Climate Variability and Food Security

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December 2009

Copies : 100
Printed at : Mac World, Thrissur
First Edition : 2009

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Published and released under AICRP on Agrometeorology in connection with Working Group Meeting held at KAU, Vellanikkara during 21-22 December, 2009

Correct citation : Rao, G.S.L.H.V.P., Rao, A.V.R.K., Krishnakumar, K.N. and Gopakumar, C.S. 2009. Climate Variability and Food Security, Kerala Agricultural University, Thrissur, Kerala, India. 83p

FOREWORD

Climate change is the subject of global concern as the occurrence of natural disasters over one or another region of the world is frequent in recent decades, leading to economic losses. The estimated economic loss due to natural disasters from January to September 2002 was $70 billion as per the UNEP preliminary report. Out of an estimated 526 significant natural disasters during the last nine months this year, the highest (195) was in Asia, followed by USA (149), Europe (99) and Africa (38). It shows that Asia is more prone to natural disasters and that too, majority of them is related to weather disasters. The study also highlighted the real risks and economic perils they are facing as a result of human-influenced climate change. Such events were more and more in recent years. The Government of India recently addressed the issues related to climate change and national action plan on climate change has been chalked out to combat climate change by reducing emission of Green House Gases (GHG) through mitigation and adaptation strategies.

Indian economy is mostly agrarian based, which depends on onset of monsoon and its further behaviour. 2002 and 2009 were classical examples to know how Indian foodgrains production is dependent on rainfall of July and August. Despite advances in science and technologies that are available to mitigate the ill-effects of lull in monsoon, the kharif foodgrains production was adversely affected. At the same time, it was the summer drought which affects plantation crop production in humid tropics like Kerala as witnessed in summer 1983 and 2004. The lull in monsoon over Kerala during 2002 was the unique since last 138 years as the monsoon rainfall was less by 35% when compared to that of long period average. Consecutively four deficit monsoon rainfall years resulted in water shortage during rabi and summer seasons in Kerala to a large extent. The lull in monsoon followed by floods in Kannur District in October 2002 due to the cyclonic storm over Karnataka Coast, devastated seasonal crops and plantations to a considerable extent. Kannur received 370 mm of rainfall on 14^{th} October 2002, which was the highest and to received since 1924. Prolonged monsoon rains in 2007 followed by unusual rains in March 2008 adversely affected the paddy crop to a large extent. It revealed that weather related disasters, viz, droughts, floods, landslides and thunderstorms are not uncommon in humid tropics, leading to economic loss to a considerable extent in Kerala. In this context, the technical bulletin entitled "Climate variability and food security" brought out by Dr. G.S.L.H.V. Prasad Rao and his team is praiseworthy.

The bulletin dealt with variability in monsoon at length based on data on onset of monsoon and monsoon rainfall for 140 years (1870-2009). It is also understood that the climate shifted from wet to dry within humid climate and significant in recent decades. The impact of climate shifts on rice and coconut production was highlighted. The coconut production in the following year was adversely affected whenever climate shifted towards semi arid and arid during summer, noticed during disastrous drought years. Of course, its impact was felt on food price also. Utilizing the information on climate variability and taking into account the crop phenology of coconut, coconut production was estimated for the State of Kerala as a whole and put in operation.

I hope the weather scientists and the scientists working in the field of climate research will be immensely benefitted with the wealth of information provided in the bulletin. I congratulate the author and his team for painstaking efforts in bringing out this publication.

Vellanikkara
20 December 2009

K.R. Viswambharan
Vice-Chancellor
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PREFACE

Rainfed agriculture is vulnerable to weather aberrations. It is more so in semi arid tropics. 2002 and 2009 were declared as the years of all India drought due to rainfall deficit during the southwest monsoon in many sub-meteorological divisions of the country. At the same time, the crops at large were not that much affected in the humid tropics like Kerala though the monsoon was deficit. Of course, the water level in major water reservoirs was less and it affects crops during ensuing seasons. The characteristic feature of the humid tropics is that the heavy monsoon is followed by prolonged droughts, leading to seasonal droughts. The occurrence of seasonal droughts is the concern in humid tropics as the plantation crop production is adversely affected. 1983 and 2004 summer droughts were still in memory as they adversely affected the majority of plantation crops to a great extent. Such phenomenal droughts are common towards north of Kerala, where the uni-model rainfall followed by prolonged dry spell is the striking feature.

The weather related disasters like drought, floods and landslips are not uncommon in the humid tropics. The deficit monsoon during 2002 was followed by floods and landslips in Kannur and Kasaragod districts of Kerala due to cyclonic affect over the Karnataka Coast. Agricultural crops had been damaged in strong winds in addition to a few human losses due to house collapses. Red rains were also noticed over Kerala in addition to landslips in surface wells. It is also understood that the intensity of rain appears to be high in the recent past. The surface air temperature appears to be high due to high vapour pressure deficit in the atmosphere during the months of February and March, causing advection affect due to warm and dry winds. All the above lead in people's mind that there is some change in recent times in climate. It is right time that the climatologists analyse the past data and bring out climate information, which is of concern to all allied disciplines, in particular agriculture.

I am indeed happy to go through the text of this publication "Climate variability and food security". The climatological data on onset of monsoon and monsoon rainfall used for analysis were quite large, covering the period from 1870 to 2009 for the State of Kerala as a whole. In that respect, the bulleting is unique. The results indicated that the decade 1981-'90 was the driest decade and the intensity of drought was showing an increasing trend in the recent decades. This alarms the adverse impact of human interventions in deforestation and decrease in wetland area on sustain development of the State. The model developed for coconut estimates over Kerala based on agroclimatic variables appears to be sound. The impacts of climate variability on Indian foodgrains production and paddy production in Kerala were also highlighted along with increase in food price.

I am sure the publication will be a bird's eye view to scientists, teachers, students, planners and decision makers related to food security under the projected climate change scenario. I compliment Dr. G.S.L.H.V. Prasada Rao and his team for concerted efforts in bringing out such a bulletin in an abridged form.

Vellanikkara
20 December 2009

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ACKNOWLEDGEMENTS

The publication is based on the research work carried out over a period of more than three decades in the University. During the period, many Research Associates worked under the project leadership of the author. A few of them, now occupied good positions in national institutes. The service rendered by Mrs Lincy Davis, Ms Lekshmi Revi, and Mrs. Mini Sathesh in data collection, computations and analysis is highly acknowledged. The support extended by my Field Staff in recording meteorolical data regularly is placed on record.

The Co-orindator is grateful to the DST, IMD, ISRO and ICAR, Government of India for funding the research projects in Climate Change Research Adaptation, but for the financial support it is difficult to take up studies of this nature.

Thanks are due to Dr. G.G.S.N. Rao, Project Co-orindator, AICRP on Agrometeorology for the technical support. The co-ordinator is also greateful for choosing the Centre for Climate Change Research, Kerala Agricultural University as the Venue for hosting Working Group Meeting of AICRP on Agrometeorology, which facilitated the Co-ordinator for release of this technical bulletin.

The Co-orindator also wishes to place on record for the service rendered by M/s Mac World, Thrissur for extending whole hearted support in bringing publications in record time.

Vellanikkara
20 December 2009

G.S.L.H.V. Prasada Rao
Co-orindator
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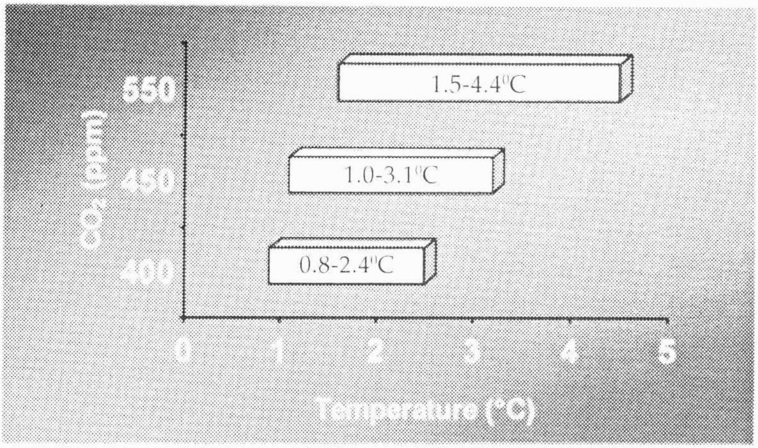
INTRODUCTION

Climate change and climate variability in recent decades are the subjects of world wide discussion as the weather related disasters, viz. droughts, floods, ice storms, dust storms, hail storms, landslides, heat and cold waves and thunder clouds associated with the lightning are not uncommon over one or another region of the World. The year 1998 was one of the recent weather related disasters, which caused hurricane havoc in Central America and floods in China, India and Bangladesh. Canada and New England in the U.S. suffered heavily due to ice storm in January which Turkey, Argentine and Paraguay with floods in June. Vast fires in Siberia burned over three million acres of forests. In 2005 also, weather related disasters across the World were noticed. Human and crop losses are the worst phenomena in such weather disasters, affecting global economy to a considerable extent. The year 2002 also led to a disaster drought due to monsoon failure, affected the economy of the whole South Asian Countries and Australia. It was declared as the all India drought after 1987 during which *kharif* foodgrains production was adversely affectd to a great extent during 2002-03. Similar was the case in 2009 in India due to monsoon failure.

The rate of increase in global warming was much slow (less than half-a-degree Celsius before 1850) before pace of industrialization in Europe and U.S. and it is projected to be fast now. The Intergovernmental Panel on Climate Change (IPCC) projected the rate or warming for the 21st Century to be between one and 4.5 degree Celsius. High global mean average temperatures were recorded consecutively for 16 months during the years 1997 and 1998. Also, the year 1999 was the fifth warmest year on record though it was a La Nina year supposed to be cooler. The above situation may lead to faster rate of global warming than projected. The warmest winter in the NHS was noticed in 2007. Increase in aerosols (atmospheric pollutants) due to emission of greenhouse gases including black carbon and cholofllurocarbons (CFCs), Ozone depletion, UV filtered radiation, cold and heat waves, global cooling and warming are seen reported frequently in addition to "human hand" in the form of deforestation and loss of wetlands in the process of imbalanced development for betterment of humankind may be the causal factors for climate variability. The UV filtered radiation due to Ozone depletion in atmosphere, if reaches to ground, may lead to several human and crop diseases. The global weather factors, viz. ENSO (popularly known as E1 Nino in combination with Southern Oscillation) and Sea Surface Temperature (SST) Index (difference between sea surface temperatures of NHS and SHS) may lead to droughts in a particular region and floods in another region of the globe. It also appeared that the equatorial Pacific Sea surface temperature is a major influencing factor influencing variations in Indian monsoon rainfall. Several institutes, viz. International Research Institutes for Climate Prediction and NASA Goddard Institute for Space Studies (USA), Hadley Centre for Climate Prediction and Research (UK), the Climate Research Unit at the university of East Anglia in eastern England, Queensland Centre for Climate Applications, Department of Primary Industries, Queensland with the support of Australian Centre for International Agricultural Research and few institutes and universities in India under Indian Climate Research Programme (ICRP) of the Department of Science and Technology, Govt. of India run mathematical models in a big way for climate prediction world over. All the climate predictions made by national and global institutes, failed during the lull Indian monsoon 2002 and 2009, will provide a wealth of information for all the climate forecast scientists to investigate further and understand the behavior of ocean – atmosphere interaction on influence of climate change to gain knowledge for future climate predictions. Perhaps, the Arabian Sea Monsoon Experiment (ARMEX) with a network of several institutes taken up by the Government of India must have understood on causal factors for failure of monsoon during 2002. Such monsoon failure was noticed in 2009 also in India.

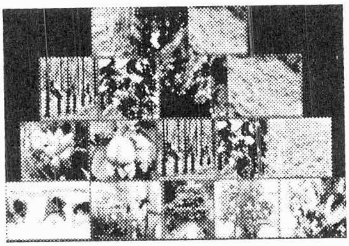
1.1 Global climate change projections

Climate change is a global problem with unique characteristics and involves complex interactions between climatic, environmental, economic, political, institutional, social and technological processes, which affect locally. India is one of the 27 countries identified as the most vulnerable to the impacts of global warming. The Global Circulation Model (GCM)-based assessment of the Inter Governmental Panel on Climate Change (IPCC) contemplates higher global surface temperature of 1.5 to 4.5°C by the year 2100 as a result of enhanced greenhouse gases. Warming generally increases the spatial variability of precipitation, contributing



to a reduction of rainfall in the subtropics and an increase at higher latitudes and in parts of the tropics. The precise location of boundaries between regions of robust increase and decrease still remains uncertain.

From the Indo-UK research project from 2002-2004, it is understood that rise in temperature is likely to be around 3°C over India by 2100 A.D. The area under wheat and rice is likely to decline along with water resources. The ill effects of climate change in various sectors like agriculture, water resources, forestry, biodiversity, fisheries, animal agricuture, health and infrastructure were also highlighted in several scientific reports. Uncertainties in monsoon and rainfall trends across the Country and frequent cyclone intensities are also projected.



Kerala is blessed with tropical rain-forests, rich bio-diversity and has many rivers and streams and is spread in 13 natural agro-ecological zones. Agricultural production in Kerala is for a large part still dependent on weather and climate despite the impressive advances in agricultural technology over the last half a century. In fact, Kerala ranks low among several Indian states on productivity of most major crops. More than ever, agrometeorological services have become essential because of the challenges in many forms being faced by agricultural production through increasing climate variability and associated extreme events as well as climate change. Reducing the vulnerability of natural and socio-economic systems to the projected climate change with emphasis on food security is an issue of highest priority to Kerala.

High monsoon rainfall from June of September followed by moderate to severe dry spell is the characteristic feature of the humid tropics. The monsoon rains are relatively stable over Kerala "Gateway of Indian Monsoon". However, the monsoon rainfall over Kerala during 2002 was one of the lowest, if not the least, less by 35% over the Long Period Average. Out of 14 district, 12 received deficient rainfall. The percentage deviation of monsoon rainfall at Vellanikkara (Trichur) from 2001 to 2009 (Table 1) indicated that the deficit of rainfall during the monsoon period varied between 20 and 28% over normal in several years except in 2007 (excess monsoon year). Similar trend was noticed over Kerala also.

Table: 1 Percentage deviation imonsoon over Normal (1980-2009) Vellanikkara

Year	June	July	August	Sept	June-Sept
2001	-8.0	-31.0	-44.0	-16.0	-21.0
2002	-28.0	-48.0	-12.0	-50.0	-28.0
2003	-22.4	-28.3	7.9	-78.1	-24.3
2004	6.9	-46.2	-14.8	-15.0	-17.5
2005	-0.4	8.7	-23.4	54.4	4.6
2006	-14.8	-22.5	21.8	93.8	4.5
2007	15.8	69.1	21.6	184.2	55.5
2008	-10.8	-37.8	-28.8	16.6	-19.8
2009	-20.9	42.8	-7.0	2.4	5.3

In contrast, a heavy wet spell due to cyclonic storm over Karnataka Coast in October 2002 wrought havoc in Kannur and Kasaragod districts of Kerala and damaged crops to a great extent. Such heavy rainfall was received since 1924 in Kannur for the first time, rained continuously for 24 hours and recorded 370mm on 14th October alone. The State as a whole also received excess rainfall of 184 percent over normal during the month as on 16th October 2002 and led to floods in several districts. Though there was an indication in some years that bad monsoon was followed by good rains in post monsoon, it cannot be said so always as the post monsoon rains mostly based on development of cyclones as noticed in October 2002. However, in detail investigations are needed on relationship between Southwest and Northest monsoons for seasonal climate forecast over South Peninsula, where the influence of Northeast monsoon is noticed.

Realizing the importance on climate variability and its impact on crops in the humid tropics, an attempt was made to study the monsson behaviour and climate shifts over Kerala utilizing the climatic data over a period of 140 years (1870 to 2009). The impact of climate shifts on coconut production over Kerala was also analysed and attempted to predict annual coconut production of Kerala, which falls under the humid tropics, where coconut gardens are grown mostly under rainfed conditions.

1.2 Onset of southwest (Summer) Monsoon

The normal date of onset of monsoon over Kerala is on 1st June with a standard deviation of seven days (Table 2), varying between 25th May and 8th June. The earliest onset of monsoon was on 11th May in 1918 while belated monsoon on 18th June in 1972. Interestingly there a delay (4th June± 7 days) in normal onset of monsoon during 1901-1930 though the standard deviation was the same to that of normal. Nevertheless, the earliest (11th May) monsoon was also noticed during the above period in 1918. On nearly half of the occasions, the onset of monsoon was between 4th and 15th June from 1901 to 1930 (Fig.1). It might be the reason for the delay in normal onset of monsoon during the above

Table 2 Normal onset of Southwest monsoon over Kerala

Year	Mean onset	The earliest onset	The most belated onset	Standard Deviation	Range of onset
1870-1900	1st June	16th May (1874)	12th June (1895)	7	25th May-8th June
930	4th June	11th May (1918)	15th June (1915)	7	28th May-11th June
1931-1960	31st May	14th May (1960)	14th June (1940)	8	23rd May-8th June
1961-2009	31st May	17th May (1962)	18th June (1972)	7	24th May-7th June
1870-2009 (Normal)	1st June	11th May (1918)	18th June (1972)	7	25th May-8th June

( ) Figures in parenthesis indicate the year in which the onset of monsoon falls

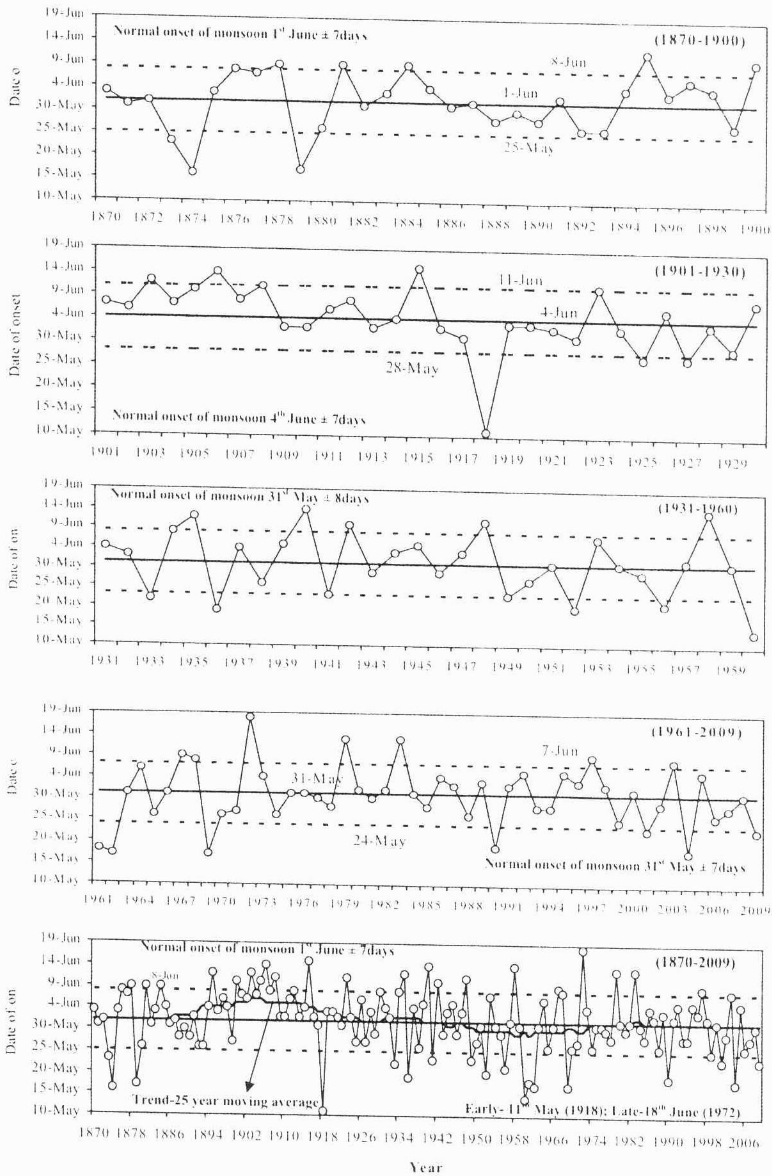
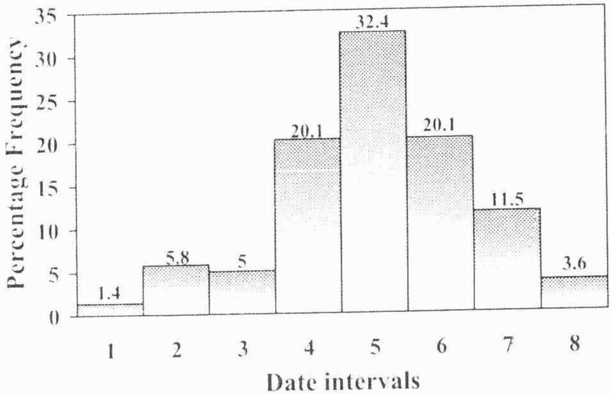


Fig. 1 Onset of Southwest monsoon over Kerala during different periods from 1870 to 2009 (140 years)

period. The onset of monsoon was before 1^{st} June on many occasions since last one decade. The trend in normal onset of monsoon also tends to be towards first week of June, revolving around 1^{st} June and it was always stable ranging between 25^{th} May and 8^{th} June as 27.5 per cent of the years only fell below or above one standard deviation of the normal onset of monsoon.

The occurrence of maximum frequency (32.4% of years) of the onset of monsoon was between 30^{th} May and 3^{rd} June, followed by June 4^{th}-8^{th}(20.1% of the years) and May 25^{th}-29^{th} and June 4^{th} and 8^{th} (11.5% of the years). The chance of early monsoon before 25^{th} May was relatively less (5-5.8% of the years). It was also true in case of occurrence of last monsoon beyond June 9^{th}-13^{th}, as 3.6% of the years only fell under the category. 73.8 percent of the years fell in the range of 25^{th} May and 8^{th} June (Fig. 2), indicating that there was no change in normal date of onset of monsoon since last 140 years if the period from 1870 to 2009 was considered as a whole though the inter-annual variation was noticed



1	2	3	4	5	6	7	8
May 10-14	May 15-19	May 20-24	May 25-29	30-June 3	June 4-8	Jun 9-13	Jun 14-18

Fig. 2 Percentage frequency distribution of onset of monsoon over Kerala (1870-2009)

within the limits of ± one standard deviation. The date of onset of monsoon in 2009 was on 23rd May.

1.3 Early and late onset of summer monsoon versus monsoon rainfall

The onset of monsoon was early (before 25th May) on 18 occasions (1873, 1874, 1879, 1918, 1933, 1936, 1941, 1949, 1952, 1956, 1960, 1961, 1962, 1969, 1990, 2001, 2004 and 2009) out of 140 years, accounting for 12.9 per cent of the years under early monsoon. Interestingly, the early onset of monsoon was seen only in 1990 (19th May) after a lapse 20 years (17th May in 1969) and 2001 (23rd May) in the recent past. Incidentally, the early onset of monsoon during 1969, 1990 and 2001 resulted in below normal rainfall during the monsoon (Table 3). The monsoon rainfall was below normal in 61.1% of the years (11 out of 18 years) during which the monsoon was early. Abnormally high rainfall was received only in 1961 (2943.4mm), followed by 1874 (2300.7mm) and 1933 (2303.8mm) when the monsoon was early as against the normal rainfall of 1928.8 ± 374.1 mm. It revealed that the monsoon rainfall is likely to be deficit rather than excess if the monsoon is early as 83 percent of the years recorded below normal rainfall or just above normal. It was tested in 2001, 2004, 2006 and 2009 and found to be correct.

The belated onset monsoon was noticed (after 8th June) on 21 occasions (1878, 1881, 1884, 1895, 1900, 1903, 1905, 1906, 1908, 1915, 1923, 1935, 1940, 1942, 1948, 1958, 1967, 1972, 1979, 1983 and 1997) out of 140 years, accounting for 15.8 per cent of the years under late monsoon. Out of 21 late onsets of monsoon, 42.8 per cent of the years (nine out of 21 years) only recorded below normal rainfall. However, the year 1881 was the only one could be classified under meteorological drought year. The meteorological drought is defined when the annual rainfall. A significant rainfall deficit was noticed in 1895 (-20.3%) and 1972 (-

Table 3. Late and early onset of Southwest monsoon and amount of rainfall (mm) over Kerala during 1870-2009

Sl. No.	Early onset				Late onset			
	Year	Date	Rainfall(mm)	% Dev.	Year	Date	Rainfall (mm)	%Dev
1	1873	23rd May	2005.1	4.0	1878	9th June	2925.4	51.7
2	1874	16th May	2300.7	19.3	1881	9th June	1339.2	-30.6
3	1879	17th May	1577.4	-18.2	1884	9th June	1696.7	-12.0
4	1918	11th May	1150.4	-40.4	1895	12th June	1541.1	-20.1
5	1933	22nd May	2303.8	19.4	1900	10th June	2027.7	5.1
6	1936	19th May	1854.9	-3.8	1903	12th June	2074.6	7.6
7	1941	23rd May	1866.1	-3.3	1905	10th June	1687.1	-12.5
8	1949	23rd May	2068.6	7.2	1906	14th June	1724.0	-10.6
9	1952	20th May	1432.2	-25.7	1908	11th June	2050.0	6.3
10	1956	21st May	1523.2	-21.0	1915	15th June	2268.6	17.6
11	1960	14th May	1867.9	-3.2	1923	11th June	2666	38.2
12	1961	18th May	2943.4	52.6	1935	12th June	1565.3	-18.8
13	1962	17th May	1948.9	1.0	1940	14th June	2129.3	10.4
14	1969	17th May	1849.9	-4.1	1942	10th June	1944.6	0.8
15	1990	19th May	1517.3	-21.3	1948	11th June	2098.2	8.8
16	2001	23rd May	1637.0	-12.6	1958	14th June	1744.4	-9.6
17	2004	18th May	1410.0	-27.9	1967	9th June	2011.0	4.3
18	2009	23rd May	1962.0	1.7	1972	18th June	1573.5	-18.4
19					1979	13th June	1868.4	-3.1
20					1983	11th June	2054	6.5
21					1997	9th June	2015.1	19.4

Mean rainfall (1871-2008) - 1928.8 mm

18.6%) in addition to 1881 (-30.7%). Abnormally excess rainfall (51.4% above normal) was noticed in 1878 when the monsoon was late, followed by 1923 (37.9% excess of normal). 57 per cent of the years (12 out of 21 years) noticed excess rainfall when compared to that of normal if the monsoon was late. It is quite interesting to note that the occurrence of deficit rainfall when compared to that of normal during the monsoon season was relatively high when the monsoon was early and no such trend was seen when the monsoon was late.

1.4 Early and late onset of summer monsoon versus monthly rainfall during monsoon over Kerala

June: Out of 17 early monsoon years, six years (35.3%) only recorded excess rainfall during June when compared to that of normal. Seven (33.33%) out of 21 late monsoon

Table 4. Monthly distribution of Southwest monsoon rainfall during early and late onset years (1871-2008)

Early onset years	Rainfall (mm)				
	Juce	July	August	September	Total
1873	831.3	856.7	188.8	128.3	2005.1
1874	1054.1	691.3	319.6	235.7	2300.7
1879	471.2	571.4	356.4	178.4	1577.4
1918	570.9	152.5	329.7	97.3	1150.4
1933	798.3	670.1	425.4	410	2303.8
1936	607.5	640.5	302.5	304.4	1854.9
1941	734.9	431.1	408.7	291.4	1866.1
1949	541.4	747	418.2	362	2068.6
1952	606.6	393.2	386	46.4	1432.2
1956	740.5	343.4	270.5	168.8	1523.2
1960	517.3	673.7	328	348.9	1867.9
1961	961.3	952.4	637.3	392.4	2943.4
1962	277.2	868.8	474.5	328.4	1948.9
1969	581.7	794.3	274.9	199	1849.9
1990	494.8	655.9	252.7	113.9	1517.3
2001	601.6	468.9	299.2	317.0	1686.7
2004	577.7	373.2	276.7	162.5	1390.1
Late onset					
1878	936.2	547.8	855.3	586.1	2925.4
1881	292.9	300	552.7	193.6	1339.2
1884	471.5	445	465.6	314.6	1696.7
1895	622.7	560.2	270.8	87.4	1541.1
1900	762.3	656.1	442.1	167.2	2027.7
1903	576.7	851.7	357.7	288.5	2074.6
1905	734.2	497.4	254.9	200.6	1687.1
1906	397.7	858.6	353.4	114.3	1724
1908	590.5	933.8	320.4	205.3	2050
1915	673.9	844.7	280.6	469.4	2268.6
1923	748.4	823.3	829.1	265.2	2666
1935	420.9	615.9	274.3	254.2	1565.3
1940	590.6	895	603.1	40.6	2129.3
1942	881.5	724.6	256.3	82.2	1944.6
1948	961.2	606.2	381.5	149.3	2098.2
1958	781.5	484.3	421.2	57.4	1744.4
1967	589.3	724.6	557.8	139.3	2011
1972	416.6	700	279.7	177.2	1573.5
1979	672.5	597.7	334.1	264.1	1868.4
1983	331.6	597.6	595.2	529.6	2054
1997	620.1	856	505.1	322.1	2303.3
Normal Rainfall (1871-2008)	684.9	637.0	377.5	229.4	1928.8

years only recorded excess rainfall (Table 4). It revealed that monthly rainfall was below normal as 65.8 percent of the years irrespective of monsoon was late or early.

July: Out of 17 early monsoon years, ten years (58.8%) recorded normal or above normal during July when the monsoon was early. At the same time eleven (52.4%) out of 21 late monsoon years, recorded normal or above normal. It revealed that the monthly rainfall was above normal in more than 50 per cent of the years irrespective of monsoon was late or early.

August: Out of 17 early monsoon years, six years (35.3%) recorded above normal during August when the monsoon was early. At the same time, ten (47.6%) out of 21 late monsoon years recorded above normal. It revealed that the monthly rainfall was below normal is more than 50 percent of the years irrespective of monsoon was late or early.

September: Out of 17 early monsoon years, none years (52.9%) recorded above normal during September when the monsoon was early. At the same time, nine (42.8%) out of 21 late monsoon years recorded above normal. It revealed that the monthly rainfall was below normal in more than 50 percent of the years irrespective of monsoon was late or early.

1.5 Rainfall during southwest (summer) monsoon over Kerala

The normal rainfall during summer season over Kerala from 1871 to 2008 is 1928.8 ± 374.1 mm. The monsoon rainfall is dependable and the inter-annual rainfall variability is relatively less, as the coefficient of variation was only 19.4 per cent. The monthly rainfall was relatively undependable, it is more so, in case of August and September as the coefficient of variation varied between 41.3 and 54.7 percent, respective (Table 5). The dependable rainfall during monsoon at 75 percent level was 1653.0 mm.

Table 5. Southwest monsoon rainfall (mm) during 1871-2008

	Rainfall (mm)				
	June	July	August	September	Total
Normal Rainfall (mm)	684.9	637.0	377.5	229.4	1928.8
75 % probability	577.7	503.9	271.9	136.3	1653.0
Standard Deviation	191.3	206.6	156.0	125.3	373.4
Coefficient of Variation (%)	27.9	32.4	41.3	54.7	19.4
Percentage contribution	35.5	33.0	19.6	11.9	

Though the variation of inter-annual during monsoon is significant, it was highly stable as the rainfall variability is within ± one standard deviation from the normal rainfall.

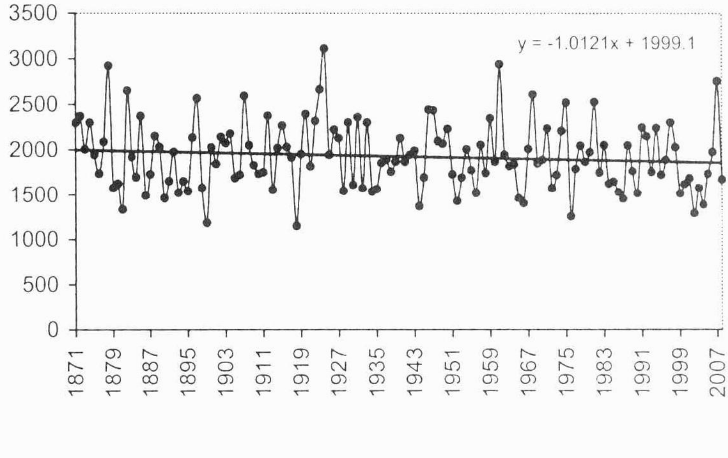


Fig 3. Southwest monsoon rainfall (mm) over Kerala from 1871 to 2008

It also showed through the trend line a decline of 139.7 mm only during the study period of 138 years (Fig.3). The rainfall trend was seen revolving around the normal since last 60 years. However, there was a marginal increase in rainfall during 1901-1930 and 1931-1960 while declining trend during 1871-1900 and 1961-2000. Interestingly, 1901-1930 was the period during which the onset of monsoon was highly variable and the normal date of onset was 4th June as against the normal onset of monsoon of 1st June (Fig. 4).

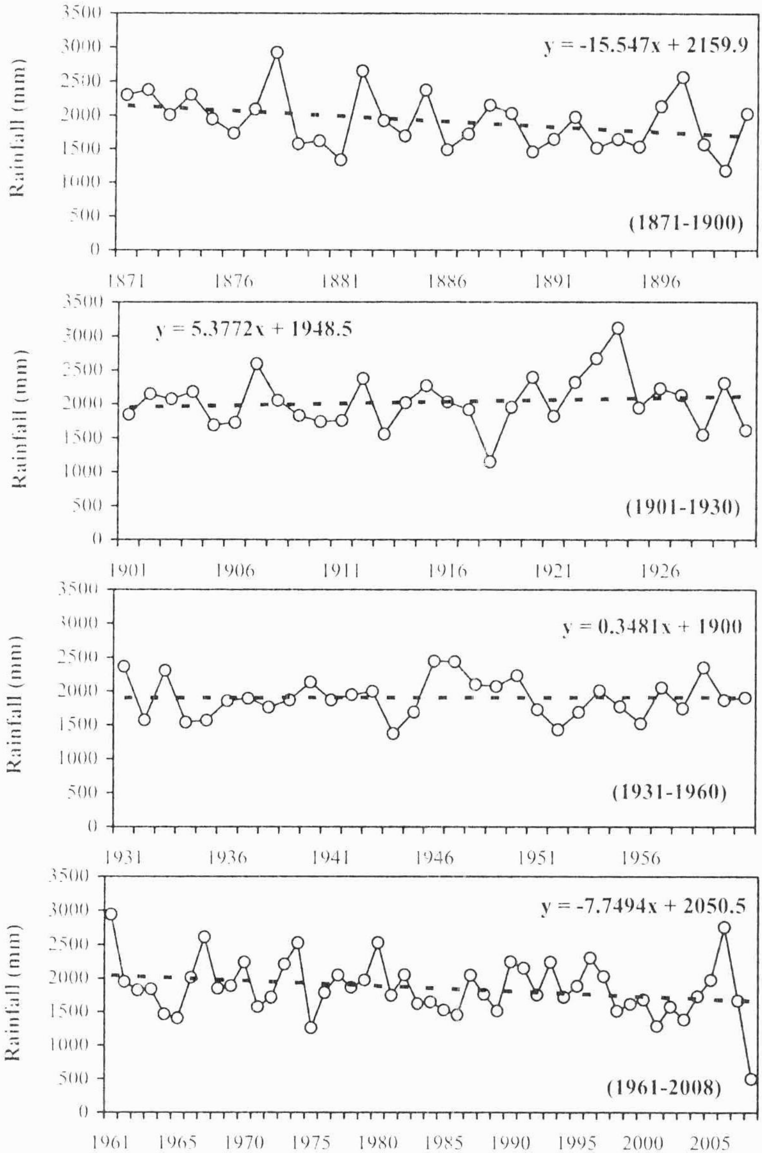


Fig. 4. Southwest monsoon rainfall (mm) of different periods over Kerala from 1871-2008

Out of 138 years, 23 years (1872, 1878, 1882, 1885, 1897, 1907, 1920, 1922, 1923, 1924, 19129, 1931, 1933, 1946, 1947, 1959, 1961, 1968, 1975, 1981, 1997, 2007) recorded excess rainfall when compared to that of normal. The highest rainfall was received in 1924 (3115.4mm), followed by 1961 (2943.4mm) and 1878 (2925.4mm). The lowest rainfall was received in 1997 (2303.3mm), 1933 (2303.8mm), 1929,

Table 6. Excess and deficit rainfall (mm) during Southwest monsoon from 1871-2008

Excess SW rainfall			Deficit SW rainfall		
Sl. No.	Year	Rainfall (mm)	Sl. No.	Year	Rainfall (mm)
1	1872	2371.7	1	1881	1339.2
2	1878	2925.4	2	1886	1491.4
3	1882	2652.9	3	1890	1462.9
4	1885	2373.3	4	1893	1523.6
5	1897	2567.2	5	1895	1541.1
6	1907	2594.7	6	1899	1185.8
7	1912	2377.0	7	1913	1554.1
8	1920	2394.9	8	1918	1150.4
9	1922	2318.4	9	1928	1543.5
10	1923	2666.0	10	1934	1536.1
11	1924	3115.4	11	1944	1374.1
12	1929	2303.9	12	1952	1432.2
13	1931	2361.5	13	1956	1523.2
14	1933	2303.8	14	1965	1464.5
15	1946	2445.4	15	1966	1405.2
16	1947	2435.9	16	1976	1260.6
17	1959	2348.8	17	1986	1528.8
18	1961	2943.4	18	1987	1456.6
19	1968	2609.4	19	1990	1517.3
20	1975	2521.6	20	1995	1534.0
21	1981	2526.4	21	1999	1516.2
22	1997	2303.3	22	2002	1292.3
23	2007	2767.1	23	2004	1390.1

(2303.9mm), 1992 (2318.4mm), 1872 (2371.7mm) 1885 (2373.3 mm) and 1912 (2377.0mm) during the excess rainfall years. It revealed that the rainfall during excess rainfall years varied between 2300mm and 3115mm (Table 6).

Out of 138 years, 23 years (1881, 1886, 1890, 1893, 1895, 1899, 1913, 1918, 1928, 1934, 1944, 1952, 1956, 1965, 1966, 1976, 1986, 1987, 1990, 1995, 1999, 2000, 2002 and 2004) recorded deficit rainfall when compared to normal. The lowest rainfall was received in 1918 (1150.4mm), 1899 (1185.8mm), 2002 (1292.3mm), 1976 (1260.6mm), 2004 (1390.1mm), 1881 (1339.2mm), 1944 (1374.1mm), 1966 (1405.2mm), 1952 (1432.2mm) 1999 (1450.0mm), 1987 (1456.6mm) 1890 (1462.9mm), 1965 (1464.5mm) and 1886 (1491.4mm). The maximum rainfall was received in 1913 (1554.1), followed by 1928 (1543.5mm), 1895 (1541.1mm) and 1893 (1523.6mm). It revealed that the rainfall during deficit years varied between 1186 mm and 1554mm.

1.6 Monthly rainfall during monsoon over Kerala

June: The monthly rainfall of June during monsoon was 684.9± 191.3mm, contributing 35.5 per cent of seasonal rainfall. The monthly rainfall in three out of four years is likely to be 577.7mm. The highest rainfall (1123.7mm) was received in 1981, followed by 1920 (1111.4mm). The lowest rainfall was received in 1976 (232.5mm) followed by 1962 (277.2mm), 1974 (285.9mm) and 1881 (292.9mm). The inter-annual variability was relatively high from 1961 to 2008 (CV-29.7%) when compared to that of 1871-1900 (CV-26.5%) and 1931-1960 (CV-26.4%). The rainfall was declining trend and a decrease of 132.5mm of rainfall was noticed over a period of time through a trend line (Fig. 5). However, the monthly rainfall was in increasing trend in all the sub-periods except 1871-1900.

July: The monthly rainfall of July during monsoon was 637.0±206.6mm, contributing 33.2 per cent of seasonal rainfall. The monthly rainfall in three out of four years is likely to be 503.9mm. The highest rainfall (1281.1 mm) was received in 1968 followed by 1924 (1253.4 mm). The lowest rainfall was received in 1918 (152.5mm) followed by 1987 (238.2mm), 1877 (264.4mm) and 1899 (274.3mm). The inter-annual variability was relatively high (CV-34.0%)

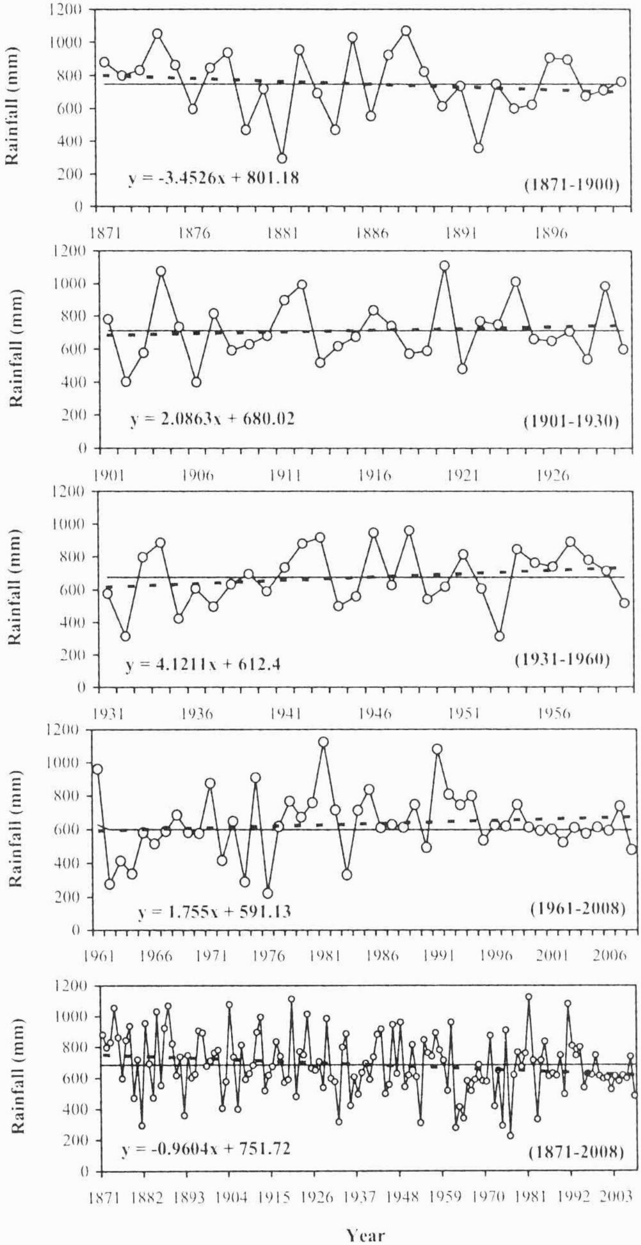


Fig. 5 Southwest monsoon rainfall (mm) in different periods over Kerala during June from 1871-2008

during 1871 to 1900 when compared to that of 1901-1930 (CV-33.5%), 1931-1960 (CV-28.1) and 1961-2008 (CV-33.0%). Quite interestingly, the monthly rainfall from 1961 to 2000 was in declining trend in contrast to the month of June during the above period. As a whole, the rainfall trend in July was in declining over a period of time (Fig.6). The trend line also indicated a decrease of 80.7mm of rainfall. However, the decline in rainfall was less in July when compared to that of June

August: The monthly rainfall of August during monsoon was 377.5± 156mm, contributing 19.6 percent of seasonal rainfall. The monthly rainfall in three out of four years is likely to be 271.9mm. The highest rainfall (388.8mm) was received in 1885 followed by 1964 (388.0 mm) and 1952 (386.0mm). The lowest rainfall was received in 1898 (107.1mm) followed by 1899 (120.9mm), 1887 (127.8 mm) and 1966 (150.4 mm). In contrast to June and July, the monthly rainfall during August was in increasing trend and the trend line indicated an increase of 22.4mm of rainfall over a period of time (Fig.7). The inter-annual variability was relatively high during 1871-1900 (CV 47.9%) and 1931-1960 (CV-47.8%) when compared to that of 1901-1930 (CV-45.2%) and 1961-2008 (CV-30.8%). In all the sub-periods except 1901-1930, the monthly rainfall was in declining trend.

September: The monthly rainfall of September during monsoon was 229.4 ±125.3mm, contributing 11.9 percent of seasonal rainfall. The monthly rainfall in three out of four years is likely to be 136.3 mm. It indicated that the monthly rainfall during September was highly variable and undependable as CV was 54.7 per cent. The highest rainfall (586.1mm) was received in 1878 followed by 1983 (529.6mm), 1915 (469.4mm), 1988 (463.1mm) and 1998 (463.0mm). The lowest rainfall was received in 1957 (36.0mm) followed by 1934 (45mm, 1940 (40.6mm) and

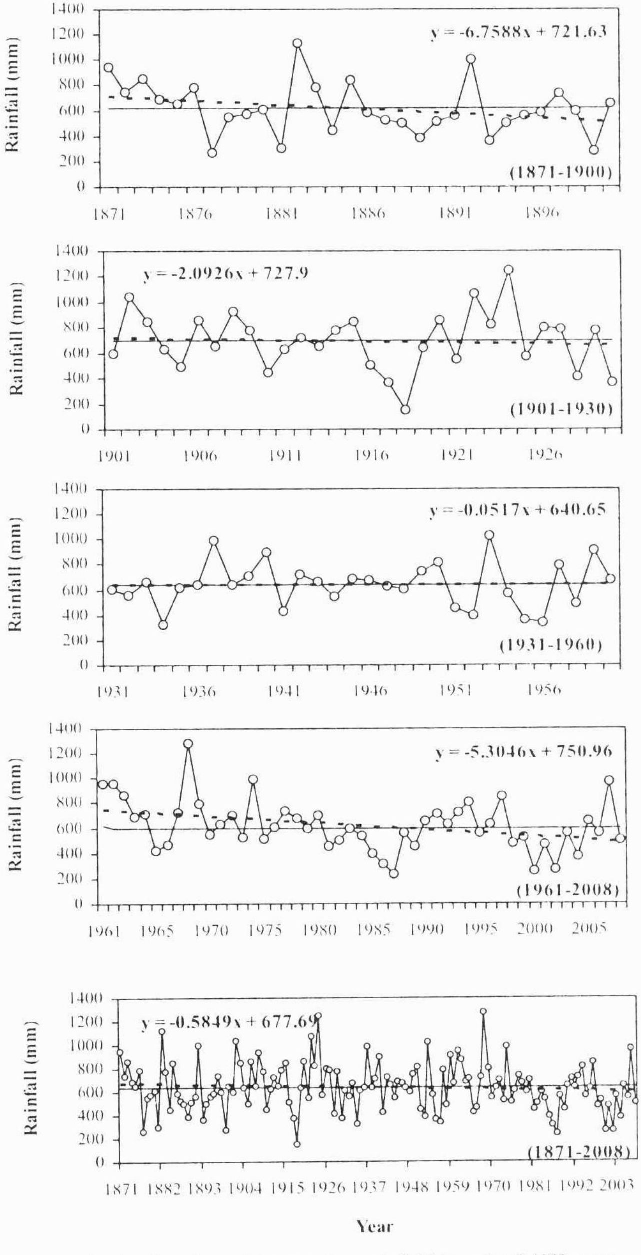


Fig.6. Southwest monsoon rainfall (mm) of different periods over Kerala during July from 1871-2008

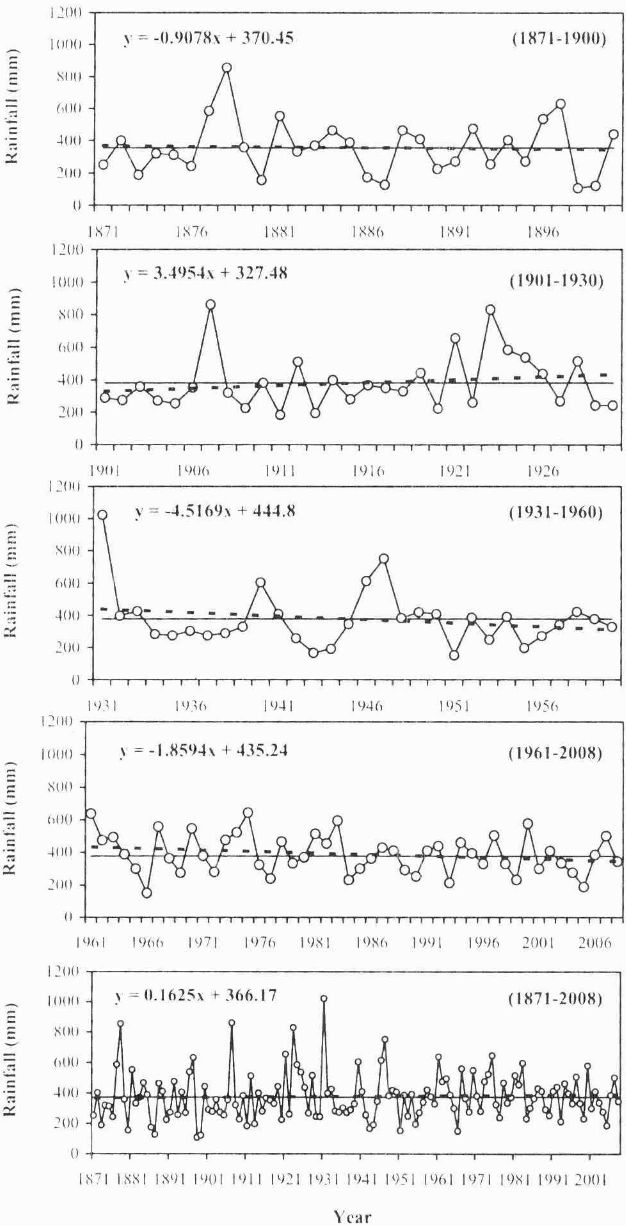


Fig.7. Southwest monsoon rainfall (mm) of different periods over Kerala during August from 1871 to 2008

1991 (45.8 mm). The monthly rainfall during September was also in increasing trend like in August. The inter-annual

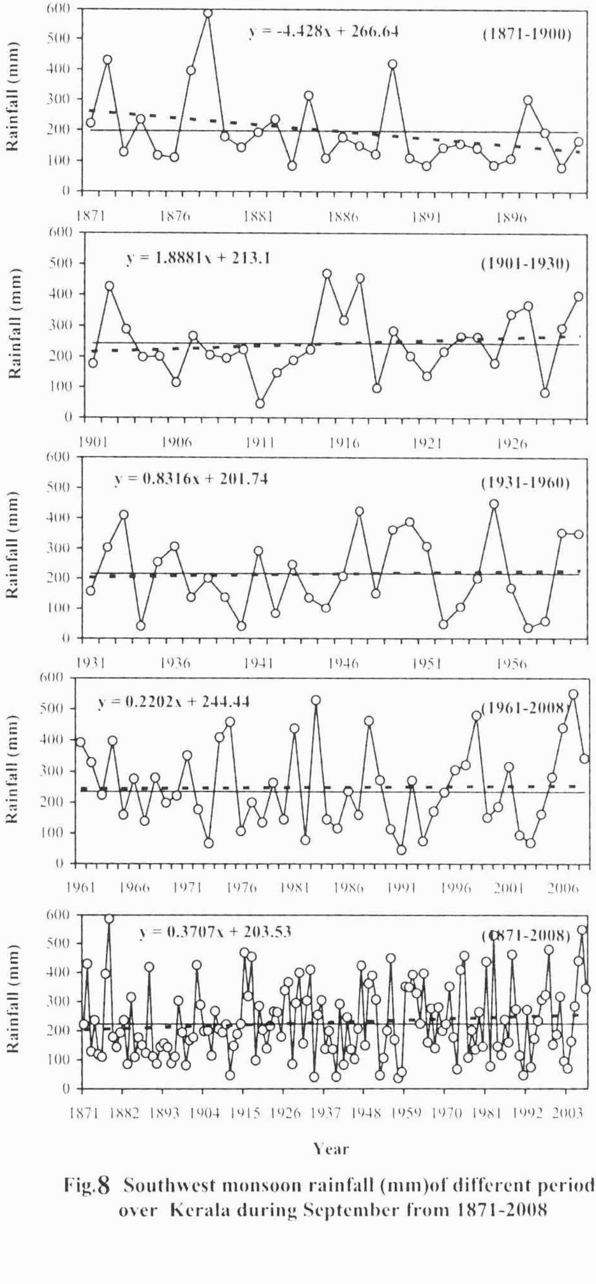


Fig.8 Southwest monsoon rainfall (mm)of different periods over Kerala during September from 1871-2008

variability was relatively high during 12871-1900 (CV-61.7%) when compared to that 1901-1930 (CV-44.4%), 19131-1960 (CV-59.7%) and 1961-2008 (CV-53.7%) (Fig. 8). The trend line indicated an increase of 51.2mm of rainfall over a period of time. However, the monthly rainfall was in declining trend in the sub-period 1871-1900 while increasing trend in other three sub-periods 1901-1930 and 1931-1960 and 1961-2008.

1.7 Rainfall during post monsoon over Kerala

The normal rainfall during post monsoon season over Kerala from 1871 to 2008 is 446.6 ± 138.4 mm. The season-wise rainfall distribution over Kerala indicated that 15.8 per cent of annual rainfall received during post monsoon season. The post monsoon rainfall is relatively undependable and the inter-annual rainfall variability is high as the coefficient of variation was 31.6 per cent when compared to that of southwest monsoon. It is more so in November as the coefficient of variation was 55.0 per cent (Table 7). The dependable rainfall during monsoon at 75 per cent level was 341.0 mm.

Table 7. Post monsoon rainfall (mm) during 1871-2008

	Rainfall (mm)		
	October	November	Total
Normal Rainfall (mm)	291.1	155.5	446.6
75 % probability	209.2	94.2	341.0
Standard Deviation	111.7	85.5	141.0
Coefficient of Variation (%)	38.4	55.0	31.6
Percentage contribution	65.2	34.8	-

Though the variation in inter-annual rainfall during northeast monsoon is significant, it was always within ± one standard deviation from the normal rainfall. A positive value of Mann-Kendall test statistic (2.2160) indicated that rainfall during post monsoon season had an increasing tendency which was significant at 5 per cent level. Such trend was more evident since 1961 onwards. It also showed through the trend line that an increase of 93.9 mm only was noticed during the study period of 138 years (Fig 9).

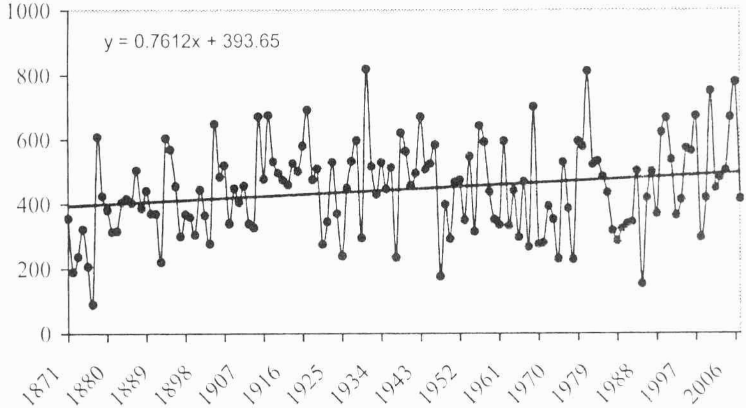


Fig. 9. Post monsoon rainfall (mm) over Kerala from 1871 to 2008

Out of 138 years, 25 years (1877, 1891, 1901,1902, 1910, 1912, 1914, 1920, 1930, 1932, 1939, 1943, 1946, 1955, 1956, 1960, 1966, 1975, 1977, 1992, 1993, 1999, 2002, 2006 and 2007) recorded excess rainfall when compared to that of normal. The highest rainfall was received in 1932 (848.0 mm), followed by 1977 (812.4 mm) and 2002 (791.0 mm). The lowest rainfall was received in 1946 (585.1 mm), 1956 (631.0 mm), 1960 (596.2 mm) and 1975 (596.3 mm) during the excess rainfall years. It revealed that rainfall during excess rainfall years varied between 631.0 mm and 848.0 mm.

Out of 138years, 22 years (1872, 1873, 1875, 1876, 1890, 1894, 1900, 1923, 1927, 1931, 1938, 1947, 1949, 1963, 1965, 1967, 1968, 1971, 1974, 1983, 1988 and 2000) recorded deficit rainfall when compared to normal. The lowest rainfall was received in 1876 (93.3 mm), 1988 (154.3 mm) and 1947 (177.4 mm). The highest rainfall was received in 1894 (333.4 mm), followed by 1963 (298.7 mm), 1931(296.3

mm) and 1949 (293.6 mm). It revealed that the rainfall during deficit years varied between 93.3 mm and 333.4 mm (Table 8).. There is marginal increasing trend post monsoon rainfall since 1961 onwards (Fig 10)

Table 8. Excess and deficit rainfall (mm) during Post monsoon from 1871-2008

Excess SW rainfall		Deficit SW rainfall		
Year	Rainfall (mm)	Sl. No.	Year	Rainfall (mm)
1877	683.8	1	1872	228.7
1891	670.4	2	1873	252.2
1901	693.8	3	1875	219
1902	631	4	1876	93.3
1910	672	5	1881	323.5
1912	697.2	6	1890	246.1
1914	654.7	7	1894	310.7
1919	643	8	1897	323.3
1920	707.3	9	1900	311.2
1925	634.6	10	1923	312.4
1930	679	11	1927	247.4
1932	848	12	1938	255.7
1942	643.3	13	1947	217.1
1943	690.2	14	1949	293.9
1946	806.2	15	1963	333.4
1955	654.9	16	1967	318.3
1966	756.7	17	1968	306.2
1972	645.3	18	1971	272.1
1977	828.2	19	1974	232.8
1987	632.9	20	1982	331.4
1993	741.9	21	1988	185.2
1999	673.7	22	2000	297.9
2002	751.6			
2006	670.5			
2007	779.2			

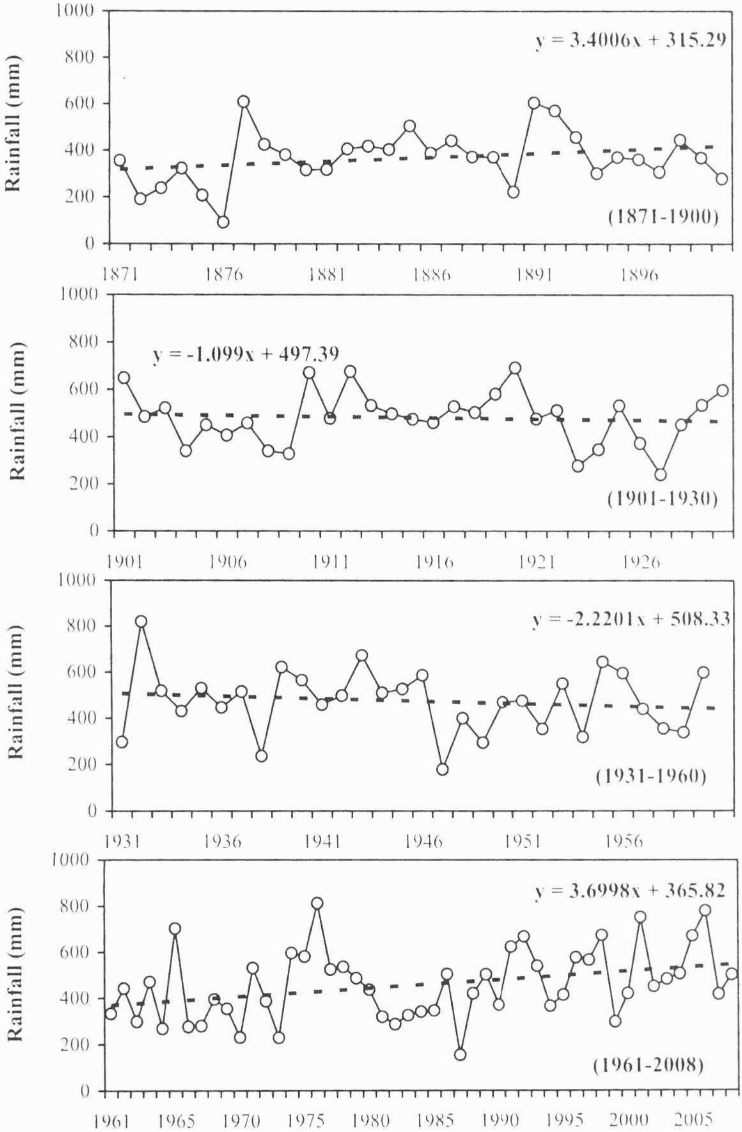


Fig. 10. Post monsoon rainfall (mm) of different periods over Kerala from 1871-2008

The occurrence of excess and deficit rainfall when compared to that of normal was seen in less equal number of years. As a whole, 34.1 per cent (47 years out of 138) of the years recorded either excess or deficit rainfall. The rainfall range and its variability was high during excess rainfall years when compared to that of deficit rainfall years.

Mann-Kendall test statistics revealed that the monthly rainfall during October and November was in increasing trend. Such trend was more evident since 1961 onwards. Overall, there was an increase of 105.1 mm in northeast monsoon rainfall over a period of time, indicating an increase of 23.5 per cent against the normal rainfall of 446.6 mm and significant at 5 per cent level.

1.8 Monthly rainfall during post monsoon over Kerala

October: The monthly rainfall of October during northeast monsoon was 291.1 ± 111.7 mm, contributing 62.4 per cent of seasonal rainfall. The monthly rainfall in three out of four years is likely to be 209.2 mm. The highest rainfall (595.0 mm) was received in 1999, followed by 1932 (569.8 mm). The lowest rainfall was received in 1876 (54.7 mm), followed by 1988 (82.3 mm), 1872 (97.1 mm) and 1881 (112.3 mm). The inter-annual variability was relatively high during 1871 to 1900 (Coefficient of Variation (CV) –43.6 %) when compared to that of 1961-2008 (CV-40.7%), 1931-1960 (CV-34.8%) and 1901-1930 (CV-31.8%). Rainfall during October was in increasing trend and an increase of 66.6 mm of rainfall was noticed over a period of time (Fig.11). It was more evident since 1961 onwards. Such phenomenon was also noticed before 1900.

November: The monthly rainfall of November during northeast monsoon was 155.5 ± 85.5 mm, contributing 34.8 per cent of seasonal rainfall. The monthly rainfall in three out of four years is likely to be 94.2 mm. The highest rainfall (379.8 mm) was received in 1977, followed by 1978 (375.5

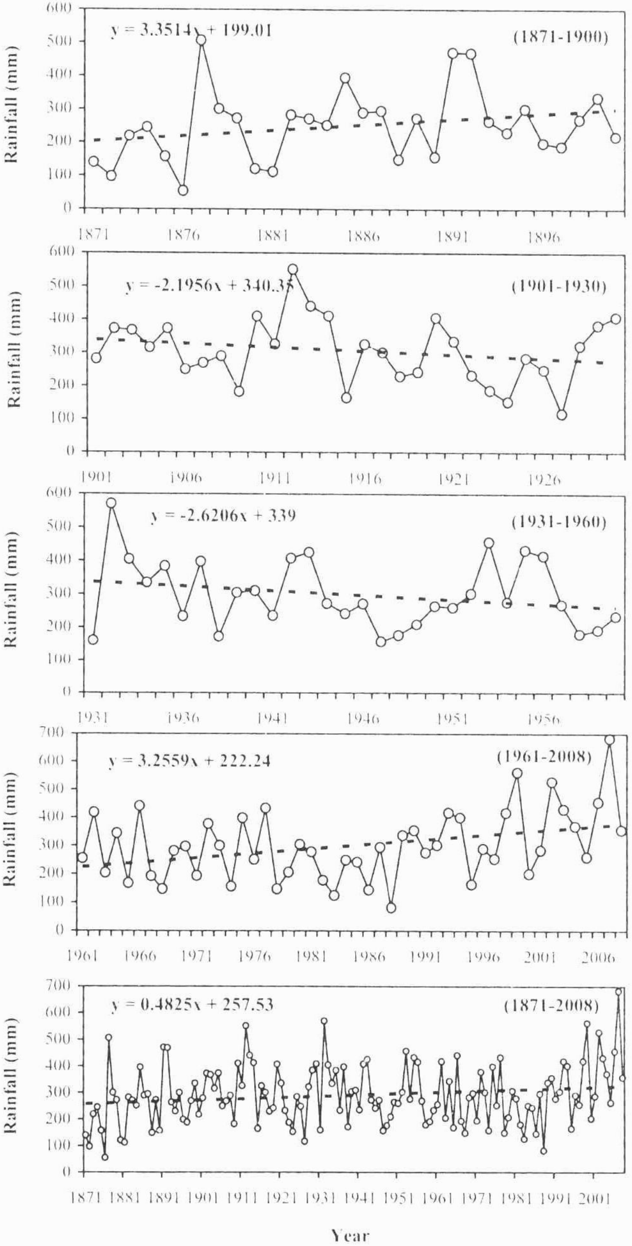


Fig.11. Post monsoon rainfall (mm) of different periods over Kerala during October from 1871 to 2008

mm) and 1901 (369.0 mm). The lowest rainfall was received in 1873 (19.0 mm), followed by 1947 (20.3 mm), 1904 (25.0 mm) and 1879 (32.0 mm). The inter-annual variability was relatively high (CV-59.2%) during 1961-2008 when compared to that of 1931-1960 (CV-50.2%), 1901-1930 (CV-50.1%) and 1871-1900 (CV-47.9%). As a whole, the rainfall trend in November was increasing over a period of time. The trend line also indicated an increase of 38.4 mm of rainfall (Fig 12). However, the increase in rainfall was less

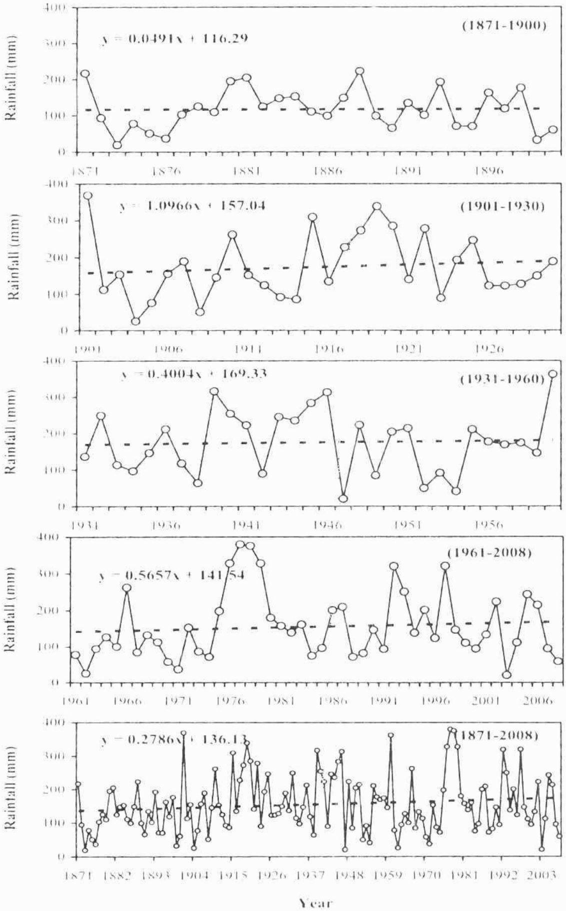


Fig.12. Post monsoon rainfall (mm) of different periods over Kerala during November from 1871 to 2008

pronounced in November when compared to that of October.

Long series of climatological data for 138 years over Kerala in the humid tropics of India indicate cyclic trend in annual rainfall with a declining trend in annual and southwest monsoon rainfall during the past 60 years. In contrast, there was an increasing trend in post monsoon rainfall, indicating likely shifts in rainfall patterns (Fig. 13).

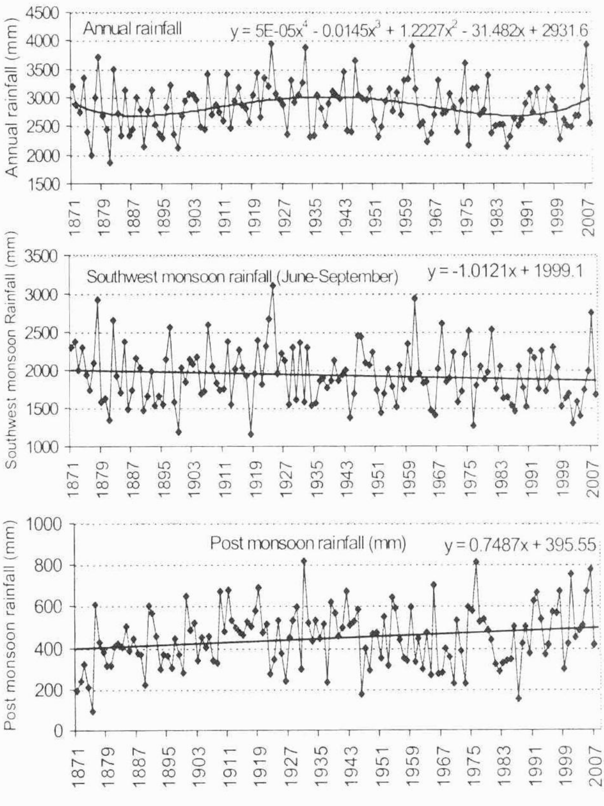


Fig. 13. Trends in rainfall over Kerala from 1871 to 2008

Though decreasing trend was noticed over Kerala as a whole, Haripad and Kasaragod showed increasing trend in annual and southwest monsoon rainfall. Similarly, Quilandi, Munnar, Hosdurg and Ponnani also showed increasing trend in annual rainfall. Unlike in temperature trends, rainfall trends are uncertain at several locations (Kumar *et al* 2002; Krishnakumar *et al.*, 2008 &2009; Rao *et al.*, 2008).

It revealed that the monthly rainfall during October and November was in increasing trend. Such phenomenon was more evident since 1961 onwards. Rainfall during November was highly variable and undependable.

1.9 Temperature trends in Kerala

The average annual maximum temperature varies from 30.4 °C at Trivandrum to 32.9° C at Punalur. Second high maximum temperature (32.4°C) was noticed at Palakkad in Kerala. On an average, the annual maximum temperature varied between 28.8°C during southwest monsoon while 32.8°C during summer (Table 9). Occasionally, the

Table 9. Season-wise surface air temperature (°C) at different locations in Kerala

Station	Maximum temperature (°C)				
	SWM	PM	Winter	Summer	Annual
Trivandrum	29.6	29.6	30.8	31.9	30.4
Punalur	30.8	31.9	34.0	35.2	32.9
Alappuzha	30.0	30.2	32.2	32.9	31.2
Kottayam	30.8	31.0	32.8	33.8	31.9
Cochin	29.5	30.8	31.7	32.4	31.0
Palakkad	30.2	30.7	33.4	35.9	32.4
Kozhikode	28.9	30.8	31.6	32.7	30.8
Pattambi	29.7	31.7	33.8	35.2	32.4
Ambalavayal	25.1	26.4	28.0	30.1	27.3
Pampadumpara	23.3	24.3	24.6	28.3	24.9
Average	28.8	29.7	31.3	32.8	30.5
	Minimum temperature (°C)				
Trivandrum	23.6	23.4	22.7	25.0	23.7
Punalur	22.7	22.1	20.7	23.3	22.3
Alappuzha	23.7	23.9	23.0	25.4	24.0
Kottayam	22.9	23.1	22.5	23.9	23.1
Cochin	23.9	23.9	23.1	25.5	24.1
Palakkad	22.9	23.0	22.2	24.7	23.2
Kozhikode	23.7	23.7	22.5	25.5	23.8
Pattambi	22.8	22.4	20.8	24.0	22.5
Ambalavayal	18.2	17.8	17.8	19.0	17.3
Pampadumpara	17.7	17.5	15.7	18.7	17.4
Average	22.2	22.1	21.1	23.5	22.1

day maxima crosses beyond 40° C over the Palakkad region in plains as noticed during summer 2004. The ever highest maximum temperature of 41° C was recorded on April 26, 1950 at Palakkad.

In the case of minimum temperature, it varies between 22 and 24° C across Kerala in plains and the mid-land regions. Across the highranges, where thermo-sensitive crops like cardamom, coffee, tea, black pepper and cocoa are grown, the annual maximum temperature revolves around 24-28°C while the night temperature around 17°C. The minimum temperature during winter varies between 15 and 18° C across the highranges while summer maximum temperature between 35 and 37°C in plains There was an increase in maximum temperature over Kerala by 0.64° C during the period of 49 years (Fig. 14), commencing from 1956 to 2004 while increase in minimum temperature was 0.23° C. Overall increase in annual average temperature was 0.44° C. A clear upward trend was noticed

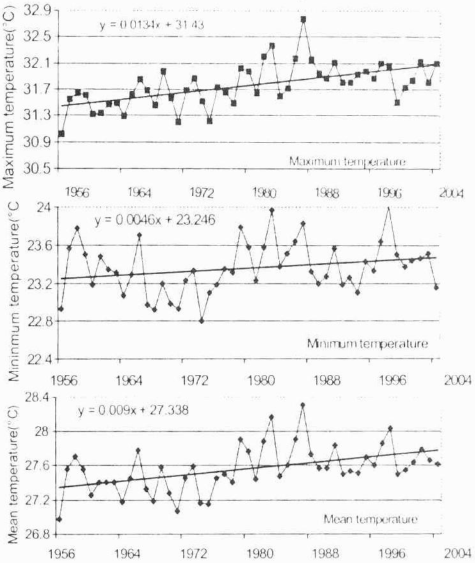


Fig. 14. Trend in maximum, minimum and mean surface air temperatures over Kerala

in surface air temperature in Kerala. The warmest (28.3°C) year over Kerala was in 1987, followed by 1983 (28.2°C). The highest annual maximum temperature over Kerala was recorded in 1987 (32.8°C) followed by 1983 (32.4°C) while lowest minimum temperature was recorded in 1974 (22.8°C) followed by 1968 (22.9°C).

Similar trend was noticed in the case of annual maximum temperature at Trivandrum, Kottayam, Punalur, Pampadumpara, Kochi, Alapuzha, Palakkad, Kozhikode, Ambalavayal and Kannur. Such trend was noticed not only in annual maximum temperature but also during all the seasons viz., southwest monsoon, post monsoon, winter and summer. Interestingly, the maximum temperature during winter at Palakkad was marginally in decreasing trend. Such trend was noticed in post monsoon season and summer at Ambalavayal also. In the case of minimum temperature, Trivandrum and Pampadumpara showed decreasing trend though overall increase was noticed across the State. The study revealed that the difference in maximum and minimum temperatures (temperature range) was increasing at some locations as the day maxima was increasing while decreasing night minimum temperature. It was more so where cardamom, tea and black pepper are commonly grown across the high ranges of Kerala in addition to warming Kerala as a whole. This trend was similar across the West Coast too, where warming is taking place.

2. Occurrence of summer droughts over Kerala

The State of Kerala experienced 72 summer drought years out of 138 (1871-2008), of which thirteen each moderate and severe, twelve large and thirty-four disastrous droughts. Though the decade 1881-90 experienced more number of droughts (nine), followed by 1971-80 (seven) the number of disastrous droughts was more (six) in 1981-90, indicating that the intensity of drought was height in 1981-90 (Table 10). None of the years fell under any category of

Table 10 occurrence and intensity of summer droughts in Kerala from 1871-2008

Decade	Intesity of drought				Total	Occurrence of droughts(%)
	Moderate	Large	Severe	Disastrous		
1871-80	0	0	1	5	6	60
1881-90	0	2	2	5	9	90
1891-00	0	1	1	2	4	40
1901-10	2	0	2	2	6	60
1911-20	1	1	1	2	5	50
1921-30	2	1	0	1	4	40
1931-40	0	1	1	1	3	30
1941-50	1	0	0	2	3	30
1951-60	0	1	0	1	2	20
1961-70	3	1	1	1	6	60
1971-80	3	2	1	1	7	70
1981-90	0	0	0	6	6	60
1991-00	0	1	2	2	5	50
2001-08	1	1	1	3	6	40
Total	13	12	13	34	72	52
Drought) Intesity(%)	18.1	16.7	18.1	47.2		

drought other than disastrous during the above decade. There was a gradual decline in number of drought years from 1901-10 (six) to 1951-60 (two) while increase from 1961-70 to 1991-2000. It varied between seven (1971-80) and five (1991-2000).

The percentage occurrence of disastrous fought was more (46.9%) across the State, followed by moderate and severe (18.1% each) and 16.7 percent only under the category of large droughts. It revealed that the intensity of drought was relatively high whenever droughts were noticed as majority of the years fell under the category of disastrous. Also, the intensity of drought was high in 1981-90, followed by 1871-80 and 1881-90. The march of aridity index over Kerala showed a marginal increasing trend 2.2% since last fifty years though such trend was not noticed for the study period as a whole. It appears that the intensity of drought was more in the recent decades, especially in 1981-90, as the aridity index was high (Figs. 15 and 16). Similar trend

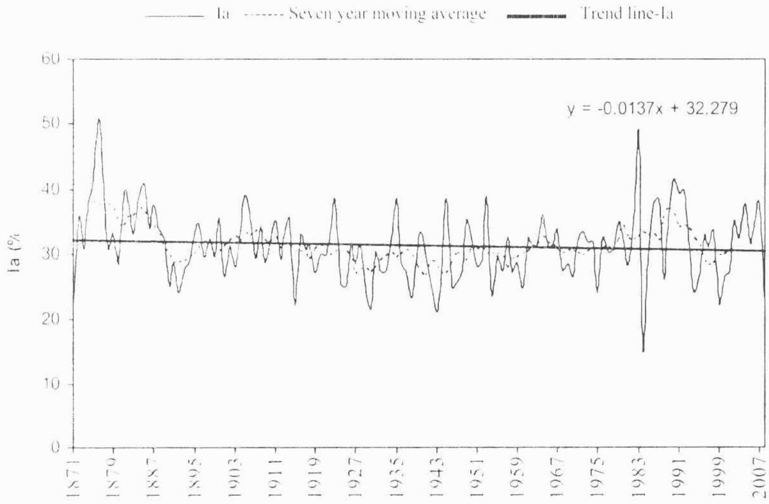


Fig.15 : March of aridity index(Ia) over Kerala during1871-2008

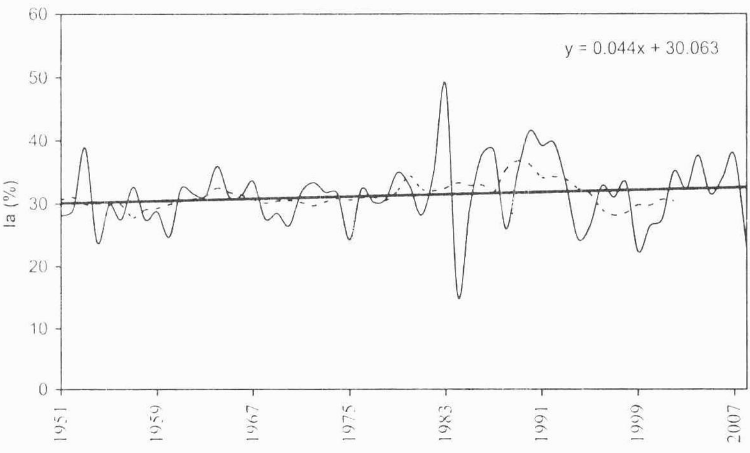


Fig. 16 : March of aridity index(Ia) over Kerala during1951-2008

was noticed between 1871 and 1890. The aridity index was increasing trend annually as well as seasonally except in monsoon towards north of Kerala. This was, more so, in case of summer (Rao, *et.al.* 1994).

3. Climate shifts over Kerala

Kerala States falls under the climate type of "B_4 to A per humid climate type in 38 years, indicated 27.5 per cent of the years on wetter side. In contrast, the State had shifted from B_4 to B_3, B_4 to B_2 and B_4 to B_1 in thirty one (22.5%), twenty six (18.9%) and five (3.6%) years respectively, indicating drier side in (45.0%) of the years. Only four years fell under per humid (A) since last 28 years (Table 11). The

Table 10 11. Climate shifts over Kerala from 1871 to 2008

Decade	Climatic type				
	B_1	B_2	B_3	B_4	A
1871-80	1	2	1	3	3
1881-90	0	5	1	2	2
1891-00	0	4	3	1	2
1901-10	0	2	1	5	2
1911-20	0	0	3	4	3
1921-30	0	1	1	4	4
1931-40	0	2	1	4	3
1941-50	0	1	1	4	4
1951-60	0	1	3	1	5
1961-70	1	0	5	1	3
1971-80	0	3	1	3	3
1981-90	2	1	5	1	1
1991-00	0	2	2	5	1
2001-08	1	2	3	0	2
Total	5	26	31	38	38
Climatic Shifts (%)	3.6	18.9	22.5	27.5	27.5

moisture index was also in decreasing trend (-19.2%) from 1951 to 2008, indicating that the climate shifted from B_4-humid to B_3, B_2 and B_1- humid in recent decades thought there was no such trend for the period as a whole (Figs. 17 and 18). It revealed that the State of Kerala experienced

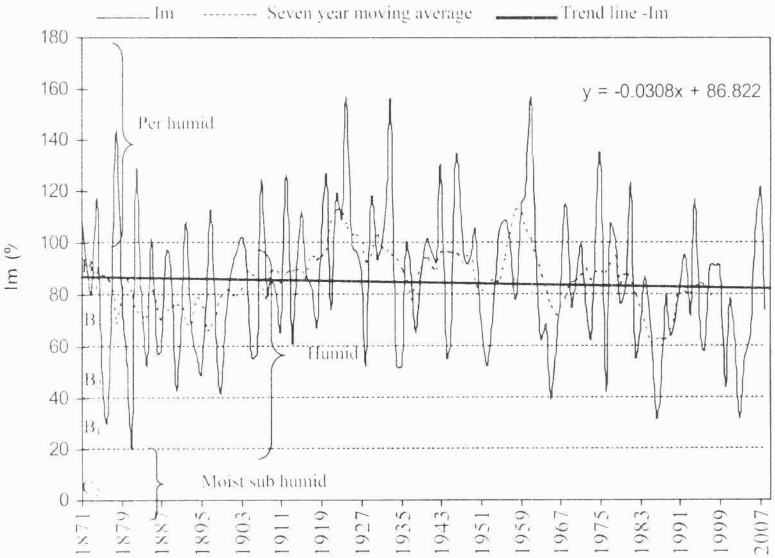


Fig. 17 : March of moisture index (Im) over Kerala during1871-2008

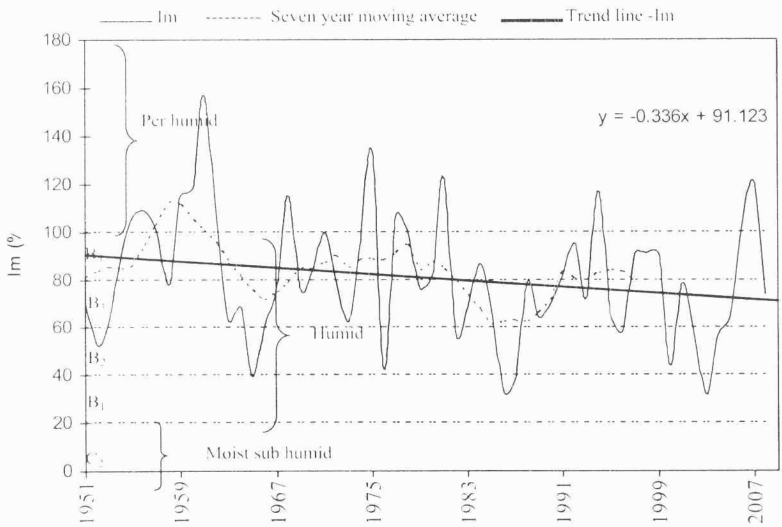


Fig. 16l8 Yearly march of moisture index (Im) over Kerala during1871-2008 from wet to dry within the B category of climate types in recent decades. The climate shift towards drier side was more in the decade 1981-90 as only one year recorded normal climate type (B_4) while eight years between B_3 and B_1 of drier side. Such trend was seen before 1900. However, 1981-90 was a typical one as only one year was seen on wet side (perhumid). If it is studied on seasonal basis, the scenario of climate shifts will be different. Majority of years fell under semi arid and arid climate types during winter and summer months towards northern districts of Kerala (Rao, *et.al.*1994).

4. Climate variability and Indian foodgrains

The Indian economy is mostly agrarian based and depends on onset of monsoon and its further behaviour. The year 2002 was a classical example to show how Indian foodgrains production depends on rainfall of July and it was declared as the all-India drought, as the rainfall deficiency was 19% against the long period average of the country and 29% of area was affected due to drought (Fig. 19). The All-India drought is defined as the drought year when the rainfall deficiency for the Country as a whole is more than 10% of normal and more than 20% of the

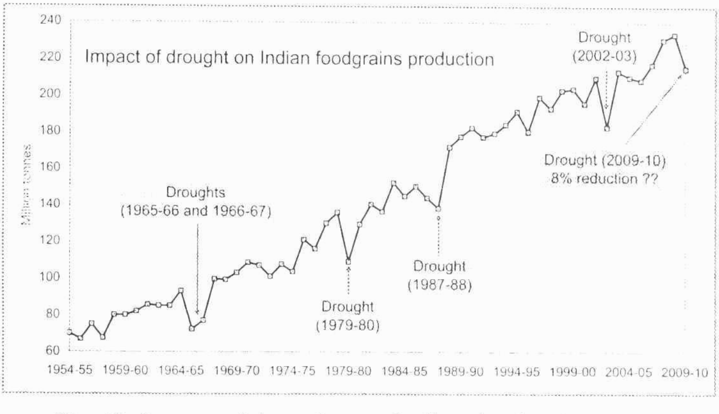


Fig. 19 Impact of droughts on Indian foodgrains production from 1950-51 to 2009-'10

Country's area is affected by drought conditions. The *kharif* foodgrains production was adversely affected by a whopping fall of 19.1% due to all – India drought during monsoon 2002. Similar was the case during all-India drought in 1979, 1987 and 2009. It reveals that the occurrence of droughts and floods during Southwest monsoon across the Country affects foodgrains production to a greater extent as evident. On regional scale also, the adverse affect on foodgrains production is significant due to occurrence of droughts and floods. They devastated rice and other crops in Andhra Pradesh and 40% cereal production was affected in Karnataka in 2006. Similar was the situation in September 2009 in the above states due to unprecedented floods.

It is one of the reasons that the food grains production is not in tune with plan estimates and likely to touch only a maximum of 260 million tonnes by 2020 (Fig. 20) at the

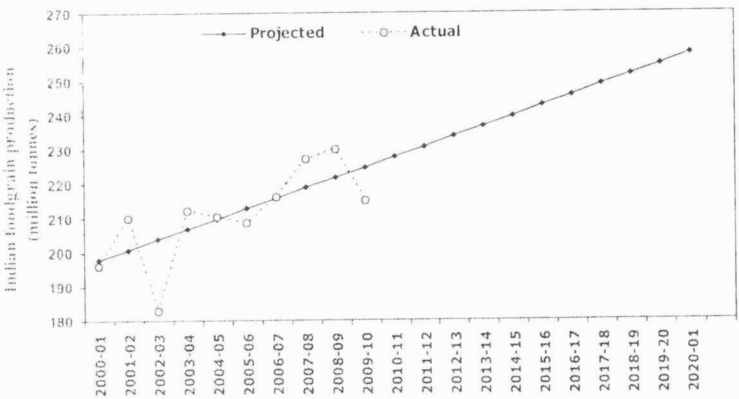


Fig. 20 Projected Indian foodgrains production from 2000-01 to 2020 - 21

present rate though it is projected as more than 350 million tonnes to declare India as one of the developed countries. Hence, there is a need to augment stagnated crop productivity under the diminished agricultural land conditions through a sort of second green revolution with concerted R&D activities in the field of Agriculture to feed the ever growing population without importing foodgrains from outside under the projected climate change scenario. The crop production is likely to decline by 30 per cent over India by 2080 A.D. according to UNIDA.

The occurrence of droughts and floods may be having direct impact on animal agriculture also like poultry as non availability of feed may lead to low egg production and mortality. Like floods and droughts, the occurrence of heat waves on poultry is detrimental as low intake of feed due to high maximum temperature lead to low egg production. The production was less by 20.9% in poultry egg due to increase in maximum temperature by 2-8° C during March 2004 in Himachal Pradesh (Rajendra Prasad and Ranbir Rana, 2006). According to Natarajan (2006), mortality is high when birds are suddenly exposed to heat wave conditions (air temperature touching mercury mark of 38° C and above) but it may not be the case when acclimatization to higher temperature is gradual or when protective measures are adapted anticipating the heat wave. Such high temperatures prevail in the central part of Kerala as noticed recently in summer 2004 when severe drought occurred. The requirement of egg production by 2020 in India is just above 30 million tonnes in addition to the requirement of other crop and animal food as per the ICMR dietary requirements for a balanced diet in tune to the expected human population increase (Table 12). It is to be achieved against the projected global warming of around 1° C by 2020 at the current level of increase in CO_2, which may lead to frequent occurrence of heat and cold waves and floods and droughts. They adversely affect poultry health and production including egg and meat production. Therefore, there is urgent need to climate change adaptation strategies in animal agriculture like poultry production under projected climate change scenario. As a part of

Table 12 Production requirements by 2020 to meet the balanced diet norms

Crops	Requirement per day in gms	Requirement in million tonnes		
		2000	2010	2020
Cereals and millets	420	198.7	237.4	280.99
Pulses and legumes	40	18.92	22.61	26.76
Foodgrains	460	212.62	260.01	307.75
Roots and tubers	75	35.48	42.39	50.18
Vegetables	125	91.66	109.52	129.62
Fruits	50	36.66	43.81	51.85
Milk	150	70.96	84.79	100.35
Fats and oils	22	10.41	12.44	14.72
Sugar	30	14.19	16.96	20.07
Egg	45	21.29	25.44	30.11
Meat	25	11.83	14.13	16.73
Fish	25	11.83	14.13	16.73
Population (millions)	-	1004.5	1200.17	1420.54

adaptation strategy, farmers are advised to look into housing design to cope up with weather extremes as a pro-active measure. Increase diet energy, stimulate feed intake, body energy reserve, wet mash feeding, protein level correction with minerals and vitamins supplement, electrolyte balance, provision of cool water with nipple type and advance planning in diet change are some of the adaptation strategies against high temperature according to Natarajan (2006). Under high humid and rainfall conditions, sufficient stocking of the grains, good drying facilities and quality measures (mycotoxin estimation) will not only safeguard the birds from a possible outbreak of mycotoxins but also minimize the loss through reduced egg production and poor feed conversion. Poultry breeders should produce genotypes which can tolerate higher levels of both biotic and abiotic stresses through appropriate bio-safety and bio-security measures, mining and blending of desired genes from wild and native poultry populations or from other animals including microbes, selection of poultry for disease resistance, efficient feed conversion and tolerance to humid and hot climatic conditions according to Yadav (2009). However, animal agriculture requires immediate and substantial changes in regulation of production practices and consumption patterns as emissions of GHGs are likely to increase and thus leading to global warming.

5. Weather abnormalities and the global food price

The global food price increase is the concern due to frequent occurrence of weather abnormalities like floods and droughts. The foodgarains production is not in tune with the demand whenever weather related disaster took place. The Indian foodgrains production is not in tune with the plan estimates in recent years as several parts experience floods and droughts or heat and cold waves. It was attributed to global warming. In addition, it appears that some of the lands cultivable under foodgrains are shifted to biofuels across the world. It aggravated the availability of foodgrains, resulting in escalation of food price world over. For example, African countries were the worst hit in 2004-05 due to drought while floods in 2007. The crop loss varied between 40 and 90% in West African countries depending upon the severity of drought in 2004-05. World cereal output in 2005 was lowered due to adverse hot and dry weather and drought also hit crops in parts of the European Union.

Protest against price rise of essential commodities

Australia and other wheat growing countries suffered heavily in 2006 due to unprecedented drought and the wheat production was only half of the mark in 2006 as against 20-25 million tonnes normally produced in Australia. India, Bangladesh, China and other countries in Southeast Asia, too suffered due to frequent floods and droughts since last one decade, where rice is produced largely. As a result, the food price escalated world over. At the regional level, unusual summer rains in southern States of India resulted to heavy loss in paddy crop and vegetables during 2008. The price of both the commodities was very high locally. On an average, the current price of these food items is more by 50-70% in 2009 when compared to that of the food prices in 2007. Even in 2007, prices were soar due to scarcity of foodgrains world over. It was attributed to rising demand for foodgrains and the impact of climate change. The global price rise led to additionally more than 50 million people world over below poverty threshold as per the latest FAO Report. One side, the farmers agitate for better price and on the other consumers need to pay heavy price for food. This scenario becomes acute when weather related disaster took place. Therefore, there is an urgent need to tackle the issue on war-footing and to take feasible steps for sustenance of foodgrains production and food security so as to stabilize food price under a projected climate change scenario. The projected climate change scenario indicates that the frequency of weather abnormalities like floods and droughts and heat and cold waves are likely to increase in ensuring years and food insecurity is likely if corrective pro-active measures are not taken up by the various political governments against weather related disasters.

6. Climate variability and rice production in Kerala

The State of Kerala also experiences decline in annual and monsoon rainfall and increase in temperature. The mean annual maximum temperature over Kerala has risen by 0.6°C, the minimum temperature by 0.2°C and the average by 0.4°C between 1956 and 2004. Increase in maximum temperature and decrease in minimum temperature were also noticed at several locations and thus there is a threat to thermosensitive crops and animal agriculture like poultry. The maximum temperature shot even up to 40 °C in Palghat during February, 2004 due to absence of rains from November, 2003 onwards. The ever highest maximum temperature of 41° C was recorded on April 26, 1950 at Palghat. The year 1987 was the warmest year over Kerala. The decade 1981-90 was the driest decade over Kerala due to failure of northeast monsoon and pre-monsoon showers during summer. Severe summer droughts were noticed in 1983 and 2004, led to abnormal increase in maximum temperature during summer during the above two years. In contrast, the monsoon behaviour in 2007 was totally different to that of previous years and heavy rains were noticed from June to September, led to floods in low lying areas. The paddy crop in Kuttanad belt was flooded and the final crop productivity as well as production was less. The average yield of paddy in farmers' fields of Kuttanad, which is one of the rice bowls of Kerala, was only 3.0 t/ha as against the expected harvest of 5.0 t/ha. Out of 9,118 ha of total cultivated land, 5623 ha of paddy was damaged in the Alappuzha belt of Kuttanad alone in Kharif 2007 due to floods. The prolonged rains also led to delay in "puncha sowing (second crop). The high acidic nature and

salinity of the Kuttanad soil were intensified due to floods and bund breaches during the monsoon season. To add to this monsoon fury, the unusual summer rains from 13-23rd March, 2008 also devastated the paddy production to a considerable extent in Alleppey District and Kole lands of Thrissur District. More than one lakh tonnes of paddy were the loss during 2007-08 due to occurrence of floods and unusual summer rains (Fig. 21).

The State of Kerala has always been a food deficit State as it produced only 45 per cent the rice it needed even in 1950s. The deficit gradually rose to 76 per cent in the end of last century and now it is 85 per cent. It was attributed to decline in paddy lands and other socio-economic factors

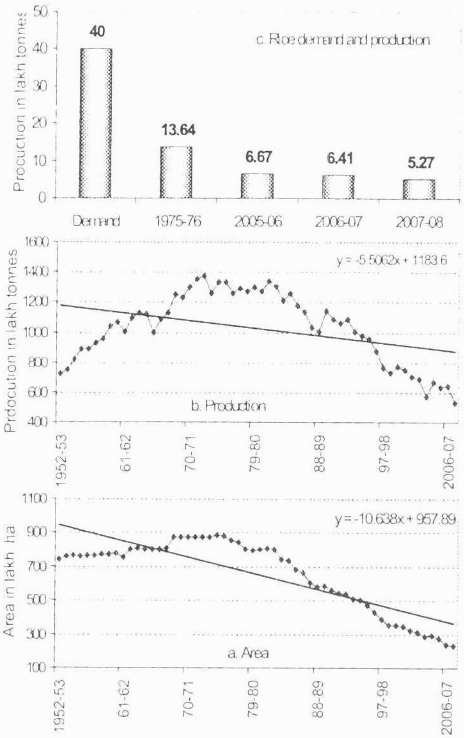


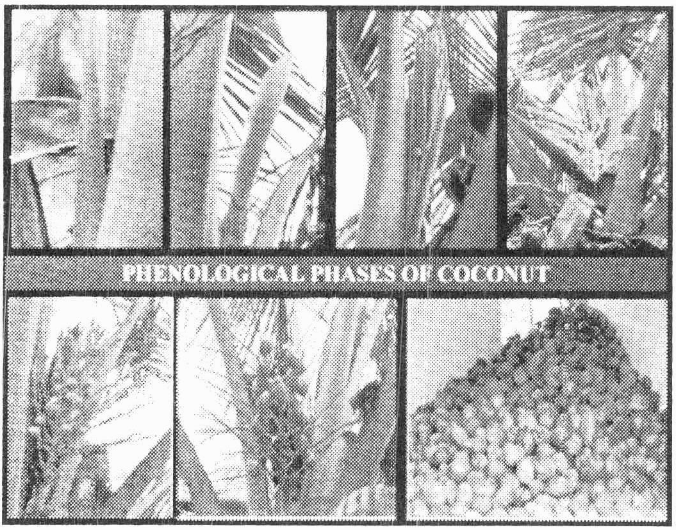
Fig. 21. Trend in area and production of paddy over Kerala from 1952-53 to 2007-08

in addition to the occurrence of floods. The area under paddy cultivation was 7.6 lakh hectares in 1950s and it is now only 2.5 lakh hectares. Decrease in wetlands might be also one of the reasons for frequent floods during rainy season and summer droughts in recent years, resulting in food crisis and price rise when such weather phenomena occur and re-occur. A clear shift was noticed from foodgrain crops to non-foodgrain crops in Kerala over a period of time due to various reasons. Increase in area under coconut, arecanut, banana, black pepper and rubber was noticed at the cost of phenomenal decline in rice area. It resulted in wide difference between production and demand of rice in addition to frequent floods in monsoon season and droughts during summer season. The prolonged wet spell in *kharif* 2007 and unusual rains in 2008 devastated the paddy production to a large extent.

Though Kerala stood first in cashew production a decade ago, at present it occupies only fourth position and likely to go down further. It was due to steady decline in cashew area and also occurrence of weather aberrations during the reproductive phase of cashew. Area under tea was also declining along the high ranges. Crop projection models outside India indicate that a rise of 2° C in temperature is likely to affect the area under tea and coffee adversely. Aberrations in blossom and backing showers adversely affect coffee production to a great extent. Lack of backing showers during summer 2009 over Wayanad district is likely to reduce considerably crop output in coffee. Almost all the plantation crops suffered to a great extent in 1983 and 2004 due to disastrous summer droughts. Increase in maximum temperature of 1-3° C during summer 2004 adversely affected thermo-sensitive crops like black pepper and cocoa (Rao *et al.,2008)*. Deforestation and decline in wetlands along with the high intensity of rainfall may lead to frequent occurrence of floods and droughts and their ill effects on all the crops will be manifested much more in addition to human and property losses. Therefore, it is high time to have climate change adaptation strategies to mitigate ill effects of weather aberrations and sustain crop production under projected climate change scenario as a part of food security. Special attention is to be given in this direction to the thermo-sensitive crops like black pepper, cardamom, tea, coffee and cocoa also as temperature range (the difference between maximum and minimum temperatures) is likely to increase and rainfall is likely to decline along with deforestation as these crops grow under the influence of typical forest-agro-ecosystems.

7. Climate variability and coconut production

The coconut productivity of Kerala (humid tropics) is relatively low (6889 nut/ha as against 7747 nuts/ha of the national average) though the total coconut production of the State is high, contributing 38.3% to all India coconut production. Low productivity is attributed to several factors, viz. high rainfall during monsoon, insignificant rainfall in several parts of Kerala during summer months, lack of irrigation during summer, poor nutrient status of soils, lack of agronomic practices, prevalence of dreaded root wilt



disease in problem zone of Kerala, incidence of stem bleeding in northern zone, of late attack of coconut mite in central zone and farmers' reluctance in application of fertilizers due to uneconomic price offered to coconut growers. The seasonal and annual variations in coconut production is mainly attributed due to dry spells within the monsoon and soil moisture deficiency from December to May, if pre-monsoon showers fail, which is not uncommon in humid tropics under rainfed conditions. The severity of soil moisture deficiency is more towards northern districts of Kerala due to uni-model high rainfall, followed by prolonged dry spell for four to six months. Of course, the soil moisture status depends not only on soil type but also on topography, which is a significant feature in Kerala as coconut cultivation is seen in low land, mid land and high lands. The failure of pre-and-post-monsoon rains led to disastrous droughts over Kerala in 46.9 per cent of the years while it was 46.4 per cent towards north of Kerala with reference to coconut when the severe and disastrous droughts put together (Rao, *et.al.*1997). The decline in coconut production over Kerala during 1983-84 was 18% due to disastrous drought during summer 1983 (Fig. 22).

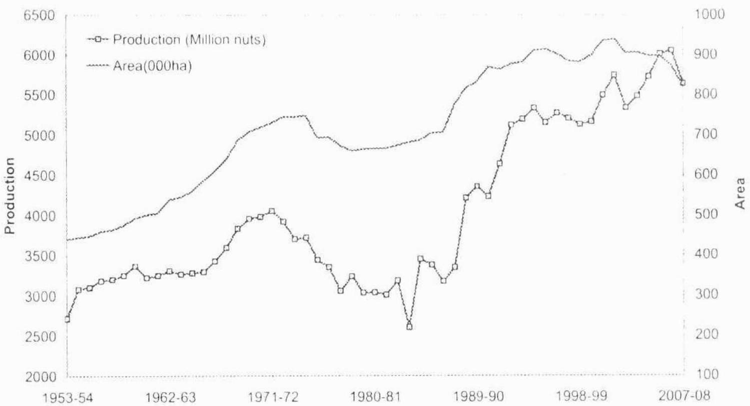


Fig 22 Area and production of coconut in Kerala from 1943-44 to 2007-08

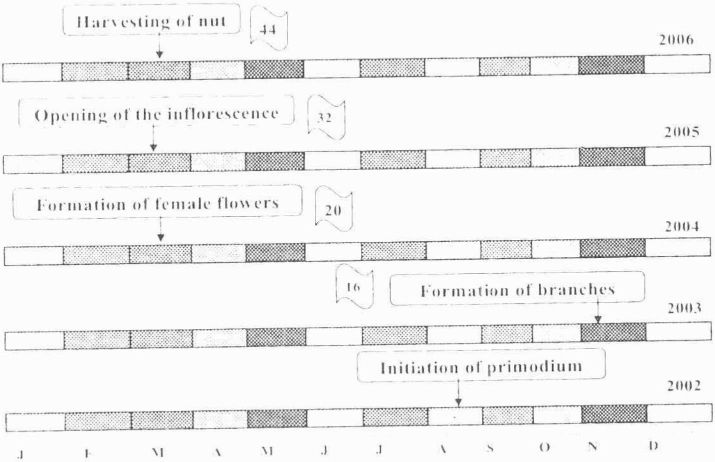
The average percentage decline in coconut yield during the subsequent year due to disastrous drought was 41.6 though it varied between 28.2 and 49.8 in disastrous drought years, viz. 1968-69, 1972-73, 1982-83, 1988-89 and 1990-91. The decline in yield was seen in all the subsequent years due to disastrous droughts during summer while the decline in nut yield was seen in 60% of the years under the category of severe drought. The average decline in nut yield was 25.1 percent during the above years (Table 13), classified under

Table 13 Intensity of drought and percentage decline in nut yield from 1961 to 1992 at RARS Pilicode

Intensity of drought	Drought years and climate type	Nut yield in the subsequent year	% decline over the previous year
Disastrous	1968 - 69 (EW ES)	76, 845	38.19
	1972 - 73 (EW DS)	1, 36, 702	28.20
	1982 - 83 (EW ES)	1, 17, 090	47.80
	1988 - 89 (EW ES)	1,18, 595	49.80
	1990 - 91 (EW DS)	1,15, 035	43.78
Average percentage decline			41.55
Severe	1960 - 61 (EW)	74, 708	20.65
	1963 - 64 (EW ES)	1, 02, 702	19.4
	1971 - 73 (EW DS)	1, 90, 381	-
	1974 - 75 (EW DS)	1, 51, 378	13.72
	1975 - 76 (EW DS)	1, 98, 277	-
	1978 - 79 (ES)	1, 44, 666	17.19
	1984 - 85 (EW DS)	1, 22, 985	42.75
	1985 - 86 (DW ES)	2, 19, 970	-
	1986 - 87 (DW ES)	1, 38, 753	36.92
	1989 - 90 (EW)	2, 04, 628	-
Average percentage decline			25.11

severe droughts. If the intensity of drought is low viz., large and moderate, the decline in nut yield during the subsequent year is not definite and yield decline did not exhibit in all the subsequent years unlike in case of disastrous drought years ((Rao, *et.al.*1994). During the disastrous drought years, the climate type was arid in both winter (December to February) and summer (March to May) or arid during winter, followed by semi arid during summer. It was also the case in four years (1971-72, 1974-75, 1975-76 and 1984-85) under the category of severe drought. It clearly indicated that the coconut yield was poor whenever the climate shifted continuously to arid for six months or arid for three months, followed by semi arid and vice versa under disastrous and severe droughts in the humid tropics. Of course under severe drought category, it always may not be true as noticed in 1971-72, 1975-76, 1985-86 and 1989-90.

In semi arid tropics with arid seasonality coconut yield will be poor and uneconomic under rainfed conditions. That is the reason, why, coconut is grown only under assured irrigated conditions in Tamil Nadu, Karnataka and Andhra Pradesh, which fall under semi arid climate. Since the crop is irrigated round-the-year during dry spells, the coconut productivity is much higher in Tamil Nadu and Andhra Pradesh. At the same time, heavy crop loss was reported in semi arid tropics due to monsoon failure in 2002 and lack of irrigation due to poor water recharge in wells. Drought during summer 2004 also adversely affected coconut yield to some extent over Kerala. It resulted to severe crop loss to the tune of 9.0 ha of coconut, 14.0 ha arecanut, 6.0 ha banana, 80.0 ha black pepper and 6.0 ha of nutmeg from the catchment area of Pananchery alone (Thrissur District). The overall crop loss was estimated as more than Rs1300 crore due to severe drought during the summer, 2004. Some crop projection models in coconut indicated that the global warming is unlikely to affect coconut



Primodium initiation to harvest in coconut takes about 44 months

production in Kerala. However, global warming is likely to increase the occurrence of floods and droughts, which affects coconut production as seen in the past. Therefore, no crop is safe from projected climate change scenario directly or indirectly.

8. Coconut estimates of Kerala based on agroclimatic indices

In an unique paper, Patel and Anandan (1936) explained that the annual coconut yield is influenced by January to April rains fro two years, previous to harvest together with the rains in January to April of the year of harvest. Abeywardena (1983) predicted coconut yield of Sri Lanka one year ahead based on drought index. Rao (1982 and 1986) revealed that the effect of high rainfall from June to September, followed by prolonged dryspell during summer in the humid tropics adversely affect the coconut production in the following year.

Based on the experimental data on coconut yield, an attempt was made to estimate coconut yield seven months ahead using agroclimatic indices (Rao and Subash, 1996). Looking at the long reproductive phase of more than three-and-a-half years from primodium initiation to final harvest in coconut, a multiple linear regression was developed for estimating coconut production for the State of Kerala using the secondary data of coconut production and derived agroclimatic indices from 1949-50 to 1993-94. The equation accounts for 97 percent variability in coconut production ((Rao, *et.al.*1999). Using the equation, the coconut production of the State was being estimated since 1994-1995 onwards. The actual and predicted coconut production over Kerala from 1994-95 to 2008-09 is given in Table 14. It was

Table 14. Actual and estimated coconut production of Kerala from 1994-95 to 2008-09

Year	Coconut production of Kerala in million nuts		
	Actual	Predicated	Percentage deviation over actual
94-95	5335.00	5109.77	-4.2
95-96	5155.00	4943.62	-4.1
96-97	5774.00	5444.18	-5.7
97-98	5209.00	4651.20	-10.7
98-99	5132.00	3942.11	-23.2
99-2000	5167.00	5963.85	15.4
2000-01	5496.00	4804.35	-12.6
2001-02	5744.00	5289.00	-7.9
2002-03	5338.00	4654.00	-12.8
2003-04	5876.00	1595.00	-72.9
2004-05	5727.00	3820.00	-33.3
2005-06	6326.00	7290.00	15.2
2006-07	6054.00	6120.00	1.1
2007-08	5641.00	6519.00	15.6
2008-09		6441.00	

less than six percent during 1994-95 (-4.2%), 1995-96 (-4.1%) and 1996-97 (-5.7%). Since 1996-97 onwards, the difference was always less than 16 per cent except in 1998-99 in which, the coconut production was underestimated by 23.2 per cent. Though the model performed extremely well in many years, it failed in 2003-04 and 2004-05. Abnormal deviation was noticed in 2003-04 (72.9%) and 2004-05 (33.3%) due to unprecendented erratic monsoon in 2002 and 2003. It appears that the model needs to be revalidated with the data of recent years during which monsoon uncertainities were abnormal.

9. Climate variability and coconut price

Weather aberrations may lead to increase in food price globally as noticed currently. Of course, the food price fluctuation is a complex one and depends on several internal and external factors in addition to weather aberrations. A steep increase in coconut price was seen in 1984 due to low coconut production Kerala as a result of summer drought in 1983 and for the first time, the coconut growers got a high premium of more than Rs.2200/- per quintal of copra. Under open action sale, on an average Rs.3.07 per coconut was obtained at the Regional Agricultural Research Station, Pilicode in 1984 as against Rs.170/- per nut in 1983 (Table 15). Such trend was seen in lean crop years. Price hike was noticed from 2002 to 2007 also as huge number of coconut palms withered in Tamil Nadu due to all India drought 2002.

Table 15. Climate variability and coconut price (RARS, Pilicode)

Year	Price of coconut in Indian Rupees			Year	Price of coconut in Indian Rupees		
	Highest	Lowest	Average		Highest	Lowest	Average
1979	1.10(March)	0.99(July)	1.03	1993	3.20 (July)	3.90	4.51 (Jan)
1980	1.64 (Oct)	1.46 (Dec)	1.50	1994	2.51 (Sep)	2.77	3.71 (Dec)
1981	1.65 (May)	1.06 (Oct)	1.31	1995	2.75 (Jan)	3.00	3.45 (Dec)
1982	1.40 (Dec)	1.00 (Jan)	1.18	1996	3.00 (Aug)	3.86	5.82 (Dec)
1983	2.10 (Sep)	1.30 (May)	1.70	1997	4.21 (Sep)	4.82	5.67 (Jan)
1984	3.50 (June)	2.10 (Jan)	3.07	1998	3.77 (Sep)	4.00	4.45 (April)
1985	2.27 (Feb)	1.30 (Nov)	1.69	1999	3.75 (Jan)	4.91	5.70 (July)
1986	2.25 (Nov)	1.30 (Nov)	1.69	2000	2.4 (Oct)	3.22	4.56 (Jan)
1987	2.25 (Nov)	2.30 (Jan)	1.89	2001	2.46 (Feb)	3.00	3.60 (Dec)
1988	3.20 (Dec)	2.30 (Jan)	2.56	2002	4.00 (April)	4.37	4.62 (Dec)
1989	2.15 (May)	1.72 (Oct)	1.93	2003	4.30 (May)	4.93	5.62 (Oct)
1990	3.00 (Dec)	1.78 (Jan)	2.26	2004	5.26 (May)	5.58	5.90 (Aug)
1991	3.80 (Feb)	1.10 (May)	3.15	2005	3.81 (Nov)	4.66	5.50 (April)
1992	4.20 (March)	3.85 (May)	3.98	2006	3.13 (July)	4.07	5.00 (Feb)

Current low price of coconut is the concern of coconut growers of Kerala. Of course, the coconut price in Kerala depends on several factors viz. import-export policy, total coconut production outside Kerala, less edible oil consumption and coconut oil use in industries as several substitutes are used in place of coconut oil. Import of palmolene oil may be one of the major contributing factors in declining coconut oil price. Of course, the aim of the author is to highlight the role of climate variability on food price as noticed currently due to weather abnormalities and as such the subject area of food price and production and vice versa is beyond the scope of the study on "climate variability and food security".

Summary

There was no change in normal onset on monsoon (1^{st} June ± 7 days) over Kerala, know as Gateway of Indian monsoon. It ranged from 25^{th} May to 8^{th} June over the period from 1870 to 2009. There was a delay in onset on monsoon (4^{th} June) during 1901-1930 when compared to that of 1870-1900, 1931-1960 and 1961-2009. 1901-'30 was the only period during which rainfall increase was seen in the monsoon season.

The earliest onset of monsoon was on 11^{th} May in 1918 while the belated monsoon on 18^{th} June in 1971. It is in confirmation with the findings of Ananthakrishnan and Soman (1988 and 1989). There was no abnormal deviation in onset of monsoon.

The onset of monsoon in recent years was early only in 1990 (19^{th} May) and 2001 (23^{rd} May), which occurred after a lapse of 20 years (17^{th} May in 1969). It was true in 2004 (18th May), 2006 (26th May) and 2009 (23rd May). All the above years recorded below normal or normal rainfall. It appears that the monsoon rainfall is likely to be deficit or normal rather than excess if the monsoon is early while no such trend if the monsoon is late. Also, there was no trend in monthly rainfall when the monsoon was late or early.

The occurrence of excess and deficit rainfall when compared to that of normal was seen in more or less equal number of years. As a whole, 33.3 percent (46 years out of 138 of the years recorded either excess or deficit rainfall. The monsoon rainfall range was high during excess rainfall years when compared to that of deficit rainfall years.

Overall, there was a decrease of 139.7 mm in monsoon rainfall, indicated a decline of 7.2 per cent of the normal rainfall of 1928.8 mm. The above trend was more evident in the rainiest months of June and July. In contrast, the monthly rainfall was in increasing trend in August and September. The rainfall during September was highly variable and undependable, followed by August. The monsoon rainfall was in declinig trend since last 60 years. The decline in monsoon rainfall is insignificant towards north of Kerala when compared to South of Kerala as reported by Joseph *et al* (2001). The annual rainfall showed a cyclic trend with marginal decline since last 60 years. A sort of raifall shift was noticed as monsoon rainfall was declining while post monsoon rainfall was increasing.

Since last one decade there was no excess monsoon except in 2007 while deficit in several years in recent years. Consecutive deficit monsoon rainfall resulted in acute shortage of water during the summer months in mid and high lands in 2003-04. Hydel power generation was adversely affected due to low water storage level in major hydel power producing reservoirs of the State. It may affect coconut production of the State as coconut growers may not be able to provide irrigation at required quantity and intervals due to shortage of power supply during summer even where water is available for irrigation. As stated by Swaminathan (2000), the "Monsoon Management Boards" at the Centre and State levels can only change the saying

"Indian agriculture is a gamble of the monsoon", into "India's strength lies in its ability to manage monsoons".

The march of aridity index over Kerala showed a marginal increasing trend since last fifty years though such trend was not noticed for the study period as a whole. It appears that the intensity of drought was more in recent decades, especially in 1981-90. Similar trend was noticed between 1871 and 1890.

Kerala State as a whole shifted from wet to dry within humid climate type (B) in recent decades. The decade 1981-90 was a typical one as only one year fell on wet side and eight on dry side. Such trend was noticed only before 1900. This alarms the adverse impact of human interventions on sustainable development of the State.

Coconut production was adversely affected over Kerala in 1983-84 due to drought during summer 1983. This was due to no significant rains from November to May. The delay in monsoon (13th June) prolonged the drought situation in 1983. Such droughts are relatively more towards north of Kerala. Majority of plantation crops suffered heavily whenever such droughts were noticed. Similar situation was noticed in some districts due to summer droughts in 2004.

Indian droughts are classified based on monsoon rains as area under crop sown is reduced or delayed due to poor rains under rainfed conditions and *kharif* foodgrains production is affected as seen in 1979, 1987, 2002 and 2009. Rice and wheat production is likely to decline due to climate change in ensuing decades as projected by crop models.

The monsoon rainfall is relatively stable and soil moisture stress is not a limiting factor in the case of rice and coconut in the humid tropics. In fact, excess rainfall management during monsoon is a problem. Of course, 2002 monsoon was totally different and monsoon rainfall was deficit by

35% when compared o normal. Such monsoon deficit rainfall was noticed in 1899, 1918 and 1976. Excess monsoon in 2007 followed by unusual rains in March 2008 adversely affected paddy production to a large extent in 2007-08. Decline in wetlands is likely to increase the frequency of floods during the monsoon season and droughts during summer. It is a threat under the projected climate change scenario.

Arid and semi arid climate types were noticed towards north of Kerala whenever disastrous droughts were noticed from November to May. The yield decline in coconut was noticed in the subsequent year during such drought years. Increase in coconut price was also noticed in lean crop years due to climate shifts.

The annual coconut production over Kerala was being estimated since last nine years based on agroclimatic variables. As per the projections, the coconut production over Kerala during 2002-2003 will be less when compared to that of previous year. It appears to be true. However, the model needs further validation since the difference between actual and predicted coconut production was on higher side from 1998-99 to 2000-01. The validity of the model is yet to be tested for the last two years since published figures are not available.

Conclusion

Occurrence of floods and droughts and heat and cold waves are common across the world. The adverse impact of weather calamities on world economy is tremendous in the form of food insecurity and increase in food prices. It is more so in India as our economy is more dependent on Agriculture. Interestingly, weather extremes of opposite in nature like cold and heat waves and floods and droughts are noticed within the same year over the same region or in different regions across the Country. Reports indicate that they are likely to increase in ensuing decades and food insecurity is likely world-over. Therefore, there should be a determined effort from developed and developing countries to make industrialisation environment-friendly by reducing greenhouse gases pumping into the atmosphere. Awareness programmes on climate change and its effects on various sectors viz., food security, health, infrastructure, water, forestry, land and ocean biodiversity and sea level and the role played by human interventions in climate change need to be taken up on priority. In the process, lifestyles of people should also be changed so as not to harm earth-atmosphere continuum by pumping greenhouse gases and CFCs into the atmosphere. Finally, we have to foresee the weather extreme events and prepare ahead to combat them so that the losses can be minimised. Therefore, strategies on mitigation and adaptation against weather extremes are to be chalked out on war-footing. Similarly attempts are to be made to forewarn local weather systems and weather extremes so as to minimise the human and crop losses. In addition, weather insurance package to the farmers against weather related disasters should be made compulsory and operational in an event of their occurrence. It will help them to maintain their livelihood in an event of weather extremes as farmers depend solely on the income of Agriculture. It is the phenomenon even world over and thus there should be a mechanism to sustain food security against weather calamities.

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Annexure - 1

Onset of monsoon over Kerala from 1870 to 2009

Year	Date of onset	Year	Date of onset	Year	Date of onset
1870	3rd June	1917	31st May	1964	6th Jun
1871	31st May	1918	11th May	1965	26th May
1872	1st June	1919	3rd June	1966	31st May
1873	23rd May	1920	3rd June	1967	9th Jun
1874	16th May	1921	2nd June	1968	8th Jun
1875	3rd June	1922	31st May	1969	17th May
1876	8th June	1923	11th June	1970	26th May
1877	7th June	1924	2nd June	1971	27th May
1878	9th June	1925	27th May	1972	18th Jun
1879	17th May	1926	6th June	1973	4th Jun
1880	26th May	1927	27th May	1974	26th May
1881	9th June	1928	3rd June	1975	31st May
1882	31st May	1929	29th May	1976	31st May
1883	3rd June	1930	8th June	1977	30th May
1884	9th June	1931	4th June	1978	28th May
1885	4th June	1932	2nd June	1979	13th Jun
1886	31st May	1933	22nd May	1980	1st Jun
1887	1st June	1934	8th June	1981	30th May
1888	28th May	1935	12th Jun	1982	1st June
1889	30th May	1936	19th May	1983	13th Jun
1890	28th May	1937	4th Jun	1984	31st May
1891	2nd June	1938	26th May	1985	28th May
1892	26th May	1939	5th Jun	1986	4th Jun
1893	26th May	1940	14th Jun	1987	2nd Jun
1894	4th June	1941	23rd May	1988	26th May
1895	12th June	1942	10th Jun	1989	3rd Jun
1896	3rd June	1943	29th May	1990	19th May
1897	6th June	1944	3rd Jun	1991	2nd Jun
1898	4th June	1945	5th Jun	1992	5th Jun
1899	27th May	1946	29th May	1993	28th May
1900	10th June	1947	3rd Jun	1994	28th May
1901	7th June	1948	11th Jun	1995	5th Jun
1902	6th June	1949	23rd May	1996	3rd Jun
1903	12th June	1950	27th May	1997	9th Jun
1904	7th June	1951	31st May	1998	2nd Jun
1905	10th June	1952	20th May	1999	25th May
1906	14th June	1953	7th Jun	2000	1st Jun
1907	8th June	1954	31st May	2001	23rd May
1908	11th June	1955	29th May	2002	29th May
1909	2nd June	1956	21st May	2003	8th June
1910	2nd June	1957	1st Jun	2004	18th May
1911	6th June	1958	14th Jun	2005	5th June
1912	8th June	1959	31st May	2006	26th May
1913	2nd June	1960	14th May	2007	28th May
1914	4th June	1961	18th May	2008	31st May
1915	15th June	1962	17th May	2009	23rd May
1916	2nd June	1963	31st May		

Annexure II

Monthly rainfall during monsoon from 1871 to 2008

Year	June	July	August	September	Monsoon rainfall (June-Sept.)
1871	880.1	944.8	250.9	221.4	2297.2
1872	798.1	741.8	402.0	429.8	2371.7
1873	831.3	856.7	188.8	128.3	2005.1
1874	1054.1	691.3	319.6	235.7	2300.7
1875	863.3	650.2	312.8	118.7	1945.0
1876	596.5	786.3	242.7	110.5	1736.0
1877	845.1	264.4	585.2	394.6	2089.3
1878	936.2	547.8	855.3	586.1	2925.4
1879	471.2	571.4	356.4	178.4	1577.4
1880	719.0	606.4	154.8	144.0	1624.2
1881	292.9	300.0	552.7	193.6	1339.2
1882	954.5	1131.2	331.1	236.1	2652.9
1883	691.4	776.6	370.0	84.4	1922.4
1884	471.5	445.0	465.6	314.6	1696.7
1885	1030.7	844.0	388.8	109.8	2373.3
1886	552.7	587.9	174.1	176.7	1491.4
1887	922.6	528.1	127.8	150.4	1728.9
1888	1068.8	497.6	463.2	123.2	2152.8
1889	821.7	382.1	409.8	419.5	2033.1
1890	615.7	511.9	223.7	111.6	1462.9
1891	736.7	557.2	271.9	86.2	1652.0
1892	357.3	1002.4	474.6	144.6	1978.9
1893	748.0	364.0	255.1	156.5	1523.6
1894	601.2	503.9	404.9	143.0	1653.0
1895	622.7	560.2	270.8	87.4	1541.1
1896	905.7	583.5	537.2	110.2	2136.6
1897	892.8	740.0	631.6	302.8	2567.2
1898	676.1	598.8	107.1	194.2	1576.2
1899	709.8	274.3	120.9	80.8	1185.8
1900	762.3	656.1	442.1	167.2	2027.7
1901	780.7	598.1	289.7	176.9	1845.4
1902	403.3	1040.2	276.3	425.7	2145.5
1903	576.7	851.7	357.7	288.5	2074.6
1904	1075.2	631.6	273.9	198.4	2179.1
1905	734.2	497.4	254.9	200.6	1687.1
1906	397.7	858.6	353.4	114.3	1724.0
1907	813.9	653.6	860.3	266.9	2594.7
1908	590.5	933.8	320.4	205.3	2050.0
1909	628.6	777.7	227.6	194.5	1828.4
1910	680.5	449.7	382.1	221.8	1734.1

Year	June	July	August	September	Monsoon rainfall (June-Sept.)
1911	895.2	627.2	183.7	46.2	1752.3
1912	994.5	723.5	511.7	147.3	2377.0
1913	516.8	653.0	196.1	188.2	1554.1
1914	616.9	781.4	398.8	223.0	2020.1
1915	673.9	844.7	280.6	469.4	2268.6
1916	835.7	510.2	366.1	318.0	2030.0
1917	739.9	371.1	350.6	454.4	1916.0
1918	570.9	152.5	329.7	97.3	1150.4
1919	588.3	638.4	441.6	284.7	1953.0
1920	1111.4	856.4	224.3	202.8	2394.9
1921	479.3	548.1	653.9	138.5	1819.8
1922	770.6	1071.5	259.9	216.4	2318.4
1923	748.4	823.3	829.1	265.2	2666.0
1924	1014.5	1253.4	583.9	263.6	3115.4
1925	660.9	569.9	535.8	179.0	1945.6
1926	649.2	801.7	435.6	338.3	2224.8
1927	705.2	787.2	268.6	367.0	2128.0
1928	536.6	407.6	514.6	84.7	1543.5
1929	984.5	779.4	245.4	294.6	2303.9
1930	596.8	371.0	243.5	399.4	1610.7
1931	575.4	606.4	1023.5	156.2	2361.5
1932	314.1	557.4	397.5	302.3	1571.3
1933	798.3	670.1	425.4	410.0	2303.8
1934	886.2	328.8	280.8	40.3	1536.1
1935	420.9	615.9	274.3	254.2	1565.3
1936	607.5	640.5	302.5	304.4	1854.9
1937	495.1	987.1	273.0	136.9	1892.1
1938	634.1	636.8	289.3	199.3	1759.5
1939	694.3	708.8	327.7	136.3	1867.1
1940	590.6	895.0	603.1	40.6	2129.3
1941	734.9	431.1	408.7	291.4	1866.1
1942	881.5	724.6	256.3	82.2	1944.6
1943	917.4	665.5	165.7	245.6	1994.2
1944	498.0	550.1	190.9	135.1	1374.1
1945	557.4	687.5	345.4	101.8	1692.1
1946	946.3	679.3	613.6	206.2	2445.4
1947	628.5	631.5	751.7	424.2	2435.9
1948	961.2	606.2	381.5	149.3	2098.2
1949	541.4	747.0	418.2	362.0	2068.6
1950	617.5	817.8	407.3	389.4	2232.0

Year	June	July	August	September	Monsoon rainfall (June-Sept.)
1951	815.7	453.6	152.2	306.6	1728.1
1952	606.6	393.2	386.0	46.4	1432.2
1953	309.3	1030.2	247.7	104.9	1692.1
1954	846.8	569.5	391.7	199.9	2007.9
1955	762.5	366.2	195.5	450.3	1774.5
1956	740.5	343.4	270.5	168.8	1523.2
1957	892.9	787.7	338.4	36.0	2055.0
1958	781.5	484.3	421.2	57.4	1744.4
1959	714.6	906.3	375.9	352.0	2348.8
1960	517.3	673.7	328.0	348.9	1867.9
1961	961.3	952.4	637.3	392.4	2943.4
1962	277.2	868.8	474.5	328.4	1948.9
1963	413.8	690.5	493.6	224.2	1822.1
1964	337.9	715.7	388.0	397.5	1839.1
1965	581.1	424.4	299.4	159.6	1464.5
1966	515.8	462.8	150.4	276.2	1405.2
1967	589.3	724.6	557.8	139.3	2011.0
1968	685.8	1281.1	362.6	279.9	2609.4
1969	581.7	794.3	274.9	199.0	1849.9
1970	576.3	543.9	547.3	222.2	1889.7
1971	875.2	632.5	379.2	351.5	2238.4
1972	416.6	700.0	279.7	177.2	1573.5
1973	648.4	529.8	475.7	66.8	1720.7
1974	289.9	988.7	522.7	409.3	2210.6
1975	909.2	509.4	644.5	458.5	2521.6
1976	222.5	608.0	323.6	106.5	1260.6
1977	618.3	731.8	238.9	200.8	1789.8
1978	767.1	679.7	466.3	134.7	2047.8
1979	672.5	597.7	334.1	264.1	1868.4
1980	759.3	701.1	370.2	144.8	1975.4
1981	1123.7	450.0	514.7	438.0	2526.4
1982	714.5	502.8	454.7	77.4	1749.4
1983	331.6	597.6	595.2	529.6	2054.0
1984	713.6	532.6	230.9	145.2	1622.3
1985	836.5	393.1	301.4	116.1	1647.1
1986	610.8	316.7	363.6	237.7	1528.8
1987	628.9	238.2	430.0	159.5	1456.6
1988	613.8	562.4	411.6	463.1	2050.9
1989	747.2	451.5	292.0	272.6	1763.3
1990	494.8	655.9	252.7	113.9	1517.3

Year	June	July	August	September	Monsoon rainfall (June-Sept.)
1991	1079.9	710.3	411.1	45.8	2247.1
1992	808.8	633.1	438.9	271.9	2152.7
1993	745.8	720.8	213.2	74.4	1754.2
1994	800.4	809.6	461.1	171.6	2242.7
1995	537.3	556.9	395.9	233.6	1723.7
1996	627.5	625.6	330.1	305.7	1888.9
1997	620.1	856.0	505.1	322.1	2303.3
1998	747.2	473.2	331.2	480.6	2032.2
1999	613.4	520.3	231.3	151.2	1516.2
2000	594.4	261.0	578.5	186.4	1620.3
2001	601.6	468.9	299.2	317.0	1686.7
2002	525.4	262.9	409.7	94.3	1292.3
2003	611.9	563.9	335.2	69.6	1580.6
2004	577.7	373.2	276.7	162.5	1390.1
2005	615.5	649.2	187.6	283.6	1735.9
2006	595.6	556.2	386.1	440.9	1978.8
2007	738.8	966.3	501.6	550.4	2757.1
2008	482.3	501.3	344.9	344.4	1672.9
Average (1871-2008)	685.0	637.0	377.5	229.3	1928.8

Annexure III

Water balance parameters and climate types over Kerala from 1871 to 2008

Year	P	PE	AE	WD	WS	Ia	Ih	Im	Climatic type	Drought Type
1871	3192	1527	1218	309	1974	20.24	129.27	109.03	A	nil
1872	2880	1527	983	544	1900	35.63	124.43	88.80	B4	D
1873	2739	1527	1060	467	1708	30.58	111.85	81.27	B4	nil
1874	3346	1527	953	574	2370	37.59	155.21	117.62	A	D
1875	2390	1527	894	633	1511	41.45	98.95	57.50	B2	D
1876	1988	1527	749	778	1257	50.95	82.32	31.37	B1	D
1877	3003	1527	930	597	2004	39.1	131.24	92.14	B4	D
1878	3715	1527	1056	471	2668	30.84	174.72	143.88	A	nil
1879	2672	1527	1021	506	1655	33.14	108.38	75.24	B3	S
1880	2433	1527	1087	440	1346	28.81	88.15	59.34	B2	nil
1881	1857	1527	922	605	950	39.62	62.21	22.59	B1	D
1882	3487	1527	963	564	2524	36.94	165.29	128.35	A	D
1883	2721	1527	1024	503	1689	32.94	110.61	77.67	B3	I
1884	2329	1527	937	590	1395	38.64	91.36	52.72	B2	D
1885	3134	1527	905	622	2178	40.73	142.63	101.90	A	D
1886	2347	1527	1011	516	1397	33.79	91.49	57.70	B2	S
1887	2439	1527	951	576	1464	37.72	95.87	58.15	B2	D
1888	2990	1527	1011	516	2000	33.79	130.98	97.19	B4	S
1889	2779	1527	1034	493	1733	32.29	113.49	81.20	B4	L
1890	2155	1527	1144	383	1035	25.08	67.78	42.70	B2	nil
1891	2755	1527	1086	441	1624	28.88	106.35	77.47	B3	nil
1892	3138	1527	1157	370	2019	24.23	132.22	107.99	A	nil
1893	2536	1527	1105	422	1427	27.64	93.45	65.81	B3	nil
1894	2367	1527	1086	441	1295	28.88	84.81	55.93	B2	nil
1895	2292	1527	1016	511	1269	33.46	83.1	49.64	B2	S
1896	2836	1527	997	530	1806	34.71	118.27	83.56	B4	D
1897	3224	1527	1074	453	2169	29.67	142.04	112.37	A	nil
1898	2367	1527	1034	493	1333	32.29	87.3	55.01	B2	L
1899	2133	1527	1075	452	1091	29.6	71.45	41.85	B2	nil
1900	2670	1527	984	543	1670	35.56	109.36	73.80	B3	D
1901	2944	1527	1123	404	1790	26.46	117.22	90.76	B4	nil
1902	3056	1527	1049	478	1941	31.3	127.11	95.81	B4	M
1903	3036	1527	1098	429	1994	28.09	130.58	102.49	A	nil
1904	2948	1527	1014	513	1993	33.6	130.52	96.92	B4	S
1905	2484	1527	929	598	1452	39.16	95.09	55.93	B2	D
1906	2453	1527	972	555	1423	36.35	93.19	56.84	B2	D
1907	3418	1527	1079	448	2348	29.34	153.77	124.43	A	nil
1908	2698	1527	1002	525	1749	34.38	114.54	80.16	B4	S
1909	2868	1527	1090	437	1751	28.62	114.67	86.05	B4	nil
1910	2733	1527	1041	486	1701	31.83	111.39	79.56	B3	M

Year	P	PE	AE	WD	WS	Ia	Ih	Im	Climatic type	Drought Type
1911	2593	1527	990	537	1551	35.17	101.57	66.40	B3	D
1912	3415	1527	1083	444	2374	29.08	155.47	126.39	A	nil
1913	2474	1527	1013	514	1463	33.66	95.81	62.15	B3	S
1914	2927	1527	988	539	1859	35.3	121.74	86.44	B4	D
1915	3164	1527	1186	341	2056	22.33	134.64	112.31	A	nil
1916	2867	1527	1026	501	1844	32.81	120.76	87.95	B4	I
1917	2811	1527	1059	468	1738	30.65	113.82	83.17	B4	nil
1918	2576	1527	1048	479	1504	31.37	98.49	67.12	B3	M
1919	3050	1527	1112	415	1941	27.18	127.11	99.93	B4	nil
1920	3433	1527	1070	457	2388	29.93	156.39	126.46	A	nil
1921	2661	1527	1071	456	1592	29.86	104.26	74.40	B3	nil
1922	3340	1527	1034	493	2303	32.29	150.82	118.53	A	L
1923	3198	1527	940	587	2262	38.44	148.13	109.69	A	D
1924	3946	1527	1139	388	2783	25.41	182.25	156.84	A	nil
1925	3068	1527	1146	381	1886	24.95	123.51	98.56	B4	nil
1926	2954	1527	1041	486	1969	31.83	128.95	97.12	B4	M
1927	2875	1527	1091	436	1788	28.55	117.09	88.54	B4	nil
1928	2355	1527	1045	482	1292	31.57	84.61	53.04	B2	M
1929	3306	1527	1159	368	2152	24.1	140.93	116.83	A	nil
1930	2924	1527	1193	334	1772	21.87	116.04	94.17	B4	nil
1931	3044	1527	1066	461	1952	30.19	127.83	97.64	B4	nil
1932	3259	1527	1110	417	2208	27.31	144.6	117.29	A	nil
1933	3885	1527	1110	417	2780	27.31	182.06	154.75	A	nil
1934	2309	1527	1028	499	1295	32.68	84.81	52.13	B2	L
1935	2336	1527	936	591	1389	38.7	90.96	52.26	B2	D
1936	3046	1527	1089	438	1955	28.68	128.03	99.35	B4	nil
1937	2812	1527	1108	419	1702	27.44	111.46	84.02	B4	nil
1938	2501	1527	1172	355	1350	23.25	88.41	65.16	B3	nil
1939	2896	1527	1068	459	1813	30.06	118.73	88.67	B4	nil
1940	3102	1527	1016	511	2068	33.46	135.43	101.97	A	S
1941	3035	1527	1079	448	1926	29.34	126.13	96.79	B4	nil
1942	2978	1527	1144	383	1805	25.08	118.21	93.13	B4	nil
1943	3441	1527	1203	324	2310	21.22	151.28	130.06	A	nil
1944	2418	1527	1141	386	1241	25.28	81.27	55.99	B2	nil
1945	2411	1527	936	591	1511	38.7	98.95	60.25	B3	D
1946	3642	1527	1146	381	2417	24.95	158.28	133..33	A	nil
1947	3037	1527	1135	392	2009	25.67	131.57	105.90	A	nil
1948	2970	1527	1107	420	1830	27.5	119.84	92.34	B4	nil
1949	2954	1527	990	537	1989	35.17	130.26	95.09	B4	D
1950	3141	1527	1037	490	2090	32.09	136.87	104.78	A	M

Year	P	PE	AE	WD	WS	Ia	Ih	Im	Climatic type	Drought Type
1951	2607	1527	1098	429	1499	28.09	98.17	70.08	B3	nil
1952	2314	1527	1082	445	1248	29.14	81.73	52.59	B2	nil
1953	2485	1527	933	594	1558	38.9	102.03	63.13	B3	D
1954	2925	1527	1163	364	1759	23.84	115.19	91.35	B4	nil
1955	3158	1527	1072	455	2081	29.8	136.48	106.68	A	nil
1956	2758	1527	1107	420	1655	27.5	136.28	108.78	A	nil
1957	3079	1527	1028	499	2034	32.68	133.2	100.52	A	L
1958	2704	1527	1108	419	1612	27.44	105.57	78.13	B3	nil
1959	3300	1527	1088	439	2200	28.75	144.07	115.32	A	nil
1960	3328	1527	1149	378	2185	24.75	143.09	118.34	A	nil
1961	3907	1527	1031	496	2894	32.48	189.52	157.04	A	L
1962	3144	1527	1045	482	2103	31.57	137.72	106.15	A	M
1963	2501	1527	1049	478	1438	31.3	94.17	62.87	B3	M
1964	2582	1527	978	549	1604	35.95	105.04	69.09	B3	D
1965	2218	1527	1053	474	1083	31.04	70.92	39.29	B1	nil
1966	2388	1527	1047	480	1402	31.43	91.81	60.38	B3	M
1967	2695	1527	1014	513	1704	33.6	111.59	77.99	B3	S
1968	3299	1527	1105	422	2186	27.64	143.16	115.52	A	nil
1969	2717	1527	1092	435	1591	28.49	104.19	75.7	B3	nil
1970	2738	1527	1122	405	1680	26.52	110.02	83.5	B4	nil
1971	3059	1527	1041	486	2013	31.83	131.83	100	A	M
1972	2832	1527	1017	510	1729	33.4	113.23	79.83	B3	S
1973	2407	1527	1041	486	1439	31.83	94.24	62.41	B3	M
1974	2946	1527	1044	483	1919	31.63	125.67	94.04	B4	M
1975	3594	1527	1157	370	2415	24.23	158.15	133.92	A	nil
1976	2172	1527	1033	494	1137	32.35	74.45	42.1	B2	L
1977	3154	1527	1065	462	2093	30.26	137.07	106.81	A	nil
1978	3170	1527	1057	470	2112	30.78	138.31	101.18	A	nil
1979	2699	1527	993	534	1698	34.97	111.2	76.23	B3	D
1980	2792	1527	1026	501	1755	32.81	114.93	82.12	B4	L
1981	3384	1527	1096	431	2309	28.23	151.21	122.98	A	nil
1982	2389	1527	992	535	1401	35.04	91.75	56.71	B2	D
1983	2516	1471	753	718	1720	48.81	116.93	68.12	B3	D
1984	2534	1385	1174	211	1418	15.23	102.38	87.15	B4	nil
1985	2533	1500	1061	439	1458	29.27	97.2	67.93	B3	nil
1986	2147	1628	1013	615	1138	37.78	69.9	32.12	B1	D
1987	2307	1609	990	619	1235	38.47	76.76	38.29	B1	D
1988	2626	1525	1128	397	1611	26.03	105.64	79.61	B3	nil
1989	2515	1525	989	536	1517	35.15	99.48	64.33	B3	D
1990	2606	1519	888	631	1706	41.54	112.31	70.77	B3	D

Year	P	PE	AE	WD	WS	Ia	Ih	Im	Climatic type	Drought Type
1991	2883	1593	968	625	1928	39.23	121.03	81.8	B4	D
1992	3054	1555	938	617	2099	39.68	134.98	95.3	B4	D
1993	2740	1542	1028	514	1633	33.33	105.9	72.57	B3	S
1994	3159	1484	1121	363	2097	24.46	141.31	116.85	A	nil
1995	2485	1522	1119	403	1370	26.48	90.01	63.53	B3	nil
1996	2451	1508	1013	495	1372	32.82	90.98	58.16	B2	L
1997	2912	1511	1042	469	1851	31.04	122.5	91.46	B4	nil
1998	2990	1520	1013	507	1893	33.36	124.54	91.18	B4	S
1999	2818	1520	1179	341	1723	22.43	113.35	90.92	B4	nil
2000	2296	1590	1169	421	1126	26.48	70.82	44.34	B2	nil
2001	2744	1565	1135	430	1662	27.48	106.2	78.72	B3	nil
2002	2525	1660	1076	584	1460	35.18	87.95	57.77	B2	D
2003	2318	1771	1198	573	1132	32.35	63.92	31.57	B1	L
2004	2786	1778	1108	670	1671	37.68	93.98	56.3	B2	D
2005	2522	1494	1022	472	1441	31.59	96.45	64.86	B3	M
2006	3053	1551	1022	529	2085	34.12	134.43	100.31	A	S
2007	3422	1540	959	581	2450	37.72	159.09	121.37	A	D
2008	2495	1433	1104	329	1391	22.95	97.06	74.11	B3	NIL
Climatic	2823.08	1531.33	1051.12	480.20	1771.62	31.33	116.02	84.68	B4	Nil

Annexure-IV

Actual and estimate coconut production (million nuts) of Kerala from 1949-50 to 2008-09

Year	Actual	Predicted	Percentage deviation over actual
1949-50	1920	2120	10.4
50-51	2026	2001	-1.3
51-52	2029	2073	2.2
52-53	2978	3039	2.0
53-54	2714	2820	3.9
54-55	3076	3029	-1.5
55-56	3099	3124	0.8
56-57	3182	3108	-2.3
57-58	3199	2966	-7.3
58-59	3248	3514	8.2
59-60	3365	3210	-4.6
60-61	3220	3504	8.8
61-62	3247	3636	12.0
62-63	3305	3137	-5.1
63-64	3262	3264	0.1
64-65	3278	3255	-0.7
65-66	3293	3441	4.5
66-67	3425	3521	2.8
67-68	3593	3736	4.0
68-69	3834	3925	2.4
69-70	3956	3825	-3.3
70-71	3981	3925	-1.4
71-72	4054	4197	3.5
72-73	3921	3650	-6.9
73-74	3703	3622	-2.2
74-75	3719	3849	3.5
75-76	3440	3723	8.2
76-77	3348	3545	5.9
77-78	3053	2886	-5.5
78-79	3237	2899	-10.4
79-80	3032	3093	2.0

Year	Actual	Predicted	Percentage deviation over actual
80-81	3036	3334	9.8
81-82	3006	2853	-5.1
82-83	3184	2953	-7.3
83-84	2602	2447	-6.0
84-85	3453	3377	-2.2
85-86	3377	3392	0.4
86-87	3173	3237	2.0
87-88	3346	3364	0.5
88-89	4215	4221	0.1
89-90	4358	4363	0.1
90-91	4233	4533	7.1
91-92	4641	4212	-9.3
92-93	5225	5416	3.7
93-94	5197	5129	-1.3
94-95	5335	5110	-4.2
95-96	5155	4944	-4.1
96-97	5774	5444	-5.7
97-98	5209	4651	-10.7
98-99	5132	3942	-23.2
99-2000	5167	5964	15.4
2000-01	5496	4804	-12.6
2001-02	5744	5289	-7.9
2002-03	5338	4654	-12.8
2003-04	5876	1595	-72.9
2004-05	5727	3820	-33.3
2005-06	6326	7290	15.2
2006-07	6054	6120	1.1
2007-08	5641	6519	15.6
2008-09		6441	

Annexure V

Data Source and Methodology

The onset of southwest monsoon over Kerala from 1870 to 2002 were collected from the published reports of the India Meteorological Department, Govt. of India from time to time. The above data were verified from the results published by Ananthakrishnan and Soman (1988 and 1989) and Joseph *et al.*(2001). The source of monthly rainfall (mm) over Kerala from 1871 to 1994 is from the IITM publication entitled "Monthly and seasonal rainfall series for all-India homogeneous regions and meteorological subdivision: 1871-1994" (Parthasarathy *et al.*, 1995). From 1995 to 2002, the monthly rainfall data were collected from the daily weather reports published by the IMD, Trivandrum.

Normal onset date of monsoon and its rainfall for the period as a whole (1870-2000) and sub-period viz., 1870-1900, 1901-1930, 1931-1960 and 1961-2000 were analysed, using time series analysis such as frequency distribution, moving averages, standard deviation and coefficient of variation. The percentage contribution of monthly rainfall for the monsoon season was also worked out. The monthly and season-wise trends were computed through a trend line. 75 percent probability rainfall of different months was also worked out using the percentile rank method (Sakamoto *et al.*, 1984). The occurrence of droughts over the period and its impact of Indian foodgrains production was highlighted through a graphical technique.

Yearly water balances were computed for a period of 131 years (1871-2001) using the Thoranthwaite and Mathers (1955) Book-keeping water balance procedure, given by Subrahmanyam (1982). The monthly Aridity Index (Ia), Moisture Index (Im) and humidity Index (Ih) were computed from 1871 to 2001 using the formula given below:

$Ia = WD/PE \times 100$ $Ih = WS/PE \times 100$ $Im = Ih - Ia$

Where, AR-Actual evapotranspiration, PE-Potential Evapotranspiration, WS-Water Surplus, WD-Water deficit.

Intensity of droughts was worked out as per the procedure given by Subrahmanyam and Subramaniam (1964 and later modified by Subramanyam and Sastri, 1969). It is classified on the basis of the percentage departure of aridity index from the median as Moderate, Large, Severe and Disastrous according to the following scheme:

Departure of Ia from median	Drought intensity
< ½ s	Moderate
½ s to s	Large
S to 2 s	Severe
> 2s	Disastrous

Where s is the standard deviation.

March of the aridity index from year to year, 7 year moving average and its trend were also computed to understand whether a place is going drier side or not. Similar exercise was done in the case of moisture index for knowing any climate shift in the State during the study period. Thornthwaite's climatic scheme (1948) was followed fro studying climate shifts:

The scheme is as follows:

Climatic Classification	Climatic type	Im
C_2	Moist sub humid	0-20
B_1	Humid	20-40
B_2	Humid	40-60
B_3	Humid	60-80
B_4	Humid	80-100
A	Perhumid	above 100

The Agricultural droughts and its impact on coconut production was worked out as per the classification given by Rao, 1991.

A multiple linear regress equation was developed (Rao and Subash, 1996 and Rao *et.al.*, 1999) for estimating coconut production based on agroclimatic variables such as humidity Index (Ih) and index of moisture adequacy (Ima). The model is put in operation since 1994-'95 onwards.