MAUSAM, 51, 3 (July 2000), 285 - 318

# Weather in India

## MONSOON SEASON (JUNE - SEPTEMBER 1999)*

### 1. Introduction

The seasonal monsoon rainfall was excess (percentage departure from normal rainfall is 20% or more) or normal (percentage departure from normal rainfall is between 19% to –19 %) in 28 meteorological sub-divisions and was deficient (percentage departure from normal rainfall is between –20% to –59%) in the remaining 7 meteorological sub-divisions. Herein after, the meteorological sub-divisions are referred as sub-divisions. No sub-division received scanty ( percentage departure from normal rainfall is between –60% to –99%) rainfall during the season. In the month of June, a land depression and one deep depression were formed. One deep depression formed in July and a depression formed in August. No cyclonic storm formed during the monsoon season. Off-shore troughs along different parts of west coast persisted on most days throughout the season. The seasonal rainfall departures, stationwise and sub-divisionwise are given in Figs. 1 and 2 respectively.

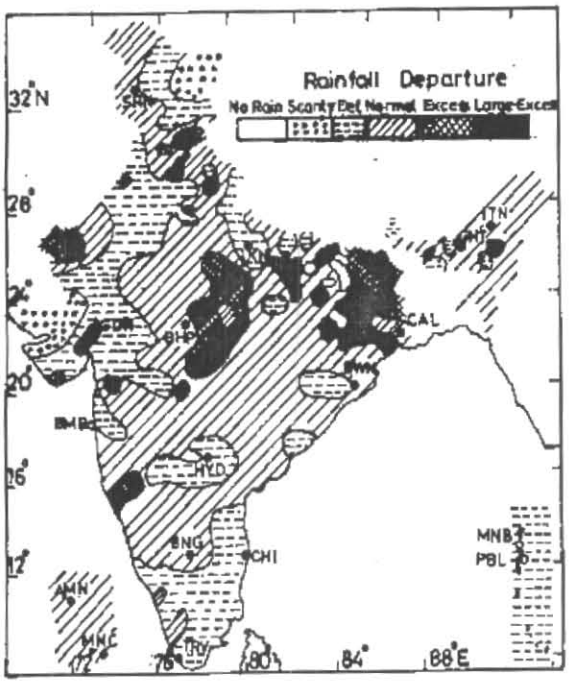



**Fig. 1.** Stationwise seasonal rainfall departure (%) for the period of June – September 1999

### 2. Characteristic features of southwest monsoon 1999

2.1. The country received total rainfall of 96 % of its long period average rainfall. Thus making 1999 as the 11th successive normal monsoon year as predicted by IMD's long range forecast.

2.2. The southwest monsoon arrived over Kerala on 25th May, one week earlier than the normal date of 1 June. In the past five years, the monsoon arrived over Kerala on 28th May in 1994.

2.3. The southwest monsoon advanced over the entire country on 12 July, three days earlier than the normal date of 15th July. Around this time, the monsoon covered the entire country in 1995 on 13 July.

2.4. Monsoon withdrew from extreme west Rajasthan on 18 September, with a delay of 17 days from the normal date of withdrawal. In the past 5 years, the monsoon withdrew from extreme west Rajasthan on 16 September in 1994. Monsoon further withdrew from Madhya Pradesh (12 days delay), Orissa (10 days delay), Maharashtra (10 days delay) and northeast India (one week's delay), by 15 October 1999. It withdrew from the entire country by 21 October.

2.5. No cyclonic storm formed during the season as in the year 1995. Four depressions (2 in June, one each in July and August) formed during the season.

2.6. Rainfall during the monsoon 1999 was excess in 3 and normal in 25 met sub-divisions. Similar rainfall distribution was found in 1998 (excess in 12 and normal in 21); in 1997 (excess in 7 and normal in 25); in 1996 (excess in 10 and normal in 22); in 1995 (excess in 7 and normal in 26) and in the year 1994 (excess in 12 and normal in 13).

2.7. Monsoon trough and Tibetan anticyclone established on 10 June. Monsoon trough was north of its normal position from 20 June to 4 July when rainfall activity was subdued over the country.

2.8. Off-shore trough on sea level chart and also in the lower levels along different parts of west coast was present on most of the days from 20 May to 22 September except on 13 – 14 August, 16 – 26 August. Thus, off

*Compiled by : V. Thapliyal, D.S. Desai & V. Krishnan, Meteorological Office, Pune - 411005, India

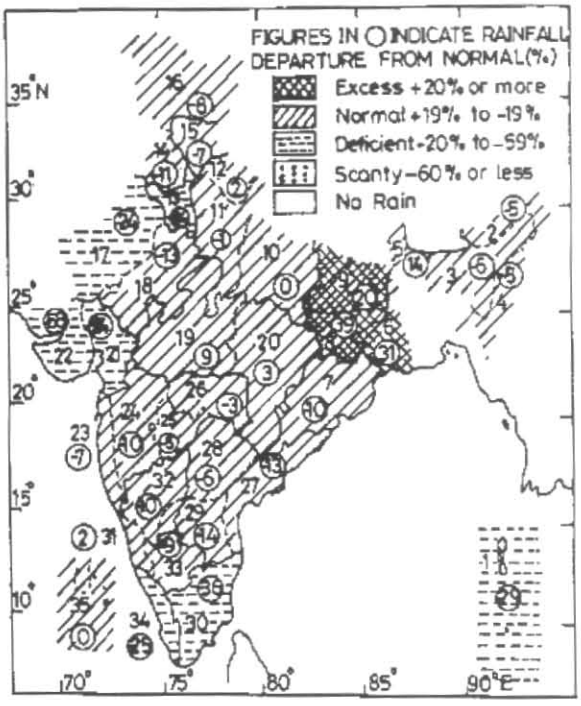



Fig. 2. Sub-divisionwise seasonal rainfall departure (%) for the period June – September 1999

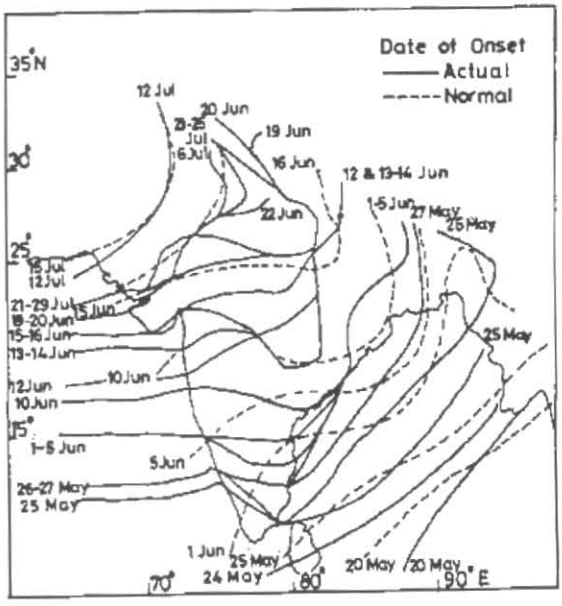



Fig. 3. Advance of southwest monsoon 1999

shore trough along west coast was almost a semi-permanent feature of the season.

2.9. Cross equatorial flow into the Arabian Sea was below normal (5-10 kts) in the 1st, 3rd and 4th week of July and in August.

2.10. Northeast monsoon rains commenced over Tamil Nadu & Pondicherry, Kerala and adjoining states of Karnataka and Andhra Pradesh on 21 October. In the past five years, northeast monsoon rains commenced over Tamil Nadu & Pondicherry, Kerala and adjoining states of Karnataka and Andhra Pradesh on 23 October in 1995 and 28 October in 1998.

2.11. Northeast monsoon withdrew from Tamil Nadu, Pondicherry, Kerala and adjoining states of Karnataka and Andhra Pradesh on 28 December. During the past five years, the northeast monsoon withdrew from Tamil Nadu, Pondicherry, Kerala and adjoining states of Karnataka and Andhra Pradesh on 22 December in 1998 and 1995, 31 December in 1997, 23 December in 1996 and 14 December in 1994.

## 3. Features of monsoon

### 3.1. *Advance of southwest monsoon*

The southwest monsoon advanced over Andaman Sea and adjoining parts of southeast Bay of Bengal on 20 May. It further advanced into some parts of Commorin area and most parts of Bay of Bengal on 24. The southwest monsoon set in over Kerala on 25 May, one week in advance against its normal date. On the same day, it set in over some parts of south Arabian Sea, Maldives and Commorin area, parts of Tamil Nadu and some more parts of Bay of Bengal. On 26, it further advanced into rest of Arabian Sea, parts of coastal and interior Karnataka and parts of northeastern states. The southwest monsoon advanced steadily and covered Orissa, West Bengal & Sikkim and most parts of Bihar Plateau and Tamil Nadu upto 2 June. By 16 June, it further advanced into central India, some parts of Gujarat State and in some parts of Madhya Pradesh, east Uttar Pradesh and coastal Andhra Pradesh. From 19 to 22 June, it further advanced into most parts of north India and east Rajasthan. The monsoon covered remaining parts of the country on 12 July, thus covering the entire country, 3 days earlier to its normal date.

Isochrones of advance of southwest monsoon 1999 are shown in Fig. 3.

### 3.2. *Week by week cumulative rainfall distribution (1 June 1999 to 30 September 1999)*

Sub-divisionwise cumulative rainfall departures (percentage departure from normal rainfall) during the southwest monsoon season from 1 June to 30 September 1999 comprising of 18 weeks are given in Fig 4. Rainfall figures given in this figure are computed from updated data.

During the week ending on June 16 and 23, July 14 and 21, August 4 and 11 and on September 1, 15 and 29; the rainfall received was excess or normal in about 66% and 71%, 51% and 80%, 49% and 57% and 51%, 54% and 71% sub-divisions respectively. Rainfall activity was subdued from the end of June to the middle of July, from

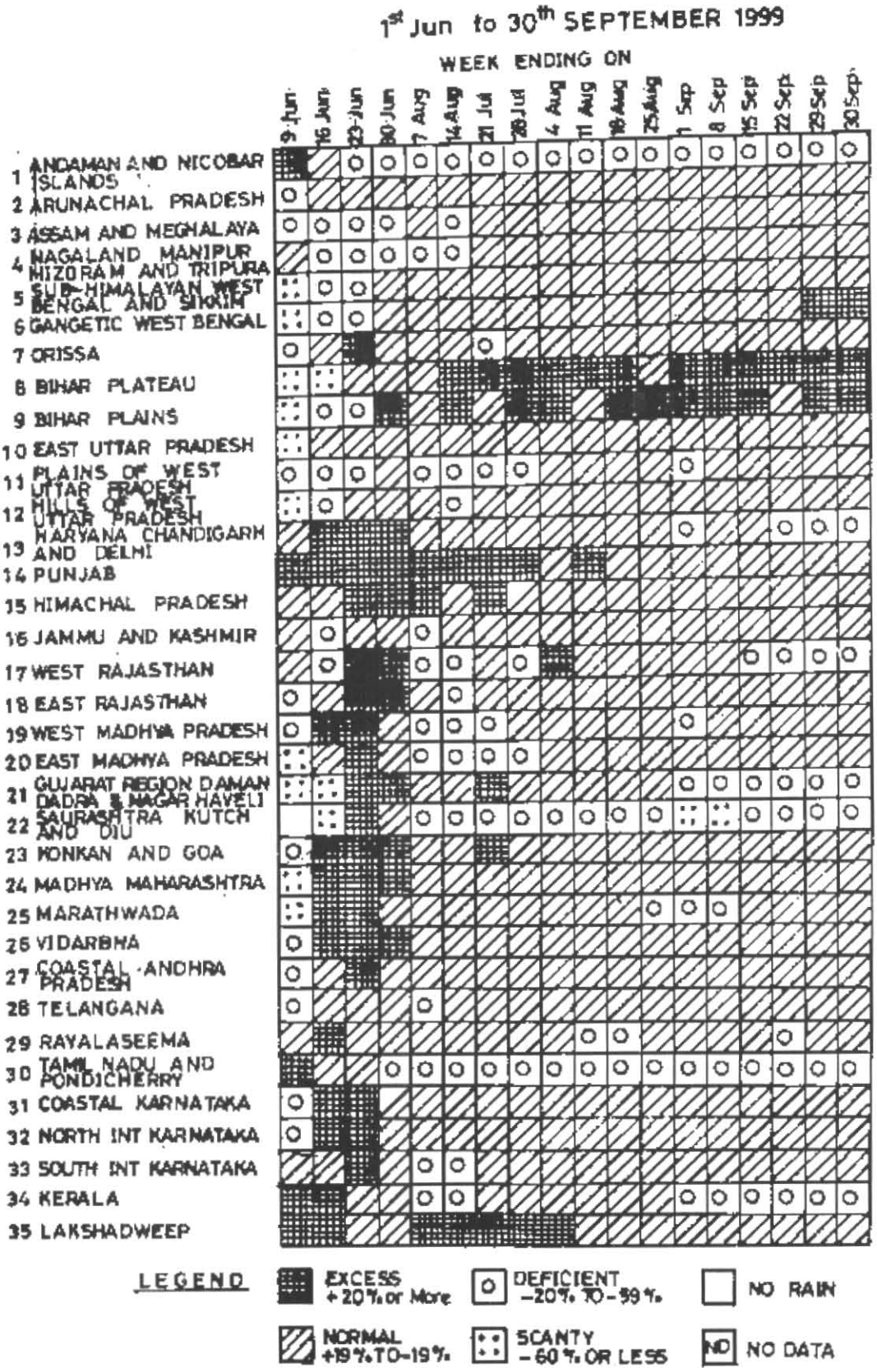



Fig. 4. Progress of southwest monsoon week-by -week (1st June to 30th September 1999)

TABLE 1

**Rainfall figures (mm) for each month and season as a whole (June – September 1999)**

| S. No. | Meteorological sub-division | June | | | July | | | August | | | September | | | Season | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Actual (mm) | Normal (mm) | Dep. (%) | Actual (mm) | Normal (mm) | Dep. (%) | Actual (mm) | Normal (mm) | Dep. (%) | Actual (mm) | Normal (mm) | Dep. % | Actual (mm) | Normal (mm) | Dep. (%) |
| 1. | A. & N. Islands | 265 | 470 | - 44 | 273 | 357 | - 24 | 282 | 360 | - 22 | 320 | 407 | - 21 | 1140 | 1595 | - 29 |
| 2. | Arunachal Pradesh | 586 | 568 | 3 | 577 | 674 | - 14 | 490 | 487 | 1 | 277 | 307 | - 10 | 1930 | 2035 | - 5 |
| 3. | Assam & Meghalaya | 434 | 552 | - 21 | 580 | 539 | 8 | 513 | 425 | 21 | 212 | 329 | - 35 | 1740 | 1844 | - 6 |
| 4. | Naga., Mani., Mizo. and Tri. | 311 | 397 | - 22 | 374 | 351 | 7 | 342 | 323 | 6 | 229 | 250 | - 8 | 1256 | 1321 | - 5 |
| 5. | Sub-Himalayan West Bengal & Sikkim | 488 | 524 | - 7 | 682 | 609 | 12 | 722 | 501 | 44 | 433 | 404 | 7 | 2325 | 2037 | 14 |
| 6. | Gangetic West Bengal | 242 | 247 | - 2 | 397 | 312 | 27 | 355 | 307 | 16 | 440 | 230 | 92 | 1435 | 1096 | 31 |
| 7. | Orissa | 218 | 221 | - 1 | 254 | 357 | - 29 | 325 | 355 | - 8 | 266 | 244 | 9 | 1063 | 1178 | - 10 |
| 8. | Bihar Plateau | 279 | 195 | 43 | 451 | 334 | 35 | 388 | 322 | 20 | 386 | 229 | 69 | 1504 | 1080 | 39 |
| 9. | Bihar Plains | 242 | 168 | 44 | 390 | 312 | 25 | 394 | 302 | 30 | 181 | 220 | - 18 | 1208 | 1003 | 20 |
| 10. | East Uttar Pradesh | 117 | 105 | 11 | 276 | 302 | - 9 | 279 | 299 | - 7 | 230 | 191 | 21 | 901 | 897 | 0 |
| 11. | Plains of west Uttar Pradesh | 72 | 80 | - 11 | 243 | 264 | - 8 | 180 | 269 | - 33 | 273 | 162 | 68 | 767 | 775 | - 1 |
| 12. | Hills of west Uttar Pradesh | 156 | 169 | - 8 | 463 | 449 | 3 | 351 | 448 | - 22 | 346 | 229 | 51 | 1315 | 1295 | 2 |
| 13. | Haryana, Chandigarh & Delhi | 68 | 51 | 34 | 149 | 175 | - 15 | 100 | 179 | - 44 | 70 | 108 | - 35 | 387 | 513 | - 24 |
| 14. | Punjab | 57 | 42 | 37 | 224 | 190 | 18 | 125 | 169 | - 26 | 44 | 101 | - 57 | 449 | 502 | - 11 |
| 15. | Himachal Pradesh | 114 | 96 | 18 | 352 | 346 | 2 | 291 | 320 | - 9 | 96 | 157 | - 39 | 852 | 919 | - 7 |
| 16. | Jammu & Kashmir | 53 | 55 | - 4 | 133 | 161 | - 18 | 158 | 159 | 0 | 72 | 80 | - 9 | 416 | 455 | - 8 |
| 17. | West Rajasthan | 33 | 27 | 19 | 59 | 101 | - 42 | 90 | 104 | - 14 | 10 | 46 | - 78 | 213 | 279 | - 24 |
| 18. | East Rajasthan | 84 | 56 | 50 | 218 | 224 | - 3 | 95 | 233 | - 59 | 102 | 117 | - 13 | 547 | 630 | - 13 |
| 19. | West Madhya Pradesh | 108 | 115 | - 6 | 298 | 318 | - 6 | 210 | 313 | - 33 | 390 | 174 | 124 | 1007 | 920 | 9 |
| 20. | East Madhya Pradesh | 166 | 166 | 0 | 327 | 385 | - 15 | 368 | 385 | - 4 | 320 | 213 | 50 | 1181 | 1149 | 3 |
| 21. | Gujarat Region | 234 | 145 | 61 | 356 | 433 | - 18 | 102 | 301 | - 66 | 112 | 183 | - 39 | 804 | 1062 | - 24 |
| 22. | Saurashtra & Kutch | 94 | 91 | 4 | 76 | 240 | - 68 | 16 | 129 | - 88 | 43 | 84 | - 50 | 229 | 544 | - 58 |
| 23. | Konkan & Goa | 981 | 685 | 43 | 1061 | 1106 | - 4 | 266 | 663 | - 60 | 300 | 348 | - 14 | 2608 | 2801 | - 7 |
| 24. | Madhya Maharashtra | 210 | 140 | 50 | 238 | 271 | - 12 | 73 | 179 | - 59 | 147 | 155 | - 5 | 668 | 745 | - 10 |
| 25. | Marathwada | 166 | 146 | 13 | 128 | 206 | - 38 | 132 | 187 | - 29 | 253 | 179 | 41 | 679 | 717 | - 5 |
| 26. | Vidarbha | 215 | 171 | 26 | 220 | 338 | - 35 | 279 | 272 | 2 | 229 | 194 | 18 | 943 | 975 | - 3 |
| 27. | Coastal Andhra Pradesh | 119 | 111 | 7 | 147 | 168 | - 13 | 138 | 160 | - 14 | 128 | 170 | - 25 | 532 | 609 | - 13 |
| 28. | Telangana | 115 | 135 | - 15 | 235 | 243 | - 3 | 207 | 212 | - 2 | 172 | 188 | - 9 | 729 | 778 | - 6 |
| 29. | Rayalaseema | 58 | 60 | - 3 | 55 | 85 | - 36 | 115 | 98 | 17 | 95 | 132 | - 28 | 323 | 375 | - 14 |
| 30. | Tamil Nadu | 36 | 52 | - 31 | 42 | 72 | - 41 | 62 | 96 | - 35 | 64 | 101 | - 37 | 205 | 321 | - 36 |
| 31. | Coastal Karnataka | 957 | 923 | 4 | 1500 | 1214 | 24 | 561 | 715 | - 22 | 210 | 326 | - 35 | 3228 | 3178 | 2 |
| 32. | North Interior Karnataka | 95 | 90 | 6 | 130 | 132 | - 2 | 95 | 109 | - 13 | 104 | 142 | - 27 | 424 | 473 | - 10 |
| 33. | South Interior Karnataka | 123 | 139 | - 12 | 262 | 256 | 2 | 131 | 172 | - 24 | 123 | 131 | - 6 | 639 | 698 | - 9 |
| 34. | Kerala | 614 | 697 | - 12 | 657 | 765 | - 14 | 250 | 440 | - 43 | 85 | 252 | - 66 | 1607 | 2154 | - 25 |
| 35. | Lakshadweep | 280 | 307 | - 9 | 459 | 283 | 62 | 135 | 191 | - 29 | 73 | 161 | - 54 | 947 | 943 | 0 |

**TABLE 2**

**Statewise distribution of number of districts with excess, normal, deficient and scanty rainfall for the period from 1 June to 30 September 1999 (Updated)**

| S. No. | State/UT | Excess | Normal | Deficient | Scanty | N.R. | ** | TOTAL |
|---|---|---|---|---|---|---|---|---|
| 1. | Andaman & Nicobar Island (UT) | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 2. | Arunachal Pradesh | 0 | 5 | 0 | 0 | 0 | 0 | 5 |
| 3. | Assam | 2 | 12 | 2 | 0 | 0 | 0 | 16 |
| 4. | Meghalaya | 0 | 1 | 1 | 0 | 0 | 0 | 2 |
| 5. | Nagaland | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 6. | Manipur | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 7. | Mizoram | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 8. | Tripura | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 9. | Sikkim | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 10. | West Bengal | 9 | 7 | 0 | 0 | 0 | 0 | 16 |
| 11. | Orissa | 0 | 10 | 3 | 0 | 0 | 0 | 13 |
| 12. | Bihar | 24 | 9 | 5 | 0 | 0 | 1 | 39 |
| 13. | Uttar Pradesh | 12 | 27 | 17 | 0 | 0 | 0 | 56 |
| 14. | Haryana | 2 | 2 | 12 | 0 | 0 | 0 | 16 |
| 15. | Chandigarh(UT) | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| 16. | Delhi (UT) | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 17. | Punjab | 1 | 6 | 4 | 0 | 0 | 1 | 12 |
| 18. | Himachal Pradesh | 3 | 6 | 3 | 0 | 0 | 0 | 12 |
| 19. | Jammu & Kashmir | 0 | 6 | 2 | 1 | 0 | 3 | 12 |
| 20. | Rajasthan | 1 | 17 | 14 | 0 | 0 | 0 | 32 |
| 21. | Madhya Pradesh | 11 | 27 | 6 | 0 | 0 | 1 | 45 |
| 22. | Gujarat | 1 | 3 | 11 | 4 | 0 | 0 | 19 |
| 23. | Dadra, Daman, N. Haveli (UTS) | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 24. | Diu (UT) | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| 25. | Goa | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| 26. | Maharashtra | 1 | 23 | 6 | 0 | 0 | 0 | 30 |
| 27. | Andhra Pradesh | 0 | 15 | 8 | 0 | 0 | 0 | 23 |
| 28. | Tamil Nadu | 1 | 1 | 20 | 0 | 0 | 0 | 22 |
| 29. | Pondicherry (UT) | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| 30. | Karnataka | 1 | 21 | 5 | 0 | 0 | 0 | 27 |
| 31. | Kerala | 0 | 4 | 10 | 0 | 0 | 0 | 14 |
| 32. | Lakshadweep(UT) | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| | Total | 70 | 208 | 134 | 6 | 0 | 6 | 424 |
| | % Distribution of no. of dist. Recd. | 17 | 50 | 32 | 1 | 0 | | |

N.R. – No Rain, ** – Data inadequate

the middle of August to the end of August and during the third week of September. During the last week of September, the monsoon rainfall was widespread over most parts of the country.

Rainfall was excess or normal throughout the period from the week ending 9 June to 30 September 1999 in Punjab, Himachal Pradesh, Konkan & Goa (except for week ending 9 June 1999, south interior Karnataka (except for the week ending 7 July and 14 July 1999) and Lakshadweep. From the week ending 16 June to 30 September 1999, rainfall was excess or normal throughout in Arunachal Pradesh, Orissa (except for week ending 21 July 1999), east Uttar Pradesh, east Rajasthan (except for the week ending 14 July 1999), Madhya Maharashtra, Vidarbha, coastal Andhra Pradesh, Telangana (except for the week ending 7 July 1999), coastal & north interior Karnataka. Rainfall was excess or normal in 13 weeks or more in Assam & Meghalaya, Nagaland, Manipur, Mizoram & Tripura, West Bengal, Bihar, hills of west Uttar Pradesh, Haryana, Jammu & Kashmir, Madhya Pradesh, Marathwada and Rayalaseema. Rainfall was excess or normal in 10 weeks in plains of west Uttar Pradesh, West Rajasthan, Gujarat Region and Kerala. Rainfall was deficient throughout the

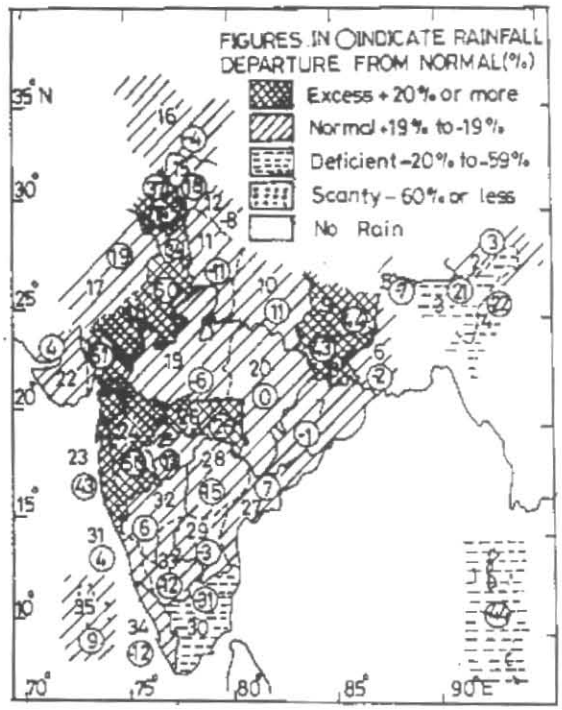



Fig. 5. Rainfall for the month of June 1999 (Figures in circle indicate rainfall percentage departure from normal)

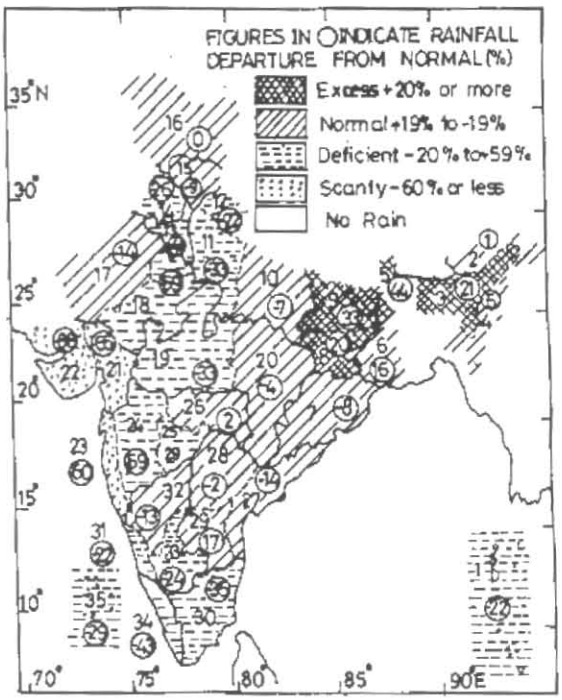



Fig. 6. Rainfall for the month of July 1999 (Figures in circle indicate rainfall percentage departure from normal)

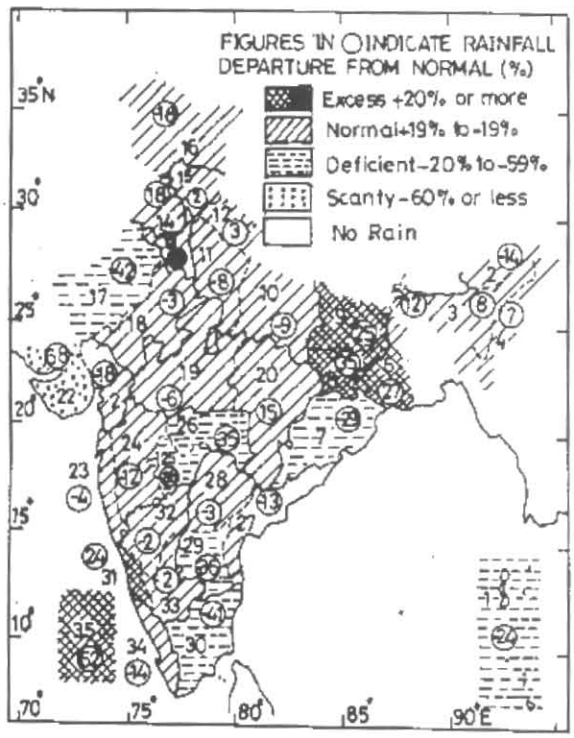



Fig. 7. Rainfall for the month of August 1999 (Figures in circle indicate rainfall percentage depature from normal)

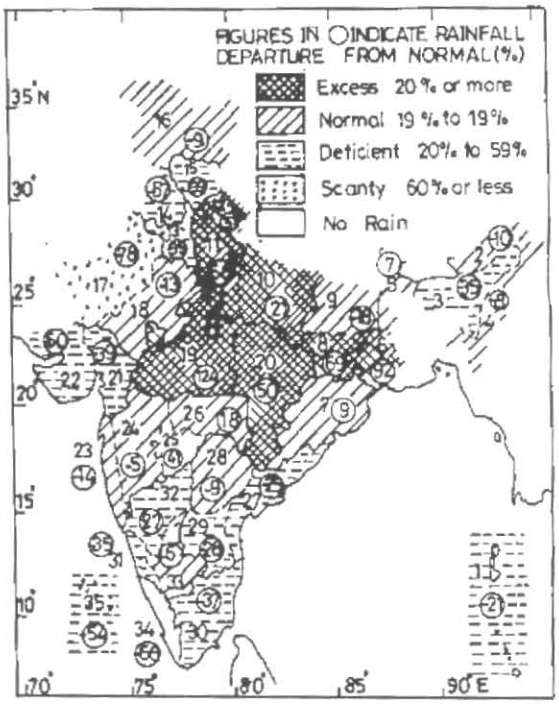



Fig. 8. Rainfall for the month of September 1999 (Figures in circle indicate rainfall percentage departure from normal)

**TABLE 3**

**Details of the weather systems during June 1999**

| S. No. | System | Period | Place of first location | Direction of movement | Place of dissipation | Remarks |
|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| **(A)** *Depressions* | | | | | | |
| 1. | Land depressions | 11-12 | West-Bengal coast & adjoining north Bay | Northwesterly to westnorthwesterly and finally northwesterly | East Uttar Pradesh | It was first seen as a cyclonic circulation in mid tropospheric levels on 3. A trough from this system ran to north Andaman Sea in the lower levels on 4 and became unimportant on 9. However, the cyclonic circulation was seen over northwest Bay off Orissa coast on 9. Under its influence, a well marked low pressure area formed over West Bengal coast and adjoining north Bay on 10 evening. It moved in a northwesterly direction and concentrated into a depression and lay centered at 0300 UTC of 11 near Lat. 23.0°N/Long. 86.5° E, very close to Purulia. It then moved in a west-northwesterly direction and lay near Hazaribagh at 1200 UTC of 11. It further moved in a northwesterly direction and lay at 0300 UTC of 12 near Lat. 26.0°N/Long. 82.0°E, about 50 kms northwest of Varanasi. It weakened into a well marked low pressure area and lay over east Uttar Pradesh and neighbourhood on 12 evening and rapidly weakened into a low pressure area and became unimportant on 13 |
| 2. | Deep depression | 17-18 | Northwest Bay & adjoining west central Bay off Orissa coast | Westnorthwesterly | North Vidarbha & adjoining parts of Madhya Pradesh | A low pressure area formed over northwest Bay and neighbourhood on 15. Associated cyclonic circulation extended upto mid tropospheric levels. It became well marked on 16 and lay over northwest Bay off Orissa – West Bengal coast. It concentrated into a depression at 0300 UTC of 17 and lay near Lat. 18.5°N/Long. 86.0°E, about 160 kms eastsoutheast of Gopalpur. It then concentrated into a deep depression at 0900 UTC of 17 and lay near Lat. 19.0°N/Long.85.0°E, about 40 kms southeast of Gopalpur. It moved in westnorthwesterly direction and crossed Orissa coast near Gopalpur at 2100 UTC. of 17. It weakened into a depression and lay centered at 0300 UTC of 18 near Lat. 20.5°N/Long. 82.0 ° E about 100 kms south of Raipur. It further moved in a westnorthwesterly direction and weakened into a well marked low pressure area and lay over north Vidarbha and adjoining parts of Madhya Pradesh at 1200 UTC of 18. It lay as a low pressure area on 20 near northwest Madhya Pradesh and neighbourhood. The low pressure area became less marked on 21 evening |

TABLE 3 (*Contd.*)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|
| **(B)** | *Low pressure area* | | | | | |
| 1. | Low pressure area | 26-27 | Bangla Desh & neighbourhood | Stationary | *In situ* | Associate cyclonic circulation extended upto lower levels on 26 and merged with the monsoon trough in the lower levels on 28 |
| **(C)** | *Western disturbance* | | | | | |
| 1. | Upper air system | 3-8 | North Pakistan & neighbourhood | Northeasterly | Jammu & Kashmir and neighbourhood | A trough from this system ran to southwest Uttar Pradesh in the lower levels on 3 and to northwest Madhya Pradesh on |
| 2. | Do | 14-16 | Do | Do | North Pakistan and adjoining Jammu & Kashmir | Moved away northeastwards |
| **(D)** | *Induced cyclonic circulation* | | | | | |
| 1. | Lower tropospheric levels | 5-6 | North west Rajasthan and neighbourhood | Northeasterly | Himachal Pradesh | Moved away across Himachal Pradesh |
| 2. | Do | 7-10 | Central parts of Pakistan & neighbourhood | Do | Jammu & Kashmir & neighbourhood | Moved away |
| **(E)** | *Other cyclonic circulation* | | | | | |
| 1. | Mid tropospheric levels | 31 May – 3 June | Punjab & neighbourhood | Northeasterly | Himachal Pradesh | Moved away across Himachal Pradesh |
| 2. | -Do- | 7-8 | Cenral parts of Uttar Pradesh | Northerly | North Uttar Pradesh | - |
| 3. | Upper tropospheric levels | 9-11 | South Andhra coasta and neighbourhood | Stationary | *In situ* | It tilted westwards with heigh on 10 |
| 4. | Lower tropospheric levels | 10-13 | West Rajasthan & neighbourhood | Northeasterly | Himachal Pradesh | Moved away across Himachal Pradesh |
| 5. | Upper tropospheric levels | 17-18 | Gulf of Cambay & neighbourhood | Stationary | *In situ* | It was tilting southwards with height on 17 |
| 6. | Lower tropospheric levels | 18-26 | Central Parts of Pakistan & neighbourhood | Northeasterly | Punjab and Haryana and neighbourhood | A trough from this system ran to southwest Uttar Pradesh on 18. On 20, it was seen from this system to the center of low pressure area over northwest Madhya Pradesh and became less marked on 21. The cyclonic circulation moved away on 26 |
| 7. | Lower levels | 26-28 | Punjab & neighbourhood | Stationary | *In situ* | - |
| 8. | Lower tropospheric levels | 29-30 | Bihar Plains and neighbourhood | Do | Do | - |
| **(F)** | *Troughs* | | | | | |
| 1. | Sea level chart | 1-9 | Northeast bay to north Andaman Sea | Do | Do | It was associated with the cyclonic circulation over northwest Bay from 3 to 9 |
| 2. | Mid tropospheric levels | 26-29 | Sub-Himalayan West Bengal & Sikkim to northeast Bay | Stationary | *In situ* | - |

**TABLE 4**

**Details of the weather systems during July 1999**

| S. No. (1) | System (2) | Period (3) | Place of first location (4) | Direction of movement (5) | Place of dissipation (6) | Remarks (7) |
|---|---|---|---|---|---|---|
| **(A)** *Depressions* | | | | | | |
| 1. | Deep depression | 27-29 | 21.0°E, about 200 kms southsoutheast of Calcutta | Northwest and then westnorth-westerly | West Rajasthan and neighbourhood | It was first seen as a cyclonic circulation extending upto mid tropospheric levels over northwest Bay & neighbourhood on 24. Under its influence, a low pressure area formed over northwest Bay and adjoining West Bengal coast on 24 evening. Associated cyclonic circulation extended upto mid tropospheric levels and tilted southwestwards with height. It was more marked on 26 evening and concentrated into a depression at 0300 UTC of 27 and lay centered near Lat. 21.0°N/Long. 89.0°E, about 200 kms southsoutheast of Calcutta. It further intensified into a deep depression at 1200 UTC of 27 and lay centered near Lat. 21.0°N/Long. 88.5°E. It crossed Orissa West bengal coast in the early morning hours of 28 and lay as a deep depression at 0300 UTC of 28 near Lat. 23.0°N/Long. 86.5°E, about 50 kms southeast of Purulia. It moved in a northwesterly direction and weakened into a depression at 1200 UTC of 28 and lay near Lat. 23.0° N/Long. 84.5°E, about 50 kms northwest of Ranchi. It further moved in a westnorthwesterly direction and lay centered at 0300 UTC of 29 near Lat. 24.5°N/Long. 81.0°E, very close to Satna. It further weakened into a well marked low pressure area in the evening of 29 over northwest Madhya Pradesh and neighbourhood and into a low pressure area on 31 morning over northeast Rajasthan and neighbourhood. It later merged with the monsoon trough over extreme west Rajasthan and neighbourhood on 3 August |
| **(B)** *Low pressure area* | | | | | | |
| 1. | Well marked low pressure area | 14-18 | Head Bay and adjoining coastal region of Gangetic West Bengal and Orissa | Initially westnorthwesterly and then northwesterly | East Rajasthan and adjoining parts of northwest Madhya Pradesh | It was first seen as a trough of low over Gangetic West Bengal and adjoining parts of north bay on 13 and the associated cyclonic circulation extended upto mid tropospheric levels. The associated cyclonic circulation tilted southwestwards with height from 15 to 17. The well marked low pressure area weakened into a low pressure area over east Rajasthan and adjoining parts of northwest Madhya Pradesh on 17. It merged with the monsoon trough on 18 |
| 2. | Do | 23-25 | Northwest Madhya Pradesh and neighbourhood | Stationary | *In situ* | It was first seen as a cyclonic circulation in upper tropospheric levels over west Madhya Pradesh and neighbourhood on 21. It tilted southwestwards with height on 21. Under its influence a low pressure area formed over northwest Madhya Pradesh and neighbourhood on 23 evening. It lay as a well marked low pressure area on 24 with central region near Jhansi. It became less marked on 25 merged with the monsoon trough |

**TABLE 4** (*Contd.*)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|
| **(C)** | *Induced cyclonic circulation* | | | | | |
| 1. | Lower levels | 13-16 | West Rajasthan and adjoining south Pakistan | Northeasterly | North parts of Rajasthan and adjoining Punjab and Haryana | Merged with the monsoon trough |
| **(D)** | *Other cyclonic circulations* | | | | | |
| 1. | Mid tropospheric levels | 30 June – 7 July | South Assam & adjoining Bangla Desh | Northerly and then northeasterly | Assam & neighbourhood | - |
| 2. | Mid tropospheric levels | 30 June – 1 July | Jammu & Kashmir and neighbourhood | Northeasterly | - | Moved away northeastwards |
| 3. | Do | 4-9 | North Bay & neighbourhood | Northwesterly | East Uttar Pradesh and neigbhbourhood | It tilted southwestwards with height on 6 |
| 4. | Do | 5-6 | Saurashtra & neighbourhood | Stationary | *In situ* | - |
| 5. | Lower tropospheric levels | 6-7 | Punjab & neighbourhood | Northeasterly | - | Moved away northeastwards |
| 6. | Mid tropospheric levels | 7-9 | Punjab and adjoining parts of Pakistan | Stationary | *In situ* | - |
| 7. | Do | 9-10 | Saurashtra and neighbourhood | Do | Do | It tilted southwards with height on 9 and 10 |
| 8. | Lower levels | 10-11 | Punjab & neighbourhood | Northeasterly | Himachal Pradesh | Moved away across Himachal Pradesh |
| 9. | Lower tropospheric levels | 12-13 | Pakistan and adjoining parts of Punjab | Northeasterly | - | Moved away across northeastwards |
| 10. | Mid tropospheric levels | 12-13 | Central parts of Uttar Pradesh | Stationary | *In situ* | - |
| 11. | Do | 16-19 | Central parts of Pakistan and adjoining west Rajashtan | - | - | Merged with the seasonal trough |
| 12. | Upper tropospheric levels | 19-20 | West Madhya Pradesh | Do | Do | It tilted southwestwards with height on 19 |
| 13. | Lower tropospheric levels | 20-21 | Plains of west Uttar Pradesh & neighbourhood | Do | Do | Merged with the monsoon trough |
| 14. | Do | 26-28 | Punjab & neighbourhood | Do | Do | Do |
| 15. | Mid tropospheric levels | 26-27 | Gujarat Region & neighbourhood | Do | Do | - |
| 16. | Lower tropospheric levels | 29-31 | Central parts of Pakistan | Do | Do | Merged with the monsoon trough |

**TABLE 4** (*Contd.*)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|
| **(E)** | *Western disturbance* | | | | | |
| 1. | Upper air system | 25-30 | North Pakistan & neighbourhood | Northeasterly | Jammu & Kashmir | Moved away |
| **(F)** | *East – West trough* | | | | | |
| 1. | Upper tropospheric levels | 13-14 | 15.0°N across Peninsula | Quasi-stationary | 14.0°N across Peninsula | - |
| 2. | Do | 16 | 18.0°N across Peninsula | Stationary | *In situ* | - |
| 3. | Do | 27-28 | Center of depression near 21.0°N/89.0 °E to Saurashtra across south Madhya Pradesh | Quasi stationary | Centre of deep depression near 23.0°N/86.5°E to Saurashtra across east Madhya Pradesh | - |
| **(G)** | *Other trough* | | | | | |
| 1. | Mid and upper tropospheric levels | 30 June – 3 July | Southwest Madhya Pradesh to Gulf of Cambay | Quasi – stationary | West Madhya Pradesh to Goa | - |

period from the week ending 23 June 1999 in Andaman & Nicobar islands and deficient or scanty in more than 15 weeks in Saurashtra & Kutch and Tamil Nadu.

### 3.3. *Month by month performance of monsoon rainfall*

Figs. 5-8 show monthwise distribution of monsoon rainfall.

Rainfall figures and departures for each month and season as a whole sub-divisionwise are given in Table 1 and principal amounts of daily rainfall are given in Table 11.

### 3.4. *Seasonal performance of monsoon rainfall*

Sub-divisionwise seasonal rainfall distribution in terms of percentage departures from normal is given in Fig. 2. The seasonal rainfall was excess in 3, normal in 25 and deficient in the remaining 7 sub-divisions. Seasonal total rainfall for the country as a whole was normal and country received 96% of its long period average value.

### 3.5. *Districtswise distribution of monsoon rainfall*

Data received from 421 (out of 424) meteorological districts show that, 71 districts (17%) received excess; 212 districts (50%) received normal rainfall. State wise number of districts which received excess/normal rainfall is given in Table 2.

### 3.6. *Withdrawal of southwest monsoon*

Monsoon withdrew from extreme west Rajasthan on 18 September, with a delay of 17 days from the normal date of withdrawal. Monsoon further withdrew from Madhya Pradesh (12 days delay), Orissa (10 days delay), Maharashtra (10 days delay) and northeast India (one week's delay), by 15 October. It withdrew from the entire country by 21 October. Withdrawal dates of southwest monsoon are given in Fig. 9.

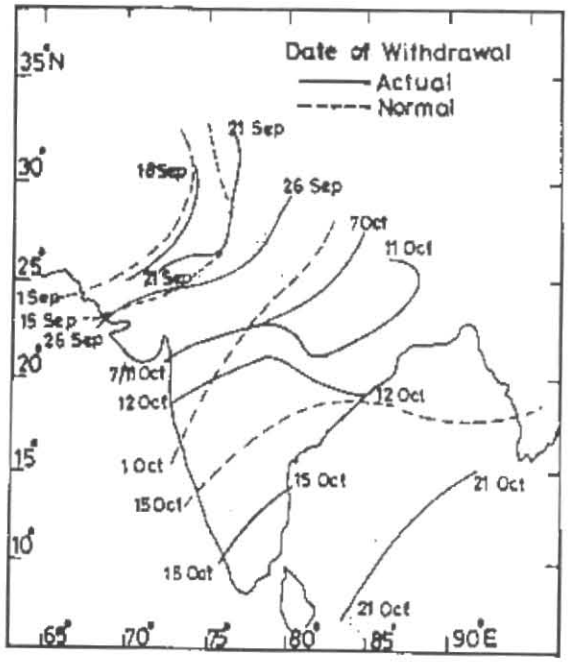



**Fig. 9.** Withdrawal of southwest monsoon 1999

TABLE 5

**Details of the weather systems during August 1999**

| S. No. (1) | System (2) | Period (3) | Place of first location (4) | Direction of Movement (5) | Place of dissipation (6) | Remarks (7) |
|---|---|---|---|---|---|---|
| **(A)** | *Depressions* | | | | | |
| 1. | Depression | 6-8 | 21.0°N/88.5E, about 160 kms south Calcutta | Westnorthwesterly | Northeast Uttar Pradesh and adjoining Bihar Plains | A low pressure area formed over northwest Bay and neighbourhood on 5. Associated cyclonic circulation extended upto mid tropospheric levels. It was well marked on 6 and lay over northwest Bay off north Orissa – West bengal coast. It concentrated into a depression at 1200 UTC of 6 near Lat. 21.0°N/Long.88.5°E, about 160 kms south of Calcutta. It moved in a westnorthwesterly direction and crossed West Bengal coast near Digha and lay as a depression at 0300 UTC of 7 near Lat. 22.5°N/Long. 87.5°E, close to Midnapore. The depression lay near Jamshedpur on 1200 UTC of 7. It moved in westnorthwesterly direction and lay near Lat. 22.5°N/Long. 85.0°E, at 0300 UTC of 8, about 80 kms southeast of Ambikapur and at 1200 UTC of 8, it layar near lat. 22.5° N/ long. 83.0° E, about 80 kms southeast Pendra. It further moved in a westnorthwesterly direction and weakened into a well marked low pressure area and lay over northeast Madhya Pradesh and neighbourhood. It lay as a low pressure area over northwest Madhya Pradesh and neighbourhood on 10 and became less marked on 12 over northeast Uttar Pradesh and adjoining Bihar Plains. Associated cyclonic circulation also became less marked on 12 |
| **(B)** | *Low pressure area* | | | | | |
| 1. | Well marked low pressure area | 1-5 | Northwest bay off Orissa coast | Northwesterly | East Madhya Pradesh and adjoining parts of Bihar Plateau | Under the influence of a cyclonic circulation over northwest Bay off north Orissa coast, a low pressure area formed over the same area on 1 and became well marked on 2. Associated cyclonic circulation extended upto mid tropospheric levels, tilting southwestwards with height. The low pressure area merged with the monsoon trough on 5 |
| 2. | Induced low pressure area | 13-15 | Punjab & neighbourhood | Northeasterly | Himachal Pradesh | Associated cyclonic circulation extended upto lower tropospheric levels. The low pressure area and the associated cyclonic circulation moved away northeastwards across Himachal Pradesh on 15 |
| 3. | Low pressure area | 24-26 | West-central Bay off north Andhra coast | Northeasterly | Northern parts of coastal Andhra Pradesh and neighbourhood | Associated cyclonic circulation extended upto mid tropospheric levels. The low pressure area and its associated cyclonic circulation merged with the low pressure area over northwest Bay off Orissa coast on 26 |
| 4. | Do | 26 Aug.-1 Sep. | Northwest Bay off Orissa coast | Northwesterly | North Orissa and adjoining parts of Bihar Plateau and of southeast Madhya Pradesh | Associated cyclonic circulation extended upto mid tropospheric levels tilting southwestwards with height on 26. Associated cyclonic circulation lay over east Madhya Pradesh and neighbourhood on 1 Sept. and extended upto mid tropospheric levels |

**TABLE 5** (*Contd.*)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|
| **(C)** | *Induced cyclonic circulation* | | | | | |
| 1. | Lower levels | 18-20 | Punajab & neighbourhood | Northeasterly | Himachal Pradesh | Moved away across Himachal Pradesh |
| **(D)** | *Other cyclonic circulation* | | | | | |
| 1. | Mid tropospheric levels | 4-8 | Southwest Rajashtan & neighbourhood | Southsoutheasterly | Gujarat Region & neighbourhood | It tilted southwards with height |
| 2. | Lower tropospheric levles | 4-5 | Punjab & neighbourhood | Northeasterly | Himachal Pradesh | Moved away across Himachal Pradesh |
| 3. | Mid & upper tropospheric levels | 15-20 | North Bay & neighbourhood | Westnorthwesterly | South Uttar Pradesh & neighbourhood | Merged with the monsoon trough on 20 |
| 4. | Mid tropospheric levels | 19-22 | Gangetic West Bengal & neighbourhood | Northwesterly | North Konkan & adjoining Gujarat Region | It tilted southwestwards with height |
| 5. | Upper tropospheric levels | 19-29 | North Konkan & neighbourhood | | East Uttar Pradesh | It tilted southwestwards with height on 19 |
| 6. | Lower tropospheric levels | 21-26 | South Pakistan & neighbourhood | Northeasterly | Punjab & adjoining parts of Pakistan | Moved away across Himachal Pradesh |
| 7. | Do | 26-28 | Punjab & neighbourhood | Northeasterly | Himachal Pradesh | Moved away across Himachal Pradesh |
| 8. | Mid tropospheric levels | 27-28 | South Pakistan & neighbourhood | Stationary | *In situ* | - |
| 9. | Upper tropospheric levels | 28-29 | Northwest Bay off south Orissa coast | Northeasterly | North Bay off West Bengal – Bangla Desh coast | Merged with the low pressure area over north bay off West Bengal – Bangla Desh coast |
| **(E)** | *Western disturbance* | | | | | |
| 1. | Upper air system | 5-8 | North Pakistan & neighbourhood | Northeasterly | Jammu & Kashmir | Moved away across Jammu & Kashmir |
| 2. | Do | 11-14 | Central Pakistan | Do | North Pakistan and adjoining Jammu & Kashmir | Moved away northeastwards |
| 3. | Do | 15-21 | North Pakistan and neighbourhood | Do | Jammu Kashmir and neighbourhood | Do |
| 4. | Do | 23-26 | Do | Do | Do | Do |
| **(F)** | *East-West trough* | | | | | |
| 1. | Upper tropospheric levels | 8-11 | Saurashtra to Bihar Plateau | Do | Gujarat Region to Bihar Plains | - |
| **(G)** | *Trough in westerlies* | | | | | |
| 1. | Mid and upper tropospheric levels | 23-26 | Bihar Plains to west central Bay | Quasi-stationary | East Uttar Pradesh to west-central Bay | - |

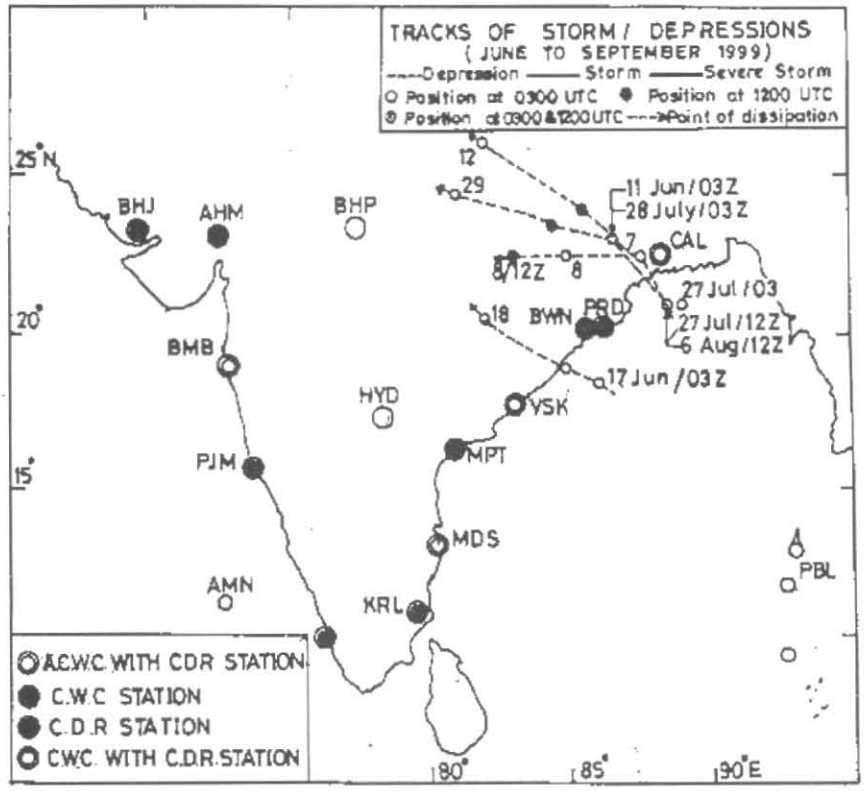
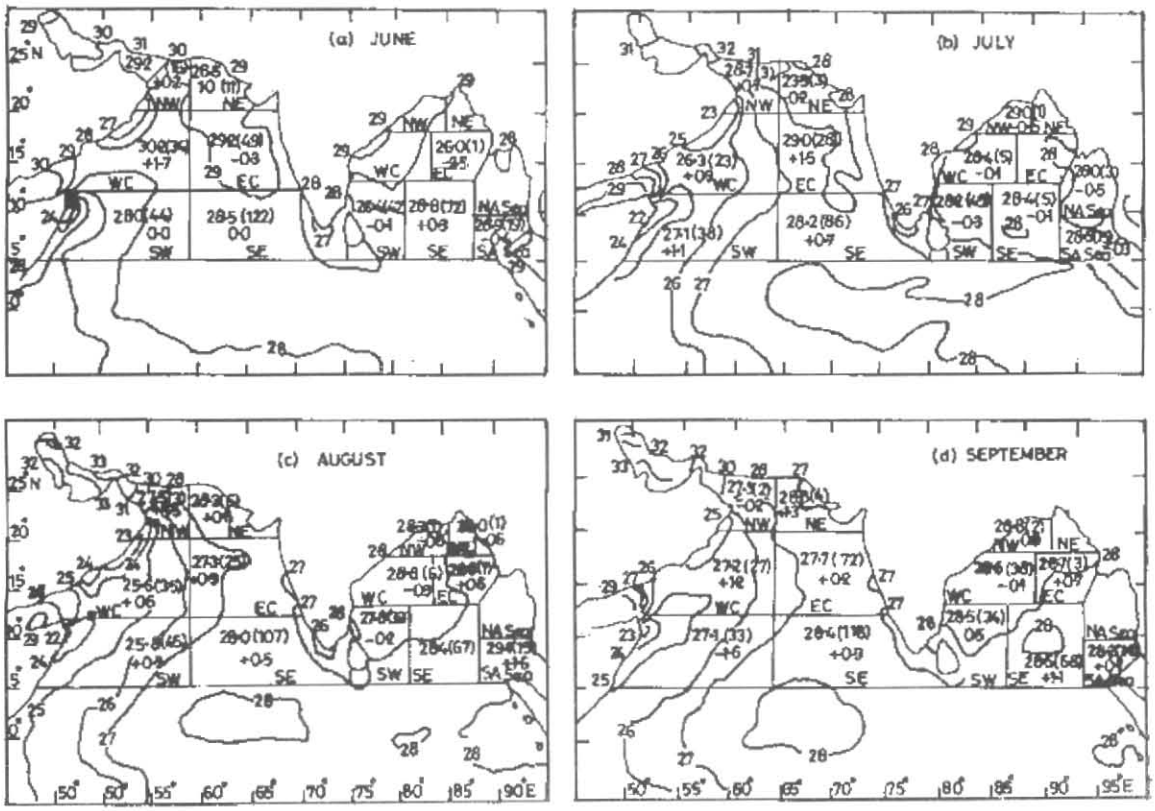



Fig. 10. Tracks of storm/depressions (June to September 1999)




Figs. 11 (a-d). Mean monthly (June-September 1999) SST anomalies of (°C) of Indian seas during southwest monsoon

**TABLE 6**

**Details of the weather system during September 1999**

| S. No. | System | Period | Place of first location | Direction of movement | Place of dissipation | Remarks |
|---|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| **(A)** | *Low pressure area* | | | | | |
| 1. | Low pressure area | 1-4 | Northwest Bay off Orissa coast | Northwesterly | North Orissa and adjoining parts of Gangetic West Bengal and of Bihar Plateau | Merged with the monsoon trough. Associated cyclonic circulation extended upto mid tropospheric levels |
| 2. | Do | 2-8 | Northeast Madhya Pradesh and neighbourhood | Northnorthwesterly | Northwest Madhya Pradesh and adjoining parts of plains of west Uttar Pradesh | Merged with the monsoon trough. Associated cyclonic circulation lay over plains of west Uttar Pradesh and adjoining parts of east Rajasthan on 9 and became less marked on 13 |
| 3. | Well marked low pressure area | 6-19 | Northwest and adjoining west-central Bay off south Orissa-North Andhra coast | Northwesterely | East Madhya Pradesh and adjoining east Uttar Pradesh | It was first seen as a cyclonic circulation over west-central Bay off Andhra coast on 5. A low pressure area formed on 6. It became well-marked on 8 over the same area<br>It lay as an extended low pressure area on 11 over north Orissa and neighbourhood and again lay as a well marked low pressure area over central Madhya Pradesh and adjoining southern parts of east Uttar Pradesh and neighbourhood on 14. It was again seen as an extended low pressure area on 17 over east Madhya Pradesh and adjoining east Uttar Pradesh and merged with the seasonal trough on 19. Associated cyclonic circulation extended upto 5.8 kms. a.s.l. tilting southwestwards with height on 6 and became less marked on 20 |
| 4. | Low pressure area | 23-27 | Bihar Plateau and adjoining parts of north Orissa and of Gangetic West Bengal | Quasi – stationary | North parts of Gangetic West Bengal and adjoining Bihar | It was seen as an upper air cyclonic circulation over Bihar Plateau and adjoining parts of Gangetic West Bengal on 21. A low pressure area formed over the same area on 23. Associated cyclonic circulation extended upto 10.6 kms a.s.l. and it became less marked on 28.<br>A trough from this system ran to south Konkan & Goa in the lower levels on 23. A trough ran from the centre of this system to north interior Karnataka across Telangano in the lower levels on 26 |
| **(B)** | *Induced cyclonic circulations* | | | | | |
| 1. | Upper tropospheric levels | 11-13 | West Madhya Pradesh and adjoining Gujarat region | Stationary | *In situ* | It tilted southwards with height on 11 |
| 2. | Lower tropospheric levels | 14-18 | Central Pakistan and adjoining west Rajasthan | Northeasterly | Punjab, Haryana and adjoining Pakistan | Moved away northeastwards |
| **(C)** | *Other cyclonic circulations* | | | | | |
| 1. | Lower levels | 30 Aug – 5 Sept | Northwest Rajasthan and neighbourhood | Northeasterly | Punjab and neighbourhood | Moved away across Himachal Pradesh |
| 2. | Mid tropospheric levels | 2-6 | Gujarat Region and neighbourhood | Northerly | North Gujarat Region and neighbourhood | - |

TABLE 6 (*Contd.*)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|
| 3. | Do | 19-22 | Gujarat State and adjoining northeast Arabian Sea | Stationary | *In situ* | - |
| 4. | Lower tropospheric levels | 23-26 | Punjab and neighbourhood | Northeasterly | Himachal Pradesh | Moved away northeastwards |
| 5. | Do | 25-28 | Central Pakistan | Stationary | *In situ* | - |
| 6. | Mid tropospheric levels | 26 Sep – 4 Oct | North Telangana and neighbourhood | Southwesterly and northwesterly | Saurashtra and neighbourhood | - |
| 7. | Do | 28-30 | Off south Andhra coast | Stationary | *In situ* | It tilted southwards with height |
| 8. | Lower tropospheric levels | 29 Sept – 2 Oct | Central Pakistan | Northeasterly | Himachal Pradesh | Moved away northeastwards |
| 9 | Lower tropospheric levels | 30 Sept – 1 Oct | North Saurashtra and neighbourhood | Stationary | *In situ* | - |
| (D) | *Western Disturbances* | | | | | |
| 1. | An an upper air system | 10-14 | Central parts of Pakistan and west Rajashtan | Eastnortheasterly | West Rajasthan and neighbourhood | Moved away eastnortheastwards |
| 2 | .Do | 11-16 | Jammu & Kashmir and neighbourhood | Eastwards | Punjab, Haryana and neighbourhood | Moved away eastwards |
| 3. | Do | 17-18 | Jammu & Kashmir and adjoining Pakistan | Northeastwards | Jammu & Kashmir and neighbourhood | Moved away northeastwards |
| 4. | Do | 19-21 | Jammu & Kashmir and adjoining central Pakistan | Eastnortheastwards | Jammu & Kashmir | Moved away eastnortheastwards There was a trough aloft in the system on 19 |
| (E) | *Troughs* | | | | | |
| 1. | Sea level chart | 17-20 | East-central Bay and adjoining north Andaman Sea | Northeasterly | Northeast and adjoining east-central Bay | - |

### 3.7. *El-Nino phenomenon*

El-Nino is the general term used to indicate the anomalous rise in sea surface temperature over the east Pacific. A see-saw relationship between sea level pressure over the southeastern Pacific Ocean and the Indian Ocean is known as southern Oscillation (SO). SO is the atmospheric response to the El-Nino, which is an oceanographic phenomenon. Both of these phenomena, atmospheric and oceanic, together is known as "El-Nino Southern Oscillation" or ENSO. The phase and magnitude of the ENSO can be indicated either by the sea surface temperature (SST) anomalies over the Pacific or by Southern Oscillation Index (SOI) expressed as the difference in atmospheric surface pressure between Tahiti, an island station in the southeast pacific and Darwin, Australia. In general, during some years an inverse relationship between ENSO and Indian summer monsoon rainfall has been observed.

It is observed that from the monsoon season of 1998, cold episode (La-Nina) conditions prevailed over tropical Pacific. In NINO 3 and NINO 4 regions, the SST anomalies were negative throughout this one year period (reference, Climate Diagnostic Bulletin, NWS, NCEP, NOAA, USA). In the NINO 4 region, the negative SST anomalies were above 1° C till April 1999 with maximum value (−1.5° C) during January and February 1999. Thereafter, it showed abrupt decrease to reach − 0.5° C - − 0.6° C during monsoon season. In the NINO3 region, the maximum negative SST anomaly was observed during December 1998 (−1.0°). Thereafter, it decreased rapidly to reach −0.2° C in March 1999. Between April to July 1999, it varied between −0.3° C & −0.6° C and then at the end of the monsoon season (September 99) increased to −0.9° C. In the (NINO1+2) region from April to September 1999 SST anomaly was persistently negative and varied between

$-0.5^{\circ}$ C & $-1.0^{\circ}$ C. Another important point noticed was that prior to monsoon season, highest negative SST anomalies were observed over Central Pacific (NINO4). During monsoon season they were shifted to eastern Pacific (NINO 1+2 & NINO 3) regions.

## 4. Chief synoptic features of southwest monsoon

The synoptic disturbances which affected the Indian monsoon region in June, July, August and September are given in Table 3,4,5 and 6 respectively.

### 4.1. *Cyclonic storms/depressions*

During the season, no cyclonic storm formed, however, four depressions formed whose tracks are shown in Fig. 10.

#### 4.1.1. *Land depression over the West Bengal (11-12 June)*

A well marked low pressure area formed over West Bengal coast and adjoining north Bay on 10 evening. It moved in a northwesterly direction and concentrated into a depression and lay centered at 0300 UTC of 11 near Lat.23.0° N/Long.86.5° E, very close to Purulia. It then moved in a westnorthwesterly direction and lay near Hazaribagh at 1200 UTC of 11. It further moved in a northwesterly direction and lay at 0300 of 12 UTC near Lat. 26.0° N/Long. 82.0° E, about 50 kms northwest of Varanasi. It weakened into a well marked low pressure area and lay over east Uttar Pradesh and neighbourhood on 12 evening and rapidly weakened into a low pressure area and became unimportant on 13.

According to reports, 12 people died along West Bengal coast 3,50,000 people were affected and more than 10,000 houses were damaged.

#### 4.1.2. *Deep depression over the Bay of Bengal (17-18 June)*

A low pressure area with associated cyclonic circulation extending upto mid tropospheric levels formed over northwest Bay and neighbourhood on 15. It became well marked on 16 and lay over northwest Bay off Orissa – West Bengal coast. It concentrated into a depression at 0300 UTC of 17 and lay near Lat.18.5°N/Long. 86.0°E, about 160 kms eastsoutheast of Gopalpur. It then intensified into a deep depression at 0900 UTC of 17 and lay centred at 1200 UTC of 17 near Lat. 19.0° N/Long. 85.0° E, about 40 kms southeast of Gopalpur. It moved in westnorthwesterly direction and crossed Orissa coast near Gopalpur at 2100 UTC of 17. It weakened into a depression and lay centered at 0300 UTC of 18 near Lat. 20.5° N/Long. 82.0° E about 100 kms south of Raipur. It further moved in a westnorthwesterly direction and weakened into a well marked low pressure area and lay over north Vidarbha and adjoining parts of Madhya Pradesh at 1200 UTC of 18. It lay as a low pressure area on 20 over northwest Madhya Pradesh and neighbourhood. The low pressure area became less marked on 21 evening.

According to press reports, 5 fishermen were missing. Heavy to very heavy rain occurred in the coastal districts of Andhra Pradesh. Principle amounts of rainfall (cms) are given below :

17 June 1999 : Kalingapatnam 9.

18 June 1999: Tekkali 20, Palasa 14, Sompeta 12, Itchapuram 9.

#### 4.1.3. *Deep depression the Bay of Bengal (27-29 July)*

A low pressure area formed over northwest Bay and adjoining West Bengal coast on 24 evening. Associated cyclonic circulation extended upto mid tropospheric levels tilting southwestwards with height. It became well marked on 26 evening. It concentrated into a depression at 0300 UTC of 27 and lay centered near Lat. 21.0° N/Long. 89.0 ° E, about 200 kms southsoutheast of Calcutta. It further intensified into a deep depression at 1200 UTC of 27 and lay centered near Lat. 21.0° N/Long. 88.5 ° E. It crossed Orissa – West Bengal coast in the early morning hours of 28 and lay as a deep depression at 0300 UTC of 28 near Lat. 23.0° N/Long. 86.5 ° E, about 50 kms southeast of Purulia. It moved in a northwesterly direction and weakened into a depression at 1200 UTC of 28 and lay near Lat. 23.5° N/Long. 84.5 ° E, about 50 kms northwest of Ranchi. It further moved in a westnorthwesterly direction and lay centered at 0300 UTC of 29 near Lat. 24.5° N/Long. 81.0 ° E, very close to Satna. Subsequently it weakened into a well marked low pressure area in the evening of 29 over northwest Madhya Pradesh and neighbourhood and into a low pressure area on 31 morning over northeast Rajasthan and neighbourhood. It later merged with the monsoon trough over extreme west Rajasthan and neighbourhood on 3 August.

Heavy rainfall (cms) recorded are given below :

27 July 1999 : *Orissa :* Paradip 22, Chandbali 10, Cuttack 6.

28 July 1999 : *Gangetic West Bengal* : Digha 16; *Orissa :* Baripada 9, Balasore 8.

29 July 1999 : *Gangetic West Bengal :* Bankura 9.

#### 4.1.4. *Depression over the Bay of Bengal (6–8 August)*

A low pressure area with associated cyclonic circulation extending upto mid tropospheric levels formed over northwest Bay and neighbourhood. It became well marked on 6 and lay over northwest Bay off north Orissa - West Bengal coast. It concentrated into a depression at 1200 UTC of 6 near Lat. 21.0° N/Long. 88.5 ° E, about 160 kms south of Calcutta. It moved in a westnorthwesterly direction and crossed West Bengal coast near Digha and lay as a depression at 0300 UTC of 7 near Lat.22.5° N/Long.87.5° E, close to Midnapore. The depression lay near Jamshedpur on 1200 UTC of 7. It

**TABLE 7**

**Tropical storms/depressions in the northwest Pacific in 1999**

| Month | TD | TS | Typhoons | Super Typhoons | Total |
|---|---|---|---|---|---|
| June | 0 | 0 | 1 | 0 | 1 |
| July | 3 | 1 | 1 | 0 | 5 |
| August | 2 | 2 | 2 | 0 | 6 |
| September | 1 | 3 | 2 | 0 | 6 |
| Total | 6 | 6 | 6 | 0 | 18 |

moved in westnorthwesterly direction and lay near Lat. 22.5° N/Long. 85.0 ° E, at 0300 UTC of 8, about 80 kms southeast of Ambikapur and at 1200 UTC of the same day, it lay near Lat. 22.5° N/Long. 83.5 ° E, about 80 kms southeast of Pendra. It further moved in a westnorth-westerly direction and weakened into a well marked low pressure area and lay over northeast Madhya Pradesh and neighbourhood. It lay as a low pressure area over northwest Madhya Pradesh and neighbourhood on 10 and became less marked on 12 over northeast Uttar Pradesh and adjoining Bihar Plains. Associated cyclonic circulation also became less marked on 12.

Heavy rainfall (cms) reported are given below :

6 August 1999 : *Gangetic West Bengal :* Digha 8.

7 August 1999: *Gangetic West Bengal* : Diamond Harbor, Midnapur 9, Contai, Digha 8.

8 August 1999 : *Orissa :* Sambalpur 11, Jharsuguda 10, Bolangir 7;

*Sub-Himalayan West Bengal & Sikkim* : Kalimpong 8.

4.2. *Low pressure areas/well-marked low pressure areas (LPA/WMLPA)*

During the season, 11 low pressure areas/well-marked low pressure areas formed. Most of the systems were associated with cyclonic circulations in the upper air. Monthwise break-up of these systems is 1 in June, 2 in July and 4 each in August and September. Details are given in Tables 3-6.

4.3. *Cyclonic circulations (CYCIR)*

In all 48 cyclonic circulations (in lower levels and upper levels) formed during the season and their contribution resulted in well-distributed rainfall over the country. The monthwise break-up of cyclonic circulations is 10 in June, 17 in July and 10 in August and 11 in September. Details are given in Tables 3-6.

4.4. *Off-shore Tough*

From 20 May to 22 September 1999, off-shore trough along different parts of west coast (surface and lower levels), persisted on most of the days except from 12 to 14, and from 16 to 26 August. Details of the positions of off-shore trough are given in Table 7(a). Details of offshore trough from 1994 to 1998 are given in 7(b).

4.5. *Low level troughs*

During the season, 2 troughs on sea level chart formed in June and September. Details are given in Tables 3-6.

4.6. *Upper level troughs*

During the season, 4 east-west troughs and 3 troughs in mid and upper tropospheric levels formed. Details are given in Tables 3-6.

4.7. *Eastward moving circulations/western disturbances*

Monthwise break-up of the eastward moving circulation / western disturbances is as follows : 2 in June, 1 in July, 4 each in August and September. Details are given in Tables 3-6.

## 5. Extra Indian systems

5.1. *Cross Equatorial Flow*

Cross equatorial flow was nearly normal in June & July and more than normal by 5-10 kts during August and September along the equator. Over the Arabian Sea, the surface wind was about 5-10 kts more than the normal during 10-23 June and normal during remaining period of June. In July, the surface wind was about 5 kts more than the normal during second week, while it was about 5-10 kts less than the normal during rest period. In August, surface wind was about 5-10 kts less the than normal. In September, surface wind was about 5 kts more than the normal.

Over the Bay of Bengal, the surface wind was about 5-10 kts more than the normal in June and nearly normal in July and August. Further, it was about 5 kts more than the normal during September.

5.2. *Mid latitude troughs*

During the season, 31 mid and upper tropospheric westerly troughs moved eastwards across Lat. 30° N and affected the north India. Out of these, 18 were at 500 hPa level and 13 at 300 hPa level. Monthwise break-up for 500 hPa includes 6 in June, 4 each in July, August and September. For 300 hPa, the monthwise break-up includes 6 in June, 3 in July and 2 each in August and September.

During the past five years, there were 29, 17, 31, 18 and 16 mid and upper tropospheric troughs in 1998, 1997, 1996, 1995 and 1994 respectively.

TABLE 7 (a)

**Positions of off-shore troughs during the monsoon period 1999**
**(On sea level chart)**

| Date | Positions |
|---|---|
| 20 May – 2 June | South Maharashtra to Kerala coast ( It became more marked from 24 May) |
| 3 June – 6 June | North Maharashtra to Kerala coast |
| 7 June – 22 June | Karnataka to Kerala coast |
| 23 June | North Maharashtra coast to Kerala coast |
| 24 June – 11 August | South Maharashtra coast to Kerala coast (became less marked on 12) |
| 15 August | Karnataka coast to Kerala coast (became less marked on 16) |
| 27 August – 3 September | Karnataka coast to Kerala coast |
| 4 September – 7 September | South Maharashtra coast to Kerala coast (became less marked on 8) |
| 9 September – 11 September | Off Karnataka – Kerala coast |
| 12 September – 15 September | South Gujarat coast to Kerala coast |
| 16 September – 17 September | Karnataka – Kerala coast |
| 18 September – 21 September | North Maharashtra coast to Kerala coast ((became less marked on 22) |

TABLE 7(b)

**Details of off-shore trough from 1994 – 98**

| YEAR | Details of off – shore trough |
|---|---|
| 1998 | From 11 June to 30 September, off-shore trough along different parts of west coast (surface and lower levels) persisted on most of the days except on 11 – 15 June, 18 – 19 July and 9 – 10 September |
| 1997 | During 8 June to 1 October 97, the off-shore trough along different parts of the west coast (surface and in lower levels) persisted on most of the days |
| 1996 | Off-shore trough along west coast (surface and lower levels) persisted on most of the days |
| 1995 | During 10 June to 17 September 95, the off-shore trough along most parts of the west coast (surface and lower levels) persisted on most of the days |
| 1994 | Off-shore trough along west coast (surface and lower levels) persisted on most of the days during June to September |

5.3. *Systems in west Pacific Ocean/South China Sea*

During June to September 1999, there were 18 disturbances (tropical depression stage and above) viz. 6 Tropical depression, 6 Tropical storms and 6 Typhoons. No super typhoon formed during the season. The monthwise breakup of these systems is given in Table 7.

5.4. *Systems in southern hemisphere*

5.4.1. *Tropical Storms*

No system formed in the south Indian Ocean during June to September 1999.

5.4.2. *Mid latitude troughs*

There were in all 13 upper air troughs at 300 hPa in westerlies that moved across the Indian Ocean to the north of Lat. 30° S during June to September 1999. The monthwise breakup includes 3 each in June and August, 2 in July and 5 in September.

During past 5 years, the troughs in mid and upper tropospheric westerly were 23 in 1998, 9 in 1997, 36 in 1996, 11 in 1995 and 23 in 1994 which moved across 30° S in the southern hemisphere.

**TABLE 8**

**Main features of weekly wind anomalies during June to September 1999**

| Week Ending (1) | 850 hPa (2) | 500 hPa (3) | 200 hPa (4) | Remarks (5) |
|---|---|---|---|---|
| | | **(a) June 1999** | | |
| 8 June | EW trough running from NW India to central Bay and EW ridge over peninsula along 10°N | A cycir over C.A.P. and N-S trough passing through it along Long. 84°E | A cycir over E. Raj. and adj. U.P. and a N-S trough passing through it along Long. 74° -83°E | Anomalous northerlies over most parts of the country over lower troposphere indicate weaker southerly meridional flow. Hence, weaker reverse Hadly cell. Upper tropospheric easterlies weaker than normal |
| 15 June | E-W trough between 22.5°-17.5°N running across central parts of the country | E-W oriented trough between 10°-15°N Lat. and E-W oriented ridge between 25°-30°N Lat | An anticyclone over NE India and ridge extending from it upto southern tip of peninsula | In the lower troposphere stronger than normal westerlies and low pressure systems over peninsular India got established. Mid and upper tropospheric anticyclone also got established over N. Eastern parts of the country |
| 22 June | E-W trough from Gujarat to east central Bay and E-W ridge at the southern most tip of India | E-W trough from cycir over Rajasthan and coastal Orissa right upto Tennasarim coast | A E-W ridge between 31°-32.5°N | Cyclonic circulations across central parts of country in both lower and mid troposphere were stronger than normal and upper tropospheric anticyclone over Tibet also stronger than normal with stronger than normal easterlies over peninsula |
| 29 June | E-W oriented ridge between 10°-20°N across peninsula | Anomalous trough in the westerlies extending from Bihar to North Maharashtra E-W oriented ridge between 10°-20°N | A E-W oriented ridge between 25°-30°N | Subdued monsoon activity with anticyclonic flow over almost entire country in the lower troposphere but stronger than normal upper tropospheric easterlies and anticyclonic flow over North India |
| | | **(b) July 1999** | | |
| 6 July | A E-W oriented ridge roughly along 20°N | A E-W oriented ridge between 25°-23°N | A E-W ridge between 29°-23°N and a trough along 10°N Lat | Lower tropospheric flow mostly anticyclonic over the country. Upper anticyclonic flow stronger than normal over northern parts. Stronger than normal easterlies over peninsular India |
| 13 July | A WNW-SSE oriented ridge between 22.5°-15°N and a cycir with NW-SE trough over Maharashtra | A E-W ridge between 22.5° - 18°N | A E-W ridge between 30°-20°N | Indication of revival of strong monsoon condition over lower troposphere with appearance of cyclonic circulation over peninsular India. Strong anticyclonic circulation over mid and upper troposphere; stronger than normal easterlies in the upper troposphere |

**TABLE 8** (*Contd.*)

| (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|
| 20 July | A N-S trough from J. and K. to Gujarath with embedded cycir, and E-W trough along 21°N in the central parts of the country through a cycir over Orissa upto SE Bay | A WSW-ENE oriented trough with two cycirs one over Maharashtra and other over Orissa and a parallel SW-NE ridge over extreme peninsula | A trough with embedded cycir north of 20°N; a ridge roughly along 15°N | Presence of cyclonic circulation/trough systems over central parts both in middle and lower troposphere. Anticyclone over northern parts weaker than normal with weaker than normal easterlies over southern parts |
| 27 July | A NW-SE oriented trough between 30°-16°N with embedded cycir and a cycir off Karnataka-Kerala Coast | A NW-E trough along 32°-25°N and E-W ridge along 10°N | Anticyclone with ridge between 25°-30°N over northern parts of the country | Presence of cyclonic circulation/trough system across the country with stronger than normal westerlies in the lower tropo-sphere. Upper tropospheric anticyclone stronger than normal |
| | | **(c) August 1999** | | |
| 3 August | A NW-SE trough from north Pakistan to north Andaman sea with embedded cycirs | A cycir over N. Madhya Maharashtra and adjoining Gujarat and M.P. and NNW-SE trough through it and a N-S oriented ridge in the Arabian Sea | A E-W trough along 24°-26°N across the country and E-W ridge along 20°N across the country and E-W trough over south Bay | Presence of cyclonic circulation/ trough across the country in lower and mid tropospheric levels, upper tropospheric anticyclonic flow-weaker than normal over Northern parts |
| 10 August | An anticyclone over Haryana and adjoining west U.P. A E-W trough between 30°-22°N with embedded cycir over head Bay | A E-W trough between 20°-22°N across the country and a ridge along 10°N across the country | A E-W ridge along 28°N across country. E-W trough along 22.5°N with embedded cycir over W. Bengal and adjoining areas and NW-SE oriented ridge over south Peninsula from Maharash-tra to SW Bay | Presence of cyclonic circulation / trough across the country in lower and middle troposphere. Upper tropospheric anticyclone stronger than normal at least over northwestern parts |
| 17 August | A E-W oriented ridge between 15°-20°N. Two troughs in the easterlies south of 15°N | N-S trough in westerlies along 89°-92°E and E-W ridge between 18°-10°N | An anticyclonic circulation over Northeast India and ridge through it from 26°N on east side to Arabian Sea in the west | In the lower troposphere, typical features of weak monsoon condition with disturbances in the easterlies in the south and in the westerlies in the northeastern parts. Upper tropospheric anticyclone in the northern parts stronger than normal |
| 24 August | A E-W oriented ridge between 25°-22°N. A trough in the easterlies south of 20°N | A E-W oriented ridge between 25°-15°N | An anticyclone over Nepal and adjoining area and northsouth ridge through it upto west central Bay | In the lower troposphere, features of weak monsoon conditions with anticyclonic flow across the country and easterly waves in the southern parts. Upper tropospheric anticyclone stronger than normal. |

TABLE 8 (*Contd.*)

| (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|
| 31 August | An anticyclonic circulation over Arabian Sea and SW-NE ridge through it extending upto N-E India. and cycir over west central Bay with E-W trough roughly along 15°N | An anticyclonic circulation over west Rajasthan. A trough with embedded cycirs along east coast | A E-W ridge roughly along 18°N | Weak monsoon features with trough/cycir in easterlies in lower and mid tropospheric levels. Upper tropospheric anticyclone shifted southwards with moderately strong westerly anomalies over northern parts |
| | | **(d) September 1999** | | |
| 7 September | A E-W ridge between 30°-24°N and a WNW-ESE oriented trough through two cyclonic circulations, one over M.P. and another off N. coastal A.P. and adjoining Orissa coast between 25°-15°N | Cycir over NW Rajasthan and adjoining Punjab & Haryana. An anticyclonic circulation over W. Bengal and Assam and E-W oriented ridge between 15°-24°N and E-W oriented trough along 10°N | A E-W ridge along 25°N across the country & E-W trough in south between 8°-10°N | Cyclonic circulation/ trough systems across central parts of the country. But anticyclonic circulation over peninsula in the lower troposphere. Upper tropospheric anticyclone stronger than normal with moderately strong easterlies over Peninsula |
| 14 September | E-W trough between 16°-20°N through a cycir over Andhra Pradesh and adjoining east Madhya Pradesh | A trough through two embedded cycirs one over Konkan & Goa and another over Assam & adjoining areas | A cycir over Bihar and adjoining west Bengal and troughs westward and southwards from it & ridge over west coast | Cyclonic circulation/ trough systems over most parts of India in lower & mid troposphere. Upper tropospheric anticyclones weaker than normal |
| 21 September | A ridge along 10°N. A cycir over Bihar and adjoining areas and ridge and trough with westerlies north of 10°N | A E-W trough along 25°N & a ridge between 14°-9°N | A cycir over West Bengal and adjoining Assam & Meghalaya and two troughs through it, one westwards across the country and the other to SSW upto Lakshadweep | Cyclonic circulation/troughs systems over N & NE parts and anticyclonic systems over S. parts in the lower and mid tropospheric levels. Upper tropospheric anticyclone weaker than normal |
| 28 September | A WNW-NE trough between 15°-20°N through a cycir over Madhya Maharashtra & adjoining Karnataka and a ridge between 14°-18°N across the country over south Peninsula | A cycir over central India extending to NE from it & anticyclonic circulation over Central Bay with ridge roughly along 16°N | A E-W ridge between 22.5°-14°N across the country and E-W trough between 28°-25°N | Trough/cyclonic circulation systems almost over entire country in the lower and mid tropospheric levels. Upper tropospheric anticyclone weaker than normal |

5.4.3. *Mascarene High*

The intensity of Mascarene High was slightly below normal (-1 hPa) (normal value of Mascarene High in 1024 hPa) during June, slightly above normal (+1 hPa) in July, normal in August and again slightly above normal (+1 hPa) in September. The position and intensity of Mascarene High in the last five years is given below :

| Year | Mascarene High |
|---|---|
| 1994 | The intensity of Mascarene high was 1-2 hPa above normal in June and September, 3-4 hPa in July and 4-5 hPa in August (normal intensity being 1024 hPa). The Mascarene high was east of normal position (Lat. 30°S/Long. 60° E) by 4° to 5° in Longitude in July. Mascarene high was south of normal position by 2° to 3° Latitude in August and north of normal position by 1° to 2° Latitude in September. |
| 1995 | The intensity of Mascarene high was 1-2 hPa above normal in July, August and September (normal intensity is 1024 hPa). In June, the Mascarene high had normal intensity. The Mascarene high was east of normal position ( 30° S /60° E) by 7° to 10° in June, 8° to 10° in July and August and about 2° in September. |
| 1996 | The intensity of Mascarene high was normal or near normal in June, July and August. Its intensity was 2 hPa below normal (1022 hPa) in September. In June, the Mascarene high moved about 8° to west and about 18° to east of its normal position (30° S/60° E) and in September, about 12° to east and 12° west of its normal position. On an average, in July it shifted by 4° to 5° to west and in August by 15 ° to east of its normal position. |
| 1997 | The intensity of Mascarene high was above normal (1024 hPa). It was above normal by 4 hPa in June and 3 hPa in August during July and in September, it was 1 hPa above normal. The normal value of pressure during June to September is 1024 hPa. |
| 1998 | The intensity of Mascarene high during June to September 1998 (at 30° S/60° E) was slightly below normal (-1 hPa) during June and August, above normal (+3 hPa) in July and nearly normal in September 1998. |

5.4.4. *Australian High*

The intensity of Australian High was above normal during June to September. The departure was +5 hPa in June, +8 hPa in July, +10 hPa in August and +7 hPa in September. The details of positions and intensity of the Australian High for the last five years is given below :

| Year | Australian High |
|---|---|
| 1994 | The intensity of Australian high was above normal by 3-4 hPa in June, 4-5 hPa in July and 5-6 hPa in August, while it was normal in September (normal intensity being 1020 hPa) the Australian high was in the normal position throughout the season except in June when it was more north of its position by 1° to 2° in Latitude. |
| 1995 | The normal intensity of Australian high is around 1020 hPa near Lat. 28 ° – 29° S. The intensity of Australian high was above normal by 3 hPa in June, 5 hPa in August and 6 hPa in September. It was normal in July *i.e.*, 1020 hPa. Australian high was 4° S of normal position (28° S) in June. While it was near normal position in July, August and September. |
| 1996 | The normal intensity of Australian high is around 1019-1020 hPa near Lat. 28°–29° S. The intensity of Australian high was below normal by 2-3 hPa in June, July, and August and by 5 hPa in September. The Australian high was near normal position in June, August and September, while it was 2° to 3° north of its normal position in July. |
| 1997 | During June to September, the Australian high was very intense compared to the normal values in all the months. It was above normal by 7 hPa in June, 10 hPa in July, 4 hPa in August and 4 hPa in September. 1024 hPa is the normal pressure value during June to August and 1018 hPa in September. |
| 1998 | The intensity of Australian high during June to September 1998 (at 30° S/140° E) was normal during July to September but was below normal by 1 hPa in June. |

## 6. Semi-permanent systems

### 6.1. *Heat low*

Heat low over Pakistan and adjoining parts of west Rajasthan on the sea level chart formed on 1 June and remained more or less in the same position till 25 September. The lowest and second lowest observed isobaric values of the heat low were :

| | |
|---|---|
| June | 99.0 hPa on 23 and 991.0 on 17 & 30. |
| July | 988.0 hPa on 2 and 988.5 hPa on 18. |
| August | 988.5 hPa on 6 and 99.0 hPa on 7. |
| September | 994.0 on 17 and 994.5 on 18. |

Details of lowest observed isobaric values of the heat low during past 5 years is given below :

| Month/Year | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| June | 990 hPa (26th) | - | 995 hPa (7th) | 986 hPa (25th) | 987.5 hPa (21st) |
| July | 992 hPa (15th, 30th and 31st) | 989 hPa (2nd) | 990 hPa (11th) | 986.8 hPa (6th) | 985.6 hPa (12th) |
| August | - | 991 hPa (13th) | 991 hPa (5th) | 990.5 hPa (4th) | 990.7 hPa (4th) |
| September | - | - | 995 hPa (8th & 14th) | 996.8 hPa (2nd) | 993.9 hPa (3rd) |

### 6.2. *Axis of the monsoon trough*

The axis of the monsoon trough on sea level chart established in its normal position by 10 June. Western end of the monsoon trough was seen north of the normal position and eastern end south of the normal position from 14 to 19, when there was a depression over northwest Bay. Further, it was north of the normal position from 20 June to 4 July, when rainfall activity was subdued over the country. Again it was in its normal position till 16 July and was south of the normal position till 3 August. The western end again moved north on 5 August and was there until 25 August. The eastern end remained slightly south of the normal position during the above period. Further, it was in its normal position from 27 August to 7 September. Again it was in the normal position for a few days towards the end of September and became less marked from 26 September onwards. The position of axis of monsoon trough in the past five years is given below :

| Year | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| Axis of Monsoon Trough | Established in the end of June. | Established on 20 June. | Established on 8 July. | Established 25 June. | Established on 21 June |
| | Less marked on 15 September. | Less marked on 6 September. | Less marked on 6 September. | Less marked on 6 September. | Less marked on 23 September. |
| | Break on 7 July | Break on July 4 and 5 and August 12 to 15 | Break from 1 to 7 July and on 8 August | Break on 10 July, 9 and 15 August | Break from 16 to 26 July and 20 to 26 August |

### 6.3. *Tibetan Anticyclone/High*

Tibetan Anticyclone/high established in its near normal position on 10 June at 300 and 200 hPa at around Lat. 26.0° N/Long. 93.0° E and Lat. 27.0° N/Long. 89.0° E respectively. It was seen on most of the days during July, August and September. It remained on most days slightly to the northeast of the normal position. In the past five years, the details of Tibetan Anticyclone is given below :

| | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| Tibetan Anticyclone | Established in 3rd week of June. Less marked in mid September | Appeared in last week of June. Less marked in 2nd week of September | Appeared in 3rd week of June . Less marked in 2nd week of September | Appeared in Last week of June. Less marked on 17 September | Appeared on 13 June. Less marked on 27 September |

6.4. *Sub-Tropical Westerly Jet (STWJ)*

STWJ was seen over Delhi, Srinagar, Gorakhpur, Lucknow, Jodhpur and Gwalior during first week of June and abruptly shifted northward. It was observed over Srinagar till 12 June and was not seen till the end of September, suggesting the shifting of sub-tropical westerly jet to the north during the season. The days STWJ was observed in the past five years is given below :

| Year | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| STWJ | Seen till 15 June | Not seen. | Seen till 1st week of June and 2nd fortnight of September | Seen till first fortnight of June and last week of September | Seen only in first week of June |

6.5 *Tropical Easterly Jet (TEJ)*

TEJ was observed over Minicoy from 3 June to the end of September (maximum wind was of the order of 140 kts at 141 hPa, on 0000 UTC of 28 July.) It was seen over Thiruvananthapuram from 6 June to 23 September (maximum reported wind was 115 kts at 110 hPa at 1200 of 24 July) and over Chennai from 7 June to 8 September (maximum reported wind was 115 kts at 111 hPa at 1200 UTC of 25 July). It was seen over Port Blair from the beginning of the season till 9 September, and then on 15 and 16 September. It was not observed afterwards. (maximum reported wind was 130 kts at 104 hPa at 0000 UTC of 17 July). It was seen over Mumbai from 10 June to 9 September (maximum wind reported was 115 kts at 102 hPa at 1200 UTC of 8 July). Details of TEJ in the last five years is as follows :

| Year | 1994 | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|---|
| TEJ | Appeared on 1 June. Less marked in mid September Max. wind 115 kts over MNC at 144 hPa on 22 July | Appeared on 8 June. Less marked on 6 September Max. wind 115 kts over MNC at 126 hPa on 27 June | Appeared on 11 June. Less marked on 27 September Max. wind 110 kts over MDS at 109 hPa on 14 July | Appeared on 14 June. Less marked on 9 September Max. wind 115 kts at 114 hPa on 25 July | Appeared from 1st week of June till the end of September Max. wind 150 kts over MNC at 103 hPa on 5 August |

## 7. Sea surface temperature (SST)

Monthly mean SST values over the Arabian Sea and the Bay of Bengal, isopleths of normal values of SST and anomalies of SST for the months of June, July, August and September are given in Figs. 11(a-d).

7.1. *June to September 1999*

In the enclosed figures, the monthly SST values alongwith the anomalies in northwest, northeast, west-central, east-central, southwest and southeast blocks of both the seas and also for North Andaman and South Andaman Seas, for months June, July, August and September have been given. The isopleths of normal values are taken from Publication "Climatic Atlas of the Indian Ocean, Part I, Surface Climate and Atmospheric Circulation" by Stephan Hastenrath and Peter J. Lamb, and using the estimated normal values for each block the anomalies have been calculated.

The mean monthly SSTs during the four months were as follows: (Blocks having > 10 observations in a month are only considered).

7.2. *June :* Over Arabian Sea, northwest & west-central blocks had positive anomalies of which the anomaly for west-central block was greater than 1.0° C and northeast and east-central blocks had negative anomalies of which the anomaly for northeast block was equal to –1.0° C. The temperatures over Arabian Sea were normal.

Over Bay, east-central block had negative anomaly more than 1.0° C, southwest block had a negative anomaly while southeast block and south Arabian Sea had positive anomalies.

7.3. *July :* Over Arabian Sea; northeast block had a negative anomaly. Both Central and South Arabian Sea

**TABLE 9**

**Weekly anomaly winds, June – September 1999**

| Week ending dates | 8 Jun | 15 Jun | 22 Jun | 29 Jun | 6 Jul | 13 Jul | 20 Jul | 27 Jul | 3 Aug | 10 Aug | 17 Aug | 24 Aug | 31 Aug | 7 Sep | 14 Sep | 21 Sep | 28 Sep |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **TRIVANDRUM (TRV)** | | | | | | | | | | | | | | | | | |
| 850 hPa | 28818 | 30907 | 31602 | 05209 | 10307 | 04207 | 26908 | 29810 | 33806 | 11501 | 06207 | 12007 | 10205 | 18904 | 02802 | 073102 | 10411 |
| 500 hPa | 28116 | 24907 | 26802 | 08309 | 08809 | 07913 | 06304 | 23503 | 00905 | 16002 | 10809 | 11310 | 32502 | 33804 | 24302 | 08005 | 09914 |
| 200 hPa | 08329 | 15211 | 09113 | 11115 | 15412 | 14807 | 04706 | 08313 | 10812 | 10815 | 12011 | 24219 | 10606 | 09507 | 11810 | 08010 | 20108 |
| **BOMBAY (BMB)** | | | | | | | | | | | | | | | | | |
| 850 hPa | 30803 | 29401 | 26908 | 30705 | 14903 | 03907 | 32909 | 27510 | 31605 | 26807 | 30803 | 11202 | 30103 | 27306 | 34305 | 23910 | 02709 |
| 500 hPa | 03020 | 00406 | 02501 | 08806 | 06906 | 13805 | 01104 | 31205 | 00711 | 35506 | 26001 | 09907 | 05306 | 18803 | 04204 | 27608 | 01704 |
| 200 hPa | 26010 | 10408 | 09520 | 11037 | 10614 | 09813 | 11709 | 15703 | 17206 | 14003 | 20606 | 17710 | 22606 | 12108 | 09502 | 08810 | 12007 |
| **NAGPUR (NGP)** | | | | | | | | | | | | | | | | | |
| 850 hPa | 35913 | 26902 | 25307 | 28406 | 24501 | 18706 | 18406 | 30515 | 33507 | 30513 | 29207 | 07303 | 01608 | 30719 | 06908 | 33114 | 12806 |
| 500 hPa | 26211 | 01508 | -- | 00609 | 05907 | 12107 | 04218 | 34902 | 17707 | 31304 | 28907 | 08405 | 03905 | 17109 | 12110 | -- | 26010 |
| 200 hPa | 21420 | -- | -- | 11718 | 05203 | 09632 | 08910 | 07107 | 28105 | 34107 | 06208 | 01903 | 33904 | 07720 | -- | -- | -- |
| **MADRAS (MDS)** | | | | | | | | | | | | | | | | | |
| 850 hPa | 32905 | 25811 | 26114 | 13304 | 11910 | 12506 | 26912 | 26515 | 27406 | 24210 | 12808 | 15308 | 22706 | 26606 | 26408 | 20003 | 15610 |
| 500 hPa | 30603 | 12804 | 26317 | 09504 | 10107 | 11110 | 25502 | 26510 | 25707 | 26808 | 05306 | 10411 | 25908 | 32605 | 19106 | 12402 | 09913 |
| 200 hPa | 27713 | 04106 | 04613 | 06113 | 09608 | 08716 | 03710 | 03610 | 31606 | 01009 | 03702 | 12702 | 35209 | 03808 | 02409 | 07212 | 10907 |

Note : 1. Easterly anomalies at 850 hPa means that westerlies are weaker than normal. 2. Westery anomalies at 200 hPa means that easterlies are weaker than normal.

3. A station reporting '--' means no data.

**TABLE 10**

**Statistics of spatial rainfall distribution**
**( No. of days for monsoon season 1999 as a whole with heavy to very heavy rainfall)**

| S. No. | Sub – division | Vigorous | Active | Very Heavy | Heavy | W/Fw |
|---|---|---|---|---|---|---|
| 1. | Andaman & Nicobar Islands | 1 | 1 | 2 | 9 | 45 |
| 2. | Arunachal Pradesh | 1 | 16 | 3 | 10 | 47 |
| 3. | Assam & Meghalaya | - | 14 | 7 | 31 | 51 |
| 4. | Naga., Mani., Mizo. & Trip. | - | 20 | - | 6 | 41 |
| 5. | S.H.W.B. & Sikkim | 6 | 20 | 20 | 15 | 57 |
| 6. | Gangetic West Bengal | 4 | 27 | 14 | 19 | 27 |
| 7. | Orissa | - | 9 | 15 | 30 | 35 |
| 8. | Bihar Plateau | 2 | 2 | 2 | 9 | 50 |
| 9. | Bihar Plains | 2 | - | 13 | 24 | 43 |
| 10. | East Uttar Pradesh | - | 8 | 11 | 16 | 19 |
| 11. | Plains of west Uttar Pradesh | 1 | 4 | 5 | 13 | 17 |
| 12. | Hills of west Uttar Pradesh | 4 | 7 | 2 | 10 | 33 |
| 13. | Haryana | 1 | 4 | 3 | 7 | 5 |
| 14. | Punjab | 5 | 3 | 4 | 7 | 6 |
| 15. | Himachal Pradesh | 2 | 15 | 9 | 17 | 20 |
| 16. | Jammu & Kashmir | - | 2 | 2 | - | 15 |
| 17. | West Rajasthan | - | 1 | 1 | 3 | 6 |
| 18. | East Rajasthan | - | - | 2 | 4 | 16 |
| 19. | West Madhya Pradesh | 3 | 21 | 11 | 20 | 11 |
| 20. | East Madhya Pradesh | 4 | 24 | 6 | 16 | 21 |
| 21. | Gujarat Region | 3 | 7 | 6 | 10 | 7 |
| 22. | Saurashtra & Kutch | - | 2 | 2 | 1 | 1 |
| 23. | Konkan & Goa | - | 18 | 26 | 17 | 46 |
| 24. | Madhya Maharashtra | 4 | 14 | 19 | 13 | 11 |
| 25. | Marathwada | 6 | 12 | 1 | 11 | 23 |
| 26. | Vidarbha | 3 | 7 | 4 | 6 | 35 |
| 27. | Coastal Andhra Pradesh | 1 | 6 | - | 3 | 10 |
| 28. | Telangana | 1 | 9 | 1 | 3 | 13 |
| 29. | Rayalaseema | - | 3 | - | 2 | 9 |
| 30. | Tamil Nadu & Pondicherry | - | - | 1 | 10 | - |
| 31. | Coastal Karnataka | 2 | 25 | 18 | 15 | 66 |
| 32. | North interior Karnataka | - | 9 | 4 | 9 | 4 |
| 33. | South interior Karnataka | 1 | 13 | 15 | 11 | 5 |
| 34. | Kerala | - | 14 | 4 | 24 | 49 |
| 35. | Lakshadweep | - | - | 1 | 1 | 31 |

Vigorous = Vigorous (Rainfall in the sub-division is fairly widespread or widespread and the average rainfall received in a sub-division is more than 4 times the normal with atleast 2 stations reporting 8 cms in the west coast and 5 cms elsewhere)

Active = Active(Rainfall in the sub-division is fairly widespread or widespread and the average rainfall received in a sub-division is 1.5 to 4 times the normal with atleast 2 stations reporting 5 cms in the west coast and 3 cms elsewhere)

Very Heavy = Very heavy rainfall (rainfall recorded more than 12.5 cms)

Heavy = Heavy rainfall (rainfall recorded more than 6.5 cms)

W/Fw = At most places (more than 75% stations of a sub-division reporting rainfall at least 2.5 mms) and or at many places (51% to 75% stations of a sub-division reporting rainfall at least 2.5 mms).

TABLE 11

**Principle amounts of rainfall during June – September 1999**

| Date (1) | June (2) | July (3) | August (4) | September (5) |
|---|---|---|---|---|
| 1 | Chauldowaghat 8, Passighat & Mhasala 7 each, Chottabekra & Chennai City 5 each, Honavar 4, Car Nicobar, Gangtok & Kuppady 3 each | Domohani 17, Agartala 11, Passighat, Triveni & Jagadhari 7 each | Bali & Medak 13 each, Kangra 12, Shivaganj 9, Kampur 8, Puri 7 | Varanasi 16, Banbasa 10, Mana & Dummagudem 7 each |
| 2 | Maya Bandar 12, Chittor 6, Chepan 5, Kailashahar, Chikhali & Idukki 4 each, North Lakhimpur, Bhira & Cuddalore 3 each | Kokrajhar 18, Ahiravalia 15, Suri, Ayodhya & Marora 9 each, Agartala & Kasauli 8 each, Tezu & Naraingarh 7 each | Dhubri & Jaisalmer 19 each, Pokhran 15, Paradip & Alipingal 14 each, Jagdalpur, Nizamsagar & Vadakara 11 each, Kailashahar, Darauli & Patur 10 each, Sevoke 9, Nanded 8, Turtipar, Mangalore & Gulbarga 7 each | Chottabekra 17, Banda 14, Chauldaowaghat 13, Berhampur 11, Parbhani & Cuddalore 8 each, Mul & Alapuzha 7 each |
| 3 | Poladpur 8, Kondul & Jenapur 6 each, Chauldowaghat 5, Agumbe & Punalur 4 each, Kailashahar, Canning Town & Morshi 3 each | Dian 25, Nagarkata 20, Barsar 9, Sardarnagar & Nangal 6 each | Chhindwada 13, Balimundali 12 Sriramsagar 9, Calcutta 8, Una 6 | Dalmau 12, Puthimari & Thakur munda 11 each, Maya Bandar 7 |
| 4 | Karwar 11, Hut Bay 6, Sriniketan & Gohar 5 each, Chepan 4, Khonsa, Nalbari, Jamshedpur, Sriganganagar & Sikar 3 each | Chepan 10, Matizuri, Diamond Harbour, Kakrahi & Minicoy 6 each | Dehragopipur 16, Jharsuguda 11, Narsampet 9, Ranchi 7 | Banda 18, Khajuraho 15, Port Blair 11, Pirawa 8, Jhansi 7 |
| 5 | Naraj, Kurnool & Salem 5 each, Haripad 4, Digha, Kahu & Bijapur 3 each | Barobisha 13, Chandradeepghat & Kozha 10 each, Purulia & Amini Divi 9 each, Ranchi & Bareilly 8 each, Kollur 7, Tikarapara 6 | Dharampur 42, Jammu 17, Mul 13, Agumbe 9, Shahapurkandi 8, Betul 7 | Kalpi 8, Khajuraho & Chiplun 7 each |
| 6 | Chenagannur 21, Mavelikara 13, Maya Bandar 7, Aizwal & Minicoy 6 each, Lakhipur & Tiruchirpalli 3 each | Karwar 16, Panampur 15, Gheropara 10, Ahirawalia & Bihubar 9 each, Narsinghpur, Bangalore & Amini Divi 8 each, Malegaon 7 | Naraingarh & Kangar 15 each, Bansda & Mahabaleshwar 14 each, Naduan 13, Bhira 12, Ajume 9, Baripada 8, Ropar 7 | Nancowire 11, Sevoke, Galgalia & Narora 9 each, Guhla & Kalingapatnam 8 each, Chiplun 7 |
| 7 | Kolar Gold Fields & Konni 16 each, Amini Divi 13, Kottayam 11, Kolasib 5, Baripada & Kanyakumari 3 each | Kalimpong & Dengraparaghat 9 each Dengraghat & Pune 7 each, Jharsuguda & Banbasa 6 each | Kharagpur 23, Bhira 18, Baripada 17, Mohanpur 16, Kangara 15, Mahabaleshwar 14, Jamsolaghat, Jabalpur & Belthangady 13 each Roopwas, Ahwa & Sindewahi 10 each, Jamshedpur & Katra 9 each, Sugar 8, Dasuya & Sankaleshpura 7 each | Kaman 14, Mukteshwar & Jangaon 11 each, Chauldhowaghat & Vaikom 10 each, Maya Bandar, Hiradharbati, Nandigama &Purna 8 each, Barelly 7 |
| 8 | Thiruvananthapuram 10, Maya Bandar 9, Kolasib 5, Betul & Mandya 4 each, Shillong, K. Paramathy & Mangalore 3 each | Bhopal 10, Navapur, 8, Thane 7, Dhengraghat & Chandur 6 each | Agumbe 21, Sundergarh 18, Subsagar 10, Jabalpur & Gaganbavada 8 each, Gangtok & Ahwa 7 each | Sriramsagar 18, Gharmura 13, Nanded 9, Jaunpur 8, Komarada 7 |
| 9 | Thaliparamba & Kanpur 11 each, Agumbe 5, Baripada 4, Numaligarh & Ramtek 3 each | Passighat & Barobisha 14 each, Chepan 13, Mangrol 11, Panbari, Dharoji, Mandi & Mammordi 10 each, Irikkur 9, Port Blair & Ashti 6 each | Sakoli 23, Manas NH-ing & Selu 18 each, Betul 10, Bhiwani & Mahabaleshwar 8 each, Shimla 7 | Agartala 10, Osmanabad 9, Pathri 8, Karimganj & Mandsour 7 each |
| 10 | Honavar 19, Panjim 12, Kasargode & Kudulu 10 each, Berhampore 7, Hasimpara 5, Hut Bay, Raichur & Agumbe 4 each, Tezpur, Hissar & Valparaj 3 each | Jalpaiguri 47, Domohani 35, Tezu 26, Dhollabazar 13, Mudibidu 12, Jhanjharpur & Karkala 11 each, Balmikinagar & Alibag 7 each | Jalpaiguri 10, Tezu, Baijnath & Vythiri 9 each, Marora 8, Guwahati, Krishnanagar, Dadahu, Khandwa & Paratwada 7 each | Naharkatia 17, Buxar 13, Gopalpur 12, Dehradun, Harnai & Malsiras 10 each, Huzurabad , Bhood & Neemuch 8 each |
| 11 | Akhuapada 21, Rajghat 18, Panjim 17, Kumta 16, Shirali 12, Rangia 9, Gangapur, Hut Bay & Adoor 7 each | Ranchi 14, Honavar 13, Karimganj & Triveni 12 each, Purulia 10, Malda & Dapoli 9, Talala & Agumbe 8 each, Sultanpur, Haripur, Baijnath, Dharampur, Mahabales-hwar & Nagpur 7 each | Masani 15, Bhoond 12, Khajuraho 9, Etawah & Surganj 8 each, Jalpaiguri 7 | Dummagudem 16, Bareilly & Nahan 11 each, Namsai & Kalingapatnam 8 each, Lakhimpur, Idar & Mangalore 7 each |

**TABLE 11** (*Contd.*)

| (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|
| 12 | Karwar 47, Kumpta 41, Shirali 39, Panjim 37, Agumbe 22, Talaguppa 13, Darjeeling & Pune 9 each, Londa 8, Nahan & Gangapur 7 each. | Mirzapur 39, Champasarai 18, Basti 15, Bareilly 11, Ropar 10, Ahirwalia & Jogindernagar 9 each, Miao, Haripur, Mahabaleshwar & Kollur 7 each | Barobisha 13, Ludhiana & Thodupuzha 10 each | Chikhali 21, Jetpur 10, Asansol, Naraingarh & Mumbai (CLB) 8 each, Passighat Uttarkashi, Betul & Paratwada 7 each |
| 13 | Panjim 14, Passighat, Cherrapunji & Malvan 13 each, Gorakhpur & Mangalore 10 each, Tilpara & Barrage 9 each | Karjan 16, Sankheda 15, Choudhowaghat, Darjeeling & Narayanpur 11 each, Chargharia 9, Agumbe 8, Siddapur & Malapuram 7 each | Ahirwalia 30, Mathabhanga 16, Cherrapunji, Jhanjharpur & Amritsar 14 each, Jaunpur 10, Surijapla & Naraingarh 9 each, Paonta & Punalur 7 each | Sandheads 16, Cuttack 15, Mumbai (CLB) 13, Chhindwara 8 |
| 14 | Cherrapunji 20, Cooch Behar 15, Barobisha & Taliparamba 11 each, Mani 10, Jayapura 9, Khonsa, Asansol & Khamgaon 8 each | Rajapur 15, Kalyan & Chandangad 13 each, Talaguppa 12, Triveni 11, Sambalpur 10, Amarghat 9, Bodhan 7 | Ahirwalia 25, Triveni 23, Ayodhya 13, Baghdogra 11, Canning Town 10 | Dhar 12, Karjat 6, Tikarapara, & Jhansi 5 each, Sriniketan, Mirzapur, Pendra & Nagpur 4 each |
| 15 | Kokrajhar 18, Bhalukpong 14, Barobisha & Pandharkawada 13 each, Maya Bandar, Jainagar & Vellore 9 each, Jaipur & Sendhawa 8 each, Malabar Hill, Mangalagin & Thirthala 7 each | Bhira 31, Mahabaleshwar 18, Dharampur 16, Mangaon & Peint 15 each, Bansda 13, Diana 11, Sibsagar 10, Agumbe 8, Ganj Basoda & Manjeri 7 each | Sriniketan 14, Ayodhya 10, Chowudhowaghat & Bhagalpur 9 each, Darjeeling 8 | Bhopal AP 17, Rengali, Dapoli & Sringeri 7 each |
| 16 | Indore 11, Mani 10, Kokrajhar 9, Maya Bandar 7 | Bhira 19, Kankavali & Gaganbavada 17 each, Mahabaleshwar 14, Paonta 11, Haripur 10, Harda 9 | Sultanpur 16, Berhampore 13, Hasimara, Basha & Idukki 7 each | Vidisha 13, Chauldhowaghat 7 |
| 17 | Mumbai (SCZ) 13, Dehra Dun 12, Garianband 11, Karimganj 10, Sambhal & Bhuj 6 each | Mhasala 49, Gaganbavada 30, Poladpur 27, Mahabaleshwar 18, Sringeri 17, Karwar, Londa & Hosanagara 13 each, Paonta 11, Khanapur 10, Dhollabazar & Jammu 9 each, Hoshangabad & Kannur 8 each, Chottabekra 7 | Jaunpur 11, Tezpur 9, Madurai 7 | Chhindwara 13, Jabalpur 8, Chhatang 7 |
| 18 | Tekkali 20, Sindhkheda 15, Palakonda 14, Ratnagiri, Jagdalpur & Nanawar 11 each, Gaganbavda & Agumbe 10 each, Khunsa 9, Sakoli 8, Dhar 7 | Hosanagara 32, Panambur 28, Shirali 24, Koppa 21, Mundgod & Thalassery 16 each, Dehra Dun & Chandgard 15 each, Radhanagari 14, Hubli & Cannur 13 each, Neamatighat 11, Begu, Varval & Amini Divi 9 each, Naraingarh & Sundernagar 8 each, Bhadrachalam 7 | NH31-17, Hasimara & Naraingarh 13 each, Hallimysore 9, Guwahati, Ranjit Sagar Dam & Narsipatnam 7 each | Balaghat 10, Annapurnaghat & Narsapur 9 each, RL-1700 & Katra 8 each, Dehradun 7 |
| 19 | Mhasala 20, Koyna (Navja) 19, Lanji 15, Mangalore & Pawli 12 each, Dungarwadi 10, Baroda City 9 | Balaghat 19, Shillong 16, Mathabhanga, Panvel & Chandgad 15 each, Madhuban & Daman 14 each, Tezu 13, Mahabaleshwar 12, Gangapur 11, Cooch Behar 10, Sohana, Amraoti & Vadakancherry 9 each, Bhatpurwaghat, Perur & Karwar 8 each, Ghamroor & Madikeri 7 each | Kangra 17, Dehra Dun 12, Chandradeepghat 11, Jalpaiguri & Calcutta (A.P.) 10 each, Miao & Tajewala 9 each, Taipur 7 | Haripur 15, Jabalpur 10, Margherita 9, Haridwar 8 |
| 20 | Dapoli 17, Harnai & Gaganbavda 16 each, Ghatol 13, Mahabaleshwar 10, Ahmedabad 8 | Mandvi 24, Limbdi 21, Olpad 20, Khed 19, Baijnath 18, Kollur 17, Mahabaleshwar 16, Basti & Balachur 15 each, Hosanagar 14, Chauda, Chiplun & Manchikere 13 each, Nokha 12, Shillong & Tantoi 10 each, Rawatbhata 9, Ambala 8, Seppa, Balurghat, Hathidah & Londa 7 each | Baijnath 30, Jogindernagar 25, Bhoond 13, Tadapatri 12, Shahapurkandi 11, Maraora 9, Damoh & Srinivaspura 8 each, Bokajan, Baripada, Bhimavaram & Manthani 7 each | Jogindernagar 8 |

TABLE 11 (*Contd.*)

| (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|
| 21 | Dungarwadi & Chotan 15 each, Dwarka & Passighat 13 each, Chittorgarh & Koyna (Navja) 11 each, Bhira 9 | Ambala, Nahan & Sholapur 17, Gaganbavda 16, Bhira 15, Sahapurkandi 14, Mukerian & Kasauli 13 each, Jalpa & Sikar 12 each, Viramgam & Kasargode 11 each, Port Blair, Ganganagar, Honavar & Medikeri 9 each, Ratlam 8 | Passighat & NH-31 16 each, Champasarai 13, Dehra Dun & Mana 8 each | Tezpur 12, Balasore 10 |
| 22 | Dawdi 22, Koyna (Navaja) 18, Devli 16, Sambalpur 15, Mahabaleshwar & Bilhaur 14 each, Darjeeling, Bharatpur & Kanpur 11 each | Panjim 19, Mahabaleshwar 18, Chandgad 16, Sangrah & Sawantwadi 11 each, Shirali 10, Kondul, Dhengarghat, Thaneswar, Tarana & Cannur 9 each | Champasrai 18, Baghdogra 16, Taibpur 14, North Lakhimpur 11 | Dehradun 11, Hut Bay, Annapurnaghat, Midnapore & Deoli 8 each |
| 23 | Dungarwadi 52, Bhira 27, Betul, Banda & Rajghat 9 each, Dhunbri 7 each | Kollur 20, Hosanagara 19, Kundapura 18, Sringeri 16, Londa 14, Mahabaleshwar 13, Gaganbavada 11, Gangapur 9, Bokajan 8, Bhopal & Bhira 7 each | Kakrahi 16, Kondul 15, Cooch Behar & Barobisha 14 each | Haripur 14, Paonta 13, Canning Town 8 |
| 24 | Mahabaleshwar 24, Cooch Behar & Gaganbavada 21 each, Kanakavali 16, Chiplun 14, Barobisha, Margherita, Rosera & Kakrani 11 each, Bansda 9, Passighat & Londa 7 each | Jhalwar 18, Gaganbavda 15, Guna 14, Rawatbhata & Bhatkal 13 each, Mahabaleshwar 12, Panjim 11, Irinijalkuda 10, Rewaghat 8 | Hasimra 18, Asansol 13, Galgalia 8, Jogindernagar 7 | Rangagora 28, Dhond 14, Jamshedpur & Ashti 12 each, Bangalore 9, Masauda & Nandigama 7 each |
| 25 | Gaganbavda 23, Rajapur 19, Vapi 18, Jainagar & Silvassa 14 each, Araria 11, Beki Road Bridge 10 | Mahabaleshwar 11, Gharmura 9, Gwalior & Dummagudem 8 each, Dapoli & Mangalore 7 each | Cooch Behar 15, Triveni 14, Ahirwalia 13, Jurala Project 8, Nancowire, North Lakhimpur & Kangra 7 each | Kursela 25, Malda 17, Dahiwadi 14, Suri 12, Ashti 9, Indore 8, Jamshedpur 7 |
| 26 | Mhasala 17, Sriniketan 11, Malda & Mahabaleshwar 9 each | Mani 15, Dehra Dun & Kammardi 11 each, Londa 9, Sonkutech 8, Thakurmunda & Balaghat 7 each | Baghdogra 23, Malda 14, Balrampur 11, Khousa 10, Khammam 9, Bankura 8, Kurnool & Gaganbavda 7 each | Dhengraghat 45, Malda 21, Kondul 11, Yelahanka 8, Calcutta (ALP) & Pratapgarh 7 each |
| 27 | Durgapur 17, Hasimmara 13, Beki Road Bridge & Kankavali 9 each, Bhagalpur 8, Uttarkashi 7 | Paradip 22, Mahabaleshwar 15, Munnar 10 Margherita & Galgalia 9 each, Lucknow, Pali & Kaleswaram 7 each | Kursela 15, Maya Bandar & Lakhipur 9 each, Mahabanda & Dapoli 8 each, Rampurhat 7 | Car Nicobar 14, Margherita, Shirala & Hungund 8 each, Hassan 7 |
| 28 | Darjeeling & Sevoke 22 each, North Lakhimpur, Triveni, Kakarhio & Honavar 10 each, Panjim 7 | Jabalpur 22, Digha 16, Chandanpur 15, Sringeri 14, Mahabaleshwar 13, Kangra 11, Mainpuri & Bhira 10 each, Palmerganj 8, Uppinangaddy & Thrissur 7 each | Cherrapunji 14, Gaganbavda 12, Balangir 9 | Doddabalapura 11, Chennai City 10, Gharmura & Haripur 8 each, Amraoti 7 |
| 29 | Jhanjharpur 7, Passighat, Fatehpur, Dehra Dun, Alibag & Ichhapuram 6 each, Singlabazar, Kharagpur, Bhubaneswar, Moradabad, Ambala & Panambur 5 each | Satna 18, Bankura & Khajuraho 9 each, Sawai Madhopur & Valparai 7 each | Jamshedpur 9, Goalpara 8, Diana 7 | Bellary 13, Vijayawada & Shirahatti 9 each, Tgondupuzha 7 |
| 30 | Kokrajhar 24, Rangagore 9, Cooch Behar & Gaganbavda 7 each | Gangrar 26, Jhalwar 21, Bhira 7, Japla, Mohana, Khajuraho & Udupi 6 each | Jamsolghat 19, Chandanpur 12, Mana 11, Tezpur 10, Berhampore 9, Chottabekra 8, Rajahmundry 7 | Ajjampura 10, Sankalan, Fatehgarh Adiramapatnam & Munirabad 9 each, Bhor, Udgir & Ananthapur 8 each, Poladpur 7 |
| 31 | — | Bilara 30, Jaswant Sagar 26, Ajmer 16, Kunnamkulam 13, Jamshedpur 9, Sringeri 8, Maya Bandar 7 | Car Nicobar 14, Miao 11, Cherrapunji 8, Durgapur 6 | — |

had positive anomalies of which east-central and southwest blocks both had an anomaly of more than 1.0° C

Over Bay; south Bay, west-central block and north Andaman Sea had negative anomalies and South Andaman Sea had positive anomaly.

7.4. *August :* Over Arabian Sea; north, central and south Arabian Sea all had positive anomalies.

Over Bay; southwest, northwest and northeast block had negative anomalies. Central block, southeast block and South Andaman Sea had positive anomalies of which south Andaman Sea had positive anomaly of more than 1.0° C.

7.5. *September :* Over Arabian Sea; west-central, east-central, southwest, southeast and northeast blocks had positive anomalies of which northeast, west-central and southwest blocks had anomalies of more than 1.0° C. Northwest block only had a negative anomaly.

Over Bay, northern-central and southern blocks had positive anomalies, out of which northeast and southeast had anomalies more than 1.0° C. South Andaman Sea had also a positive anomaly.

## 8. Other features

### 8.1. *Weekly anomalies in monsoon circulation 1999*

Using weekly wind vector anomalies at three standard levels *i.e.* 850, 500 and 200 hPa representing lower, middle and upper tropospheric levels respectively, the main anomalous circulation features of Monsoon-99 is given in Table 8.

#### 8.1.1. *June anomaly features*

In the first week, the circulation indicated weaker than normal southerly meridional flow and weaker than normal upper tropospheric easterlies. But during second and third week, lower and mid-tropospheric westerlies were stronger than normal and upper tropospheric easterlies were normal/stronger than normal. In the last week of the month again subdued monsoon circulation features were present with anti-cyclonic flow covering almost the entire country in the lower troposphere. The upper tropospheric easterlies were stronger than normal.

#### 8.1.2. *July anomaly features*

During first week, subdued monsoon circulation features continued due to anticyclone flow in lower troposphere over most of the country with stronger easterlies in upper troposphere. During second week and third week, conditions improved due to cyclonic circulation in lower levels over peninsular India and stronger than normal easterlies in the upper troposphere in the second week which became weaker than normal subsequently over southern parts. The condition remained almost same during the last week also.

#### 8.1.3. *August anomaly features*

During first two weeks, low pressure/troughs systems were present in the lower and mid troposphere but the upper tropospheric anticyclone flow was in general weaker than normal except over northwest India where it was stronger than normal in the second week. During rest of the month, in the lower and mid tropospheric levels typical features of weak monsoon condition with disturbances in the easterlies in the south were present. The upper tropospheric anticyclone was stronger than the normal.

#### 8.1.4. *September anomaly features*

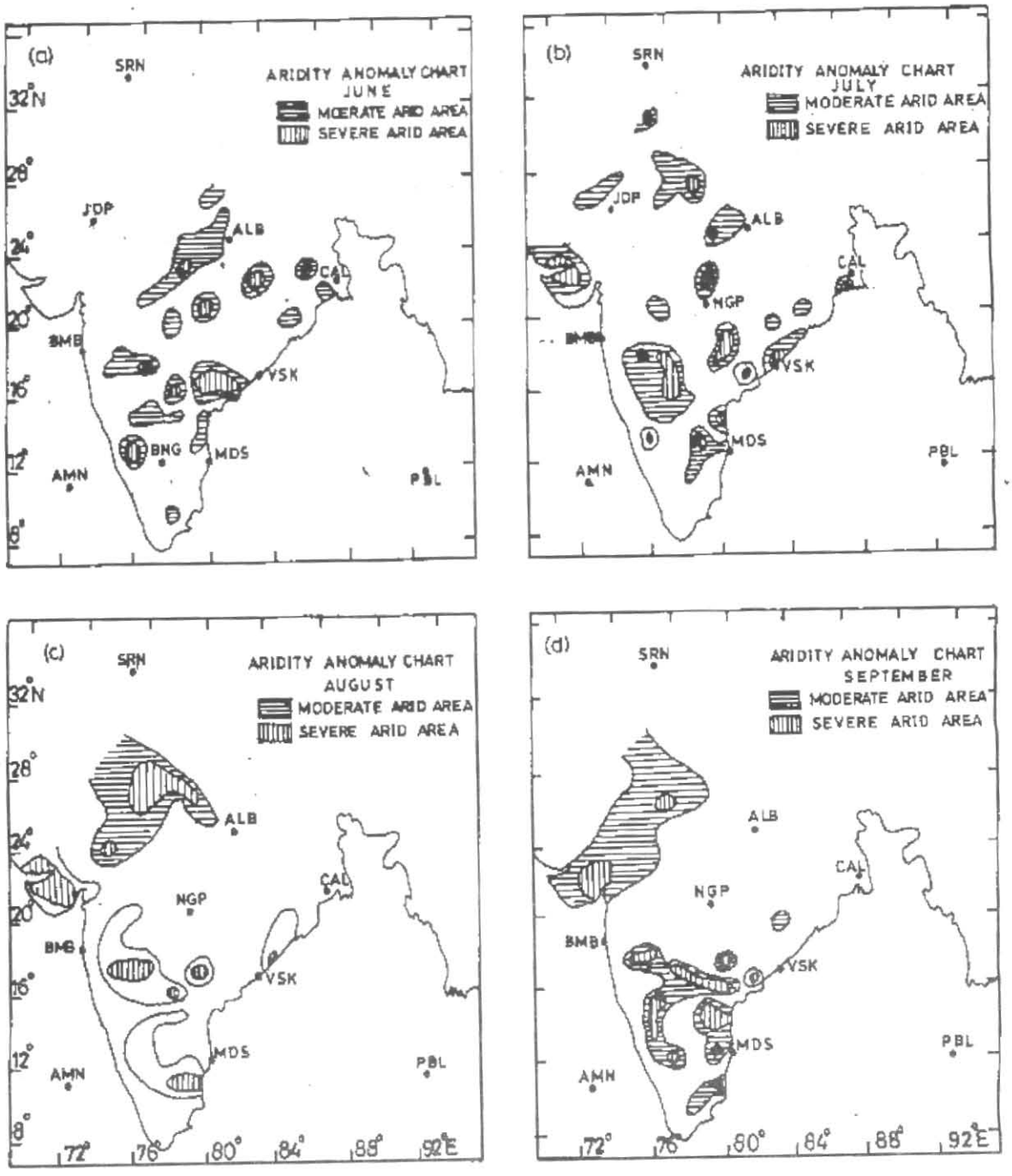
Low pressure/trough systems were present almost through out the month in the lower and mid troposphere and upper troposphere anticyclone was weaker than normal.

### 8.2. *Stratospheric features*

Upper wind data of all available RS/RW stations over the country have been analysed during the monsoon period-1999. Weekly wind anomaly values at three levels (850, 500 and 200 hPa) for a few representative stations over India are given in Table 9. Following features are noted :

#### 8.2.1. *Winds at 10 hPa*

During monsoon season, the winds over the country were easterlies through out the season with varying wind speeds. Zonal winds indicate interesting features in different months of the monsoon season. In June, the strength of easterlies over the country varied between 20 to 25 mps. Wind speeds recorded at different stations (on dates given within bracket) indicate that Minicoy experienced the wind of 20 mps (on 12 and 14); Bangalore 25 mps (on 13, 14 and 15); Jagdalpur 25 mps (on 26); Calcutta 20 mps (on 7); Gorakhpur 25 mps (on 20) and Lucknow 25 mps (on 10 and 19). In July, the strength of easterlies varied from 20–30 mps. During the month, Chennai experience the wind of 25 mps (on 27); Jagdalpur 30 mps (on 22 and 27); Calcutta 30 mps (on 25 and 29); Lucknow 20 mps (on 11) and Gorakhpur 25 mps (on 4, 9, 10, 12, 14, 15, 16 and 19). In August, the strength of easterlies over the country varied from 30–35 mps. During the month Minicoy experienced the wind of 30 mps (on 12); Hyderabad 30 mps (on 14); Calcutta 30 mps (on 2 and 21); Lucknow 35 mps (on 5 and 14) and Jagdalpur 35 mps (on 31). In September, the wind speed varied from 25 to 30 mps at different locations. During the month, Santacruz experienced the wind of 35 mps (on 14); Minicoy 25 mps (on 5, 7, 9, 11 and 23); Jagdalpur 30




**Figs. 12 (a-d).** Meteorological sub-divisions affected by moderate to severe aridity conditions during (a) June, (b) July, (c) August and (d) September 1999

mps (on 5); Guwahati 25 mps (on 5) and Raipur 30 mps (on 26).

8.2.2. *Winds at 30 hPa*

Compared to 10 hPa wind observations, the frequency of observations at 30 hPa was fairly good. The observations indicated that the easterlies prevailed through out the season. Variation of winds in different months show interesting features. In June, the easterlies were of the order of 20 mps between 20° N to 25° N and gradually reduced to the speed of the order of 10 mps. Towards north and south of this latitudinal belt, winds were above normal over eastern and central parts of India (1 to 3 mps) and below normal over the rest of the country(3 to 10 mps). In July, the easterlies were of the order of 20–25 mps between 15° N to 25° N. Towards north and south of this latitudinal belt, wind speeds gradually reduced to the speed of the order of 10 mps. The wind speeds were above normal (2 to 5 mps) north of 20° N and below

normal (5 to 10 mps) towards south. In August, the wind speeds were observed to be of the order of 20–30 mps over central and eastern parts of the country and reduced to the order of 10 mps over rest of India. The wind speeds were above normal over central and eastern parts (1 to 5 mps) and below normal over the rest of the country(5 to 15 mps). In September, the wind speeds were of the order of 20 mps over central parts of the country and reduced to 10 mps towards north and south. These wind speeds were nearly normal.

8.3. *Aridity conditions during monsoon 1999*

Aridity index (AI) is computed based on Thornthwaite's formula :

$$AI = \frac{PE - AE}{PE} \times 100$$

Where, PE is potential evaporation *i.e.* combined loss of water vapour to atmosphere in the form of evaporation from soil, water surfaces and transpiration from the plants, when the supply to the water is unlimited. This is water need of the plants. AE denotes the actual evapotranspiration and PE – AE denotes the water deficiency. PE is computed by Penman's modified equation and AE is obtained from the water balance procedure which takes into account the water holding capacity of the soil.

The difference between actual aridity for the week and normal aridity *i.e.* the aridity anomaly is worked out. The aridity anomalies have been classified into the following classes :

| *Anomaly* | *Class* |
|---|---|
| Zero or less | Non arid |
| 1 to 25 | Mild arid |
| 26 to 50 | Moderate arid |
| more than 50 | Severe arid |

Aridity anomaly maps for June, July, August and September are given in Figs. 12(a-d) respectively.

In June, Moderate to severe arid conditions were noticed in some northern, central and southern parts of the country. However, the arid areas also appeared over northwestern parts of the country in July. The arid areas increased over the country, in general, during August. In September, the aridity conditions over areas over northwestern and western parts of the country persisted. The total area of the country affected by severe arid conditions, was 4%, 6%, 9% and 8% during June, July, August and September 1999 respectively.

## 9. Damages due to floods etc. during monsoon season

According to press reports, floods, heavy rains, landslides took a toll of 592 lives (Bihar 289, West Bengal 70, Kerala 55, Maharashtra 54, Karnataka 32, Gujarat 30, Assam & Meghalaya 27, Madhya Pradesh 14, Orissa 8, Rajasthan 7 and Haryana 6 persons.) Damages due to floods and heavy rains in June, July, August and September are given in para 13.1., 13.2., 13.3. and 13.4. respectively.

## 10. Significant spells of heavy rains during monsoon season

During monsoon, the spatial distribution of heavy (rainfall during past 24 hours ≥ 6.5 cms) and very heavy (past 24 hours rainfall is ≥ 12.5 cms) rainfall is given in Table 10. The table also indicates activity of monsoon and the sub-divisionwise extent of rainfall in number of days like, widespread (more than 75% stations of a sub-division reporting rainfall at least 2.5 mms) and fairly widespread (51% to 75% stations of a sub-division reporting rainfall at least 2.5 mms). Monthwise description is given below :

10.1. *Heavy rainfall during June*

During the month, heavy to very heavy rainfall occurred on 10 to 15 days over Konkan & Goa, on 5 to 9 days in Sub-Himalayan West Bengal & Sikkim, Himachal Pradesh, Gujarat Region, Madhya Maharashtra, coastal Karnataka and Kerala and on 1 to 4 days in Andaman & Nicobar Islands, Arunachal Pradesh, Assam & Meghalaya, Gangetic West Bengal, Orissa, Bihar Plains, Uttar Pradesh, Haryana, Madhya Pradesh, Saurashtra & Kutch and south interior Karnataka.

10.2. *Heavy rainfall during July*

During the month, heavy to very heavy rainfall occurred on 16 to 22 days in Bihar Plains, Konkan & Goa and coastal & south interior Karnataka; on 10 to 15 days over Assam & Meghalaya, Sub-Himalayan West Bengal & Sikkim, Himachal Pradesh, west Madhya Pradesh, Madhya Maharashtra, north interior Karnataka and Kerala; on 5 to 9 days in Gangetic West Bengal, Orissa, Uttar Pradesh, Haryana, Punjab, east Rajasthan and Gujarat Region and on 1 to 4 days in Andaman & Nicobar Islands, Arunachal Pradesh, Nagaland, Manipur, Mizoram & Tripura, Bihar Plateau, Hills of west Uttar Pradesh, Jammu & Kashmir, west Rajasthan, east Madhya Pradesh, Saurashtra & Kutch, Marathwada, Vidarbha, Rayalaseema, Tamil Nadu and Lakshadweep.

10.3. *Heavy rainfall during August*

During the month, heavy to very heavy rainfall occurred on 10 to 16 days over Assam & Meghalaya;

West Bengal & Sikkim, Orissa, Bihar Plains, east Uttar Pradesh and east Madhya Pradesh; on 5 to 9 days in Arunachal Pradesh, Bihar Plateau, west Uttar Pradesh, Himachal Pradesh, west Madhya Pradesh, Madhya Maharashtra, Vidarbha, Tamil Nadu and Kerala and on 1 to 4 days in Andaman & Nicobar Islands, Nagaland, Manipur, Mizoram & Tripura, Haryana, Punjab, Jammu & Kashmir, west Rajasthan, Gujarat Region, Konkan & Goa, Marathwada, Telangana and Karnataka.

10.4. *Heavy rainfall during September*

During the month, heavy to very heavy rainfall occurred on 20 days in Orissa; on 10 to 12 days over Assam & Meghalaya, Gangetic West Bengal and west Madhya Pradesh; on 5 to 9 days in Andaman & Nicobar Islands, Bihar Plains, east Uttar Pradesh, east Madhya Pradesh, Konkan & Goa, Madhya Maharashtra and Marathwada and on 1 to 4 days in Arunachal Pradesh, Nagaland, Manipur, Mizoram & Tripura, Sub-Himalayan West Bengal & Sikkim, Bihar Plateau, west Uttar Pradesh, Gujarat Region, Vidarbha, Andhra Pradesh, Tamil Nadu, Karnataka and Kerala.

## 11. Significant temperature during the season

Significant temperatures were noticed only in the month of June. In remaining three months of the season, the temperatures were within reasonable limits.

Severe heat wave (departure from normal maximum temperature is +7° C or more for the regions where normal maximum temperature is 40° C or less and the temperature departure is +5° C or more for the regions where normal maximum temperature is more than 40° C) conditions prevailed on 1 day in east Uttar Pradesh.. Day temperatures were appreciably (departure from normal maximum temperature is between +3° C to +4° C) to markedly (departure from normal maximum temperature is between +5° C to +6° C for the regions where normal maximum temperature is 40° C or less) above normal on 5 to 8 days in Bihar Plains and Jammu & Kashmir and on 1 to 3 days in Bihar Plateau, east Uttar Pradesh, Madhya Pradesh, Saurashtra & Kutch and Vidarbha. Highest day temperature of 50° C was recorded at Barmer (Rajasthan) on 18 June.

## 12. Significant monthly rainfall

Monthly rainfall is given in Figs. 5 - 8 and principal amounts of rainfall are given in Table 11.

## 13. Disastrous weather events and damages during monsoon months

13.1. *June*

According to press reports, heavy rains and floods took a toll of 32 persons in Kerala and 14 in Maharashtra. Properties worth crores of rupees were damaged due to floods and heavy rains.

13.2. *July*

According to press reports, in all, 289 persons lost their lives in Bihar due to heavy rains and floods. Floods in north Bihar and northeast India inundated more than 300 villages. 31 persons lost their lives due to heavy rains accompanied by strong winds in Maharashtra. Heavy rains and floods also took a toll of 30 human lives in Gujarat, 30 in West Bengal, 32 in Karnataka and 23 in Kerala.

13.3. *August*

According to press reports, heavy rains and floods took a toll of 27 people in Assam & Meghalaya, 14 in Madhya Pradesh, 8 in Orissa, 7 in Rajasthan and 6 in Haryana.

13.4. *September*

According to press reports, 40 persons in West Bengal and 9 in Madhya Maharashtra lost their lives due to heavy rains and floods.

## 14. Concluding remarks

The southwest monsoon set in over Kerala on 25 May and covered the entire country by 12 July. The rainfall for the monsoon season was excess in 3, normal in 25 and deficient in the remaining 7 sub-divisions. No cyclonic storm formed during the season, however four depressions were formed. The country received total rainfall of 96% of its long period average.

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