India Rainfall series of IITM) during 1901-2011 is summarised as under:



Flood Years (i.e., anomaly exceeding +10%)	**Drought Years (i.e., anomaly below -10%)**
1874, 1878, 1892, 1893, 1894, 1916, 1917, 1933, 1942, 1947, 1956, 1959, 1961, 1975, 1983, 1988, 1994.	1873, 1877, 1899, 1901, 1904, 1905, 1911, 1918, 1920, 1928,1941, 1951, 1965, 1966, 1968, 1972, 1974, 1979, 1982, 1985, 1986, 1987, 2002, 2004, 2009
Some researchers have indicated presence of alternating periods extending to 3-4 decades with less and more frequent weak monsoons over India.	

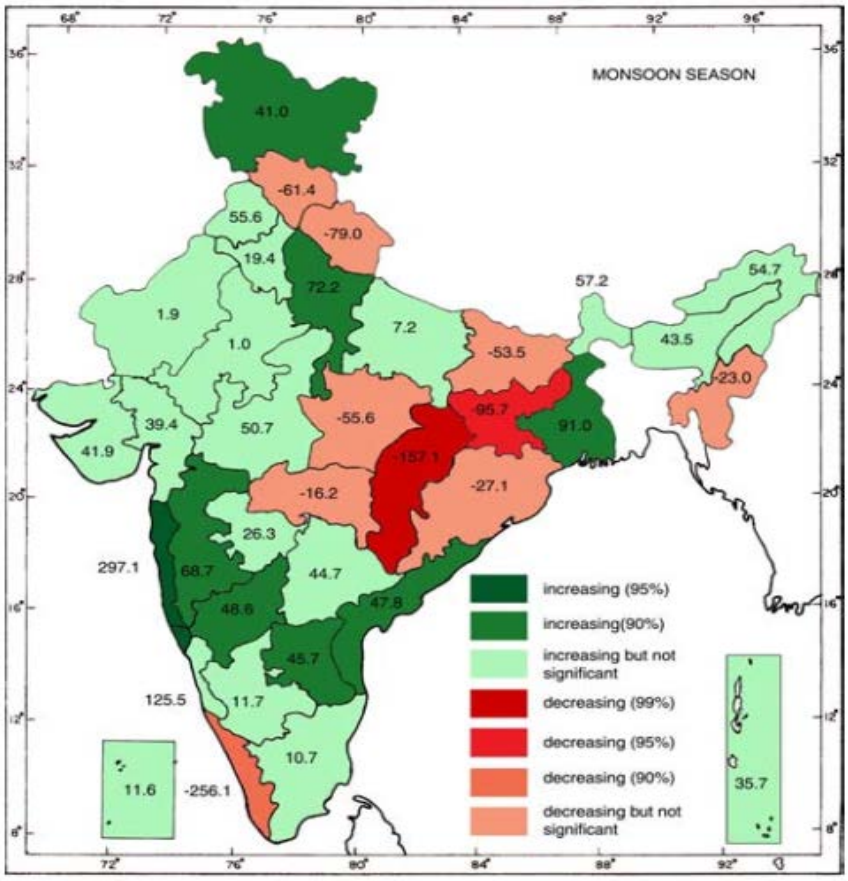
Trends in Rainfall Data:

34.11 Although several studies suggest an intensification of the Asian summer monsoon rainfall with increased atmospheric carbon dioxide concentrations (Zhao and Kellogg 1988; Meehl and Washington 1993, Bhaskaran et al. 1995, Kitoh et al. 1997), there is still a controversy about the regional climate change impact, especially over the Indian subcontinent (Hirakuchi and Giorgi, 1995). No evidence has been found in the observational record to suggest that the all-India average rainfall has increased systematically over the last century (Pant et al. 1993).

34.12 All India Average Rainfall: The IITM rainfall series was analyzed for detection of trends and it was found that **All India summer monsoon season (June to September) rainfall as well the all India rainfall for all the four monsoon months does not show any significant trend**. The same was confirmed by both parametric (Slope coefficient of regression) and non parametric methods (Mann Kendall Test) (Since most hydrological data do not follow normality & other assumptions, non parametric tests are preferred over parametric tests even though they do not quantify the size of trend identified)

34.13 Trends In Regional Distribution of Rainfall : Even though no significant trend has been noticed in annual/ monsoon rainfall at all India levels , trends (both increasing and decreasing) have been observed in the spatial distribution of the rainfall .

*Analysis based on IMD rainfall series indicated that during the monsoon season , three subdivisions viz. Jharkhand, Chattisgarh, Kerala show significant decreasing trend and eight subdivisions viz. Gangetic West Bengal, West Uttar Pradesh, Jammu & Kashmir, Konkan & Goa, Madhya Maharashtra, Rayalaseema, Coastal Andhra Pradesh and North Interior Karnataka show significant increasing trends **



Increase/ decrease in rainfall in mm in 100 years for each of 36 Sub Divisions for SW Monsoon season. Different level of significance are shaded with colors

* : Trends in the rainfall pattern over India , P Guhathakurta and M Rajeevan , National Climate centre , IMD , Pune-2006

34.14 However, analysis of IITM rainfall series (1871-2011) indicates presence of significant trend only in case of Chattisgarh (decreasing) and Konkan and Goa (increasing) (non parametric Mann Kendall Test, Run test). Both these were observed to have strongest trend even in IMD series study (99 and 95 per cent level of significance respectively).

34.15 *Significant trends (both increasing & decreasing) have been observed across several sub divisions in cases of monthly rainfall data for individual months of monsoon (June- September) *.*

34.16 High Impact Weather Events

All-India Summer Monsoon Rainfall
June 01 to September 30, 2015

- **Actual: 737 mm**
- **Normal: 870 mm**
- **Departure from Normal: -15%**
- **Proportion of Seasonal Normal: 85%**

During this season namely June-September, 2015 the heat wave conditions continued to have impact over Odisha subdivision and claimed 35 lives. Due to relatively more cyclogenetic activity during the first half of season, incessant heavy rains and major floods were observed over the regions along the track of the systems. The presence of cyclonic vortex and formation of a couple of low pressure areas, of which one intensified into a cyclonic storm 'Komen' led to incessant heavy rainfall and major floods in Assam, West Bengal, Odisha and Uttar Pradesh. Heavy rain and floods incidences over Gujarat State and Rajasthan were mainly due to formation and movement of couple of Deep Depressions. Similarly the formation and movement of other various systems led to active monsoon conditions that caused heavy rainfall leading to flash floods/landslides in Arunachal Pradesh, Assam & Meghalaya, Nagaland-Manipur-Mizoram-Tripura, Sub-Himalayan West Bengal & Sikkim Konkan & Goa and Vidarbha causing damages to property and life. Frequent Intense convective activity over Western Himalayan region also led to flash floods/landslides and damaged life and property in Himachal Pradesh, Jammu & Kashmir and Uttarakhand.

34.17 Rainfall Distribution

The realized 2015 southwest monsoon season (June to September) rainfall over the country as a whole and four broad geographical regions are given in the table below along with respective long period average (LPA) values. The rainfall during the 4 monsoon months and the second half of the monsoon season (August + September) over the country as whole are also given.

Season (June to September) rainfall			
Region	LPA (mm)	Actual Rainfall for 2015 SW Monsoon Season	
		Rainfall (mm)	Rainfall (% of LPA)
All India	887.5	760.6	86
Northwest India	615.0	510.6	83
Central India	975.5	815.5	84
Northeast India	1437.3	1317.5	92
South Peninsula	715.1	605.7	85
Monthly & second half of the monsoon season rainfall over the country as a whole (All India)			
Month	LPA (mm)	Actual Rainfall for 2015 SW Monsoon Season	
		Rainfall (mm)	Rainfall (% of LPA)
June	163.6	189.5	116
July	289.2	241.9	84
August	261.3	204.2	78
September	173.4	131.4	76
August + September	434.7	335.6	77

34.18 Verification of the Long Range Forecasts

Based on an indigenously developed statistical model, it was predicted on 15th May 2015 that monsoon will set in over Kerala on 30th May with a model error of ±4days. However, the actual monsoon onset over Kerala took place on 5th June, 2 days later than the upper forecast limit.

34.19 This year, the long range forecast for the 2015 southwest monsoon rainfall was issued in 3 stages. The first stage long range forecast issued on 22nd April consisted of only forecast for season (June-September) rainfall over the country as a whole. In the second stage (2nd June), along with the update for the April forecast, forecast for season rainfall over the four broad geographical regions (northwest India, central India, south Peninsula and northeast India) and that for monthly rainfall over the country as a whole for the months of July and August were issued. In the 3rd stage (2nd August), the forecast for the rainfall during the second half of the monsoon season over the country as a whole was issued.

34.20 The first stage forecast for the season (June-September) rainfall over the country as a whole issued in April was 39% of LPA (below normal) with a model error of ±5% of LPA. This forecast was updated to 88% ±4% of LPA (deficient) in June. The actual season rainfall for the country as a whole was 86% of LPA, which is within the kimits of second stage forecast issued in June.

34.21 Considering the four broad geographical regions of India, the forecasts issued in June for the season rainfall over northwest India, Central India, northeast India and

south Peninsula were 85%, 90%, 90% & 92% of the LPA respectively all with model errors of ±8%. The actual rainfalls over northwest India, central India, northeast India and south Peninsula were 83%, 84%, 92% and 85% of the LPA respectively. The actual season rainfall of northwest India is 2% of LPA less than the forecast and that of northeast India is 2% of LPA more than the forecast. However, the actual season rainfalls over Central India & South Peninsula were less than the forecast by 6% & 7% of LPA respectively but well above the lower forecast limits.

34.22 The forecast for the second half of the monsoon season (August-September) for the country as a whole was 84% with a model error of ±8% of LPA against the actual rainfall of 77% of LPA. Thus the forecast for the rainfall during the second half of the monsoon season over the country as a whole is also within the forecast limits.

34.23 The forecasts for the monthly rainfall over the country as a whole for the months of July & August issued in June were 92% & 90% respectively with a model error of ±9%. The actual monthly rainfalls during July and August were 84% 7 78% of LPA respectively, which are below the forecasts by 8% of LPA and 12% of LPA respectively. Thus whereas the actual July rainfall was within the forecast limit, the actual August rainfall was 3% of LPA below the lower forecast limit.

The Table below gives the summary of the verification of the long range forecasts issued for the 2015 Southwest monsoon.

Table : Details of long range forecasts and actual rainfall.

Region	Period	Forecast (% of LPA)		Actual Rainfall (% of LPA)
		22th April	2th June (Update)	
All India	June to September	93 ± 5	88 ± 4	86
Northwest India	June to September		85 ± 8	83
Central India	June to September		90 ± 8	84
Northeast India	June to September		90 ± 8	92
South Peninsula	June to September		92 ± 8	85
All India	July		92 ± 9	84
All India	August		90 ± 9	78
All India	August to September		84 ± 8	77

34.24 As seen in the table, the season rainfall over the country as a whole and that over four broad geographical regions (northwest India, central India, northeast India and south Peninsula) are within the limits of the forecasts issued in June and accurate. Similarly, the forecasts for the July as well as that for the rainfall during the second half of the monsoon season over the country as a whole are also accurate. However, the August forecast was an overestimate to the realized rainfall.

34.25 Moderate to strong El Nino conditions during the second half of the monsoon season and absence of other favourable intra seasonal or synoptic conditions except formation of 2 low pressure systems (one low pressure and one depression) in Bay of Bengal, may have resulted large rainfall deficiency (-23% of LPA) during second half of the season.

References:

- Trends in the rainfall pattern over India , P Guhathakurta and M Rajeevan , National Climate centre , IMD , Pune
- South West Monsoon End of Season Report 2014, Indian Meteorological Department and website of Indian Institute of Tropical Meteorology.