Earth System Science Organization (ESSO)
Ministry of Earth Sciences (MoES)

India Meteorological Department

2016 Southwest Monsoon End of Season Report

HIGHLIGHTS

- The rainfall during monsoon season (June-September) over the country as a whole was 97% of its long period average (LPA).
- Seasonal rainfalls over Northwest India, Central India, South Peninsula and Northeast India were 95%, 106%, 92% and 89% of respective LPA.
- Out of the total 36 meteorological subdivisions, 23 sub-divisions constituting 72% of the total area of the country received normal rainfall and 4 sub-divisions received excess rainfall (13% of the total area) during the season. However, 9 sub-divisions constituting 15% of the total area of the country received deficient seasonal rainfall.
- Monthly rainfall over the country as a whole was 89% of LPA in June, 107% of LPA in July, 91% of LPA in August and 97% of LPA in September.
- Southwest monsoon advanced into south Andaman Sea and Nicobar Islands on 18th May (2 days ahead of its normal date). However, further advance was sluggish. It set in over Kerala on 8th June (7 days behind the normal schedule of 1st June) and covered the entire country by 13th July (against the normal date of 15th July).
- Monsoon withdrawal commenced from West Rajasthan on 15th September with a delay of 2 weeks. It has withdrawn from most parts of Northwest India as on 10th October, 2016.

1. Onset and Advance of southwest Monsoon

Associated with the genesis phase of the Cyclonic Storm '**Roanu**', southwest monsoon advanced over parts of south Bay of Bengal, Nicobar Islands and adjoining Andaman Sea on 18th May (2 days ahead of its normal date). It further advanced into some more parts of southeast Bay of Bengal, remaining parts of Andaman Sea and Andaman Islands on 20th May. However, further progress of monsoon was sluggish. As a result, monsoon set in over Kerala only on 8th June (7 days after its normal date of 1st June). On the same day, it advanced into south Arabian Sea, Maldives-Comorin area, most parts of Kerala & Tamil Nadu, some parts of south interior Karnataka, remaining parts of south Bay of Bengal and some more parts of central Bay of Bengal.

In the subsequent two days, it advanced rapidly up to Lat. 15°N. Thereafter, a hiatus occurred on western part due to weakening of the Arabian Sea branch of the monsoon. A comparatively stronger Bay of Bengal branch led to advance of monsoon into Northeast India by 14th June. In the third week of June, as the active phase of the Madden Julian Oscillation (MJO) moved eastwards over the Indian Seas, the Bay of Bengal became more convectively active. Triggered by this, the further advance of monsoon was rapid and it covered most parts of peninsular India & western Himalayan region, entire central & east India and some parts of north Arabian Sea and northwest India by 22nd June. After a brief hiatus during the last week of June, monsoon advanced further very rapidly to cover most parts of the country, outside some areas of Kutch and west Rajasthan by 5th July. The monsoon covered the entire country on 13th July in association with the formation of an east-west shear zone at mid tropospheric levels and its northward shifting to the north of Lat. 20° N. **Isochrones of advance of monsoon 2016 is shown in Fig. 1.**

2. Chief Synoptic Features

During the season, 14 monsoon low pressure systems (LPSs) (2 Deep Depressions, 2 Depressions, 3 well marked low pressure areas & 7 low pressure areas) formed against an average of 6 Depressions & 8 low pressure areas. The frequencies of monsoon depressions were subdued over Bay of Bengal. Out of four depressions/deep depressions, one depression formed over the Bay of Bengal & one over Arabian Sea and remaining two over the land region.

Table : Frequency of low pressure systems over Indian region during monsoon season, 2016

Systems / Month	Deep Depression	Depression	Well marked low pressure area	Low pressure area
June	0	1	0	1
July	0	1	0	1
August	2	0	2	3
Sept.	0	0	1	2

The first Depression formed over northeast Arabian Sea in June (27^{th}–29^{th}) and the second as a Land Depression over northeast Madhya Pradesh & neighborhood in July (6^{th}–7^{th}). Thereafter, two Deep Depressions formed in August (9^{th}–12^{th} & 16^{th}–20^{th}); 1^{st} over coastal areas of West Bengal & neighborhood and the 2^{nd} over northwest Bay of Bengal. In addition, 5 low pressure areas also formed in August. In the month of September, 3 low pressure areas formed. **Tracks of Depressions & Deep Depressions are given in Fig.2.**

In general, the southwest monsoon circulation was weak in June. However with the, weakening of the Southern Hemispheric Equatorial Trough in the south Indian Ocean towards the end of June helped in the strengthening of cross equatorial flow and hence strengthening of monsoon circulation. With the deepening of southwesterlies towards the Indian landmass, a feeble off-shore trough developed off Karnataka-Kerala coasts in the last week of June. The Heat Low gradually strengthened and got established over Pakistan along with a shallow 'heat trough' extending along the Indo-Gangetic plains during the week.

Also, the MJO moved eastwards over the Indian Seas, the Bay of Bengal became more convectively active. The formation and movement of cyclonic vortices at upper levels off both the coasts and one over central India during the third week of June triggered the monsoon activity over most parts of the country. The first Depression (27^{th} – 29^{th} June) and first Low pressure area (26^{th} – 28^{th} June) of the season formed over northeast Arabian Sea and over westcentral & adjoining northwest Bay of Bengal off north Andhra Pradesh-south Odisha coasts respectively. However, the Depression over Arabian Sea weakened *in-situ* over the Sea area due to a large vertical wind shear. An east-west shear zone was also observed along Lat. 15°N. All these systems enhanced the rainfall activity over northern plains, Peninsular India and central India towards the end of the June.

A cyclonic circulation extending between lower & mid tropospheric levels lay over Kutch & neighborhood during 1st - 5th July, which increased the rainfall activity over the Gujarat Region and West Rajasthan. A Land Depression (6th – 7th July) formed over northeast Madhya Pradesh & neighbourhood, which caused active to vigorous monsoon conditions over Madhya Pradesh and East Rajasthan. Two low pressure areas (on 30th June- 5 July & 7th July -8thJuly) along the east-west trough caused fairly widespread to widespread rainfall activity with heavy to very heavy rain at few places and extremely heavy at isolated places mainly over east & central India. The presence of an off-shore trough along the west coast caused active to vigorous monsoon conditions over western parts of central India during the 2nd week of July. The deep convection over central & western parts of peninsular India due to northward shifting of an east-west shear zone during 10th – 13th July increased the rainfall activity over the extreme western parts during same period.

In third week of July, the monsoon trough shifted northwards closes to the foothills of the Himalayas and led to weak monsoon conditions over major parts of India. Thus, a lull in the monsoon activity was noticed over major parts of the country and break like situation prevailed. The monsoon trough remained close to the foothills of the Himalayas up to 21st July and shifted back to its normal position from 22nd July. However, the instability in the basic flow generated several cyclonic circulations which helped in maintaining near normal rainfall for the country as a whole. Towards the end of July and beginning of August, due to active monsoon trough and the enhanced convection over major parts of the country, triggered with the Somali Low Level Jet, there was formation of a couple of low pressure areas over north Bay of Bengal. These systems moved nearly west-northwestwards along the monsoon trough and caused active to vigorous monsoon conditions over parts of north & central India as well as northern parts of peninsular India with extremely heavy rainfall activity at isolated places over northern parts of Peninsular & Central India.

Thereafter, with the formation of a Depression over the coastal areas of West Bengal & neighborhood on 9th of August and its immediate intensification into a Deep Depression on next day, the rainfall activity shifted northwards. Due to movement of Deep Depression and formation of two more low pressure areas during 2nd week of August led to active to vigorous monsoon activity over Gangetic West Bengal, Odisha, Jharkhand, Madhya Pradesh, Rajasthan and Gujarat State.

In mid-August, the western end of the monsoon trough gradually shifted northwards and lay close to the foothills of the Himalayas on 17th August. However, the eastern end of the trough continued to remain active with the formation of a Deep Depression on 16th August over northwest Bay of Bengal & neighbourhood. The system followed the west-northwestward track after crossing the coast and traversed up to East Rajasthan. While moving west-northwestwards, it caused fairly widespread to widespread rainfall with isolated extremely heavy falls and caused flood situations all along its track. However, the subdued rainfall activity continued to prevail over south peninsular India since second week of August. Thereafter, the weakening of cross equatorial flow led to weak monsoon flow pattern over the Indian regime during the last week of August. The troughs in mid- latitude westerlies which intruded more southwards affected the monsoon flow. However, it maintained the rainfall activity mainly over the northwestern parts. The remnant cyclonic circulation of the low pressure area formed over westcentral Bay of Bengal off Andhra Pradesh coast caused fairly widespread to widespread rainfall activity with isolated extremely heavy falls over the eastern parts of south Peninsular India towards the end of August. During the first half of September, the monsoon trough shifted to the foothills of the Himalayas, which led to weak monsoon activity over the country. However, due to formation of three low pressure areas over the Bay of Bengal active to vigorous monsoon activity prevailed over many parts of east, central and Peninsular India. In the third week, in association with the strong MJO activity over the Maritime continent, strengthening of the monsoon circulation and increased convective activity, active to vigorous monsoon activity prevailed mainly over north peninsular India.

3. Withdrawal of southwest Monsoon

The rainfall activity over the northwestern parts of Rajasthan remained subdued since 5th September. Due to change in the lower tropospheric circulation pattern over the region from cyclonic to anti-cyclonic on 15th September, the southwest monsoon withdrawal commenced from west Rajasthan. Subsequent to this, moisture incursion due to the low level southeasterlies caused isolated rainfall over most parts of northwest India. The monsoon further withdrew from some more parts of the northwest India on 28th. Thereafter, with the southward shift of the Sub-tropical westerly Jetstream over to the northern most Indian Latitudes from 5th October. The southwest monsoon further withdrew from remaining parts of Jammu &

Kashmir and Punjab, most parts of Himachal Pradesh and some more parts of Haryana & Chandigarh and West Rajasthan on 5th October. Thereafter, it has further withdrawn from remaining parts of Himachal Pradesh, Haryana, Chandigarh & Delhi, most parts of Uttarakhand, some parts of West Uttar Pradesh & East Rajasthan and some more parts of West Rajasthan on 8th October. The withdrawal line passes through Dharchula, Aligarh, Jaipur and Barmer as on 10th October. Isochrones of withdrawal of monsoon 2016 are shown in **Fig. 3**.

4. High Impact Weather Events

Fig. 4 depicts the met. Sub-divisions or parts thereof, which experienced high impact weather events like, floods, landslides and Heat waves during the southwest monsoon season (June- September) along with the dates. **Fig.4** also indicates areas that experienced isolated extremely heavy rainfall (Rainfall amount ≥20 cm reported during the 24 hours ending at 0830 hrs IST) events during the season without any reference to the dates of these occurrences. Incessant rainfall associated with the formation and movement of the monsoon low pressure systems in the presence of strong cross equatorial flow often caused flood situations over various areas during different parts of the season.

5. Rainfall Distribution

The realized rainfall during southwest monsoon season (June to September) 2016 over the country as a whole and four broad geographical regions are given in the table below along with respective LPA values. The rainfall during the four monsoon months and the second half of the monsoon season (August + September) over the country as whole are also given.

Table: Realized rainfall during southwest monsoon 2016 over the country as a whole and four broad geographical regions

Season (June to September) rainfall			
Region	**LPA (mm)**	**Actual Rainfall for 2016 SW Monsoon Season**	
		Rainfall (mm)	**Rainfall (% of LPA)**
All India	887.5	862.0	97
Northwest India	615.1	584.2	95
Central India	975.3	1034.1	106
Northeast India	1437.8	1281.5	89
South Peninsula	715.6	661.5	92

Monthly & second half of the monsoon season rainfall over the country as a whole (All India)			
Month	**LPA (mm)**	**Actual Rainfall for 2016 SW Monsoon Season**	
		Rainfall (mm)	**Rainfall (% of LPA)**
June	163.6	145.4	89
July	289.2	308.2	107
August	261.3	238.1	91
September	173.4	167.7	97
August + September	434.6	405.9	93

As seen in the table above, the seasonal rainfall over the country as a whole was 97% of LPA and thus it was in the normal (96-104% of LPA) category. The seasonal rainfall over three of the four geographical regions of the country except central India was less than the respective LPAs. The highest rainfall (106% of LPA) was received by central India and lowest rainfall (89% of LPA) was received by northeast India. Northwest India and South Peninsula received seasonal rainfall of 95% of LPA and 92% of LPA respectively.

Month-wise, the rainfall over the country as a whole was less than LPA during all the months except in July, where it was above LPA (107% of LPA). The rainfall during June, August and September were 89%, 91% & 97% of respective LPA. Sub-division wise seasonal (June to September) rainfall is shown in **Fig. 5**.

Out of the total 36 meteorological sub-divisions, the seasonal rainfall was normal in 23 sub-divisions (72% of the total area of the country) and excess in 4 sub-divisions (13% of the total area of the country). However, the seasonal rainfall was deficient in 9 sub-divisions constituting 15% of the total area of the country. Out of the 9 deficient sub-divisions, 4 sub-divisions were from South Peninsula (Coastal Karnataka, South Interior Karnataka, Kerala and Lakshadweep), 3 from Northwest India (Haryana, Chandigarh & Delhi, Punjab and Himachal Pradesh), and 1 each from Northeast India (Assam & Meghalaya) and Central India (Gujarat region). Similarly, out of the 4 excess sub-divisions, 2 each were from northwest India (west and east Rajasthan) and Central India (Konkan & Goa and Marathwada). **Fig. 5** shows that except for some parts of North India, Southwest Peninsula, West India and Northeast India, most parts of the country received well distributed rainfall.

Sub-division wise monthly rainfall is shown in **Fig.** 6. In June, 2 sub-divisions (Gujarat and Saurashtra & Kutch) received scanty rainfall, 10 sub-divisions deficient, 6 sub-divisions received excess and 18 sub-divisions normal rainfall. Out of the 10

deficient sub-divisions, 5 were from Northeast India, 3 from Central India, and 2 from Northwest India. All the 6 excess sub-divisions were from South Peninsula.

In July, 16 sub-divisions received normal rainfall and 10 sub-divisions each received excess and deficient rainfall. Out of the 10 deficient sub-divisions, 5 sub-divisions (Gujarat, Saurashtra & Kutch, west Rajasthan, Punjab and Himachal Pradesh) were from western and northwestern most part of the country, 4 sub-divisions (A & N Island, Coastal Andhra Pradesh, Coastal Karnataka, and Kerala) were from South Peninsula and 1 sub-division (NMMT) was from Northeast. Out of 10 excess sub-divisions, 5 were from Central India (both sub-divisions of Madhya Pradesh and 3 of the 4 sub-divisions of Maharashtra), 3 were from South Peninsula and 2 were from Northwest India.

In August, 2 sub-divisions were scanty, 17 sub-divisions were deficient and 8 sub-divisions each were normal and excess. Most noticeable feature of rainfall distribution during the August was that all the 10 sub-divisions from south Peninsula were deficient or scanty resulting in large rainfall deficiency (-40% of LPA) over the region. Similarly, out of the 7 sub-divisions from Northeast India, 2 each received deficient and scanty rainfall. Out of the 8 excess sub-divisions, 4 were from Central India and 2 each were from Northeast India and Northwest India.

In September, 20 sub-divisions were deficient or scantly (4 subdivisions), 10 were excess and 6 were normal. The most noticeable feature of the rainfall distribution during September was that all the 9 sub-divisions from Northwest India were deficient or scanty resulting in large rainfall deficiency (-52% of LPA) over the region. In addition, 4 sub-divisions from Central India, 5 sub-divisions from South Peninsula and one sub-division from Northeast were deficient or scanty. However, Northeast India was the main beneficiary as 6 out of 7 sub-divisions were normal or excess with the region as a whole receiving 115% of LPA rainfall during the month.

Fig. 7 & 8 depict the all India weekly and cumulative weekly rainfall anomaly expressed as percentage departure from the LPA. The all India weekly rainfall anomalies during 10 of the 17 weeks of the monsoon season were negative. Out of the 7 positive rainfall anomaly weeks, 2 weeks each were from July (weeks ending 6th & 13th), August (weeks ending 3rd & 10th) and September (weeks ending 21st & 18th). The last week of June (week ending 29th) was a positive rainfall week. However, the rainfall anomalies were negative during first 3 weeks of June, last two weeks of July and 5 successive weeks in the second half of the season (between week ending 17th August

and week ending 14th September). The highest negative weekly rainfall anomaly of -29% of LPA was recorded during the weeks ending 15th June & 14th September. Highest positive rainfall anomaly of 38% of LPA was recorded during the week ending 28rd September.

The all India cumulative weekly rainfall anomalies were negative during the season except for the period of week ending 6th July to 10th August. The weekly all India cumulative rainfall after remaining negative in June jumped to positive in the first week of July itself due significant amount of rainfall received during that week. The cumulative weekly rainfall anomaly reached to its highest positive value of 3.5% of LPA during the second week of July and remained positive till second week of August. Thereafter, it kept decreasing and reached to its highest negative value of -5.2% in the week ending 14th September. The season ended with all India cumulative rainfall anomalies of -3% of LPA.

The below normal rainfall in June was mainly caused by the delay in the onset over the Kerala and unfavorable phases of Madden Julian Oscillation (MJO) during early monsoon progress. During August, large rainfall deficiency was observed over south peninsula (40% less than its LPA) and East and Northeast India (30% less than its LPA). The possible reasons for the same are discussed below:

The Indian Ocean Dipole (IOD), was negative throughout August with significantly above normal SSTs over equatorial east India Ocean. This resulted above normal convective anomalies over the equatorial India Ocean. After about 10th August, the MJO was mostly over Pacific causing above normal convective activity over the region. As a result, triggering mechanism for the northward propagation of inter tropical convergence zone (ITCZ) over Indian monsoon region was absent. Westward propagation of the remnants of low pressure systems formed over the west Pacific helped in the formation of number of low pressure systems over Bay of Bengal. These low pressure systems mostly moved along the monsoon trough region causing good rainfall activity over Central & northwest India and below normal rainfall over Northeast India. The above normal convective activity over equatorial Indian Ocean (due to the negative IOD) and along the monsoon trough region (due to the propagation of low pressure systems) and associated anomalous rising motion over these regions resulted in anomalous subsidence motion between these two regions causing below normal convective activity and below normal rainfall over most of the Peninsular India and neighbouring Indian seas.

6. Verification of the Long Range Forecasts

Based on an indigenously developed statistical model, it was predicted on 15th May, 2016 that monsoon will set in over Kerala on 7th June with a model error of ±4 days. However, the actual monsoon onset over Kerala took place on 8th June.

This year, the long range forecast for the 2016 southwest monsoon seasonal rainfall was issued in 3 stages. The first stage long range forecast issued on 12th April consisted of only forecast for season (June-September) over the country as a whole. In the second stage (2nd June), along with the update for the April forecast, forecast for seasonal 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 (1st August), the forecast for the rainfall during the second half of the monsoon season over the country as a whole was issued.

The first stage forecast for the season (June-September) rainfall over the country as a whole issued in April was 106% of LPA with a model error of ± 5% of LPA. The update forecast issued in June was also same (106% of LPA), but with a model error of ± 4% of LPA. The actual seasonal rainfall for the country as a whole was 97% of LPA.

Considering the four broad geographical regions of India, the forecasts issued in June for the seasonal rainfall over Northwest India, Central India, Northeast India and South Peninsula were 108%, 113%, 94% & 113% of the LPA respectively all with model errors of ±8%. The actual rainfall over Northwest India, Central India, Northeast India and South Peninsula were 94%, 106%, 89% and 92% of the LPA respectively. Thus the forecast for Central & Northeast India found to be correct.

The forecast for the second half of the monsoon season (August –September) for the country as a whole was 107% with a model error of 8% of LPA against the actual rainfall of 93% of LPA. Thus the forecast for the rainfall during the second half of the monsoon season over the country as a whole was an overestimate to the actual rainfall.

The forecasts for the monthly rainfall over the country as a whole for the months of July & August issued in June were 107% & 104% respectively with a model error of ± 9%. The actual monthly rainfalls during July and August were 107% & 91% of LPA respectively. Thus the forecast of July rainfall was accurate. However, the forecast of the August rainfall was over estimated.

The Table below gives the summary of the verification of the long range forecasts issued for the 2016 Southwest monsoon.

Table: Details of long range forecasts and actual rainfall.

Region	Period	Forecast (% of LPA)		Actual Rainfall (% of LPA)
		22th April	2nd June (Update)	
All India	June to September	106 ± 5	106 ± 4	97
Northwest India	June to September		108 ± 8	95
Central India	June to September		113 ± 8	106
Northeast India	June to September		94 ± 8	89
South Peninsula	June to September		113 ± 8	92
All India	July		107 ± 9	107
All India	August		104 ± 9	91
All India	August to September (issued on 1st August)		107 ± 8	93

Prior to June, most of the climate forecasting models were indicating high probability for the development of La Niña during the second half of the monsoon season, which was supposed to favour normal to above normal rainfall over India. However, that did not happen. The conditions over pacific till now has remained ENSO neutral, with cooler than the normal Sea Surface Temperatures (SSTs) over Equatorial Central Pacific. Thus the ENSO impact was neutral on the monsoon over India with fairly distributed rainfall during monsoon 2016. The non development of La Niña against the expectation as per global El Niño/ La Niña forecast and below normal rainfall during June and August due to unfavorable phases of intra-seasonal activity caused the most of the operational forecasts to be overestimates to the actual rainfalls.

7. Resultant Scenario across the country at the end of September 2016

The rainfall distribution during monsoon season has been fairly well distributed over all parts of the country leading to 8.6% higher crop sown area compared to last year with significant increase of crop sown area by 22.5% in pulses and 5.5% in cereals etc. It is to be noted that till end of the season, no moisture stress has been reported for the rainfed agricultural production zones in the country despite the increased percentage of sowing during the current Kharif season. Accordingly, as per the assessment of Ministry of Agriculture, increased yields of overall rainfed crops, specifically pulses, oilseeds and cereals are expected.

The live storage of all major reservoirs monitored by Central Water Commission stands at 97% of the Full Reservoir Levels (FRL) as on 29th September, 2016, which suggests that the resultant 97% of live storage has been accumulated at the end of the season after fully meeting the irrigation requirement over three months of the kharif season so far in their respective ayacuts.

At the same time, as it happens in every monsoon season, some of the sub-divisions experienced deficient rainfall. The following Meteorological Sub-divisions received deficient rainfall during monsoon season 2016.

Subdivision	Deficiency (%)
Assam and Meghalaya	-30
Haryana, Chandigarh and Delhi	-27
Punjab,	-28
Himachal Pradesh	-24
Gujarat region	-24
Coastal Karnataka	-21
South Interior Karnataka	-21
Kerala	-34
Lakshadweep	-25

It may be noted that deficiency in Punjab, Haryana, Chandigarh and Delhi is not expected to affect the crop yields as the whole region falls under assured irrigation segment of the country. The deficiency of Himachal Pradesh could be possibly covered from the expected winter season rainfall. Deficiency in Gujarat region could affect marginally oilseeds productions since the region is receiving fairly widespread rainfall even after 30th September, 2016. The deficiency of Coastal Karnataka may not be covered in October 2016 whereas South Interior Karnataka, Kerala and Lakshadweep are expected to receive normal northeast monsoon rainfall activity till December 2016.

The fairly good distribution of rainfall during monsoon season 2016 has resulted into above normal sowing of rainfed crops and substantial resultant surface water storage to serve irrigation requirement of Rabi crops further during the current financial year.

(K. J. Ramesh)
Director General of Meteorology

New Delhi
the 10th October, 2016
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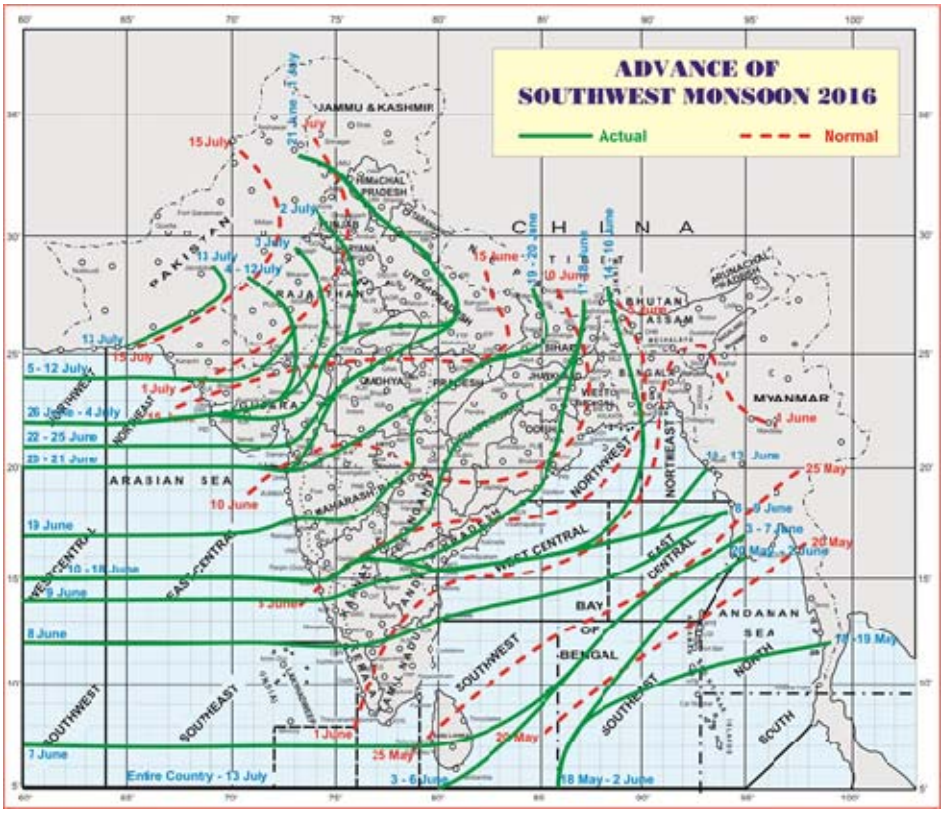

Fig.1: Progress of Southwest Monsoon – 2016

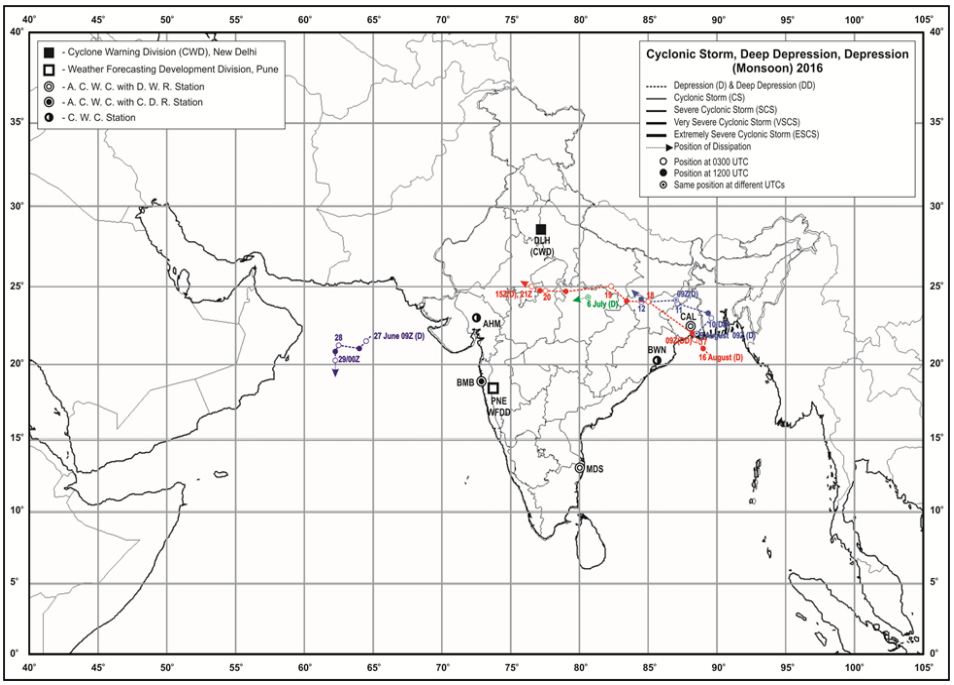

Fig.2: Track of the monsoon Depressions and Cyclonic Storms

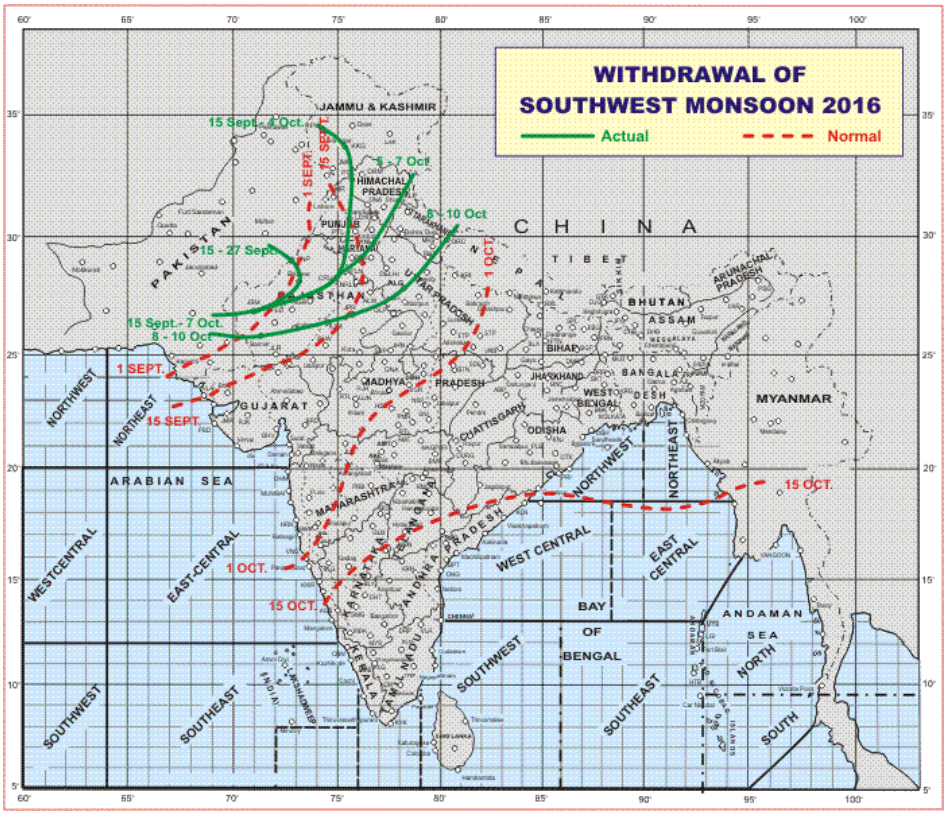

Fig.3: Isochrones of withdrawal of southwest monsoon - 2016

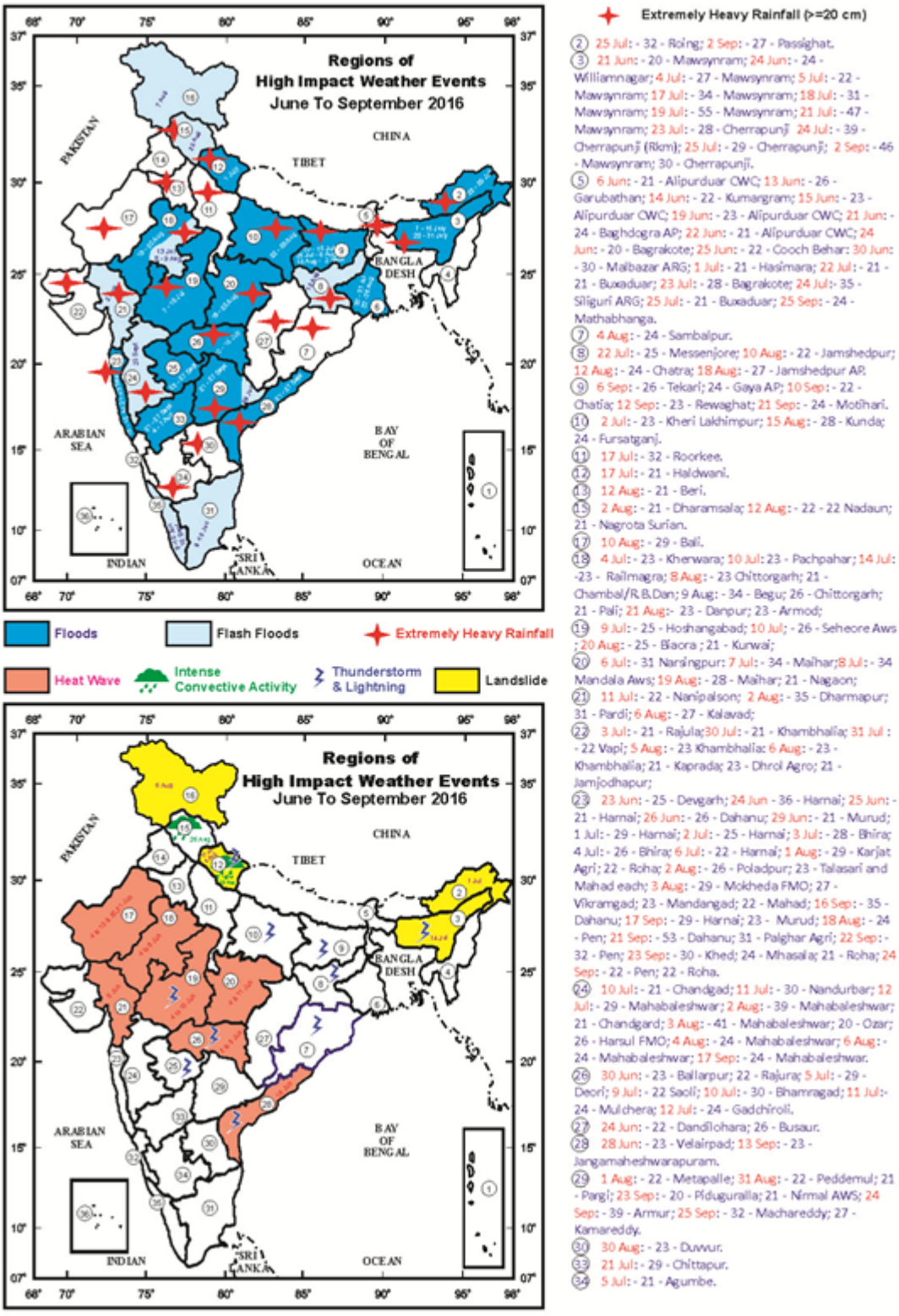

Fig.4: Areas and dates of high impact weather events during the 2016 southwest Monsoon.

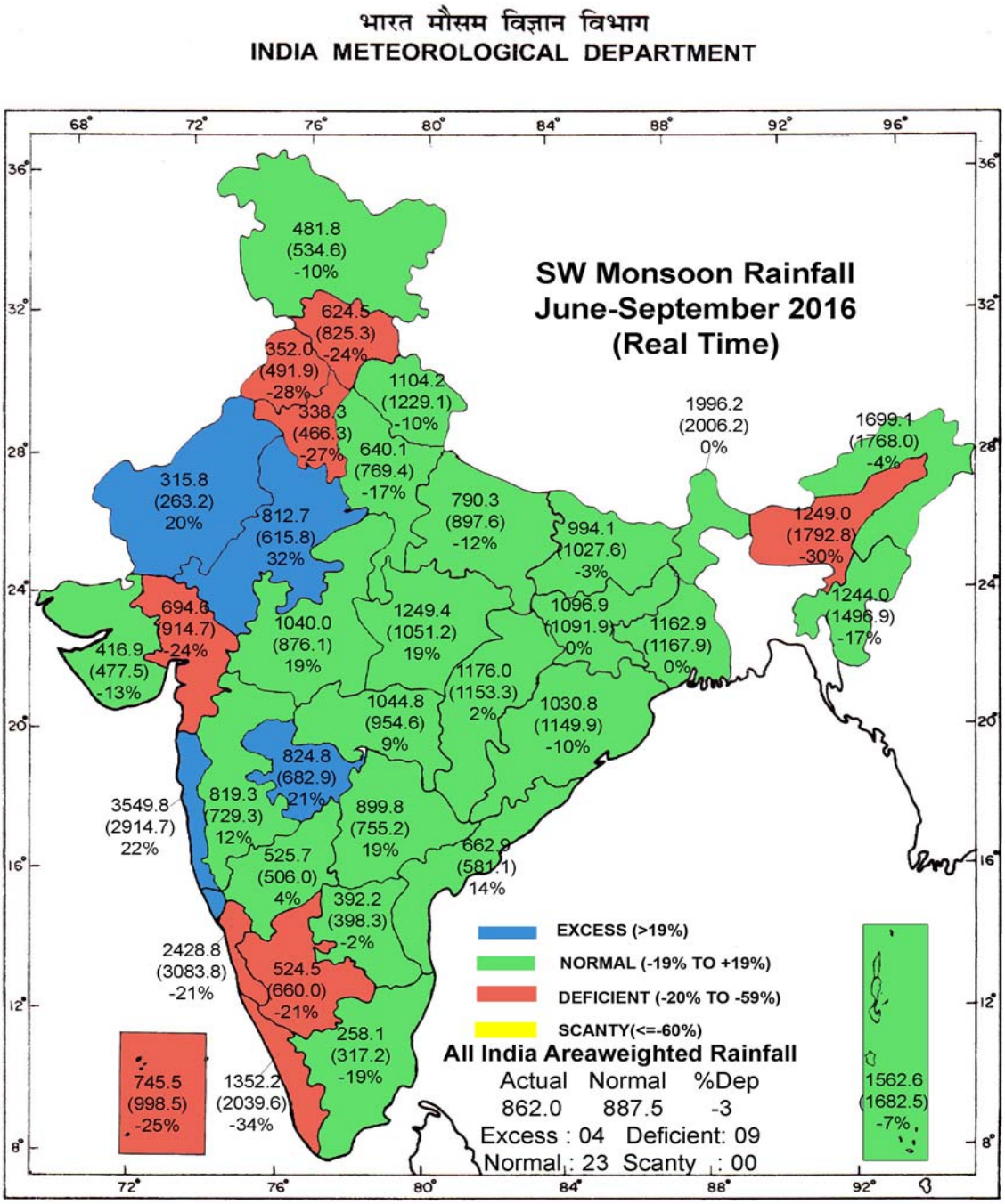

Fig.5: Sub-divisionwise rainfall distribution over India during southwest monsoon season (June to September) – 2016.

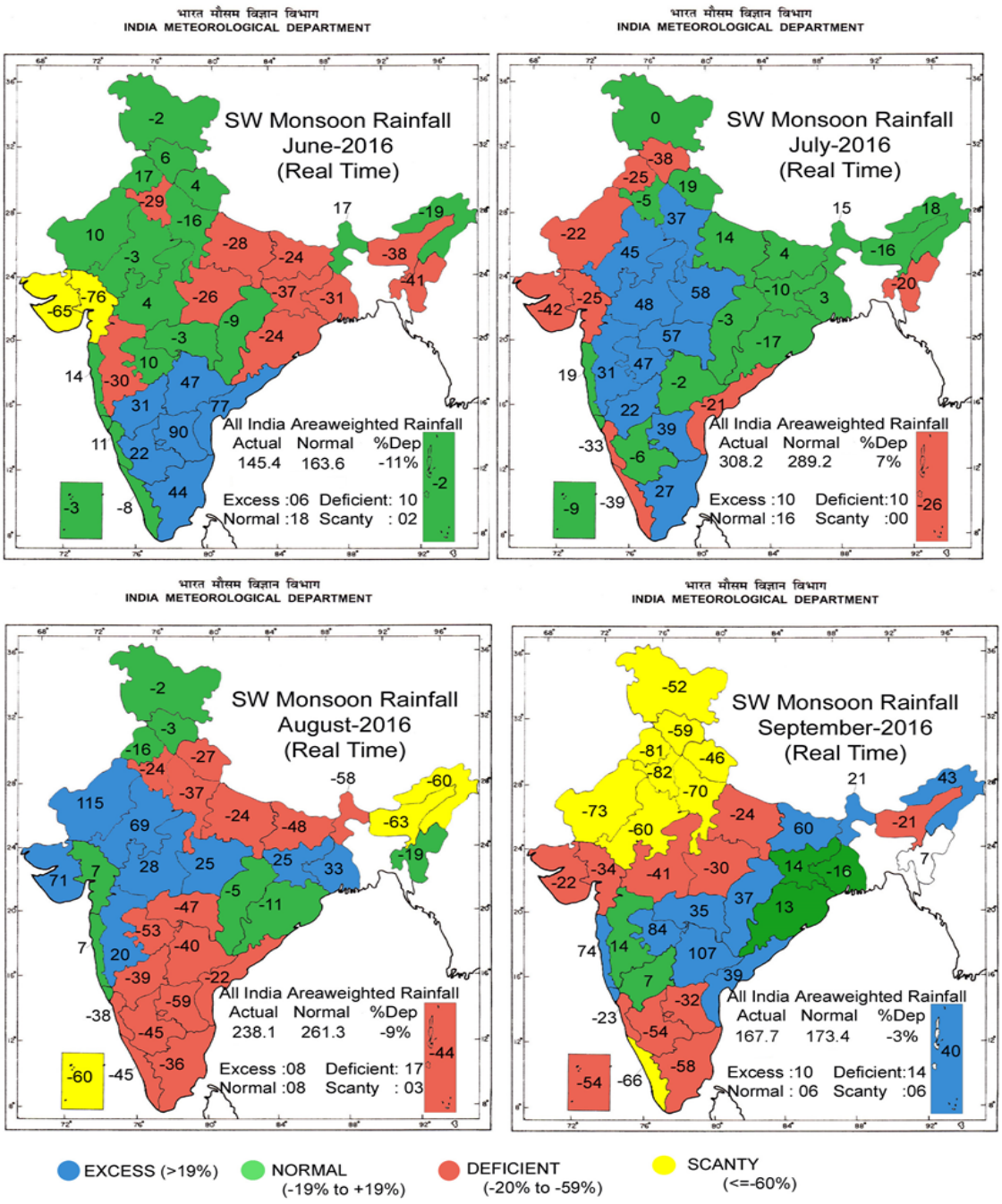

Fig.6: Sub-division wise monthly rainfall distribution over India during southwest monsoon season – 2016

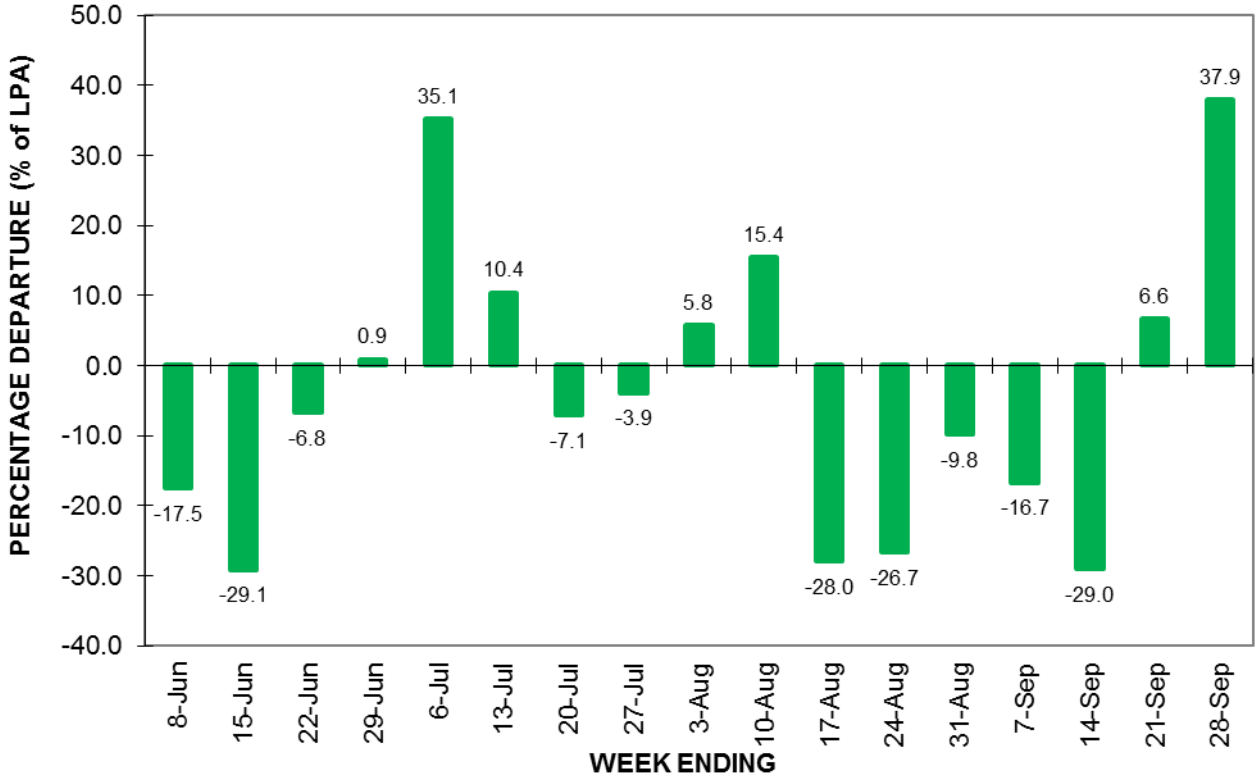

Fig.7: Week - by - Week Progress of the all India monsoon Rainfall during the 2016 southwest monsoon season

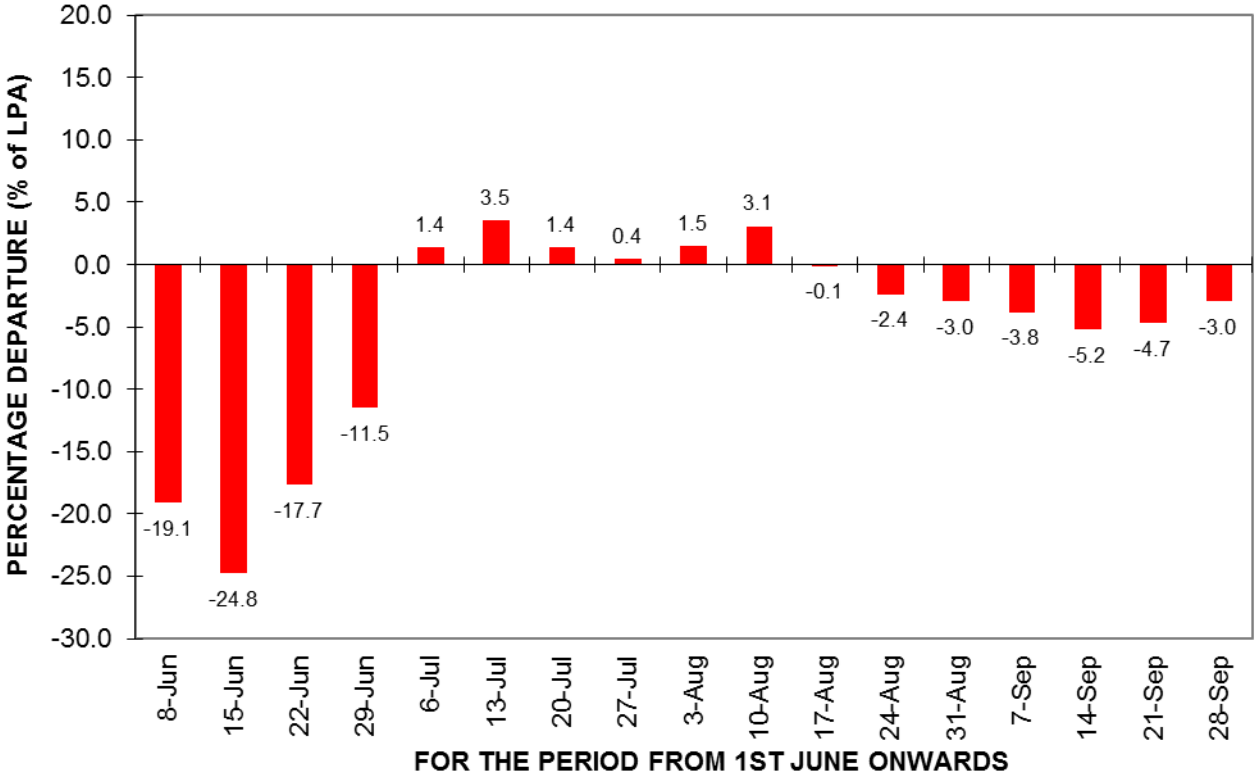

Fig.8: Week - by - week progress of the all India cumulative monsoon Rainfall during the 2016 southwest monsoon season.