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Preparation of a detailed approach paper for adaptation and mitigation measures to deal with climate change in the forestry sector of Kerala State

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Abstract of Project Proposal

Project Number	KFRI 570/2009
Title	Preparation of a detailed approach paper for adaptation and mitigation measures to deal with climate change in the forestry sector of Kerala State
Objectives	1. To examine the kind of impacts that are possible due to climate change in the forestry sector of Kerala based on global predictions and regional models already existing. 2. To suggest adaptation and mitigation measures to overcome the impacts of climate change in the forestry sector of Kerala.
Project period	November 2009- October 2010
Funding Agency	Kerala Forest Department
Principal Investigator	Dr. U.M. Chandrashekara
Associates	Dr. Jose Kallarackal Mr. Lakhwinder Singh (Chairman, Climate Change Cell, KFD)

CONTENTS

1. Abstract

Climate change is generally recognized as one of the greatest challenges of this century. In the present paper, the climate change impact factors such as precipitation, atmospheric temperature seal level changes and emission of greenhouse gases (GHGs) are discussed in the context of Kerala State. The high resolution daily gridded dataset for a period of 100 years (1901-2000) provided by the Climate Research Unit Time Series (CRU TS- version 2.10) was used to analyse the long-term trend of rainfall and temperature in Kerala. The mean annual rainfall and seasonal rainfall over the State showed an insignificant declining trend. The number of wet days during the south-west monsoon increased significantly and decreased during pre-monsoon and winter seasons. However, throughout the State daily average, maximum and minimum temperatures increased irrespective of the season. The data available for a period of 68 years (1939-2007) showed that the sea level rose significantly at the rate of 1.49 mm/year. Among different landuse systems, forests are particularly sensitive to climate change. In the present paper, some possible impacts of climate change on forest species composition and diversity in Kerala are discussed. The forest cover in the State seems to be stabilised to around 17,382 km^2. However, information on the quality of existing forest cover and its current ability for buffering the impacts of climate change is lacking. In the context of increasing anthropogenic activities, without adopting suitable mitigation and adaptation strategies, forests cannot contribute to mitigate avoid the ill effects of climate change. Among several actions that can be taken in the forestry sector to promote mitigation include a) managing forests with high carbon uptake potential, b) expanding such forests through reforestation and afforestation, and c) reducing deforestation and reversing the loss of forest cover. Several of the forest conservation measures already taken up by the Kerala Government are actually are compatible to and contributing to the mitigation of the effects of climate change and are therefore to be continued and organised to target specific regions. By strengthening or continuing with programmes like social forestry projects and protection and conservation of forests, including sacred groves, adverse effects of climate change can be mitigated. With the long experience in promotion of forest conservation, participatory forest management and forest governance, the Kerala Forest Department can greatly facilitate comprehensive programmes for climate change mitigation. In the forest sector of Kerala, adaptation to climate change is also crucial due to the fact that the climate change could cause irreversible damage to unique ecosystems such as sholas, mangroves, *Myristica* swamps, etc. In the present paper, actions to maintain or enhance a) forest extent, b) biodiversity, c) forest health, d) productivity in forest ecosystems and e) forest soil and water, are identified as important adaptation strategies. A number of options are highlighted under each adaptation strategy.

2. Introduction

Climate change is becoming a reality. Climate observation proves the existence of a global warming trend: global average temperature has increased by 0.8^0 C since 1900 (Handsen et al., 2006) and all the 12 hottest years observed globally since 1880 occurred between 1900 and 2005. The Inter-governmental Panel for Climate Change (IPCC) report concludes that warming of the climate is unequivocal, as is now evident from observations of increase in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (IPCC, 2007). The recent highest temperature of 40^0 C in Palakkad of Kerala State during February and March 2004 is an indication of the extent of impact one needs to expect often in future. Among different landuse systems, forests are particularly sensitive to climate change because the long life-span of trees does not allow for rapid adaptation to environmental changes. At the same time, forests can contribute to avoiding dangerous impacts of climate change. Roles played by forest ecosystems in the global biogeochemical cycles enabled them to reduce to some extent the impact of both climate change and anthropogenic emissions (Anderson and Spencer, 1991; Lewis et. al., 2009). Being act as both sources and sinks of greenhouse gases (GHGs), forest can contribute to an extent to the mitigation of climate change (Clark, 2002). For instance, over the period 2000-2005, the tropical forest biomass carbon sink absorbed 12% of the total anthropogenic emissions, accounting for about 47% of the total carbon sink (Malhi, 2010). In his recent overview of the state of knowledge of the carbon balance of tropical forests Malhi (2010) also pointed out that if the tropical biomass carbon sink were not present and this excess carbon were instead allocated to ocean and atmospheric pools, atmospheric CO_2 would have risen at a mean rate 17% higher than the currently observed, and oceans would have absorbed CO_2, leading ocean acidification and coral reef decline. This is a substantial global ecosystem service that intact tropical biomes appear to be currently providing. Thus forests can contribute to the mitigation of climate change through carbon sequestration, carbon substitution and carbon conservation. It is also a known fact that forest are much more than pools of carbon; they house a large part of the world's biological wealth, perform an important role in the provision of water and other ecosystem services, sustain many indigenous cultures, and support the livelihoods of hundreds of millions of people (FAO,2012). However, the extent to which forests help in mitigating the adverse effects of climate change and also their ability to adjust in response to climate change are the functions that call for their management and framing at local, national and global levels.

Research on the possible impacts of climate change on forest in India started in late 1990s, shortly after the first concerns were raised about the consequences on Earth's climate of anthropogenic greenhouse gas (Ravindranath and Sukumar, 1998; Deshingkar *et al.,* 1997; Chandrashekara, 2004). Since then, assessments of climate change, its impacts and subsequent consequences to natural resource management have been the focus of continuous research efforts (Ravindranath et.al., 2006; Sathaye et al., 2006). It may be mentioned here that literature pertaining to the possible impacts of climate change are available on forests in terms of the impact on affecting tree growth and productivity (Achantha and Kanetkar, 1996; Gopalakrishnan et al., 2010), changing forest area and competition between species (Lexer et al., 2002), and altering the quality and quantum of damage caused by natural disturbances (Seidl et al., 2007). It was also recognised that protective functions of forests will be affected by climate change as well (Kochli and Brang, 2005). In fact such information is lacking for forests of Kerala. However, it can be expected that the forests of Kerala will be affected by climate changes and also they have the potential to reduce the impacts of climate changes when they are sustainably managed. The two efforts widely recognised to address climate change are mitigation and adaptation (IPCC, 2002). Mitigation is defined as an anthropogenic intervention to reduce the sources or enhance the sinks of GHGs. On the other hand, adaptation is the adjustment in natural or human systems in response to actual or expected climatic stimuli and their impacts on natural and socio-economic systems, which moderate the harm or exploits beneficial opportunities. Thus, effort needs to be made at regional scale to evolve forest-based approaches for climate change mitigation and adaptation for reducing the potential impacts of climate change. It can also be noted that unlike in agriculture, adaptation measures for forest sector need to be planned well in advance of expected changes in growing conditions because the forest regeneration today will have to cope with the future climatic conditions of at least several decades, often more than 100 years. In this context, the Kerala Forest Department (KFD) aimed to provide the State Government with an improved understanding of the potential implications of climate change on forests and mitigation and adaptation options for forest sector of Kerala. The present approach paper is one such effort helping to guide future strategies for increasing the resilience of forests to the unfolding climatic changes.

This paper presents the climate impact factors pertaining to Kerala, summarises the existing knowledge about impacts of climate change on forests, reviews the strengths and weaknesses of the forest ecosystems to adapt to climate change, analyses the efforts made by the Government of Kerala in the field of conservation and sustainable management of forests that are key to add resilience to the forest ecosystems in coping with anthropogenic and climate change stresses, and finally analyses possible adaptation measures to combat climate change.

3. Climate change impact factors

a. Precipitation

Recent studies projected an increase in precipitation over India (Rupakumar et al., 2006). However, temporal changes in precipitation showed a significant increasing trend in rainfall along the west-coast of India and a significant decreasing trend in annual and south-west monsoon rainfall (Guhathakartha and Rajeevan, 2007). In the present report, in order to understand precipitation variability in Kerala, the State has been divided into twenty six grids each of size 0.5° x 0.5° latitude and longitude (Figure 1). The high resolution daily gridded rainfall dataset for a period of 100 years (1901-2000) provided for each grid (0.5° x 0.5° latitude and longitude) by the Climate Research Unit Time Series (CRU TS) version 2.10 (Mitchell and Jones, 2005) was used. Grid-wise dataset is analyzed to determine annual and seasonal variability in rainfall both at grid and state level.

The annual normal rainfall over Kerala from 1901 to 2000 was 2019 mm with a standard deviation of 334 mm (Table 1). The seasonal rainfall for pre-monsoon (March-May), southwest monsoon (June-September), post-monsoon (October-November) and winter season (December-February) was 324±95 mm, 1581±327 mm, 201±55 mm and 23±13 mm respectively.

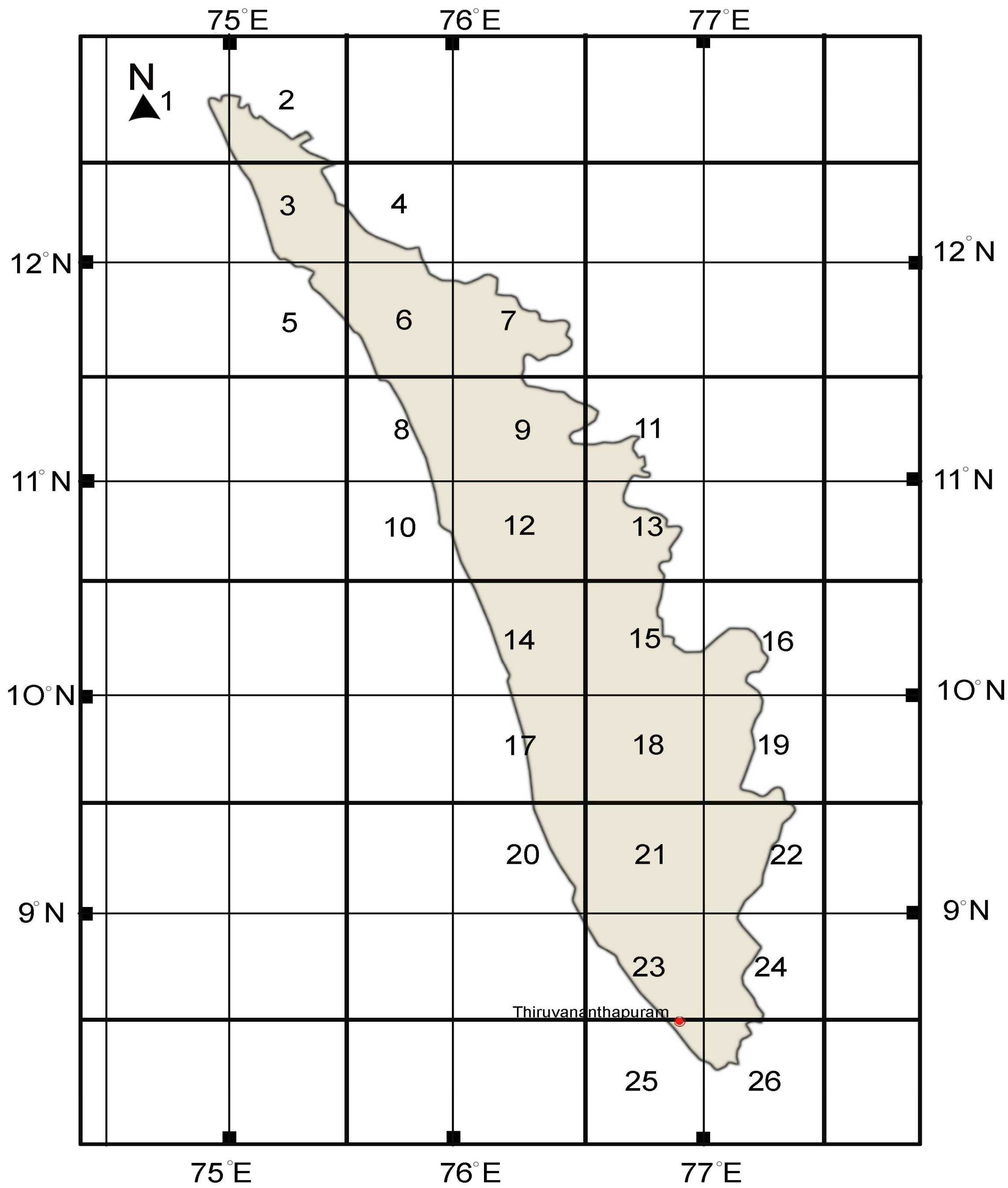

Figure 1. Map showing the gridded regions in Kerala. Each grid (numerical numbers 1 to 26) is 0.5° x 0.5° in size.

The coefficient of variation of annual rainfall is 15.5% indicating that it is highly stable. The seasonal rainfall during pre-monsoon, monsoon and post-monsoon are also dependable as the coefficient of variations ranged from 21 to 29%. However, rainfall during winter is undependable as the coefficient of variation is very high (55.1%).

Table 1. Monthly and seasonal rainfall (mm) over Kerala from 1901 to 2000.

	Mean	Standard deviation	Coefficient of variation (%)
January	13	14	114
February	16	20	121
March	28	25	88
April	104	51	49
May	191	86	45
June	504	191	38
July	533	179	34
August	356	137	39
September	189	76	41
October	250	79	31
November	151	78	52
December	40	35	88
Annual	2019	334	16
Pre-monsoon	324	95	29
Southwest monsoon	1581	327	21
Post-monsoon	201	55	27
Winter	23	13	55

The mean annual rainfall over the State showed a long-term insignificant declining trend ($t=-0.428$; $P>0.05$) (Figure 2). In the State, some grids showed increasing trend in rainfall while other grids showed decreasing trend. However, in both cases, values are not significant statistically ($P>0.05$) (Table 2).

Investigations were also made using the dataset of CRU TS version 2.1 to determine whether there have been any significant changes in the rainfall in different seasons in Kerala. The spatially averaged trends in total precipitation in different seasons over Kerala (Figure 3) revealed the fact that in all seasons rainfall showed decreasing trend though not statistically significant ($P>0.05$). Consequently, increasing or decreasing trends in seasonal rainfall in different grids are also not statistically significant ($P>0.05$) (Figure 4).

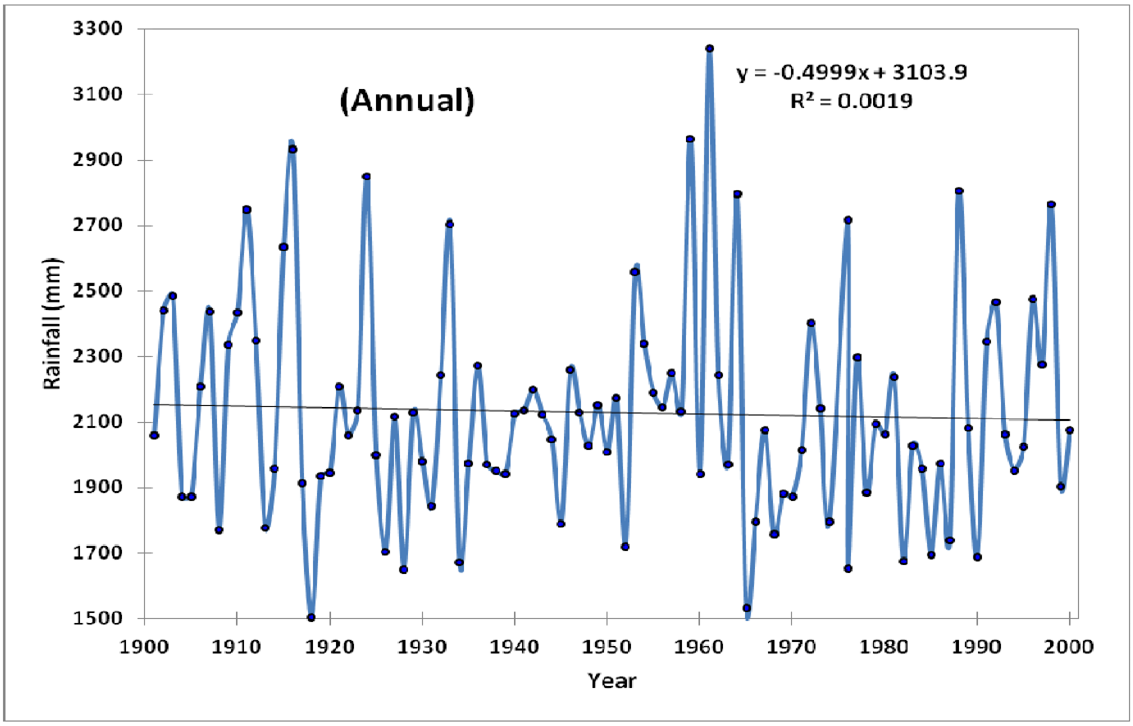

Figure 2. Annual rainfall trends over Kerala from 1901 to 2000

Table 2. Linear equations developed between years and annual rainfall in different grids of Kerala.

Grid no.	Linear equation (t-value with level of significance)	Grid no.	Linear equation (t-value with level of significance)
1	y=-1.04x+5326.8 (t= -0.49^{ns})	14	y=0.54x+1796.4 (t=0.34^{ns})
2	y=-1.04x+5280.9 (t= -0.48^{ns})	15	y=-0.051x+1596.3 (t=-0.08^{ns})
3	y=-1.04x+5123.7 (t= -0.62^{ns})	16	y=-0.51x+82.5 (t=-0.81^{ns})
4	y=-3.94x7869.4 (t=1.57^{ns})	17	y=0.54x+1812.3 (t=0.36^{ns})
5	y=-1.03x+5656.9 (t= -0.49^{ns})	18	y=-0.41x+2856.8 (t=-0.46^{ns})
6	y=-3.93x10124.9 (t=1.76^{ns})	19	y=-0.51x+89.6 (t=-0.91^{ns})
7	y=0.29x+ 1235.8 (t=0.20^{ns})	20	y=0.54x+1806.2 (t=0.65^{ns})
8	y=-3.93x10693.8 (t=1.51^{ns})	21	y=-0.41x+2867.8 (t=-0.68^{ns})
9	y=0.29x+ 1112.6 (t=0.36^{ns})	22	y=-0.09x+1260.8 (t=-0.07^{ns})
10	y=-3.91x9890.9 (t=1.55^{ns})	23	y=-0.41x+2901.8 (t=-0.33^{ns})
11	y=-0.051x+1600.3 (t=-0.06^{ns})	24	y=-0.09x+1341.9 (t=-0.17^{ns})
12	y=0.29x+ 1224.9 (t=0.28^{ns})	25	y=-0.41x+2998.9 (t=-0.87^{ns})
13	y=-0.051x+1580.4 (t=-0.05^{ns})	26	y=-0.09x+1341.2 (t=-0.12^{ns})

Level of significance of equation tested by t-test is given in parentheses. t -value with ns in superscript is statically not significant P>0.05.

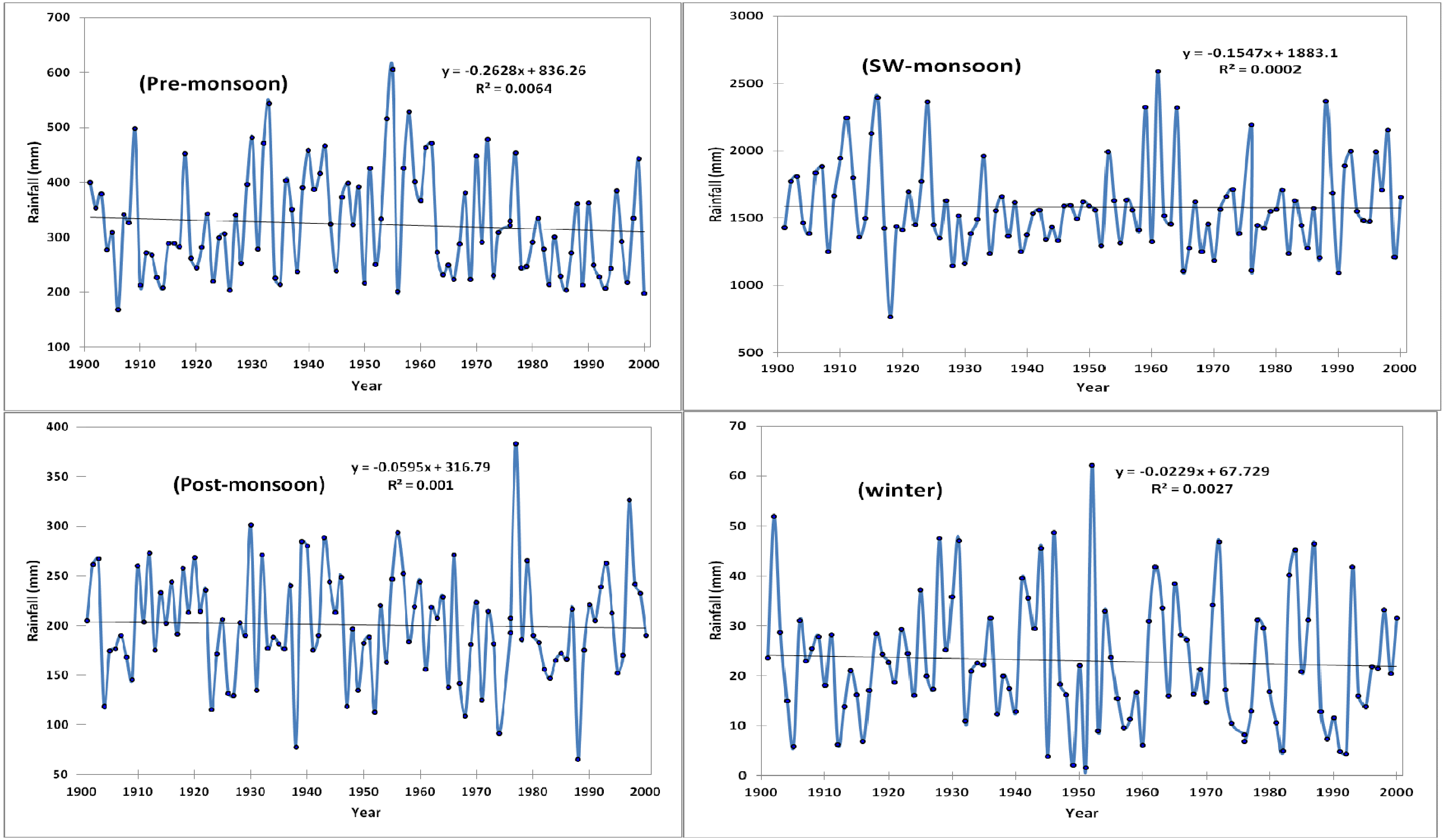

Figure 3. Seasonal rainfall trends over Kerala from 1901 to 2000

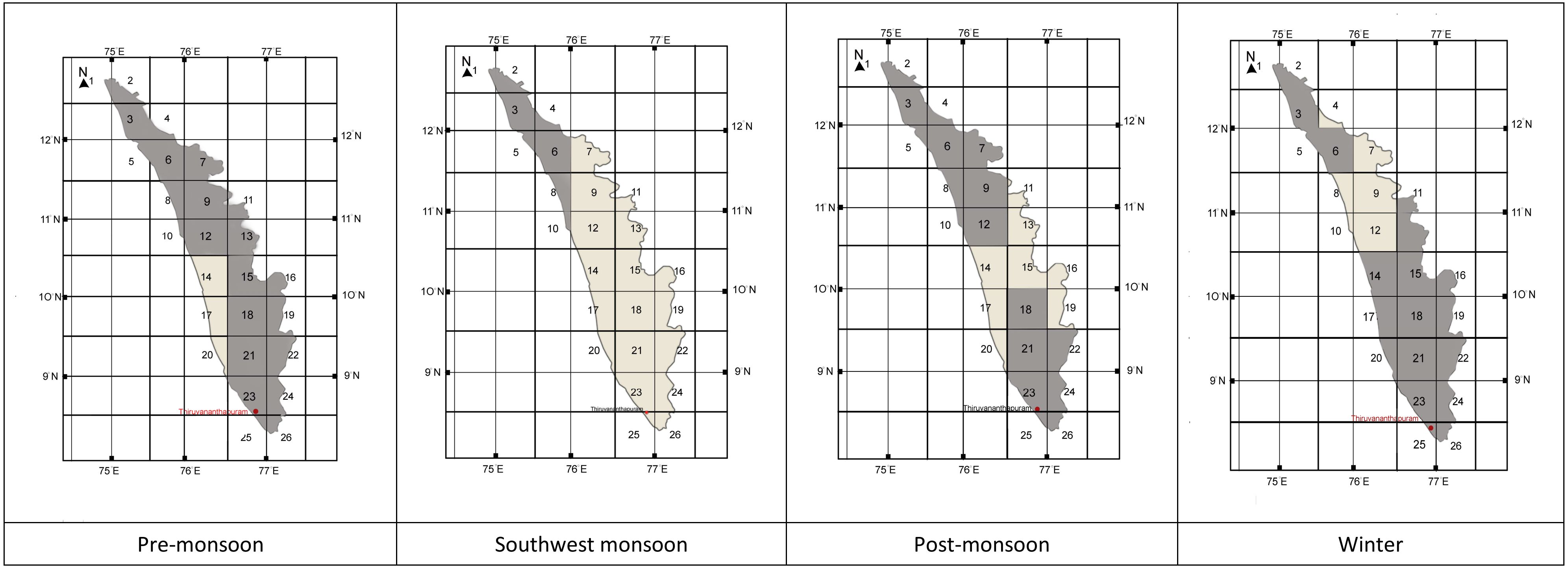

Figure 4. Map of Kerala showing seasonal rainfall trend in various gridded regions of kerala in 1901-2000.

Decreasing trend but not statistically significant

Increasing trend but not significant

Analysis of spatially averaged trends of total wet days (wet days: daily precipitation (DP) more than 1 mm) in various seasons is useful to determine increase or decrease in water stress, which in turn is important for forest vegetation. The annual normal number of wet days in Kerala from 1901 to 2000 is 94 days with a standard deviation of 6 days (Table 3). Spatially averaged trends of total number of wet days in a year did not show the significant decreasing tendency (t=-0.477; P>0.05) (Figure 5).

Table 3. Total number of wert day in different months and season in Kerala from 1901 to 2000.

	Mean	Standard deviation	Coefficient of variation (%)
January	1	1	100
February	1	1	100
March	2	1	50
April	5	1	20
May	8	2	25
June	17	3	18
July	17	3	18
August	15	3	20
September	9	2	22
October	11	2	18
November	7	2	29
December	2	1	50
Annual	94	6	6
Pre-monsoon	15	2	13
Southwest monsoon	57	6	11
Post-monsoon	17	3	18
Winter	5	2	40

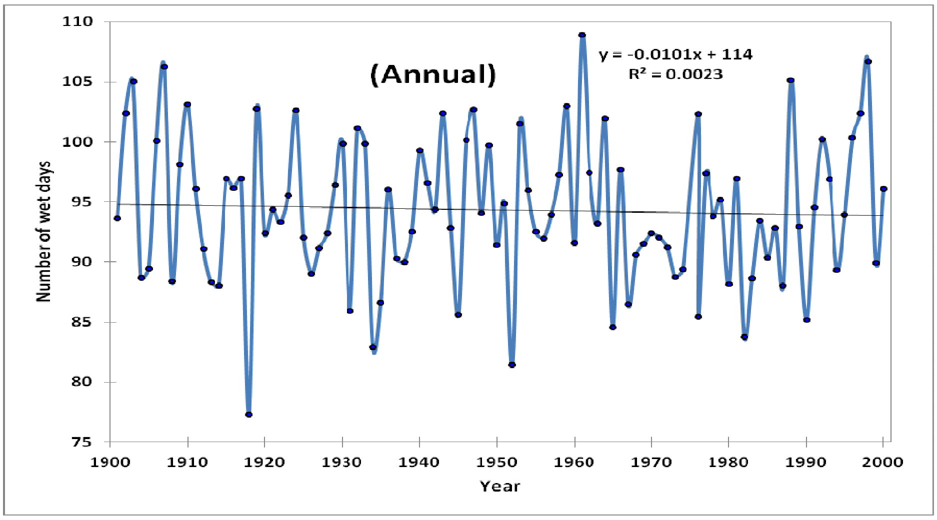

Figure 5. The trend of number of wet days in a year in Kerala from 1901 to 2000

In fact, the trends corresponding to large scale spatial averages are not representative of the local regional changes. Therefore, for analysing the impact of climate change at very small scales gridded regional analysis will be useful (Bardossy and Hundecha, 2003). In this context, results obtained for the trends in total number of wet days in a year in different grids in the State are provided here. In the State, some grids showed increasing trend in total number of wet days in a year while other grids showed a decreasing trend. However, in both the cases, values are statistically not significant (Table 4).

Table 4. Linear equations developed between years and total number of wet days in a year in different gridded regions of Kerala.

Grid no.	Linear equation (t-value with level of significance)	Grid no.	Linear equation (t-value with level of significance)
1	y=0.02x+64.9 (t= 0.98^{ns})	14	y=-0.003x+118.6 (t=-0.11^{ns})
2	y=0.02x+68.8 (t= 0.71^{ns})	15	y=-0.001x+98.2 (t=-0.78^{ns})
3	y=0.02x+64.3 (t= 0.52^{ns})	16	y=-0.01x+88.8 (t=-0.48^{ns})
4	y=-0.006x136.7 (t=-0.26^{ns})	17	y=-0.003x+116.4 (t=-0.12^{ns})
5	y=0.02x+64.8 (t= 0.98^{ns})	18	y=-0.02x+149.1 (t=-0.68^{ns})
6	y=-0.006x129.1 (t=-0.65^{ns})	19	y=-0.01x+87.3 (t=-0.51^{ns})
7	y=0.046+ 172.1 (t=-1.38^{ns})	20	y=-0.003x+117.2 (t=-0.11^{ns})
8	y=-0.006x122.7 (t=-0.21^{ns})	21	y=-0.02x+148.7 (t=-0.76^{ns})
9	y=0.046+ 163.1 (t=-1.79^{ns})	22	y=-0.004x+91.2 (t=-0.15^{ns})
10	y=-0.006x119.8 (t=-0.29^{ns})	23	y=-0.02x+145.4 (t=-0.68^{ns})
11	y=-0.001x+112.8 (t=-0.88^{ns})	24	y=-0.004x+98.7 (t=-0.16^{ns})
12	y=0.046+ 146.9 (t=-1.98^{ns})	25	y=-0.02x+142.4 (t=-0.78^{ns})
13	y=-0.001x+104.4 (t=-0.58^{ns})	26	y=-0.004x+89.1 (t=-0.26^{ns})

Level of significance of equation tested by t-test is given in parentheses.

When the trend of number of wet days per year (Wet days: daily precipitation more than 1 mm; DP>1mm) over 100 years was considered for the south-west monsoon, the wet days increased significantly (t=2.686; $P<0.05$) (Figure 6) while trends of total number of wet days in pre-monsoon and winter seasons had a decreasing tendency (pre-monsoon, t= -3.492; winter, t=-6.21; $P<0.05$). No significant decrease was observed in total number of wet days in post-monsoon (t= -0.738; $P>0.05$).

Further analysis indicated that the number of wet days in certain seasons decreased significantly while in some other gridded regions decrease in values was statistically not significant (Figure 7).

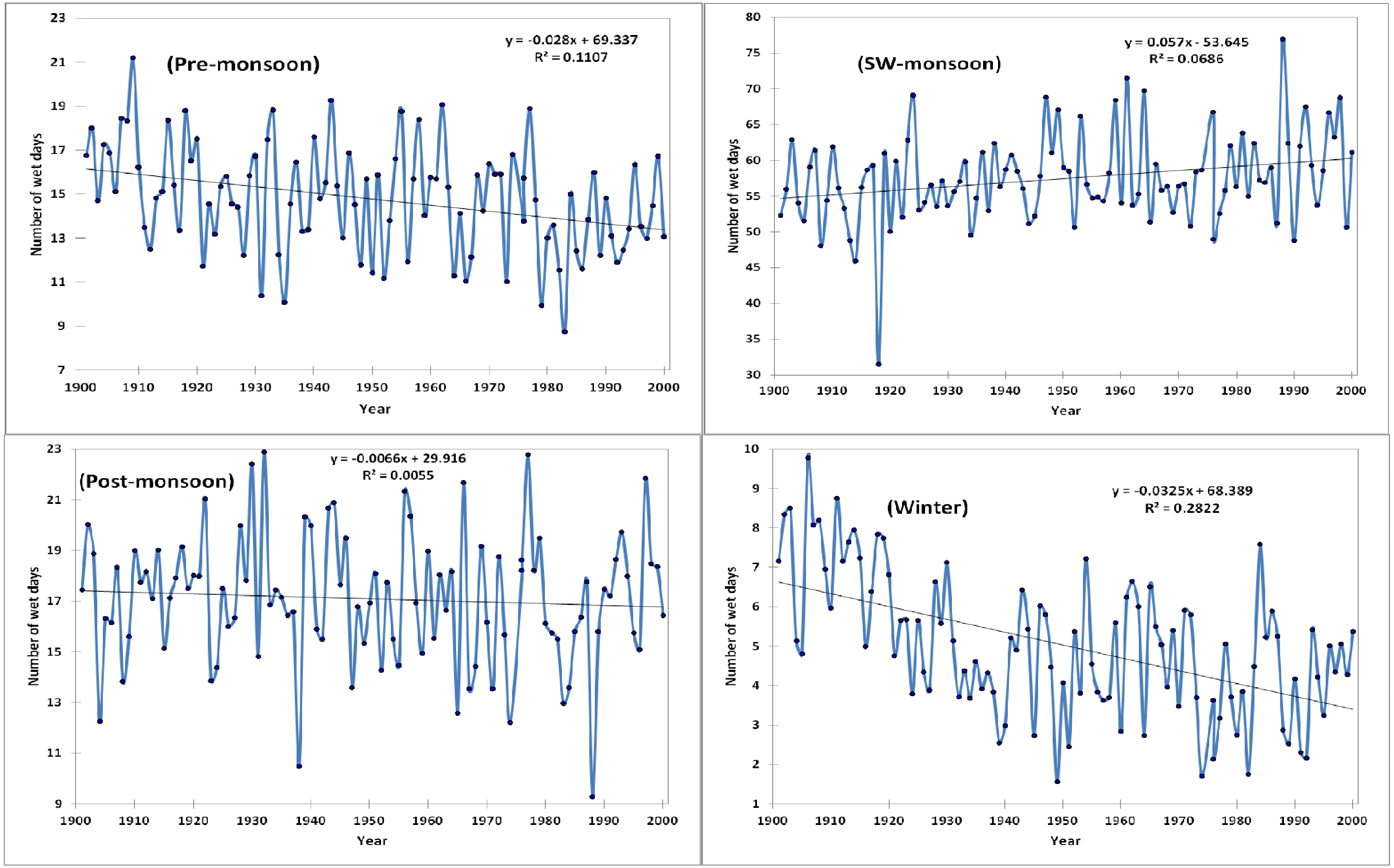

Figure 6. Seasonal trends in total number of wet days in Kerala from 1901 to 2000

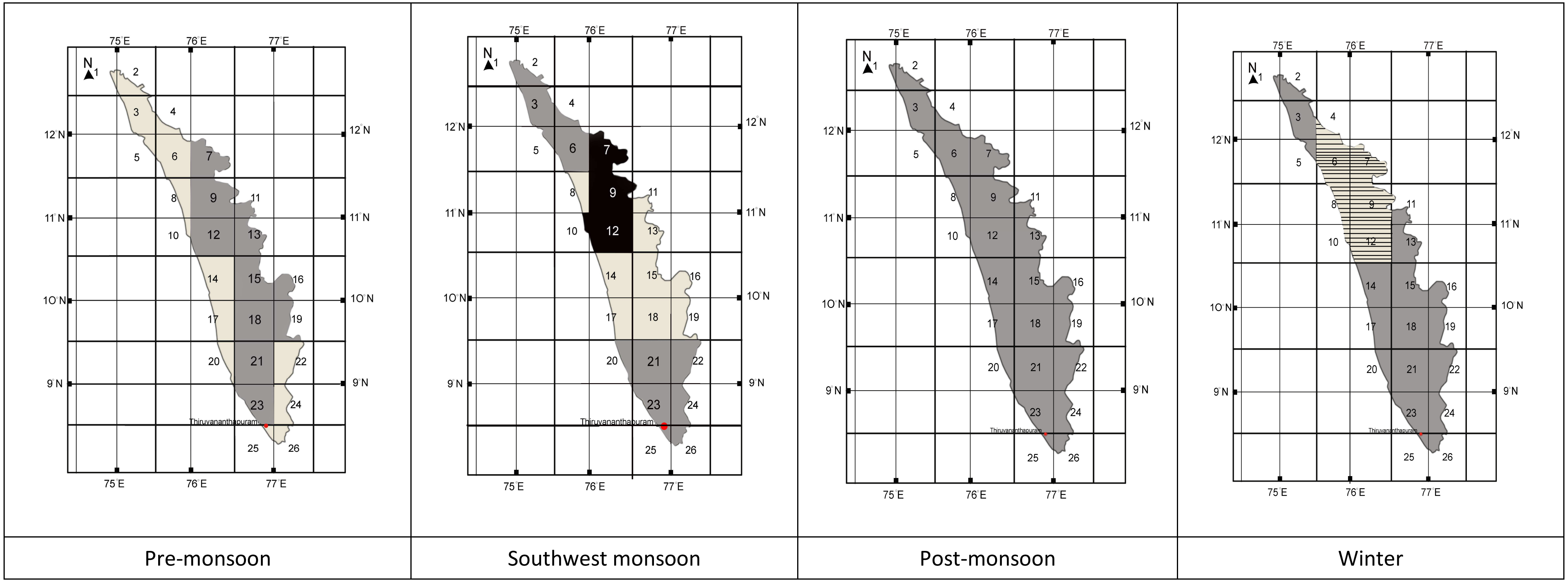

Figure 7. Map of Kerala showing seasonal trends in number wet days of various gridded regions of Kerala in 1901-2000.

decreasing trend not significant incrasing trend not significant

decreasing trend significant increasing trend significant

It is reported that the number of monsoon depressions formed during the south-west monsoon, strength of monsoon current and strength of tropical easterly jet stream are the important rain bearing systems during the south-west monsoon season (Joseph et al., 2005). The frequency changes and fluctuations of the above weather systems in recent years over peninsula may be important reasons to varying rainfall and number of rainy days in Kerala. In addition to this, anthropological interventions leading to landuse and land-cover changes are also responsible either directly or indirectly for disrupting the earth-atmosphere continuum drastically and they in turn alter the distribution of local rainfall during winter and pre-monsoon season.

b. Atmospheric temperature

i. Daily average temperature

The high resolution daily gridded average atmospheric temperature dataset for a period of 100 years (1901-2000) provided for each grid (0.5° x 0.5° latitude and longitude) by the Climate Research Unit Time Series (CRU TS) version 2.10 was used to determine annual and seasonal trends in temperature both at the grid and State level.

Table 5. Daily average temperature (^oC) in different months and seasons in Kerala from 1901 to 2000.

	Mean	Standard deviation	Coefficient of variation (%)
January	24.70	1.68	6.8
February	25.65	1.56	6.1
March	27.07	1.50	5.6
April	27.93	1.47	5.3
May	27.46	1.42	5.2
June	25.60	1.44	5.6
July	24.80	1.46	5.9
August	25.03	1.45	5.8
September	25.40	1.43	5.6
October	25.49	1.51	5.9
November	25.11	1.65	6.6
December	24.57	1.74	7.1
Annual	25.73	0.30	1.2
Pre-monsoon	27.49	0.60	2.2
Southwest monsoon	25.21	0.52	2.1
Post-monsoon	25.30	0.46	1.8
Winter	24.97	0.70	2.8

The daily average temperature in Kerala from 1901 to 2000 was 25.73±0.30^{o} C (Table 5) and showed a significant increasing trend (t=7.35**; p<0.01) (Figure 8). Decade-wise percentage departure of average daily temperature also indicated a fact that from 1980 onwards the increase was drastic (Figure 9).

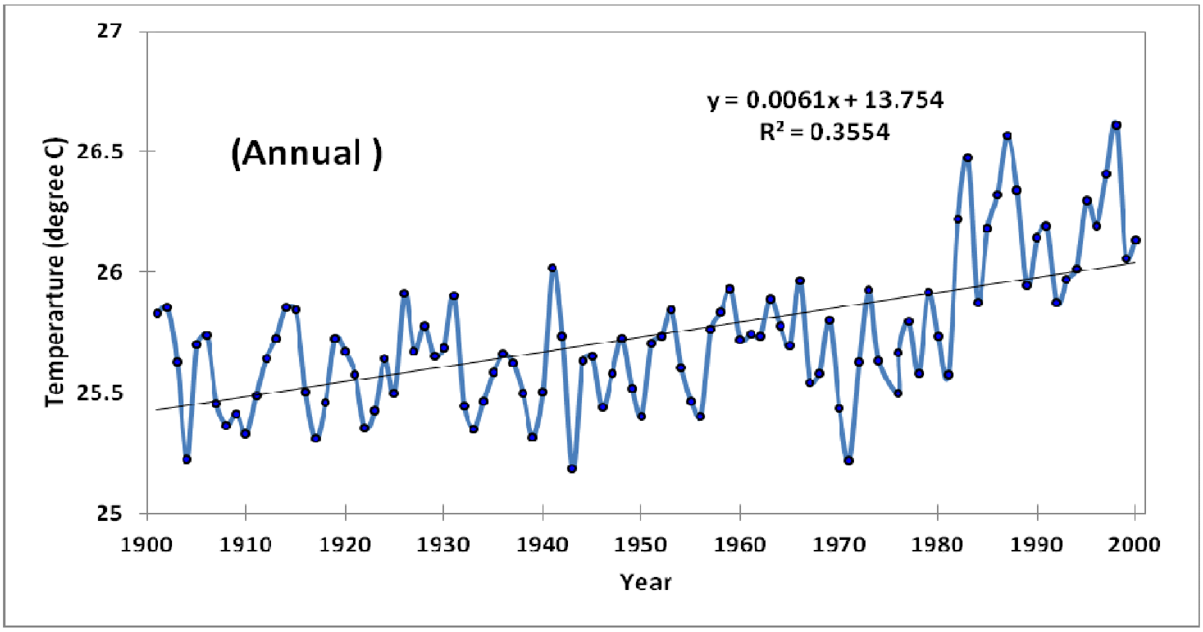

Figure 8. The trend of daily average temperature in Kerala from 1901 to 2000

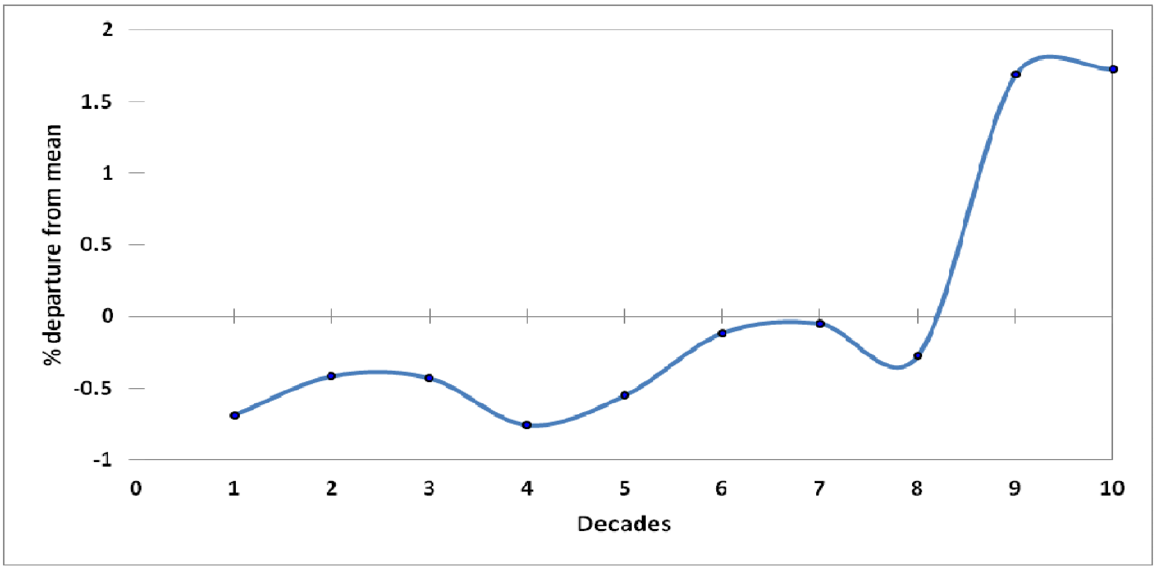

Figure 9. Decadal mean (% departure from average) of daily average atmospheric temperature in Kerala from 1901 to 2000.

When the trend of average daily temperature in different seasons were considered significant increase was recorded in all seasons (t= 4.69, 3.13, 6.42, 9.20 respectively in pre-monsoon, southeast monsoon, post-monsoon and winter season; $P<0.01$-0.05) (Figure 10). In all gridded regions in the State, significant increase in daily average temperature was recorded (Table 6). In these regions, temperatures also increased for all seasons.

Table 6. Linear equations developed between years and daily average temperature (^{o}C) in different gridded regions of Kerala.

Grid no.	Linear equation (t-value with level of significance)	Grid no.	Linear equation (t-value with level of significance)
1	y=0.005x+17.64 (t= 6.32*)	14	y=0.006x+15.02 (t=7.14*)
2	y=0.006x+14.80 (t= 7.41*)	15	y=0.006x+13.88 (t=7.77*)
3	y=0.005x+12.18 (t= 7.56*)	16	y=0.007x+9.17 (t=7.89*)
4	y=0.005x+11.02 (t= 7.23*)	17	y=0.006x+15.54 (t=7.25*)
5	y=0.005x+12.18 (t= 7.98*)	18	y=0.006x+13.12 (t=7.54*)
6	y=0.006+16.12 (t=7.88*)	19	y=0.007x+10.09 (t=7.32*)
7	y=0.006x+ 11.48 (t=7.79*)	20	y=0.006x+15.02 (t=7.06*)
8	y=0.006+15.08 (t=7.59*)	21	y=0.006x+13.09 (t=7.65*)
9	y=0.006x+12.18 (t=7.61*)	22	y=0.007x+10.74 (t=7.60*)
10	y=0.006+15.78 (t=7.99*)	23	y=0.007x+13.84 (t=7.07*)
11	y=0.006x+14.02 (t=7.55*)	24	y=0.007x+10.24 (t=7.65*)
12	y=0.006x+16.13 (t=7.78*)	25	y=0.006x+13.43 (t=7.45*)
13	y=0.006x+14.23 (t=7.61*)	26	y=0.006x+14.12 (t=7.67*)

Level of significance of equation tested by t-test is given in parentheses.
* Significant at 0.05 level

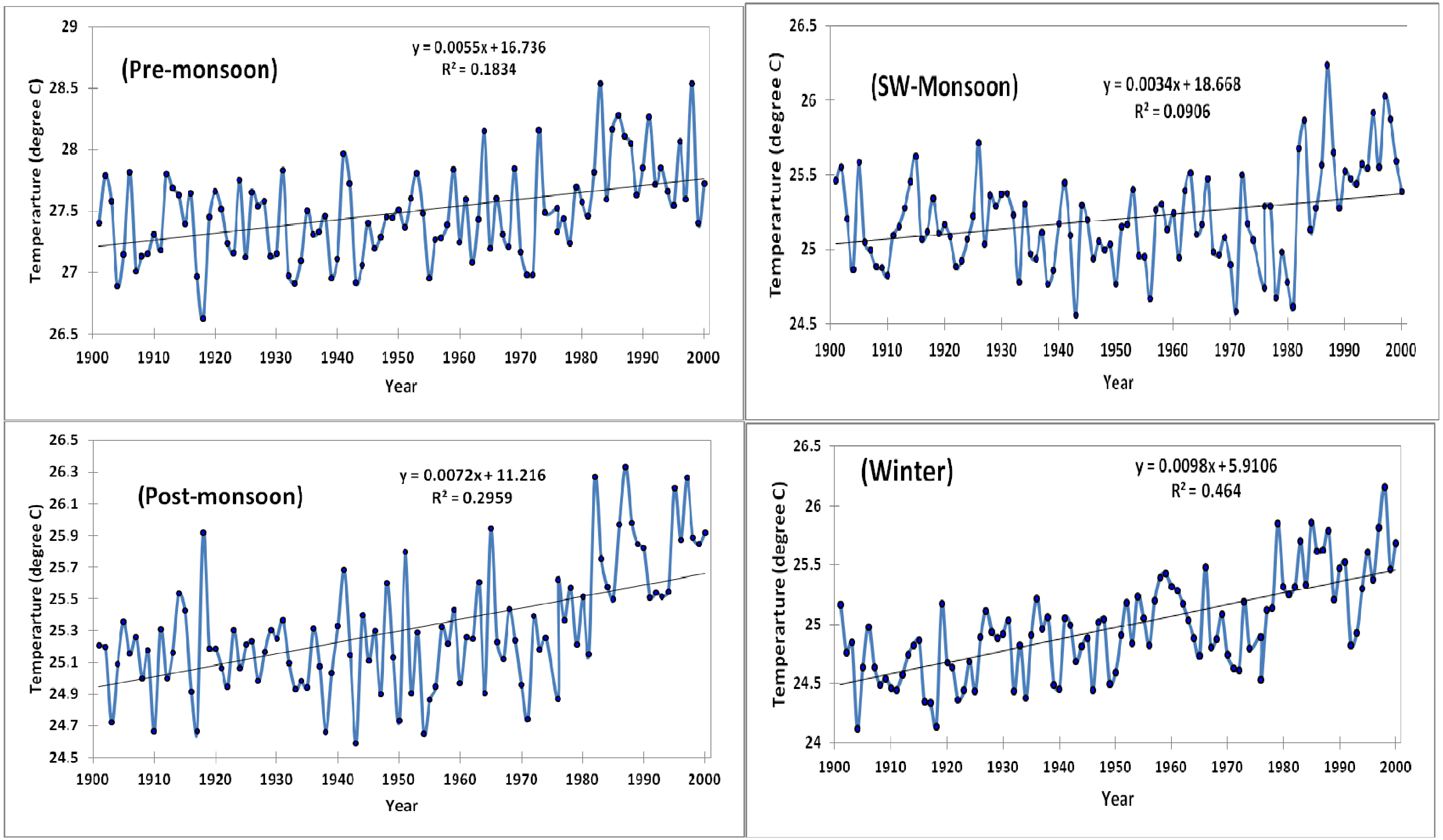

Figure 10. Seasonal trends in daily average temperature (^oC) in Kerala from 1901 to 2000

ii. Daily maximum temperature

The mean daily maximum temperature in different months and seasons over 100 year period is given Table 7. The coefficient of variation of maximum temperature ranges from 1.01 to 1.77 indicating that it is highly stable.

Table 7. Daily maximum temperature (^{o}C) in different months and seasons in Kerala from 1901 to 2000.

	Mean	Standard deviation	Coefficient of variation (%)
January	29.76	0.51	1.71
February	30.78	0.52	1.70
March	32.01	0.45	1.42
April	32.51	0.44	1.36
May	31.53	0.56	1.77
June	28.96	0.50	1.74
July	27.94	0.45	1.60
August	28.17	0.33	1.19
September	28.90	0.38	1.32
October	29.26	0.38	1.28
November	29.15	0.47	1.61
December	29.13	0.49	1.69
Annual	29.90	0.30	1.01
Pre-monsoon	32.02	0.37	1.16
Southwest monsoon	28.49	0.32	1.13
Post-monsoon	29.21	0.39	1.32
Winter	29.89	0.42	1.39

The long-term data of daily maximum temperature in the State showed significant increasing trend ($t= 7.84$; $p<0.01$) (Figure 11) with steep increase during 1980-2000 (Figure 12). In all gridded regions of the State, daily maximum temperature increased significantly (Table 8). Significant increase in daily maximum temperature was recorded in all seasons for all gridded regions.

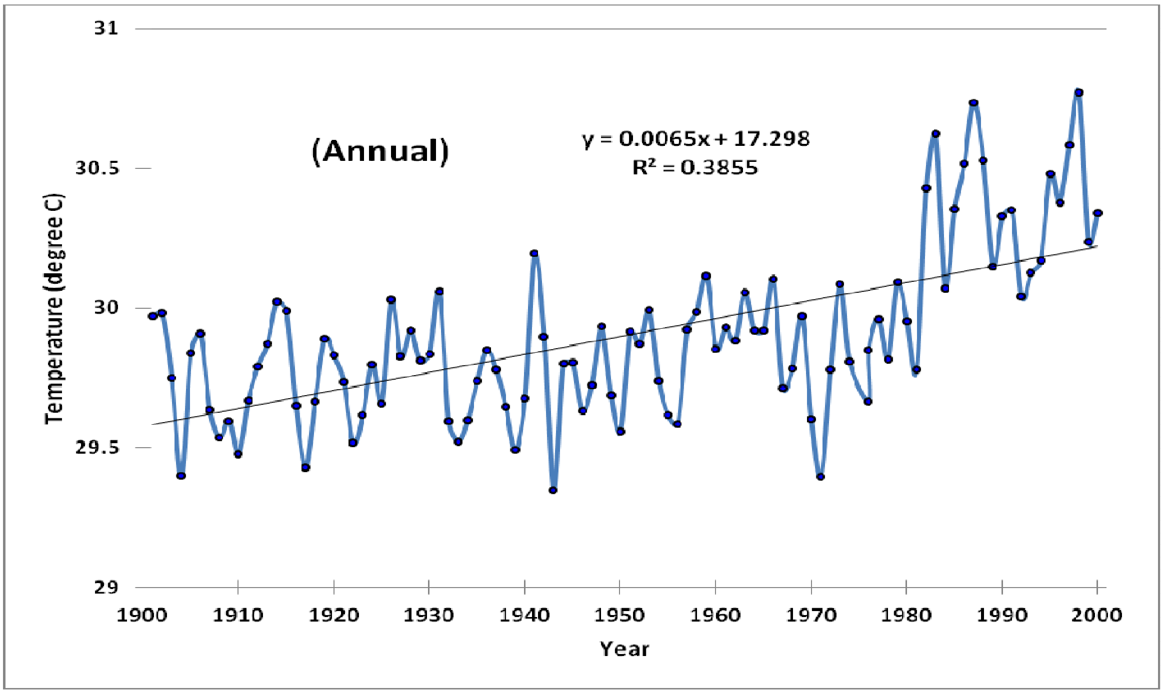

Figure 11. The trend of daily average temperature in Kerala from 1901 to 2000

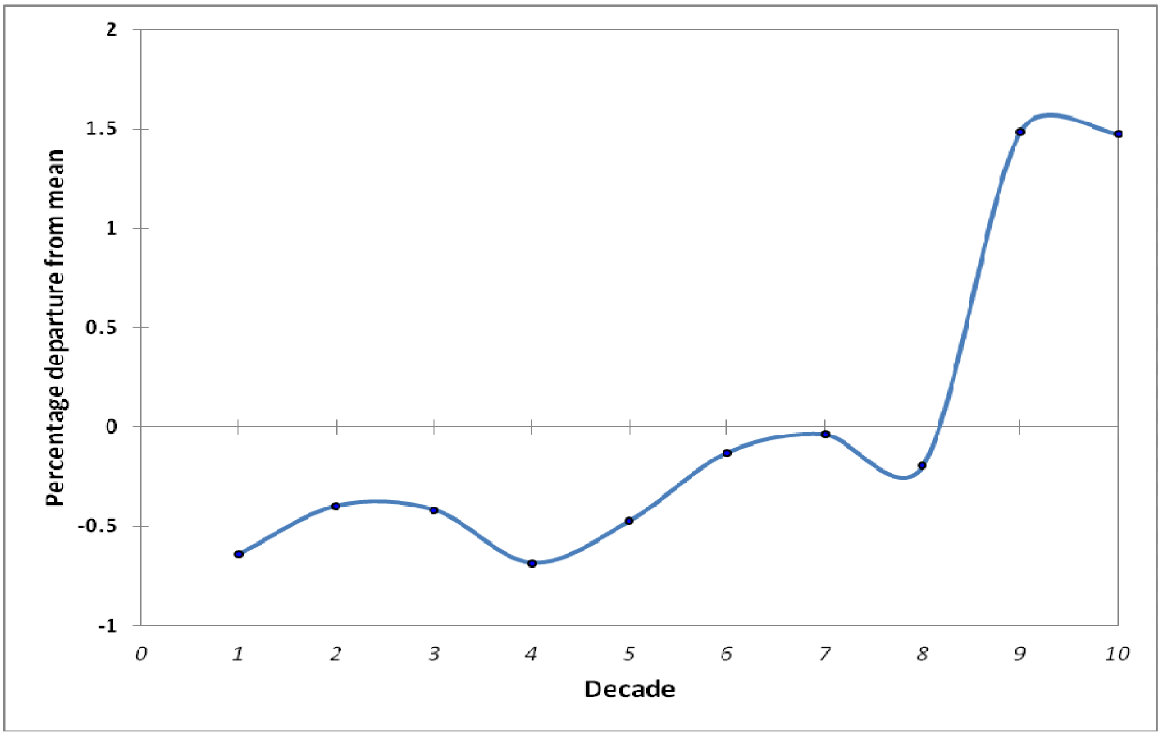

Figure 12. Decadal mean (% departure from average) of daily maximum atmospheric temperature in Kerala from 1901 to 2000.

Table 8. Linear equations developed between years and daily maximum temperature (^oC) in different gridded regions of Kerala.

Grid no.	Linear equation (t-value with level of significance)
1	y=0.006x+19.12 (t= 7.46*)
2	y=0.006x+18.84 (t= 7.40*)
3	y=0.006x+19.02 (t= 7.09*)
4	y=0.006+16.24 (t=7.08*)
5	y=0.006x+19.36 (t= 7.24*)
6	y=0.006+18.21 (t=7.23*)
7	y=0.006x+ 16.29 (t=7.78*)
8	y=0.006+18.89 (t=7.59*)
9	y=0.006x+ 15.78 (t=7.78*)
10	y=0.006+19.78 (t=7.35*)
11	y=0.006x+19.21 (t=7.60*)
12	y=0.006x+ 17.12 (t=7.98*)
13	y=0.006x+18.89 (t=7.65*)
14	y=0.006x+18.95 (t=7.10*)
15	y=0.006x+19.76 (t=7.65*)
16	y=0.007x+13.62 (t=7.91*)
17	y=0.006x+19.46 (t=7.44*)
18	y=0.006x+12.10 (t=7.98*)
19	y=0.007x+13.09 (t=7.56*)
20	y=0.006x+19.12 (t=7.56*)
21	y=0.006x+12.14 (t=7.88*)
22	y=0.007x+14.59 (t=7.65*)
23	y=0.006x+12.52 (t=7.07*)
24	y=0.007x+14.13 (t=7.12*)
25	y=0.006x+12.98 (t=7.12*)
26	y=0.007x+14.01 (t=7.42*)

Level of significance of equation tested by t-test is given in parentheses.
* Significant at 0.05 level.

When the trend of daily maximum temperature in different seasons was considered significant increase was recorded in all seasons (t= 4.69, 3.23, 6.72, 9.12 respectively in pre-monsoon, southeast monsoon, post-monsoon and winter season; P<0.01-0.05) (Figure 13).

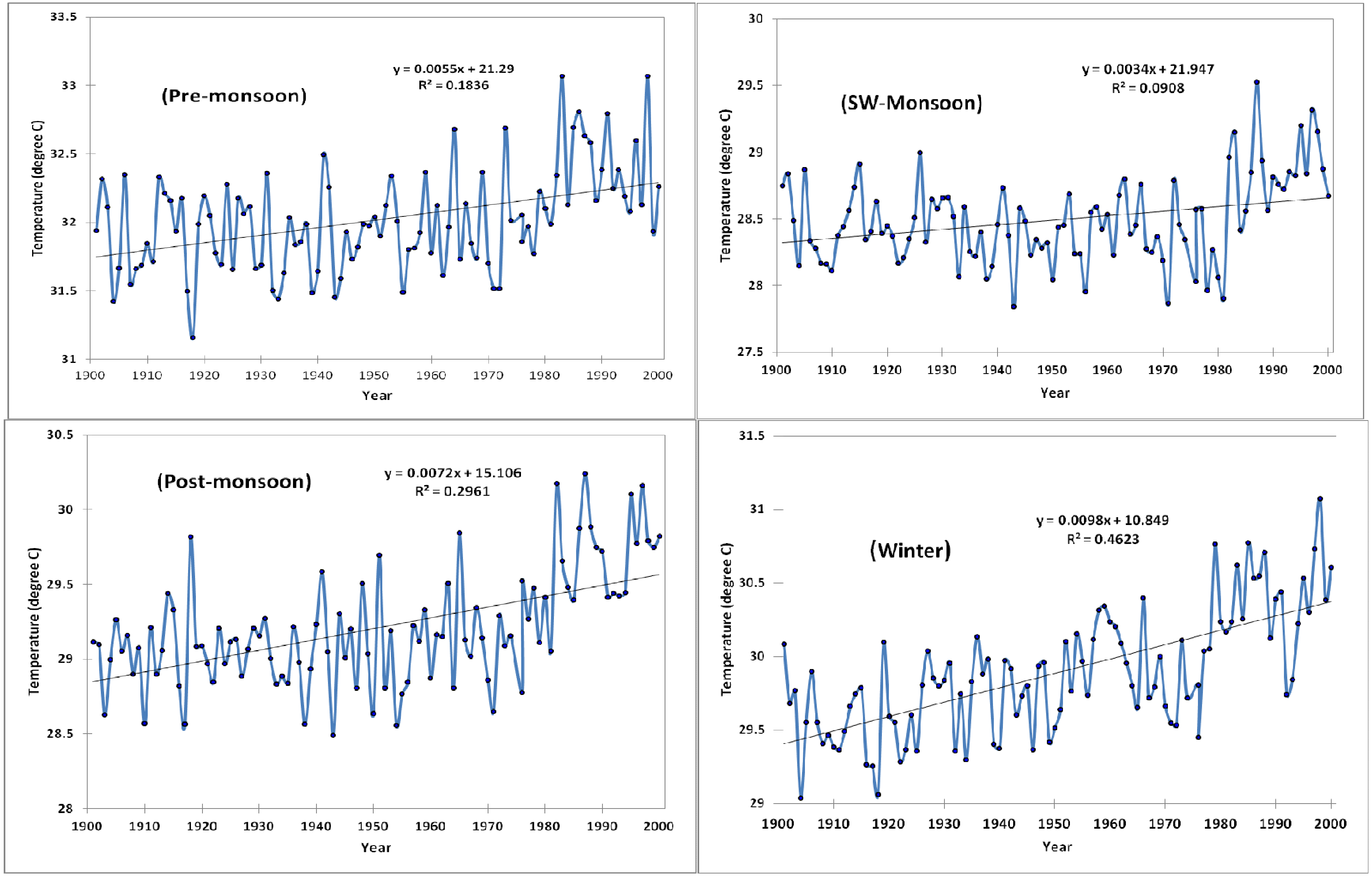

Figure 12. Seasonal trends in daily maximum temperature (^{o}C) in Kerala from 1901 to 2000.

iii. Daily minimum temperature

The mean daily minimum temperature recorded in different months and seasons in Kerala over 100 year period is given Table 9. The coefficient of variation of minimum temperature in a given month or season ranged from 1.4 to 2.5, indicating that it is highly stable.

Table 9. Daily minimum temperature (^{o}C) in different months and seasons in Kerala from 1901 to 2000.

	Mean	Standard deviation	Coefficient of variation (%)
January	19.6	0.5	2.5
February	20.5	0.5	2.5
March	22.1	0.4	2.0
April	23.3	0.4	1.8
May	23.4	0.5	2.3
June	22.2	0.5	2.1
July	21.6	0.4	2.0
August	21.8	0.3	1.4
September	21.9	0.4	1.7
October	21.7	0.4	1.7
November	21.1	0.5	2.2
December	20.0	0.5	2.4
Annual	21.6	0.3	1.4
Pre-monsoon	23.0	0.4	1.6
Southwest monsoon	21.9	0.3	1.4
Post-monsoon	21.4	0.4	1.8
Winter	20.0	0.4	2.0

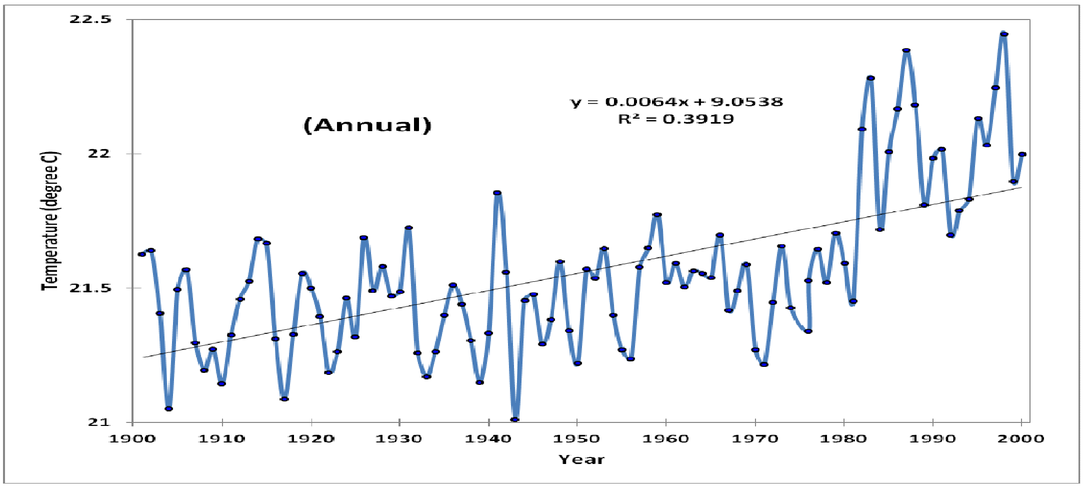

Figure 13. The trend of daily average temperature in Kerala from 1901 to 2000

As in the case of daily maximum temperature, the long-term data of daily minimum temperature in the State also showed significant increasing trend (t= 7.45; p<0.01) (Figure

13) with steep increase during 1980-2000 (Figure 14). In all gridded regions of the State, daily minimum temperature increased significantly (Table 10). Significant increase in daily minimum temperature was recorded in all seasons for all gridded regions.

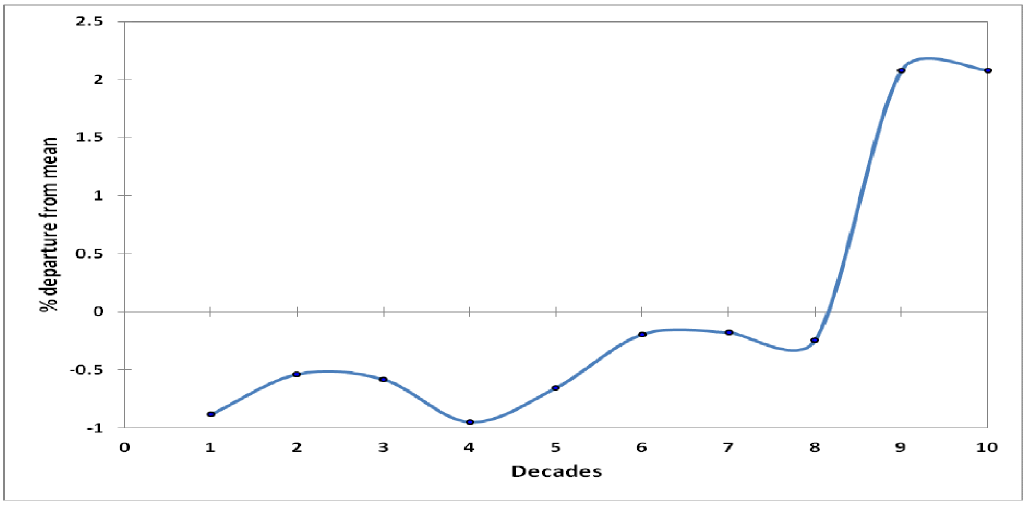

Figure 14. Decadal mean (% departure from average) of daily minimum atmospheric temperature in Kerala from 1901 to 2000.

Table 8. Linear equations developed between years and daily minimum temperature (^{o}C) in different gridded regions of Kerala.

Grid no.	Linear equation (t-value with level of significance)	Grid no.	Linear equation (t-value with level of significance)
1	y=0.006x+11.09 (t= 7.67*)	14	y=0.006x+11.15 (t=7.02*)
2	y=0.006x+10.89 (t= 7.42*)	15	y=0.006x+10.03 (t=7.46*)
3	y=0.006x+10.98 (t= 7.43*)	16	y=0.007x+5.65 (t=6.82*)
4	y=0.006+11.03 (t=7.97*)	17	y=0.006x+11.87 (t=7.12*)
5	y=0.006x+11.06 (t= 7.12*)	18	y=0.006x+11.02 (t=7.16*)
6	y=0.006+11.96 (t=7.12*)	19	y=0.007x+5.76 (t=6.92*)
7	y=0.006x+ 6.76 (t=7.74*)	20	y=0.006x+11.09 (t=7.78*)
8	y=0.006+11.24 (t=7.57*)	21	y=0.006x+10.87 (t=7.15*)
9	y=0.006x+ 6.98 (t=7.79*)	22	y=0.007x+6.86 (t=7.61*)
10	y=0.006+11.98 (t=7.13*)	23	y=0.006x+10.22 (t=7.05*)
11	y=0.006x+9.32 (t=7.98*)	24	y=0.007x+ 7.14 (t=8.02*)
12	y=0.006x+ 7.34 (t=6.98*)	25	y=0.006x+10.98 (t=7.65*)
13	y=0.006x+9.66 (t=7.64*)	26	y=0.007x+7.08 (t=7.98*)

Level of significance of equation tested by t-test is given in parentheses.
* Significant at 0.05 level

The daily minimum temperature in different seasons also showed significant increase (t= 4.85, 3.44, 6.41, 9.45 respectively in pre-monsoon, southeast monsoon, post-monsoon and winter season; P<0.01-0.05) (Figure 15).

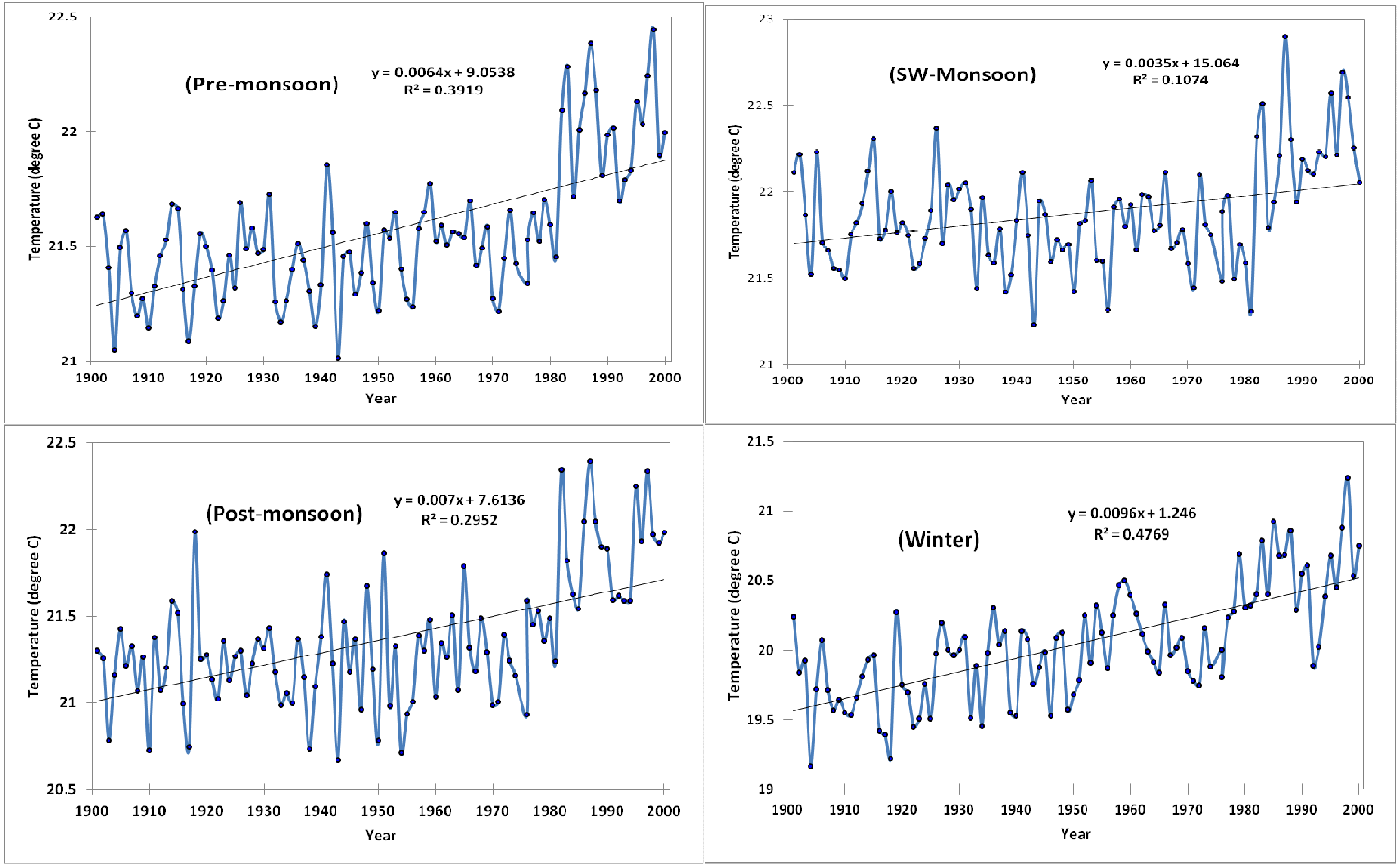

Figure 15. Seasonal trends in daily minimum temperature (^{o}C) in Kerala from 1901 to 2000.

Analysis of trends of atmospheric temperature (daily average, maximum and minimum) thus clearly indicates that the annual temperatures are set to increase from a minimum of 26.8^{o}C to a maximum of 27.5^{0}C in the 2030s. It is also possible to project that temperatures will rise for all seasons from 1.5 to 2.2^{o}C, with no significant change in the rainfall in all seasons in the State.

c. Sea level change

Global sea-level change results mainly from two processes, a) thermal expansion and b) the exchange of water between oceans and other reservoirs (glaciers and ice caps, ice sheets, other land water reservoirs, including through anthropogenic change in land hydrology and the atmosphere). Some oceanographic factors such as changes in ocean circulation or atmospheric pressure also cause changes in regional sea level. For the present report, in order to assess the mean sea level trend in Kerala, annual mean value sea level data for the only one tidal gauge station located in the State at Cochin (Willington Island) has been collected from the data base of the Permanent Service for Mean Sea Level (Woodworth and Player, 2003; PSMSL, 2012). The Indian Authority for providing the data to PMSL from tide gauge station of India is the Director, Survey of India, Geodic and Research Branch, Dehradun. The data available for a period of around 68 years showed that the sea level is raising significantly (Figure 16). The mean sea level trend is 1.49 mm/year with a 95% coefficient of variation of +/- 0.30 mm/year. The long-term data of annual mean sea level also indicated that increase in mean sea level is more prominent during 1989 to 2007 (Figure 17). It is also projected that, with climate change, the sea level in the Kerala coast may rise further and the model-based global average sea level rise may 1.75 mm/ year (Solomon *et al.,* 2007). It is also predicted that due to combined effect of sea level rise and warming of the oceans, the intensity and frequency of cyclonic activities and storm surges may increase leading to large-scale inundation of the low-lying areas along the coast-line.

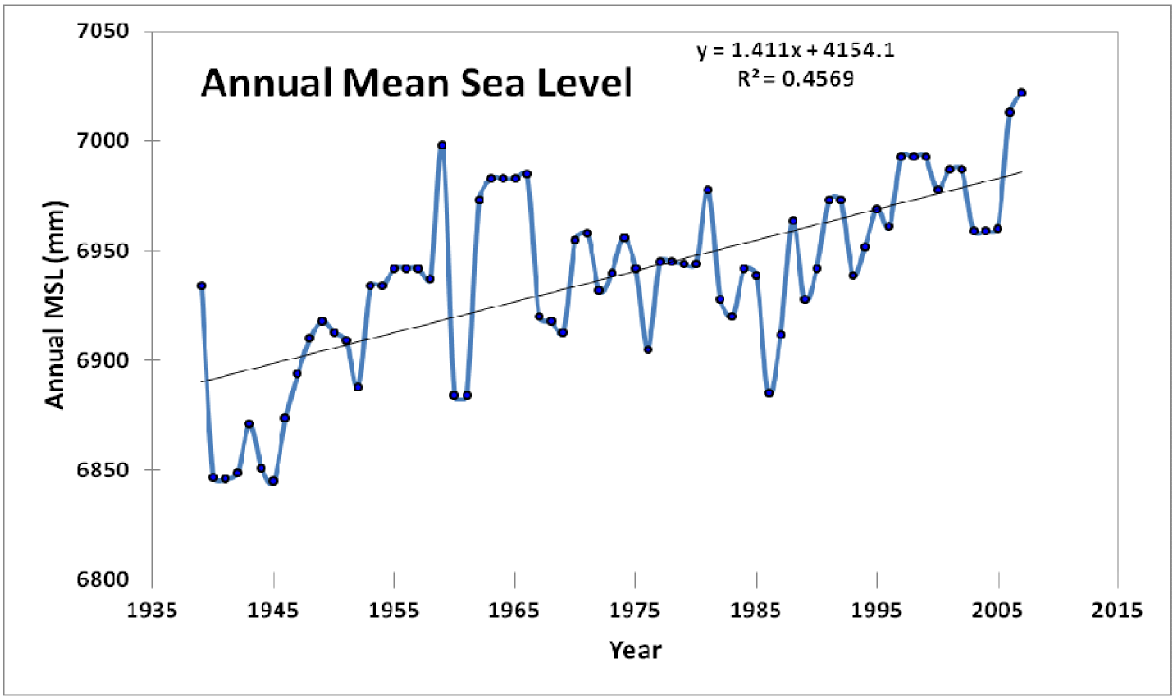

Figure 16. The trend of daily annual mean seal level (mm) in Kerala from 1939 to 2007.

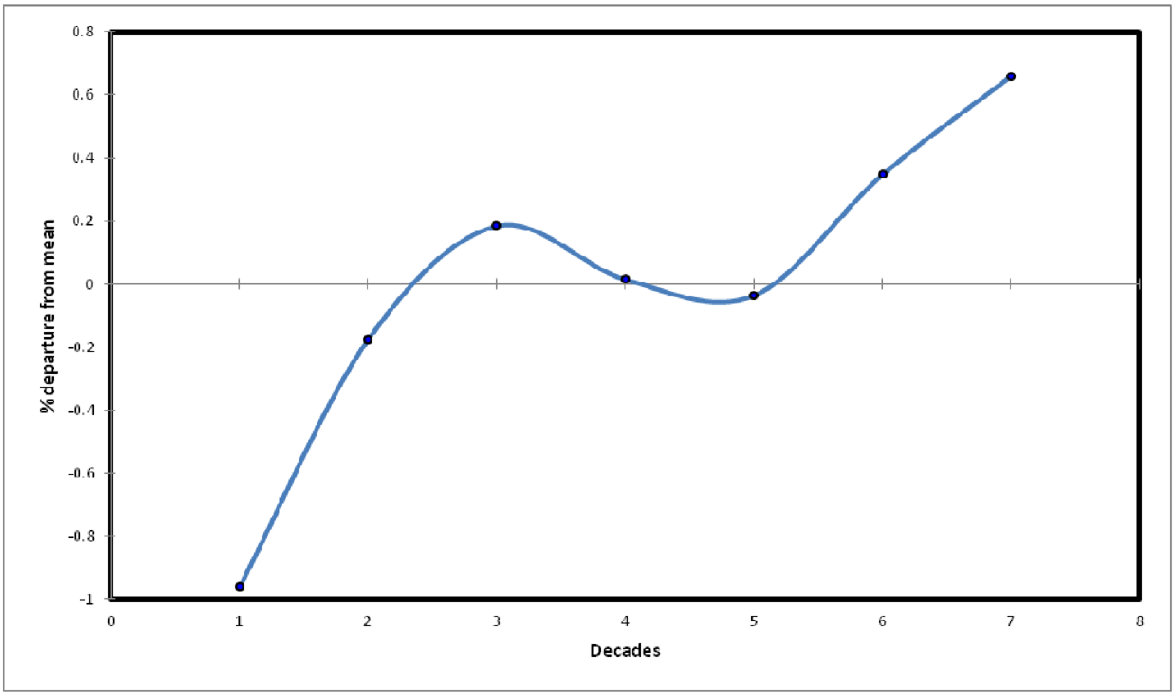

Figure 17. Decadal mean (% departure from average) of annual mean sea level in Kerala from 1939 to 2007.

d. Green house gas emission

It is a well known fact that, due to anthropogenic activities since pre-industrial era, the earth's climate has demonstrably changed on both global and regional scale. Human activities during industrial period began to induce greenhouse gas (GHGs) emissions to the atmosphere resulting in increase in its concentration in the atmosphere. The main GHGs are CO_2, methane and nitrous oxide. In Kerala, the major source for the release of CO_2 is the burning of firewood and of fossil fuels. It is estimated that nearly 37.5 million kg of firewood and 3,087, 589 tons of petroleum products per year are used in the State of Kerala (KSCSTE, 2005). Converting the quantity of fuelwood and petroleum products to CO_2 equivalent it can be estimated that around 19,320,000 tons of CO_2 is consumed annually. Methane is the second important GHG The estimated quantity of methane emitted annually is around 2,030,000 tons. Apart from this, annually around 15,000 tons of nitrous oxide is also released. Now it is recognised that the GHGs concentrations in the atmosphere are at a level that would pose dangerous anthropogenic interference with the climate system. In order to maintain the level of GHG below the dangerous level, necessary adaptation strategies need to be undertaken in all sectors including the forestry sector.

4. Climate change and forests

Among the ecosystems, forest ecosystem is considered as important in the context of climate change. It is estimated that the deforestation and land degradation contribute about 20% of global CO_2 emissions. Forest ecosystems are projected to be adversely impacted by climate change, affecting biodiversity, biomass growth and forest regeneration. Forestry sector provides a large opportunity to mitigate climate change. However, ability of the forest to adapt to the changing climate and mitigate the impacts of climate change is determined by the extent of forest cover and forest ecosystem health (Locatelli et al., 2010). In this context, the status of forests in Kerala is discussed below:

In Kerala, over the 30-years period from 1940-1970, there was a steep drop in the state's forest area with the cumulative loss of publicly managed forests (*c.* 154,000 ha) averaging 5,000 ha annually (Kumar, 2005). The comparisons, involving topographical maps of 1905 and the LANDSAT images of 1973 and 1983 also reflected the declining trend in the forest cover in the State (Chattopadhyay and Hulme, 1997). The National Remote Sensing Agency, based on the study conducted for a period from 1972 to 1982, reported an annual deforestation rate of 1.4% of the total forest cover in Kerala (Nair, 1991) However, from 1980 onwards, the official statistics show that the effective forest cover (under public management) in Kerala has stabilised at about 940,000 ha. The increment of approximately 200,000 ha between 1970 and 1980 is due to the annexation of private forests under the 'Kerala Private Forests (Vesting and Assignment) Act' of 1971. It is also reported that during 1993-2001, there is not much of a change or reduction in the extent of forests. However, during 2003, there was a slight increase, which is a positive trend, i.e. an area of 47 km^2 was added during the year and the coverage has almost attained 29 per cent. However, this also includes about 75,000 ha of plantations of different species. Studies based on satellite imagery clearly show that the primary forests of Kerala have declined. For example, Prasad *et al.* (1998) indicated that the annual decline in natural forest cover of Kerala for the period from 1961 to 1988 was ~0.90%. Likewise, Jha et al. (2000) showed that forest cover in the southern part of the Western Ghats (~4,000,000 ha) declined by 25.6% over the 22 years from 1973 to 1995. There has been, however, a great deal of temporal and spatial variability in this respect. According to Jha et al. (2000), Palghat district experienced an annual rate of 2.1% loss of dense forests between 1973 and 1995, while Ernakulum and Kozhikode experienced relatively lower loss rates (0.1% and 0.6% respectively). According to Ramesh et al. (1997), in Kerala, deforestation rates have also accelerated in recent times. For instance, the Agastyamalai region in southern Western Ghats recorded a five-fold increase in deforestation between 1920 to 1960 and 1960 to 1990.

Recently, Forest Survey of India (FSI, 2009) reported that the total forest cover in Kerala State, based on interpretation of satellite data of December 2006- March 2007, is 17,382 km^2, which is 44.73% of the State's geographical area. The distribution of forest cover in the State and district-wise forest cover in different canopy density classes and shrub are given in Figure 18 and Table 9 respectively. In terms of forest canopy density classes, the State has 1,443 km^2 very dense forest, 9410 km^2 moderately dense forest and 6,471 km^2 open forest and 58 km^2 scrub forest.

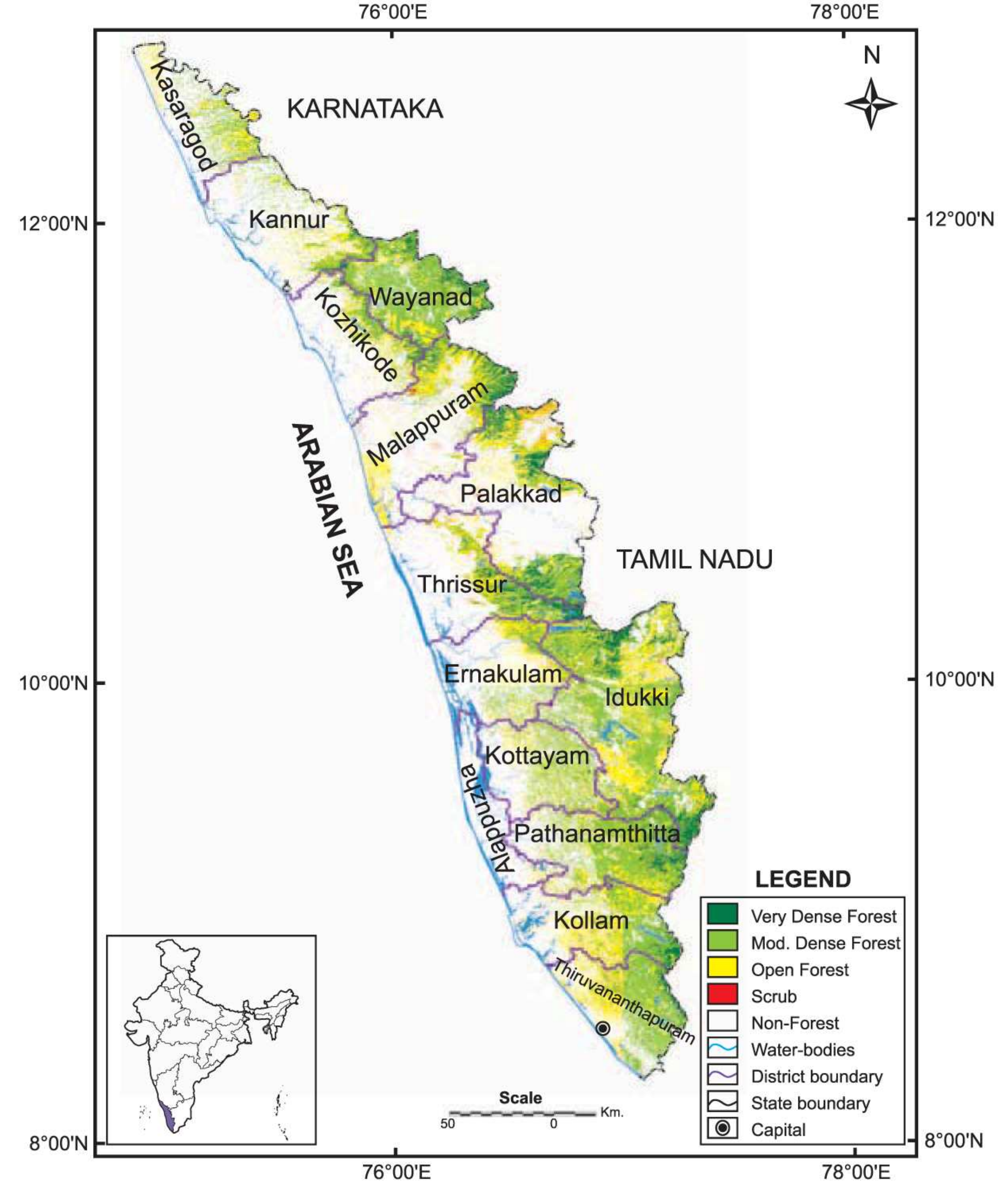

Figure 18. Forest cover map of Kerala (Source: FSI, 2009).

Table 9. District – wise forest cover (in 2007) in Kerala State.

(area in Km^2)

District	Geographical area	Very dense forest	Moderately dense forest	Open forest	Total	% of Geographic Area	Change (compared to 2005 assessment	scrub
Alappuzha	1,414	0	12	26	38	2.69	1	0
Ernakulam	2,407	12	299	385	696	28.92	-2	1
Idukki	5,019	350	2,160	1,422	3,932	78.34	28	5
Kannur	2,966	21	351	269	641	21.61	0	0
Kasaragod	1,992	0	307	285	592	29.72	1	1
Kollam	2,491	75	636	626	1,337	53.67	9	0
Kottayam	2,203	13	546	336	895	40.63	-11	1
Kozhikode	2,344	32	288	271	591	25.21	-3	0
Malappuram	3,550	144	407	660	1,211	34.11	13	9
Palakkad	4,480	276	693	606	1,575	35.16	-3	35
Pathanamthitta	2,642	144	1,149	465	1,758	66.54	7	0
Thriruvananthapuram	2,192	55	826	469	1,350	61.59	1	0
Thrissur	3,032	181	389	363	933	30.77	-7	5
Wayanad	2,131	140	1,347	288	1,775	83.29	6	1
Total	38,863	1,443	9,410	6,471	17,324	44.58	40	58

Comparison of the current forest cover (satellite data of Dec 2006- March 2007) with the previous assessment (satellite data of Dec 2004- February 2005) shows a gain of 42 km^2 of forest cover (an increase in 6 km^2 in the moderately dense forest, 34 km^2 in open forest and 2 km^2 in scrub forest). The main reason attributed to such an increase in the forest cover in the State is the inclusion of the plantations of trees outside forest species such as coconut, arecanut and other miscellaneous species in the forest cover (Jha et.al. 2000). Even though the forest cover in the State seems to be stabilised to around 17,382 km^2, the quality of forest patches in terms of stand density, basal cover, species diversity succession and regeneration patterns needs to be thoroughly investigated to understand the potential of the existing forest cover in adapting to the changing climate as well as mitigating the effects of climate change.

The accumulation of CO_2 in the atmosphere due to fossil fuel use, deforestation and other anthropogenic sources is changing the global climate (IPCC 2002). It is a known fact that forests play a prominent role in the global carbon cycle and the accumulation of GHG in the atmosphere, but the roles vary regionally (Dixon *et al.* 1997). In India, the significance of the role of forests in different regions including Kerala, in the carbon cycle is not studied. In the absence of such information, an attempt has been made to estimate the carbon stock using data available on basal area of tree community in permanent plots established in different types of forests of Kerala (Chandrashekara and Jayaraman, 2002). The biomass estimated using the equations specifically developed to estimate above-ground standing biomass (AGSB) from basal area data of the forests in the Western Ghats (Ravindranath *et al*., 2000). Carbon stock was estimated assuming that it forms 50% of the biomass (Dixon *et al*., 1994). The average above-ground standing biomass (AGSB) in evergreen forest, semi-evergreen forests, moist deciduous forest and dry deciduous forests of Kerala is 358.3 t/ha, 303.2 t/ha, 238 t/ha and 176.9 t/ha. By multiplying the total extent of a given forest type in the State with its AGSB value, total biomass was calculated and then the value was converted into carbon stock (Table 10). In fact, several semi-evergreen forests and moist deciduous forests in the State are secondary forests of wet evergreen type of forest. Thus, by undertaking rehabilitation measures area under evergreen forests can be increased and that in turn can enhance forest carbon stock.

Table 10. Carbon stock in the forests of Kerala

Forest type	Area (ha)	Above-ground biomass (t/ha)	Total above-ground biomass (t)	Total carbon stock (t)
Evergreen forest	2,38,060	358.3	85296898	42648449
Semi-evergreen forest	1,60,400	303.2	48633280	24316640
Moist deciduous forest	5,58,640	238.8	133403232	66701616
Dry deciduous forest	28,080	176.9	4967352	2483676
Total Carbon stock (t)				13,61,50,381

It is a known fact that due to habitat destruction, fragmentation and degradation, forests are more vulnerable to climate change and that in turn leads to biodiversity loss (Dawson et al., 2011). Apart from affecting the biodiversity, climate change and increased CO_2 will also affect the species-assemblage and net primary productivity. For instance, at the individual tree level, an increase in atmospheric concentrations of CO_2 is expected to lead to increased levels of net primary productivity and an increase in overall biomass accumulation and an increase in overall biomass accumulation (Hexeltine and Prentice, 1996). In forests, where photosynthesis is limited by CO_2 concentration, the degree to which such increase can be sustained over time will be limited by other factors such as the availability of nitrogen and water. For instance, it was shown that forest patches subjected to a 100 mm decrease in rainfall under the effect of drought in the Amazon lead to tree mortality amounting to loss of 5.3 tons of C per hectare in one year period (Phillips et al., 2009). Even though, we do not have data to demonstrate the impact of climate change on forest tree stands, it is expected that the current trend of south-west monsoon and uncertainties in post-monsoon rainfall could affect the productivity and overall biomass accumulation. Apart from effects on individuals' productivity, increased atmospheric CO_2 concentrations are also expected to alter leaf chemical composition, affecting herbivores as a result. Either in addition to or in concert with increased concentrations of atmospheric CO_2, climate change-induced shift in temperature and precipitation is expected to affect individual plants' fitness and productivity as well. Changes in absolute temperature as well as changes in the form, timing and amount of precipitation can affect forests directly. In the context of Kerala State, increase in temperature with decrease in wet days during southwest monsoon and post-monsoon seasons can affect both productivity and phenological patterns of the forest. The predicted warmer climate in Kerala will likely to allow herbivores and pests to expand in both number and range.

5. Possible impacts of climate change on forest structure and composition

Under a changing climate, the combined and individual influence of temperature, precipitation, atmospheric CO_2 concentration is expected to have dramatic effects on forest systems. However, in India in general and in Kerala in particular, studies to assess the impacts of climate change on forest structure, composition and individual plant or animal are highly limited (Sukumar et al., 1995). One attempt has been made to predict the possible impact of climate change in three forest types, namely, the lowland evergreen forests, midland evergreen forests and shola forests of Kerala (Chandrashekara, 2004). The results of the study are presented here. According to Pascal (1998), in the Western Ghats of India, the major gradient in temperature is linked to altitude and a corresponding decrease in annual mean temperature of 0.8 to 0.9^{o}C per 100 m elevation is seen. Thus, for analysing the potential impact of climate change on vegetation structure and composition, studies on vegetation along transects are useful. This is because the current climate conditions in the relatively higher altitude locations are expected to change in future in such a way that this area would experience the climatic conditions of lower elevations. Thus, due to climate change, the present day vegetation structure and composition in the lower elevations would be seen in higher elevation localities. With this background in mind, for each forest type (lowland evergreen forests, midland evergreen forests and shola forests), plots were selected along the altitudinal gradients and analysed for species diversity and phytosociological features. A comparative study carried out in a swamp forest (altitude 76 m above mean sea level) and in a forest patch located at 372 m above msl indicated that in both the plots, tree species such as, *Knema attenuata*, *Myristica dactyloides* and *Polyalthia fragrans* are dominant. However, contribution by these species to the total Importance Value Index (IVI) is relatively less in the higher altitude forest patch. In addition, these species show certain morphological features such as, stilt roots and breathing roots only when they are growing in the swampy areas. In higher altitude forest patch (372 m above msl), comparatively high species diversity is recorded and this can be attributed to two factors, namely, the low dominance of Myristicaceous species and partitioning of resources by species characteristic to a wide range of elevation. It is clear from this study that the *Myristica* swamps represent a distinct plant association in lowlands of Kerala. Climate change in Kerala, which is expected to increase the water table in the low-lying areas, need not directly alter the habitats and their vegetation structure and composition in *Myristica* swamps located here. Nevertheless, loss of coastal land due to inundation and intrusion of salinity as a consequence of climate change, may lead to the encroachment of *Myristica* swamps and their conversion for agriculture, construction, industrial uses, etc.

The possible impact of climate change in midland forests and a high elevation forest (shola forests) is in the form of increase in mean annual surface temperature. It is also expected that the temperature in a forest patch located at a given altitude could rise to the level being experienced in the lower altitude forests. In this context, in a given forest type, comparison of vegetation structure and composition of forest patches located in the relatively higher altitude with those in the lower altitude was made, to provide an indication of possible species composition and other phytosociological features in the higher altitude forest patches. The study indicated that in the relatively undisturbed forest patches, located in an altitudinal gradient (810 m, 1090 m, 1250 m and 1475 m above mean sea level) in the midland evergreen forests, *Palaquium ellipticum*, *Mesua ferrea* and *Cullenia exarillata* remained as the dominant tree species. Thus, climate change may not alter the composition of the dominant species. However, number of species, density and values obtained for species diversity index, both in tree and seedling communities are more in high altitude forests. Therefore, possible impact of climate change on relatively high altitude forests in the midland could be the reduction in species diversity and density of tree and seedling communities. A clear increasing trend in density, basal area and contribution to the total species importance index values by *Mesua ferrea* and the family Lauraceae with increase in elevation was noticed. Thus, it is also possible to predict that due to climate change, in higher elevation forest patches, current dominance of *Mesua ferrea* and Lauraceae may be reduced.

Shola forest patches along the altitudinal gradient are different from each other in terms of dominant species in their tree communities. In this forest type, as the elevation increases, the dominance of *Cinnamomum perrottetii* and *Microtropis ramiflora* increased respectively in tree and seedling communities. In addition, the species composition in higher altitude forests is significantly different from the plots located in lower elevation shola forests as indicated by the similarity index values obtained for tree and seedling communities. This implies that, due to climate change, in the higher altitude shola forests, the dominance of *Cinnamomum* *perrottetii* and *Microtropis ramiflora* may become less dominant and species composition will tend to become that of lower altitude sholas. Currently, in higher altitude shola forest patches, density of tree and seedlings is more than those in lower altitude patches. The height of the trees is also relatively less. Thus, it can also be predicted that due to climate change, density of trees and seedling and height of the trees could increase in the higher elevation sholas.

From the Western Ghats, only one study is available that evaluates the potential impacts of climate change on individual species (Sukumar et al., 2005). Montane grasslands in the Western Ghats are the only habitats of the Nilgiri tahr. In the montane region, enhanced CO_2 could fertilize the growth of C_3 plants such as the exotic wattles. Warmer temperatures could likewise facilitate the spread of woody plants including the invasive wattle and scotch broom. As a result, grasslands could further reduce with adverse consequences for the tahr and montane species.

It is also predicted that in the long run, climate change can alter the amount, quality and types of non-wood forest products available. Climate change can also threaten existing protected areas which are designed to represent specific natural features, species and ecological communities. Besides the effects on biodiversity conservation, such changes can affect nature-based tourism and recreation.

Along with several anthropogenic activities such as illicit cutting of trees, grazing, collection of fodder, green leaf manure, litter and non-wood forest products that are increasing in alarming rate (Jayanarayanan, 2001; Amruth, 2004; KFRI, 2005; Muraleedharan et al., 2005; Chandrashekara,2011), and climate change is also expected to increase the pressure on remaining forests.

6. Role of forests in addressing climate change

Despite the fact that the forests are affected by climate change, they also play an important role for addressing climate change. However, it is increasingly recognised that well-managed and relatively undisturbed forests can help societies to adapt to both current climate hazards and future climate change, by providing a wide range of ecosystem services. A secure flow of ecosystem services can significantly reduce social vulnerability as well. Therefore, a primary task should be assessing the quality of existing forest cover and its current ability for buffering the impacts of climate change.

It may be pointed out here that very little quantitative information is available on many of anthropogenic activities. Thus, it is impossible to segregate and assess the precise impacts of climate change. Nonetheless, it is reasonable to assume that increasing levels of disturbance are accompanied by a reduction in forest biomass, impaired vegetation structure, altered regeneration spectrum, floristic changes and opening of the forest canopy. All these factors can lead to the forest ecosystem to become highly sensitive to climate change and also reduce its inherent adaptive capacity. In the following section, certain mitigation and adaptation strategies ideal to the Kerala condition to reduce the impacts of climate change on forests and also to enhance the adaptive capacity of forest ecosystems are discussed.

7. Mitigation practices in forestry sector of Kerala

Mitigation involves attempts to slow the process of global climate change, usually by lowering the level of greenhouse gases in the atmosphere. Among several actions that can be taken in the forest sector to promote mitigation include a) managing forests with high carbon uptake potential, b) expanding such forests through reforestation and afforestation, and c) reducing deforestation and reversing the loss of forest cover. Several forest conservation measures taken by the Kerala Government can be considered activities to mitigate the effects of climate change; though some are intentional and others incidental. For instance, during 1949, under the Madras Preservation of Private Forest Act (MPPF), tree felling or alienation of land through sale, mortgage or leasing of private forests without the prior permission of the District Collector was prohibited. This Act, an example for unintentional activity to promote mitigation, helped to some extent to control the indiscriminate conversion of forests to agriculture in Kerala. However, due to the absence or inadequacy of implementing machinery and the unsurveyed nature of the private forest holdings the objectives of the Act were not fulfilled (Mammen, 1993).

The Kerala Social Forestry Project funded by the World Bank was aimed to enhance the fuel wood and fodder stock of the State by planting around 0.853 lakh ha with a tree density of 4,900 per ha in public and private lands. A review of this Project by the Estimate Committee of the Kerala Legislature showed that the emphasis has been given on fast growing exotic species and 390.8 lakh seedlings have been distributed to farmers up to 1986-87. The Review report also indicated that against a target of 0.853 lakh ha the achievement was 0.98 lakh ha (Tewari, 1991). The survival rate of seedling planted under the World Bank aided Social Forestry programme in forests and public lands was over 80% at 1.5 years after planting and this dropped down to about 60% in later years (Jayaraman et al., 1992).

Restriction of timber harvesting in Wildlife Sanctuaries also indirectly helped to maintain or increase the stand–level carbon stock. In the sanctuaries, during final felling of teak plantations, felling was limited to only 25% of the mature trees. Since 1985 clear felling of plantations at rotation age has also been stopped.

The Forest Conservation Act 1980 enacted by the Government of India assumes wide ranging powers for regulating forest landuse decisions. Under this Act, the states have effectively lost all powers to modify forest landuse for non-forestry purposes without the prior sanction of the Central Government. In Kerala, since 1987 selection felling in natural forests has also been abandoned.

The Forest Policy of 1988 also strengthened some of the efforts made by the State to ensure environmental stability and maintenance of ecological balance for sustenance of all life forms, including humans, animals and plants. The policy specifically stressed the need for safeguarding tropical rain/moist forests, particularly in areas like Arunachal Pradesh, Kerala and Andaman and Nicobar islands.

The World Bank aided Kerala Forestry Project has been launched in 1998 to promote conservation of biodiversity and arrest the degradation of forest land, to improve productivity of wood and non-timber forest produces from forest and non-forest lands, and to improve the living condition of local people residing in and around forest area. According to the Implementation Completion Report of the World Bank (2004), the Kerala Forestry Project has made significant progress towards arresting the retrograde trend in forest cover through the implementation of a series of treatment practices in natural forests. These were designed to assist the regeneration of these forests by promoting and protecting natural regeneration of desirable tree species, reeds, bamboos, canes, and non-timber forest products (NTFPs) from fire and biotic destruction. The forestry treatments under this project also supported, where necessary, planting and maintenance of native species. Initially, such treatments were undertaken on a scattered basis, but following a mid-term review, and consequent recognition of importance of water conservation, a micro-watershed approach was taken, combining treatments for forests in different categories of degradation. Although it is too early to assess the full impact of the treatments on the forests, there is, nevertheless, clear evidence from sample plots showing a significant increase in regeneration (World Bank, 2004). There has been at least 50 percent increase in fresh and established seedlings and saplings in over 50 percent of the sites, while many sites showed an increase of over 100 percent even at this early stage. With the expected continued protection, this regeneration will result in much improved high forest cover. There has been a dramatic reduction in the occurrence of fire in the forest since the introduction of participatory fire protection programmes under the project. The report also says that the forest areas covered by participatory forest management programmes show a considerable decrease in the number of offences related to illegal harvesting of forest products. With regard to forest plantations, the report highlights the fact that a solid technical basis has been provided through the project for sustainably improving productivity in forest plantations. This has involved the development and use of improved planting material, including establishing sources for improved genetic quality seed for teak and pulpwood species as well as establishing the capacity to provide clonal planting materials for pulpwood species. Nursery technology and management was upgraded with the introduction of root trainers and the construction of one central nursery for each circle. As a result of these improvements, planting materials are of higher quality and vigour compared to prior to the project and field survival has improved from approximately 60 percent to over 90 percent with generally better growth in the early years (World Bank, 2004). The report also observed that although it is too early to predict accurately the impact on teak plantation development, nevertheless, the improved genetic quality of seed and survival plus early growth in some areas should give improved yields.

The introduction of a participatory approach to forest protection and management (PFM) has not only shown a positive contribution to improving forest cover and potential yield, but has already given indications of a sustained improvement in the livelihoods of the rural communities involved. The adoption of PFM was slow for the first three years of the project, but it eventually exceeded the target number of Forest Protection Committees (Societies) or Vana Samrakshana Samithi (VSS), with a total of 36,500 families being involved, most of which are poor and marginal, including 10,000 families of different tribes and 4,000 families of scheduled castes (KFD, 2010). PFM has provided additional income to these families through wage employment for forest management and protection, but, in many cases has also provided a basis for future income generation through forest-based activities and ecotourism. There is also evidence that the establishment of the VSS has provided a sense of empowerment to the communities resulting in additional funding and fostering numerous self-help groups. Women are major recipients of these livelihood benefits. A formal evaluation suggested that the PFM should, by and large, successfully protect and manage the forests as well as provide improved livelihoods to the communities involved. The continuity of the Programme under the National Afforestation Program, and the positive attitudinal changes across the communities and Kerala Forest Department (KFD) is expected to help the sustainability of the Programme.

The above developments in forest and plantation management are underpinned by positive institutional changes that have occurred through the Kerala Forestry Project. These include the introduction of bottom-up, site-specific planning that reflects more realistically on particular site conditions, and silvicultural requirements, widespread acceptance by KFD staff of improved plantation nursery and silvicultural technology, an overall improvement in data compilation, management and distribution, improved communications, a widespread acceptance of the value of involving local communities in forest management, and the dissemination of applied research results.

Massive afforestation programmes launched by the Social Forestry wing of the Kerala Forest Department since 2007 are the best examples for institutional and intentional programmes to mitigate the impacts of climate change. The programmes to realise the slogan, `Global warming- Tree is the Answer', were launched with the participation and involvement of public. Following are the afforestation schemes launched in the State (KFD, 2011).

My Tree Programme (Ente Maram Scheme)

In association with the Kerala Education Department, the Kerala Forest Department implemented this programme. Under this novel scheme, all students from Standard V to IX all over the State, participated in planting of trees in their own household compounds and in places available to them nearby, and nurturing them. Under this programme, during 2007 to

2010, nearly 42.12 lakh of seedlings were planted. The enthusiasm shown by the students and their whole hearted participation and involvement gave an about 80% survival of the seedlings.

Our Tree Programme (Nammude Maram Scheme)

This programme of planting in the college/school campuses was implemented by involving school and college teachers and students. For this programme, necessary seedlings have been supplied to the educational institutions during June 2008. A total of around 10.57 lakh seedlings were planted during 2008 to 2010.

Greening the Coast Scheme (Haritha Theeram Scheme)

This project aims at the protection of the State's coastline from natural calamities by establishing a bio-shield of sand binding trees like *Casuarina equisetifolia* and shrubs wherever possible along the coast. Under this forestry activity, during 2007 to 2009, 163.4 ha of casuarinas and 14.65 ha of mangrove plantations were raised and around 22.52 lakhs of popularly demanded species were distributed to the public along the coastal belt.

Roadside planting of shade trees (Vazhiyoura Thanal Scheme)

This scheme aimed at planting shade trees on roadsides was implemented with the participation of head load workers from various trade unions in the State. During 2007 to 2009 around 1.22 lakh of seedlings were planted.

Greening Kerala Scheme (Haritha Keralam Scheme)

This scheme was designed to create woodlands outside the forest areas. Under this people's programme, during 2009-2011 around 101.4 lakh seedlings have been planted in community lands, institutional lands, roadsides, railway-sides, river banks, areas surrounding ponds and lakes and other private lands including homesteads in villages of the State with the involvement of panchayaths, school children, senior students, youth organisations, religious institutions, NGOs, media establishments, civil society organisations and individuals.

Protection and Conservation of Sacred Groves

In Kerala, sacred groves represent community conserved biodiversity areas. The government of Kerala has identified the fact that protection and conservation of sacred groves is one option for mitigating the effects of climate change as well as to recognise, appreciate and strengthen the traditional method of forest conservation in the State. Thus, the Kerala Forest and Wildlife Department joined hands with owners of sacred groves and local communities in implementing a new component, 'Protection and Conservation of Sacred Groves' under the Central Government sponsored scheme 'Intensification of Forest Management'.

Thus it is clear that the Government of Kerala have already undertaken several forest conservation measures and among them some are unintentional other are intentional activities to mitigate the effects of climate change. By strengthening or continuing with programmes like Kerala Social Forestry Project and protection and conservation of sacred groves adverse effects of climate change can be mitigated. With its broad experience in the promotion of forest conservation, participatory forest management and forest governance, the Kerala Forest Department can greatly facilitate comprehensive approaches to the role of forests in climate change mitigation.

8.Adaptation measures for the forestry sector of Kerala

Adaptation is adjustment in natural or human systems in response to actual or expected climate stimuli and their impacts on natural and socio-economic systems, which moderates harm or exploits beneficial opportunities (IPCC, 2002). While the climatic mitigation strategies will have a long-term global impact on green house damage, the adaptative actions will have a positive direct and immediate effects for regions that implement them. In the forestry sector of Kerala, adaptation to climate change is crucial due to the fact that the climate change could cause irreversible damage to unique ecosystems such as sholas, mangroves, *Myristica* swamps, etc. Kerala is rich in biodiversity with several endemic and RET species. For instance, among the 4,465 taxa of flowering plants in the State, 1387 are endemic to peninsular India and 495 species belong to the Rare and Threatened (RET) categories, including 151 tree species (Sasidharan, 2002). Loss of unique ecosystems could lead to extinction of many such species (CBD, 2009). Apart from unique ecosystems and biodiversity, the forest dwellers in the State are also likely to be adversely impacted due to climate change.

The forest dwelling communities being one of the poorest communities of society (IUFRO, 2009) will have low capacity to cope up with or adapt to adverse impact. They will also have least resources to adapt and are thus most vulnerable to climate change. Due to climate change, the forestry sector may be vulnerable to extreme events such as drought coupled with warming leading to increased occurrence of fire with which the Forest Department could have difficulty to cope with. Therefore, adaptation to climate change is no longer a secondary and long-term response option only to be considered as a last resort. It is now established that suitable adaptation actions have to be taken considering the vulnerability of forests to the climate change.

Adaptation strategies can be of two types namely; `no-regret' strategies and dedicated strategies. No-regret strategies are required to address current stresses such as deforestation, fragmentation, cattle grazing and non-sustainable extractions. On the other hand, dedicated strategies are required to reduce vulnerability of forests and plantation ecosystems to climate change.

The dedicated strategies for adaptation to climate change and their implementation in the forest sector of Kerala are discussed below.

a) Maintenance of forest extent

In the context of forest sector in Kerala, there is no evidence to say how the extent of forest is affected by climate change. In addition, due to occurrence of a large number of tree species, as in other tropical forests, it is difficult to predict the response of natural forests to climate change, especially due to lack of information on the ecophysiology of tree species. However, the State has been experiencing rapid population and economic growth, infrastructure expansion and rising demand for timber and other forest-based commodities and they are the major drivers of change in the extent and quality of forests. Despite socio-economic factors, climate change may also be responsible, either directly or indirectly, for altering the extent of different types of forests in the State. For instance, in some places where the moisture availability is a controlling factor, closed forest will change to open forests and savannah. In this context, the desire of the Kerala Government to ensure that forest area in the State is maintained (Kerala Forest Policy, 2007) is commendable. The State Government has also initiated implementing several programmes for sustainable forest management. However, such programmes need to be further strengthened and fine-tuned to improve the ability of forests to cope up with possible impacts of expected climatic stimuli. Some of the adaptation options, specifically aimed towards maintaining forest cover, are listed below.

i. Provide alternative coping mechanisms for vulnerable communities (forest dwelling and forest-fringe farming communities) that would otherwise use forests when facing crop and livestock failures.
ii. Increase forest law enforcement in areas impacted by illegal collection of wood and non-wood resources from the forests.
iii. Reduce the use of wood for domestic energy by launching schemes to promote use of renewable energy sources
iv. Enhance local welfare through promotion of community-based forest management and restoration and development agroforestry
v. Intensify social forestry programmes to improve community and individual welfare through community plantings, village woodlots, shelterbelts, public awareness campaigns through the media, children's education programmes and field demonstrations.

b) Maintenance of biodiversity

Forest biodiversity is essential to support the ecosystem services provided by forests and to maintain the adaptive capacity of forests to climate change. However, the biodiversity itself can be affected by climate change (Sukumar et al., 1995). The effects of climate change such as altered forest ecosystems (species composition and structure), altered processes (increased fire, extreme events leading to gaps) altered productivity and altered physical habitats (changes in microclimates) either together or independently may cause extinction of species, particularly in some specific areas such as tropical mountains (Price et al., 2011). Therefore, management of forests for resisting changes, enabling system to maintain its biodiversity and avoid undesirable impacts on biodiversity is the key aspect in the current context. A number of options are given below. Forest will benefit from these adaptation actions, even if the ecosystems that develop differ markedly from current forests.

i. Minimize fragmentation of habitat and maintain connectivity
ii. Protect primary forest
iii. Identify and protect functional groups and keystone species
iv. Strategically increase size and number of protected areas, especially in ecologically fragile areas
v. Protect most highly threatened species ex-situ
vi. Create artificial reserves or arboreta to preserve rare species
vii. Practice low-intensity forestry and prevent conversion to plantations
viii. Design tree plantations to have a diverse understorey
ix. Transform failed/less productive plantations in species rich productive plantations by undertaking rehabilitation programmes
x. Adopt multi-species and multi-tier forestry using indigenous species
xi. Reduce the rate of deforestation and forest degradation
xii. Allow forests to regenerate naturally following natural disturbance
xiii. Control invasive species

Thus, a range of management options are available to assist biodiversity adaptation to climate change. However, in taking any action, it is necessary to consider what the forest composition might be under different scenarios of climate change, since major changes are likely in some areas. The adaptation actions should be designed to increase the forests' ability to achieve this new composition through an understanding of natural process. For instance, while increasing the size of protected areas the successional pathways need to be followed.

Over broad regions, such as national parks, landscape approach of forest and biodiversity conservation need to be employed. The landscape-level strategies have several advantages for facilitating natural adaptation of biodiversity. For instance, forest management by landscape approach will enable natural migration of species to areas with more suitable climates. The landscape level management will also provide both geographic corridors and spatially distributed in different stages of forest development. Such heterogeneity both in space and forest structure is helpful to some species which need particular stages of forest development for their survival.

An important strategy in any long-term management plan to adapt to climate change is to increase in size and number of reserves as they are generally rich in biodiversity and they are the enabling systems to adapt naturally to climate change in the absence of active management. However, very often even within the reserves, one can see several patches of forests under arrested succession or infested with weeds. Thus without managing such areas the forest diversity cannot be maintained or increased.

The Government of Kerala is making substantial efforts in implementing several adaptation options. However, some specific management strategies that have not been considered seriously are mentioned below

a) Forest Division-wise or Forest Circle-wise creation of arboreta or reserve to preserve RET and endemic species
b) Assist changes in the distribution of species by introducing them to new areas
c) Design tree plantations to have a diverse understorey
d) Adopt multi-species and multi-tier forestry using indigenous species
e) Reduce the rate of deforestation and forest degradation
f) Control invasive species

Thus further appropriate actions to conserve as well as possible, existing forest biodiversity in areas with suitable conditions and at managing change as efficiently as possible to improve future forest conditions.

c) Maintenance of forest health

Studies carried out elsewhere in the tropics have shown that climate change will affect the health and vitality of forests (Mark et al., 2011). These effects may be subtle and long-term, such as droughts and insect epidemics, or they may be sudden and catastrophic, such as the occurrence of devastating storms and fires. In this context, some important adjustments to be made in forest management actions and programme to minimise the impacts of climate change are to be identified. For instance, the forests of Kerala are dominated by secondary forests and many of them are characterised by profuse growth of understorey and climbing weeds that affect the growth of primary species of evergreen forests. The weed community is also responsible for reducing forest productivity, stand vigour, increasing incidences of fire and tree fall and altering forest structure, composition and dynamics. Thus appropriate silvicultural practices to promote forest productivity and increase stand vigour need to be employed. The cultural practices should also be aimed to stimulate the regeneration of species characteristic to native primary forests, develop their crown and eventual fruiting of seed trees. In the case of forest plantations, efforts need to be made to increase genetic diversity of component trees. It may be pointed out that even in some parts of protected areas and biospheres, continued non-climatic stress such as biomass removal, grazing, green manure, litter and plant propagules collection are leading to the poor stand quality (Chandrashekara, 2011). Without removing such non-climatic stresses, it will not be possible to enhance the alibility of ecosystems to respond to climate change.

The devastating effects of pathogens in mono-specific plantations will likely be higher in future due to pathogens benefitting from climatic conditions. It can also be anticipated that the host- specificity of most pathogens, could lead to major outbreaks affecting most or all trees in such plantations (Ayres and Lombardero, 2000). The plantation forests in tropics may be susceptible to major pathogen attacks unless genetic diversity is maintained. In the context of maintaining health and vigour of forest plantations to cope up with climate change also, therefore genetic diversity of trees used in plantations needs to be increased.

d) Maintenance of productivity in forest ecosystems

It is speculated that due to climate change the tropical forest productivity, at least in some regions like Kerala, can increase considerably (NIC, 2009). A meta-analysis of tree productivity responses (Boisvence and Running, 2006) has suggested that where water is not limiting, productivity will generally increase. However, there is a range of different factors that are involved in determining the final productivity of forests. Some of these such as nitrogen deposition, are independent of climate change, whereas others are related to climate change (eg. increasing concentrations of atmospheric carbon dioxide). Thus it is uncertain that climate change increases the forest productivity. In this context, appropriate silvicultural operations need to be undertaken to maintain the productivity even in the tropical regions. Some of the adaptation options that may be considered to maintain the productivity capacity of forest ecosystems are listed below:

i. Assist in tree regeneration
ii. Enhance forest growth by sustainable management of soil nutrients, organic carbon and water
iii. Design and establish long-term multi species trails to test improved genotypes across a diverse array of climatic and latitudinal environments
iv. In plantations, avoid the use of materials selected purely on the basis of past growth rates
v. Control invasive non-native species and undesirable plant species that will become more competitive with harvestable species in changed climate.

Many productivity issues can be addressed through genetics. Thus, genetic studies can be undertaken to shed light on the extent to which forest trees will be able to adapt to climate change. Attempts can also be made to identify genes that control the adaptive ability of trees of species that are characteristic to different forest types.

It is argued that when compared to temperate and boreal plantations, the tropical plantations are more likely to remain viable under future climate as their shorter rotation times will reduce the risk of mal-adaptation and damage by extreme events during a particular rotation (Sohngen et al., 2001; Guariguata et al., 2008). Therefore, there may be a greater global demand for forest products from tropical plantations. The ability of such plantations to meet this demand will depend on how well adapted they are to the evolving climate. Thus adaptive management aiming at maintaining the potential productivity of plantations to meet changes in site conditions under climate will also be helpful to improve the economic benefits from plantations in future.

e) Maintenance of soil and water

Climate change may have major impacts on the environment, through droughts, flood and increased erosions, landslides and other impacts. Some of these phenomena, such as droughts, soil erosion and landslides, are natural processes that can be affected by human activities. Therefore, the KFD and other agencies have already recognised the need of forest protection, particularly in hills and mountain areas, of the State to safeguard infrastructure and human life. However, existing strategies towards maintenance of soil and water in natural forests and plantations have to be appropriately modified in the light of climate change. The potential management strategies to maintain soil and water resources under climate change are listed below.

i. Maintain, decommission and rehabilitate roads to minimise sediment runoff due to increased precipitation
ii. Minimise density of permanent road network and decommission and rehabilitate roads to maximise productive forest area
iii. Change road and ski track specifications to anticipate higher frequency of intense rainfall events
iv. Continue to carry out works such as gully plugging, and
v. Initiate to conserve soil and water in forest plantations by digging staggered trenches and litter management.

It can be concluded that in Kerala, current efforts to maintain the quality and quantity of soil and water associated with forest have to be intensified. Most current efforts focusing on soil and water conservation need to be monitored and evaluated to determine their effectiveness and to redesign methods to conserve these resources even under changing climate.

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