INDIA METEOROLOGICAL DEPARTMENT
(MINISTRY OF EARTH SCIENCES)
SOUTHWEST MONSOON-2010
END OF SEASON REPORT

HIGHLIGHTS

- **For the country as a whole, the rainfall for the season (June-September) was 102% of its long period average (LPA) of 89 cm.**

- **Seasonal rainfall was 112% of its LPA over Northwest India, 104% of its LPA over Central India, 118% of its LPA over south Peninsula and 82% of its LPA over Northeast (NE) India.**

- **Monthly rainfall over the country as a whole was 84% of LPA in June, 103% of LPA in July, 106% of LPA in August and 113% of LPA in September.**

- **Out of 597 meteorological districts for which data are available, 173 districts (29%) received excess, 240 districts (40%) received normal, 173 districts (29%) received deficient and the remaining 11 districts (2%) received scanty rainfall during the season.**

- **Southwest monsoon current advanced over the Andaman Sea on 17th May. The monsoon set in over Kerala on 31st May, one day earlier than its normal date of 1st June and covered the entire country by 6th July, 9 days earlier than its normal date of 15th July. The withdrawal of monsoon was delayed and it commenced from west Rajasthan only on 27th September compared to its normal date of 1st September.**

- **Though there were two intense systems viz., the Severe Cyclonic Storm (LAILA, 16th–21st May) over the Bay of Bengal and the Very Severe Cyclonic Storm (PHET, 31st May–2nd June) over the Arabian Sea during the advance phase, the entire monsoon season was devoid of any monsoon depressions. Thus, 2010 has been the only year in the recorded history after 2002, to have no depressions during the entire season.**

- **The forecast for monsoon onset over Kerala has been correct for the sixth consecutive year since its first issuance in 2005.**

- **Most of the operational long range forecasts issued for the 2010 southwest monsoon rainfall have been correct. The rainfall forecast for the country as a whole for the entire season, second half of the season and for the months of July, August & September have been accurate.**

1. ONSET OF SOUTHWEST MONSOON

Southwest monsoon set in over Andaman Sea on 17th May, 3 days prior to normal date in association with a severe cyclonic storm (LAILA, 16th–21st May 2010) over the Bay of Bengal. The southwest monsoon further advanced over parts of Comorin area and some more parts of Bay of Bengal on 21st May and thereafter there was a hiatus in the monsoon advance lasting for more than a week. However, monsoon set in over Kerala on 31st May, just one day before its normal onset date (1st June). The advance of monsoon over northeastern parts of the country was earlier than normal date. But monsoon advance over most parts of Bihar and Jharkhand, interior Orissa, Chhattisgarh was delayed by 2-3 weeks than the normal.

Subsequent to the onset over Kerala, a very severe cyclonic Storm (PHET, 31st May–2nd June) formed over the Arabian Sea and it delayed further advancement of the monsoon across west coast by about one week. Around 6th June, monsoon got activated and by middle of June, it covered nearly half of the country. A prolonged hiatus was observed in the further advance till 30th June, due to weakening of monsoon current and prevalence of non-conducive conditions for the formation of low pressure systems over the Bay of Bengal. As a result, over most parts of central and north India including Madhya Pradesh and Uttar Pradesh, monsoon advance was delayed by 2-3 weeks and 1-2 weeks respectively. Severe heat wave/heat wave conditions prevailed over many parts of north, northwest and central India during this period.

Associated with the formation of a low pressure area over the North Bay of Bengal and neighbourhood on 2nd July and its subsequent west-northwestward movement, the monsoon current advanced over most parts of the country, outside parts of west Rajasthan by 5th July itself. The southwest monsoon covered the entire country by 6th July, about 9 days earlier than its normal date of 15th July. The isochrones of advance of southwest Monsoon-2010 is depicted in Fig 1.

2. CHIEF SYNOPTIC FEATURES

Weak cross equatorial flow prevailed during most parts of June and in the first fortnight of July. Though the monsoon trough, displayed rapid north-south oscillations, there had been active periods often in association with the low pressure areas and remnant cyclonic circulations embedded with the monsoon trough extending upto mid-tropospheric levels, and tilting southward with height.

Though there had been spells of subdued rainfall activity all through the season in different spatial and temporal scales, there was no all India break monsoon condition during this year.

Normally 4-6 monsoon depressions form per season (June - September). However, no depression formed over Indian monsoon region during this monsoon season. The causative factors which inhibited the low pressure areas from intensifying further might be, (a) basin wide warming of sea surface temperature (SST) over the north Indian Ocean [absence of favourable SST gradient] (b) presence of a weak negative Indian Ocean Dipole pattern over the equatorial India Ocean and (c) a weaker than normal low level monsoon flow which prevailed quite often, which in turn with its slackened horizontal wind shear curtailed the generation of barotropic instability required for intensification of monsoon lows.

Two low pressure areas formed over the northwest Bay of Bengal and neighbourhood in the month of June. One low pressure area (9^{th} – 13^{th} June) dissipated in situ and the other low pressure area (24^{th}– 26^{th}June) was short lived and dissipated over Gangetic west Bengal and neighbourhood. Because of its very short trajectory, it could not revive the monsoon current which resulted in the prolonged hiatus during 19^{th}– 30^{th} June in further advance of southwest monsoon over the country, but it contributed to the active monsoon conditions over Orissa with very heavy rainfall.

Out of four low pressure areas that formed in the month of July over the Bay of Bengal, two low pressure areas formed during the first week and the other two in the last week of July. The first low pressure area (2^{nd}–6^{th}July) formed over northwest Bay of Bengal became well marked, moved west-northwestwards across Orissa, Chhattisgarh and Madhya Pradesh and merged with the monsoon trough. This system was responsible for strengthening of monsoon current and rapid advance of the monsoon in the country. The second low pressure area (6^{th}–9^{th} July) formed over northwest and adjoining west central Bay of Bengal off south Orissa & north Andhra coast, moved west-northwestwards and dissipated over north Madhya Pradesh and neighbourhood. These two systems gave good rainfall over central India and Andhra Pradesh. The third low pressure area (24^{th}–27^{th}July) formed over northwest Bay of Bengal, moved west-northwestwards along the monsoon trough and dissipated over south Rajasthan and adjoining Gujarat State. Active/ vigorous monsoon conditions prevailed over central, western and north Peninsular India in association with this system. The fourth low pressure

area (28th July–2nd August) developed over northwest Bay of Bengal, moved west-northwestwards across south Orissa, Chhattisgarh and dissipated over Rajasthan on 3rd August.

The month of August also witnessed formation of four low pressure areas over the Bay of Bengal The first low pressure area (4th-9th August) formed over northwest Bay of Bengal off Orissa coast and moved west-northwestwards across Orissa, Chhattisgarh and Madhya Pradesh and dissipated over Rajasthan. After the dissipation of this low pressure area, the monsoon trough shifted to north and monsoon activity remained subdued over major parts of the country outside northwest and western parts. The second low pressure area (12th -14th August) formed over northwest and adjoining west central Bay of Bengal off south Orissa – north Andhra coast and dissipated over south Chattisgarh and east Madhya Pradesh. After the dissipation of this low pressure area, the monsoon flow pattern in general resembled weak condition. With the formation of two more low pressure areas, one over west central Bay off Andhra coast during 23rd-27th August and another over northwest Bay of Bengal during 30th–31st August and their subsequent west-northwestward movement, active to vigorous monsoon conditions prevailed over major parts of south peninsula and central India in the last week of August.

Four low pressure areas formed in the month of September. Two formed over west central Bay of Bengal off north Andhra-south Orissa coast. One of these two (3rd- 6th September) weakened over Orissa and neighbourhood and second (17th–20th September) weakened over north Madhya Pradesh. The third low pressure area (8th–13th September) formed over Vidarbha and neighbourhood and weakened over northeast Rajasthan and adjoining Haryana. The fourth low pressure area formed over the southeast Arabian Sea on 29th and lay over the southeast and adjoining east central Arabian Sea on 30th Sept.

Considering season as a whole, 14 low pressure areas formed during the season including 13 over the Bay of Bengal and one over the Arabian Sea. As normally 13.5 low pressure systems including lows and depressions form during monsoon season, the formation of higher number of low pressure areas compensated the adverse impact of the absence of depression during the season. Further, most of the low pressure areas formed over relatively southerly latitudes (over northwest and adjoining westcentral Bay) and moved west-northwestwards along the monsoon trough upto Rajasthan leading to a good rainfall activity over

Central and Peninsular India. On the other hand, it caused deficient rainfall over many parts of east and northeast India including north Orissa, Gangetic West Bengal, Jharkhand, Bihar, east Uttar Pradesh and Assam & Meghalaya. The remnant of some of the low pressure areas interacted with the mid-latitude westerly systems and caused excess rainfall over northwest India. Frequent development of these lows in regular intervals led to frequent oscillation of monsoon trough and hence absence of prolonged all India weak monsoon conditions during this season. Comparing with the past years, there was only one year (2002) in the recorded history when there was no depression like this year. While the year 2002 was all India drought year, the year 2010 has been a normal year.

3. FLOOD SITUATIONS

Disorganized convective activity during the weak phase of the monsoon and interaction of monsoon current with the mid-latitude troughs in westerlies caused flood situation in some states viz., Rajasthan, Arunachal Pradesh, Uttar Pradesh, Uttarakhand, Haryana, Punjab and Himachal Pradesh. The low pressure areas induced flood situations over some parts of Gujarat, Maharashtra, Chattisgarh, Madhya Pradesh, Karnataka and Orissa.

4. WITHDRAWAL OF SOUTHWEST MONSOON

The withdrawal started from west Rajasthan on 27th September with a delay of nearly 4 weeks as the normal date of withdrawal from extreme western parts of Rajasthan is 1st September. Subsequently, it withdrew from the entire northwest India and some parts of west Uttar Pradesh, west Madhya Pradesh and Gujarat State on 28th September and from most parts of Uttar Pradesh, some more parts of Madhya Pradesh and some parts of Bihar on 1st October. Fig. 2 depicts the isochrones of withdrawal of southwest monsoon - 2010.

5. RAINFALL DISTRIBUTION

The rainfall during monsoon season (June to September) for the country as a whole and the four broad geographical regions are as follows

Region	Actual (mm)	Long Period Average (LPA) (mm)	Actual % of LPA	Coefficient of Variation (CV) % of LPA
All-India	912.8	893.2	102	10
Northwest(NW) India	688.2	613	112	19
Central India	1027.9	991.5	104	14
South peninsula	853.6	722.9	118	15
Northeast (NE) India	1175.8	1436.2	82	8

The seasonal rainfall is classified as normal when the actual rainfall is within LPA ± CV. The CV for seasonal rainfall over various regions is given in the Table above. Similarly, seasonal rainfall is classified as deficient when the actual rainfall is less than (LPA – CV) and as excess when the actual rainfall is more than (LPA+CV). Considering the above criteria, the monsoon seasonal rainfall over the country as a whole has been normal during 2010 (102% of LPA). Similarly, the seasonal rainfall has been normal over northwest and central India, excess over the Peninsular India and deficient over the northeast India.

The cumulative seasonal rainfall from 1st June to 30 September 2010 was excess in 14 meteorological subdivisions (43% of the total area of the country) and normal in 17 meteorological subdivisions (42% of the total area of the country) Five subdivisions (East U.P, Bihar, Jharkhand, Gangetic W. B and Assam & Meghalaya) constituting 15% of the country received deficient rainfall. The sub-divisional cumulative seasonal rainfall distribution is shown in Fig.3.

The monthly monsoon rainfall over the country as a whole was above the LPA, during all the months except June as shown below:

June: 16% below LPA July: 3% above LPA.

August: 6% above LPA September: 13% above LPA.

The spatial distribution of monthly rainfall is shown in Fig.4. In June, large rainfall deficiency was observed over many subdivisions of central, northern and eastern parts of the country due to delayed monsoon advance over these regions. However, the rainfall situation over the country improved significantly during July, especially during second half of this month. Normal or excess rainfall was received over most of the subdivisions except a few subdivisions from eastern and northeastern parts of the country where the rainfall was deficient. Rainfall distribution over the country during August was more non-uniform than July, as number of subdivisions with excess and deficient rainfall during August (excess 18 & deficient 9) was more than that during July (excess 13 & deficient 5). During August, most of the subdivisions from northwest and Peninsular India received excess rainfall and most of the subdivisions from eastern part of the country were deficient. However, subdivisions from northeastern part received normal or excess rainfall.

Figures 5 and 6 depict the monsoon rainfall as received week by week and the cumulative rainfall during the season. The weekly rainfall was negative during all the weeks of June. In July, the weekly rainfall was positive during the first and last weeks and negative during the two weeks between them. During second and third weeks of August and last week of September the rainfall was deficient. Except for these three weeks, the weekly rainfall during the second half of the season (August-September) was positive. The cumulative rainfall distribution shows the large deficiency in rainfall during early part of the season. As a result, the cumulative weekly rainfall remained negative till end of August. In the first week of September only, the cumulative weekly rainfall became positive and remained so till the end of the season. The cumulative seasonal rainfall deficiency by more than 10% prevailed from the week ending 23rd June to the week ending 21st July.

6. LONG RANGE FORECAST OF MONSOON RAINFALL

Based on an indigenously developed statistical model, it was predicted on 14th May 2010 that monsoon will set in over Kerala on 30th May with a model error of ±4 days. The forecast came correct as the actual monsoon onset over Kerala took place on 31st May, one day later than the

forecasted date. Thus this is the sixth consecutively correct operational forecast for the monsoon onset over Kerala since it was issued operationally in 2005.

As per the first stage long range forecast issued on 23rd April, the seasonal (June-September) rainfall for the country as a whole was expected to be 98% ± 5% of LPA. In the updated forecast issued on 25th June, the forecast for the country as a whole was revised to a higher value of 102%±4% of LPA. The updated forecast turned out to be very accurate as the actual area-weighted seasonal rainfall for the country as a whole was 102% of LPA. The forecast for the second half of the monsoon season (August–September) for the country as a whole issued in July was 107% with a model error of 7% of LPA. This forecast also became correct as the actual rainfall over the country as a whole during the second half of the season was 109% of LPA.

The forecasts for monthly rainfall over the country as a whole for the months of July and August issued in June were 98% & 101% respectively with a model error of ± 9% and that for September issued in August was 115% of LPA with a model error of ± 15%. All the monthly forecasts turned out to be correct as the actual rainfall were 103%, 106% and 113% of LPA respectively.

Considering 4 broad geographical regions of India, the seasonal rainfall was expected to be 102% of its LPA over northwest India, 99% of LPA over Central India, 103% of LPA over northeast India and 102% of LPA over South Peninsula, all with a model error of ±8%. The actual rainfall over northwest India, central India, northeast India and south Peninsula were 112%, 104%, 82% and 118% of the LPA respectively. Thus the actual seasonal rainfall over central India is within the forecast limit and that over northwest India is slightly above the forecast limit. However, the forecast for seasonal rainfall over northeast India and south Peninsula were not accurate as northeast India experienced deficient rainfall and south peninsula experienced excess rainfall against the normal rainfall predicted for both the regions.

The Table below gives the summary of the verification of the long range forecasts issued for Southwest monsoon 2010.

Table: Details of long range forecasts and actual rainfall.

Region	**Period**	Date of Issue	**Forecast (% of LPA)**	**Actual Rainfall (% of LPA)**
All India	June to September	23rd April	98 ± 5	102
All India	June to September	25th June	102 ± 4	
Northwest India	June to September		102 ± 8	112
Central India	June to September		99 ± 8	104
Northeast India	June to September		103 ± 8	82
South Peninsula	June to September		102 ± 8	118
All India	July		98 ± 9	103
All India	August		101 ± 9	106
All India	August to September	30th July	107 ±7	109
All India	September	27th August	115 ± 15	113

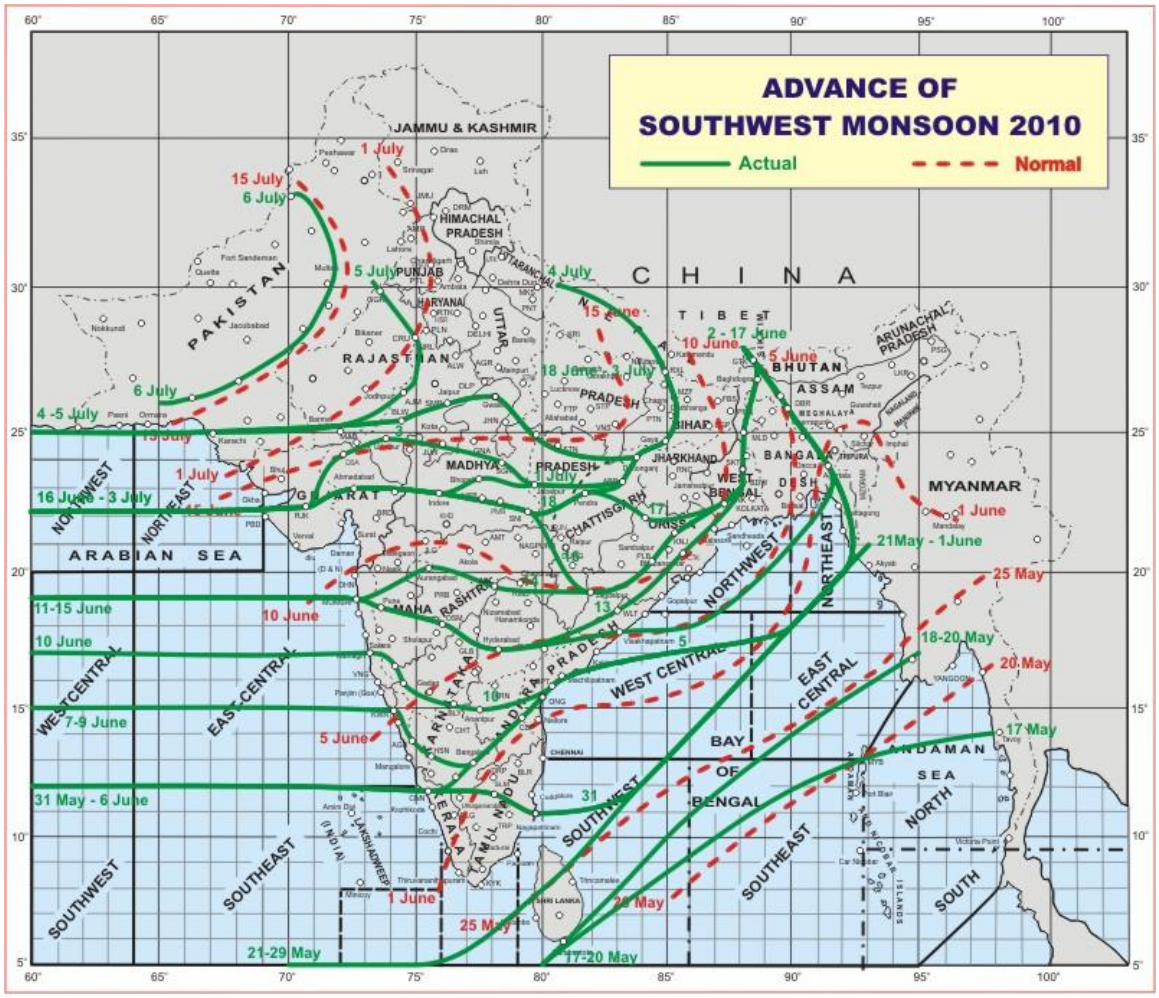

Fig.1: Progress of Southwest Monsoon – 2010

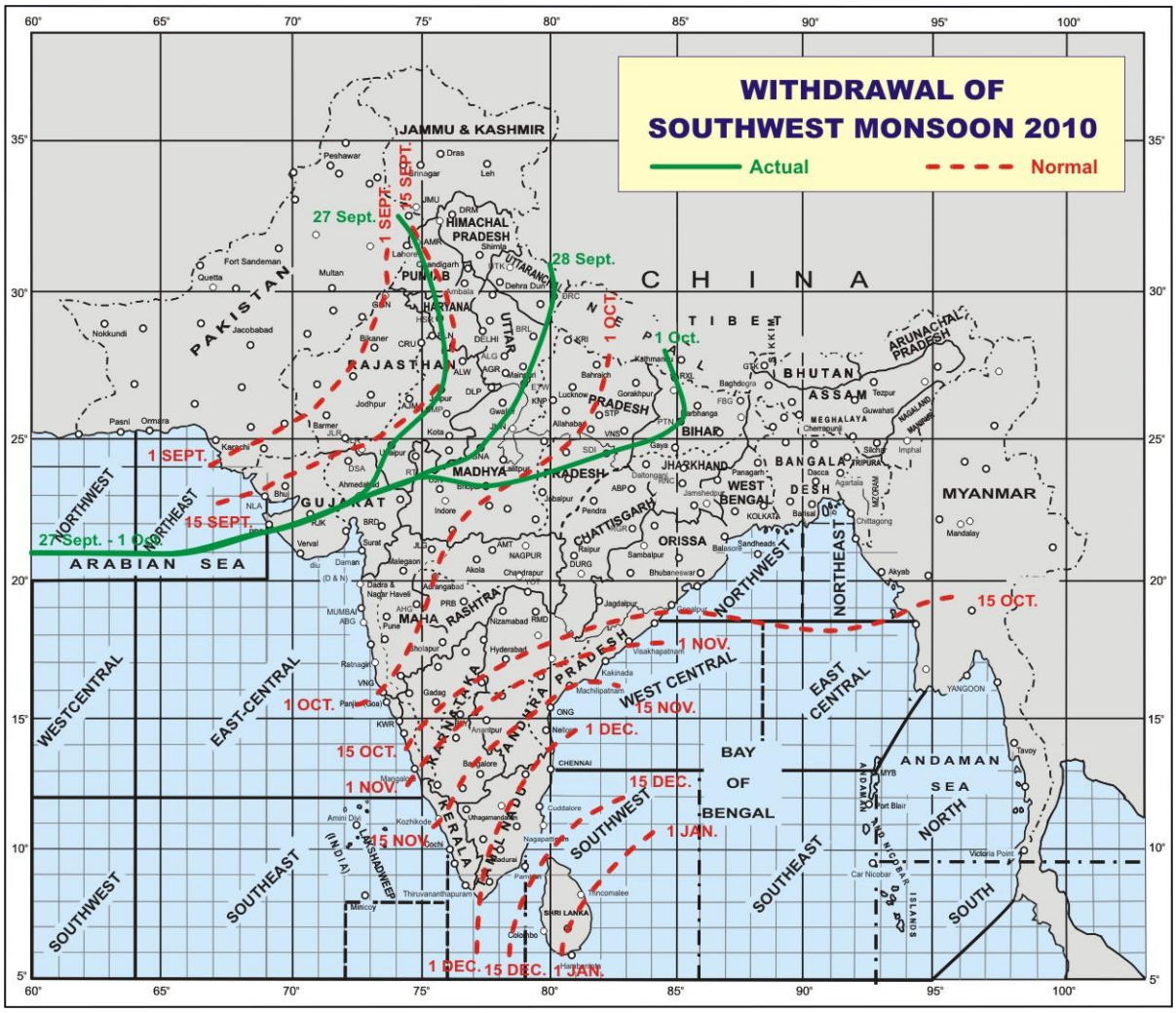

Fig.2: Withdrawal of the Southwest Monsoon– 2010.

भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT

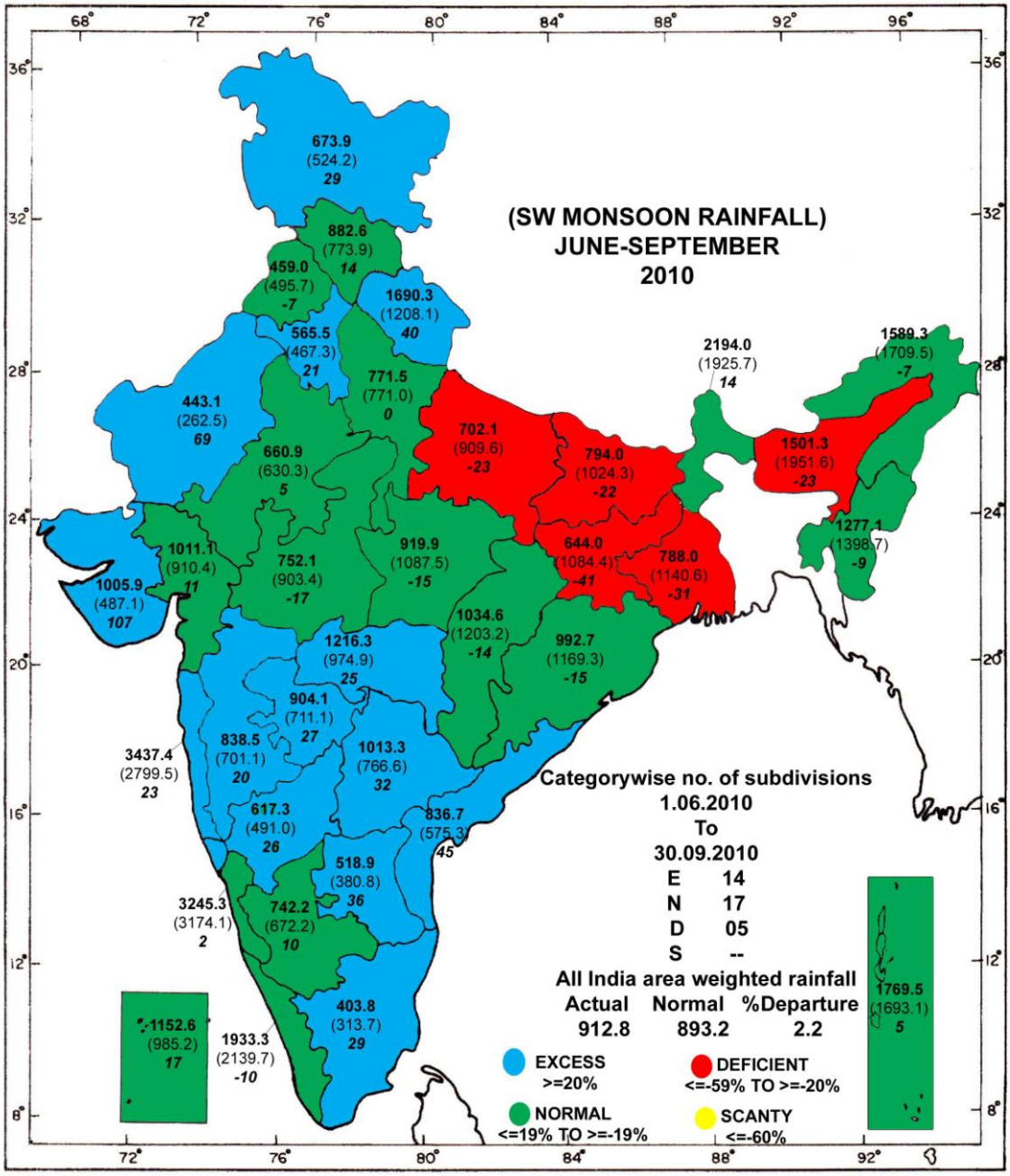

Fig.3: Sub-divisionwise rainfall distribution over India during southwest monsoon season (June to September) – 2010

भारत मौसम विज्ञान विभाग
INDIA METEOROLOGICAL DEPARTMENT
2010

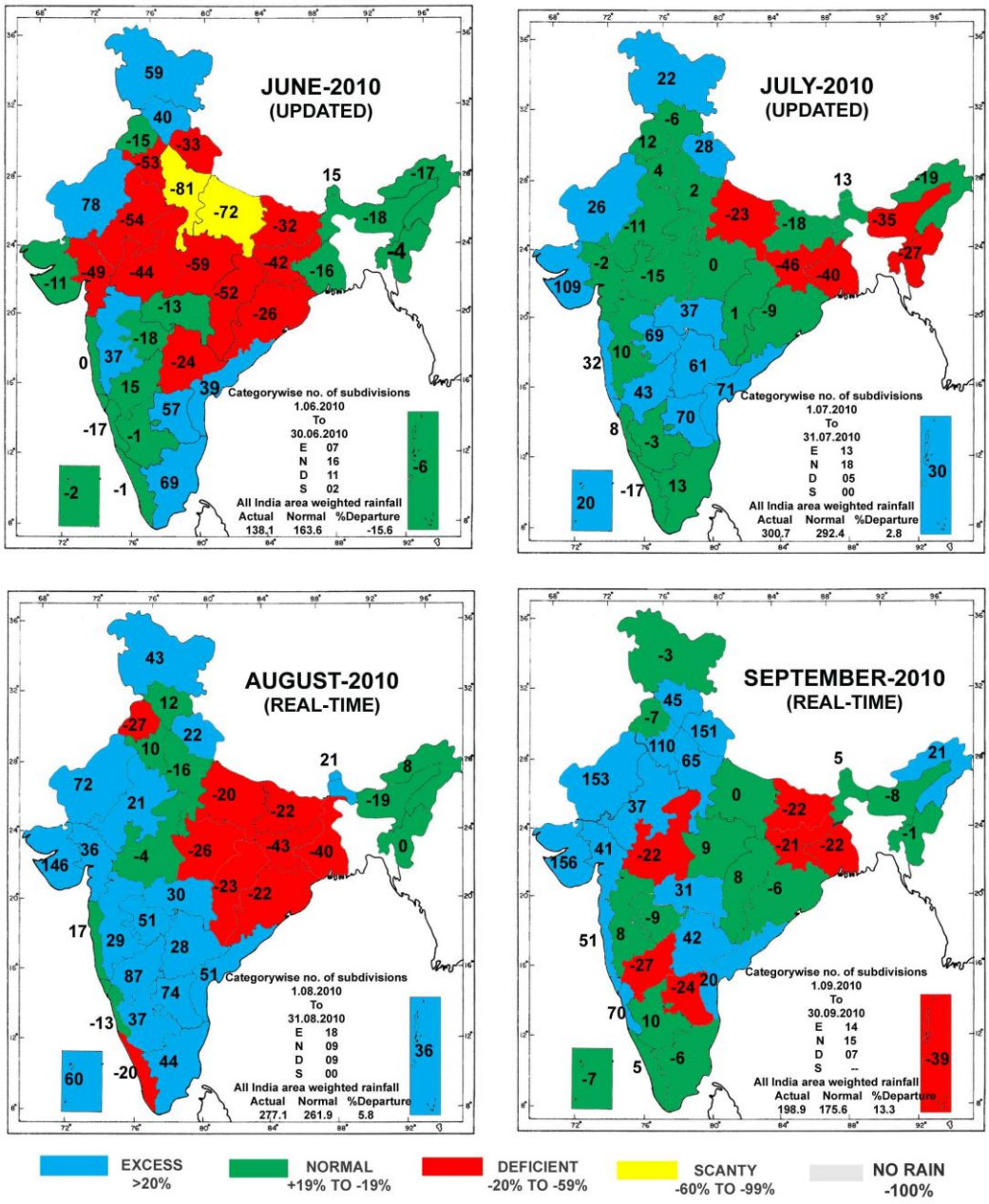

Fig.4: Sub-divisionwise monthly rainfall distribution over India during southwest monsoon season – 2010

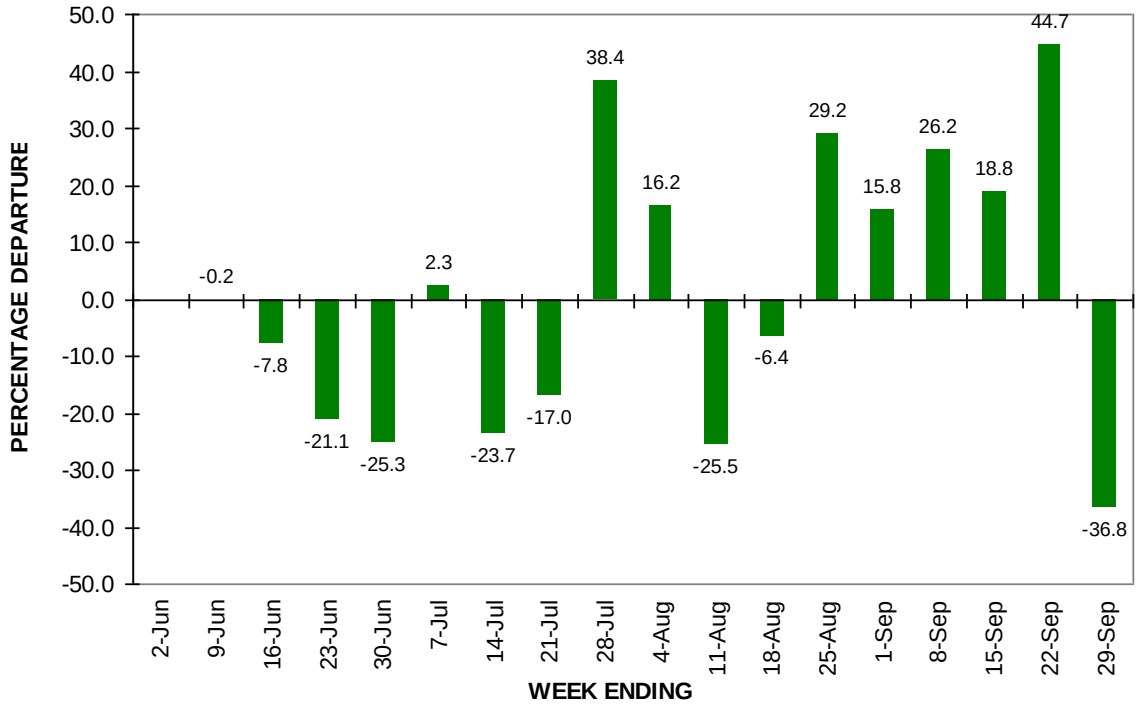

Fig.5: Week - by - Week Progress of the Monsoon Rainfall – 2010

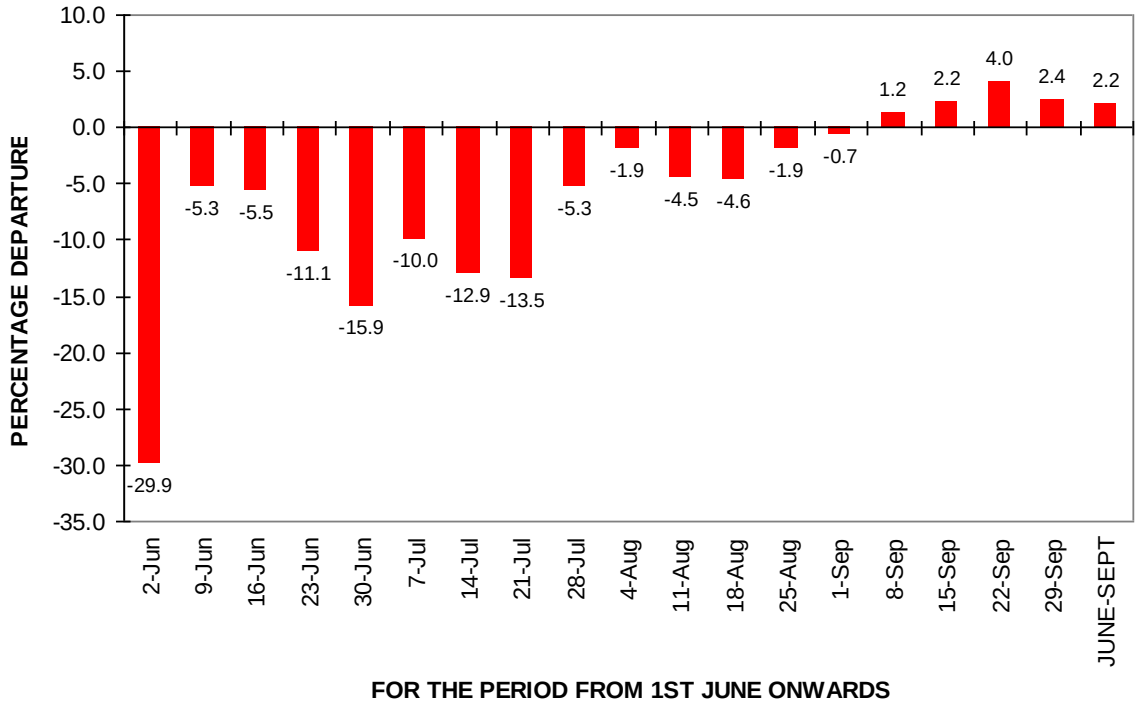

Fig.6: Week - by - Week Progress of the Monsoon Rainfall - 2010 (Cumulative)