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[Research]

Centennial rainfall variation in semi arid and tropical humid environments in the cardamom hill slopes, southern Western Ghats, India

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ABSTRACT
Studies of rainfall variation generally focus on large areas. For example, in India, the area average monsoon rainfall series of the whole country or meteorological subdivisions are used. This would be of no use for local agriculture, particularly in places where rainfall is very high or very low, especially for crops like small cardamom and vanilla which are very sensitive to soil moisture and atmospheric air relative humidity. With this view, we present the data and analysis of the long term rainfall variations in semi arid as well as tropical humid environments in cardamom hill slopes in south-WesternGhats in India. In our analysis, the semi-arid cardamom hill slopes showed decreasing trend in rainfall over the recent past three decades ranging from 2.7 to 3.4 mm/yr with R^2 values ranging from 0.42 to 0.85 (P= 0.05). Year-to-year variation in rainfall was considerable. No alternating pattern of increase and decrease in rainfall was seen in decads, epochal trends as accounted by ISM for the rest of the country were absent. If the present trend continues, agricultural production in this semi-arid, poor rain fed system will suffer, unless conservation and mitigation efforts are undertaken. In case of windward side humid tropics, the year- to- year variations in the monthly rainfall values were very large. For example, January and February rainfall values changed by a factor as high as two or more from one year to another. The lowest rainfall during a period was reported in 1987 which was one of the intense El-Nino years. There was a strong association of El-Nino phenomenon with below average rainfall (67% of the El-Nino years), indicating a good ENSO relationship. In case of La-Nina years, fifty per cent of the years had enjoyed excess rainfall. However, the impact of El-Nino phenomenon was not severe during the first pentad of this century (2000-2005) in this mountain range. This indicates that the relationship seems to have weakened. The coefficient of variation of rainfall for the entire data series ranged from 9 to 27%. The decadal averages for the first three decades (1896-1925) and the last three decades (1976-2005) studied, reported less than the annual mean (5000 mm) for the whole period (1896-2005). Only during the middle period (1926-1975) the decadal average rainfall exceeded the series annual mean.

Keywords: Cardamom hills, Semi-arid and humid tropics, Rainfall variability, Southern Western Ghats, India.

INTRODUCTION
It is important to understand the rainfall/ climate over small but homogenous areas as it is important for agriculture and related industries. Spatially organized summer monsoon arrives in the Indian Ocean bringing much-needed rain to the sub-continent during every summer. The most southern states of Tamil Nadu and Kerala in the West and part of the East coast enjoy high and low

rainfall during Indian Summer Monsoon (ISM) respectively. One of the sources of information on climatic-scale is rain gauge observation, which has advantages and shortcomings (Barrett &Martin 1981; Arkin & Ardanuy 1989). However, long-term gauge data of a particular region can be the important source to understand the nature of the interannual variation of the monsoon and its links with land and ocean phenomena. Rainfall variability, which is an important determinant of agricultural activities in any region, is a complex environmental feature that is intimately associated with several factors such as temperature, surface features, sunlight and wind. Knowledge and understanding of such variability can lead to improved risk management practices in agriculture and other industries. Recently, all over the world, soil site and crop specific management are taken as the policy for management of agro ecosystem. This necessitates a reasonable understanding of local rainfall climatology. In this context, an understanding of rainfall variability is essential for appropriate agricultural management. In India, the area average monsoon rainfall series of the whole country or meteorological sub divisions have been used, which would be of no use to local agriculture, particularly places where the rainfall is very high or very low (an example is west or east facing south Western Ghats). A comprehensive study on long-term climatology of such places or ecosystems does not seem to exist in India.

The problem of trends and periodicity in Indian climate has always attracted the attention of laymen and scientists all over the globe. Branford (1886) was the first meteorologist who made extensive studies of Indian rainfall. He calculated the annual rainfall of British India (the whole country as one unit), and found it to vary from a high of 124 cm in 1878 to the lowest value of 90 cm in 1868. Sir Gilbert Walker (1910,1914,1922) examined the south-west monsoon (JJAS months) rainfall of British India (the whole country as one unit) by considering all available rain gauge data for the period of 1841-1908 and observed that the rainfall was below normal during 1843-1860 and1895-1907, the worst drought years were 1848,1855,1877 and 1899. After Walker's studies, little work was done during the next 50 years. Later analysis of average rainfall of India (as one unit) was done by Parthasarathy and Dhar (1976), Parthasarathy and Mooley (1978) and Mooley and Parthesarathy (1979) with variable number of rain gauge stations.

Even in the satellite era, rain gauge data for long period would be advantageous because uncertainties and large errors are involved in satellite observations in heavy rainfall areas (Xie & Arkin 1996; Wentz 1999; Kummerow *et al.*, 2000) and winter season. Over land and mesoscale mountains (includes Western Ghats in South India), the surface properties(boundary layer condition) such as vegetation and soil moisture are considered to be important, but their interaction with rainfall and their role in determining distributions are complicated and not well understood. In fact the Asian summer monsoon is almost always discussed as if these mountains don't exist (Xie *et al*., 2006). In southern India, only a few have been conducted on the variation of rainfall in mountainous areas, where the contribution of orographic effects (both wind and lee ward effects) is high. This is due to non-availability of long-term data for such remote regions; therefore, this information would be in particular interest of scientists' concern (Murugan *et al.,* 2003).The North-East Monsoon (NEM) is the main rainy season in Tamil Nadu, accounting 40-50% of the annual rainfall in the interior parts. The predominant rain fed agricultural system (60% of the arable agriculture) here is limited by the availability of rainfall during summer. Understanding the recent history of monsoons and past dynamics of a regional climate can improve our ability to respond to changing global climate. Such information can also be useful for testing dynamical and statistical models aimed at rainfall forecast (Sulochana *et al*., 2005) as well as for being used in conjunction with satellite data for model validation purposes. The present work can give better insights about the nature of rainfall fluctuation during the past century in semi-arid and high altitude humid tropical ecosystem in relation to the global climate indices such as ENSO, which can sometimes impact the regional rainfall in these overlooked mountains, which are an important element of the summer monsoon through interaction between convection and circulation.

The rainfall climatology of two contrasting ecosystems that are spread on either side (wind and leeward sides) of the Cardamom hills, south-Western Ghats (WG) in India were analyzed using rain gauge data collected over one hundred years. Generally, rain gauge observation data are relatively accurate and only suffer from sampling error in representing aerial means. Long-term rain gauge data can be very well used in conjunction with satellite data for understanding and forecasting tropical rainfall. As the current global warming proceeds, the hydrological cycle and Asian monsoon (Indian summer monsoon) in particular are likely to intensify (Cubasch *et al*., 2001), and this may lead to a shift of the rainfall maximum westward of these ranges. It is quite possible that under this situation, the rainfall in the WG mountains may even decrease, particularly in regions under the rain shadow eastern slopes; this needs to be tested with available long-term data. We report for the first time the longest rainfall pattern for the semi arid (Leeward side) slopes of the cardamom hills, south-Western Ghats, Tamil Nadu showing extreme variation in rainfall pattern over the last one hundred years (1905-2004) as well as the humid tropics rainfall climatology (one of the highest rainfall areas in south India) of the West facing (facing Arabian sea) slopes of cardamom hills, Kerala, India (Windward side) during the period 1895-2004. The main objective of the paper is to examine climate records from these two extreme climates, and trace the impact of the trend in these climates on the major crop production patterns.

MATERIALS AND METHODS

The data from two stations were used in this study. The first is instrumental data from the Elappara during 110 years (1896-2005), representing high altitude humid tropics in the Elappara range of cardamom hills (part of Periyar basin in Kerala facing the Arabian Sea). The station is one of the few hill stations in southern India, which has a record of more than 110 years of rainfall data. The station is located in high altitude (1500 msl) mixed tropical forest, which is a major type of forest in Western Ghats, where there is no clear seasonality in environmental factors such as rainfall and temperature. The other data set is from the Bodinayakkanur station located in Tamil Nadu, on the eastern slopes of the cardamom hills facing the Bay of Bengal (falling under semi-arid tropics) and provided 100 years of rainfall data (1906-2005). This rain gauge station is attached with TWAD (Tamilnadu Water and Drainage Board) board, Bodinayakkanur (10.02° N, 77.35° E [1] , Altitude 800 msl) (part of Vaigai-Periyar basin in Tamilnadu), Tamil Nadu. The Elappara range forms the western boundary of the cardamom hills' reserves (CHR). The Bodinayakanur range forms the eastern boundary of CHR in Tamil Nadu. The Chokkanadu and Kolukku Malai form the northern boundary. To the west of Elappara range, tropical rainy climate prevails.

As one moves eastwards, the climate gets more arid, till it is regarded as completely arid in the region between Saptur and Usilampetti ranges. The CHR thus constitutes an area of 334 square miles, with the centre point located at 9.52°N, 77.09°. E. Bodinayakanur and the Elappara are the representative stations for the two extreme ecosystems the humid and semi-arid tropics (Fig 1) respectively. At least 20 million people in the plains of Kerala and Tamilnadu depend on these basins for water.

From the data, Standard Rainfall Anomaly (SRA) was calculated for the whole period (1896-2004). This SRA is defined as,

$$SRA = \frac{x - \bar{x}}{\sigma}$$

where x: is the annual rainfall of any year, $\bar{x}$: is the Mean annual rainfall for 1896-2005, and σ : Standard deviation of the rainfall series.

The Precipitation Concentration Index (PCI) was calculated for the semi arid annual rainfall series. The PCI is defined as follows:

$$PCI = \frac{\sum_{i=1}^{12} p_i^2}{\left[\sum_{i=1}^{12} p_1\right]^2}$$

Where p_i is the annual amount of the i^{th} month. The PCI indicates the monthly variability in a given year. PCI values below 10 indicate a uniform monthly rainfall distribution in a year.

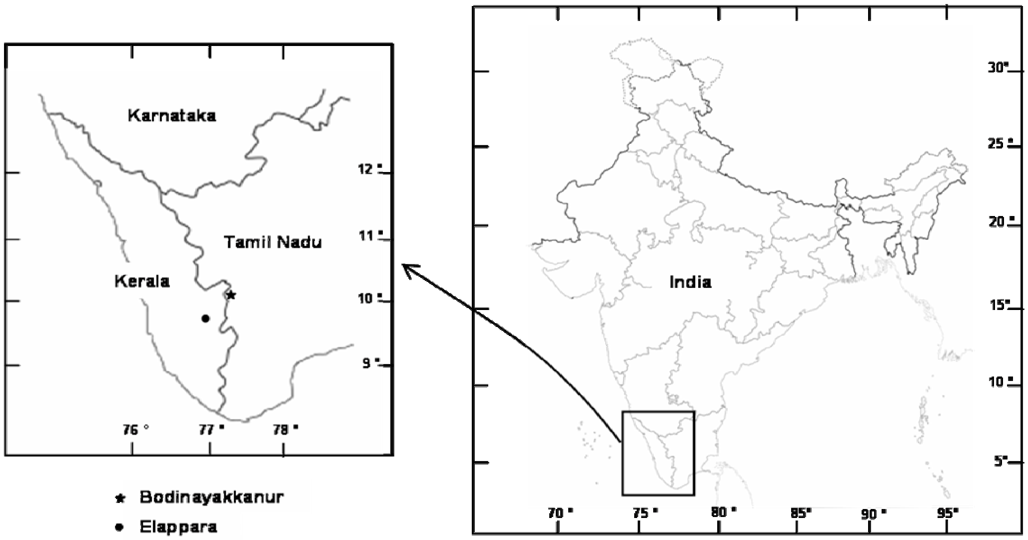

Fig 1. Location map of rainfall stations in Kerala (9.3°N, 77.02°E, 1300 msl) and Tamil Nadu (10.01° N, 77.24° E [1], 800 msl).

Values from 11 to 20 signified seasonality and values above 20 corresponded to climates with substantial monthly variability. The PCI is a very simple, yet useful tool to understand seasonality of a particular station in semi arid agriculture. Global warming influences the occurrence, severity and frequency of ENSO episodes remains highly uncertain in any region. The effect of ENSO episodes on the respective year rainfall also analyzed to confirm its affectivity on these contrasting environments.

RESULTS AND DISCUSSION

Semi-Arid environment (lee side eastern slopes of cardamom hills facing Bay of Bengal, Bodinayakkanur, Tamil Nadu)

Semi-arid slopes and the plains of Bodinayakkanur are characterized by a high temporal variability of seasonal and annual rainfall. The data show a drastic change in the rainfall pattern from seasonal to decadal scales (Fig 2 and 3), but no significant periodicity appears to be present. Over the last hundred years, the contributions of the ISM, NEM and BR (Blossom Rainfall) were 21.3%, 48.1% and 30.6% respectively. The highest rainfall of 2270.4mm was recorded in the year 1958 and the lowest rainfall of 328.5mm was reported in 1983. Mean annual rainfall for entire period was 767.1mm with a co-efficient of variation (CV) of 36.9% and standard deviation of 282.8mm. Highest CV was reported for ISM (108.6%) followed by BR (44.30%) and NEM (40.3%). ISM rainfall ranged from19.82 to 1327.8mm while NEM rainfall varied from 83.8 to 773.3mm. BR also varied greatly from 32.9 to 665.4mm. Since CV was higher than 30% for all the seasons, the region experienced more frequent and severe droughts during the period. Higher Precipitation Concentration Index (PCI) (>20) was recorded only in the recent past three decades, which implies very long dry periods for up to 3-5 months. The PCI denotes uniformity of monthly distribution in a year over a particular station or the inter-annual variability. Therefore year-to-year variation in rainfall was considerable and showed definite decreasing trend during the last three decades. The index value was always below 20 for the previous decades. The mean rainfall of the recent past three decades was well below the centennial average rainfall, clearly indicating decreased monsoon activity. This could be related to increase in tropical deforestation and land use change occurring in the areas surrounding this semi arid ecosystem, like the Montane cloud forest high *waives (Mehamalai)* and the cardamom hills during the report period. This is in confirmation with earlier studies (Thaplial and Kulshrestha 1992) using a simulated global climate model. No alternating pattern of increasing and decreasing rainfall in the decades is seen and no epochal trends in ISM as observed for the rest of the country (Thaplial & Kulshrestha 1992). The 20, 30, 40 and 50 year running means showed declining trends (2.7 to -3.4 mm per year, with R^2 values ranging from 0.42 to 0.85, significant at 95%). This means the future rainfall in the rain shadow slopes of the cardamom hills is likely to decrease. Though historical records say that the eastern slopes have enjoyed good rainfall, in the last century the slopes had lost their thick evergreen forest (90% of primary forest). Whether this has triggered or will trigger changes in rainfall pattern, questionnable and sensitivity analysis performed elsewhere showed some teleconnected effects of deforestation in the precipitation change of south East Asia (Werth & Avissar 2006).

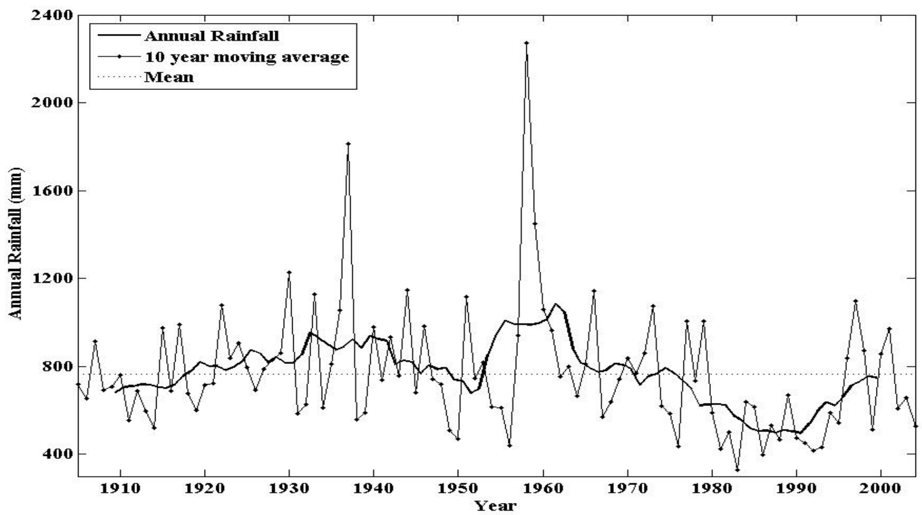

Fig 2. Mean and annual march of the rainfall from 1896-2005 in the semi arid eastern slopes of the cardamom hills, Bodinayakkanur, Tamil Nadu.

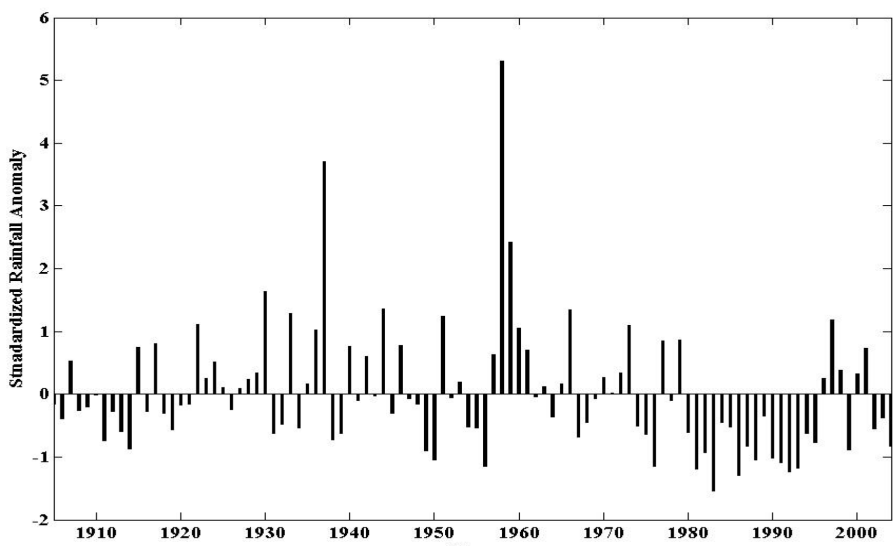

Fig 3. Standardized rainfall anomaly of the annual rainfall for the period of 1906-2005 in the semi arid eastern slopes of the cardamom hills, Bodinayakkanur, Tamil Nadu.

El Nino and La Nina events have profound influence on the rainfall of this region. The most intense El Nino year in the last century was 1997, when the rainfall was well above the average. Nearly 58% of the El Nino years had below average rainfall. On the other hand 42% of the El Nino years accounted above normal rainfall. Amazingly the lowest rainfall of the last century was in 1983(328.5mm), which happened to be a typical La Nina year, and the effect was spectacular. 70% of the 17 La Nina years brought about below average rainfall and only 30% of the La Nina years experienced more than average rainfall. This shows a changing relationship between semi-arid rainfall climatology and ENSO in this region. As a result of reduced and altered rainfall pattern in the eastern slopes of CHR, the actual area under cultivation of cardamom on north-eastern bordering ranges like the Bodimettu, Puliyuthu and Kolukku malai has significantly reduced, and this has contributed to the over all reduction in area under cardamom cultivation. Originally, 80,620 hectares were allocated for the purpose of cardamom cultivation.

Up to many decades ago, the entire area was under cardamom cultivation. For the past 8-10 years, the actual area under cardamom cultivation has shrunk to about 40,000 hectares. Relatively drought resistant crops like coffee and silk cotton are cultivated in the remaining areas. This is indicate the insufficiency of rainfall on the eastern and northern borders of CHR, and the severity of aridity is advancing towards up in the cardamom hills' reserves into the state of Kerala.

Humid tropical environment (windward side of the cardamom hill slopes facing the Arabian sea, Elappara, Kerala)

In our analysis for the period (1896-2005) (Fig 4 and 5) the highest rainfall of 7000 mm (1961) was reported. This could be the second highest rainfall in the lee ward hill slope of south-Western Ghats in peninsular India after Shimoga in Karnataka where in 8000 mm in a year was received. Careful study of the long term climate record has shown that even seemingly modest fluctuations in rainfall can create havoc in vulnerable societies. Orographic lifting favors the windward to the leeward side of mountains for convection. However, a close examination of other gauge stations data of the cardamom hills (10-20 years data) indicate that the constant high rainfall (>5000 mm in a year) is received near Anaimudi peak (2694 msl). The putative reason for the rainfall maximum in these mountains could be attributed to the strong convection, which undergoes diurnal cycle in which these mesoscale mountains play important role (Xie *et al*., 2006). However, the studies on the reasons for local rainfall maximum need careful observation and analysis besides understanding the physics behind convection -circulation interaction in the mesoscale mountains. The interannual variations in the monthly rainfall values are very large; for example the values for January and February changed by as much as a factor of two or more from one year to another. The lowest rainfall during the period was reported in 1987 which was one of the two most intense El-Nino years in the world.

In our analysis there was a strong association of El-Nino phenomenon with below average rainfall (67% of the El-Nino years), indicating a good ENSO relationship. In the case of La-Nina years, fifty per cent of the years enjoyed excess rainfall and rest of the years were low rainfall years. However, the impact of El-Nino phenomenon was not severe during the first pentad of this century in this mountain range. This shows the relationship seems to have weakened in the recent past. Considering these, the scientists concerned should take precautions in forecasting local climate. The coefficient variation of rainfall (CV) for the entire series ranged from 9 to 27%. The decadal averages for the first three decades (1896-1925) and the last three decades (1976-2005) studied, reported values less than the annual mean (5000 mm) for the whole period (1896-2005). Only during the middle period (1926-1975), the decadal average rainfall did exceed the series annual mean. Interestingly the strongest El-Nino years (1997-1998) had received (5120 mm) fairly well above the annual mean. Since 1896, of the total El Nino years, only ten years each in El-Nino and La-Nina years had envisaged less than average. Otherwise all other El-Nino and La-Nina years found to be more than the annual average (5000 mm). These results are found to be for and contradictory to the results reported for many regions of varied environment in India (Kane, 2006; Khole & De, 2003; Ropelwski & Halpert, 1987; Sridharan & Muthusamy, 1990; Singh & Sontakke, 1999). Therefore, extreme rainfall anomaly can occur even in the absence of strong ENSO events, thus uncertainty in ENSO effects is quite large from one environment to another even that are close to each other.

Interestingly the ENSO relationship with the weather and climate of the cardamom hills has not been well studied and therefore this information could be of important source for future research. The overall impact of recent climate on the production trend of major spices and plantation crops shows a negative trend for the first one and half a pentads (2000-2007) of this century. Cardamom reported a maximum percentage change of -12.5.1% followed by black pepper (-10.0%) in CHR. In particular, tea production in the cardamom hills has gone down significantly reporting a percentage change of -20% during the recent past seven years. Therefore, this unhealthy trend of production of specific crops is certainly due to the change in the climatic condition which affects both quantity and quality of crops (ITC, 2007).

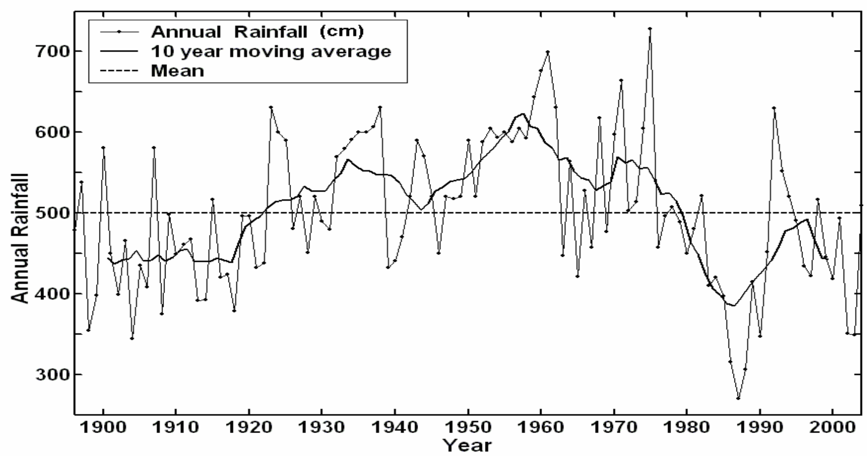

Fig 4. Mean and annual march of rainfall from 1896-2005 in the cardamom hills, Elappara, Kerala.

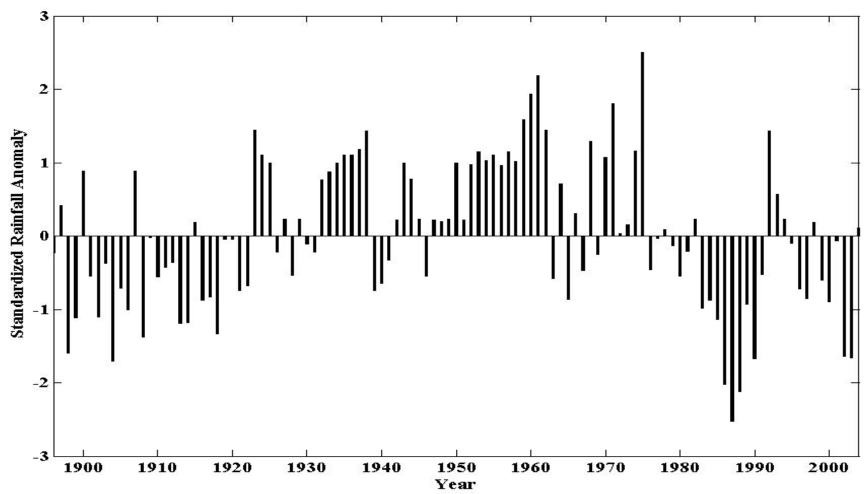

Fig 5. Standardized rainfall anomaly of the annual rainfall for the period of 1896-2005 in the cardamom hills, Elappara, Kerala.

SUMMARY

Rainfall variations can produce droughts and floods in vulnerable regions like eastern slopes of the cardamom hills, which can be influenced by El-Nino events, although it is highly variable and uncertain. The mesoscale WG orography could be the key element of summer monsoon convection-circulation interaction which appears to be important for both seasonal and interannual variability of rainfall in high rainfall zone of the cardamom hills. This aspect should be studied for proper understanding of the role of the mesoscale mountains on the local rainfall climatology. Though at this point in time the cardamom hills receive more rainfall than the crops require (for the successful production of tea and cardamom), in the near future the cardamom and tea ecosystem hydrology may get affected as the demand for water is expected to raise many fold. Already many stream flows have been found to decrease and become short lived. Thereby, the ecosystem degradation could be more pronounced at than the present level because cardamom is very sensitive to drought conditions (Reyes *et al*., 2006). The most semi-arid eastern slopes of the cardamom hills are experiencing down ward march of rainfall. Under the decreasing rainfall pattern coupled with continuing atmospheric warming scenario, the near future could jeopardize the agriculture and sustainable development in this resource (water) poor semi-arid ecosystem, and the coming years could be highly challenging to climate and agriculture scientists as the demand for water would increase by 20-80% in this densely populated valley. Already half a million people from the eastern slopes have moved to western slopes in search of livelihood and the eastern slopes now look like a desert, with at least 100 sq.km area (Thevaram- Bodi tract)which have been rendered into a desert like system. Since agriculture is localized, local climate forecast is important, which seems extremely difficult under this condition management of ecosystem.

Immense ecological degradation and dangerous climatic variability of cardamom agriculture has already been an immutable truth (Reyes *et al*., 2006) elsewhere in the world. Therefore, understanding rainfall variability in these limited ecosystems is important for both understanding of the way rainfall is affected by local features, and leading to improved risk management practices in agriculture and other industry.

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