CHAPTER-I : INTRODUCTION

1.1 The Problem

1.1.1 The rainfall of the four summer monsoon months of June to September accounts for about 75 percent of the total amount of rainwater that falls over India during the whole year; in large areas of central and north-west India the monsoon contribution to the annual rainfall is 90 percent or more. Monsoon rainfall of India has shown considerable year to year variations and large scale droughts and floods have occurred in some years. Since Indian agriculture is still largely dependent on monsoon rainfall, droughts and floods seriously affect food production and thereby the national economy. The present production of food grains in India is about 120 million tons per year. Only about a quarter of the cultivated area is under irrigation. Therefore it has been said that in India 'agriculture is a gamble on the monsoon'. With a population of about 700 million to be fed, a year of poor rainfall brings great hardship to this large population and severe strain on the economy of the country. There is therefore pressing need to understand the vagaries of the monsoon and to develop capability to forecast the behaviour of the monsoon a few months ahead, to enable the Government to make adequate preparations to face a year of abnormal monsoon.

1.1.2 The studies incorporated in the present thesis comprise the following:

(i) Monsoon rainfall has spatial and temporal variabilities of various scales. The inter-annual variability of the total quantum of rain falling over India during the monsoon season 1 June to 30 September
has been studied utilising the Parthasarathy-Hoolay (1976) rainfall series of more than 100 years (described in section 1.2).

(ii) Utilising surface, aerological and satellite data, the relationships between the observed inter-annual variability of monsoon rainfall and the concurrent and antecedent conditions of the atmosphere and the oceans on the monthly scale have been studied, to understand the processes that lead to large deviations of monsoon rainfall of India from the normal. In its climatological archives, the India Meteorological Department has rainfall records of more than a hundred years from a large number of observatories well distributed over the country. Surface meteorological observations are available for a large part of the inhabited areas of the world and along the shipping lanes in the oceanic areas for the last about one hundred years. Meteorological soundings of the upper air are available for the past few decades. A wealth of other sophisticated measurements on the ocean and the atmosphere, like measurements from weather satellites are now available for more than a decade.

(iii) Using the persistence of the atmospheric circulation features, attempt has been made to develop a method for the long range forecasting of the monsoon rainfall of India. After the serious drought and famine of 1877, the Government of India was seized of the problem of long range forecasting of monsoon vagaries, with the result that India is one of the pioneers in long range forecasting; a statistical method using meteorological parameters antecedent to the monsoon from several parts of the world has been in use in India for almost a century, with limited success.
(iv) Many large scale features of the global atmosphere and the ocean are linked with the inter-annual variability of the Indian monsoon. The literature on these have been examined and the salient features of such linkages have been brought out.

1.1.3 The last two decades will be remembered as a period when climate (particularly rainfall) became a major destabilizing factor in the world economy. In the 1930s only very severe droughts attracted attention. Since that decade, world population has doubled and food production, even with a lot of scientific inputs, has not been able to keep pace with the population multiplication. As a consequence, mankind's vulnerability to climatic variability and to droughts in particular has markedly increased. The vagaries in rainfall of greatest significance, in this context are those around the sub-tropical regions of the world and these arid and semi-arid regions cover almost one-third of the earth's land surface. These areas have become particularly vulnerable to the ravages of droughts. Mention may be made of the drought that struck the Sahel region of Africa during 1968-1973 causing widespread devastation and suffering. India too has a large arid and semi-arid region which has been experiencing high inter-annual variability in rainfall and occasional disastrous droughts.

1.2 The Parthasarathy-Mooley monsoon rainfall series

1.2.1 The average monsoon rainfall of India has been computed by Parthasarathy and Mooley (1978) for the period since 1866 by weighting the areas of the different meteorological sub-divisions of India. These subdivisions as of 1 January 1971 are shown in Figure 1.1. For the period 1901 to 1970, data of about 3000 rain gauges have been used. The earlier period has data of 1500-2000 stations. For the period since 1970 data
from about 350 observatory stations only have been used. The rainfall series thus made has been shown in figure 1.2 for the period from 1866 to 1982.

1.2.2 The statistical properties of this long time series have been investigated by Parthasarathy and Mooley (1978) using data of the homogeneous period 1866 to 1970. The average (normal) monsoon rainfall (1 June to 30 September) of India is 88.75 cm with a standard deviation of 7.64 cm. The time series is normally distributed. Power spectrum analysis indicates a significant periodicity of 2.7 years. The rainfall of years when monsoon rainfall was below the normal by one standard deviation have been shaded in figure-1.2. The decade averages of monsoon rainfall are given in table-1.1 along with their standard deviation. The years with monsoon rainfall one standard deviation less than the long period mean (normal) are also listed against the decades. An asterisk mark is added to the years with monsoon rainfall 2 standard deviations less than the normal. During the period 1870 to 1920 the decade average was generally very steady around 87 cm. From 1921 onwards the decade mean increased and attained the maximum value of about 95 cm during 1941-50 and declined thereafter.

1.2.3 One prominent feature seen in the rainfall series is the large fluctuation from year to year in the monsoon rainfall. In 1917 there was monsoon rainfall of 106.61 cm, whereas in the very next year 1918, monsoon rainfall was only 70.16 cm. Monsoon rainfall went up to 94.68 cm in 1919 and came sharply down to 75.01 cm in 1920. Such large fluctuations are seen throughout the rainfall series, particularly so in some epochs like a period around the beginning of this century and the years since 1965 to the present. The worst monsoon during the period under study (1866 to date) was 1972
which had rainfall of only 66.29 cms and the best was 1917. Such large inter-annual variability of the Indian monsoon should have repercussions in the weather and climate of major portions of the globe, before, during and after a monsoon season; it should affect the oceans as well.

1.2.4 Figure 1.3 gives departures from normal of monsoon rainfall of sub-divisions of India for 5 years of poor monsoon rainfall 1965, 1966 and 1972 and 3 years of normal or excess rainfall 1967, 1970 and 1973. The normals used to calculate the percentage departures are the 1901-1950 normals. In drought years, central and north-west India are the areas generally affected by large rainfall deficiencies. One of the factors in common in the 5 years of large scale failure of monsoon 1965, 1966 and 1972, is the occurrence of long spells of 'break monsoon' conditions during July and August. In 1965 there was a long spell of break monsoon conditions from 4 to 15 August, in 1966 from 2 to 11 July and in 1972 from 17 July to 4 August. Other factors that caused large-scale failure of monsoon in these years are delayed onset and advance of the monsoon over the country in June and or its early withdrawal from north-west India and portions of central India during September, which reduce the effective duration of the monsoon over central and north-west India. For instance monsoon set in over Kerala in 1972 on 18 June, instead of the normal 1 June. The advance of monsoon over south peninsula was delayed by about a fortnight, over north peninsula by about 10 days and over central parts of India by about a week. The monsoon in 1972 withdrew from north-west India by 6 September and from Madhya Pradesh and Gujarat state by 13 September, i.e. about one to two weeks earlier than normal. In 1965 the advance of the monsoon over central and northwest India was delayed by about two weeks.
In 1966 monsoon arrived over Kerala on the normal date. However, its advance was delayed over central parts of India by about a week. The withdrawal of monsoon both in 1965 and 1966 was normal. In 1966 and 1967 monsoon depressions behaved erratically; they had more northerly tracks than normal, depriving central and north-west India of rainfall from such systems. The major factors contributing to the large scale failure of monsoon over India during these years are summarized in Table-1.2 (Joseph, 1978).

1.3 Years of large scale drought/flood in Indian monsoon

1.3.1 Bhalme and Mooch (1980) studied droughts and floods over India during the monsoon seasons of the period 1901 to 1975. The following accounts collected by them from different sources give details associated with some of the major drought and flood years during the period 1901 to 1975.

(a) The drought of 1899

The monsoon of 1899 started on time but by the end of June showed signs of failure in several parts of India. The monsoon rainfall of this year failed almost over the entire country. The consequent famine was more widespread and severe than any the country had experienced earlier. It was not merely a food famine but also one of fodder and water. Cattle died by the millions.

(b) The drought of 1911

The monsoon of 1911 was characterised by its extreme weakness from about the middle of June to the middle of August. During the second half of August the monsoon revived with the result that the drought mitigated considerably. The river discharges of the Godavari and Krishna basins were
30% below average. The famine was however severe only in Maharashtra.

(c) The drought of 1918

The monsoon of 1918 was exceptionally feeble and rainfall was seriously deficient over the whole of the country with the exception of north-east India. The river discharges of Godavari and Krishna basins were 60% below average. This drought was more widespread and severe than what the country had experienced in the past two centuries. Available reports clearly indicate that this drought resulted in famine of both food and fodder over practically the whole of the country.

(d) The drought of 1965

The monsoon of 1965 was deficient over the whole of the country, being appreciably so in north-west India, central parts of the country and part of eastern India. To meet the heavy shortfall in food grains production in the country, the Government intensified internal procurement and arranged for massive imports.

(e) The drought of 1966

The monsoon rainfall was characteristic of drought conditions over most of northern parts of India. The food situation in the country continued to be extremely difficult due to widespread drought and the consequent failure of crops for the second year in succession. 10.6 million tons of food grains had to be imported.

(f) The drought of 1972

Severe drought conditions developed particularly in many parts of north India and north peninsula. The food situation in the country was rather difficult in 1972 because of extensive damage to monsoon season crops due to drought conditions. The worst affected areas were Maharashtra,
Gujarat, Rajasthan and Andhra Pradesh. Towards the end of 1972, arrangements were made to import 2 million metric tons of food grains to replenish the buffer stocks and to ensure uninterrupted flow of food grain supplies through the public distribution system.

The flood of 1917

The monsoon of this year was phenomenally vigorous. India Meteorological Department described this year as one of the big flood years over a large part of the country. The river discharges of Godavari and Krishna basins were respectively 40 and 10% above average.

The flood of 1961

Many states of India experienced floods during the monsoon of 1961 and many rivers recorded highest ever levels. The suffering and losses of life and property due to the floods caused by the bursting of dams were alarmingly high.

The flood of 1975

During the vigorous monsoon of 1975, West Bengal, Bihar, Orissa, Uttar Pradesh, Kerala etc. experienced floods with heavy damage to life, property and standing crops.

1.3.2 In the very recent times there was a major drought during the MONEX year of 1979. The monsoon set in late over the peninsula in 1979 and there was a rather prolonged break in the monsoon which began in mid-August and lasted almost a month. The drought of 1979 was almost as severe as that of 1972 as may be seen from figure-1.2, but with the adequate buffer stocks of food grains progressively built up by the Government of India, the country did not have to import food-grains in 1979.
1.4 Some studies on Inter-annual Variability of 
Monsoon Rainfall of India

1.4.1 The variability of the monsoon rainfall of India expressed as 
coefficient of Variation (C.V.) defined by

\[ \text{C.V.} = \frac{\text{Standard Deviation}}{\text{Mean}} \times 100 \quad \text{(in percentage)} \]

is given in figure-1.4 (from India Meteorological Department - 1971) C.V. 
varies from 60% in the extreme northwestern desert areas (arid zones) 
to 20% or less in the most rainy areas. It is seen that areas of low 
monsoon rainfall are areas of large variability. Rao et al (1972) 
analysing data of a large number of rain gauge stations over the country found 
that the coefficient of variation decreased with increasing rainfall upto 
about 100 cms and thereafter remained constant around about 20%.

1.4.2 Raghavendra (1973) constructed monsoon rainfall series for the 
period 1875 to 1970 for two major divisions of India named 'Peninsula' and 
'North-west India' for which seasonal forecasts are being issued by India 
Meteorological Department. 'Peninsula' comprises of Maharashtra, Gujarat, 
Madhya Pradesh, Coastal Andhra Pradesh, Telangana, Interior Karnataka, 
North and Coastal Karnataka (excluding South Karnataka). 'North-west India' 
comprises of Jammu and Kashmir, West Uttar Pradesh, Haryana, Punjab, Himachal 
Pradesh, Delhi, Chandigarh and Rajasthan. These areas and the spectral 
analyses of their rainfall series may be seen in figure-15. The main 
conclusions of the study are the following:

(a) Peninsula receives 90 cm of rain during the monsoon season with 
a CV of 14%; North-west India receives 54 cms with a CV of 22%.

(b) The frequency distribution is normal for north-west India; it 
has slight kurtosis for peninsula.
(c) The data show ed absence of any long term trend.

(d) Power spectra analysis indicated the existence of a significant periodicity of 2.7 years in both series.

1.4.3 Parthasarathy and Dhar (1976) calculated mean annual and monsoon rainfall of India using data of about 3000 raingauge stations for each year of the period 1901 to 1980. They found that the mean annual rainfall of India is 119 cms with a standard deviation of 9.5 cm. It varied from the normal between +21 percent in 1917 to -19 percent in 1918 on the basis of 60 years of rainfall of the period 1901 to 1960. 75% of the annual rainfall occurs in the south-west monsoon season. The frequency distribution of the time series of monsoon and annual rainfalls are normally distributed.

1.4.4 Bhalme and Meoley (1990) calculated a Drought Area Index (DAI) and a Flood Area Index (FAI) for the monsoon season rainfall. For this a numerical drought index based on monthly monsoon rainfall and duration was developed by them for the assessment of drought intensity. The DAI is defined as the percentage area of India having a mean monsoon index \( \leq -2 \). Likewise the FAI is the percentage area of India with mean monsoon index \( \geq 2 \). The mean monsoon index is taken as the mean drought index for the four monsoon months. A year is defined as a large scale drought or flood year when DAI or FAI \( \geq 25 \). Power spectrum analysis of their DAI series of the period 1891 to 1975 revealed a weak triennial cycle. Power spectrum analysis of the FAI series showed a highly significant periodicity of 21 years, in phase with the double sun-spot cycle.

1.4.5 Walker (1910) examined the monsoon rainfall (June to September) of India as it existed then, comprising of the present India, Pakistan, Bangladesh, Burma and Sri Lanka, using data from about 2000 raingauge stations.
for the 68 year period 1841-1908. The mean monsoon rainfall for India thus defined was obtained as 35 inches (90 cms). This figure is very close to the value of 88.75 cm arrived at by Parthasarathy and Noclely (1978). From an analysis of the data it was found that the rainfall during the 18 year period 1843 to 1860 was exceptionally low. Rainfall was also below normal during the period 1891-1908. During the period 1841-1908 years of very poor monsoon rainfall were 1843, 1855, 1877 and 1899.

1.4.6 There are a large number of other studies, old and new, relating to Indian rainfall which have examined trends and periodicities in annual and monsoon rainfall of large portions of India and of individual stations. An exhaustive review of these may be found in Parthasarathy and Dhar (1978).
REFERENCES


2. India Meteorological Department (1971) - "Rainfall Atlas of India."


7. Raghavendra, V.K. (1973) - "A statistical study of the south-west monsoon rainfall in the Indian peninsula and south-west monsoon rainfall and winter precipitation in north-west India" - Meteorological Monograph, Climatology, No. 6, India Meteorological Department, Pune 5.


* Monthly Weather Review
### Table 1.1: Statistical parameters of monsoon rainfall for standard decades

<table>
<thead>
<tr>
<th>Standard decade</th>
<th>Average monsoon rainfall (cm)</th>
<th>Standard deviation of monsoon rainfall (cm)</th>
<th>Difference of decadal mean from long period average of 88.75 (cm)</th>
<th>Year with rainfall one standard deviation (7.64 cm) less than the long period normal of 88.75 cm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1871-1880</td>
<td>87.97</td>
<td>3.32</td>
<td>-0.68</td>
<td>1873, 1876, 1877*</td>
</tr>
<tr>
<td>1881-1890</td>
<td>89.61</td>
<td>2.94</td>
<td>0.54</td>
<td>NIL</td>
</tr>
<tr>
<td>1891-1900</td>
<td>87.01</td>
<td>3.51</td>
<td>-1.74</td>
<td>1891, 1895, 1899*</td>
</tr>
<tr>
<td>1901-1910</td>
<td>86.83</td>
<td>7.95</td>
<td>-1.92</td>
<td>1901, 1904, 1905</td>
</tr>
<tr>
<td>1911-1920</td>
<td>86.39</td>
<td>12.01</td>
<td>-1.86</td>
<td>1911, 1913, 1918*, 1920</td>
</tr>
<tr>
<td>1921-1930</td>
<td>83.90</td>
<td>4.76</td>
<td>0.15</td>
<td>NIL</td>
</tr>
<tr>
<td>1931-1940</td>
<td>90.37</td>
<td>5.23</td>
<td>2.12</td>
<td>NIL</td>
</tr>
<tr>
<td>1941-1950</td>
<td>93.17</td>
<td>5.90</td>
<td>4.42</td>
<td>1941</td>
</tr>
<tr>
<td>1951-1960</td>
<td>91.40</td>
<td>3.36</td>
<td>2.65</td>
<td>1951</td>
</tr>
</tbody>
</table>

*Years with monsoon rainfall 2 standard deviations less than normal.
Table 1.2: Factors responsible for large scale monsoon failure in 1965, 1966 and 1972 (shown by a * mark)

<table>
<thead>
<tr>
<th>Year</th>
<th>Delayed advance of monsoon in June</th>
<th>Early withdrawal of monsoon in September</th>
<th>Long break monsoon spells in July and August</th>
<th>More northerly tracks of monsoon depressions during June to September</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>*</td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>1966</td>
<td></td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>1972</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>
Fig. 1.2 - Sub-division area weighted monsoon season (1 June to 30 September) rainfall series of India of period 1866-1982 (Parthasarathy and Mooley-1978). Rainfall less than the normal by one standard deviation shaded. Normal (1866-1970) shown by dotted line.
Fig. 1.3 - Rainfall excesses and deficiencies (from normal) sub-divisionwise for the period 1 June to 30 September. (From Weekly Weather Reports of India Meteorological Department).

(Monsoon rainfall is shown against the years.)
COEFFICIENT OF VARIATION OF MONSOON RAINFALL OF INDIA (JUNE - SEPTEMBER)

FIG. I-4 (I.M.D.-1971)
MONSOON (JUNE – SEPTEMBER) RAINFALL – NORTHWEST INDIA

MONSOON (JUNE – SEPTEMBER) RAINFALL – PENINSULA

Fig. 1.5 - Spectrum analysis of monsoon (1 June to 30 September) rainfall series of peninsula and north-west India of period 1875-1970 (from Raghavendra-1973).