CHAPTER 34
RAINFALL

Key Finding:

- Despite of theories suggesting increase in rainfall in Asian Region due to global warming, no significant trend has been observed at all India level (confirmed by both parametric & non parametric method)
- Significant trends, both increasing and decreasing have been found at regional level (Viz decreasing trend in rainfall for Chhattisgarh & increasing trend for Konkan & Goa) suggesting slight change in distribution.
- Even though month wise rainfall during monsoon has not changed at all India level, increase/decrease in different months has been noticed in some regions.

During 2013:

- Normal Monsoon was witnessed at all India level with 6.3 % excess rains. Most of the Western & Central India witnessed excess rains while North Eastern regions , Bihar & Jharkhand recorded deficient rainfall. Monsoon started with higher initial downpour during June resulting in the catastrophe in Uttarakhand that affected several districts including Uttarkashi, Chamoli & RudraPrayag.

34.1 **Rain in Indian Tradition:** In ancient India, it was believed that the sun causes rainfall (AdityatJayateVrishti) and that good rainfall in the rainy season is the key to bountiful agriculture and food for the people. Kautilya'sArthashastra 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.

34.2 **Measuring Rain**

34.2.1 Rain gauges 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 gives sampling error if the network is not adequately dense.

34.2.2 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.

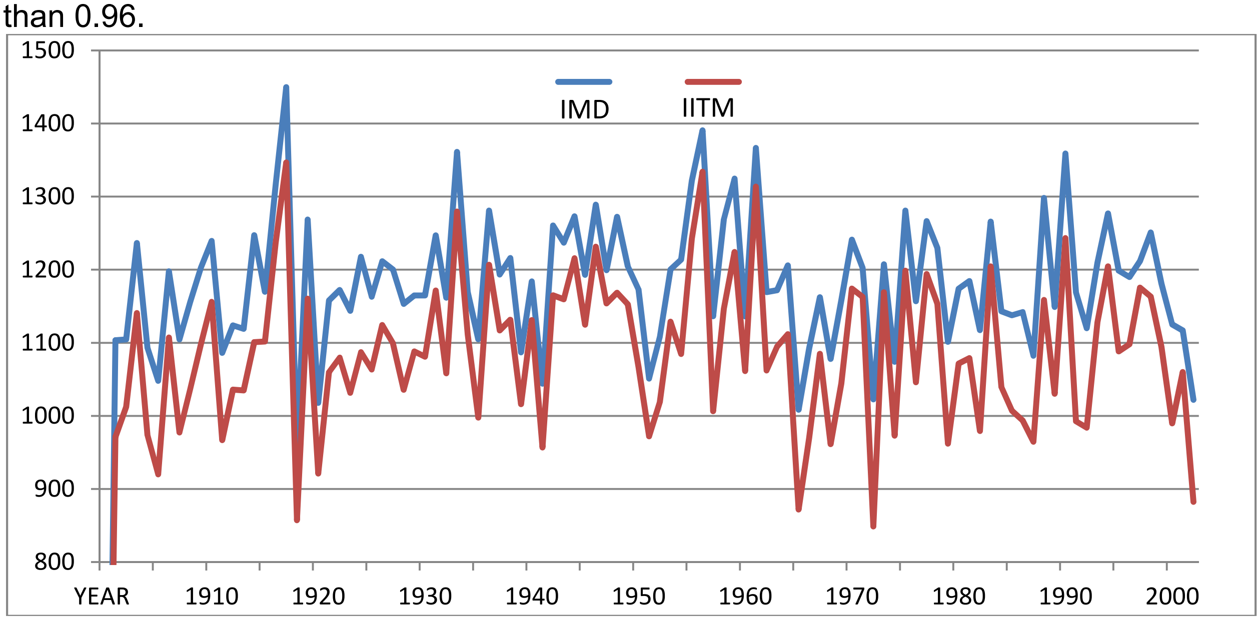
34.2.3 When the rainfall for the monsoon season of June to September for the country as a whole is within 10% of its long period average, it is categorized as a “Normal” monsoon. It is categorized as "Excess" monsoon, if it is above 110 % of long period average and "Deficient", if it is below 90% of 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.

34.3 Sources of Rainfall Data

34.3.1 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.

34.3.2 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.

34.3.3 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.

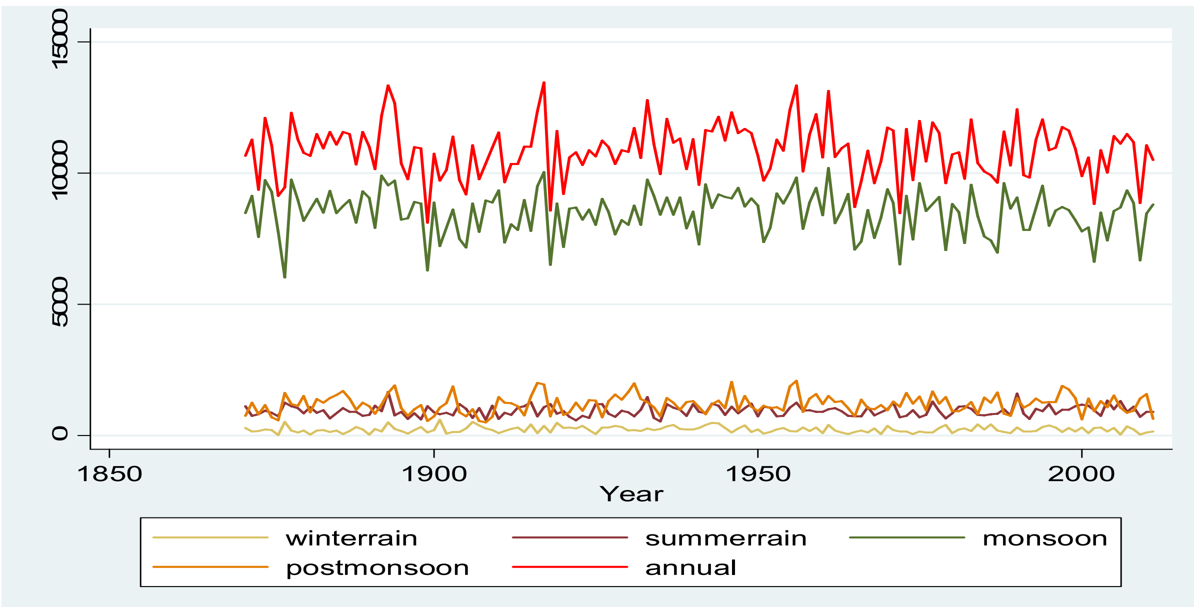


34.4 Spatio Temporal Variation In Rainfall :

34.4.1During 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

34.4.2 **Spatial Variations In The Rainfall**

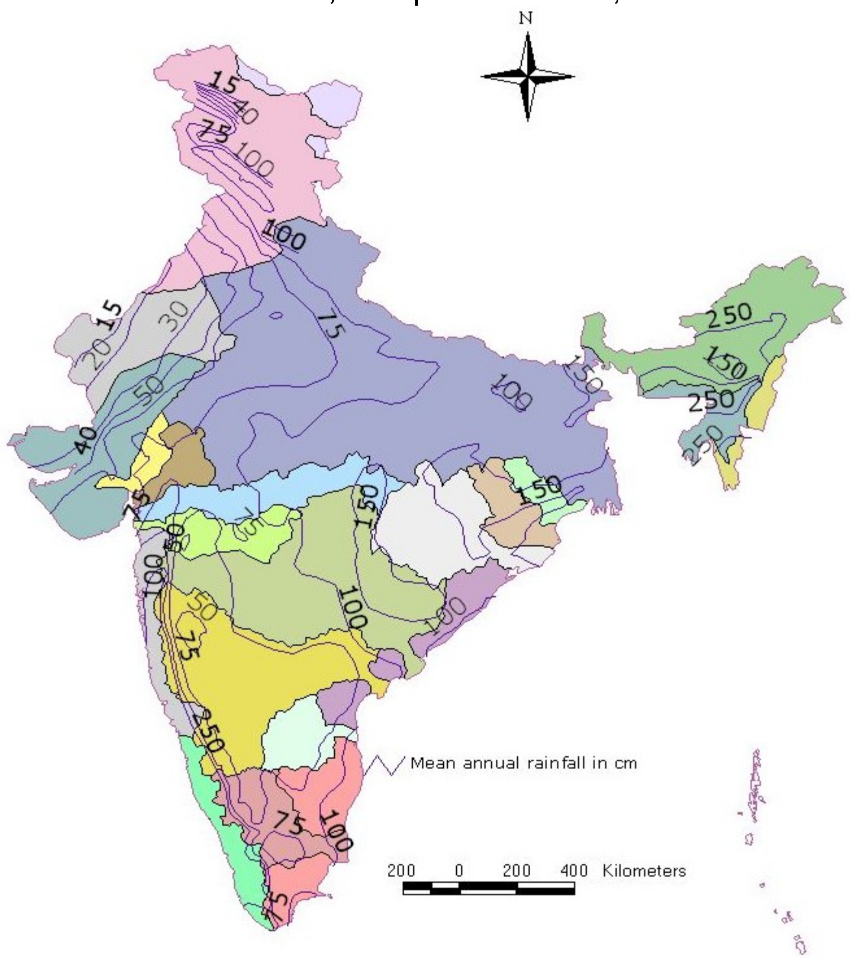
a. Areas of Heavy Rainfall (Over 200cm) : The highest rainfall occurs in west coast, on the western Ghats as well as the Sub-Himalayan areas in North East and Meghalaya Hills, Assam, West Bengal, and Southern slopes of eastern Himalayas.

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.

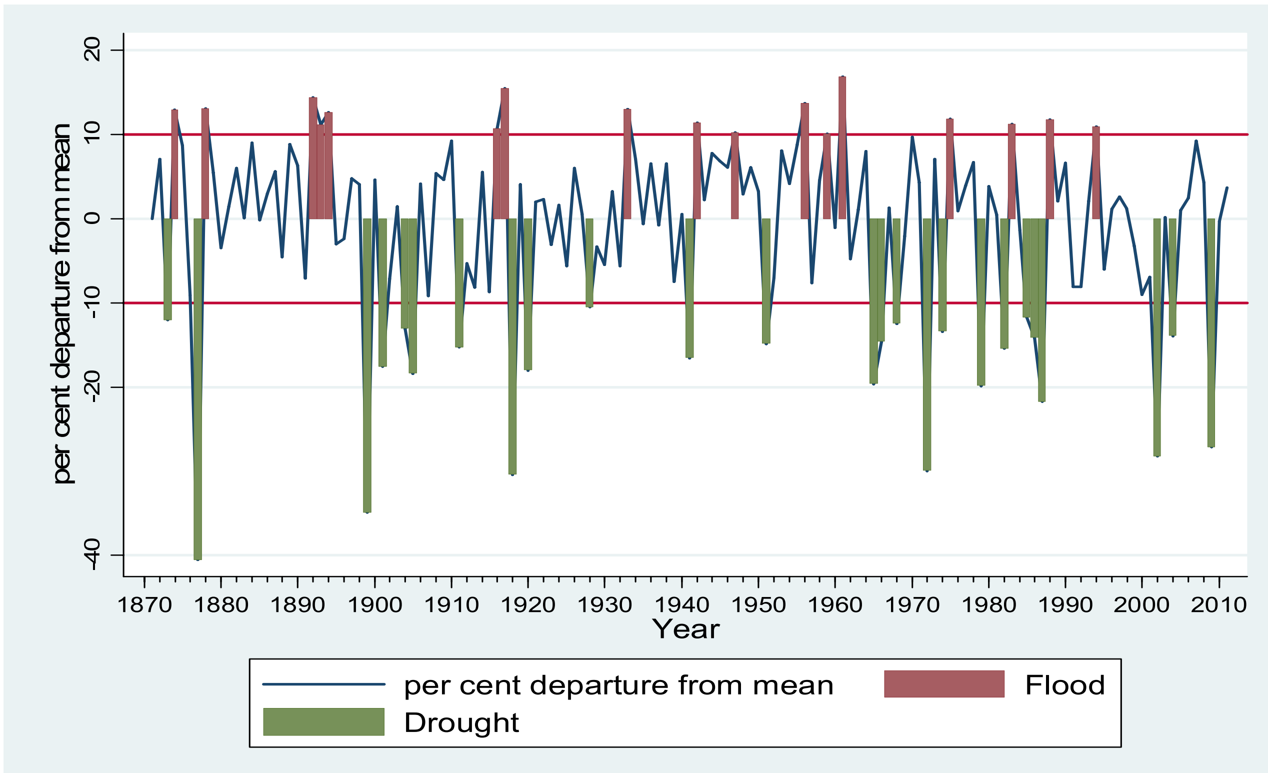


Distribution of Area According to Annual Rainfall

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

34.5 Summary of Rainfall Since 1871

34.5.1 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.	

34.6 Trends In Rainfall Data :

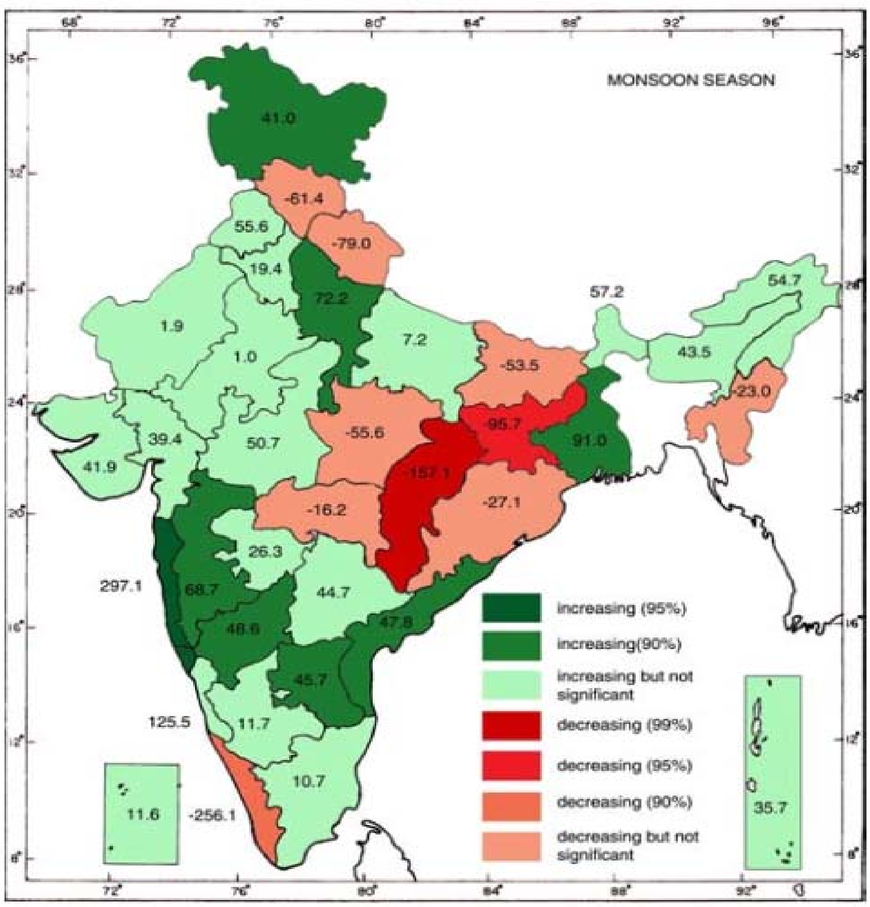
34.6.1 Although several studies suggest an intensification of the Asian summer monsoon rainfall with increased atmospheric carbon dioxide concentrations (Zhao and Kellogg 1988; Meehl and Washington 1993, Bhaskaran et al. 1995, Kitoh et al. 1997), there is still a controversy about the regional climate 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).

34.6.2 **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)

34.6.3 **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 .

34.6.4 *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

34.6.5 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).

34.6.6 *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) *.*

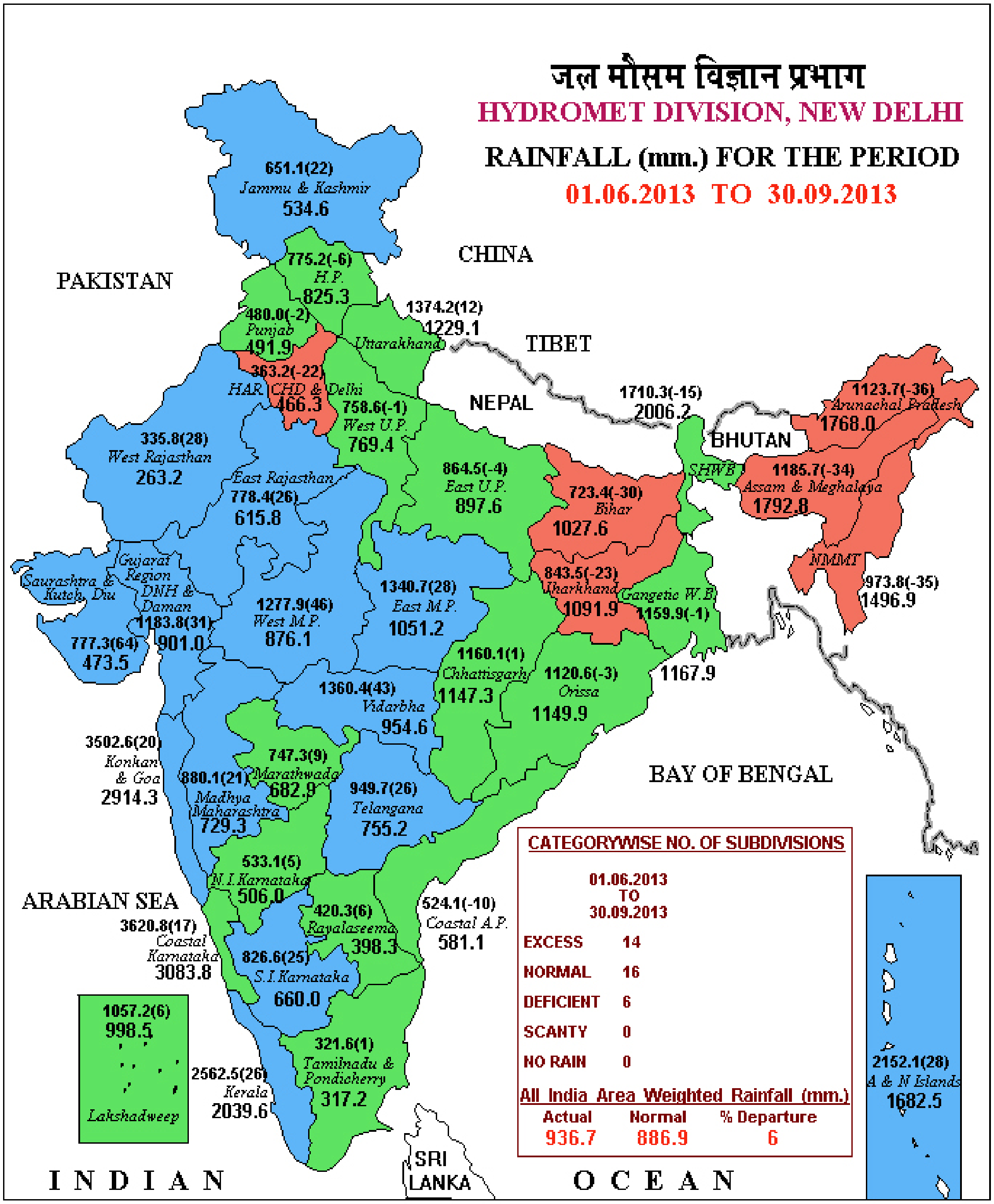
34.7 Highlights : All-India Summer Monsoon Rainfall (June- September 2013)

Actual: 925 mm
Normal: 870 mm
Departure from Normal: 6.3 %
Proportion of Seasonal Normal: 106.3 %

34.7.1 After slow start followed by a recovery, resulting in a normal monsoon (less than 10 % deficient , 7.78 % to be more precise) during 2012 , **normal monsoon** was witnessed in 2013 also which started with a reverse trend (excess initial monsoon rains followed by marginal deficiency in September) and resulted in excess rains than normal on the whole , though within the 10% margins of normalcy (6.3 % to be more precise).

34.7.2 Except for Haryana, Bihar Jharkhand & North Eastern States , which witnessed deficient rain (less than 20 % from normal), most regions received either normal or excess rains. Saurashtra & Kutch witnessed highest excess rains (64 %) followed by Western MP (46%) and Vidarbha (43%). Highest deficiency was recorded in case of Arunanchal Pradesh with 36 % deficient rains.

34.7.3 Regions along the Eastern Coast , UttarPradesh, Uttarakhand, Punjab, Himachal Pradesh received normal rains. However the initial rush of Monsoon resulted in heavy downpour in Uttarakhand causing heavy damage to life and property . Regions of Himachal Pradesh and some other northern regions were also affected, but Uttarakhand bore the brunt as heavy rains lashed around June 15th resulting in heave destruction in the districts of Rudraprayag, Chamoli & Uttarkashi.



LEGEND: EXCESS (+20% OR MORE) NORMAL (+19% TO -19%) DEFICIENT (-20% TO -59%)
SCANTY (-60% TO -99%) NO RAIN (-100%) NO DATA

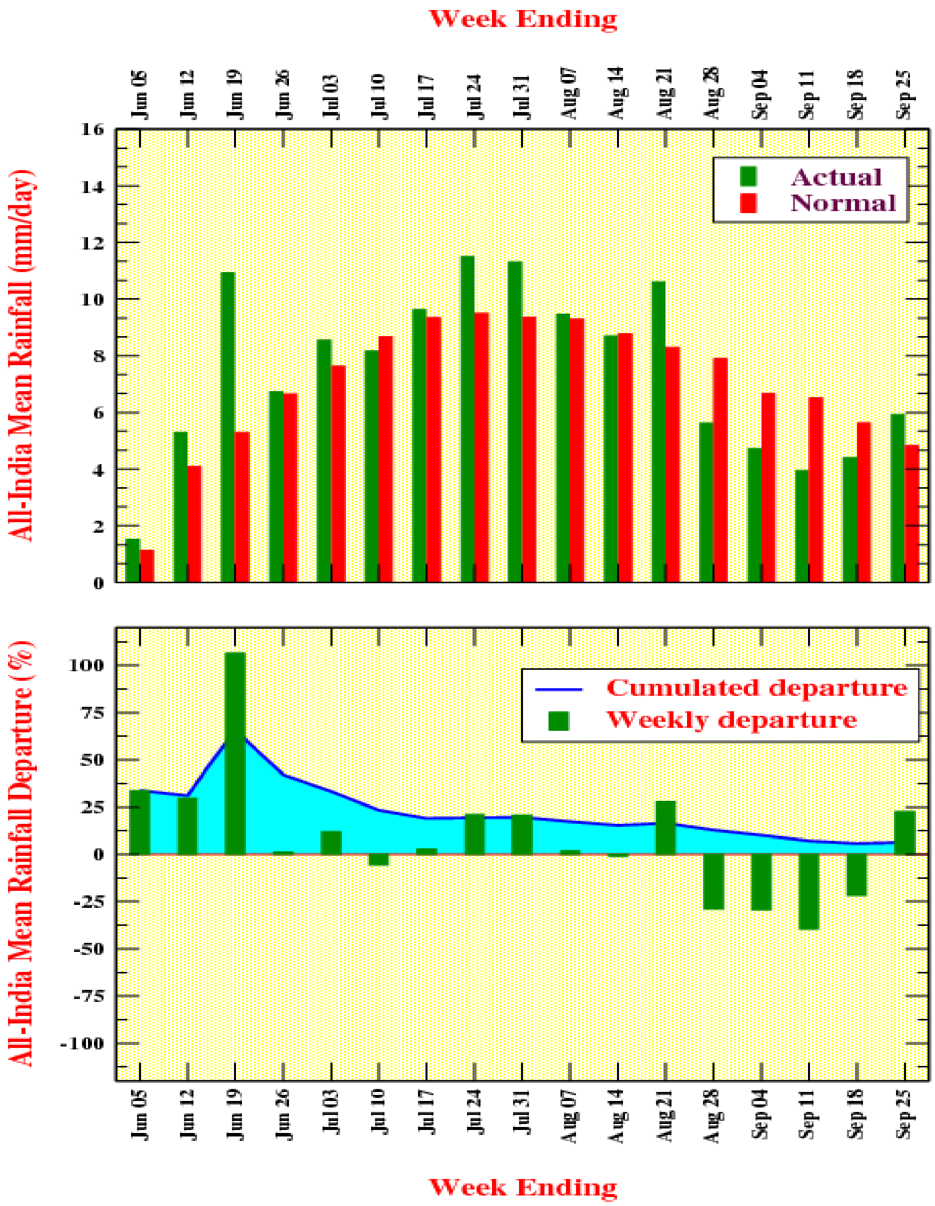
NOTES:

(a) Rainfall figures are based on operational data.
(b) Small figures indicate actual rainfall (mm.), while bold figures indicate Normal rainfall (mm.)
Percentage Departures of Rainfall are shown in Brackets.

Source : Indian Meteorological Department , Pune

34.8 Weekly Monsoon 2013 All India.

34.8.1 Graphs below indicates about normal monsoon on the whole with higher than the normal rains witnessed during the start , specially June and the trend reversing in September. On the whole departure of about 6 % (excess) was observed .



These pictures are based on the near-real-time reports from more than 1000 stations well-spread over India, as published in the Weekly Weather Summaries issued by the India Meteorological Department.

Source : Website of Indian Institute of Tropical Metrology

References :

- Trends in the rainfall pattern over India , P Guhathakurta and M Rajeevan , National Climate centre , IMD , Pune
- Trend Analysis of Precipitation data in Pieria region (Greece), D K Karpouzos, S Kavalieratou and C Babajimopoulos

Annexure
(Outputs of Statistical Analysis)

Detection of trend in All India Annual Monsoon Rainfall series (IITM)
Since most hydrological data usually does not follow normality and other assumptions, Non Parametric tests are preferred over Parametric tests even though they do not quantify the size of trend identified. However, in the present case both type of tests were applied for trend detection.

Parametric Method: The graph of monsoon rain over time revealed stable mean and variance thereby indicating a stationary series. Absence of any autoregressive feature was indicated by values of AC & PAC (autocorrelation & partial auto correlation) at various lag orders. However , following generalized model (allowing auto regressive component of lag length one) was used to test for presence of any trend.

Model
Monsoon in Year t (i) $(M_t)= \alpha + \beta M_{t-1} + \mu t + \epsilon_t$

Or (ii) $\Delta M_t = \alpha + (\beta-1) M_{t-1} + \mu t + \epsilon_t$

if $(\beta-1)=0$ then the series is not stationary.
if $\mu>0$ then series contain a trend
if $\mu=0$ and $(\beta-1)\neq 0$ then the series is stationary.

Tests for the assumptions of CLRM (Classical Linear Regression Model) revealed that the assumption of Normality of errors was being violated(Shapiro Wilk Test, Jarque Bera Test) . Though in large samples we can rely on Central Limit Theory to ensure that even if the error terms are not normally distributed, the sampling distribution of partial slope coefficient estimator will be normally distributed (Hanushek & Jackson 1977:68). Bohrnstedt and Carter (1971) have shown , regression analysis is quite robust against violations of normality .But since in present case normality assumption could easily be achieved by dropping outliers (eight), those observations were dropped and the resultant series satisfied all major assumptions of CLRM.

The insignificant coefficient of trend variable however still indicated **absence of any significant trend.**

. dfuller M, trend regress

Dickey-Fuller test for unit root Number of obs = 126

	Test Statistic	Interpolated Dickey-Fuller 1% Critical Value	5% Critical Value	10% Critical Value
Z(t)	-11.547	-4.031	-3.447	-3.147

MacKinnon approximate p-value for Z(t) = 0.0000

D.M	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
M						
L1.	-1.061631	.0919386	-11.55	0.000	-1.243618	-.8796441
_trend	-1.657657	1.738196	-0.95	0.342	-5.098311	1.782996
_cons	9187.177	809.3927	11.35	0.000	7585.034	10789.32

Above D Fuller Test indicates that the series may be treated as stationary. Other assumptions viz normality (tested by Shapiro Wilk Test , homoscedasticity (Breausch Pagan Test) , autocorrelation (Durbin Watson Statistic), linearity & independence of error terms (Rvf and other plots) etc are also found to hold true. Rvf plot , actual(M) vs fitted values (Mhat) and residual (ehat) vs year plot indicate that assumption of linearity & independence of error terms may be valid.

Non Parametric Tests for detection of Trend :

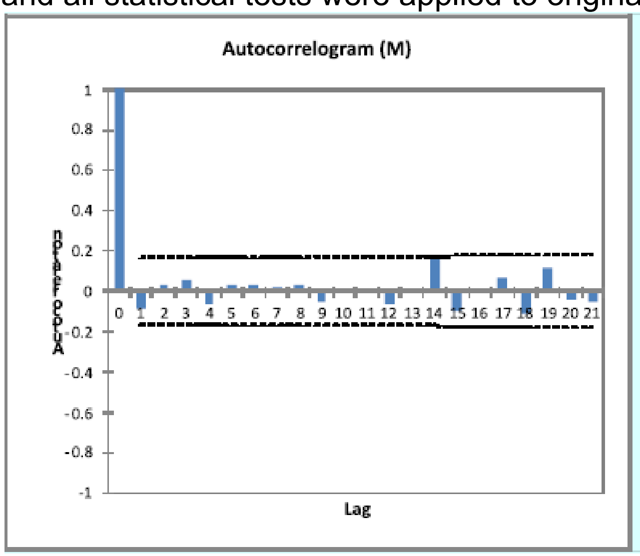
Run Test (All India monsoon & annual rainfall series of IITM) : Null Hypothesis of serial independence & randomness may be accepted.

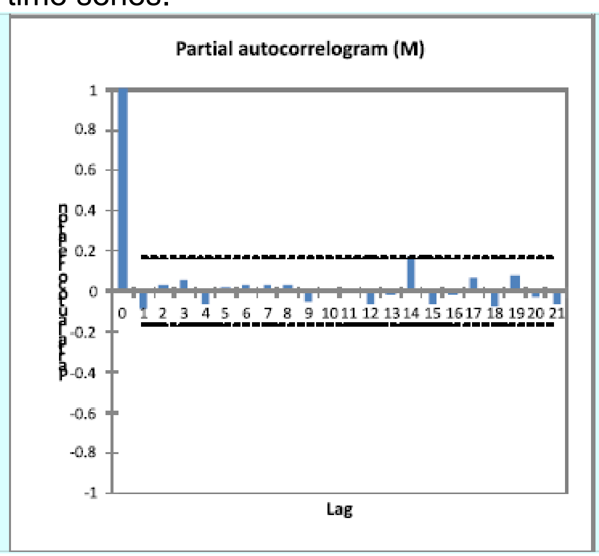
```
. runtest  monsoon
 N(monsoon <= 8608) = 71
 N(monsoon > 8608) = 70
          obs = 141
      N(runs) = 76
            z = .76
    Prob>|z| = .45

. runtest annual
 N(annual <= 10949) = 71
 N(annual > 10949) = 70
          obs = 141
      N(runs) = 71
            z = -.08
    Prob>|z| = .9300000000000001
```

The Mann Kendall Test (M-K Test) : It is robust to influence of extreme values , skewed variables (Hamed 2008), non normally distributed data containing outliers & non linear trends (Helsel & Hirsch 1992; Birsan et al 2005)

Null hypothesis: deseasonalised data is a sample of n independent & identically distributed random variables (Hirsh et al 1982).

Initially, the autocorrelation test was performed to all time series in order to check randomness of data (Modarres and Da Silva 2007) . As all lag -1 serial correlation coefficients were statistically not significant , there was no need to pre white the data , and all statistical tests were applied to original time series.





MK Test indicated that the Null hypothesis of no trend in the series, in case of overall Monsoon rainfall(M), could not be rejected. However , **at regional level , trend was observed in case of Konkan & Goa (increasing trend)& Chhatisgarh(decreasing**

trend). Outputs of all the three cases are given below . Due to space constraints , outputs indicating absence of significant trend (90% level of significance) elsewhere have not been included.

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
M	141	0	141	6039.000	10201.000	8484.043	834.458

Mann-Kendall trend test / Two-tailed test (M):

Kendall's tau	-0.067
S	-666.000
Var(S)	314741.333
p-value (Two-tailed)	0.236
alpha	0.05

The exact p-value could not be computed. An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

As the computed p-value is greater than the significance level alpha=0.05, **one cannot reject the null hypothesis H0.**

The risk to reject the null hypothesis H0 while it is true is 23.59%.

Monsoon Rainfall (Konkan & Goa) : (Increasing trend)

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Konkan and Goa	141	0	141	10517.000	37543.000	23817.241	4556.939

Mann-Kendall trend test / Two-tailed test (Konkan and Goa):

Kendall's tau	0.121
S	1198.000
Var(S)	314743.333
p-value (Two-tailed)	0.033
alpha	0.05

The exact p-value could not be computed. An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

As the computed p-value is lower than the significance level alpha=0.05, **one should reject the null hypothesis H0, and accept the alternative hypothesis Ha. The risk to reject the null hypothesis H0 while it is true is lower than 3.29%.**

Monsoon Rainfall (Chhattisgarh) : (decreasing trend)

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
Chhatisgarh	141	0	141	7334.000	18812.000	11879.858	2086.080

Mann-Kendall trend test / Two-tailed test (Chhatisgarh):

Kendall's tau	-0.189
S	-1863.000
Var(S)	314742.333
p-value (Two-tailed)	0.001
alpha	0.05

The exact p-value could not be computed. An approximation has been used to compute the p-value.

Test interpretation:

H0: There is no trend in the series

Ha: There is a trend in the series

As the computed p-value is lower than the significance level alpha=0.05, **one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.The risk to reject the null hypothesis H0 while it is true is lower than 0.09%.**