# Climate Variability and Small Cardamom across the Western Ghats



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Crop Weather Relationships
of Cardamom in the Humid Tropics

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# 1. INTRODUCTION

Small cardamom (*Elettaria cardamomum* Maton) - popularly known as the Queen of Spices - is indigenous to the evergreen rain forests of the Western Ghats. It is confined to the States of Kerala, Karnataka and Tamil Nadu, accounting for an area of 41,288 ha, 25,947 ha and 5,085 ha, respectively (Spices Board, 2001). Among these States, Kerala accounts for the major portion of production (72.4 %), followed by Karnataka (20 %) and Tamil Nadu (7.6 %).

The crop is of great importance as a foreign exchange earner and Indian cardamom is still adjudged as the best in the international market. Until 1970, India had topped the world trade in cardamom and thereafter Guatemala emerged as a keen competitor for India and has been pulled down from its prime position. The productivity of cardamom in India is 195 kg $ha^{-1}$ as against that of 595 kg $ha^{-1}$ in Guatemala (Spices Board, 2001). Over dependence on monsoon, deforestation and recurring of droughts are believed to be some of the reasons for low production of cardamom across the Western Ghats.

The natural habitat of cardamom is characterised by cool-humid-microclimate and the Western Ghats provide an ideal conditions for cardamom cultivation. The forests exert a domineering influence on soil, water resources and microclimate of cardamom. At the turn of twentieth century, forests constituted around 50 per cent of the combined geographical area of Travancore, Cochin and Malabar. But by the end of the century, area under forest cover in Kerala constituted only 29 per cent to the total area (FSI, 1999). The fast-dwindling forest cover and its consequence over climate (associated environment problems) are the concern across the cardamom tract of the Western Ghats since last two decades.

On the other hand, the projected global warming and rainfall changes may adversely affect forest ecosystems. The studies in India predict that there are shifts in boundary of forest and climate types during the transient periods (Ravindranath, 2002). Though there are uncertainties with respect to projections of climate change on forest ecosystems, evidence is growing to show that climate change couples with socio-economic and land use pressures is likely to affect the forest ecosystems adversely. A study of the Western Ghats region, based on bio-climatic models concluded that for Nilgiris, the projected change was an increase in area under evergreen and dry thorny forests due to increased rainfall and temperature, respectively. In Uttara Kannada part of Western Ghats, the projections indicate a shift from dry to moist vegetation types (Ravindranath *et al.*, 1997).

Cardamom is a sensitive plant and any disturbance in the environment, especially the climatic factors, will adversely affect the growth, development and production. In India, nearly 75 per cent of cardamom area is still under rainfed condition. It is estimated that about 80 to 90 per cent of the rainfall is received during the period from May to November. So, not only the amount of rainfall but also distribution throughout the year is also important to reap a better cardamom production. In 1983, the cardamom tract throughout the Western Ghats witnessed very low production due to failure of rainfall from November to May. Cardamom plantation faces dry spell from December to May if pre monsoon showers fail. A major portion of panicle emergence and its development is noticed from December to April while flowering in April during which the distribution of rainfall will decide the crop success or failure in the case of cardamom.

It is also true that cardamom thrives well within the altitude range from 600 m to 1200 m above the mean sea level and within the certain thermal regimes. It is believed that such diurnal symmetries in temperature trends, if any, have close links with the changes in cloudiness, humidity, atmospheric circulation pattern, winds and soil moisture (Kumar *et al.*, 2002). Besides this, land use pattern of cardamom tracts has also changed to a great extent. As a result, crops like coffee, black pepper and arecanut are being cultivated at many locations in place of cardamom.

In the light of the above facts, the present investigations were undertaken with the following objectives:

1. To study the distribution of rainfall and its variability over the cardamom tract of the Western Ghats.
2. To study the distribution of surface air temperature and its variability over the cardamom tract of the Western Ghats.
3. To study the interaction between climatic variability and cardamom production.
4. To delineate agroclimatic zones for small cardamom across the Western Ghats.

# 2. REVIEW OF LITERATURE

The literature on cardamom is mostly seen with respect to crop improvement, crop management and crop protection. The meteorological aspects and the phenology of cardamom are the areas where limited work is done so far. However, works pertaining to the influence of climate on cardamom and related aspects have been reviewed to understand the status of agrometeorological investigations related to cardamom and presented in this chapter.

## 2.1 Role of Climatic Factors on The Growth and Productivity of Cardamom

Abraham and Tulasidas (1958) reported on the ecological features of the cardamom growing tracts of south India. It was observed that the natural habitat of cardamom is characterized by heavy rainfall, low to medium temperature and high atmospheric humidity.

It is evident from the reports of Srivastava *et al.* (1967) that cardamom is very particular with respect to its climatic requirement. The growth of cardamom in Coorg area of Karnataka flourishes well in the hot, sub-mountainous regions of the tropical evergreen rain forests either on the hill slopes or valleys and the streams running in between.

According to George (1976), dependence on the climatic conditions and deforestation in cardamom growing tracts are the constraints in the production of cardamom. Cherian (1977) identified environmental ecology as a vital factor in cardamom cultivation. He analysed cardamom yield for three decades and concluded that productivity in 1970's was too low as compared to that obtained in the past. It also highlights that unless due attention is given to improve the environmental situations, in such a way as to satisfy the requirements of the cardamom plants, the position will not improve with any amount of artificial tillage operations, irrigation, manuring and pesticide application.

The production of cardamom was limited by the deterioration of ecology (Sundaram, 1977). Kithu (1986) reported that cardamom plant is highly susceptible to even minor variations in climate and environment as such annual production of cardamom in the country fluctuates according to climatic factors prevailing every year.

According to Pruthi (1993), cardamom thrives at an elevation of 600-1500 m but the most productive range of elevation is from 1000m - 1800 m.

Raj and Murugan (2000) opined that cardamom is a sensitive plant and any serious disturbance in the environment; especially climatic factors will adversely affect the growth, development and production.

Cardamom will not come up well in plains and the shade in coconut garden was insufficient for the crop and the elevation of Vellayani (8°29′N; 76°57′E; 64m AMSL) was unsuitable for cardamom cultivation. The study also indicated that cardamom thrives well only under definite moisture, shade and thermal regimes (KAU, 2001).

### 2.1.1 Effect of rainfall on cardamom

According to Santiago (1967), an average rainfall of 1500 mm - 2500 mm is ideal for cardamom growth and development. Rainfall pattern and yield of cardamom over a period of time revealed that the years of low production were those in which timely rainfall was inadequate and prolonged dry summers prevailed (George, 1976).

Abeysinghe (1980) reported that cardamom comes up well in the areas where annual rainfall varied from 2750 mm to 5000 mm with 175-225 wet days a year in Sri Lanka.

Nanjan *et al.* (1981) concluded that there should be more than 322.80 mm rainfall during planting for the highest percentage of establishment under Yercaud condition (87.92 %).

The study conducted by Rao and Korikanthimath (1983) revealed that yield of cardamom was influenced more by distribution of monthly rainfall rather than the total rainfall and number of rainy days. They opined that showers during April could not give any clue for predicting yield nor the preceding year's rainfall on the succeeding year's crop and the cardamom yield in Coorg district of Karnataka was better in most of years when the annual rainfall was below 2000 mm.

The one reason for the increased productivity of 250 kg $ha^{-1}$ in Gautemala was the availability of well distributed rainfall where rainfall varies from 2000 to 5000 mm per annum in cardamom growing belts (Mohanchandran, 1984). He also explained the impact of distribution of rainfall on cardamom production in Gautemala and India. Generally fairly good and assured rains are received from April - May to October - November in Gautemala. September-October usually records the heaviest rain as against the peak periods of June-July in India. The cardamom plants are reported to grow luxuriantly with about 150-200 tillers in each clump under evenly distributed rainfall and very short dry period. He concluded that, the well distributed rainfall is most important than the total rainfall for realizing higher yield in cardamom.

There was a considerable variation in rainfall pattern among different cardamom tracts and it was grown in the area where the annual rainfall ranges from 1500 mm to 4000 mm (Bavappa, 1985).

Korikanthimath (1986) opined that cardamom yield could be increased and mortality rate reduced if cardamom gardens are well maintained with proper adoption of package of practices, as the impact of drought during 1982-83 was the worst on cardamom yield as well as mortality rate under neglected condition.

Korikanthimath (1987) studied the rainfall data recorded during the period from 1961 to 1985 at Mercara, Coorg district, Karnataka and its impact on cardamom production. He noticed that the meagre rainfall received from January to April in 1964, 1973, 1974, 1979 and 1983 resulted in lesser crop yields. The unprecedented drought during 1983 caused a great setback on the growth and yield of cardamom in Coorg district and the same trend prevailed in other cardamom growing tracts of India.

Natarajan (1988) reported that the productivity of cardamom in many of the areas was decreasing not due to low and erratic distribution of rainfall alone but also as a result of faulty cultural practices adopted by many of the planters.

The cardamom tract of the Western Ghats demarcated into eight zones based on the rainfall distribution, intensity and duration of rainy seasons and a well distributed annual rainfall in the range of 2000-3000 mm, an optimum annual rainfall considered for the productive growth of cardamom, was noticed only in 40 per cent of the area under cardamom (Nair, 1988). He also revealed that there is a close relationship between the rainfall distribution and cardamom production in both Kerala and Karnataka region, but for Tamil Nadu it is not evident.

A rainfall of 2000 - 3000 mm per year distributed well over a period of about eight to nine months was considered optimum for the cardamom crop (Jacob *et al.*, 1995). They also opined that summer showers are very important and in the absence of those rains, cardamom plants are killed extensively due to drought.

According to Hegde and Korikanthimath (1996), the higher productivity of cardamom in Gautemala was due to availability of well distributed (Bi-model) rainfall.

George and Mathew (1996) revealed that the cardamom crop in a particular season depends mainly on the rainfall received during the initial growth period of panicles till they come into flowering stage, which normally covers 6 to 7 months from December to June and showers received towards the close of north-east monsoon and summer showers are of decisive importance in growth and production.

A well distributed high rainfall with only a short period of less rain may be good for high cardamom production when compared to less rain concentrated from October to January, having a longer period of less rains under Sri Lanka conditions. (Wickremasinghe *et al.*, 1998).

Korikanthimath and Padmini (1999) opined that due to indiscriminate deforestation, the distribution of rainfall particularly the pre monsoon showers in the Western Ghats was affected though there was not much difference in the total average quantity of rainfall.

Murugan *et al.* (2000) and Gowda and Venugopal (2001) observed that rainfall had positive correlation with production of cardamom while there was a significant relationship with number of rainy days. They also revealed that the distribution of rainfall is very important for obtaining better cardamom yield.

Rebello (2002) reported that drought due to failure of monsoon had affected cardamom out put by about 40 per cent in Kerala and 25 per cent in Karnataka.

There is a close relationship between cardamom production and rainfall distribution during summer in which both panicle and flower production in cardamom are more. (Rao, 2003).

It is understood that the even distribution of rainfall round the year with a range of 1500-3000 mm appears to be optimum for better productivity. Guatemala obtains better cardamom yields due to the above reasons when compared to that of cardamom growing tracts of India. The prolonged dry spell during winter (Dec-Feb) and summer (Mar-May) are detrimental to cardamom production under rainfed conditions.

### 2.1.2 Effect of temperature on cardamom

Khader and Syed (1977) reported that an unfavourable microclimate changes the temperature, which in turn influences the release of N, P and S from organic matter. It also affects nitrification and absorption of P and K by the plants.

Cardamom thrives better in the temperature range of 10°C - 35°C. According to Abeysinghe (1980), the monthly maximum temperature varies between 24°C and 27°C while minimum temperature between 14°C and 17°C in cardamom growing tracts of Sri Lanka.

Nanjan *et al.* (1981) reported that maximum and minimum temperature should not be more than 19.5 to 25.0 and 15.5 to 17.5°C, respectively during the period of planting for better establishment of cardamom under Yercaud condition, which is located in shevaroy hill of the Eastern Ghats.

Experiments were conducted by Gurumurthy and Hegde (1987), to find out causes of low germination of cardamom seeds in winter season at Regional Research Station, Mudigere (mean maximum temperature 30°C and mean minimum temperature 10°C) and Agricultural Research Station, Ullal (mean maximum temperature 33.7°C and mean minimum temperature 18.8°C). They observed that germination was significantly correlated with minimum and maximum temperature.

Korikanthimath *et al.* (1998) reported that the increase in minimum temperature in cardamom growing tracts was due to deforestation, felling and excessive opening of canopy during the last decade.

Cardamom is very sensitive to temperature fluctuations (Jacob *et al.*, 1995). They also revealed that cardamom prefers a mean annual temperature of around 26°C and at high temperature, plants show symptoms of drying out and both growth and yield are considerably reduced.

Murugan *et al.* (2000) studied temperature trend in cardamom hills (Kerala) by analyzing 20 years of temperature data. They revealed that minimum temperature exhibited drastic variation over the years and the difference between the warmest and coolest month had narrowed considerably and the days have become warmer markedly.

John (2003) reported that the temperature was in the range of 18°C to 24°C in the cardamom tracts of Guatemala.

It is understood from the above that the cardamom thrives better in a thermal regime of 14°C – 27°C, reflecting the thermal environment of hills as optimum in the tropics.

### 2.1.3 Effect of light intensity on cardamom

Kuttappa (1969) opined that disturbances in the microclimatic compounds led to improper development of pistil and weakens the stalk end of the flowers and immature capsules, favouring abscission of the capsules.

According to Zachariah (1976), shade acts as a moisture and temperature regulator, thus creating a microclimate, which promotes vegetative growth and creates a favourable environment for root development in cardamom plantations.

Kololgi (1976) opined that, cardamom is shade loving plant but excess shade is quite detrimental.

The adequate number of trees that can provide shade at three storey-levels such as upper, middle and lower improved the growth and productivity of cardamom (Cherian, 1977).

Dandin (1980) noticed that the maintenance at high moisture content and fertility level of soil, which are most important factors influencing the yield, are influenced by shade trees.

According to Jose (1982), humus rich loamy soils under the canopy of lofty evergreen forest provide the best habitat for cardamom at an altitude range of 800-1500 m.

George *et al.* (1984) described characteristics of an ideal shade tree in cardamom plantation. They are (i) wide canopy (ii) minimum side branching to provide diffused light to cardamom plants (iii) no shedding of leaves during the flowering phase of cardamom so that the pollination is not affected by the leaves falling on panicles (iv) shedding of leaves during monsoon and production of flush or new growth before the commencement of dry season.

Kurup (1984) viewed that the immediate requirement for the rejuvenation of cardamom plantation is to establish a secondary canopy of shade trees to create ideal condition similar to that existing in an evergreen forest. Such a condition would help to improve the microclimate within the estates and enrich the soil to a considerable extent.

Vasanthakumar *et al.* (1989) reported that maximum fixation of $^{14}Co_2$ in cardamom was noticed under the light intensity of 30.86 $\mu$ E $S^{-1}$ $m^{-2}$ while very low amount of $^{14}Co_2$ under the light intensity of 195.30 $\mu$ E $S^{-1}m^{-2}$ and observed a significant negative correlation between the $^{14}Co_2$ fixed by cardamom leaves at different intervals during a day and the light intensities prevailed at that time.

Korikanthimath (1991) reported that the shade has to be regulated based on layout of land, moisture retentivity and to get 50-60 per cent filtered sunlight for better performance of cardamom.

Cardamom seedlings grown under medium light (45-55% of total light - 675-825 $\mu E\ S^{-1}m^{-2}$) were healthy and showed better performance in growth and biomass production than the leaf scorch affected seedlings which were grown under full light level (100% of total sunlight - 1500 $\mu\ E\ s^{-1}\ m^{-2}$) (Ravindran and Kulandaivelu, 1998a).

Experiment conducted by Ravindran and Kulandaivelu (1998b) revealed that approximately 50 per cent increase in the fresh and dry weight of capsules was found under medium light (720-980 $\mu\ E\ s^{-1}\ m^{-2}$) and they clearly indicated that the medium light level favoured the maximum yield and productivity in cardamom.

Korikanthimath and Padmini (1999) opined that tall trees having well distributed branching habit and small leaves are ideal for cardamom.

The inability to maintain the canopy cover over a long period leads to changes in microclimate, thereby reducing the yield. Thus, in the long run cardamom cultivation under evergreen forest canopy is not sustainable (Anonymous, 2002)

The studies reveal that medium shade is a must for better growth and production of cardamom under which only the maximum fixation of the $^{14}Co_2$ takes place.

### 2.1.4 Effect of wind on cardamom

Cardamom, being a moisture loving plant, is greatly affected by dry and high winds as there is no windbreak in absence of trees due to deforestation in cardamom growing tracts (Abraham *et al.*, 1979). They further reported that the rate of transpiration and evaporation would be increased due to high velocity of wind and moreover plants suffer due to the physical pull of the high velocity wind.

Zachariah (1980) and Korikanthimath and Padmani (1999) reported that hot wave of air from hinterland pass across the cardamom tracts without much hindrance due to deforestation and cardamom has to grow in a hostile environment resulting in poor growth and yield.

It would be a good practice to grow trees as windbreaks along the contours particularly in western slopes of cardamom plantations for better protection from desiccating wind in summer (Hegde and Korikanthimath, 1996).

The above mentioned studies reveal that high and dry winds in the absence of windbreaks (deforestation) may not be conducive for cardamom. The trees in the cardamom plantations may act not only as shade regulators but also as windbreaks and soil moisture regulators.

**2.1.5 Effect of irrigation on cardamom**

According to Mathew (1989), for better performance of cardamom irrigation should be started from December and continued till the commencement of southwest monsoon according to requirement.

Sulikeri (1987) reported that the cardamom plants irrigated at 75 per cent available soil moisture (1977 kg $ha^{-1}$) and at 25 per cent available soil moisture (1832 kg $ha^{-1}$) resulted in high yield as against plants without irrigation (850 kg $ha^{-1}$).

Failure or delay in irrigation to cardamom crop during summer severely affects the production of new suckers and panicles and ultimately yield (Gurumurthi *et al.*, 1996). They also found that plots irrigated between December 15$^{th}$ and February 16$^{th}$ gave more yield than plots irrigated after February and concluded that early irrigation commencing from December 15$^{th}$ favoured panicle and sucker production and increased yield.

Korikanthimath *et al.* (2002) opined that it would be ideal to commence the irrigation during first week of February and continue at an interval of 10-12 days till the regular monsoon commences.

## 2.2 PHENOLOGY OF CARDAMOM

Phenology is the science that relates climate to periodic events in plant life. The rate of plant development at successive stages of growth is important in determining climatic limits of economic crop production (Critchfield, 1994). Every stage of crop depends on climatic conditions preceding each event as well as at the time of the event.

### 2.2.1 Tiller phenology in cardamom

According to Pattanshetti and Prasad (1972), tillers had a vegetative phase of about 12 months, reproductive phase for the next 12 months and senility of 4 to 6 months in its total longevity of 28-30 months. They also added that the rate of linear growth was maximum between June and July.

Growth and development studies on individual tillers of cardamom revealed a distinct vegetative phase during the first year, a dominant reproductive phase during the second year and subsequent death of tillers at the end of second year's growth (Vasanthakumar, 1986). He also observed that, the mean life span of cardamom tillers was 22.98 months in Malabar, 26.37 months in Mysore and 24.58 months in Vazhukka and tillering in three cultivars was more during the months characterised by high rainfall, relative humidity and soil moisture.

Sudharshan *et al.* (1988) studied the tiller phenology in three cardamom cultivars viz., Malabar, Mysore and Vazhukka. They found that it took almost ten months to develop the vegetative bud and about a year for the panicle to emerge from newly formed tillers. Their study also revealed that the pattern of production and growth of tillers did not vary among the cultivars.

The maximum production of tillers was during pre-monsoon and middle of active monsoon period and progressive growth of tillers did not vary among the cultivars under Myladumpara (Kerala) and Saklespur (Karnataka) conditions (Kuruvilla *et al.*, 1992). They also found that linear elongation of tiller increased with onset of monsoon and the growth rate slowed down with cessation of rain.

It is understood from the above that cardamom tiller completes its life cycle within three years varying between two and three years depending upon the cultivars. The maximum production of tillers could be seen during pre-monsoon and middle of the active monsoon period.

**2.2.2 Panicle phenology in cardamom**

Warm dry period (January to March) with occasional showers conducive for development of panicles in Nilagiri, Tamil Nadu (Subbiah and Abraham, 1958).

Pattanshetty and Prasad (1972) reported that panicles of cardamom emerged from the swollen base of the stem almost throughout the year in one or the other plant, but majority of the panicles (nearly 60%) emerged during the post monsoon and winter seasons (September to February). They also opined that the linear growth of panicles extended over a period of seven months under Mudigere conditions.

A distinct dry spell that prevailed from January to April triggered the panicle initiation process and the peak period of panicle emergence was from January to May under Pampadumpara conditions (Vasanthakumar, 1986).

Sudharshan *et al.* (1988) observed that the major peak in panicle production was from January to March (60-70%) and the minor peak in July (10-15%). They also reported that panicle formation was the maximum in October, followed by November in Palney Hills of Tamil Nadu.

According to Kuruvilla *et al.* (1992) the linear growth of panicle extended over a period of six months under Myladumpara (Kerala) conditions and the rate of growth was slow in early stages (December to March) and it was very fast during April due to the interruption of dry season caused by pre-monsoon showers obtained during March-April. They also found that under Saklespur (Karnataka) conditions cv. Malabar did not produce panicles from August to October while cv. Mysore and cv. Vazhukka had similar behaviour only during October, and the major peak of panicle production during January to March (60 to 70%).

It is understood that the panicle emergence is maximum during post monsoon (Oct-Nov), winter (Dec-Feb) and summer (Mar-May) while minimum during the southwest monsoon (June-Sep).

**2.2.3 Flower phenology in cardamom**

Aiyar (1944) stated that the peak period of flowering was in May and June. Subbiah and Abraham (1958) conducted investigations in the Nilagiri tracts of Tamil Nadu on flowering of cardamom. They observed that flowering in cardamom was low in January-March period (7%) and October to December period (15%) and the maximum flowering period was in April - September period (78%).

The total duration of flower production was spread over a period of six months from May to October and nearly 75 per cent of the flowers were produced during the months of June, July and August (Pattenshetty and Prasad, 1972). Parameswar (1973) observed that the flower buds required about 31 days from initiation to full bloom.

The onset of rains coupled with high temperature was conducive to more of flower opening and the peak period of flowering was from April to September (Vasanthakumar, 1986).

According to Sudharshan *et al.* (1988) noticed that nearly 70-90 per cent of the flower production was recorded between May and August and the peak flower production period did not vary with cultivars.

A study conducted by Kuruvilla *et al.* (1992) revealed that it took 90 -110 days for the first flower in a fresh panicle to bloom irrespective of cultivars. They further stated that under Saklespur conditions flowering was noticed from April to December. In Malabar flowering ceased by October while extended up to December in Mysore. Nearly 70 per cent of the flower production was recorded between May and August.

From the above studies, it is clear that the peak flowering in cardamom varies from April to September depending upon the cultivars and the least from January to March.

**2.2.4 Capsule phenology in cardamom**

Subbiah and Abraham (1958) found that it took four to five - and - a - half months for a flower to develop into a fruit and the ratio of number of fruit to number of flower was maximum from April to September (30.7%).

Pattenshetty and Prasad (1972) reported that percentage of fruit set was high (56 to 59) from June to September because of humid atmosphere that prevailed during the period and it was practically nil during the dry season (December to March).

Parameswar (1973) stated that the capsule development took about 110 days from the full bloom. A high soil moisture regime combined with a high status of relative humidity (which resulted from a well distributed rainfall) improved the fruit set and increased the number of capsules carried to maturity (Vasanthakumar, 1986).

Sudharshan *et al.* (1988) found that less than 30 per cent of the capsule mature by September irrespective of the cultivars and it took about 120-135 days for a flower to develop to a mature capsule.

The capsule formation increased from June to August and thereafter declined slowly in all the cultivars of cardamom (Kuruvilla *et al.*, 1992).

It is clear that the capsule production follows the flowering behaviour and it is maximum during the southwest monsoon season while minimum from December to March.

## 2.3 NUTRIENT STATUS OF CARDAMOM GROWING SOILS

Mathew and Mir (1968) reported that the soils of Chickmagalur, Hassan and Kodagu districts of Karnataka where large cardamom plantations located were high in organic carbon, low in available phosphorus and medium in available potash.

Kulkarni *et al.* (1970) found that the cardamom growing soils of Koppa and Mudigere of Chickmagalur district were high in organic carbon and low in available potash.

According to Bleak (1970), the gradual rise in organic carbon in plantations with altitude is due to the lower rates of tiller decomposition because of low temperature.

Rao (1971) classified the soils of Koppa and Sringeri taluks of Chickmagalur and soils of Hassan district as medium in organic carbon while Mudigere soils were high in organic carbon. Further, these soils were low in available phosphorus as well as potash.

Zachariah (1972) based on his studies on the mineralisation of nitrogen in the cardamom growing soils of Kerala and Karnataka has observed that there was a high degree of mineralisation of nitrogen in these soils.

Biddappa and Rao (1973) showed that organic matter and nitrogen content of soils showed a tendency to increase with altitude and rainfall.

Srivastava and Bopaiah (1973) reported that the available phosphorus, available potash, total calcium and organic carbon content of soils were positively correlated with the yield of green capsules of cardamom per clump

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and the available phosphorus, potash and soil $p^H$ were found positively correlated with the number of tillers per clump.

Nair and Zachariah (1975) analysed the soils collected from different cardamom growing locations and reported that the cardamom soils were poor in available phosphorus despite their richness for nitrogen and potassium. They also revealed that in certain locations, about 80 per cent of the soils were highly deficient in phosphorus.

Zachariah (1975a) studied the fertility status of cardamom growing soils from 5000 soil samples collected from Kerala, Karnataka and Tamil Nadu and reported that majority of the soils were high to very high in organic matter and low to medium in available phosphorus.

Zachariah (1975b) classified the soils of Vandanmettu and Vandiperiyar of Idukki district of Kerala as low in available phosphorus, high in available potash, very high in available magnesium and high in organic carbon.

According to Zachariah (1975c), most of the cardamom growing soils were situated in heavy rainfall areas and therefore suffer from leaching of nutrients. Moreover, cardamom soils tend to be acidic ($p^H$ 5.0 to 5.5) due to leaching of bases.

The soil test results in Karnataka have indicated that cardamom soils were rich in organic matter, 90 per cent soils were low to medium in available potassium (UAS, 1976).

Nair *et al.* (1978) studied the distribution of major nutrients in different layers of cardamom soils and found that the total nitrogen and organic matter decreased with increase in soil depth and the C/N ratio narrowed towards lower layers. They also revealed that there was not much difference in the content of total potassium between the various layers and the availability of nutrients decreased with soil depth in all cases.

According to Korikanthimath (1978), cardamom growing tracts generally experience heavy rainfall, so the topsoil is subjected to erosion resulting in the loss of soil nutrients.

Soils having 8 per cent slope lost 61 tonnes of soils per acre, while 3.7 per cent slope resulted in a loss of 20 tonnes per year during the same period in cardamom plantations (Kubendran, 1980).

According to Lekshmanan (1981) the physical condition of the soil could be greatly improved by proper shade management in cardamom plantations.

The cardamom growing soils of Shimoga, Hassan and Kadur were loamy in texture containing 50 per cent finer fraction and rich in organic matter (Krishna, 1982a).

Krishna (1982b) noticed that the cardamom growing soils in the Vandiperiyar region had a low to medium status of phosphorus and were highly acidic ($p^H$ 4.5-5.5).

Kumar (1983) revealed that among the various nutrients, yield was well correlated with phosphorus content in the soil and plant. According to Korihanthimath (1984), leaching of bases (calcium) would result in reduced soil reaction thus bringing down the availability of phosphorus.

Tandon (1989) described that most of the cardamom growing soils were low in phosphorus and therefore priority should be given to that important element in fertilizer application.

Srinivasan and Biddappa (1990) collected soils from Kerala, Karnataka and Tamil Nadu and they found that the soil $p^H$ was in the range of 4.9 to 6.2, organic carbon 1.42 to 3.37 per cent, available phosphorus 2.3 to 69 kg $P_2O_5$ $ha^{-1}$ and available potassium 228 to 1196 kg $K_2O$ $ha^{-1}$.

Cardamom growing soils of Kerala had higher organic matter content compared to Karnataka and Tamil Nadu soils (Vadiraj *et al.*, 1998a).

Vadiraj *et al.* (1998b) analysed major nutrient status of cardamom soils of Kerala by collecting 669 surface samples (0-15 cm depth) from 52 villages of major cardamom growing districts of Idukki, Wynad and Palakkad. They concluded that most of cardamom growing soils of Kerala is medium to high in available nitrogen, low to medium in available phosphorus and high in available potassium.

It is understood that the cardamom growing soils are rich in organic content, medium to low in available phosphorous and high to medium in available potash. The cardamom growing soils of Kerala possess high organic matter content when compared to the cardamom soils of Karnataka and Tamil Nadu. The available phosphorous and potassium was relatively poor towards north of the cardamom soils across the Western Ghats.

# 3. MATERIALS AND METHODS

## 3.1 COLLECTION OF DATA

The climatological data on rainfall and surface air temperature, cardamom production and productivity and information on soil nutritional status were collected to take up this study and the details are as follows.

### 3.1.1 Climatological data

Monthly rainfall and surface air temperature (maximum and minimum temperature in °C) were collected from six Cardamom Research Stations located across the Western Ghats comprising of Kerala, Karnataka and Tamil Nadu (Fig 3.1). The study period varied from 10 years to 43 years depending upon availability of data. The geographical co - ordinates viz., latitude, longitude and altitude of each location under study along with the period for which climatological data collected are given in Table 3.1.

**Table 3.1 Geographical co - ordinates of selected stations across the cardamom tract**

| Name of Location | State under which it falls | Latitude (°N) | Longitude (°E) | Altitude (m) (amsl) | Period for which climatological data collected | |
|---|---|---|---|---|---|---|
| | | | | | Rainfall | Temperature |
| CRS, Pampadumpara | Kerala | 09°45' | 77°10' | 1100 | 1960-2002 (43) | 1978-2002 (25) |
| RARS, Ambalavayal | | 11°37' | 76°12' | 974 | 1980-2002 (23) | 1984-2002 (19) |
| Regional Station, IISR, Madikeri | | 12°26' | 75°47' | 1307 | 1986-2002 (17) | 1986-2002 (17) |
| Regional Station, ICRI, Saklespur | Karnataka | 12°56' | 75°48' | 976 | 1992-2002 (11) | 1992-2002 (11) |
| RRS, Mudigere | Karnataka | 13°7' | 75°37' | 982 | 1964-2002 (39) | 1971-2002 (32) |
| RCRS, Thandikudi | Tamil Nadu | 10°13' | 77°32' | 1310 | 1986-2002 (17) | 1993-2002 (10) |

Figures in parenthesis indicating number of years for which data recorded.

### 3.1.2 Soil data

The nutritional status of soils was collected from the stations concerned.

### 3.1.3 Yield data

The year wise area under cardamom and its production were collected from Spices Board, Kochi for the period from 1970 to 2001 for all the three cardamom growing states viz., Kerala, Karnataka and Tamil Nadu.

## 3.2. SEASONS

The climatological data were pooled season wise, which was classified by the IMD as follows:

| Season | Period |
|---|---|
| Summer | March to May |
| South West Monsoon | June to September |
| North East Monsoon | October to November |
| Winter | December to February |

## 3.3 METHODOLOGY

### 3.3.1 Rainfall

The mean monthly, seasonal and annual rainfall for all the six stations were computed to understand the spatial distribution of rainfall. The standard deviation and coefficient of variation of rainfall for different periods were also worked out to explain the variability of rainfall.

The data on mean monthly rainfall were commonly used for climatic trends and patterns and can be used as a tool to indicate agro - climatic zones. At the same time, the mean rainfall may not be useful for crop planning for which the better measure may be the probability of rain at 75 per cent level as suggested by Hargreaves (1977). The rainfall received at 75 per cent probability level, as dependable rainfall, is the minimum rainfall expected to be received in three out of four years and hence risk involved is relatively less in crop planning. A simple ranking method as described by Doorenbos and Pruitt (1975) and Frere and Popov (1979) was used for the computation of dependable rainfall. The method is as follows:

The monthly rainfall records for each station were arranged in decreasing order and each record was assigned a ranking number 'm'. Every ranking number has a probability level Fa (m) which is expressed as,

$$Fa\ (m) = \frac{100\ m}{n + 1}$$

Where, n = Number of records.

The rank number that has a probability level of 75 per cent was calculated. The rainfall record corresponding to this rank number gave the dependable rainfall.

### 3.3.2 Potential evapotranspiration (PE)

The potential evapotranspiration is defined as the evapotranspiration from a large vegetation covered land surface with adequate soil moisture at all times. The concept of potential evaporation put forward by Thornthwaite (1948) is widely accepted and utilized in various fields such as delineating climatic zones, length of crop growing seasons and irrigation scheduling based on water balance concept.

The main advantage of Thornthwaite's method is that PE can be estimated if mean temperature data are available. It also gives good estimates in coastal states where mild winter is noticed and the monthly temperature range is not very large. Because of the simplicity of the method and relatively low data input, Thornthwaite's method was used in this study.

Thornthwaite considered temperature and possible number of sunshine hours for the estimation of potential evapotranspiration. The formula given by Thornthwaite for unadjusted potential evaporation (e) is as follows:

$$e = 1.6\ (10t\ /\ I)^{a}$$

where e=Monthly unadjusted potential evaporation in cm/month

t = Mean monthly temperature in °C.

I= Annual heat index $\left(\sum_{i=1}^{12} i\right)$,

i = Monthly heat index and is equal to $(t\ /\ 5)^{1.514}$

and a = non linear function of the heat index, approximated by expression,

$$a = 0.000000675\ I^{3} - 0.0000771\ I^{2} + 0.01792\ I + 0.49239$$

The unadjusted potential evaporation (e) so obtained is for average 12 hours of sunshine and 30 day month. The values can be adjusted by multiplying with a correction factor depending on the latitude and season.

### 3.3.3 Water availability periods

The knowledge on the length of water availability periods will help in understanding irrigational needs of crop at different phenological stages. Though, rainfall is the main source of water, the actual availability does not depend on rainfall alone as it should be balanced against the amounts due to evapotranspiration. There are several methods for assessing the water availability periods based on monthly rainfall. However, mean rainfall data have limited utility and hence, Cocheme and Franquin (1967) have presented a method to determine the water balance of a place, which was utilized here to determine the water availability periods across the cardamom tracts of the Western Ghats. Based on precipitation and potential evapotranspiration, the humid and sub humid periods were computed as defined by Cocheme and Franquin (1967) and given below:

| | | |
|---|---|---|
| Humid period | : | P > PET |
| Sub humid period | : | PET > P > PET/2 |
| Moderately dry period | : | PET/2 > P > PET/4 |
| Dry period | : | PET/4 > P > PET/8 |
| Very dry period | : | P < PET/ 8 |

The moisture availability periods were worked out by combining the humid and sub humid periods.

### 3.3.4 Water balance studies

The water balance elements viz., precipitation, potential evapotrnspiration (PE), actual evapotranspiration (AE), water surplus (WS) and water deficit (WD) were computed by the revised book-keeping procedure of Thornthwaite and Mather (1955). The field capacity of the soil to hold the moisture for each station was extracted from Soils of India Series, published by NBSS & LUP, Nagpur.

For the evaluation of the complete water balance of a station, it is necessary to compare precipitation (water supply) with potential evapotranspiration (water need) making allowance for the storage of water in the soil and its subsequent utilization for evapotranspirational purposes.

Water balance indices such as humidity index ($I_h$) and aridity index (Ia), the index of moisture adequacy (Ima) and moisture index (Im) were calculated making use of the following formulae:

1. Humidity index $I_h$ = WS / PE X 100
2. Aridity index Ia = WD / PE X 100
3. Index of Moisture Adequacy Ima = AE / PE X 100
4. Moisture Index Im = $I_h - I_a$

The water balance elements and climatic indices so obtained for all the six stations under study on monthly and annual basis were presented and discussed.

## 3.4 AGROCLIMATIC ZONES

The cardamom tract of the Western Ghats has been delineated into different agroclimatic zones based on Index of Moisture Adequacy (Ima), soil type and district-wise cardamom productivity (kg $ha^{-1}$). The district-wise cardamom productivity of each location was collected from the Spices Board, Kochi for the period from 1999 to 2001. The Index of Moisture Adequacy was worked out as per Thornthwaite and Mather book keeping water balance method (1955).

## 3.5 STATISTICAL ANALYSIS

The linear trend method given in MS-Excel was used to find out the trend for the following climatic parameters.

1. Annual and seasonal rainfall
2. Annual and seasonal maximum and minimum surface air temperature
3. Annual and seasonal surface air temperature range
4. Annual and seasonal moisture index (Im)
5. Cardamom area, production and productivity (Kerala, Karnataka and Tamil Nadu).

Correlation and regression analysis were done between the different weather parameters viz., annual and seasonal rainfall, rainy days, maximum temperature, minimum temperature, temperature range and annual and seasonal Ima and annual water deficit and cardamom production and productivity to determine the crop weather relationships. Unavailability of district-wise cardamom production data to represent the six selected locations forced to take state level data. Hence, weather parameters recorded at Pampadumpara were used in this study, as the district of Idukki accounts 80 per cent area under cardamom in Kerala. Regression equations were worked out through stepwise regression method to eliminate the multi-collinearity effect among different weather parameters.

## 3.6 COMPUTER PROGRAMMES

MS – EXCEL package was used to find out the trends and SPSS package was used for correlation and regression analysis.

## 3.7 FORECASTING MODELS BY ARIMA

As an introductory work in this area, forecasting models were evolved by time-series analysis using Box-Jenkins methods. Uni-variate Box-Jenkins models, or Auto Regressive Integrated Moving Average (ARIMA) models were worked out for predicting rainfall and maximum and minimum temperatures using the past data. ARIMA models were fitted with different 'p' value (Auto Regressive factor), 'd ' value (Auto Integrating factor) and ' q ' value (Moving Average factor). The Best models were selected based on minimum AIC (Akike Information Criterion) values and models are presented in Appendix Ia, Ib, Ic, Id and Ie.

# 4. RESULTS AND DISCUSSION

The results of the present study "Climatic variability and small cardamom (*Elettaria cardamomum* Maton) production across the Western Ghats" conducted at the Department of Agricultural Meteorology, College of Horticulture, Kerala Agricultural University, Vellanikkara are presented and discussed in this chapter. The study was undertaken to understand the effect of rainfall and surface air temperature and its variability on cardamom production across the Western Ghats of India. The study also highlighted the climatic variability across the cardamom tract of Western Ghats using the moisture index. The agroclimatic zonation of cardamom was also delineated and presented along with the length of crop growing seasons. The impact of water deficit on cardamom production was also highlighted in this present study.

## 4.1 RAINFALL

Rainfall is the primary source of water to all forms of life on the earth. Deficient rainfall limits the crop growth and heavy rains are even more harmful to crops. The mean rainfall has no significance in rainfed agriculture, instead the dependable rainfall and its distribution are relevant for successful crop planning. Keeping its importance in view, rainfall variability and 75 per cent probability were worked out. The rainfall variability, in terms of standard deviation and coefficient of variation, was worked out for all the six stations for different periods viz., monthly, seasonal and annual across the cardamom tract of the Western Ghats.

### 4.1.1 Spatial distribution of annual rainfall

The mean annual rainfall over Pampadumpara and Ambalavayal (Kerala) is 1873 ± 326 mm and 1948 ± 367 mm, respectively while 1452 ± 249 mm over Thandikudi (Tamil Nadu). It is the highest (2608 ± 494 mm) at Saklespur, followed by 2566 ± 494 mm at Madikeri while 2355 ± 421 mm at Mudigere over Karnataka (Table 4.1). It indicated that the mean annual rainfall across the cardamom tract is

**Table.4.1 Mean annual rainfall (mm) and its variability at different locations across the cardamom tract of the Western Ghats**

| Station | Annual rainfall (mm) | Standard deviation | CV (%) | Dependable rainfall (mm) at 75 % | Number of rainy days |
|---|---|---|---|---|---|
| Pampadumpara | 1873 | 326 | 17.4 | 1611 | 117 |
| Ambalavayal | 1948 | 367 | 18.8 | 1752 | 113 |
| Madikeri | 2566 | 494 | 19.3 | 2158 | 127 |
| Saklespur | 2608 | 494 | 18.9 | 2338 | 114 |
| Mudigere | 2355 | 421 | 17.9 | 2090 | 113 |
| Thandikudi | 1452 | 249 | 17.1 | 1265 | 81 |

the highest (2608 mm) over Karnataka (Saklespur) and the lowest (1452 mm) over Tamil Nadu (Thandikudi) while intermediary over Kerala (1873-1978 mm). The mean annual rainfall increases from south (Pampadumpara) to north across the cardamom tract while the western parts of the Western Ghats receive high annual rainfall, ranging from 1873 mm to 2608 mm when compared to that of eastern parts (1452 mm).

The standard deviation of annual rainfall is relatively high, towards north (Karnataka), indicating that the inter-annual variability is high. The coefficient of variation of mean annual rainfall varies between 17.1 per cent and 19.3 per cent, indicating that it is dependable from year to year across the cardamom tract. The dependable rainfall at 75 per cent probability level varied between 1265 mm over Tamil Nadu and 2338 mm over Karnataka (Saklespur). It is intermediary (1611- 1752 mm) over Kerala as seen in the case of mean annual rainfall.

The number of rainy days over cardamom tract is less (81 days) over Thandikudi and high (127 days) over Madikeri, followed by Pampadumpara (117 days). It also indicated that the rainfall over Tamil Nadu is spread in less number of rainy days when compared to that of other locations across the cardamom tract. However, the distribution of rainfall is relatively better over Tamil Nadu due to the influence of southwest and northeast monsoon.

### 4.1.2 Spatial distribution of seasonal rainfall (Southwest monsoon – June to September)

The seasonal rainfall during the southwest monsoon over Pampadumpara and Ambalavayal (Kerala) is 1125 ± 280 mm and 1258 ± 305 mm respectively while 473 ± 148 mm over Thandikudi (Tamil Nadu). It is the highest 2164 ± 469 mm at Saklespur, followed by 2054 ± 479 mm at Madikeri while 1894 ± 415 mm at Mudigere over Karnataka (Table 4.2). It indicated that the southwest monsoon rainfall across

**Table 4.2 Rainfall (mm) during southwest monsoon and its variability at different locations across the cardamom tract of Western Ghats**

| Station | Annual rainfall (mm) | SWM rainfall (mm) | % Contribution | Std.deviation | CV (%) | DR at 75 % (mm) | Ann. No. of rainy days | Rainy days in SWM | % Contribution |
|---|---|---|---|---|---|---|---|---|---|
| Pampadumpara | 1873 | 1125 | 60.1 | 280 | 24.9 | 888 | 117 | 73 | 62.4 |
| Ambalavayal | 1948 | 1258 | 64.6 | 305 | 24.2 | 1046 | 113 | 71 | 62.8 |
| Madikeri | 2566 | 2054 | 80 | 479 | 23.3 | 1628 | 127 | 90 | 70.9 |
| Saklespur | 2608 | 2164 | 83 | 469 | 21.7 | 1936 | 114 | 83 | 72.8 |
| Mudigere | 2355 | 1894 | 80.4 | 415 | 21.9 | 1644 | 113 | 83 | 73.5 |
| Thandikudi | 1452 | 473 | 32.6 | 148 | 31.3 | 376 | 81 | 31 | 38.3 |

the cardamom tract is the lowest 473 mm over Tamil Nadu and the highest over Karnataka (Saklespur), showing the same trend as in the case of annual rainfall. The southwest monsoon rainfall increases from south (Pampadumpara) to north across the cardamom tract. The western parts of the Western Ghats receive high southwest monsoon rainfall, ranging from 1125 mm to 2164 mm when compared to the eastern parts (473 mm). The coefficient of variation of southwest monsoon rainfall varied between 21.9 per cent and 24.9 per cent in western parts whereas it is 31.3 per cent in eastern parts of cardamom tract. It conveys the meaning that the southwest monsoon rainfall is relatively dependable over western parts than that of eastern parts of Western Ghats. The dependable rainfall at 75 per cent probability level varied between 376 mm over Tamil Nadu and 1936 mm over Karnataka. It is intermediary (888 mm – 1046 mm) over Kerala. The percentage contribution of southwest monsoon rainfall to annual is high over Karnataka (80-83 %) and less over Tamil Nadu (33 %). It is intermediary (60-65 %) over Kerala.

The number of rainy days over the cardamom tract during the southwest monsoon is less (31 days) over Tamil Nadu and high (90 days) over Madikeri, followed by Saklespur and Mudigere (83 days). The percentage contribution of rainy days during the southwest monsoon season to annual is high over Karnataka (71-74 %) and less over Tamil Nadu (38 %). It is intermediary (62-63 %) over Kerala.

As a whole, the trend in southwest monsoon rainfall across the cardamom tract is similar to that of annual rainfall as it contributes more to the annual except over Tamil Nadu.

### 4.1.3 Spatial distribution of seasonal rainfall (Post monsoon season – October to November)

The seasonal rainfall during the post monsoon over Pampadumpara and Ambalavayal (Kerala) is 432 ± 139 mm and 314 ± 90 mm, respectively while 514 ± 226 mm over Thandikudi (Tamil Nadu). It is 284 ± 110 mm at Madikeri, followed by 254 ± 141 mm at Saklespur while 252 ± 96 mm at Mudigere over Karnataka (Table 4.3). It is envisaged that the post monsoon rainfall across the cardamom tract is the

**Table 4.3 Rainfall (mm) during post monsoon and its variability at different locations across the cardamom tract of Western Ghats**

| Station | Annual rainfall (mm) | PM Rainfall (mm) | % Contri bution | Std.dev iation | CV (%) | DR at 75 % (mm) | Ann. No. of rainy days | Rainy days in PM season | % Contri bution |
|---|---|---|---|---|---|---|---|---|---|
| Pampadumpara | 1873 | 432 | 23.1 | 139 | 32.2 | 343 | 117 | 24 | 20.4 |
| Ambalavayal | 1948 | 314 | 16.1 | 90 | 28.5 | 248 | 113 | 18 | 15.9 |
| Madikeri | 2566 | 284 | 11.1 | 110 | 38.9 | 201 | 127 | 17 | 13.4 |
| Saklespur | 2608 | 254 | 9.7 | 141 | 55.8 | 133 | 114 | 16 | 14.0 |
| Mudigere | 2355 | 252 | 10.7 | 96 | 38.4 | 177 | 113 | 15 | 13.3 |
| Thandikudi | 1452 | 514 | 35.4 | 226 | 44.0 | 294 | 81 | 24 | 29.6 |

lowest 252 mm over Mudigere (Karnataka) and the highest 514 mm over Thandikudi (Tamil Nadu). In contrast to the pattern of southwest monsoon rainfall, seasonal rainfall during the post monsoon decreases from south (Pampadumpara) to north (Mudigere) while the eastern parts of the Western Ghats receive high rainfall, followed by southern parts when compared to northern parts across the cardamom tract.

The coefficient of variation of post monsoon rainfall varied between 28.5 per cent and 55.8 per cent in western parts whereas it is 44.0 per cent in eastern parts of the cardamom tract. It indicated that the post monsoon rainfall is relatively dependable over southern parts of the Western Ghats (Kerala) than northern (Karnataka) and eastern parts (Tamil Nadu). The dependable rainfall at 75 per cent probability level varied between 133 mm over Karnataka (Saklespur) and 343 mm over Kerala (Pampadumpara). It is intermediary (294 mm) over Tamil Nadu. The percentage contribution of post monsoon rainfall to annual is high over

Tamil Nadu (35.4 %) and less over Karnataka (9.7-11.1 %). It is intermediary (16.1-23.1%) over Kerala.

The number of rainy days over the cardamom tract during the post monsoon is less (15 days) over Karnataka (Mudigere) and high (24 days) over Pampadumpara and Thandikudi, followed by Ambalavayal (18 days). The percentage contribution of rainy days during the post monsoon season to annual is high over Tamil Nadu (30 %) and less over Karnataka (13-14 %). It is intermediary (16-20 %) over Kerala.

As a whole, the pattern of post monsoon rainfall is in reverse trend (rainfall decreases from south to north) when compared to that of southwest monsoon and its contribution to the annual rainfall is high over Thandikudi (Tamil Nadu) across the cardamom tract of the Western Ghats.

### 4.1.4 Spatial distribution of seasonal rainfall (Winter season – December to February)

The seasonal rainfall during the winter over Pampadumpara and Ambalavayal (Kerala) is 91± 66 mm and 62 ± 70 mm, respectively while 192 ± 110 mm over Thandikudi (Tamil Nadu). It is the lowest 12 ± 13 mm at Saklespur, followed by 18 ± 22 mm at Mudigere while 22 ± 22 mm at Madikeri over Karnataka (Table 4.4). It indicated that seasonal rainfall during the winter across the cardamom tract is the lowest 12 mm over Saklespur (Karnataka) and the highest 192 mm over Thandikudi (Tamil Nadu). The eastern parts of the Western Ghats receive high rainfall, followed by southern parts (Kerala) and the northern parts (Karnataka) receive very meagre rainfall.

The coefficient of variation of seasonal rainfall during the winter varies between 57.1 per cent and 123.3 per cent over cardamom tract. It indicated that the seasonal rainfall during the winter is dependable over eastern parts (Tamil

## Table 4.4 Rainfall (mm) during winter and its variability at different locations across the cardamom tract of Western Ghats

| Station | Annual rainfall (mm) | Winter rainfall (mm) | % Contribution | Std.deviation | CV (%) | DR at 75 % (mm) | Ann. No. of rainy days | Rainy days in Winter | % Contribution |
|---|---|---|---|---|---|---|---|---|---|
| Pampadumpara | 1873 | 90.5 | 4.8 | 66.2 | 73.1 | 35.5 | 117 | 6 | 5.1 |
| Ambalavayal | 1948 | 62 | 3.2 | 70.2 | 113.2 | 13.2 | 113 | 2 | 1.8 |
| Madikeri | 2566 | 21.6 | 0.84 | 22.0 | 101.9 | 0.0 | 127 | 2 | 1.6 |
| Saklespur | 2608 | 12.2 | 0.47 | 12.6 | 103.3 | 0.0 | 114 | 1 | 0.9 |
| Mudigere | 2355 | 17.6 | 0.75 | 21.7 | 123.3 | 0.0 | 113 | 0 | 0.0 |
| Thandikudi | 1452 | 192 | 13.2 | 109.9 | 57.1 | 72.3 | 81 | 10 | 12.3 |

Nadu) than rest of the Western Ghats. The dependable rainfall at 75 per cent probability level varied between 72 mm over Tamil Nadu and 13-36 mm over Kerala. Interestingly, the dependable rainfall over Karnataka is negligibly small. The percentage contribution of winter rainfall to annual is high over Tamil Nadu (13.2 %) and negligible over Karnataka (less than 1 %). It is intermediary (3-5 %) over Kerala.

The number of rainy days over the cardamom tract during winter season is negligible (less than two days) over Karnataka and ten rainy days are seen over Tamil Nadu, followed by Pampadumpara (six days). The percentage contribution of rainy days during the winter to annual is high over Tamil Nadu (12 %) and less over Karnataka (0-2 %). It is intermediary (2-5 %) over Kerala.

It is clear from the above that the contribution of winter rainfall to the annual is very meagre over Karnataka and Kerala and relatively better over Thandikudi (Tamil Nadu). The pattern of rainfall during winter is similar to that of post monsoon season.

### 4.1.5 Spatial distribution of seasonal rainfall (Summer season – March to May)

The summer season rainfall over Pampadumpara and Ambalavayal (Kerala) is 227 ± 128 mm and 316 ± 94 mm, respectively while 275 ± 94 mm over Thandikudi (Tamil Nadu). It is the lowest 180 ± 59 mm at Saklespur, followed 192 ± 76 mm at Mudigere while 208 ± 51 mm at Madikeri over Karnataka (Table 4.5). It indicated that rainfall during the summer across the cardamom tract is the lowest 180 mm over Saklespur (Karnataka) and the highest 316 mm over Kerala (Ambalavayal) while intermediary (275 mm) over Tamil Nadu. The northern parts receive less rainfall during summer than southern parts (Kerala) and the eastern parts across the cardamom tract of the Western Ghats.

**Table 4.5 Rainfall (mm) during summer and its variability at different locations across the cardamom tract of Western Ghats**

| Station | Annual rainfall (mm) | Summer rainfall (mm) | % Contribution | Std.deviation | CV (%) | DR at 75 % (mm) | Ann. No. of rainy days | Summer rainy days | % Contribution |
|---|---|---|---|---|---|---|---|---|---|
| Pampadumpara | 1873 | 227 | 12.1 | 128 | 56 | 152 | 117 | 14 | 12 |
| Ambalavayal | 1948 | 316 | 16.2 | 94 | 30 | 253 | 113 | 21 | 18.6 |
| Madikeri | 2556 | 208 | 8.1 | 51 | 25 | 172 | 127 | 17 | 13.4 |
| Saklespur | 2608 | 180 | 6.9 | 59 | 33 | 147 | 114 | 14 | 12.3 |
| Mudigere | 2355 | 192 | 8.2 | 76 | 39 | 142 | 113 | 14 | 12.4 |
| Thandikudi | 1452 | 275 | 18.9 | 94 | 34 | 206 | 81 | 16 | 19.8 |

The coefficient of variation of summer season rainfall varied between 24.5 per cent (Madikeri) and 56.4 per cent (Pampadumpara) over cardamom tract. It indicated that the summer season rainfall is highly variable over Pampadumpara than the rest of the locations of the Western Ghats. The dependable rainfall at 75 per cent probability level varied between 142 mm over Mudigere (Karnataka) and 253 mm over Ambalavayal. The percentage contribution of rainfall during summer to annual rainfall is high over Tamil Nadu (19 %) and less over Karnataka (7-8 %). It is intermediary over Kerala (12-16 %).

The number of rainy days over the cardamom tract during summer season is ranging from 14 days (Pampadumpara, Saklespur and Mudigere) to 21 days (Ambalavayal). The percentage contribution of rainy days during the summer to annual is high over Tamil Nadu (20 %) and less over Karnataka (12-13 %). It is intermediary (12-19 %) over Kerala.

From the above it is understood that, the rainfall during summer is higher over Kerala and Tamil Nadu when compared to Karnataka while the variability of rainfall is high over Kerala and Tamil Nadu than Karnataka.

### 4.1.6 Spatial distribution of monthly rainfall

Bi-model distribution of rainfall is noticed at Pampadumpara, Ambalavayal and Thandikudi due to influence of both the southwest and northeast monsoons. July is the rainiest month over Kerala and Karnataka while October over Tamil Nadu (Table 4.6). The cardamom tract in Kerala receives 51- 57 per cent of annual rainfall during the rainy months (June-August) while Karnataka receives

**Table 4.6 Mean monthly rainfall (mm) at different locations across the cardamom tract of the Western Ghats**

| Stations | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pampadumpara | 17.6 | 15.6 | 33.8 | 91.9 | 101.1 | 303.8 | 366.7 | 280.4 | 174.2 | 260.4 | 171.3 | 55.8 |
| Ambalavayal | 12.6 | 17.2 | 39.5 | 121.8 | 155.1 | 362.7 | 426.9 | 314.3 | 153.7 | 221.6 | 92.6 | 29.6 |
| Madikeri | 3.8 | 1.7 | 8.1 | 72.6 | 127.0 | 521.4 | 826.2 | 503.5 | 202.6 | 217.7 | 66.2 | 15.7 |
| Saklespur | 0.1 | 5.7 | 9.8 | 68.4 | 101.4 | 600.2 | 775.4 | 562.6 | 225.3 | 182.1 | 71.5 | 5.2 |
| Mudigere | 2.0 | 3.1 | 11.8 | 68.1 | 112.5 | 483.9 | 728.7 | 461.2 | 219.6 | 197.0 | 54.5 | 12.6 |
| Thandikudi | 26.7 | 38.4 | 36.6 | 117.6 | 120.4 | 78.5 | 77.7 | 134.1 | 183.0 | 272.3 | 241.6 | 125.5 |

contribution of rainfall during summer to annual rainfall is high over Tamil Nadu (19 %) and less over Karnataka (7-8 %). It is intermediary over Kerala (12-16 %).

The number of rainy days over the cardamom tract during summer season is ranging from 14 days (Pampadumpara, Saklespur and Mudigere) to 21 days (Ambalavayal). The percentage contribution of rainy days during the summer to annual is high over Tamil Nadu (20 %) and less over Karnataka (12-13 %). It is intermediary (12-19 %) over Kerala.

From the above it is understood that, the rainfall during summer is higher over Kerala and Tamil Nadu when compared to Karnataka while the variability of rainfall is high over Kerala and Tamil Nadu than Karnataka.

### 4.1.6 Spatial distribution of monthly rainfall

Bi-model distribution of rainfall is noticed at Pampadumpara, Ambalavayal and Thandikudi due to influence of both the southwest and northeast monsoons. July is the rainiest month over Kerala and Karnataka while October over Tamil Nadu (Table 4.6). The cardamom tract in Kerala receives 51- 57 per cent of annual rainfall during the rainy months (June-August) while Karnataka receives

**Table 4.6 Mean monthly rainfall (mm) at different locations across the cardamom tract of the Western Ghats**

| Stations | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pampadumpara | 17.6 | 15.6 | 33.8 | 91.9 | 101.1 | 303.8 | 366.7 | 280.4 | 174.2 | 260.4 | 171.3 | 55.8 |
| Ambalavayal | 12.6 | 17.2 | 39.5 | 121.8 | 155.1 | 362.7 | 426.9 | 314.3 | 153.7 | 221.6 | 92.6 | 29.6 |
| Madikeri | 3.8 | 1.7 | 8.1 | 72.6 | 127.0 | 521.4 | 826.2 | 503.5 | 202.6 | 217.7 | 66.2 | 15.7 |
| Saklespur | 0.1 | 5.7 | 9.8 | 68.4 | 101.4 | 600.2 | 775.4 | 562.6 | 225.3 | 182.1 | 71.5 | 5.2 |
| Mudigere | 2.0 | 3.1 | 11.8 | 68.1 | 112.5 | 483.9 | 728.7 | 461.2 | 219.6 | 197.0 | 54.5 | 12.6 |
| Thandikudi | 26.7 | 38.4 | 36.6 | 117.6 | 120.4 | 78.5 | 77.7 | 134.1 | 183.0 | 272.3 | 241.6 | 125.5 |

71-74 per cent and 20 per cent only over Tamil Nadu. Interestingly, the monthly rainfall is high from August to December over Tamil Nadu when compared to other locations. Uni-model rainfall distribution is noticed over Karnataka, having the highest monthly rainfall from June to August when compared to Kerala and Tamil Nadu across the cardamom tract (Fig 4.1). At the same time, Karnataka receives insignificant rainfall from December to March, indicating that the cardamom plantations are under moderate to severe soil moisture stress if the pre-monsoon shower fails. It is not the case across the cardamom tract of Kerala and Tamil Nadu.

### 4.1.7 Trends in annual rainfall across the cardamom tract

The maximum annual rainfall (2575 mm) was noticed in 1961 while minimum (1221 mm) in 1972 at Pampadumpara. A marginal increase of 2.17 mm per year was noticed during the period from 1960 to 2002. The maximum annual rainfall (2599 mm) was observed in 1980 while minimum (1195 mm) in 2002 at Ambalavayal. A decrease of 17.9 mm per year was noticed during the period from 1980 to 2002.

At Madikeri, the maximum annual rainfall (3566 mm) was received in 1994 while minimum (1629 mm) in 1987. A marginal increase of 13 mm per year was noticed during the period from 1986 to 2002.

At Saklespur, the maximum annual rainfall (3675 mm) was received in 1992 while minimum (1832 mm) in 2002. A drastic decrease of 86.6 mm per year was noticed during the period from 1992 to 2002. The maximum annual rainfall (3492 mm) was noticed in 1994 while minimum (1500 mm) in 1987 at Mudigere. A marginal decrease of 4.8 mm per year was noticed during the period from 1964 to 2002.

The maximum annual rainfall (1833 mm) was noticed in 1993 while minimum (952 mm) in 2001 at Thandikudi.

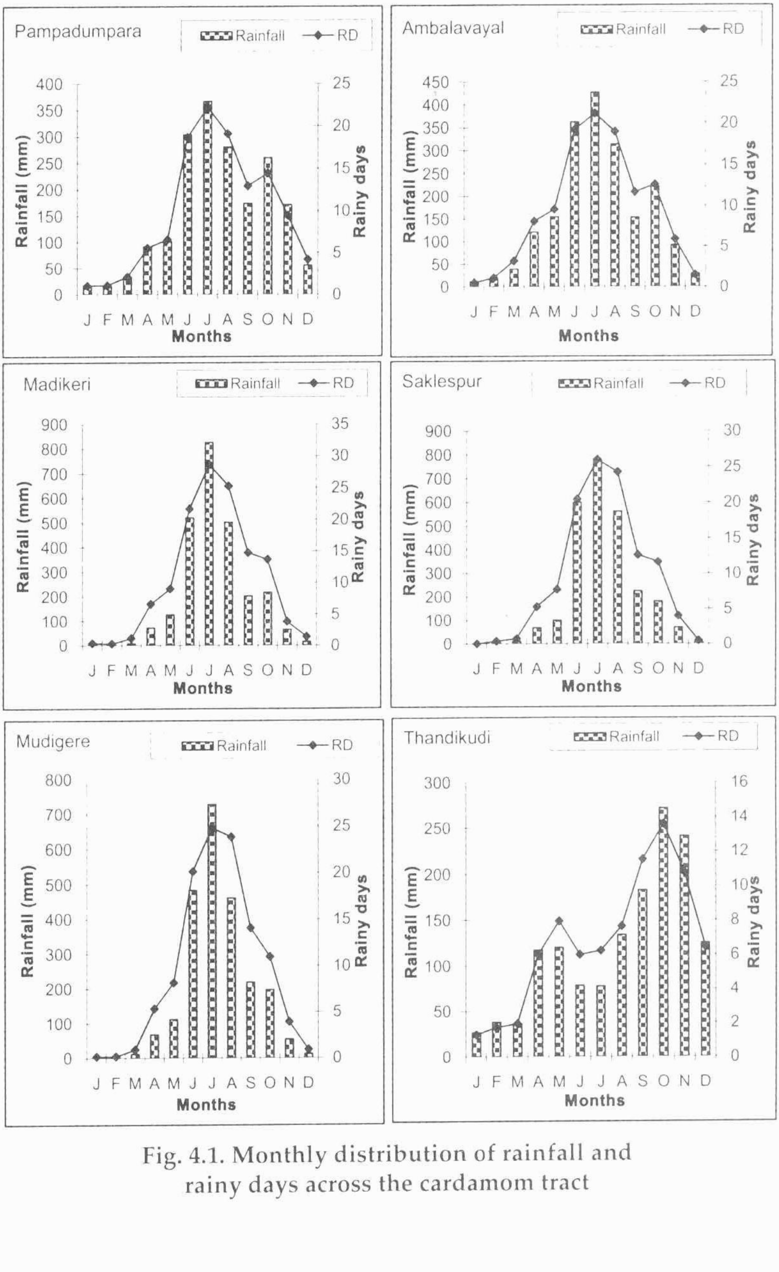


Fig. 4.1. Monthly distribution of rainfall and rainy days across the cardamom tract

A marginal decrease of 21.7 mm per year was noticed during the period from 1986 to 2002.

Out of six locations, four locations viz., Ambalavayal, Saklespur, Mudigere and Thandikudi showed a marginal declining trend in annual rainfall (Fig 4.2). In contrast, the other two locations viz., Pampadumpara and Madikeri showed a marginal increasing trend. However, the annual rainfall was one of the lowest during 2002 at all the locations.

### 4.1.8 Trends in southwest monsoon rainfall

The maximum rainfall (1886 mm) during southwest monsoon was noticed in 1961 while minimum (587 mm) in 1965 at Pampadumpara. A marginal decrease of one mm per year was noticed during the period from 1960 to 2002. The maximum rainfall (1738 mm) during southwest monsoon was observed in 1994 while minimum (678 mm) in 2002 at Ambalavayal. A marginal decrease of 16.4 mm per year was noticed during the period from 1980 to 2002.

At Madikeri, the maximum rainfall (3011 mm) during southwest monsoon was received in 1994 while minimum (1126 mm) in 1987. A marginal increase of 4.9 mm per year was noticed during the period from 1986 to 2002. At Saklespur, the maximum rainfall (2956 mm) during southwest monsoon was noticed in 1992 while minimum (1386 mm) in 2002. A drastic decrease of 89.5 mm per year was noticed during the period from 1992 to 2002.

The maximum rainfall (2993 mm) during southwest monsoon was noticed in 1994 while minimum (1014 mm) in 1987 at Mudigere. A marginal decrease of 5.2 mm per year was noticed during the period from 1964 to 2002. The maximum rainfall (743 mm) during southwest monsoon was noticed in 1988 while minimum (283 mm) in 1994 at Thandikudi. A marginal decrease of 21.7 mm per year was noticed during the period from 1986 to 2002.

### 4.1.9 Trends in post monsoon rainfall

The rainfall during post monsoon was maximum (765 mm) in 1977 while minimum (184 mm) in 2000 at Pampadumpara. A marginal increase of 2.2 mm per year was noticed during the period from 1960 to 2002. The rainfall during post monsoon was maximum (436 mm) in 1990 while minimum (107 mm) in 1988 at Ambalavayal. A marginal decrease of 0.9 mm per year was noticed during the period from 1980 to 2002.

At Madikeri, the rainfall during post monsoon was maximum (418 mm) in 2002 while minimum (60 mm) in 1988. A marginal increase of 10.1 mm per year was noticed during the period from 1986 to 2002. At Saklespur, the rainfall during post monsoon was maximum (520 mm) in 1992 while minimum (119 mm) in 1995. A marginal decrease of 4 mm per year was noticed during the period from 1992 to 2002.

The rainfall during post monsoon was maximum (465 mm) in 1992 while minimum (119 mm) in 1973 at Mudigere. A marginal increase of 1.2 mm per year was noticed during the period from 1964 to 2002. The rainfall during post monsoon was maximum (743 mm) in 1988 while minimum (283 mm) in 1994 at Thandikudi. A marginal decrease of 8.6 mm per year was noticed during the period from 1986 to 2002.

Saklespur and Thandikudi showed a declining trend in post monsoon rainfall and all other four locations showed an increasing trend (Fig 4.4).

### 4.1.10 Trends in winter rainfall

The maximum winter season rainfall (269 mm) was noticed in 1988 while minimum (3.7 mm) in 1980 at Pampadumpara. A marginal increase of 1.3 mm per year was noticed during the period from 1960 to 2002. The maximum winter season rainfall (207.5 mm) was observed

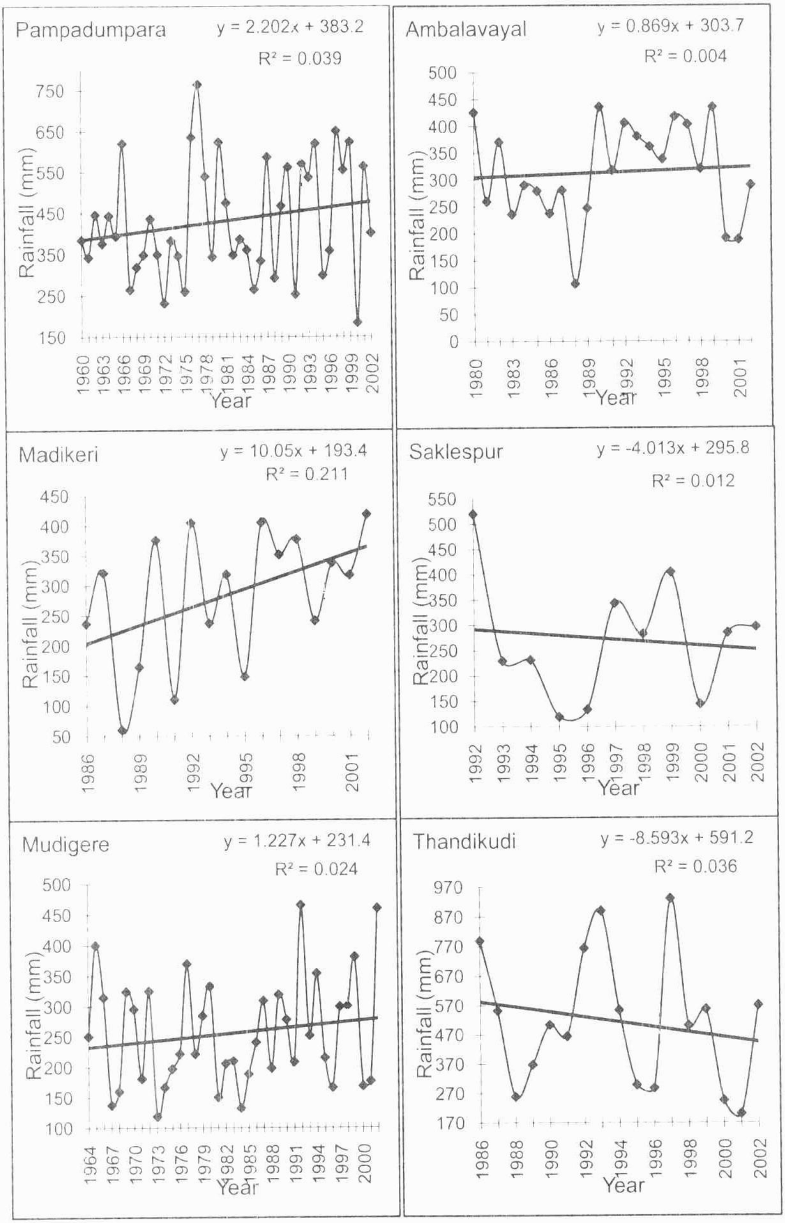


**Fig 4.4 Trends in post monsoon rainfall across the cardamom tract over the Western Ghats**

in 1984 while no rainfall in 2001 and 2002 at Ambalavayal. A marginal decrease of 0.2 mm per year was noticed during the period from 1980 to 2002.

At Madikeri, the maximum winter season rainfall (68.3 mm) was received in 1997 while no rainfall from 1990 to1993, 1996 and 2000. An insignificant increase was noticed during the period from 1986 to 2002. At Saklespur, the maximum winter season rainfall (36 mm) was noticed in 1999 while no rainfall in 1993, 1995, 1996 and 2000. A marginal decrease of 0.9 mm per year was noticed during the period from 1992 to 2002.

The maximum winter season rainfall (83 mm) was noticed in 1997 while no rainfall in many years at Mudigere. A marginal increase of 0.1 mm was noticed during the period from 1964 to 2002. The maximum winter season rainfall (386 mm) was noticed in 1988 while minimum (31 mm) in 1996 at Thandikudi. A marginal decrease of 4.1 mm per year was noticed during the period from 1986 to 2002.

Ambalavayal and Thandikudi showed a declining trend in winter rainfall and all other four locations showed an increasing trend (Fig 4.5).

### 4.1.11 Trends in summer rainfall

The rainfall during summer was maximum (806 mm) in 1960 while minimum (56 mm) in 1969 at Pampadumpara. A decrease of 0.2 mm per year was noticed during the period from 1960 to 2002. The rainfall during summer was maximum (517 mm) in 1995 while minimum (141 mm) in 1983 at Ambalavayal. A marginal decrease of 2.3 mm per year was noticed during the period from 1980 to 2002.

At Madikeri, the rainfall during summer was maximum (314 mm) in 1992 while minimum (130 mm) in 1997. A marginal decrease of 1.5 mm per year was noticed during the period from 1986 to 2002. At Saklespur, the rainfall

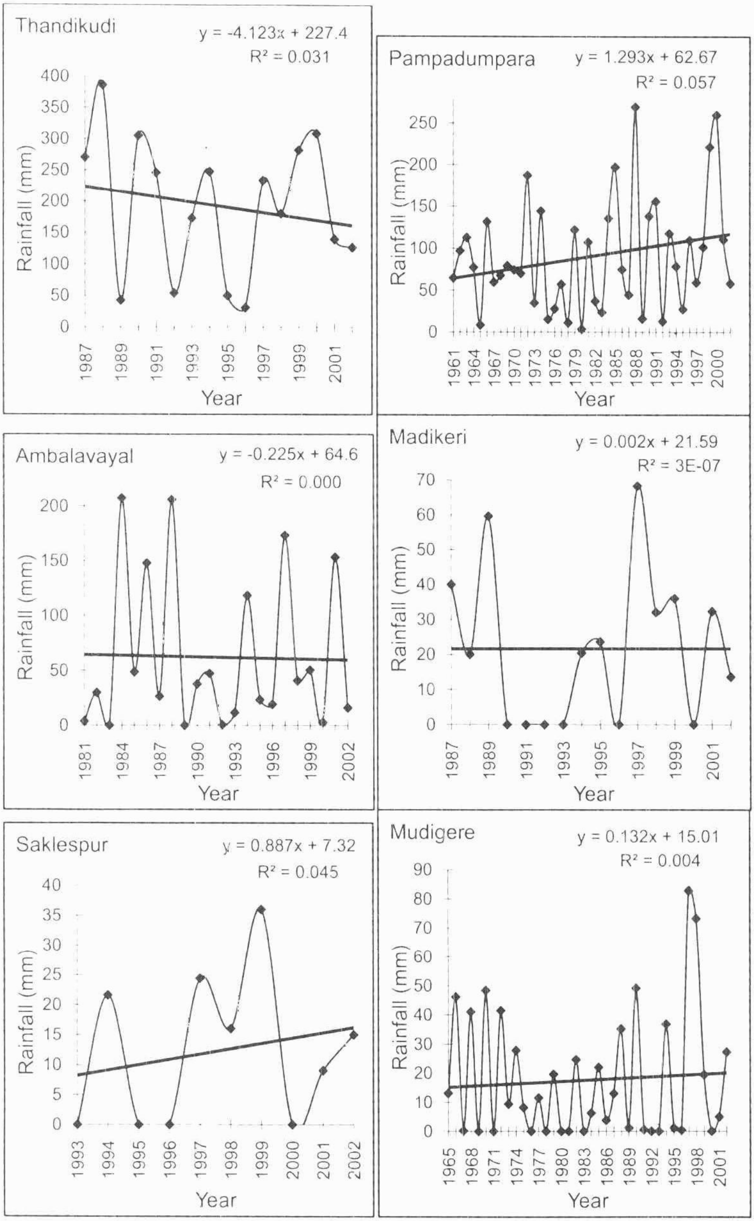


Fig 4.5 Trends in winter rainfall across the cardamom tract over the Western Ghats

during summer was maximum (294 mm) in 1999 while minimum (84 mm) in 1998. An increase of 0.8 mm per year was noticed during the period from 1992 to 2002.

The rainfall during summer was maximum (384 mm) in 1970 while minimum (72 mm) in 1989 at Mudigere. A marginal decrease of 0.6 mm per year was noticed during the period from 1964 to 2002. The rainfall during summer was maximum (496 mm) in 1995 while minimum (134 mm) in 2000 at Thandikudi. A marginal decrease of 4.9 mm per year was noticed during the period from 1986 to 2002.

Except Saklespur, all other five locations showed decreasing trend in summer rainfall (Fig 4.6).

As a whole, a marginal decline in rainfall was noticed at all locations during the southwest monsoon except at Madikeri. However, it is insignificant as the amount of rainfall received was very high during the southwest monsoon at all locations except at Thandikudi. In contrast, a marginal increasing trend in rainfall from October to March (Post monsoon and Winter) at Pampadumpara, Ambalavayal (October and November), Madikeri, Saklespur (December – March) and Mudigere across the cardamom tract was noticed. If such trend continues at the above locations, it may be beneficial to cardamom producers. The decline, though insignificant, in summer showers (March-May) at all the locations across the cardamom tract except at Saklespur was the concern of the cardamom growers for sustenance of cardamom plantations. The marginal decrease in annual rainfall was more evident since last one-and- a-half decade across the cardamom tract at many locations.

## 4.2 TEMPERATURE

### 4.2.1 Spatial distribution of annual mean temperature

The mean annual maximum temperature over Pampadumpara and Ambalavayal is 24.6° C and 27.3° C,

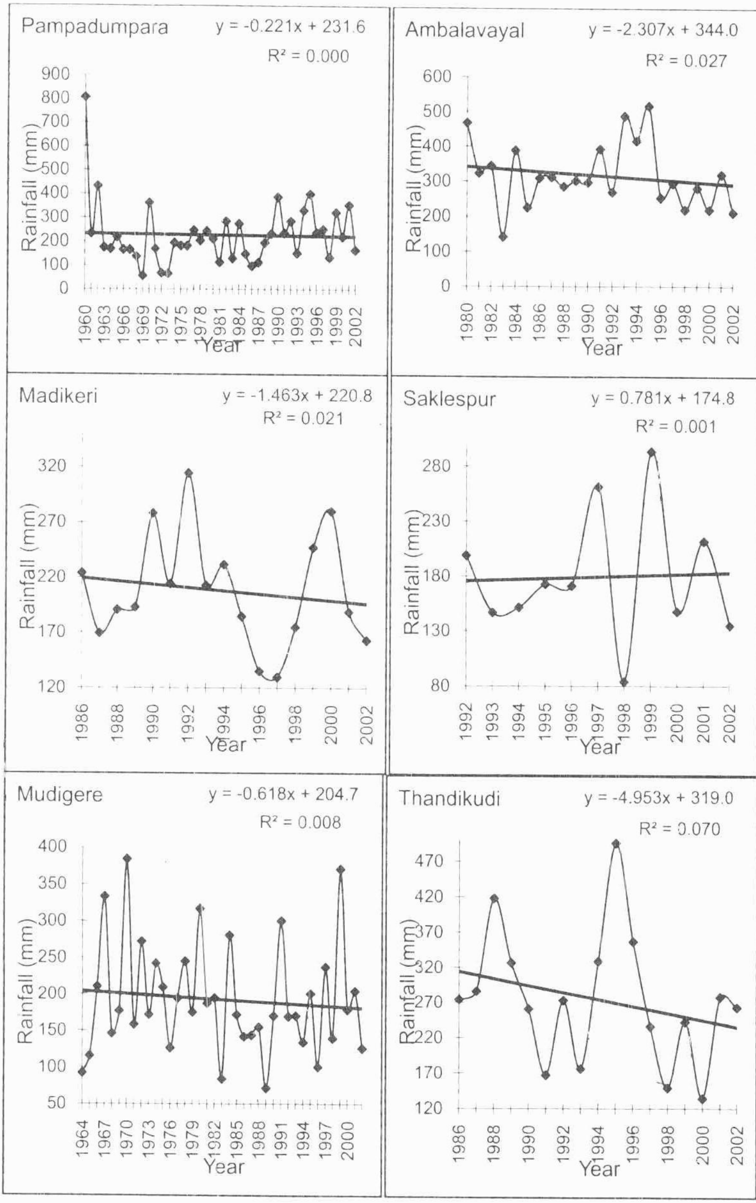


**Fig 4.6 Trends in summer rainfall across the cardamom tract over the Western Ghats**

respectively while 24.1° C over Thandikudi (Tamil Nadu). It is the highest 30.0° C at Saklespur, followed by Madikeri (27.4° C) and Mudigere (26.9° C) over Karnataka. It indicated that the mean annual maximum temperature across the cardamom tract is the lowest 24.1° C over Tamil Nadu (Thandikudi) and the highest 30.0° C over Karnataka (Saklespur) and intermediary over Kerala (24.6 - 27.3° C).

The mean annual minimum temperature over Pampadumpara and Ambalavayal is 17.5° C and 17.8° C, respectively while 15.4° C over Thandikudi. The mean annual minimum temperature ranges between 16.9° C and 17.6° C over Karnataka (Table 4.7).

The range between the mean annual maximum and minimum temperature is 7.1° C and 9.5° C over Pampadumpara and Ambalavayal, respectively while it is 8.7° C over Thandikudi. It is between 10.0° C and 12.4° C over Karnataka. It is evident that the annual temperature range is high over Karnataka and less over Kerala and Tamil Nadu across the cardamom tract of the Western Ghats.

### 4.2.2 Spatial distribution of temperature during southwest monsoon season

The maximum temperature during southwest monsoon season over Pampadumpara and Ambalavayal is 22.6 °C and 25.1 °C, respectively while 25.4 °C over Thandikudi (Tamil Nadu). It is the highest 25.8 °C at Saklespur, followed by 24.6 °C at Madikeri and 23.7 °C at Mudigere over Karnataka. It indicated that the mean maximum temperature across the cardamom tract is the lowest 22.6 °C over Kerala (Pampadumpara) and the highest 25.8°C over Karnataka (Saklespur). It can be attributed to heavy rains in addition to that of high altitudinal effect which reflects on surface air temperature.

The mean minimum temperature over Pampadumpara and Ambalavayal is 17.7°C and 18.3 °C, respectively while

Table 4.7 Mean annual and seasonal temperature (°C) at different locations across the Western Ghats

| Location | Annual | | | SWM | | | PM | | | Winter | | | Summer | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | Range | Max | Min | Range | Max | Min | Range | Max | Min | Range | Max | Min | Range |
| Pampadumpara | 24.6 | 17.5 | 7.1 | 22.6 | 17.7 | 4.9 | 24.0 | 17.6 | 6.4 | 24.3 | 15.9 | 8.4 | 28.1 | 18.9 | 9.3 |
| Ambalavayal | 27.3 | 17.8 | 9.5 | 25.1 | 18.3 | 6.8 | 26.4 | 17.8 | 8.6 | 27.9 | 15.8 | 12.1 | 30.1 | 19.0 | 11.2 |
| Madikeri | 27.4 | 17.0 | 10.4 | 24.6 | 18.2 | 6.4 | 26.8 | 17.5 | 9.3 | 28.2 | 14.0 | 14.2 | 30.8 | 18.1 | 12.7 |
| Saklespur | 30.0 | 17.6 | 12.4 | 25.8 | 18.4 | 7.4 | 30.1 | 17.7 | 12.4 | 32.0 | 15.3 | 16.8 | 33.7 | 18.7 | 15.0 |
| Mudigere | 26.9 | 16.9 | 10.0 | 23.7 | 17.9 | 5.7 | 26.3 | 16.9 | 9.3 | 28.0 | 14.3 | 13.7 | 30.7 | 17.9 | 12.8 |
| Thandikudi | 24.1 | 15.4 | 8.7 | 25.4 | 16.7 | 8.7 | 22.8 | 15.5 | 7.2 | 21.3 | 13.2 | 8.1 | 26.2 | 16.0 | 10.2 |

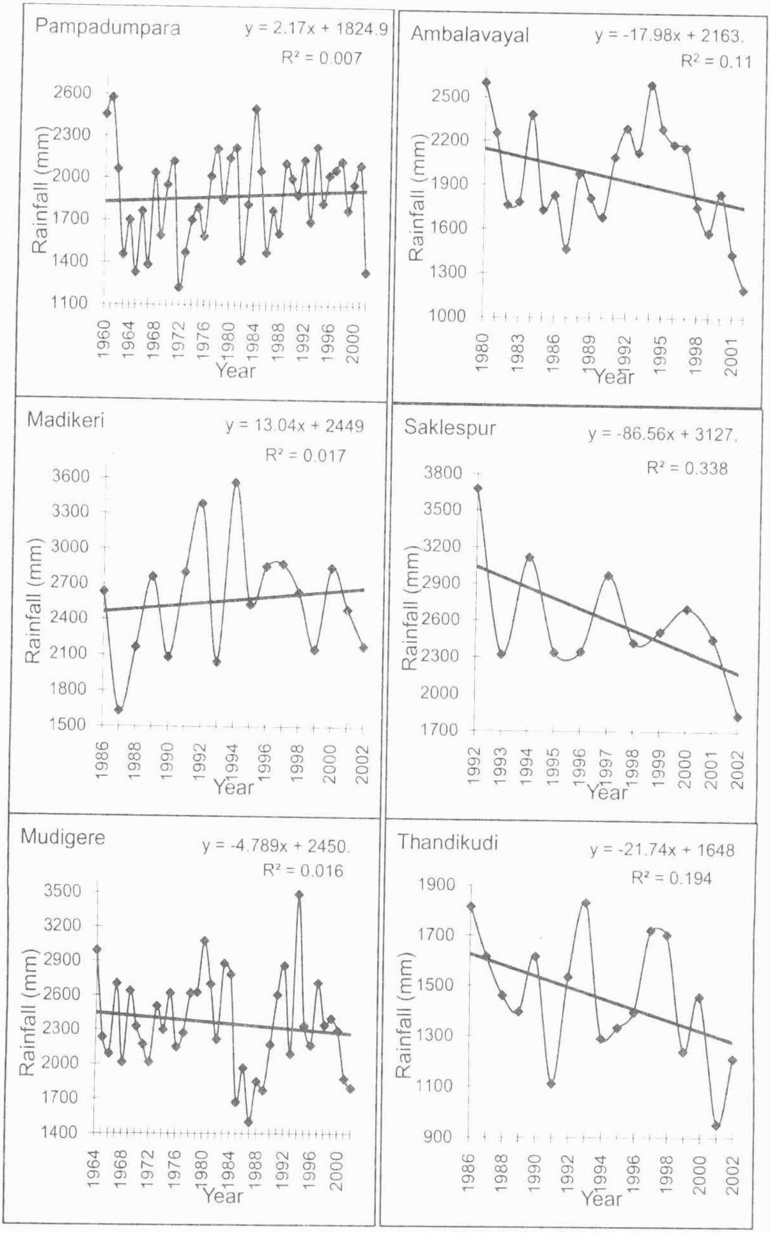


**Fig 4.2 Trends in annual rainfall across the cardamom tract over the Western Ghats**

Except Madikeri, all other five locations showed a declining trend in southwest monsoon rainfall (Fig 4.3).

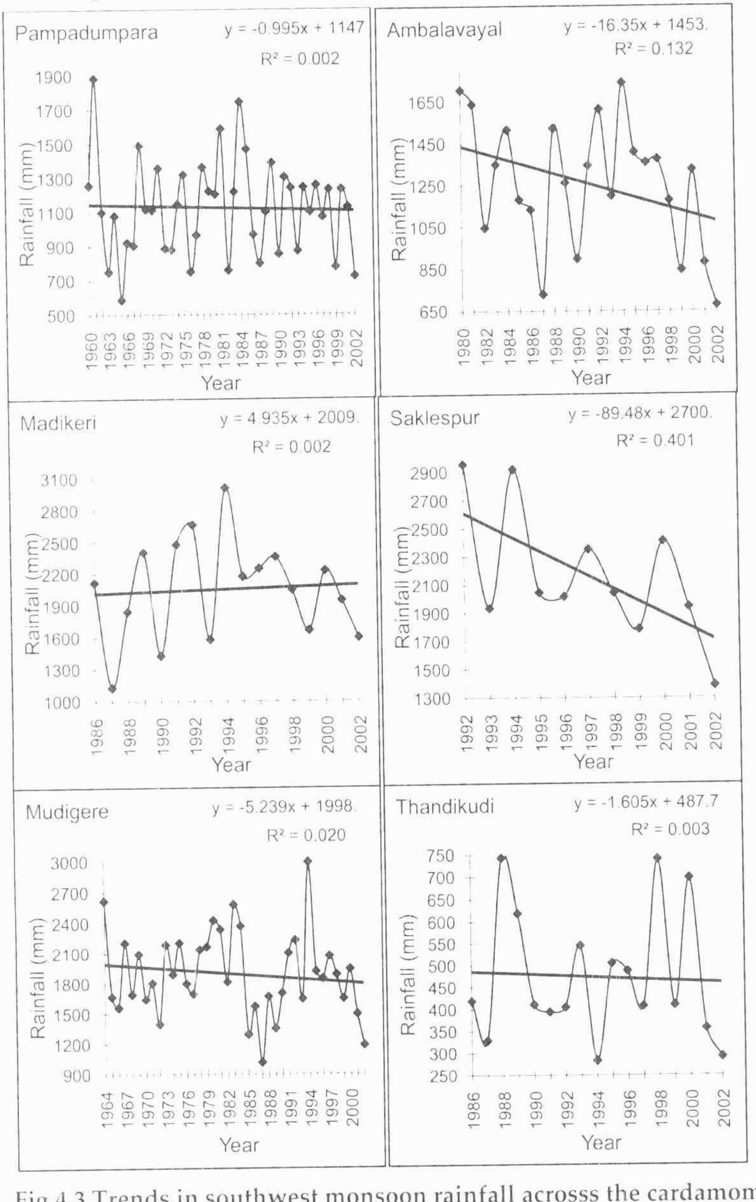


Fig 4.3 Trends in southwest monsoon rainfall acrosss the cardamom tract over the Western Ghats

16.7 °C over Thandikudi. The mean minimum temperature ranges between 17.9 °C and 18.4 °C (Table 4.7).

The range between the mean maximum and minimum temperature during southwest monsoon season is 4.9 °C and 6.8 °C over Pampadumpara and Ambalavayal, respectively while it is 8.7 °C over Thandikudi. The annual temperature range is noticed between 5.7 °C and 7.4 °C over Karnataka. The seasonal temperature range during the southwest monsoon is high over Tamil Nadu when compared to that of Kerala and Karnataka unlike in annual maximum temperature range due to less rains.

### 4.2.3 Spatial distribution of temperature during post monsoon season

The maximum temperature during post monsoon season over Pampadumpara and Ambalavayal is 24.0 °C and 26.4 °C, respectively while 22.8 °C over Thandikudi (Tamil Nadu). It is the highest 30.1 °C at Saklespur, followed by 26.8 °C at Madikeri while 26.3 °C at Mudigere over Karnataka. It indicated that the mean maximum temperature across the cardamom tract is the lowest 22.8 °C over Tamil Nadu and the highest 30.1°C over Karnataka (Saklespur).

The mean minimum temperature during post monsoon season over Pampadumpara and Ambalavayal is 17.6°C and 17.8 °C, respectively while 15.5 °C over Thandikudi. The mean minimum temperature ranges between 16.9 °C and 17.7 °C over Karnataka (Table 4.7).

The range between the mean maximum and minimum temperature during post monsoon season is 6.4 °C and 8.6 °C over Pampadumpara and Ambalavayal, respectively while it is 7.2 °C over Thandikudi. The seasonal range during post monsoon season is noticed between 9.3 °C and 12.4 °C over Karnataka.

### 4.2.4 Spatial distribution of temperature during winter season

The maximum temperature during winter season over Pampadumpara and Ambalavayal is 24.3 °C and 27.9 °C, respectively while 21.3 °C over Thandikudi (Tamil Nadu). It is the highest 32.0 °C at Saklespur, followed by 28.2 °C at Madikeri while 28.0 °C at Mudigere over Karnataka. It indicated that the mean maximum temperature across the cardamom tract during winter season is the lowest 21.3 °C over Tamil Nadu and the highest 32.0°C over Karnataka (Saklespur).

The mean minimum temperature during winter season over Pampadumpara and Ambalavayal is 15.9°C and 15.8 °C, respectively while 13.2 °C over Thandikudi. The mean minimum temperature ranges between 14.0 °C and 15.3 °C over Karnataka (Table 4.7).

The seasonal range between the mean maximum and minimum temperature during winter is between 8.4 °C and 12.1 °C over Kerala while it is 8.1 °C over Thandikudi. It is between 13.7 °C and 16.8 °C over Karnataka.

It is apparent from the above that the range between maximum and minimum temperature is the highest in winter than the rest of the seasons across the cardamom tract of the Western Ghats.

### 4.2.5 Spatial distribution of temperature during summer season

The mean maximum temperature during summer season over Pampadumpara and Ambalavayal is 28.1 °C and 30.1 °C, respectively while 26.2 °C over Thandikudi (Tamil Nadu). It is the highest 33.7 °C at Saklespur, followed by 30.8 °C at Madikeri and 30.7 °C at Mudigere over Karnataka. It indicated that the mean maximum temperature across the cardamom tract during summer is the lowest 26.2 °C over Tamil Nadu and the highest 33.7°C at Saklespur in Karnataka.

The mean minimum temperature during summer season over Pampadumpara and Ambalavayal is 18.9°C and 19.0 °C, respectively while 16.0 °C over Thandikudi. The mean minimum temperature ranges between 17.9 °C and 18.7 °C over Karnataka (Table 4.7).

The range between the mean maximum and minimum temperature during summer season is between 9.3 °C and 11.2 °C over Kerala while it is 10.2 °C over Thandikudi. The range is noticed between 12.7 °C and 15.0 °C over Karnataka.

It is evident that the annual maximum temperature is relatively high over Karnataka during all the seasons and low over Tamil Nadu except during southwest monsoon in which Kerala recorded relatively high. It can be attributed to heavy and prolonged rains during southwest monsoon over Kerala.

In case of minimum temperature, Tamil Nadu recorded the lowest in all the seasons across the cardamom tract when compared to that of Kerala and Karnataka. Kerala recorded relatively high minimum during winter and summer seasons.

The annual temperature range, including all the seasons except southwest monsoon, is high over Karnataka. Winter season recorded the highest range of temperature ranging between 13.7 °C and 16.8 °C over Karnataka, followed by summer (12.8 – 15.0 °C).

### 4.2.6 Spatial and temporal distribution of monthly temperature

The mean monthly maximum temperature is high (28.8 °C) in April over Pampadumpara while at Ambalavayal during March (30.9 °C). The northern parts of the cardamom tract experienced the highest maximum temperature during March, varying between 31.6 °C and 35.3 °C (Table 4.8). The highest maximum temperature (27.3 °C) is observed in the month of May in the eastern parts of cardamom tract (Tamil Nadu). It indicated that the mean monthly maximum temperature was maximum (35.3 °C) over Karnataka (Saklespur) and the lowest (27.3 °C) over Tamil Nadu (Thandikudi). It is intermediary over Kerala (28.8 – 30.9°C). January recorded the lowest temperature, followed by December across the cardamom tract (Table 4.9). It is the

**Table 4.8 Spatial distribution of monthly mean maximum temperature (°C)**

| Stations | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pampadumpara | 23.8 | 26.2 | 28.4 | 28.8 | 27.1 | 22.8 | 21.7 | 22.0 | 24.0 | 24.4 | 23.5 | 22.9 | 24.6 |
| Ambalavayal | 27.7 | 29.3 | 30.9 | 30.5 | 29.1 | 25.2 | 24.3 | 24.5 | 26.3 | 26.4 | 26.4 | 26.6 | 27.3 |
| Madikeri | 28.1 | 29.7 | 31.7 | 31.0 | 29.8 | 25.4 | 23.5 | 23.5 | 26.0 | 26.5 | 27.0 | 26.7 | 27.4 |
| Saklespur | 32.0 | 33.1 | 35.3 | 33.8 | 32.0 | 27.0 | 24.0 | 24.6 | 27.7 | 29.9 | 30.2 | 30.4 | 30.0 |
| Mudigere | 27.8 | 29.6 | 31.6 | 31.2 | 29.4 | 24.2 | 22.8 | 22.9 | 24.8 | 26.1 | 26.4 | 26.6 | 27.0 |
| Thandikudi | 21.0 | 22.4 | 25.1 | 26.1 | 27.3 | 25.9 | 25.5 | 24.8 | 25.3 | 23.5 | 22.1 | 20.6 | 24.1 |

**Table 4.9 Spatial distribution of monthly mean minimum temperature (°C)**

| Stations | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pampadumpara | 15.3 | 16.4 | 17.9 | 19.3 | 19.5 | 18.0 | 17.4 | 17.6 | 17.9 | 17.9 | 17.3 | 15.9 | 17.5 |
| Ambalavayal | 15.3 | 16.7 | 18.1 | 19.3 | 19.5 | 18.6 | 18.2 | 18.3 | 17.9 | 18.3 | 17.6 | 15.6 | 17.8 |
| Madikeri | 13.2 | 14.4 | 16.4 | 18.7 | 19.2 | 18.3 | 18.1 | 18.4 | 18.1 | 18.0 | 16.9 | 14.2 | 17.0 |
| Saklespur | 14.8 | 15.8 | 17.8 | 19.3 | 19.1 | 18.7 | 18.4 | 18.3 | 18.2 | 18.1 | 17.2 | 15.1 | 17.6 |
| Mudigere | 13.7 | 14.5 | 16.6 | 18.4 | 18.8 | 18.3 | 18.0 | 17.9 | 17.6 | 17.6 | 16.3 | 14.7 | 16.9 |
| Thandikudi | 12.7 | 13.3 | 14.4 | 16.4 | 17.2 | 17.1 | 16.5 | 16.8 | 16.2 | 15.8 | 15.2 | 13.1 | 15.4 |

lowest (12.7 °C) over Tamil Nadu while the highest (15.3 °C) over Kerala. Karnataka recorded intermediary (13.2 – 14.8 °C). The range between the mean maximum and minimum temperature during summer season is between 9.3 °C and 11.2 °C over Kerala while it is 10.2 °C over Thandikudi. The range is between 12.8 °C and 15.0 °C noticed over Karnataka, indicating relatively high (Fig 4.7).

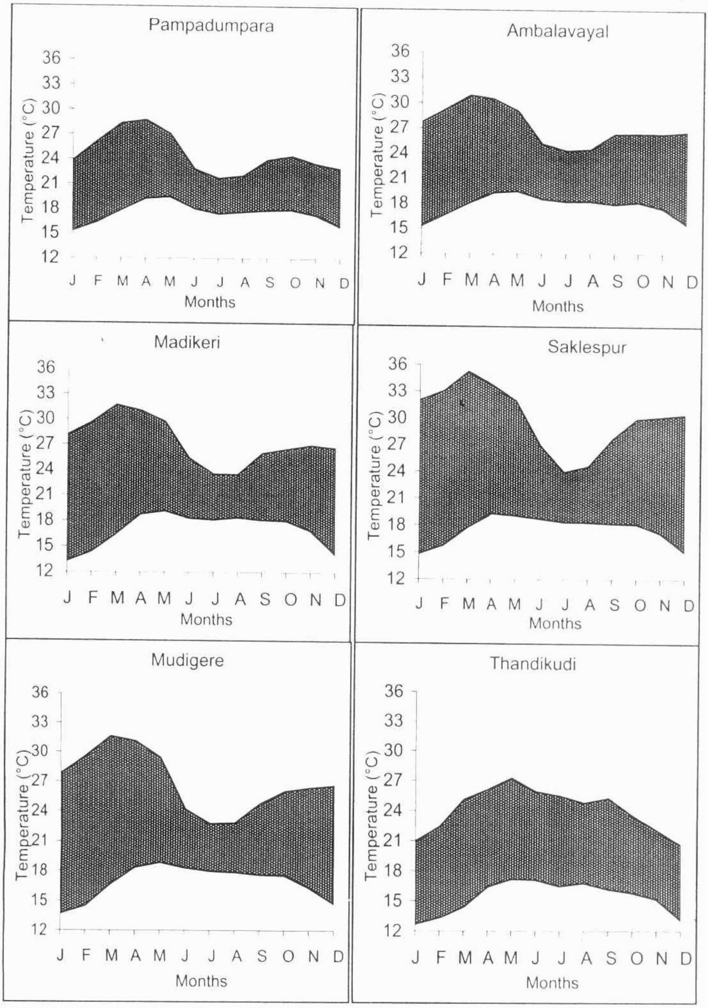


**Fig 4.7 Thermal regime of cardamom across the Western Ghats**

A relatively uniform temperature range is maintained (6.9 -10.7 ° C) over Tamil Nadu, followed by Kerala (5.2 - 11.7° C). It is high (5.3 -15.9° C) over Karnataka (Fig 4.8). It is evident that the surface air temperature is high over Karnataka and Kerala along its range when compared to that of Tamil Nadu across the cardamom tract, which put

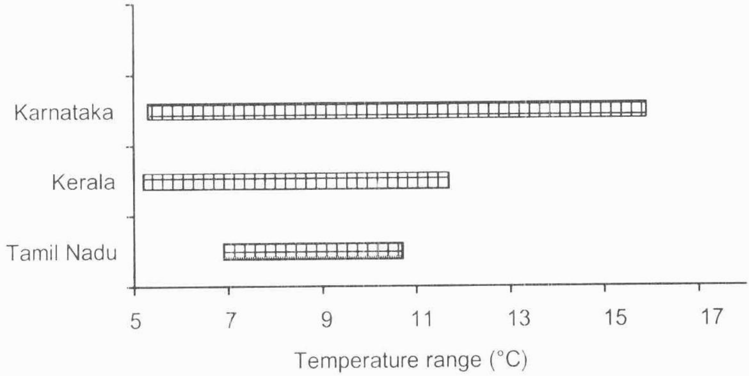


**Fig 4.8 Temperature range (°C) across the cardamom tract of the Western Ghats**

the State of Tamil Nadu also under a favourable environment in terms of surface air temperature.

### 4.2.7 Trends in annual maximum temperature

The highest maximum temperature was recorded in 1983 and 1985 (25.4 °C) while the lowest in 1990 (23.5°C) at Pampadumpara. A decrease of 0.5 °C in 25 years was noticed during the period from 1978 to 2002. The highest maximum temperature was recorded in 1998 (27.7 °C) while the lowest in 1986 and 1994 (26.9°C) at Ambalavayal. An increase of 0.2 °C in 19 years was noticed during the period from 1984 to 2002.

At Madikeri, the highest maximum temperature was observed in 1995, 1996 and 2002 (27.9°C) while the lowest in 1986 (26.7 °C). An increase of 0.9° C in 17 years was noticed during the period from 1986 to 2002 (Table 4.10).

**Table 4.10 Spatial occurrence of maximum temperature extremes in different seasons across the cardamom tract of the Western Ghats**

| Location | ANNUAL | | SWM | | PM | | WINTER | | SUMMER | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min |
| Pampadumpara | 25.4 (1983,1985) | 23.5 (1990) | 23.8 (2002) | 21.6 (1990) | 25.3 (1985) | 22.4 (1993) | 25.9 (1995) | 23.0 (1993,1994) | 29.9 (1983) | 26.2 (1999) |
| Ambalavayal | 27.7 (1998) | 26.9 (1986,1994) | 25.7 (1997, 1999) | 24.5 (1989) | 27.3 (1984) | 25.7 (1989,1992) | 28.6 (1985) | 26.7 (1997) | 31.3 (1998) | 29.1 (1994) |
| Madikeri | 27.9 (1995,1996, 2002) | 26.7 (1986) | 25.3 (1995) | 23.6 (1989) | 27.8 (2000) | 25.7 (1992) | 29.0 (2000) | 27.3 (1987) | 31.8 (1996) | 30.0 (1986) |
| Saklespur | 30.8 (1995) | 29.3 (2000) | 26.7 (1995) | 25.2 (2001,2002) | 31.3 (1997) | 28.8 (1998) | 33.1 (1995) | 30.7 (2000) | 34.2 (1992) | 33.0 (2002) |
| Mudigere | 27.9 (1993) | 26.2 (1979) | 25.2 (1993) | 22.4 (1981,1984) | 27.9 (1997) | 25.1 (1974,1979, 1985) | 29.4 (1991) | 26.6 (1987) | 32.1 (1992) | 29.7 (1997) |
| Thandikudi | 24.6 (2000) | 23.6 (1993) | 26.7 (2000) | 23.9 (1993) | 24.1 (1996) | 21.6 (2001) | 22.3 (2001) | 19.8 (2002) | 27.3 (2001) | 25.1 (2000) |

At Saklespur, the highest maximum temperature was observed in 1995 (30.8 °C) while the lowest in 2000 (29.3 °C). A decrease of 1.1 ° C in 11 years was noticed during the period from 1992 to 2002.

The highest maximum temperature was recorded in 1993 (27.9 °C) while the lowest in 1979 (26.2°C) at Mudigere. An increase of 0.9 °C in 32/years was noticed during the period from 1971 to 2002. The highest maximum temperature was recorded in 2000 (24.6 °C) while the lowest in 1993 (23.6°C) at Thandikudi. An increase of 0.8 °C in 10 years was noticed during the period from 1993 to 2002.

Pampadumpara and Saklespur showed a declining trend (0.5 to 1.1 °C) in annual maximum temperature while increasing trend (0.2 to 0.9 °C) at all other locations viz., Ambalavayal, Madikeri, Mudigere and Thandikudi (Fig 4.9).

### 4.2.8 Trends in maximum temperature during southwest monsoon

The highest maximum temperature was recorded in 2002 (23.8 °C) while the lowest in 1990 (21.6°C) at

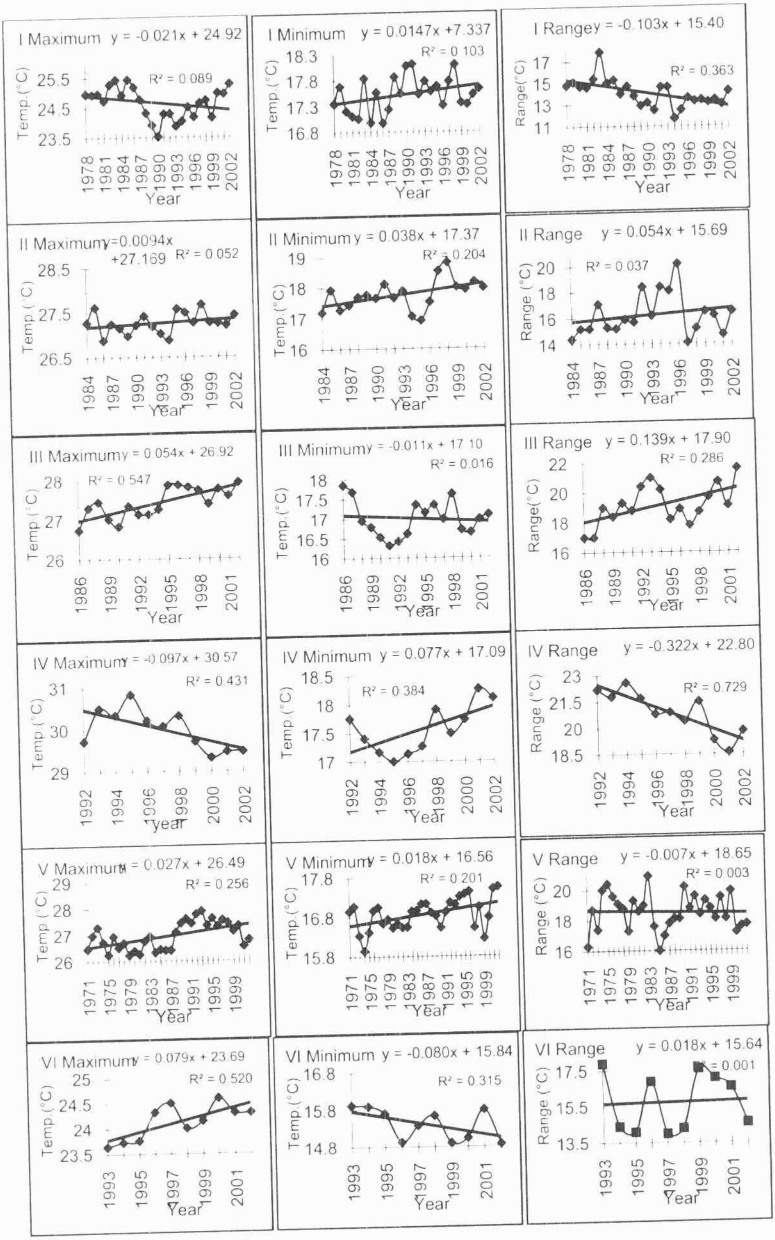


**Fig 4.9 Trends in annual temperature across the cardamom tract**

Pampadumpara. An increase of 0.2 °C in 25 years was noticed during the period from 1978 to 2002 (Table 4.10). The highest maximum temperature was recorded in 1997 and 1999 (25.7 °C) while the lowest in 1989 (24.5°C) at Ambalavayal. An increase of 0.7 °C in 19 years was noticed during the period from 1984 to 2002.

At Madikeri, the highest maximum temperature was observed in 1995 (25.3 °C) while the lowest in 1989 (23.6 °C). An increase of 0.9 ° C in 17 years was noticed during the period from 1986 to 2002. At Saklespur, the highest maximum temperature was observed in 1995 (26.7 °C) while the lowest in 2001 and 2002 (25.2 °C). A decrease of 0.5 ° C in 11 years was noticed during the period from 1992 to 2002.

The highest maximum temperature was recorded in 1993 (25.2 °C) while the lowest in 1981 and 1984 (22.4°C) at Mudigere. An increase of 1.2 °C per year was noticed during the period from 1971 to 2002. The highest maximum temperature was recorded in 2000 (26.7 °C) while the lowest in 1993 (23.9°C) at Thandikudi. An increase of 2.6 °C in 10 years was noticed during the period from 1993 to 2002.

All the locations except Saklespur showed an increasing trend (0.9 to 2.6 °C) in maximum temperature during southwest monsoon season as influenced by decrease in rainfall (Fig 4.10).

### 4.2.9 Trends in maximum temperature during post monsoon

The highest maximum temperature was recorded in 1985 (25.3 °C) while the lowest in 1993 (22.4°C) at Pampadumpara. A decrease of 0.3 °C in 25 years was noticed during the period from 1978 to 2002.

The highest maximum temperature was recorded in 1984 (27.3 °C) while the lowest in 1989 and 1992 (25.7°C) at Ambalavayal. A decrease of 0.2 °C in 19 years was noticed during the period from 1984 to 2002 (Table4.10).

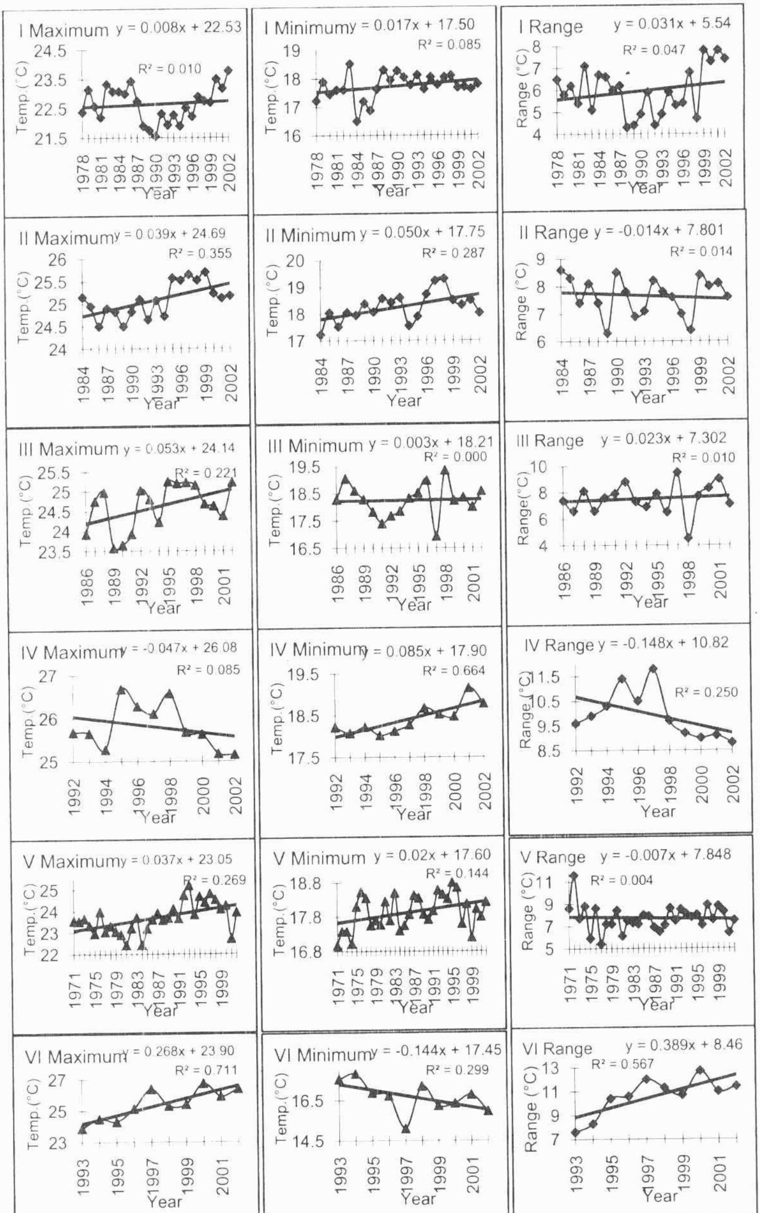


**Fig 4.10 Trends in southwest monsoon temperature across the cardamom tract**

At Madikeri, the highest maximum temperature was observed in 2000 (27.8 °C) while the lowest in 1992 (25.7 °C). An increase of 1.1 ° C in 17 years was noticed during the period from 1986 to 2002.

At Saklespur, the highest maximum temperature was observed in 1997 (31.3 °C) while the lowest in 1998 (28.8 °C). A decrease of 1.8 ° C in 11 years was noticed during the period from 1992 to 2002. The highest maximum temperature was recorded in 1997 (27.9 °C) while the lowest in 1974,1979 and 1985 (25.1°C) at Mudigere. An increase of 1 °C in 32 years was noticed during the period from 1971 to 2002.

The highest maximum temperature was recorded in 1996 (24.1 °C) while the lowest in 2001 (21.6°C) at Thandikudi. An increase of 0.9 °C in 10 years was noticed during the period from 1993 to 2002.

Pampadumpara, Ambalavayal and Saklespur showed a decreasing trend (0.2 to 1.8 °C) while increase (0.9 to 1.1 °C) over Madikeri, Mudigere and Thandikudi in maximum temperature during post monsoon season (Fig 4.11).

### 4.2.10 Trends in maximum temperature during winter

The highest maximum temperature was recorded in 1995 (25.9 °C) while the lowest in 1993 and 1994 (23.0°C) at Pampadumpara. A decrease of 0.7 °C in 24 years was noticed during the period from 1979 to 2002. The highest maximum temperature was recorded in 1985 (28.6 °C) while the lowest in 1997 (26.7°C) at Ambalavayal. A decrease of 0.4 °C in 18 years was noticed during the period from 1985 to 2002 (Table 4.10).

At Madikeri, the highest maximum temperature was observed in 2000 (29.0 °C) while the lowest in 1987 (27.3 °C). A decrease of 0.4 °C in 16 years was noticed during the period from 1987 to 2002. At Saklespur, the highest

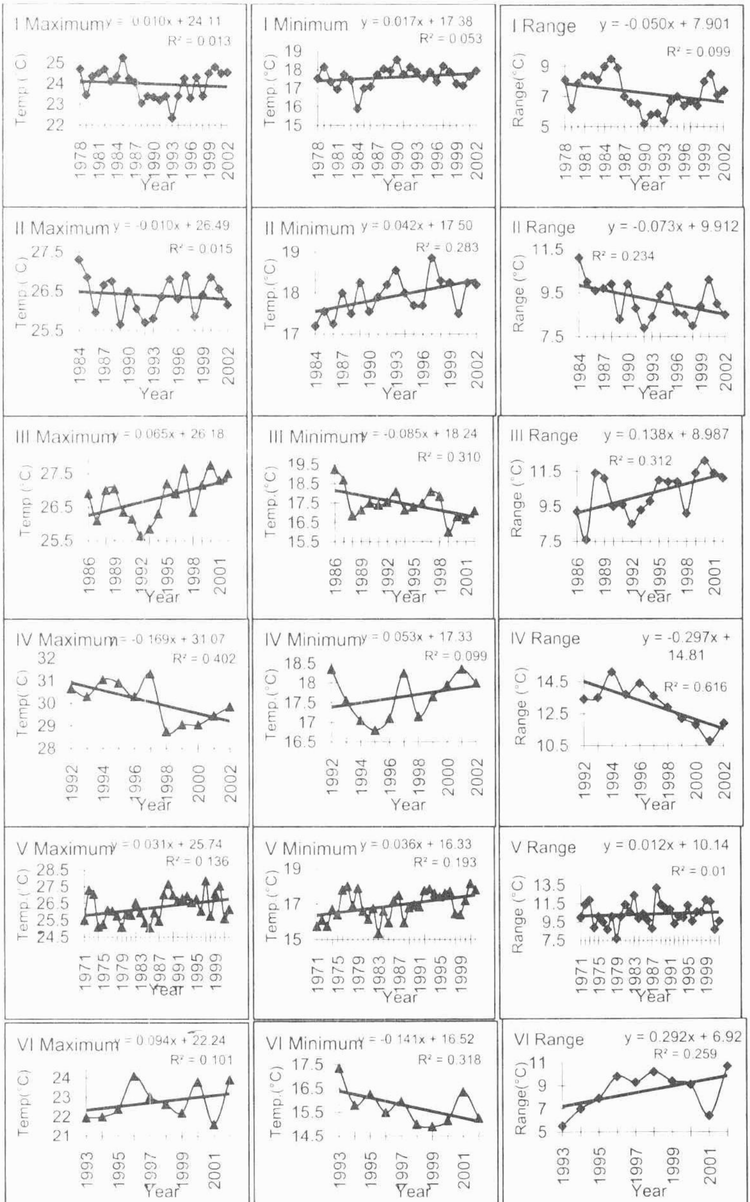


**Fig 4.11 Trends in post monsoon temperature across the cardamom tract**

maximum temperature was observed in 1995 (33.1 °C) while the lowest in 2000 (30.7 °C). A decrease of 1.6 °C in 10 years was noticed during the period from 1993 to 2002.

The highest maximum temperature was recorded in 1991 (29.4 °C) while the lowest in 1987 (26.6°C) at Mudigere. An increase of 0.8 °C in 31 years was noticed during the period from 1972 to 2002. The highest maximum temperature was recorded in 2001 (22.3 °C) while the lowest in 2002 (19.8°C) at Thandikudi. A decrease of 0.8 °C in 9 years was noticed during the period from 1994 to 2002.

All the locations except Mudigere showed a decreasing trend in maximum temperature (0.4 to 1.6 °C) during winter season (Fig 4.12).

**4.2.11 Trends in maximum temperature during summer**

The highest maximum temperature was recorded in 1983 (29.9 °C) while the lowest in 1999 (26.2°C) at Pampadumpara. A decrease of 1.6 °C in 25 years was noticed during the period from 1978 to 2002. The highest maximum temperature was recorded in 1998 (31.3 °C) while the lowest in 1994 (29.1°C) at Ambalavayal. A marginal decrease of 0.2 °C in 19 years was noticed during the period from 1984 to 2002.

At Madikeri, the highest maximum temperature was observed in 1996 (31.8 °C) while the lowest in 1986 (30.0 °C). An increase of 0.8 °C in 17 years was noticed during the period from 1986 to 2002. At Saklespur, the highest maximum temperature was observed in 1992 (34.2 °C) while the lowest in 2002 (33.0 °C). A decrease of 1.7 °C in 11 years was noticed during the period from 1992 to 2002 (Table 4.10).

The highest maximum temperature was recorded in 1992 (32.1 °C) while the lowest in 1997 (29.7°C) at Mudigere. A marginal increase of 0.4 °C in 32 years was noticed during the period from 1971 to 2002. The highest maximum

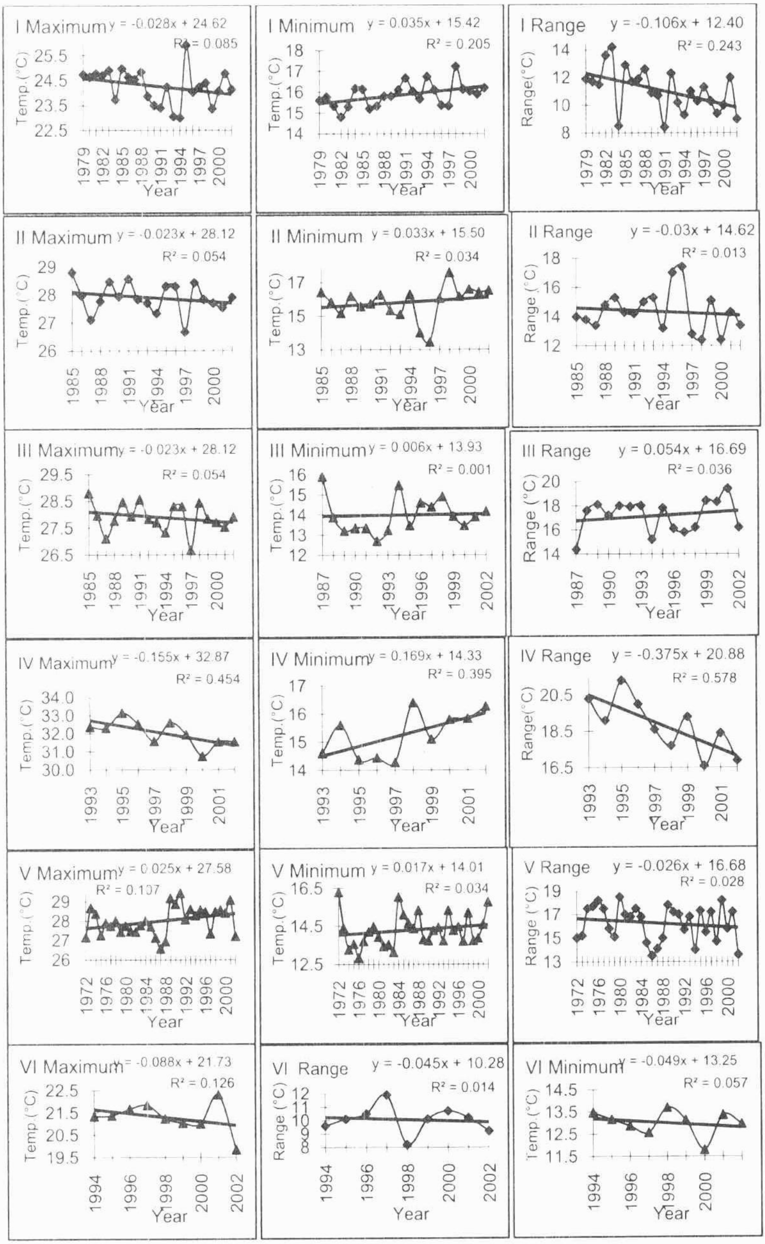


**Fig 4.12 Trends in winter temperature across the cardamom tract**

temperature was recorded in 2001 (27.3 °C) while the lowest in 2000 (25.1°C) at Thandikudi. A decrease of 0.4 °C in 10 years was noticed during the period from 1993 to 2002.

All the locations except Madikeri and Mudigere showed a decreasing trend (0.4 to 0.8 °C) in maximum temperature during summer (Fig 4.13). The unprecedented drought during summer 1983 over Kerala recorded high temperature as seen at Pampadumpara. Similarly, the highest maximum temperature at Thandikudi in 2001 was in tune with the global second warmest year after 1998, which was noticed at Ambalavayal also.

### 4.2.12 Trends in annual minimum temperature

The highest minimum temperature was recorded in 1990,1991 and 1998 (18.1 °C) while the lowest in 1984 and 1986 (17.0°C) at Pampadumpara. An increase of 0.4 °C in 25 years was noticed during the period from 1978 to 2002. The highest minimum temperature was recorded in 1998 (18.8 °C) while the lowest in 1995 (16.9°C) at Ambalavayal. An increase of 0.7 °C in 19 years was noticed during the period from 1984 to 2002 (Table 4.11).

At Madikeri, the highest minimum temperature was observed in 1986 (17.9 °C) while the lowest in 1991 (16.3 °C). A decrease of 0.2 ° C in 17 years was noticed during the period from 1986 to 2002. At Saklespur, the highest minimum temperature was observed in 2001 (18.3 °C) while the lowest in 1995 (17.0 °C). An increase of 0.8 ° C in 11 years was noticed during the period from 1992 to 2002.

The highest minimum temperature was recorded in 2001 and 2002 (17.5 °C) while the lowest in 1974 (15.9°C) at Mudigere. An increase of 0.6 °C in 32 years was noticed during the period from 1971 to 2002. The highest minimum temperature was recorded in 1993 and 1994 (15.9 °C) while the lowest in 1996,1999 and 2002 (14.9°C) at Thandikudi.

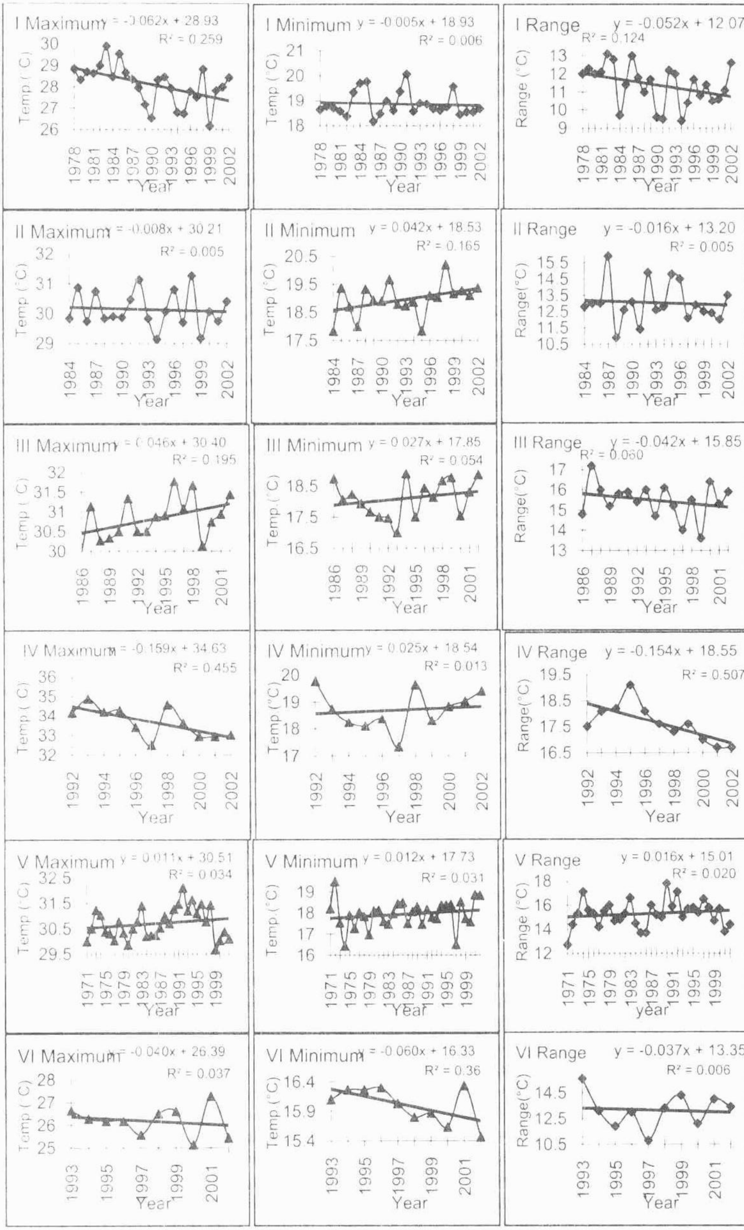


Fig 4.13 Trends in summer temperature across the cardamom tract

**Table 4.11 Spatial occurrence of minimum temperature extremes in different seasons across the cardamom tract of the Western Ghats**

| Location | ANNUAL | | SWM | | PM | | WINTER | | SUMMER | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min |
| Pampadumpara | 18.1 (1990,1991, 1998) | 17.0 (1984,1986) | 18.5 (1983) | 16.5 (1984) | 18.6 (1990) | 15.9 (1984) | 17.2 (1998) | 14.8 (1982) | 20.1 (1991) | 18.2 (1986) |
| Ambalavayal | 18.8 (1998) | 16.9 (1995) | 19.3 (1998) | 17.2 (1984) | 18.9 (1997) | 17.2 (1984) | 17.6 (1998) | 13.4 (1996) | 20.2 (1998) | 17.8 (1984,1995) |
| Madikeri | 17.9 (1986) | 16.3 (1991) | 19.4 (1994) | 16.9 (1997) | 19.3 (1986) | 16.0 (1999) | 15.9 (1987) | 12.7 (1992) | 18.9 (1994,2002) | 17.0 (1993) |
| Saklespur | 18.3 (2001) | 17.0 (1995) | 19.2 (2001) | 18.0 (1995) | 18.4 (1992,2001) | 16.8 (1995) | 16.4 (1998) | 14.3 (1997) | 19.8 (1992) | 17.3 (1997) |
| Mudigere | 17.5 (2001,2002) | 15.9 (1974) | 18.8 (1995) | 17.0 (1991) | 18.2 (2001) | 15.4 (1983) | 16.3 (1972) | 12.8 (1976) | 19.5 (1972) | 16.4 (1974) |
| Thandikudi | 15.9 (1993,1994) | 14.9 (1996,1999, 2002) | 17.8 (1994) | 15.1 (1997) | 17.4 (1993) | 14.9 (1999) | 13.7 (1998) | 11.8 (2000) | 16.3 (1994) | 15.5 (2002) |

A decrease of 0.8 °C in 10 years was noticed during the period from 1993 to 2002.

Madikeri and Thandikudi showed a declining trend (0.2 to 0.8 °C) in annual minimum temperature while increasing trend (0.4 to 0.8 °C) at other four locations viz., Pampad umpara, Ambalavayal, Saklespur and Mudigere (Fig 4.9).

### 4.2.13 Trends in minimum temperature during southwest monsoon

The highest minimum temperature was recorded in 1983 (18.5 °C) while the lowest in 1984 (16.5°C) at Pampadu mpara. An increase of 0.4 °C in 25 years was noticedduring the period from 1978 to 2002. The highest minimum temperature was recorded in 1998 (19.3 °C) while the lowest in 1984 (17.2°C) at Ambalavayal. An increase of 0.9 °C in 19 years was noticed during the period from 1984 to 2002 (Table 4.11).

At Madikeri, the highest minimum temperature was observed in 1994 (19.4 °C) while the lowest in 1997 (16.9 °C). An increase of 0.5 °C in 17 years was noticed during the period from 1986 to 2002. At Saklespur, the highest minimum temperature was observed in 2001 (19.2 °C) while the lowest in 1995 (18.0 °C). An increase of 0.9 °C in 11 years was noticed during the period from 1992 to 2002.

The highest minimum temperature was recorded in 1995 (18.8 °C) while the lowest in 1971 and 1974 (17.0°C) at Mudigere. A marginal increase of 0.6 °C in 32 years was noticed during the period from 1971 to 2002. The highest minimum temperature was recorded in 1994 (17.8 °C) while the lowest in 1997 (15.1°C) at Thandikudi. A decrease of 1.4 °C in 10 years was noticed during the period from 1993 to 2002.

All the locations except Thandikudi showed an increasing trend (0.4 to 0.9 °C) in minimum temperature during the southwest monsoon season (Fig 4.10).

### 4.2.14 Trends in minimum temperature during post monsoon

The highest minimum temperature was recorded in 1990 (18.6 °C) while the lowest in 1984 (15.9°C) at Pampadumpara. An increase of 0.4 °C in 25 years was noticed during the period from 1978 to 2002. The highest minimum temperature was recorded in 1997 (18.9 °C) while the lowest in 1984 (17.2°C) at Ambalavayal. An increase of 0.8 °C in 19 years was noticed during the period from 1984 to 2002.

At Madikeri, the highest minimum temperature was observed in 1986 (19.3 °C) while the lowest in 1999 (16.0 °C). A decrease of 1.4 °C in 17 years was noticed during the period from 1986 to 2002 (Table 4.11). At Saklespur, the highest minimum temperature was observed in 1992 and 2001 (18.4 °C) while the lowest in 1995 (16.8 °C). An increase of 0.6 °C in 11 years was noticed during the period from 1992 to 2002.

The highest minimum temperature was recorded in 2001 (18.2 °C) while the lowest in 1983 (15.4°C) at Mudigere. An increase of 1.2 °C in 32 years was noticed during the period from 1971 to 2002. The highest minimum temperature was recorded in 1993 (17.4 °C) while the lowest in 1999 (14.9°C) at Thandikudi. A decrease of 1.4 °C in 10 years was noticed during the period from 1993 to 2002.

All the locations except Madikeri and Thandikudi showed an increasing trend (0.4 to 1.2 °C) in minimum temperature during the post monsoon season (Fig 4.11).

**4.2.15 Trends in minimum temperature during winter**

The highest minimum temperature was recorded in 1998 (17.2 °C) while the lowest in 1982 (14.8°C) at Pampadumpara. An increase of 0.8 °C in 34 years was noticed during the period from 1979 to 2002. The highest minimum temperature was recorded in 1998 (17.6 °C) while the lowest in 1996 (13.4°C) at Ambalavayal. An increase of 0.6 °C in 18 years was noticed during the period from 1985 to 2002.

At Madikeri, the highest minimum temperature was observed in 1987 (15.9 °C) while the lowest in 1992 (12.7 °C). An increase of 0.1 °C in 16 years was noticed during the period from 1987 to 2002 (Table 4.11). At Saklespur, the highest minimum temperature was observed in 1998 (16.4 °C) while the lowest in 1997 (14.3 °C). An increase of 1.8 °C in 11 years was noticed during the period from 1993 to 2002.

The highest minimum temperature was recorded in 1972 (16.3 °C) while the lowest in 1976 (12.8°C) at Mudigere. An increase of 0.5 °C in 31 years was noticed during the period from 1972 to 2002. The highest minimum temperature was recorded in 1998 (13.7 °C) while the lowest in 2000 (11.8°C) at Thandikudi. A decrease of 0.5 °C in 9 years was noticed during the period from 1994 to 2002.

All the locations except Thandikudi showed an increasing trend (0.1 to 1.8 °C) in minimum temperature during winter season (Fig 4.12). Out of six locations, four locations recorded the highest minimum in 1998, which was the global warm year.

### 4.2.16 Trends in minimum temperature during summer

The highest minimum temperature was recorded in 1991 (20.1 °C) while the lowest in 1986 (18.2°C) at Pampadumpara. A decrease of 0.1 °C in 25 years was noticed during the period from 1978 to 2002. The highest minimum temperature was recorded in 1998 (20.2 °C) while the lowest in 1984 and 1995 (17.8°C) at Ambalavayal. An increase of 0.8 °C in 19 years was noticed during the period from 1984 to 2002.

At Madikeri, the highest minimum temperature was observed in 1994 and 2002 (18.9 °C) while the lowest in 1993 (17.0 °C). An increase of 0.5 °C in 17 years was noticed during the period from 1986 to 2002 (Table 4.11). At Saklespur, the highest minimum temperature was observed in 1992 (19.8 °C) while the lowest in 1997 (17.3 °C). An increase of 0.3 °C in 11 years was noticed during the period from 1992 to 2002.

The highest minimum temperature was recorded in 1972 (19.5 °C) while the lowest in 1974 (16.4°C) at Mudigere. An increase of 0.4 °C in 32 years was noticed during the period from 1971 to 2002. The highest minimum temperature was recorded in 1994 (16.3 °C) while the lowest in 2002 (15.5°C) at Thandikudi. A decrease of 0.6 °C in 10 years was noticed during the period from 1993 to 2002.

All the locations except Pampadumpara and Thandikudi showed an increasing trend (0.3 to 0.8 °C) in minimum temperature during summer (Fig 4.13).

Increase in surface maximum and minimum temperature was phenomenal at Pampadumpara since 1990 onwards irrespective of seasons. It was true in case of minimum temperature at Ambalavayal while such trend is only evident in annual as well as southwest monsoon in case of maximum temperature. In contrast, the minimum temperature showed a declining trend at Thandikudi though increase in maximum temperature was noticed except during winter and summer seasons. The maximum temperature at Madikeri recorded an increasing trend in all the seasons except in winter while such trend was not seen in case of minimum temperature. At the same time, it is quite interesting to note that increase in minimum temperature while decrease in maximum temperature was noticed in all the seasons at Saklespur. At Mudigere, both maximum and minimum temperature showed an increasing trend.

### 4.2.17 Trends in annual temperature range

The highest range in temperature was recorded in 1983 (17.9 °C) while the lowest in 1994 (11.7°C) at Pampadumpara. A decrease of 2.6 °C in 25 years was noticed during the period from 1978 to 2002. The highest range in temperature was recorded in 1996 (20.2 °C) while the lowest in 1997 (14.1 °C) at Ambalavayal. An increase of 1.0 °C in 19 years was noticed during the period from 1984 to 2002 (Table 4.12).

At Madikeri, the highest range in temperature was observed in 2002 (21.6 °C) while the lowest in 1986 and 1987 (17.0 °C). An increase of 2.4 ° C in 17 years was noticed during the period from 1986 to 2002. At Saklespur, the highest range in temperature was observed in 1994 (22.6 °C) while the lowest in 2001 (18.6 °C). A decrease of 3.6 ° C in 11 years was noticed during the period from 1992 to 2002.

The highest range in temperature was recorded in 1983 (20.9 °C) while the lowest in 1985 (16.0 °C) at Mudigere. A decrease of 0.4 °C in 32 years was noticed during the period from 1971 to 2002. The highest range in temperature was recorded in 1993 (17.9 °C) while the lowest in 1997 (14.0 °C) at Thandikudi. An increase of 0.2 °C in 10 years was noticed during the period from 1993 to 2002.

Ambalavayal, Madikeri and Thandikudi showed an increasing trend (0.2 to 2.4 °C) in annual temperature range while decreasing trend (0.4 to 3.6 °C) at other locations viz., Pampadumpara, Saklespur and Mudigere (Fig 4.9).

**4.2.18 Trends in temperature range during southwest monsoon**

The highest range in temperature was recorded in 1999, 2001 (7.8 °C) while the lowest in 1988 (4.3 °C) at Pampadumpara. An increase of 0.8 °C in 25 years was noticed during the period from 1978 to 2002. The highest range in temperature was recorded in 1984 (8.6 °C) while the lowest in 1989 (6.3 °C) at Ambalavayal. A decrease of 0.3 °C in 19 years was noticed during the period from 1984 to 2002 (Table 4.12).

At Madikeri, the highest range in temperature was observed in 1997 (9.5 °C) while the lowest in 1998 (4.5 °C). An increase of 0.4 ° C in 17 years was noticed during the period from 1986 to 2002. At Saklespur, the highest range in temperature was observed in 1997 (11.8 °C) while the lowest in 2002 (8.8 °C). A decrease of 1.6 ° C in 11 years was noticed during the period from 1992 to 2002.

The highest range in temperature was recorded in 1972 (11.6 °C) while the lowest in 1977 (5.4 °C) at Mudigere. A decrease of 0.3 °C in 32 years was noticed during the period from 1971 to 2002. The highest range in temperature was recorded in 2000 (12.7 °C) while the lowest in 1993 (7.6 °C) at Thandikudi. An increase of 3.9 °C in 10 years was noticed during the period from 1993 to 2002.

Pampadumpara, Madikeri, and Thandikudi showed an increasing trend (0.4 to 3.9 °C) in temperature range during

Table 4.12 Spatial occurrence of temperature range extremes in different seasons across the cardamom tract of the Western Ghats

| Location | ANNUAL | | SWM | | PM | | WINTER | | SUMMER | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Max | Min | Max | Min | Max | Min | Max | Min | Max | Min |
| Pampadumpara | 17.9 (1983) | 11.7 (1994) | 7.8 (1999,2001) | 4.3 (1988) | 9.5 (1985) | 5.2 (1990) | 14.2 (1983) | 8.4 (1991) | 13.1 (1982) | 9.4 (1994) |
| Ambalavayal | 20.2 (1996) | 14.1 (1997) | 8.6 (1984) | 6.3 (1989) | 11.1 (1984) | 7.9 (1992) | 17.4 (1996) | 12.4 (1998,2000) | 15.9 (1987) | 10.9 (1988) |
| Madikeri | 21.6 (2002) | 17.0 (1986,1987) | 9.5 (1997) | 4.5 (1998) | 12.1 (2000) | 7.6 (1987) | 19.4 (2001) | 14.4 (1987) | 17.2 (1987) | 13.6 (1999) |
| Saklespur | 22.6 (1994) | 18.6 (2001) | 11.8 (1997) | 8.8 (2002) | 15.1 (1994) | 10.8 (2001) | 21.3 (1995) | 16.6 (2000) | 19.1 (1995) | 16.7 (2001,2002) |
| Mudigere | 20.9 (1983) | 16.0 (1985) | 11.6 (1972) | 5.4 (1977) | 13.2 (1988) | 7.7 (1979) | 18.5 (1980) | 13.5 (1986) | 17.8 (1990) | 12.7 (1971) |
| Thandikudi | 17.9 (1993) | 14.0 (1997) | 12.7 (2000) | 7.6 (1993) | 10.7 (2002) | 5.5 (1993) | 11.9 (1997) | 8.2 (1998) | 15.6 (1993) | 10.8 (1997) |

southwest monsoon while decreasing trend (0.3 to 1.6 °C) at other locations viz., Ambalavayal, Saklespur and Mudigere (Fig 4.10).

### 4.2.19 Trends in temperature range during post monsoon

The highest range in temperature was recorded in 1985 (9.5 °C) while the lowest in 1990 (5.2 °C) at Pampadumpara. A decrease of 1.3 °C in 25 years was noticed during the period from 1978 to 2002. The highest range in temperature was recorded in 1984 (11.1 °C) while the lowest in 1992 (7.9 °C) at Ambalavayal. A decrease of 1.4 °C in 19 years was noticed during the period from 1984 to 2002.

At Madikeri, the highest range in temperature was observed in 2000 (12.1 °C) while the lowest in 1987 (7.6 °C). An increase of 1.5 ° C in 17 years was noticed during the period from 1986 to 2002 (Table 4.12). At Saklespur, the highest range in temperature was observed in 1994 (15.1 °C) while the lowest in 2001 (10.8 °C). A decrease of 3.3 ° C in 11 years was noticed during the period from 1992 to 2002.

The highest range in temperature was recorded in 1988 (13.2 °C) while the lowest in 1979 (7.7 °C) at Mudigere. A decrease of 0.4 °C in 32 years was noticed during the period from 1971 to 2002. The highest range in temperature was recorded in 2002 (10.7 °C) while the lowest in 1993 (5.5 °C) at Thandikudi. An increase of 2.9 °C in 10 years was noticed during the period from 1993 to 2002.

All the locations except Madikeri, Mudigere and Thandikudi showed a decreasing trend (1.3 to 3.3 °C) in temperature range during post monsoon (Fig 4.11).

### 4.2.20 Trends in temperature range during winter

The highest range in temperature was recorded in 1983 (14.2 °C) while the lowest in 1991 (8.4 °C) at Pampadumpara. A decrease of 2.6 °C in 24 years was noticed during the period from 1979 to 2002. The highest range in temperature was recorded in 1996 (17.4 °C) while the lowest in 1998 and 2000 (12.4 °C) at Ambalavayal. A decrease of 0.5 °C in 18 years was noticed during the period from 1985 to 2002.

At Madikeri, the highest range in temperature was observed in 2001 (19.4 °C) while the lowest in 1987 (14.4 °C). An increase of 0.9 ° C in 16 years was noticed during the period from 1987 to 2002 (Table 4.12). At Saklespur, the highest range in temperature was observed in 1995 (21.3 °C) while the lowest in 2000 (16.6 °C). A decrease of 3.8 ° C in 10 years was noticed during the period from 1993 to 2002.

The highest range in temperature was recorded in 1980 (18.5 °C) while the lowest in 1986 (13.5 °C) at Mudigere. A decrease of 0.8 °C in 31 years was noticed during the period from 1972 to 2002. The highest range in temperature was recorded in 1997 (11.9 °C) while the lowest in 1998 (8.2 °C) at Thandikudi. A decrease of 0.4 °C in 9 years was noticed during the period from 1993 to 2002.

All the locations except Madikeri showed a decreasing trend (0.4 to 3.8 °C) in temperature range during winter (Fig 4.12).

**4.2.21 Trends in temperature range during summer**

The highest range in temperature was recorded in 1982 (13.1 °C) while the lowest in 1994 (9.4 °C) at Pampadumpara. A decrease of 1.3 °C in 25 years was noticed during the period from 1978 to 2002. The highest range in temperature was recorded in 1987 (15.9 °C) while the lowest in 1988 (10.9 °C) at Ambalavayal. A decrease of 0.3 °C in 19 years was noticed during the period from 1984 to 2002.

At Madikeri, the highest range in temperature was observed in 1987 (17.2 °C) while the lowest in 1999 (13.6 °C). A decrease of 0.7 ° C in 17 years was noticed during the period from 1986 to 2002 (Table 4.12). At Saklespur, the highest range in temperature was observed in 1995 (19.1 °C) while the lowest in 2001 and 2002 (16.7 °C). A decrease of 1.7 ° C in 11 years was noticed during the period from 1992 to 2002.

The highest range in temperature was recorded in 1990 (17.8 °C) while the lowest in 1971 (12.7 °C) at Mudigere. An increase of 0.5 °C in 32 years was noticed during the period from 1971 to 2002. The highest range in temperature was recorded in 1993 (15.6 °C) while the lowest in 1997 (10.8 °C) at Thandikudi. A decrease of 0.4 °C in 10 years was noticed during the period from 1993 to 2002.

All the locations except Mudigere showed a decreasing trend (0.3 to 1.7 °C) in temperature range during summer season (Fig 4.13).

The range in temperature at Pampadumpara and Ambalavayal showed a declining trend in all the seasons except in southwest monsoon in former and annual in later. In contrast, the temperature range showed an increasing trend in all the seasons except in summer at Madikeri while declining trend at Saklespur irrespective of seasons and at Mudigere, increasing trend was noticed only in post monsoon and summer seasons. Thandikudi witnessed increasing trend in annual, southwest and post monsoon seasons while declining trend is seen in winter and summer.

## 4.3 TRENDS IN MOISTURE INDEX (Im)

The Im at Pampadumpara showed a declining trend on annual basis and during southwest monsoon, while increasing during post monsoon, winter and summer seasons. In the case of Ambalavayal, the same trend was noticed except summer during which Im was at declining trend. At Mudigere also similar trend was noticed as in case of Pampadumpara, except during summer. The trend at Saklespur was similar to that of Mudigere. In contrast, the Im at Madikeri was in increasing trend during southwest monsoon and annual basis unlike Mudigere and Saklespur. At Thandikudi, the Im was in declining trend except during winter. The decline was significant during summer.

The study revealed that the Im declined at all the locations during southwest monsoon and an annual basis except at Madikeri (Fig 4.14a & 4.14b). During post monsoon and winter, an increasing trend in moisture index was noticed at all the locations except Thandikudi in post monsoon period. All the locations except at Pampadumpara, showed a declining trend in moisture index during summer. However, the climatic type at all the station fall under the per-humid only, since the index was always above 100 per cent. Though, all the stations fall under per humid, the climate scenario is different when we consider the changes on seasonal basis. It is evident during winter and summer (December to May) as all the stations experience dry sub humid to arid climates. Interestingly, Thandikudi experienced dry sub-humid to semi-arid from humid climate.

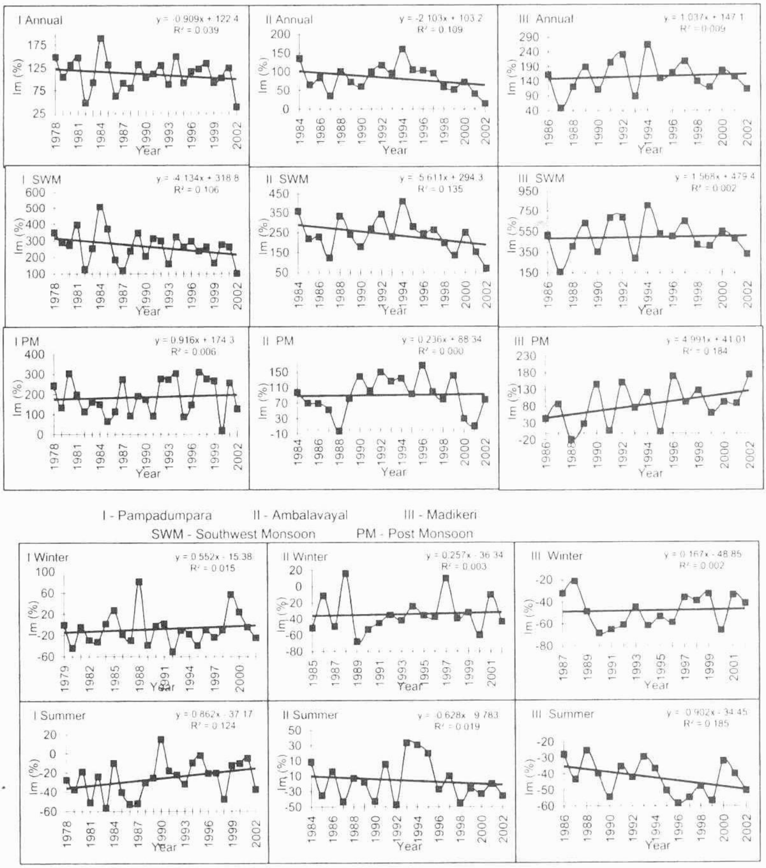


**Fig 4.14a Trends in moisture index (Im) across the cardamom tract over the Western Ghats**

The same was true at all the locations during summer and the intensity of aridity was high towards north of cardamom tract across the Western Ghats.

## 4.4 LENGTH OF CROP GROWING SEASON ACROSS THE CARDAMOM TRACT

The duration of humid period (P > PE) is high (226 days) at Thandikudi, Ambalavayal (224 days) and Pampadumpara (211 days), followed by Madikeri (184 days), Mudigere (181 days) and low at Saklespur (170 days).

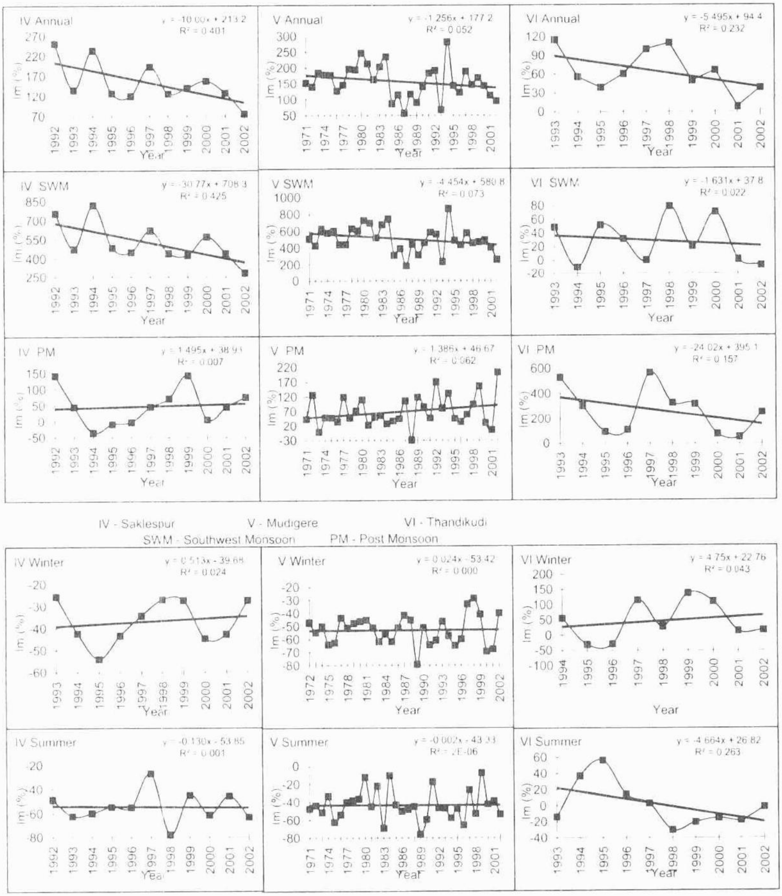


**Fig 4.14b Trends in moisture index (Im) across the cardamom tract over the Western Ghats**

Also, the number of moist days (humid period plus sub humid period) is higher (327 days) at Thandikudi, followed by Pampadumpara (274 days) and Ambalavayal (265 days) and Saklespur recorded the least (223 days). It revealed that Tamil Nadu records the highest number of moist days, followed by Kerala and the least over Karnataka across the cardamom tract of the Western Ghats (Table 4.13). Influence of both the monsoons reflects in high number of moist days over Tamil Nadu.

The commencement of humid period is earlier (4 th April) at Thandikudi and Ambalavayal (12 th April) and late at Saklespur (May 23). However, intermittent humid periods are noticed at Thandikudi unlike at other locations across the cardamom tract of Western Ghats. This could be explained as vagaries in southwest monsoon over Tamil Nadu. Interestingly, no dry period (PET/4 > P > PET/8) is noticed at Thandikudi as well as at Pampadumpara (Fig 4.15). At the same time, the dry period is noticed towards north of cardamom tract (Ambalavayal, Madikeri, Saklespur and Mudigere) from December to March. The cardamom tract over Karnataka not only experienced dry period but also very dry period (P < PET/ 8). The duration of very dry period is maximum at Saklespur.

**Table 4.13 Duration of water availability periods at different locations across the cardamom tract of the Western Ghats**

| State | Location | Sub humid period (PET > P > PET/2) | Humid period (P > PET) | Sub humid period (PET > P > PET/2) | Number of moist days |
|---|---|---|---|---|---|
| Kerala | Pampadumpara | April2-May15 (44) | May16-Dec12 (211) | Dec 13-Dec 31 (19) | 274 |
| | Ambalavayal | March22-April11 (21) | April 12-Nov21 (224) | Nov22-Dec11 (20) | 265 |
| Karnataka | Madikeri | April 10-May11 (32) | May 12-Nov11 (184) | Nov12-Dec2 (21) | 237 |
| | Saklespur | April 18-May 22 (35) | May 23-Nov 8 (170) | Nov 9 –Nov 26 (18) | 223 |
| | Mudigere | April 11-May11 (31) | May 12-Nov 8 (181) | Nov 9 –Nov 26 (18) | 230 |
| Tamil Nadu | Thandikudi | Jan 25-March 6 (41) March21-April 3 (14) | April4-June3 (61) July20-Dec31 (165) | June 4-July 19 (46) | 327 |

It revealed that the cardamom plantation towards south (Thandikudi and Pampadumpara) experience no dry period unlike in north of the cardamom tract across the Western Ghats.

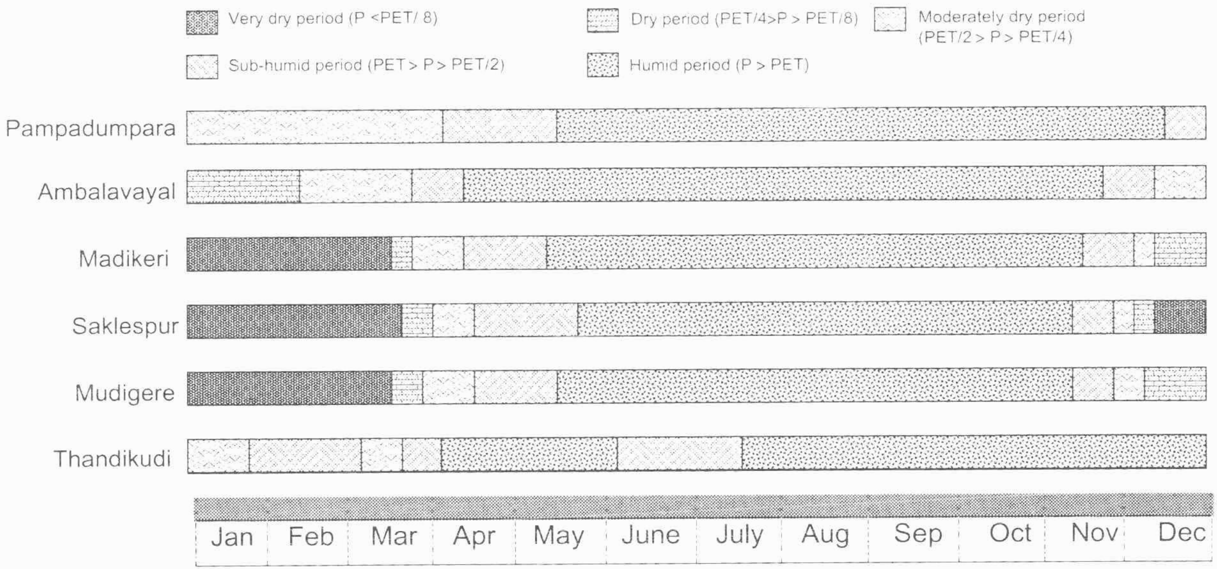


Fig 4.15 Water availability calendar for different stations in cardamom tract of the Western Ghats

## 4.5 WATER BALANCE

The term water balance refers to the climatic balance obtained by comparing the precipitation as input with evapotranspiration as output, soil being medium for storing water during periods of excess precipitation and utilizing during periods of deficient precipitation. In the tropics, precipitation is the main source for moisture to crops. It shows relatively wide variations when compared to surface air temperature. The availability of water in right quantity at the right time and its management with suitable agronomic practices are essential for better plant growth and yield. Hence, the water balance elements viz., Precipitation (P), Potential evapotranspiration (PE), Actual evapotranspiration (AE), Water surplus (WS), Water deficit (WD) and also the water balance indices such as humidity index (Ih), aridity index (Ia) and the Index of Moisture Adequacy (Ima) of six representative stations across the Western Ghats on an annual basis were worked to understand the water balance of the cardamom tract across the Western Ghats.

The potential evapotranspiration is maximum at Saklespur (1235 mm) and low at Thandikudi (905 mm), followed by Pampadumpara (982 mm). The potential evapotranspiration is intermediary (1092 mm) over Ambalavayal, Madikeri (1072 mm) and Mudigere (1022 mm). The annual water deficit is comparatively low at Thandikudi (90 mm), followed by Pampadumpara (141 mm). It is maximum at Saklespur (424 mm). Madikeri and Mudigere recorded 258 mm and 269 mm respectively. It revealed that the cardamom plantations over Saklespur experienced more water deficit when compared to other locations while least at Thandikudi. The Ima also revealed that the available moisture is relatively low (65.7 %) at Saklespur when compared to that of other locations (Table

4.14). It is high (90.1 %) at Thandikudi, followed by Pampadumpara (85.6 %).

## 4.6 NUTRITIONAL STATUS OF CARDAMOM SOILS ACROSS THE WESTERN GHATS

Table 4.14 Annual water balance parameters for different locations across the cardamom tract of the Western Ghats

| Stations | P (mm) | PE (mm) | AE (mm) | WD (mm) | WS (mm) | Ima (%) |
|---|---|---|---|---|---|---|
| Pampadumpara | 1918 | 982 | 841 | 141 | 1077 | 85.6 |
| Ambalavayal | 1916 | 1092 | 907 | 185 | 1009 | 83.1 |
| Madikeri | 2566 | 1072 | 814 | 258 | 1752 | 75.9 |
| Saklespur | 2608 | 1235 | 811 | 424 | 1797 | 65.7 |
| Mudigere | 2338 | 1022 | 753 | 269 | 1635 | 73.7 |
| Thandikudi | 1414 | 905 | 815 | 90 | 599 | 90.1 |

The soil reaction, $P^H$ is relatively same ranging from 5.6 to 5.8 across the western parts of the Western Ghats (Table 4.15). The soils of the eastern parts of the Western Ghats (Thandikudi) possessed relatively high $P^H$ (6.3). The low $P^H$ across the western parts of the Western Ghats is due to the result of the high amount and intensity of rainfall, which leads to leaching of bases from the soils.

The organic carbon content of soil is high over Ambalavayal (2.9 %), followed by Thandikudi (2.8 %) and Pampadumpara and Madikeri (2.6 %). Mudigere soils having 1.1 per cent organic carbon and soils over Saklespur records the lowest amount of organic carbon (1.0 %).

The total nitrogen content in the soil is high over Ambalavayal (6428.8 $kgha^{-1}$), followed by Thandikudi (6160 $kgha^{-1}$). The soils over Pampadumpara are having the total nitrogen content of 5756.8 kg $ha^{-1}$ and it is almost on par

**Table 4.15 Nutritional status of cardamom soils across the Western Ghats**

| Location | pH | OC (%) | Total Nitrogen ($kgha^{-1}$) | Available Phosphorous ($kgha^{-1}$) | Available Potassium ($kgha^{-1}$) |
|---|---|---|---|---|---|
| Pampadumpara | 5.6 | 2.57 | 5756.8 | 33.0 | 258.0 |
| Ambalavayal | 5.7 | 2.87 | 6428.8 | 72.0 | 492.8 |
| Madikeri | 5.6 | 2.55 | 5712.0 | 110.0 | 398.7 |
| Saklespur | 5.7 | 0.98 | 2195.2 | 16.0 | 235.0 |
| Mudigere | 5.8 | 1.12 | 2509.0 | 12.0 | 224.0 |
| Thandikudi | 6.3 | 2.75 | 6160.0 | 9.0 | 336.0 |

with the soils over Madikeri (5712 $kgha^{-1}$). The Mudigere soils having low total nitrogen content when compared to other locations and Saklespur soils witnessed for the lowest amount of total nitrogen content (2195.2 $kgha^{-1}$).

The available phosphorous is high over Madikeri (110 $kgha^{-1}$), followed by Ambalavayal (72 $kgha^{-1}$). The soils over Thandikudi (Tamil Nadu) had the lowest available phosphorous (9 $kgha^{-1}$), followed by Mudigere (12 $kgha^{-1}$), Saklespur (16 $kgha^{-1}$) and Pampadumpara (33 $kgha^{-1}$).

The available potassium is seen high over Ambalavayal (493 $kgha^{-1}$), followed by Madikeri (399 $kgha^{-1}$) and Thandikudi (336 $kgha^{-1}$). The soils over Mudigere having the lowest available potassium (224 $kgha^{-1}$). It is intermediary over Pampadumpara (258 $kgha^{-1}$) and Saklespur (235 $kgha^{-1}$).

The soils in the south across the cardamom tract relatively rich in organic and nitrogen contents while low in available phosphorous and medium in available potash.

## 4.7 TRENDS IN AREA, PRODUCTION AND PRODUCTIVITY OF SMALL CARDAMOM ACROSS THE WESTERN GHATS

A sharp decline in area under cardamom was noticed over Kerala and Tamil Nadu. It is true in the case of Karnataka also in the recent years though a marginal increase was seen as a whole. A sudden decline in area of cardamom was noticed in 1989 over Kerala and Tamil Nadu while 1996 over Karnataka. Nevertheless, the production as well as productivity of small cardamom was in increasing trend over a period of time (Fig 4.16). This could be attributed to the technologies generated for sustenance of cardamom production since last three decades. However, the inter annual fluctuations in cardamom production was not uncommon due to weather aberrations. For example, the cardamom production was badly hit during 1983 due to unprecedented drought that occured during summer 1982-83 across the cardamom tract of the Western Ghats. From the print media, it is also understood that the cardamom production over Kerala in recent years was also badly hit due to dry spells that occurred during 2002 and 2003.

## 4.8 AGRO CLIMATIC ZONES OF SMALL CARDAMOM ACROSS THE WESTERN GHATS

The whole cardamom tract across the Western Ghats was delineated into three agroclimatic zones based on climate indices viz., length of crop growing seasons, available soil moisture (Ima), soil type and productivity of cardamom and presented in Table 4.16.

From the above table it is clear that the production potential of Zone I was relatively better (>200 $kgha^{-1}$) when compared to Zone II and III across the Western Ghats, where the length of crop growing season more than 300 days with annual Ima of more than 90 per cent. The annual

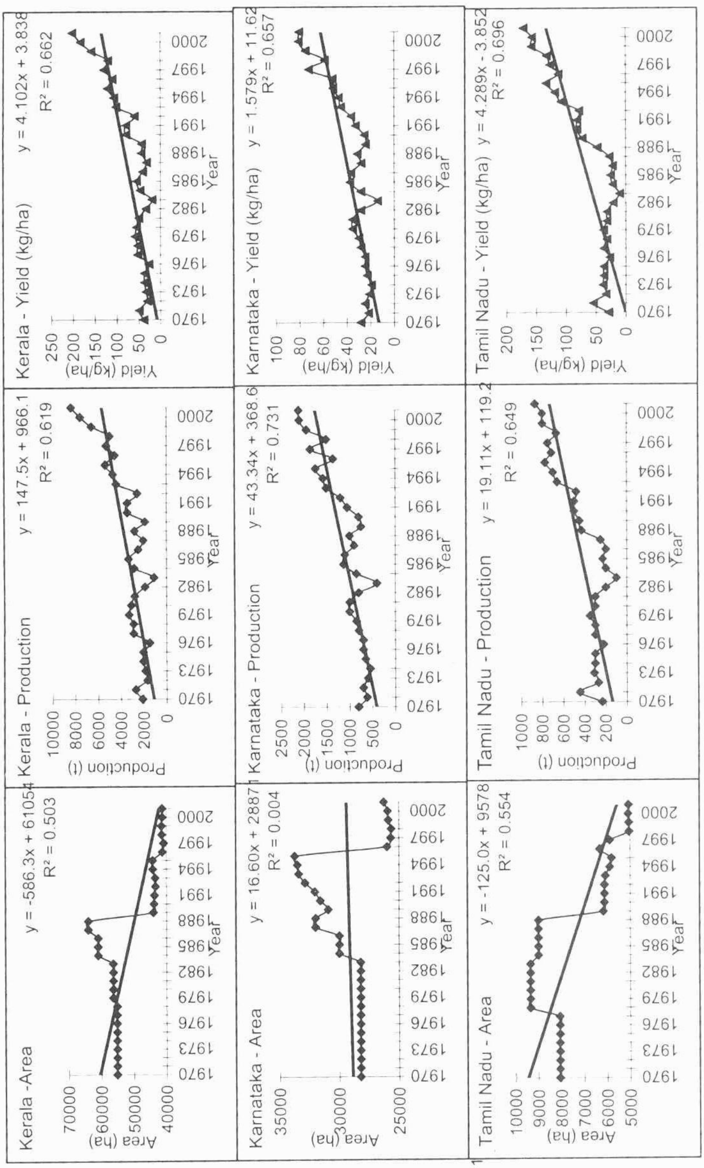


Fig 4.16 Trends in area, production and productivity of small cardamom across the Western Ghats

## Table 4.16 Agroclimatic zones of small cardamom across the Western Ghats

| Zone | Location | Soil type | Ima (%) | | Length of crop growing season | Tempera-ture range (°C) | Producti-vity ($kgha^{-1}$) |
|---|---|---|---|---|---|---|---|
| | | | Annual | Summer | | | |
| I | Vandanmettu,Ayyapan Koil,Pampadumpara,Udumbanchola, Santhanpara villages in Idukki district of Kerala (an ideal Cardamom Hill Reserve) and Sethur hills, Meghamalai, Agasthiamalai, Palani hills of Tamil Nadu. | Clay and fine loam | < 90 | 80 - 90 | 301 days | 14.1 | More than 200 |
| II | Wayanad district of Kerala and Gudallur district of Tamil Nadu (Nilgiri Biosphere) | Fine loam | 80-85 | >70 | 265 days | 15.6 | 150-200 |
| III | Virajpet, Madikeri, Somwarpet, Saklespur and Mudigere taluks of Karnataka (Coorg, Chikmagalur and Hassen districts of Karnataka) | Red loam | 70-75 | 50 | 230 days | 19.0 | 100-150 |

temperature range was very low (14.1°C) and optimum across the Zone I.

The production potential of small cardamom was low (100-150 $kgha^{-1}$) over Zone III (Karnataka) where the length of crop growing season was less than 250 days with annual Ima of 70-75 per cent. The annual temperature range was also high (19.0°C), which may be detrimental, in the case of cardamom.

The Zone II falls under intermediary category (150-200 $kgha^{-1}$), where the length of crop growing season was more than 250 days with annual Ima varied between 80 and 85 per cent. It is evident that the zone II and III can be made better in terms of production of small cardamom by improving in-situ soil moisture conservation practices as it experiences uni-model rainfall. It is understood that Tamil Nadu (Thandikudi) and southern parts of Kerala (Pampadumpara) are relatively better suited for cardamom in obtaining high yields as the areas are conducive in terms on soil and weather conditions, followed by northeast hill regions of Kerala (Fig 4.17), whereas weather risk is involved in the case of Karnataka under the rainfed conditions.

## 4.9 CROP WEATHER RELATIONSHIP

It is the environmental factor, which decide the plant characters and final yield for a given genotype under uniform crop management practices. It is presumed that among several environmental factors, weather conditions drive the plant husbandry if the crop management practices are strictly followed. Keeping the above in view, attempts were made to develop a relationship between various weather elements, water balance parameters and cardamom production and productivity through correlation and regression techniques. It was found that the rainfall during winter (Dec-Feb), summer (Mar-May) and rainfall from December to May were positively correlated with cardamom production while rainfall during summer and rainfall from December to May were positively correlated with productivity. Though the annual rainfall and rainfall during southwest and post monsoon had the positive correlation with production and productivity, it was not significant (Table 4.17). In cardamom, the important phenological phases viz., panicle emergence, its elongation and flowering are very important in deciding final yield, which fall mostly in winter and summer seasons. Hence, it is evident that rainfall from December to May plays a critical role in cardamom production and productivity. This is in agreement with the reports given by Mathew (1989) and George and Mathew (1996).

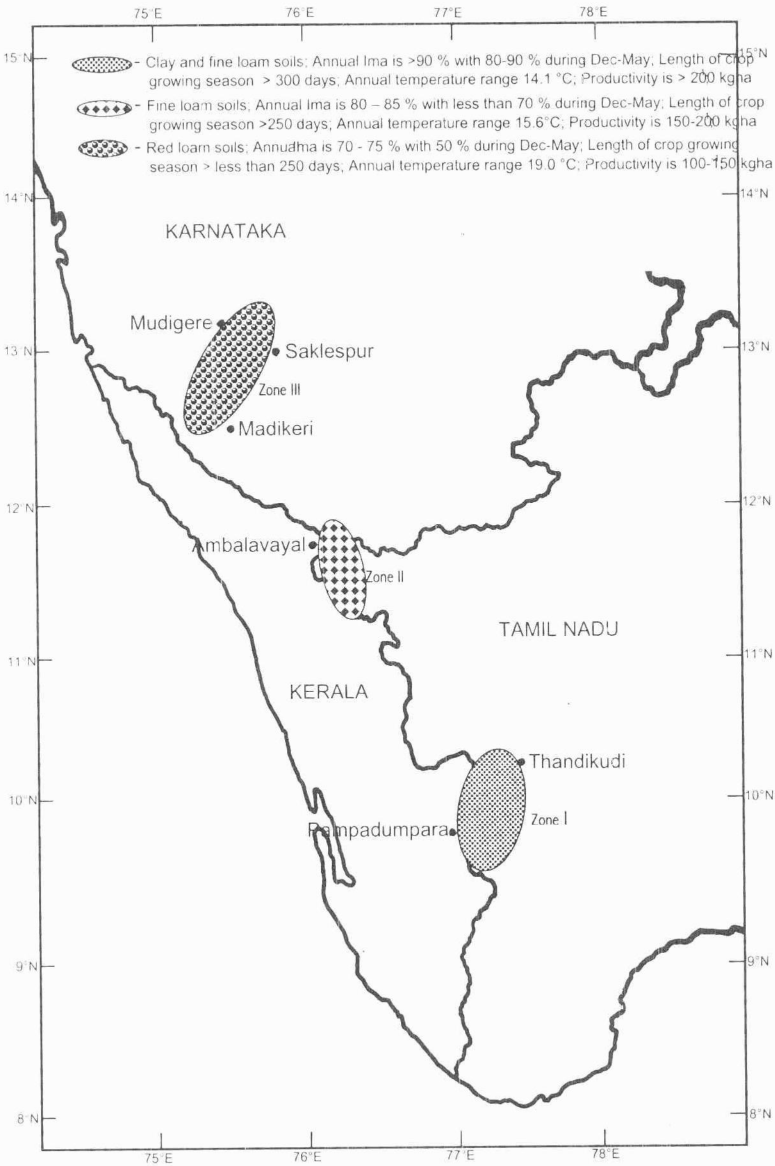


Fig 4.17 Agroclimatic zones of small cardamom across the Western Ghats

Table 4.17 Correlation coefficient between weather parameters and cardamom production and productivity over Kerala

| Parameters | Production | Productivity |
|---|---|---|
| Rainfall | | |
| Annual | 0.141 | 0.137 |
| SWM | -0.137 | -0.171 |
| PM | 0.101 | 0.140 |
| Winter | 0.426* | 0.370 |
| Summer | 0.442* | 0.463* |
| Winter + Summer (Dec-May) | 0.611** | 0.590** |
| No. of Rainy days | -0.501 | -0.530 |
| Annual | 0.212 | 0.161 |
| SWM | -0.033 | -0.084 |
| PM | 0.103 | 0.131 |
| Winter | 0.290 | 0.234 |
| Summer | 0.371* | 0.322 |
| Index of Moisture Availability | | |
| Annual | 0.595** | 0.574** |
| SWM | 0.109 | 0.127 |
| PM | 0.044 | 0.016 |
| Winter | 0.347 | 0.302 |
| Summer | 0.509* | 0.511* |
| Winter + Summer | 0.590** | 0.564** |

* significant at 5 % level

** significant at 1 % level

The number of rainy days during summer had a positive correlation with the small cardamom production. Though the rainfall and its distribution from December to May showed a positive correlation, it is the soil moisture availability, which is very important for plant growth, development and production. The annual Ima, which is the index considered for moisture availability, had positive correlation with cardamom production and productivity. The summer Ima as well as Ima during winter plus summer (Dec-May) had also positive correlation with cardamom production. It shows that the duration of the moisture availability from December to May is more important in deciding small cardamom production and productivity.

In the case of surface air temperature, only maximum temperature during summer season had a negative correlation with production and productivity. Interestingly, the annual and summer temperature range also showed a negative correlation with small cardamom production while southwest monsoon season had the positive correlation with production (Table 4.18). Similar was also the case in productivity except during winter, in which significant negative correlation was noticed. The positive correlation with temperature range during the southwest monsoon could be attributed to better yield in cardamom as rainless days and less rain during the heavy southwest monsoon may shoot to high temperature range, which is conducive in case of cardamom while detrimental if the annual temperature is high. The multi-collinearity effect among different weather variables was eliminated through stepwise regression and the regression equation so obtained is given below:

$Y = 6534.674 + 4.071\ x_1 + 724.931\ x_2 - 591.622\ x_3$ $(R^2 = 0.78)$

Where, Y – Annual cardamom production (tonnes); $x_1$ – Dec-May rainfall (mm);

Table 4.18 Correlation coefficient between temperature and cardamom production and Productivity over Kerala

| Parameters | Production | Productivity |
|---|---|---|
| Maximum temperature | | |
| Annual | -0.151 | -0.216 |
| SWM | 0.209 | 0.160 |
| PM | 0.130 | 0.065 |
| Winter | -0.120 | -0.175 |
| Summer | -0.501* | -0.530** |
| Minimum temperature | | |
| Annual | 0.132 | 0.180 |
| SWM | 0.053 | 0.137 |
| PM | 0.003 | 0.070 |
| Winter | 0.362 | 0.364 |
| Summer | -0.161 | -0.165 |
| Temperature range | | |
| Annual | -0.576** | -0.591** |
| SWM | 0.497* | 0.446* |
| PM | -0.083 | -0.160 |
| Winter | -0.406 | -0.419* |
| Summer | -0.452* | -0.447* |

* significant at 5% level

** significant at 1 % level

$x_2$ – Temperature range during southwest monsoon season (°C); $x_3$ – Annual temperature range (°C)

From the above, it is understood that the rainfall from Dec-May, temperature range during southwest monsoon and annual temperature range could explain the variability in cardamom production by 78 per cent. The actual and predicted cardamom production is presented in Fig 4.18 and it revealed that, the actual cardamom production is more than the predicted in recent years. This may be attributed to improved varieties and better irrigation practices during summer.

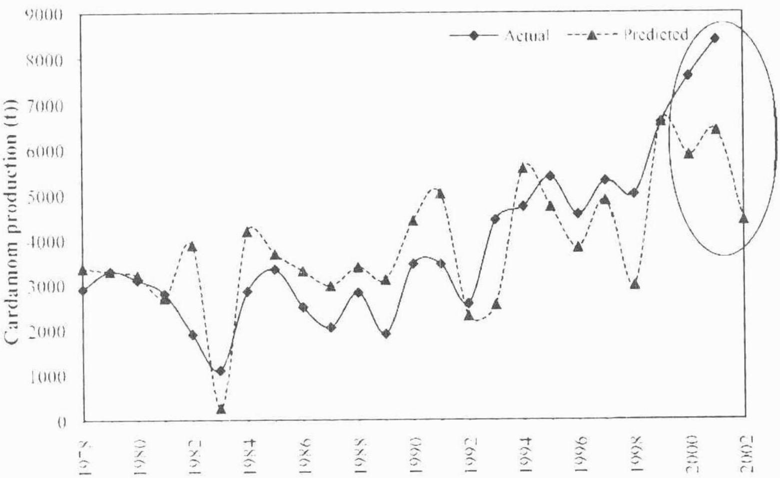


Fig 4.18 Actual and predicted cardamom production over Kerala from 1978 to 2002

$$Y = 6534.674 + 4.071\ X1 + 724.931\ X2 - 591.622\ X3 \quad (R2 = 0.78)$$

where Y is the estimated cardamom production;
X1 - Dec- May rainfall;

X2 - Temperature range during southwest monsoon;
X3 - Annual temperature range

## 4.10 WATER DEFICIT VERSUS CARDAMOM PRODUCTION AND PRODUCTIVITY

There exists a strong relationship between the water deficit during summer and cardamom production. The cardamom production is high if the water deficit from December to May is less and vice-versa (Fig 4.19a). As the period of water deficit during summer coincides with

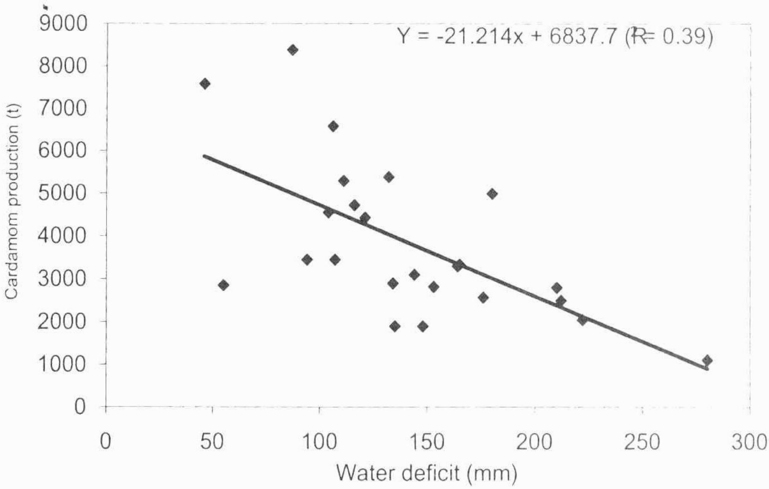


**Fig 4.19a Water deficit during summer (Dec-May) and cardamom production over Kerala**

panicle emergence, its elongation and flowering of cardamom, it affects the cardamom production adversely. In the case of cardamom production, more than 3000 tonnes if the water deficit was less than 125 mm and at the same time the production varied between 2000 and 3000 tonnes if the water deficit was between 125-225 mm. It was only around 1000 tonnes if the water deficit was more than 225 mm. The same trend was noticed in the case of cardamom productivity. For the same limits of water deficit during summer, the cardamom productivity was more than 100 $kgha^{-1}$, 50 $kgha^{-1}$ and less than 25 $kgha^{-1}$, respectively (Fig 4.19b). Hence, it is better to irrigate the crop from the beginning of water deficit period (Dec/Jan) to onset of monsoon (May/June) to avoid stress period and yield loss in cardamom. This is supported by Gurumurthy *et al.* (1996). However, Korikanthimath *et al.* (2002) reported that the stress period for 45-60 days from December to January has been found to be beneficial for the cardamom and it would be ideal to commence the irrigation during the first week of February till the regular monsoon commences, instead of

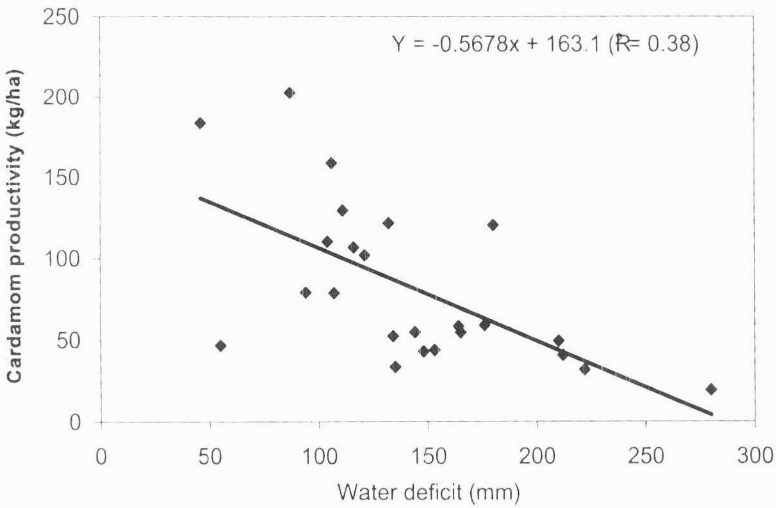


**Fig 4.19b Water deficit during summer (Dec-May) and cardamom productivity over Kerala**

from December or January onwards as cardamom needs mild stress for reproductive period.

It is also confirmed when compared the water deficit during summer with good and poor cardamom production years (Table 4.19). In the poor cardamom production years

**Table 4.19 Cardamom production over Kerala for the selected poor and good cardamom years from 1970 to 2001**

| Poor cardamom production years | Water deficit (mm) | Cardamom production (tonnes) | Good cardamom production years | Water deficit (mm) | Cardamom production (tonnes) |
|---|---|---|---|---|---|
| 1983 | 280 | 1100 | 1984 | 55 | 2850 |
| 1989 | 148 | 1900 | 1990 | 107 | 3450 |
| 1992 | 176 | 2570 | 1993 | 121 | 4430 |

viz., 1983,1989 and 1992, the water deficit was 280 mm, 148 mm and 176 mm, respectively. In contrast, in good cardamom production years viz., 1984, 1990 and 1993, the water deficit was only 55 mm, 107mm and 121 mm, respectively. It clearly indicated that the water deficit during panicle initiation, elongation and flowering phases (Dec –

May) adversely affect the cardamom production to a large extent of about 40 per cent.

## 4.11 ARIMA MODELS

ARIMA models were evolved based on annual rainfall data from 1960 to 1997 for Pampadumpara as a test case. The deviation between actual and predicted annual rainfall at Pampadumpara was in agreement except in 2002 during which the actual amount was less by 46 per cent (Table 4.20). This was the case with all the global predicted rainfall models on seasonal forecast. For example the forecast given for monsoon rainfall of India was 102 %. But the actual rainfall received was only 65 per cent of Long Period Average. Since ARIMA models evolved in the case of Pampadumpara for predicting rainfall is in agreement except in 2002. The same model was developed using the data from 1960 to 2002 and predicted for the next five years from 2003 to 2007. Same exercise was done in the case of maximum and minimum temperature also and appended. (Appendix Ia – Ie).

**Table 4.20 Actual and predicted rainfall (mm) using ARIMA models at Pampadumpara**

| Year | Actual rainfall (mm) | Predicted rainfall (mm) | Deviation (%) |
|---|---|---|---|
| 1998 | 2124 | 1959 | -8 |
| 1999 | 1776 | 1984 | +12 |
| 2000 | 1960 | 1985 | +1 |
| 2001 | 2097 | 1957 | -7 |
| 2002 | 1340 | 1952 | +46 |

# 5.SUMMARY

A study was undertaken at the Department of Agricultural Meteorology, College of Horticulture, Kerala Agricultural University, Vellanikkara to analyse the variability of rainfall, surface air temperature and moisture index over a period of time across the cardamom tract of the Western Ghats. The length of crop growing seasons was worked out for all the six locations based on monthly precipitation and potential evapotranpiration, which was worked out using the Thornthwaite formula. The crop weather relationship of cardamom was worked out based on weather variables and cardamom production and productivity. The agroclimatic zones of small cardamom were delineated based on climatic indices viz., index of moisture adequacy (Ima), length of crop growing season, temperature range, soil type and crop productivity. The relationship between water deficit during summer and cardamom production and productivity was also highlighted. The salient results of the study were summarized and presented in this chapter.

The mean annual rainfall increases from south (Pampadumpara) to north across the cardamom tract while the western parts of the Western Ghats receive high annual rainfall, ranging from 1873 mm to 2608 mm when compared to that of eastern parts (1452 mm). The coefficient of variation of mean annual rainfall indicated that it is dependable from year to year across the cardamom tract though winter rainfall is variable. The annual number of rainy days is high over western parts of the cardamom tract (113-127 days) and low over eastern part (81 days).

The southwest monsoon rainfall is relatively dependable over western parts than that of eastern parts (Tamil Nadu) of the Western Ghats. The percentage contribution of southwest monsoon to annual is high over Karnataka (80-83 %) and less over Tamil Nadu (33 %). It is intermediary (60-65 %) over Kerala. It holds well in the case of rainy days also.

The post monsoon rainfall decreases from south (Pampadumpara) to north (Mudigere) unlike annual rainfall and rainfall during southwest monsoon. The eastern parts (Tamil Nadu) of the Western Ghats receive high rainfall during the post monsoon (Oct to Nov), followed by southern parts (Pampadumpara) when compared to northern parts (Karnataka) across the cardamom tract. The percentage contribution of post monsoon rainfall to annual is high over Tamil Nadu (35.4 %), followed by Kerala (16.1-23.1%) and less over Karnataka (9.7-11.1 %). The number of rainy days is high over Tamil Nadu and Pampadumpara (Kerala) than the other locations during the post monsoon.

The contribution of winter rainfall to the annual is very meagre over Karnataka and Kerala and relatively better over Thandikudi (Tamil Nadu). The pattern of rainfall during winter is similar to that of post monsoon season across the cardamom tract unlike annual rainfall.

The northern parts (Karnataka) receive less rainfall during summer than southern parts (Kerala) and the eastern parts (Tamil Nadu) of cardamom tract. The percentage contribution of rainfall (19 %) and number of rainy days (20 %) during summer is relatively high over Tamil Nadu when compared to that of Kerala (12-16 %; 12-19 %) and Karnataka (7-8 %; 12-13 %).

Bi-model rainfall is noticed over Kerala (Pampadumpara, Ambalavayal) and Tamil Nadu (Thandikudi) while uni-model rainfall over Karnataka. July is the rainiest month over Kerala and Karnataka while October over Tamil Nadu across the cardamom tract of the Western Ghats.

The annual rainfall showed a marginal declining trend at Ambalavayal, Saklespur, Mudigere and Thandikudi while increasing trend over Pampadumpara and Madikeri regions. It was declining at all locations except Madikeri during southwest monsoon, which is the main season for rains. Saklespur and Thandikudi showed a declining trend in post monsoon rainfall and Ambalavayal and Thandikudi showed a declining trend in winter rainfall while increasing trend at all other four locations. Except Saklespur, all other five locations showed decreasing trend in summer rainfall. It revealed that there was a shift in rainfall from southwest monsoon to winter as it was increasing at many locations during winter (Dec-Feb). In contrast, there was a decline in rainfall during summer (Mar-May).

The mean annual maximum temperature across the cardamom tract is the lowest (24.1 °C) over Tamil Nadu and the highest (26.9 - 30.0 °C) over Karnataka while intermediary over Kerala (24.6 - 27.4 °C). The mean annual minimum temperature is high (16.9 - 17.8 °C) over the western parts of the Western Ghats and low (15.4 °C) over eastern parts. The annual temperature range is high (10.0 - 12.4 °C) over Karnataka and less over Kerala (7.1 – 9.5 °C) and Tamil Nadu (8.7 °C) across the Western Ghats.

The maximum temperature varied between 23.7 and 33.7 °C over Karnataka while 21.3 – 26.2 °C over Tamil Nadu. During southwest monsoon, Kerala recorded relatively low (22.6 – 25.1 °C) due to heavy rains. In the case of minimum temperature, Tamil Nadu recorded the lowest (13.2 – 16.7 °C) in all the seasons when compared to that of Kerala (15.8 – 19.0 °C) and Karnataka (13.7 – 18.7 °C). It was relatively high over Kerala during winter (15.9 °C) and summer seasons (19.0 °C) when compared to that of Karnataka and Tamil Nadu.

There was an increasing trend in annual temperature at all locations except Pampadumpara and Saklespur in maximum temperature and at Madikeri and Thandikudi in minimum temperature. During southwest monsoon, increasing trend was noticed in both maximum and minimum temperature at all locations except at Saklespur in maximum temperature and at Thandikudi in minimum temperature. In post monsoon season, the maximum temperature was in decline over Pampadumpara, Ambalavayal and Saklespur while in minimum temperature over Madikeri and Saklespur. While other locations showed an increasing trend in both maximum and minimum temperatures. During winter, a declining trend in maximum temperature was noticed at all locations except at Mudigere and in the case of minimum temperature, increasing trend was noticed except at Thandikudi. In summer, maximum temperature showed a declining trend except at Madikeri and Mudigere and increasing trend was noticed except Pampadumpara and Thandikudi across the cardamom tract.

The study on the trends in moisture index (Im) showed that it declined at all locations during southwest monsoon and an annual basis except at Madikeri. During post monsoon and winter, an increasing trend in moisture index was noticed at all the locations except Thandikudi in post monsoon period. All the locations, except at Pampadumpara, showed a declining trend in moisture index during summer. The climatic type at all locations fell under the perhumid (A). However, all the locations experienced dry sub-humid to arid climates during winter and summer (December to May). The intensity of aridity was high towards north of cardamom tract across the Western Ghats.

The annual potential evapotranspiration was maximum at Saklespur (1235 mm) and low at Thandikudi (905 mm), followed by Pampadumpara (982 mm). The potential evapotranspiration was intermediary over

Ambalavayal (1092 mm), Madikeri (1072 mm) and Mudigere (1022 mm).

The length of crop growing season was more over Tamil Nadu (327 days), followed by Kerala (265-274 days) and the least (223-237 days) over Karnataka across the cardamom tract of the Western Ghats. The influence of both monsoons reflected in more length of crop growing season over Tamil Nadu. The commencement of humid period was earlier (4 th April) at Thandikudi and Ambalavayal (12 th April) and late at Saklespur (May 23). No dry period (PET/4 > P > PET/8) was noticed at Thandikudi and Pampadumpara. At the same time, the dry period was noticed towards north of cardamom tract (Ambalavayal, Madikeri, Saklespur and Mudigere).

The mean annual water deficit was comparatively low at Thandikudi (90 mm), followed by Pampadumpara (141 mm). It was maximum at Saklespur (424 mm). Madikeri and Mudigere recorded a water deficit of 258 mm and 269 mm, respectively.

A sharp decline in area under cardamom was noticed across the cardamom tract of the Western Ghats in recent decades. However, the production as well as productivity of small cardamom was increasing during the study period.

The studies on the agro-climatic zones of small cardamom revealed that the cardamom production of Zone I (South Kerala and Tamil Nadu) was relatively better as the annual Ima was more than 90 per cent with Ima of Dec-May was 80-90 per cent. In addition the annual temperature range was very low and optimum (14.1 °C) across the Zone I. The Karnataka region (Zone III), having annual Ima of 70-75 per cent with Ima of Dec-May was less than 50 per cent, produced less cardamom (100-150 kg/ha). The annual temperature range was also high (19.0 °C), which may be detrimental, in the case of cardamom.

The cardamom productivity over the Wayanad region (Zone II) was intermediary (150-200 kg/ha), which experienced the annual Ima of 80-85 per cent with Ima of Dec-May of less than 70 per cent. The temperature range was intermediary (15.6 °C) in the Zone II.

There existed a strong relationship between the water deficit during summer and cardamom production. The cardamom production was high if the water deficit from December to May was less and vice-versa. The cardamom production was more than 3000 tonnes if the water deficit was less than 125 mm and at the same time, the production varied between 2000 and 3000 tonnes if the water deficit was between 125-225 mm. It was only around 1000 tonnes if the water deficit was greater than 225 mm. The same trend was noticed in case of cardamom productivity. The water deficit during the poor cardamom production years of 1983, 1989 and 1992 was 280 mm, 148 mm and 176 mm, respectively. In contrast, the water deficit in good cardamom production years of 1984, 1990 and 1993 was only 55 mm, 107 mm and 121 mm, respectively.

The studies on crop weather relationship studies indicated that the rainfall from December to May, the annual temperature range and temperature range during southwest monsoon could explain the variability in cardamom production up to 78 per cent.

**Suggested future line of work**

- Recording and correctness of the climatological data should be verified before the analysis on "Climatic variability and its trends". Otherwise, it will lead to corroborative results.
- A systematic study on crop phenology should be initiated at all the cardamom research stations across the Western Ghats as it is lacking at present. It is very important in the studies on "crop weather relationships".

- Agromet network should be strengthened across the cardamom tract to generate the weather data along with crop information since the number of agrometeorological stations is very limited.
- Agrometeorological investigations in cardamom should be strengthened at all the cardamom stations as such studies in this direction are scant.
- Hopkins Bio-climatic law should be tested in the case of cardamom across the country to understand the influence of geographical co-ordinates viz., latitude, longitude and altitude as they influence biotic events to a larger extent.
- In a changed climate scenario, cardamom area is under threat. More and more studies are to be initiated in this direction to understand the effects of climate change / variability on area and production of cardamom.
- The role of deforestation and climate variability on "cardamom area and production" should be highlighted as the area under cardamom was dwindling and replaced by other suitable crops.
- The agroclimatic zonation was delineated only based on three years data on cardamom productivity (1999-2001). It can be improved in future based on the large series of data.

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* Originals not seen

## APPENDIX Ia

Minimum AIC values for different locations across the cardamom tract

| Location | Parameters | ARIMA values | | | AIC value |
|---|---|---|---|---|---|
| | | p | q | d | |
| **Pampadumpara** | Rainfall | 2 | 1 | 1 | 613.7 |
| | Maximum temperature | 0 | 1 | 1 | 25.9 |
| | Minimum temperature | 2 | 0 | 1 | 22.9 |
| **Ambalavayal** | Rainfall | 1 | 1 | 1 | 318.7 |
| | Maximum temperature | 2 | 0 | 1 | 6.2 |
| | Minimum temperature | 1 | 0 | 1 | 26.1 |
| **Madikeri** | Rainfall | 2 | 1 | 1 | 247.5 |
| | Maximum temperature | 1 | 0 | 1 | 11.2 |
| | Minimum temperature | 1 | 1 | 1 | 19.5 |
| **Saklespur** | Rainfall | 1 | 0 | 1 | 156.1 |
| | Maximum temperature | 1 | 1 | 1 | 13.0 |
| | Minimum temperature | 1 | 1 | 1 | 9.4 |
| **Mudigere** | Rainfall | 2 | 1 | 1 | 574.6 |
| | Maximum temperature | 1 | 1 | 1 | 29.0 |
| | Minimum temperature | 1 | 1 | 1 | 32.5 |
| **Thandikudi** | Rainfall | 2 | 1 | 1 | 228.1 |
| | Maximum temperature | 2 | 0 | 1 | 0.65 |
| | Minimum temperature | 2 | 1 | 1 | 9.0 |

**APPENDIX Ib**

ARIMA models developed for different locations for predicting rainfall and temperature

| Location | Model |
|---|---|
| | Rainfall |
| Pampadumpara | $Y_t - 1.57\ Y_{t-1} + 0.57\ Y_{t-2}\quad 0.35\ Y_{t-2} + 0.35\ Y_{t-3} = e_t\quad 0.62\ e_{t-1}$ |
| Ambalavayal | $Y_t - 1.31\ Y_{t-1} + 0.34\ Y_{t-2} - e_t - 0.34\ e_{t-1}$ |
| Madikeri | $Y_t - 1.99\ Y_{t-1} + 0.99\ Y_{t-2} - 0.58\ Y_{t-2} + 0.58\ Y_{t-3} - e_t - 0.86\ e_{t-1}$ |
| Saklespur | $Y_t - 1.53\ Y_{t-1} + 0.53\ Y_{t-2} - e_t$ |
| Mudigere | $Y_t - 1.61\ Y_{t-1} + 0.61\ Y_{t-2} - 0.27\ Y_{t-2} + 0.27\ Y_{t-3} - e_t - 0.56\ e_{t-1}$ |
| Thandikudi | $Y_t - 1.6\ Y_{t-1} + 0.6\ Y_{t-2} - 0.37\ Y_{t-2} + 0.37\ Y_{t-3} = e_t - 0.99\ e_{t-1}$ |
| | Maximum Temperature |
| Pampadumpara | $Y_t - Y_{t-1} = e_t - 0.28\ e_{t-1}$ |
| Ambalavayal | $Y_t - 1.63\ Y_{t-1} + 0.63\ Y_{t-2} - 0.42\ Y_{t-2} + 0.42\ Y_{t-3} = e_t$ |
| Madikeri | $Y_t - 1.13\ Y_{t-1} - 0.13\ Y_{t-2} = e_t$ |
| Saklespur | $Y_t - 1.26\ Y_{t-1} + 0.26\ Y_{t-2} = e_t - 0.23\ e_{t-1}$ |
| Mudigere | $Y_t - 1.3\ Y_{t-1} + 0.3\ Y_{t-2} = e_t - 0.34\ e_{t-1}$ |
| Thandikudi | $Y_t - 1.34\ Y_{t-1} + 0.34\ Y_{t-2} - 0.82\ Y_{t-2} + 0.82\ Y_{t-3} = e_t$ |
| | Minimum Temperature |
| Pampadumpara | $Y_t - 1.7\ Y_{t-1} + 0.7\ Y_{t-2} - 0.35\ Y_{t-2} + 0.35\ Y_{t-3} = e_t$ |
| Ambalavayal | $Y_t - 1.06\ Y_{t-1} - 0.06\ Y_{t-2} = e_t$ |
| Madikeri | $Y_t - 1.11\ Y_{t-1} + 0.11\ Y_{t-2} = e_t - 0.1\ e_{t-1}$ |
| Saklespur | $Y_t - 1.09\ Y_{t-1} + 0.09\ Y_{t-2} = e_t - 0.12\ e_{t-1}$ |
| Mudigere | $Y_t - 1.12\ Y_{t-1} + 0.12\ Y_{t-2} = e_t - 0.19\ e_{t-1}$ |
| Thandikudi | $Y_t - 1.82\ Y_{t-1} + 0.82\ Y_{t-2} - 0.97\ Y_{t-2} + 0.97\ Y_{t-3} - e_t - 1.0\ e_{t-1}$ |

## APPENDIX Ic

Predicted rainfall (mm) using ARIMA models for different locations across the cardamom tract

| Location | Predicted value (Rainfall (mm)) | | | | |
|---|---|---|---|---|---|
| | 2003 | 2004 | 2005 | 2006 | 2007 |
| Pampadumpara | 1683.1 | 1656.6 | 1630.1 | 1603.5 | 1577.0 |
| Ambalavayal | 1220.7 | 1156.9 | 1093.1 | 1029.3 | 965.6 |
| Madikeri | 2625.3 | 2288.7 | 2293.1 | 2412.1 | 2217.5 |
| Saklespur | 1877.8 | 1571.6 | 1452.0 | 1233.4 | 1067.3 |
| Mudigere | 1921.6 | 1890.1 | 1858.6 | 1827.1 | 1795.6 |
| Thandikudi | 1170.2 | 1132.5 | 1094.8 | 1057.1 | 1019.4 |

## APPENDIX Id

Predicted maximum temperature (°C) using ARIMA models for different locations across the cardamom tract

| Location | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|
| Pampadumpara | 25.31 | 25.32 | 25.34 | 25.35 | 25.36 |
| Ambalavayal | 27.33 | 27.30 | 27.36 | 27.35 | 27.30 |
| Madikeri | 27.95 | 28.03 | 28.1 | 28.17 | 28.25 |
| Saklespur | 29.47 | 29.45 | 29.43 | 29.41 | 29.39 |
| Mudigere | 26.80 | 26.81 | 26.82 | 26.83 | 26.84 |
| Thandikudi | 24.71 | 24.74 | 24.56 | 24.77 | 25.01 |

## APPENDIX Ie

Predicted minimum temperature (°C) using ARIMA models for different locations across the cardamom tract

| Location | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|
| Pampadumpara | 17.47 | 17.55 | 17.56 | 17.54 | 17.57 |
| Ambalavayal | 18.06 | 18.10 | 18.15 | 18.19 | 18.23 |
| Madikeri | 17.03 | 16.98 | 16.93 | 16.88 | 16.83 |
| Saklespur | 18.15 | 18.19 | 18.21 | 18.24 | 18.27 |
| Mudigere | 17.49 | 17.51 | 17.52 | 17.54 | 17.55 |
| Thandikudi | 14.79 | 14.68 | 14.57 | 14.46 | 14.34 |