MODELING THE RICE PRODUCTION UNDER VARIED AGRO-ECOLOGICAL SITUATIONS OF PALAKKAD DISTRICT AND ITS VULNERABILITY TO CLIMATE CHANGE

By

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **“Modeling the rice production under varied Agro-Ecological Situations of Palakkad district and its vulnerability to climate change”** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

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Chapter 1. Introduction

Climate change poses an emerging hazard to sustainability of social and economic development, livelihoods, and environmental management across the world. The rise in greenhouse gases especially CO_2 due to high energy usage causes rise in temperature which in turn leads to unpredictable weather and other several natural disasters. Rising temperatures linked with climate change will likely have a harmful impact on agricultural and allied sectors. With the ever-increasing need for food, shelter and energy, the subject of maximizing the productivity of land by agriculture has become the most important problem for the entire human race. India is highly susceptible to climate change because of high physical exposure to climate related disasters and also the Indian economy and population depends more on climate sensitive sectors like agriculture, forests, tourism and fisheries.

Agricultural production, and thus global food security, is directly affected by global warming (Ainsworth and Ort, 2010). Increasing atmospheric greenhouse gas concentrations are expected to induce significant climate change over the next century and beyond, but the impacts on society remain highly uncertain (Chavas, *et al.,* 2009). The agriculture sector is already under pressure for increasing food demand, problems associated with agricultural land and water resource depletion. The issues of climate change make the pressure more acute for the sector.

Rice (*Oryza sativa* L.) is the most important staple food for more than half of the world population, accounting for approximately 30 percent of the total dietary intake, globally and in South Asia (Lobell *et al.*, 2008). Rice production in the tropics is sensitive to climatic factors (temperature, rainfall, and solar radiation) which affect the crop in two various ways during different stages of its growth (Yoshida, 1978). The fact that climate impacts often exceed 10 per cent of the rate of yield change indicates that climate changes are already exerting a considerable drag on yield growth (Lobell *et al.*, 2011).

India is the second most populous country in the world and will take the number one position by 2030. It is imperative to increase food production in order to meet the growing demand for food emanating from population growth. Although, there have been ups and downs in the domestic production of food grain. The diverse climatic phenomena like cyclone, drought, changing rainfall patterns and temperature; there has been a significant lost in food grain production in every year.

There is a large gap between potential and actual grain yield of rice in Kerala and the growth and yield is largely depends on the various weather factors like temperature, rainfall, solar radiation and relative humidity that prevail during the growing season. The rice cultivation in Kerala is mainly confined to Palakkad and Kuttanad regions Palakkad district occupies the largest area under rice cultivation and is known as the Granary of Kerala. In spite of the vast area under rice, Palakkad is considered as very highly vulnerable to climate change because of the higher percentage of population relying on agriculture, a lower ranking in the human development index and higher social deprivation. Rice in Palakkad is grown under varying eco-system on a variety of soils under varying climatic and hydrological conditions ranging from waterlogged to water deficit situations. Besides, rice is also grown under rainfed and irrigated conditions. Therefore, the productivity levels of rice, where it is grown under different eco-systems and climatic conditions, productivity status has been changed drastically. Hence the present investigation was taken up with a view to study the major abiotic stresses limiting the rice production under different Agro-ecological units of Palakkad district and to study the climate change impact on rice production, we have taken following objectives:

1. Development of crop weather relationship for the predominant rice varieties and assessment of possible changes in yield due to climate change.

2. Study the impact of abiotic factors and farming practices on rice production using simulation model.

Chapter 2. Review of Literature

Rice is the most vital staple food of Kerala. For the past few years, there was a drastic decrease in area and production of rice due to soil associated constraints (Maneesh and Deepa, 2016). About 65 per cent of Kerala soils are lateritic in nature which requires distinct management package as these soils are low to medium in OC, N and K, very low in Ca and Mg. In addition to low fertile soils, high acidity, iron and aluminum toxicities are important soil linked constraints, resulting poor crop productivity in iron toxic laterite soils, especially in low land situation (GOK, 2016).

2.1. Rice and Weather

Rice is a unique crop among the major food crops by virtue of its extent and adaptability to wider range of edaphic, climatic and cultural conditions. About 90 per cent of the rice production takes place in the tropical/sub-tropical Asia where 60 per cent of the world population lives. The slogan "Rice is life" during International Year of Rice 2006 reflects the importance of rice as primary source of food. Rice is essential for food security, poverty alleviation and improved livelihoods. Rice is the staple food of over half of the world population (Anonymous, 2013). Climate influences the distribution of crops over different regions of the world, while weather influences the potential production of the concerned crop. Among the abiotic stresses, weather plays the dominant role in influencing the growth and yield of rice. The elements that combined express weather are solar radiation, temperature, rainfall, relative humidity and wind velocity. Climatic factors such as temperature, sunlight, and rainfall influence the growth and yield of rice in two ways. Directly, they affect physiological processes involved in grain production, such as vegetative growth, development of spikelets, and grain filling. Indirectly, they affect grain yield through incidence of diseases and insects (Yoshida, 1978).

2.1.1 TEMPERATURE

In India, studies by several authors has shown that during the last century there is an observed increasing trend in surface temperature (Hingane *et al.,* 1985; Srivastava *et* *al.,* 1992; Rupa Kumar et al., 1994; De and Mukhopadhyay, 1998; Pant *et al.,* 1999; Singh and Sontakke, 2002; Singh *et al*., 2001). Integrated impact of a rise in temperature and CO_2 concentration on yield of crops may be negative (Sinha and Swaminathan,1991). They estimated that a 2 ˚C increase in mean air temperature could decrease rice yield by about 0.75 t ha^{-1} in the high yield areas and by about 0.06 t ha^{-1} in the low yield coastal regions. The sensitivity experiments of the CERES-rice model to CO_2 concentration changes by Saseendran *et al.*, (1999) indicated that over the Kerala State, an increase in CO_2 concentration leads to yield increase due to its fertilization effect and also enhances the water use efficiency. The temperature sensitivity experiments have shown that for a positive change in temperature up to 5˚C, there is a continuous decline in the yield. For every one-degree increment, the decline in yield is about 6%. Also, in another experiment, it was noticed that the physiological effect of ambient CO_2 at 425-ppm concentration compensated for the yield losses due to increase in temperature up to 2˚C. Watson *et al.* (1998) reviewed that various climate change scenarios for different regions of the world. According to this study, by 2010 and 2070, temperature increase in south Asia will range between 0.1–0.3^{0}C and 0.4–2.0 ^{0}C, respectively. Relatively high increase in CO_2 and low increase in temperatures can be considered as an optimistic scenario since this is expected to favor crop growth. On the contrary, high increase in temperature and low increase in CO_2 can be assumed as suspicious because of negative effects on crop growth.

Higher maximum and minimum temperature during ear initiation depress the yield. In general, high temperature accelerates the floral initiation (Vergara *et al*., 1972). The rice plant is considered most sensitive to low temperature about 9 days before flowering, which corresponds to the young microspore stage (Satake, 1976). In a low-temperature situation, both day and night temperatures appear to affect spikelet sterility, and a daily mean temperature of less than 20°C may induce sterility. Rice is most sensitive to high temperature at flowering stage. A daytime temperature higher than 35°C at flowering time may increase spikelet sterility (Satake and Yoshida 1978). Tashiro and Wardlaw (1991) revealed that, at lower temperature, translocation of photosynthates to grain took place at a slower rate and thus the maturity period got delayed. Temperature less than 28ºC during grain filling increased its duration and seed size. Crop growth, development, water use and yield under normal conditions are largely determined by weather during the growing season. Even with minor deviations from the normal weather, the efficiency of extremely applied inputs and food production is seriously impaired. The accompanied increase in minimum temperatures increases maintenance respiration requirement of the crops and thus further reduces net growth and productivity (Aggarwal, 2003). Changes in temperature and in precipitation patterns and amount will influence soil water content, run-off and erosion, salinization, biodiversity, and organic carbon and nitrogen content. The increase in temperature would also leads to increased evapotranspiration. There is need to quantify the specific regional soil-related problems and that affect the global environmental change will have on soil fertility and its functioning for crop growth and production (Mall *et al.,* 2006).

These changes indicate warming trend. Since solar radiation is closely related to crop growth, any decrease in this will significantly reduce agricultural productivity. Climate change is no longer a distant scientific prognosis but is becoming a reality. Some studies indicate a probability of 10-40 % loss in crop production in India with increase in temperature by 2080–2100 (Aggarwal, 2008). The anthropogenic increases in emissions of greenhouse gases and aerosols in the atmosphere result in a change in the radioactive forcing and a rise in the Earth's temperature. The bottom-line conclusion of the Third Assessment Report of the Inter-governmental Panel on Climate Change (IPCC, 2001) is that the average global surface temperature will increase by between 1.4°and 3°C above 1990 levels by 2100 for low emission scenarios and between 2.5°and 5.8°C for higher emission scenarios of greenhouse gases and aerosols in the atmosphere.

2.1.2 RAINFAL

Amount of rainfall and distribution is the most critical weather component in rain fed rice ecologies (Upland, lowland and flood prone). Daily rainfall is more critical than monthly or annual rainfall. A rainfall of 100 mm/month distributed evenly during the growing period was preferable than 200mm/month, which fell in two or three days. Availability of about 200-300 mm of water per month is considered minimum to produce good crop of rain fed rice. Increasing temperatures and changes in rainfall pattern are also impacting the agricultural sector. Although there are ongoing studies to understand the impacts, some studies have shown certain trends. There are two major crop growing season in India as for climate point of view. The summer or '*kharif*' crop growing season (June–September) coincides with southwest monsoon. The major '*kharif*' crops are rice, maize, sugarcane, cotton, jute, groundnut, soybean and Bajra etc. Depending on crop duration, '*kharif*' crops can be harvested during the autumn (October–November) or winter (December–February) months. The southwest monsoon is critical to the *kharif* crop, which accounts for more than 50% of the food-grain production and 65% of the oilseeds production in the country. In India, agriculture is substantially dependent on the south-west monsoon. This is evident from the fact that the net irrigated area of the country is 60.9 million hectares from a total net sown area of 140.3 million hectares. Thus, a large part of the net sown area is rain-fed, thereby making the agriculture sector in India very sensitive to any changes in the pattern of rainfall. For instance, the impact of overall deficit of 23% in rainfall during the south-west monsoon in 2009-10, which adversely affected kharif production, is reflected in the agriculture GDP growth rate which shows a decline of 0.2 per cent as against the previous year's growth rate of 1.6 per cent (Pramod *et al.,* 2010).

In the tropics, too little or too much rainfall at any stage of rice growth causes partial or total crop failure (Satake 1976). The World Food Institute (1988) records show a large reduction in food production in India and neighbouring countries in 1987 due to monsoon failure. Thus, weather still plays a vital role in agricultural productivity in these countries despite of the innovations and technological advances in this field. Also, climate variations to the extent that may be considered as climate change have been recorded in India (Sinha, 1993). In this context, it is important to know how the climate change will affect growth, development, water use and productivity of rice crop in India. The inter annual monsoon rainfall variability in India leads to large-scale droughts and floods, resulting in a major effect on Indian food grain production (Parthasarathy and Pant, 1985; Parthasarathy *et al.,* 1992; Selvaraju,2003; Kumar *et al.,* 2004) and on the economy of the country (Gadgil *et al.,* 1999a; Kumar and Parikh, 2001). Overall, the temperature rise is likely to be much higher during the winter (*Rabi*) rather than in the rainy season (*Kharif*). It is projected that by the end of the 21st century, rainfall over India will increase by 10-12% and the mean annual temperature by 3-5°C. The warming is more pronounced over land areas with a maximum increase over northern India. Rice yield variability is more influenced by precipitation variability in India indicating the rainfed paddy growing conditions. (Deepak *et al.,* 2015).

2.1.3 SOLAR RADIATION

Solar radiation intercepted in rice canopy plays a major role in determining biomass and grain yield. Low light intensity during the vegetative stage slightly affected the yield and yield components of rice (Yoshida, 1981). Sunshine in a week prior to transplanting and the two weeks period coinciding with the grand period of elongation was conducive for better yield (Sreenivasan and Banerjee, 1978) considerably, because of a decrease in the percentage of filled grains. Yoshida (1981) reported that, grain yield is most affected by solar radiation at the reproductive stage. Solar radiation at the ripening stage has the next highest effect on yield Solar radiation during the vegetative state has an extremely small overall effect on grain yield.

In both the tropics and the temperate region, productivity, or rice yield per hectare, is primarily determined by the level of incident solar radiation. In the tropics, with appropriate management, a dry-season crop which has more sunlight, normally yields higher than a wet-season crop (Yoshida, 1977). Sreedharan and Vamadevan (1981) reported that LAI reduced to a greater extent in plants shaded from planting to panicle initiation and shading also caused death of many lower leaves. In deep water rice, with increase in light intensity, the length of elongated internodes decreased and dry matter content increased (Gomosta and Vergera, 1988). Low light intensity decreases the tiller growth due to lack of photosynthates. At low light intensity, photosynthesis becomes low causing mortality of the weak and unproductive tillers during this phase when there was greater demand for photosynthates from the developing grains (Thangaraj and Sivasubramanian, 1990). Due to heavy cloudiness during the growing period in the tropics, duration of bright sunshine hours is about 3-4 hours day^{-1} and yield of rice in this region is low (1.5-2.5 t ha^{-1}). Rice yield during summer season becomes almost double of that of monsoon season in eastern and southern India whereas it increases marginally in Punjab (Biswas, 1996).

2.1.4 ATMOSPHERIC HUMIDITY

Atmospheric humidity is an important factor in plant growth. Previously, we found that the relative humidity during the light period plays an important role in the growth and photosynthesis of rice seedlings, that is, high humidity during the light period increased the rate of leaf emergence, plant height, leaf area, leaf blade length, leaf sheath length, the number of roots, total root length and photosynthesis (Hirai *et al.,* 1996). Similar effects of high humidity on growth and photosynthesis in rice plants has been reported by Sato and Otomo, 1976; Ishihara and Kuroda, 1986). Recently, found that a high relative humidity (90%) during the dark period increased dry matter production and leaf area, plant height and leaf emergence, as compared with a low relative humidity (60%) (Hirai *et al.,* 1998).

However, the effects of high humidity during the dark period were observed in the plants cultured at a moderate relative humidity (75%) during the light period. High humidity during the dark period increased the rate of leaf emergence, plant height, leaf area, leaf blade length, the number of roots, total root length and dry matter production, even in the plants exposed to low humidity during the light period of rice (Hirai *et al.,* 2000). High relative humidity with high solar radiation positively influenced the number of leaves per plant. Low relative humidity shortened the days taken from transplanting to panicle initiation (Sunil, 2000).

2.1.5 WIND

High wind speed during flowering had caused pollen dehydration and consequent spikelet sterility in rice (Prasada Rao, 2003). During reproductive phase higher temperature coupled with speedy wind may cause poor setting of seed, consequently leads to pitiable harvest (Singh and Singh 2007).

Ebata and Ishikawa (1989) reported that wind damage to rice crop at the reproductive phase was triggered by temporary water stress in the panicle spikelet and the injury was less when wind was accompanied by rain. Fertilization in rice was inhibited by wind speed of more than four meter per second (Viswambaran *et al.,* 1989).

Sunil (2000) reported that wind speed during active tillering to heading stage had a significant negative correlation with number of panicles per plant and straw yield.

Crop Simulation Models

The Decision Support System for Agrotechnology Transfer (DSSAT) model was contrived by International Benchmark Site Network for Agrotechnology Transfer (IBSNAT) in 1989 (Tsuji *et al.,* 1998).

DSSAT is a software application program that includes crop simulation models for 28 crops. The program assimilates the effects of soil, crop phenotype, weather and management options. The DSSAT software cartels crop, soil and weather databases into standard setups for access by crop models and application programs. The user can then simulate multi-year conclusions of crop management strategies. The program and its crop simulation models have been used for numerous applications, extending from on-farm and precision management to regional assessments of the impact of climate variability and climate change.

DSSAT also provides for evaluation of crop model outputs with trial data, allowing users to relate simulated outcomes with experiential results. Crop model evaluation is accomplished by inputting the user's minimum data, running the model and then comparing outputs with observed data. By simulating probable outcomes of crop management strategies, DSSAT offers users information with which to rapidly appraise new crops, products and practices for adoption (Jones, et al., 2003). We have used CERES- Rice model (Ritche, 1986) for our study.

2.5.1.1 *CERES- Rice model*

The distinct origin CERES crop models were united into a single module to simulate wheat, maize, barley, sorghum, and millet (Tsuji *et al.,*1998). There is only the CERES rice model kept isolated, because its major differences in soil water, nitrogen balance procedures, and the need to simulate transplanting effects. The CERES models increment grow in a daily time steps and require daily weather data (maximum and minimum temperature, solar radiation, and precipitation). To compute crop basic morphological development temperature, day length, and cultivar characteristics are input factors. The daily dry matter growth is based on light intercepted by the leaf area index multiplied by conversion factors. Biomass partitioning into various plant components is based on potential growth of organs and daily amount of growth supply to demand ratios of water and nitrogen balance. Sub-models providing daily values of supply to demand ratios of water and nitrogen, respectively, which are used to influence growth and development rates.

Godwin *et al.* (1990) used the CERES- Rice model, which simulates the effect of weather, soil properties and crop management on nitrogen dynamics, crop growth and its performance in simulating field experiments.

Kumar and Sharma (2004) used the CERES-Rice model to simulate the growth, development and yield of four different rice cultivars (RP 2421, HPR 927, HPR 957 and Kasturi). The model was efficient in predicting the phenology of all cultivars and the association between actual and simulated data on number of days to flowering and physiological maturity was significant.

CERES-Rice model is a process based, management-oriented model that could simulate the growth and development of rice as affected by varying levels of water and Nitrogen (Boutraa, 2010).

CLIMATE CHANGE IMPACT ON RICE PRODUCTION

The increase in atmospheric temperature causes harmful effects on growth, yield and quality of the rice crop by affecting its phenology, physiology and yield components (Singh, 2001; Sheehy *et al.*, 2005; Peng *et al.,* 2004).

Presently, most of the rice production occurs in regions where temperatures are already above the ideal for crop growth (daytime maximum 28.8°C and night time minimum 22.8°C) (Krishnan *et al.,* 2011).

Each 18°C increase in the day time maximum-night time minimum temperatures within the 288.0-218.0 to 348.0-278.0° F range can decrease rice yields by about 7-8 per cent (Baker *et al.*, 1992).

A net negative impact on yield from moderate warming in coming decades may be observed. The impact of maximum temperature becomes negative at higher levels.

Diurnal temperature variation must be considered when investigating the impacts of climate change on irrigated rice in Asia. Rice crops in tropical and subtropical Asia have higher yields as maximum daily temperatures increase and lower yields as minimum daily temperatures increase (Welch *et al*., 2010).

Towards the end of this century (2091-2100), the yield loss would be around one tone per ha with the rise of 3.1°C of temperature and 46 per cent increase in rainfall, respectively. It is worth noting that the projected yield loss estimated by agronomic models (DSSAT and PRECIS models) was 356 kg ha^{-1} per decade (Geethalakshmi *et al*., 2011) in Tamil Nadu.

Krishnan *et al.,* (2007) reported that every 1.8°C increase in temperature decreases rice yield by 7.2 per cent at the current CO_2 concentration (380 ppm), but increases in CO_2 enrichment up to 700 ppm will lead to an average yield increase of about 31 per cent in India.

According to Bhuvaneswari *et al.,* (2014), rice yield reduction will be ranged from 4 -56 per cent with increase in temperature from 1.0 to 5.0°C respectively from the current climate. The different sowing windows tested as adaptation strategy to climate change indicated that the change in yield from current condition under early, normal, late planting during kharif season was -21.2, -15.0 and -16.3 per cent respectively for 3.0°C increase in temperature and 650 ppm CO_2 enrichment, during rabi season, it was -9.2, +10.2 and +11.0 per cent respectively.

On an average over the state with the climate change scenario studied, the rice maturity period is projected to shorten by 8 per cent and yield increase by 12 per cent. When temperature elevations only are taken into consideration, the crop simulations show a decrease of 8 per cent in crop maturity period and 6 per cent increase in yield. This shows that the increase in yield due to fertilization effect of elevated CO_2 and increased rainfall over the state as projected in the climate change scenario nearly makes up for the negative impact on rice yield due to temperature rise (Saseendran *et al*., 2000).

Without adaptation, losses in aggregate production are expected for wheat, rice and maize in both temperate and tropical regions by 2.0°C of local warming. Crop level adaptations increase simulated yields by an average of 7 to 15 per cent, with adaptations more effective for wheat and rice than maize. Yield losses are greater in magnitude for the second half of the century than for the first (Challinor *et al.,* 2014).

Direct effect of climate change in irrigated and well managed rice crops will always be positive in different agro climatic regions in India irrespective of the various uncertainties. Southern and western India, which are at present relatively cooler during the rice season compared to northern and eastern regions, are likely to show a greater sensitivity to climate change. In case climatic change has a negative effect on productivity effect on productivity varieties with greater temperature tolerance can easily mitigate the negative effects. There is an urgent need to document the temperature sensitivities of major crop varieties to changes in temperature (Aggarwal and Mall, 2002).

Some areas show no significant influence of climate variability, in substantial areas of the global bread baskets, more than 60 per cent of the yield variability can be explained by climate variability. Globally, climate variability accounts for roughly a third (-32 to -39 per cent) of the observed yield variability (Deepak *et al.,* 2015).

The change in yield from current condition under early, normal, late planting during kharif season was -21.2, -15.0 and -16.3 per cent respectively for 3.0°C increase in temperature and 650 ppm CO_2 enrichment. During rabi season, it was -9.2, +10.2 and +11.0 per cent, respectively (Bhuvaneswari, *et al.,* 2014).

Two potent short-lived climate pollutants (SLCPs), tropospheric ozone and black carbon, have direct effects on crop yields beyond their indirect effects through climate, emissions of black carbon and ozone precursors have risen dramatically in India over the past three decades. Yields in 2010 were up to 20 per cent lower for Rice than they otherwise would have been, absent climate and pollutant emissions trends (Burney and Ramanathan, 2014).

Aggregate yields are projected to decrease by an average of 18 per cent by 2030-2050 relative to 1980-2000 while the coefficient of variation of yield increases by an average of 47 per cent. Projections from 13 out of 15 climate models result in an aggregate increase in national yield coefficient of variation, indicating that maize yields are likely to become more volatile (Urban *et al.,* 2012).

Both maize and rice exhibit non-linear increases with time, with total area exposed for rice, during reproductive stage to critical temperature, projected to grow from eight per cent in the 2000s to 27 per cent by the 2050s, and maize from 15 to 44 per cent over the same period.

Warming is already slowing yield gains at a majority of wheat-growing locations. Global wheat production is estimated to fall by 6 per cent for each degree centigrade of further temperature increase and become more variable over space and time.

2.4 CLIMATE CHANGE ADAPTATION STRATEGIES FOR RICE

According to Smit *et al.* (1999) adaptation to climate change can be defined as an adjustment in natural or human systems in response to actual or expected climatic conditions or risks.

According to Smit and Skinner (2002) general adaptation strategies in crop management are improved varieties of crop and agronomy, including efficient use of fertilizers and water.

Akram *et al.* (2007) noted the effect of different planting dates from July 1 to 30 with 10 days interval on six rice varieties (98001, PK-5261-1-2-1, 97502, 98409, Basmati- 385 and super Basmati) at AARI, Faisalabad during 2002-2003. Different yield and yield parameters like number of tillers, grains per spike, plant height, 1000 grain weight and sterility were significantly affected. Basmati 385 and super Basmati produced maximum paddy yield when planted on July 11 and July 1 respectively. Prevailing weather conditions play a vital role in the performance of any crop including rice crop.

Kurukulasuriya and Mendelsohn (2008) stated that adaptation is a policy option for limiting the negative effects of climate change.

According to Munang *et al.* (2009) adjusting sowing date cannot be considered as a very effective method in mitigating the adverse effects of climate change. They also stated that the use of crop cultivars with specific genetic traits was a most effective method in reducing the adverse effects of climate change.

Nahar *et al.* (2009) reported that grain weight of Aman rice was influenced by transplanting dates. Among the planting dates 1st September transplanting provided the highest results whereas 30th September transplanting provided the lowest results for both cultivars (BRRI dhan 46 and BRRI dhan 31) during the year 2008 at Dhaka, Bangaladesh. BRRI dhan 46 had significantly higher values of yield attributes and yields than the BRRI dhan 31 in late transplanted conditions.

Aggarwal *et al.* (2010) noted that various adaptation methods such as growing improved varieties, efficient irrigation, fertilizer management and application of additional nitrogen will help to reduce the impact of climate change on rice. They also found that growing improved variety with better management of irrigation and fertilizer and provide additional but balanced fertilizers help to harvest a higher yield up to 15%.

According to Geethalakshmi *et al.* (2011) changing cultivation method can be accepted as an adaptation strategy on rice production. They also indicated that it will be helpful to reduce the use of water because under changing climate conditions more water scarcity is expected. They also added that field experiment conducted in the farmer's field of the Cauvery basin with different cultivation methods indicated that under the system of rice intensification (SRI) method, 22% increase in grain yield and 24.5% water saving were noticed compared to transplanted rice.

Foliar fertilizers cannot replace soil applied fertilizer completely but foliar fertilization enhance the uptake of nutrients applied to the soil (Bhuyan *et al.*, 2012).

According to Bhuyan *et al.* (2012) foliar fertilization is more suitable for micro nutrients but it is also applicable for major nutrients like Nitrogen, Phosphorous and Potassium mainly because the amount applied at any time is small and thus it requires several applications to meet the needs of a crop. They also added that foliar application of nitrogen fertilizer may be the most effective means for maximizing yield of rice.

Bhuyan *et al.* (2012) found that 9.33% increase in yield by foliar spray in bed planting over conventional method. They also noted a similar increase in number of panicles, grains per panicle and 1000 grain weight (gm).

Soora *et al.* (2013) reported that adaptation to climate change by sowing improved rice varieties can not only reduce negative impacts but also provide improved productivity–ranging from 1 % to 5 % in climate change scenarios. Even with current varieties, increasing input use efficiency and providing additional nitrogen fertilizers can improve yields by ~15 % in the 2020, and by ~25 % in the 2050 and later scenarios. In addition, adopting improved varieties can further improve yields by ~20% in the 2020, and by ~35–38 % in the 2050 and later scenarios.

The different sowing windows tested as adaptation strategy to climate change indicated that the change in yield from current condition under early, normal, late planting during kharif season was -21.2, -15.0 and -16.3% respectively for 3°C increase in temperature and 650 ppm CO_2 enrichment, during rabi season, it was -9.2, +10.2 and +11.0% respectively (Bhuvaneswari *et al.*, 2014).

According to Ahn Chun *et al.* (2015) adaptive management of fertilizer application degree and adjustment of planting dates in response to the varying climate are an effective combination as farmer-level adaptations. They also found that 100 kg N ha^{-1} of fertilizer application as the best fertilizer application in future to offset the negative impacts of climate change on rice. They also added that combinations of adaptation strategies such as irrigation, fertilizer management practices, and adjustment of planting dates may be able to substantially reduce the negative impacts of climate change on rice production. However, additional adaptation strategies may be required to offset the negative impacts of climate change on rice yields in the 2080s under RCP 8.5.

JiKun (2015) stated that considering farm management measures as an adaptation option will significantly increases the rice yield.

Banerjee *et al.* (2016) found that the simplest and effective adaptation option for rice will be adjustment of sowing time. They also indicated that increased rate of nutrient application will also help to sustain the rice yield under future climate.

Chapter 3. Materials and Methods

The present work entitled "Modeling the rice production under varied Agro-Ecological Situations of Palakkad district and its vulnerability to climate change" was taken up to study the impact of abiotic factors and farming practices on rice production with special emphasis to climate change under different agro-ecological situations. The materials used and methods followed are described below:

Figure 1. Agro-Ecological Units Maps of Palakkad

3.1 Collection of data

3.1.1 Meteorological data

Daily rainfall data for the period 1991-2014 were collected from 60 stations of Kerala state from the India Meteorological Department, Thiruvananthapurm Table 1 shows the name, latitude, longitude of the stations under study.

Table 1. Weather stations taken for the study

Sl.No	District	Station / Location	Latitude	Longitude
1	Palakkad	Palakkad	10°46’N	76°39’E
2		Alathur	10°38’N	76°33’E
3		Chittur	10°42’N	76°45’E
4		Kollengode	10°37’N	76°43’E
5		Mannarkkad	10°09’N	76°34’E
6		Ottappalam	11°40’N	76°15’E
7		Parambikulam	10°20’N	76°45’E
8		Pattambi	10°48’N	77°12’E
9		Trithala	10°50’N	76°06’E

3.1.2. Crop and Soil data

Agro Ecological Unit wise information on area and production of various crops were collected fiom Agro Ecology of Kerala, Published by NBSS & LUP and Kerala State Planning Board, 2012.

3.1.2.1. Soil Sample Collection

Soil samples were collected in a stratified random sampling by selecting individual soil cores in a random pattern from 15 plots. These plots were selected from major five rice growing AEUs of Palakkad district.

Surface soil samples (0 - 20 cm) were taken in each of the selecting sites and used for the study. Enough number of such pits were taken depending upon the site characteristics. For determining the bulk density, soil samples were collected by using cylinder. Geographical coordinates of the sampling sites were marked during the sample collection. Soil samples were packed and taken to the laboratory.

The samples that are collected for determining bulk density was directly placed into the oven by determining its fresh weight. Samples that are used for nutrient analysis were dried and sieved through 0.5mm and 2mm sieve.

3.1.2.2. Analysis of Basic Soil Properties

Analytical methods of soil properties like soil pH, bulk density, texture, soil organic carbon and soil available nitrogen, phosphorous and potassium are described below:

3.1.2.3. pH

The pH of the soil was determined in 1:2:5 soil water suspension. 5g sample of soil was transferred into a 50 ml beaker through 2 mm sieve. 25 ml of distilled water was added, stirred well for about 5 minutes and kept for half an hour. Stirred well again and took the reading using pH meter (Jackson, 1958).

3.1.2.4. Soil Texture

The texture of the soil was carried out by using the international pipette method.

$$\text{Clay (\%)} = \frac{\text{Corrector reading at 2 hrs}}{\text{Weight of the soil}} \times 100$$

$$\text{Slit (\%)} = \frac{\text{Reading at 4min} - \text{Corrector reading at 2hrs}}{\text{Weight of the soil}} \times 100$$

$$\text{Sand (\%)} = 100 - (\text{\% slit} + \text{\% clay})$$

3.1.2.5. Bulk density

The bulk density of the soil was found out by using core of soil by using a core sampler. The core was taken out without pressing the cylinder too hard on the soil so that the natural bulk density of the soil may not get disturbed. The collected soil was oven dried and weight was determined. The volume of the soil was calculated by measuring the volume of the cylinder ($\pi r^2 h$). The bulk density was calculated by dividing the oven dry weight of soil samples (g) by volume of the soil.

3.1.2.6. Soil organic carbon

Organic fraction of the soil is oxidised by treatment with a hot mixture of potassium dichromate ($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4) . Immediately swirl the flask gently until the soil and the reagents get mixed. Allow the stand about 30 minutes, then add 200 ml of water to the flask and 3-4 drops of phenaphthaline indicator and titrate the solution with 0.5N ferrous ammonium sulphate. Make a blank determination in the same manner, but without soil for the calculation (Walkely, 1947).

$$\text{Organic carbon (\%)} = \frac{(\text{Blank value} - \text{Titre value}) \times 0.5 \times 0.003 \times 100}{\text{Weight of soil}}$$

3.1.2.7. Available nitrogen

Available nitrogen in the soil was determined by alkaline permanganate method (Subbiah and Asija, 1956).

3.1.2.8. Available phosphorus

Available phosphorus was extracted using Bray-1 extractant (Bray and Kurtz, 1945) and the P content was colorimetrically assayed (Chloromolybdic acid blue colour method). The reducing agent was ascorbic acid (Jackson, 1973).

Phosphorus (kg/ha) = Reading× (25/5) × (25/2.5) × 2.24

3.1.2.9. Available potassium

Available potassium was determined by flame photometry using 1N neutral normal ammonium acetate solution as the extractant (Jackson, 1973).

Potassium (kg/ha) = Reading × (25/5) × 2.24

3.2 Methodology

The daily weather data has been analysed on weekly, monthly, seasonal and annual basis. Mean values for the above periods have been computed for maximum temperature and minimum temperature, while totals were computed for rainfall for all the years. Seasons have been identified as per the following:

1. Winter: January to February
2. Summer: March to May
3. South West Monsoon: June to September
4. North East Monsoon: October to November

3.2.1 Rainfall

Mean weekly, monthly, seasonal and annual rainfall were worked from the totals obtained as above. Coefficient of variation for the above periods were also woked out. Spatial variation mean rainfall and coefficient of variation during the different seasons over the entire state has been presented.

In rainfed agriculture, it is important to know the amount of rainfall that can be expected at least in 3 out of 4 years rather than simple mean rainfall. This is known as the dependable rainfall i.e., rainfall received at 75 per cent probability level. A simple ranking method as described by Doorenbos and Pruitt (1977) and Frere and Papov (1982) was used for the computation of dependable rainfall for the stations. The method is as follows:

The monthly rainfall records for every station were arranged in decreasing order and each record was assigned a ranking number 'm'. Every ranking number has a 1 Probability level Fa (m) which is expressed as, = 100 m.

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

Where, n = Number of records. The rank number which has a probability level of 75 per cent and 90 per cent was calculated. The rainfall record corresponding to this rank number gave the rainfall having the corresponding probability. Weekly dependable rainfall at 75 per cent and 90 per cent were calculated using the above mentioned ranking method. As month is too long a period for agricultural operational planning, analysis on weekly rainfall was carried out. Both the initial and conditional probabilities of receiving 30 mm or more rainfall per week were worked out, following the methodology given by Virmani *et al.* (1982) which is as follows:

If the rainfall in a particular week is more than the specified amount, it is called a Wet week (W) otherwise called a Dry week (D).

$$\mathrm{P(Wj)} = \frac{\mathrm{N(Wj)}}{\mathrm{N}}$$

Where

P (Wj) is the probability of receiving a certain amount of rainfall during the jth week

N (Wj) is the Number of occurrence of W during the jth week

N is Number of observation

Hence, P (Dj) = 1- P (Wj)

Similarly, probability of next week being wet, if the current week is wet P (w/w) were also worked out. Initial and conditional probabilities of receiving 30mm or more rainfall was worked out for all the stations.

3.2.2. Potential Evapotranspiration (PET)

The potential evapotranspiration has been computed on a weekly basis for the all the stations where data on temperature, humidity, wind and sunshine duration are available. The method suggested by Doorenbos and Pruitt (1977) is used as it is widely accepted. The method is as follows:

$$ET_o = c\,[W.Rn + (1-w).\,flu).\,(ea-ed)]$$

Where

ETo = Reference crop evapotranspiration in mm/day

W = Temperature - related weighting factor

Rn = Net radiation in equivalent evaporation in mm/day

f(u) = Wind related function

(ea-ed) = Difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air both in millibar.

C = adjustment factor to compensate for the effect of day and night weather conditions.

PET for all the rain gauge stations has been interpolated based on Agro Ecological Units.

3.2.3. Water Balance Studies

Water balances have been computed following the book-keeping method of Thornthwaite and Mather (1955). The field capacity of the soil to hold moisture was assumed considering the type of soil and vegetation. Weekly water balances for all the stations have been computed by taking the dependable rainfall and the interpolated PET. The spatial variation of actual evapotranspiration, water surplus and water deficit over the state is presented.

Thornthwaite's Method of Water-Balance Computation

An example of Thornthwaite's method of water – balance computation is given in the table. To facilitate the use of this method step by step description to estimate the various components and book – keeping procedures follows:

The requirements are the data of mean monthly temperature, the latitude of the station, the monthly precipitation and tables and charts prepared by the author (Thornthwaite and Mather, 1957).

Step 1. Unadjusted potential evapotranspiration (Unadj *PE*) to be ascertained from the monogram and the tables given by Thornthwaite (Thornthwaite and Mather, 1957).

Step 2. Adjusted potential evapotranspiration (*PE*). Correct the unadjusted *PE* values according to the latitude of the stations and to the month of the year (Thornthwaite and Mather, 1957).

Step 3. *P* is the rainfall and can be snowfall.

Step 4. *P – PE*.

This is the difference between precipitation and the adjusted potential evapotranspiration.

If *P* is less than *PE*, the value is negative.

If *P* is more than *PE* the value is positive.

Step 5. Accumulated Potential Water Loss (Acc Pot WL).

In wet climate

Where $P > PE$ (annual values)

Start with 0 in the month just before the one where negative value of *P – PE* has started.

In dry climate where $P < PE$ (annual values)

Find the potential value of water deficiency with which to start accumulating negative value of *PE*.

The starting value can be found as follows:

a) Sum up all the negative *P – PE* values
b) Sum up all the positive *P – PE* values

c) Locate the value arrived in '*a*' (Thornthwaite and Mather, 1957) and locate corresponding value of actual retention

d) Locate the value arrived in step c on the vertical scale on the left side of the figure 1.2 (Thornthwaite and Mather, 1957).

e) Follow horizontally across on this line until it intersects the sloping line whose value equals the sum of the positive $P - PE$ (step b). Read the value of the potential deficiency with which start accumulation.

Step 6. Storage (St)

For the negative values of $P - PE$, locate the storage figures using table 1.3 (Thornthwaite and Mather, 1957)

For the positive $P - PE$ values proceed as

a) Locate the las negative value in the column $P - PE$
b) Note the storage value of '*a*'
c) Add to the value of (b) the first positive integer (That is the positive value next to the negative value).
d) Complete the procedure for the rest of the months.

***Step** 7*. Change in soil moisture (ΔSt)

It is the difference in the storage value of two consecutive months. No difference is recorded when the values are above 300.

Step 8. Actual Evapotranspiration (AE)

When $P > PE$

Then $PE = AE$

When $P < PE$

then $AE = P + St$* (Soil moisture storage)

*The negative sign of S is not considered.

It means teat AE is the sum of P and St without considering the sign of St.

Step 9. Moisture deficit (D)

It is the difference between $PE - AE$ or $D = PE - AE$

Step 10. Moisture surplus (S)

1) Surplus exists when storage (St) is 300 and more and $P - PE$ is positive.

2) When the storage values are moving up towards 300, the first surplus will be $(P - PE) - St$.

Step 11. Water Run-off (*RO*)

RO is the one half of the surplus (*S*), the rest half goes to the next month. This should be added to the surplus of that month. Again, one-half of that month will be the run-off Add the remaining one-half to the Sof the next month and the procedure continues.

Step 12. Snow-Melt Run Off (*SMRO*)

It is computed in areas of snow fall.

Step 13. Total Run-Off (*Tot. RO*)

It is the sum of the water surplus run-off and the snow-melt run-off.

Step 14. Total Moisture Detention (*DT*)

It is the sum of storage *St* and total run-off.

3.2.4. Index of moisture adequacy

The index of moisture adequacy (IMA) is the ratio of the actual evapotranspiration to the potential evapotranspiration, expressed as a percentage. This can be used for assessing the moisture status in relation to the water need at a place. IMA quantifies the moisture supply to potential need which becomes unity under conditions of potential water supply. The index of moisture adequacy can be utilized for determination of crop distribution and estimation of irrigation scheduling. IMA for all the stations in the central zone has been computed.

3.2.5. Water availability periods

The knowledge on the length of water availability periods will help to understand 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 evaporation. There are several methods for assessing the water availability periods based on monthly or weekly mean f rainfall. However, mean rainfall data has limited utility and hence, Subramaniam and Kesava Rao (1983) have presented a method to determine water availability for optimization of crop growth. The method requires computation of water balances using dependable rainfall and comparison of AET with PET. The four water availability periods are defined as follows:

Humid period: AET ≥ PET/2

Sub humid period: PET/2 > AET > PET/4

Semi dry period: PET/4 > AET > PET/8

Dry period: PET/8 > AET

Following the above, the number of days under different categories were worked out for all the stations. Moisture availability periods were estimated by combining the humid and sub humid periods. The number of days under humid period and sub humid period were added to get the total number of moist days.

3.3. Software

Weather cock v.1.5 developed by Central Research Institute for Dryland Agriculture (CRIDA) has been used for convert the daily weather data into standard week, month and seasonal formats. It is also used to compute initial and conditional probabilities of rainfall, PET and Thornthwaite water balances.

QGIS, which is a cross-platform free and open-source desktop geographic information system (GIS) application that provides data viewing, editing, and analysis is used for spatial representation and to create maps.

CERES-Rice has been used in this study to model the effect of weather parameters on crop growth and yield. The CERES models have been extensively used for assessment of the impact of climatic change on agricultural crop production. CERES-Rice model is physiologically oriented and simulates rice response to climate variables (Singh *et al.,* 1994).

The simulation of rice growth was performed with the CERES-Rice. Model developed by the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). The IBSNAT models were employed for the simulation of crop response to climate change because they have been already validated for a wide range of climates all over the world and are independent of location or soil type encountered.

The CERES-Rice (Crop Estimation through Resource and Environment Synthesis) model (Ritchie, 1986 and Godwin *et al.*, 1990) was adopted as the basis to simulate the effects of cultivar, planting density, weather, soil water and nitrogen on crop growth, development and yield. CERES- Rice model shared a common input and output data format, which had been developed and embodied in a software package called Decision Support System for Agro-technology Transfer (DSSAT) (Tsuji *et al.*, 1994).

Validation of CERES-Rice requires to develop genetic coefficients based on the varietal characters of the variety and the details are as follows:

Table 2. Genetic Coefficients for the CERES Rice model

P1	Time period (expressed as growing degree days [GDD] in °C above a base temperature of 9°C) from seedling emergence to end of juvenile phase during which the rice plant is not responsive to changes in photoperiod. This period is also referred to as the basic vegetative phase of the plant.
P2R	Extent to which phasic development leading to panicle initiation is delayed (expressed as GDD in °C) for each hour increase in photoperiod above P2O.
P2O	Critical photoperiod or longest day length (in hours) at which the development occurs at maximum rate. At values higher than P2O the development rate is slowed (depending on P2R), there is delay due to longer day length.
P5	Time period in GDD in °C from beginning of grain-filling (3-4 days after flowering) to physiological maturity with base temperature of 9.0°C
G1	Potential spikelet number coefficient as estimated from number of spikelet per g of main culm dry weight (less leaf blades and sheaths plus spikes at anthesis. A typical value is 55.
G2	Single dry grain weight (g) under ideal growing conditions. i.e., non-limiting light, water, nutrients, and absence of pests and diseases.
G3	Tillering coefficient (scalar value) relative to IR64 cultivars under ideal conditions. A higher tillering cultivar would have coefficient greater than 1.
G4	Temperature tolerance coefficient. Usually 1.0 for cultivars grown in normal environment. G4 for japonica type rice grown in warmer environments would be ≥ 1.0. Tropical rice grown in cooler environments or season will have G4 < 1.0

The minimum data set required for the operation and calibration of the CERES -Rice is (Hoogenboom, *et al.,* 2012) given below,

3.3.1. Data required

3.3.1.1 Level 1 Data

Weather Data Required (Daily)

1. Minimum and maximum temperature
2. Rainfall
3. Total solar radiation or sunshine hours
4. Dew point temperature or relative humidity
5. Average daily wind speed

Soil Data

1. General site information
2. Soil surface information
3. Soil profile data, for each soil horizon in which roots are likely to grow

Initial Conditions

1. Previous field history
2. Initial soil profiles conditions
3. Surface residues at the start of simulation or at planting

Management Data

1. Planting
2. Input information

3.3.1.2 Level 2 Data

Crop and Soil Response Measurements

1. Treatments
2. Yield and yield components
3. General observations

3.3.1.3 Level 3 Data

1. Growth analysis measurements
2. Soil water content versus depth
3. Soil fertility versus depth

3.3.2 *Calibration of CERES-Rice model*

Data obtained from the previous experiments and literatures were used for calibration of the model. Major varieties used for simulation are Jyothi, Uma, Kanchana and Vyshak. The genetic coefficients that influence the occurrence of developmental stages in the CERES –Rice model were derived iteratively, by manipulating the relevant coefficients to achieve the best possible match between the simulated and observed phenological events as well as the model was calibrated for yield parameters and grain yield.

3.3.3 *Validation of CERES Rice*

Validation is the comparison of the results of model simulations with observations that were not used for the calibration. The experimental data collected were used for independent model validation. Statistical index used for model validation is

$$\text{RMSE (Root Mean Square Error)} = \sqrt{\frac{\sum_{t=1}^{n}(\text{Pi} - \text{Oi})^2}{\text{n}}}$$

Where Pi and Oi refer to the predicted and observed values for the studied variables (e.g. grain yield and total biomass) respectively and n is the mean of the observed variables.

3.4. Climate change Scenarios

Impacts of climate change will depend not only on the response of the Earth system but also on how humankind responds. These responses are uncertain, so future scenarios are used to explore the consequences of different options. The scenarios provide a range of options for the world's governments and other institutions for decision making. Policy decisions based on risk and values will help determine the pathway to be followed.

The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) has introduced a new way of developing scenarios. These scenarios span the range of plausible radiative forcing scenarios and are called representative concentration pathways (RCPs).

RCPs are concentration pathways used in the IPCC Assessment Report5 (AR5). They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modelling community.

The pathways are characterized by the radiative forcing produced by the end of the 21st century. Radiative forcing is the extra heat the lower atmosphere will retain as a result of additional greenhouse gases, measured in Watts per square meter.

Table 3. Description of representative concentration pathway (RCP) scenarios

RCP	Description
RCP2.6	Its radiative forcing level first reaches a value around 3.1 Wm^{-2} mid-century, returning to 2.6 Wm^{-2} by 2100. Under this scenario greenhouse gas (GHG) emissions and emissions of air pollutants are reduced substantially over time.
RCP4.5	It is a stabilization scenario where total radiative forcing is stabilized before 2100 by employing a range of technologies and strategies for reducing GHG emissions.
RCP6.0	It is a stabilization scenario where total radiative forcing is stabilized after 2100 without overshoot by employing a range of technologies and strategies for reducing GHG emissions.
RCP8.5	It is characterized by increasing GHG emissions over time representative of scenarios in the literature leading to high GHG concentration levels.

Climate change data projected by GCM's on daily basis is used for the present study. Daily data of following variables has taken

1. Rainfall
2. Maximum Temperature
3. Minimum Temperature
4. Solar radiation

The regional climate scenarios including radiation, Maximum temperature (T_{max}), Minimum temperature (T_{min}) and precipitation as inputs of the Thornthwaite water balance to simulate the impacts of climate change on water balance of Kerala.

The results of the experiment entitled "Modeling the rice production under varied Agro-Ecological Situations of Palakkad district and its vulnerability to climate change" are presented in this chapter. The effect of different weather parameters and other abiotic parameters on growth and yield of different varieties were studied. The Crop simulation model DSSAT-developed by IBSNAT was used for studying the impact of climate change based on IPCC projections for the year 2030, 2050 and 2080 under different Representative Concentration Pathways.

4.1. Rainfall analysis of various AEUs of Palakkad district

The Palakkad district has alienated in to eight agro-ecological units such as North central laterites (AEU10), Northern foothills (AEU13), Southern high hills (AEU14), Northern high hills (AEU15), Attappady hills (AEU18), Attappady dry hills (AEU19), Palakkad central plains (AEU22), Palakkad eastern plains (AEU23) and these agro-ecological units covers an area of 86,134 ha.(19.24%), 54,961 ha.(12.28%), 55,452 ha.(12.39%), 54,828 ha.(12.25%), 8872 ha.(1.98%), 18495 ha.(4.13%), 112,957 ha.(25.23%) and 47,049 ha.(10.51%) respectively. Out of the eight agro-ecological units rice cultivation is predominant in five AEUs and the are North central laterites (AEU10), Northern foothills (AEU13), Northern high hills (AEU15), Palakkad central plains (AEU22) and Palakkad eastern plains (AEU23). The amount and distribution of rainfall is considered as the most important weather parameter that determines area and production of rice in the district. Palakkad district is blessed with irrigation facilities. Eight irrigation dams have been constructed across almost all the important tributaries of the Bharathapuzha to provide irrigation facilities to the district.

4.1.1. Impact of climate change on rainfall distribution in North central laterites (AEU10) in Palakkad districts

The North Central Laterites (AEU 10) is delineated to represent midland laterite terrain with extended dry period. Thrithala block, Pattambi block, Ottappalam block, Shornur Municipality and Ottappalam municipality are come under this AEU.

4.1.2. Rainfall and Rainy days of North central laterites (AEU10) in Palakkad district

The monthly rainfall distribution of North central laterites (AEU10) for the present and projected climate (RCP 4.5 and 8.5) were studied and presented in table 4.

Table 4. Monthly rainfall distribution of North central laterites (AEU10) and the projected climate in Palakkad district

Rainfall (mm)		RCP 4.5			RCP 8.5		
Month	Present	2030	2050	2080	2030	2050	2080
January	0	0	0	0	0	0	0
February	0	0	5	12.1	0	5.9	0
March	0	6.6	8.6	12.4	10.3	7.2	10.9
April	23.6	44.8	8.7	28	9.2	3.9	9.3
May	236.1	296.2	282.1	228.9	256.5	325.1	258
June	522.9	1060.3	996.5	1050.1	1098.2	864.5	867.9
July	671.9	1121.7	1343.4	1000.5	1144.7	1048.4	1084.7
August	705.1	379.9	441.3	453.4	462.9	473.8	475
September	195.9	3.9	5.1	3.1	2.9	10.3	72.8
October	303.4	236.3	231.8	258.4	253.3	256.2	249.2
November	72.1	16.2	23.3	61.4	44.7	46.1	19
December	21.5	36.8	45.1	50.9	21.3	20.6	18.9
Total	**2752.5**	**3202.7**	**3390.9**	**3159.2**	**3304**	**3062**	**3065.7**

In the current situation July and August are the wettest months, having a rainfall of 671.9 mm and 705.1 mm. There is no rainfall during the months January, February and March. Based on RCP 4.5 and 8.5, there will be a probability of getting maximum rainfall during June and July in the projected climate. And the lowest rainfall gets during January and February. Compared to the present condition the rainfall of projected climate will shows a drastic decrease during August and September. As per RCP 4.5 the total rainfall shows an increase in 2050 from 2030 and it decreases in 2080. But according to RCP 8.5

the total rainfall shows a decreasing trend. In projected climate there will be an increase in yearly rainfall with contrast to the present condition.

The monthly rainy days of North central laterites (AEU10) for the present and projected climate (RCP 4.5 and 8.5) were analyzed and represented in table 5.

Table 5. Monthly rainy days of North central laterites (AEU10) and the projected climate in Palakkad district

Rainy days		RCP 4.5			RCP 8.5		
Month	Present	2030	2050	2080	2030	2050	2080
January	1	0	0	0	0	0	0
February	1	0	1	2	0	1	0
March	1	1	2	2	2	1	2
April	5	4	1	3	1	1	1
May	7	11	12	13	12	12	12
June	22	25	25	27	25	26	26
July	23	25	25	26	25	26	27
August	18	12	13	15	15	15	15
September	12	1	1	0	0	1	4
October	12	11	10	10	10	10	10
November	6	3	3	4	3	3	2
December	1	4	5	3	3	3	3
Total	**109**	**97**	**98**	**105**	**96**	**99**	**102**

In the present condition, June and July have the maximum number of rainy days and it is about 22 to 23 days. December, January, February and March showed the lowest number of rainy days. According to RCP 4.5 and 8.5, the maximum rainy days will be 27 days in July and the there will be no rainy days in January. As per RCP 4.5 and 8.5 the projected climate shows an increasing trend in the yearly rainy days of north central laterites. The annual rainy days of projected climate shows a slight decrease from the present condition.

For the current condition and projected climate, the seasonal rainy days of north central laterites (AEU10) were examined and given in table 6.

Table 6. Seasonal rainy days of North central laterites (AEU10) and the projected climate in Palakkad district

RCP	Season	Winter		Summer		South West		North East	
	Year	Rainy Days	Rainfall	Rainy Days	Rainfall	Rainy Days	Rainfall	Rainy Days	Rainfall
	Present	1	15	13	263.7	75	1889.6	18	409.9
4.5	2030	0	0	16	347.6	63	2565.8	18	289.3
	2050	1	5	15	299.4	64	2786.3	18	300.2
	2080	2	12.1	18	269.3	68	2507.1	17	370.7
8.5	2030	0	0	15	276	65	2708.7	16	319.3
	2050	1	5.9	14	336.2	68	2397	16	322.9
	2080	0	0	15	278.2	72	2500.4	15	287.1

Presently, the maximum number of rainy days occurs during south west monsoon followed by north east, summer and winter season. According to projected climate the highest number of rainy days will get in South West monsoon followed by north east and summer season and there will be an intensified rainfall during south west monsoon. North West monsoon shows a decreasing trend in rainfall in projected climate compared to the existing condition. In projected climate there will be a drastic decrease in rainfall during winter season and a slight increase in summer rainfall.

4.1.2. High rainfall events of North central laterites (AEU10) in Palakkad district

For the present condition and projected climate, the high rainfall events of north central laterites (AEU10) were studied and given in table 7.

Table 7. High rainfall events of north central laterites (AEU10) and the projected climate in Palakkad district

Year		RCP 4.5					RCP 8.5				
	Rainfall (mm)	10 <25	25 <50	50 <75	75 <100	>= 100	10 <25	25 <50	50 <75	75 <100	>= 100
	Season	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
Present	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	1	1	0	1	1	1	1	0	1	1
	SWM	25	18	7	2	2	25	18	7	2	2
	NEM	6	3	2	0	0	6	3	2	0	0
	Total	**32**	**22**	**9**	**3**	**3**	**32**	**22**	**9**	**3**	**3**
2030	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	3	1	2	1	0	3	3	1	0	0
	SWM	19	23	8	4	4	20	16	9	7	4
	NEM	6	3	1	0	0	6	2	0	1	0
	Total	**28**	**27**	**11**	**5**	**4**	**29**	**21**	**10**	**8**	**4**
2050	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	3	4	1	0	0	4	2	3	0	0
	SWM	19	21	7	7	5	22	17	11	4	2
	NEM	6	3	1	0	0	6	2	0	1	0
	Total	**28**	**28**	**9**	**7**	**5**	**32**	**21**	**14**	**5**	**2**
2080	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	6	2	1	0	0	2	2	2	0	0
	SWM	19	19	11	5	2	29	17	11	3	3
	NEM	7	4	0	1	0	5	3	1	0	0
	Total	**32**	**25**	**12**	**6**	**2**	**36**	**22**	**14**	**3**	**3**

In projected climate based on RCP 4.5 the number of high rainfall events shows an increasing trend but in the case of low rainfall events there will be a slight variation in 2030 and 2050. And it increases in 2080. In the case of RCP 8.5 the low rainfall events show an increasing trend compared to the present condition but there will be decrease in high rainfall events from 2030. In projected climate as indicated by RCP 8.5 there will be an increase in high rainfall events as compared to the present condition.

4.2. Rainfall analysis of Northern foothills (AEU13) and climate change impacts in Palakkad districts

4.2.1. Rainfall and Rainy days of Northern foothills (AEU13) in Palakkad district

The monthly rainfall distribution of Northern foothills (AEU13) for the present and projected climate (RCP 4.5 and 8.5) were analyzed and presented in table 8.

Table 8. Monthly rainfall distribution of Northern foothills (AEU13) and the projected climate in Palakkad district

Rainfall (mm)		RCP 4.5			RCP 8.5		
Month	Present	2030	2050	2080	2030	2050	2080
January	1.7	0	0	0	0	0	0
February	11.3	0	0	0	0	0	0
March	33.4	35.5	10.3	15	20.3	40.6	28.6
April	114.8	20.6	10.2	34.3	24	35.6	8.1
May	165.1	189.1	256.3	346.1	280.8	265.8	272.6
June	515.2	722.5	824.4	883.3	769.9	621.3	695
July	571.9	1083.3	1093.4	1097.7	1005.1	1035.5	913.2
August	332	451	477	510.1	468.5	540	568.9
September	266.8	2.7	8.8	7.3	8.7	7.2	61
October	371	245.5	254.8	265.1	249.5	264.2	280.8
November	158.5	42.2	57.9	61	57.3	44.3	45.2
December	18.3	22.1	40.3	50.3	40.6	56.7	64.4
Total	**2560**	**2814.5**	**3033.4**	**3270.2**	**2924.7**	**2911.2**	**2937.8**

In the present situation, there is sufficient amount of rainfall getting in April, May, June, July and August. June and July are the months having maximum amount of rainfall and the lowest rainfall in January and February. Based on RCP 4.5 and 8.5 in projected climate there will be a chance of getting high amount of rainfall in June and July as compared to the present climate. But there will be a drastic decrease in rainfall during March, April and September. As per RCP 4.5 in the case of annual rainfall there will be an increase compared to the present condition and in RCP 8.5 it shows a slight variation. The amount of yearly rainfall going to occur will be higher than the present condition.

The month to month rainy days of Northern foothills (AEU13) for the present and projected climate (RCP 4.5 and 8.5) were investigated and given in table 9.

Table 9. Monthly rainy days of Northern foothills (AEU13) and the projected climate in Palakkad district

Rainy days		RCP 4.5			RCP 8.5		
Month	Present	2030	2050	2080	2030	2050	2080
January	1	0	0	0	0	0	0
February	1	0	0	0	0	0	0
March	2	3	2	3	2	3	5
April	6	2	2	4	2	2	2
May	8	13	11	14	14	14	9
June	20	23	23	24	23	23	23
July	23	27	25	24	26	24	26
August	17	15	14	14	15	15	16
September	12	0	1	1	1	1	3
October	16	10	10	10	10	10	10
November	7	3	4	4	4	3	3
December	1	3	3	3	3	4	5
Total	**114**	**99**	**95**	**101**	**100**	**99**	**102**

In the current condition, June and July have the most extreme number of rainy days and it is around 20 to 23 days. Also, the least is in January, February and December. According to RCP 4.5 and 8.5, the most extreme number of rainy days will be happening in June and July and the base will be in January and February. The most extreme rainy days will be 26 days. The projected climate demonstrates a diminishing pattern in the yearly rainy days of Northern foothills contrasted with the current condition. According to RCP 4.5 there will be a lessening in the quantity of rainy days from 2030 to 2050 however it increments in 2080. But, as per RCP 8.5 there will be no variety in the quantity of rainy days in 2030 and 2050 yet it demonstrates a slight expansion in 2080.

The seasonal rainy days of Northern foothills (AEU13) for the existing condition and projected climate were examined and given in table 10.

Table 10. Seasonal rainy days of Northern foothills (AEU13) and the projected climate in Palakkad district

RCP	Season	Winter		Summer		South West		North East	
	Year	Rainy Days	Rainfall	Rainy Days	Rainfall	Rainy Days	Rainfall	Rainy Days	Rainfall
	Present	1	13	16	313.3	72	1685.8	24	547.8
4.5	2030	0	0	18	245.2	65	2259.5	16	309.8
	2050	0	0	15	276.8	63	2403.6	17	353
	2080	0	0	21	395.4	63	2498.4	17	376.4
8.5	2030	0	0	18	325.1	65	2252.2	17	347.4
	2050	0	0	19	342	63	2204	17	365.2
	2080	0	0	16	309.3	68	2238.1	18	390.4

Currently, the maximum number of rainy days occurs during south west monsoon time (72 days) followed by North East (24 days), summer season (16 days) and winter season (1 day). According to projected climate the highest number of rainy days and high amount of rainfall will get in South west monsoon followed by North East. There will be no rainy day occurring in winter season. There will be a drastic decrease in rainfall during winter season as compared to the current condition. The projected climate shows an intensified rainfall in Southwest as compared to the previous years. There will be a decreasing trend in the north east monsoon rainfall and summer rainfall shows a slight variation.

4.2.2. High rainfall events of Northern foothills (AEU13) in Palakkad district

For the present condition and projected climate, the high rainfall events of Northern foothills (AEU13) were studied and given in table 11.

Table.11. High rainfall events of Northern foothills (AEU13) and the projected climate in Palakkad district

Year	Rainfall (mm)	RCP 4.5					RCP 8.5				
		10 <25	25 <50	50 <75	75 <100	>= 100	10 <25	25 <50	50 <75	75 <100	>= 100
	Season	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
Present	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	3	3	0	0	0	3	3	0	0	0
	SWM	25	24	9	1	1	25	24	9	1	1
	NEM	7	2	0	0	1	7	2	0	0	1
	Total	**35**	**29**	**9**	**1**	**2**	**35**	**29**	**9**	**1**	**2**
2030	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	7	3	0	0	0	8	3	1	0	0
	SWM	22	15	13	3	1	23	16	11	3	2
	NEM	6	2	0	1	0	8	2	0	1	0
	Total	**35**	**20**	**13**	**4**	**1**	**39**	**21**	**12**	**4**	**2**
2050	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	2	3	1	0	0	8	4	1	0	0
	SWM	20	16	10	4	4	20	17	5	9	1
	NEM	8	2	0	1	0	7	3	0	1	0
	Total	**30**	**21**	**11**	**5**	**4**	**35**	**24**	**6**	**10**	**1**
2080	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	5	3	2	0	0	2	2	1	1	0
	SWM	17	19	8	6	4	20	21	6	3	3
	NEM	6	5	0	1	0	7	3	0	1	0
	Total	**28**	**27**	**10**	**7**	**4**	**29**	**26**	**7**	**5**	**3**

Currently the number of rainfall events occurring is more in the range of 10 to 50 mm. But in the case of heavy rainfall which is in the range 50 to more than 100 mm the number of rainfall events is less. Comparing the present to the projected climate based on RCP 4.5 there will be a decreasing trend in the number of rainfall events during low rainfall.

In the case of heavy rainfall, the number of rainfall events shows an increasing trend. As per RCP 8.5, there will be an increase in low rainfall events in 2030 and then it shows a decreasing trend. But based on RCP 8.5, in 2050 the number of rainfall events in the scope of 75 to 100 mm, there will be a chance of drastic increase.

4.3. Rainfall analysis of Northern high hills (AEU15) and climate change impacts in Palakkad districts

4.3.1. Rainfall and Rainy days of Northern high hills (AEU15) in Palakkad district

The monthly rainfall distribution of Northern high hills (AEU15) for the present and projected climate (RCP 4.5 and 8.5) were studied and represented in table 12.

Table.12. Monthly rainfall distribution of Northern high hills (AEU15) and the projected climate in Palakkad district

Rainfall (mm)		RCP 4.5			RCP 8.5		
Month	Present	2030	2050	2080	2030	2050	2080
January	8.6	0	11.2	2.5	0	11	18.8
February	12.8	7.2	16.9	15.7	9.9	16.8	12.6
March	18.2	18.2	15.9	18.5	25.2	16.6	12.6
April	113.5	2.4	23.3	60.4	0.4	34.3	14.9
May	156.7	235	94.1	108.2	332.7	119.5	129.1
June	495.5	272.7	297.4	354.8	412.5	324.5	295.5
July	579.6	556.8	506.9	425.2	511.1	509.6	671.8
August	370.6	411.1	380.6	386	393.2	391.4	355
September	206.8	42.6	80.9	82	47.8	82.2	66.2
October	270	236.5	269.6	283.5	212.7	244.3	200.7
November	135.4	12.3	146.9	144.3	24.1	185.2	96.7
December	30.1	27.5	55.3	25.3	32.3	54.5	48.7
Total	**2397.8**	**1822.3**	**1899**	**1906.4**	**2001.9**	**1989.9**	**1922.6**

In the present condition January is the month having low rainfall. July and August are the months having highest rainfall of 495.5 mm and 579.6 mm. As per RCP 4.5 and

8.5, there will be a decreasing trend in rainfall during June and July. And August shows an increase in rainfall in projected climate. Comparing the projected climate and present condition, the rainfall distribution shows a drastic decrease in the month April and September. As per RCP 4.5 and 8.5 the total rainfall shows a diminishing pattern as compared to the present climate.

The monthly rainy days of Northern high hills (AEU15) for the present and projected climate (RCP 4.5 and 8.5) were examined and given in table 13.

Table.13. Monthly rainy days of Northern high hills (AEU15) and the projected climate in Palakkad district

Rainy days		RCP 4.5			RCP 8.5		
Month	Present	2030	2050	2080	2030	2050	2080
January	1	0	2	1	0	2	1
February	1	1	1	1	2	1	2
March	2	3	2	2	3	2	2
April	10	0	2	4	0	3	2
May	11	9	8	10	11	9	7
June	20	20	14	18	18	18	18
July	24	22	24	22	21	23	26
August	20	18	18	18	19	19	18
September	13	2	4	4	3	4	4
October	16	8	12	13	8	12	10
November	9	1	4	4	3	5	4
December	2	4	7	4	4	7	4
Total	**129**	**88**	**98**	**101**	**92**	**105**	**98**

In the current condition, July has the maximum number of rainy days and it is about 24 days. And the lowest is in January and February. According to RCP 4.5 and 8.5, the maximum rainy days will be 26 days in July and the minimum in January. As per RCP 4.5 and 8.5 the projected climate shows a decreasing trend in the rainy days during June. As indicated by RCP 8.5 the yearly rainy days shows an increasing trend from 2030 to 2050 and then it decreases in 2080 and in RCP 4.5 rainy days shows an increasing trend. The annual rainy days of projected climate will be less as compared to the present condition.

For the current condition and projected climate, the seasonal rainy days of Northern high hills (AEU15) were examined and presented in table 14.

Table.14. Seasonal rainy days of Northern high hills (AEU 15) and the projected climate in Palakkad district

RCP	Season	Winter		Summer		South West		North East	
	Year	Rainy Days	Rainfall	Rainy Days	Rainfall	Rainy Days	Rainfall	Rainy Days	Rainfall
	Present	2	21.41	22	288.37	77	1652.56	28	435.37
4.5	2030	1	7.2	12	255.6	62	1283.2	13	276.3
	2050	3	28.1	12	133.3	60	1265.8	23	471.8
	2080	2	18.2	16	187.1	62	1248	21	453.1
8.5	2030	2	9.9	14	358.3	61	1364.6	15	269.1
	2050	3	27.8	14	170.4	64	1307.7	24	484
	2080	3	31.4	11	156.6	66	1388.5	18	346.1

Currently, the maximum number of rainy days occurs during south west monsoon time (77 days) followed by North East (28 days), summer season (22 days) and winter season (2 days). According to projected climate the highest number of rainy days will get in South West monsoon followed by north east and summer season. As per RCP 4.5 and 8.5, there will be a decrease in rainy days and rainfall during south west monsoon from the present condition. North east monsoon rain also shows a decreasing trend compared with the existing condition. There will be a considerable variation in summer rain contrast with the current situation. As per RCP 4.5 and 8.5, in winter rain there will be a extreme decrease in rainfall during 2030 and then it increases.

4.3.2. Heavy rainfall events of Northern high hills (AEU15) in Palakkad district

The heavy rainfall events of Northern high hills for the existing condition and projected climate based on RCP 4.5 and 8.5 were examined and presented in table 15.

Table.15. Heavy rainfall events of Northern high hills (AEU 15) and the projected climate in Palakkad district

Year	Rainfall (mm)	RCP 4.5					RCP 8.5				
		10 <25	25 <50	50 <75	75 <100	>= 100	10 <25	25 <50	50 <75	75 <100	>= 100
	Season	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
Present	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	7	2	0	0	0	7	2	0	0	0
	SWM	24	18	4	2	0	24	18	4	2	0
	NEM	7	0	0	0	0	7	0	0	0	0
	Total	**38**	**20**	**4**	**2**	**0**	**38**	**20**	**4**	**2**	**0**
2030	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	4	1	2	0	0	3	5	2	0	0
	SWM	25	18	1	1	0	22	17	2	2	0
	NEM	6	0	1	1	0	6	2	1	0	0
	Total	**35**	**19**	**4**	**2**	**0**	**31**	**24**	**5**	**2**	**0**
2050	Winter	1	0	0	0	0	1	0	0	0	0
	Summer	3	1	0	0	0	6	1	0	0	0
	SWM	27	12	4	1	0	29	10	6	0	0
	NEM	5	3	2	1	0	5	3	2	1	0
	Total	**36**	**16**	**6**	**2**	**0**	**41**	**14**	**8**	**1**	**0**
2080	Winter	1	0	0	0	0	1	0	0	0	0
	Summer	5	1	0	0	0	3	2	0	0	0
	SWM	27	12	3	1	0	29	17	1	0	1
	NEM	3	3	1	2	0	6	1	1	1	0
	Total	**36**	**16**	**4**	**3**	**0**	**39**	**20**	**2**	**1**	**1**

At present the quantity of rainfall events happening is more in the scope of 10 to 50 mm. In projected climate but there is least variation in the number of high rainfall events which is in the range 50 to more than 100 mm. Comparing the present with the projected climate based on RCP 8.5 there will be an increment in the low rainfall events during 2050 and 2080. But in the case of RCP 4.5, there will be least variations in low rainfall events.

4.4. Rainfall analysis of Palakkad central plains (AEU22) and climate change impacts in Palakkad districts

The Palakkad Central Plain agro-ecological unit is delineated to represent the land areas of moderate rainfall and dry period around five months in the Palakkad plain. It is transitional to the drier Eastern Plain and humid western parts (AEU 10). This unit comprises 37 panchayats spread over Alathur, Chittur and Palakkad taluks and the Palakkad Municipality. The unit covers around 1, 12,957 ha (2.91 %) in the state.

4.4.1. Rainfall and Rainy days of Palakkad central plains (AEU22) in Palakkad district

The monthly rainfall distribution of Palakkad central plains (AEU22) for the present and projected climate (RCP 4.5 and 8.5) were studied and presented in table 16.

Table.16. Monthly rainfall distribution of Palakkad central plains (AEU22) and the projected climate in Palakkad district

Rainfall (mm)		RCP 4.5			RCP 8.5		
Month	Present	2030	2050	2080	2030	2050	2080
January	143.8	8.1	4.2	1	0.5	3.9	0
February	126.6	0	0	0	0	0	0
March	114.7	8.7	10.6	12.4	17.2	7.5	18.9
April	164.2	2.4	37.4	61.5	3.4	25	19.5
May	214.8	196.3	290.9	251	199.7	235.4	158.5
June	233	1066.4	706.2	629.1	1015.6	786.2	759.5
July	302.4	914.1	1086.8	1051.8	964.5	1031	1038.7
August	222.3	445.1	466.7	497.4	437.7	497.2	561.5
September	177.1	2.7	9	7.6	2.7	7.4	14
October	197	218.9	227.9	237.8	223.3	237.6	255.8
November	158.1	40.2	42.3	59	42	42.2	42.2
December	132.1	24.6	20.2	49.1	19	20.5	53.8
Total	**2186.1**	**2927.5**	**2902.2**	**2857.7**	**2925.6**	**2893.9**	**2922.4**

In the existing condition July is the wettest month, having a rainfall of 302.4 mm. Every month is getting sufficient amount of rainfall greater 100mm. Based on RCP 4.5 and 8.5; there will be a probability of getting maximum rainfall during June and July in the projected climate. There will be a severe reduction in rainfall distribution during the months January, February, March, April and September. As per RCP 4.5 and 8.5 there will be a considerable change in the yearly rainfall distribution but the projected climate shows an increasing trend as compared with the current state.

The monthly rainy days of Palakkad central plains (AEU22) for the present and projected climate (RCP 4.5 and 8.5) were analyzed and represented in table 17.

Table.17. Monthly rainy days of Palakkad central plains (AEU22) and the projected climate in Palakkad district

Rainy days		RCP 4.5			RCP 8.5		
Month	Present	2030	2050	2080	2030	2050	2080
January	6	1	1	0	0	1	0
February	6	0	0	0	0	0	0
March	5	2	2	2	3	1	3
April	7	0	3	1	0	2	2
May	9	10	11	10	11	9	8
June	12	24	21	24	25	26	23
July	13	25	25	24	26	24	27
August	11	15	15	14	15	15	17
September	8	0	1	1	0	1	2
October	10	10	10	10	10	10	10
November	7	3	3	4	3	3	3
December	5	3	3	3	3	3	4
Total	**99**	**93**	**95**	**93**	**96**	**95**	**99**

Currently the maximum numbers of rainy days are occurring in July and the minimum in March and December. Comparing with the present condition the projected climate as per RCP 4.5 and 8.5 the maximum rainy days will happen during June and July and the minimum in January and February. In projected climate there will be an invariable number of rainy days in October. Comparing the present and projected climate there will be least variations in the yearly rainy days.

For the current condition and projected climate, the seasonal rainy days of Palakkad central plains (AEU22) were examined and given in table 18.

Table.18. Seasonal rainy days of Palakkad central plains (AEU22) and the projected climate in Palakkad district

RCP	Season	Winter		Summer		South West		North East	
	Year	Rainy Days	Rainfall	Rainy Days	Rainfall	Rainy Days	Rainfall	Rainy Days	Rainfall
	Present	12	270.36	22	493.82	44	934.83	22	487.18
4.5	2030	1	8.1	12	207.4	64	2428.3	16	283.7
	2050	1	4.2	16	338.9	62	2268.7	16	290.4
	2080	0	1	13	324.9	63	2185.9	17	345.9
8.5	2030	0	0.5	14	238.1	66	2219	16	282.1
	2050	1	3.9	12	267.9	66	2321.8	16	300.3
	2080	0	0	13	196.9	69	2373.7	17	351.8

At present, the maximum numbers of rainy days are occurring in south west monsoon and minimum in winter season. In projected climate based on RCP 4.5 and 8.5 the maximum rainfall will get in south west monsoon and there will be an increase in the amount of rainfall contrast with the current condition. In projected climate the summer and north east rain shows a decreasing trend from the present state. But in winter season there will be severe decrease in rainfall.

4.4.2. High rainfall events of Palakkad central plains (AEU22) in Palakkad district

For the present condition and projected climate, the high rainfall events of Palakkad central plain (AEU22) were studied and given in table 19.

Table.19. High rainfall events of Palakkad central plain (AEU22) and the projected climate in Palakkad district

Year	Rainfall (mm)	RCP 4.5					RCP 8.5				
		10 <25	25 <50	50 <75	75 <100	>= 100	10 <25	25 <50	50 <75	75 <100	>= 100
	Season	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
Present	Winter	15	6	1	2	1	15	6	1	2	1
	Summer	7	1	0	0	1	7	1	0	0	1
	SWM	2	0	0	0	0	2	0	0	0	0
	NEM	7	11	2	1	1	7	11	2	1	1
	Total	**31**	**18**	**3**	**3**	**3**	**31**	**18**	**3**	**3**	**3**
2030	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	3	3	0	0	0	7	0	1	0	0
	SWM	21	15	8	6	3	21	16	11	2	4
	NEM	6	2	1	0	0	6	2	1	0	0
	Total	**30**	**20**	**9**	**6**	**3**	**34**	**18**	**13**	**2**	**4**
2050	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	6	3	0	1	0	4	3	1	0	0
	SWM	18	16	12	2	3	21	17	8	3	4
	NEM	6	2	0	1	0	6	2	0	1	0
	Total	**30**	**21**	**12**	**4**	**3**	**31**	**22**	**9**	**4**	**4**
2080	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	5	2	1	1	0	4	1	1	0	0
	SWM	24	14	9	5	2	25	16	5	7	3
	NEM	8	3	0	1	0	8	2	0	1	0
	Total	**37**	**19**	**10**	**7**	**2**	**37**	**19**	**6**	**8**	**3**

Comparing the present condition with projected climate as per RCP 4.5 and 8.5, there will be not much variation in rainfall events. But in projected climate the low and high rainfall events show an increasing trend.

4.5. Rainfall analysis of Palakkad eastern plains (AEU23) and climate change impacts in Palakkad districts

The Palakkad Eastern Plain agro-ecological unit is delineated to represent the drier parts of Palakkad plain in the gap region of Western Ghats, having low rainfall, long dry period and fertile soils. The unit comprises 11 panchayats in eastern Palakkad. This unit covers 47,049 ha (1.21 %) in the state.

4.5.1. Rainfall and Rainy days of Palakkad eastern plains (AEU23) in Palakkad district

The monthly rainfall distribution of Palakkad eastern plains (AEU23) for the present and projected climate (RCP 4.5 and 8.5) were studied and presented in table 20.

Table.20. Monthly rainfall distribution of Palakkad eastern plains (AEU23) and the projected climate in Palakkad district

Rainfall (mm)		RCP 4.5			RCP 8.5		
Month	Present	2030	2050	2080	2030	2050	2080
January	0.9	0	14.5	5.3	0	0	0
February	13.9	0	0	0	0	0	0
March	22.7	15.6	12.9	17.5	13	16.5	26.8
April	59.3	13	11.9	6	11.2	15.2	9.8
May	91.3	250.6	149.8	129.9	146.6	172.7	251.4
June	276.4	291.2	353.8	581.2	350.9	390.2	329.3
July	412	599.9	503.3	491.3	494.3	465	557.8
August	221.7	356.3	338.8	345.1	338.6	416	486.9
September	127.4	4.1	0.3	0.3	0.1	0.3	0.1
October	162.7	170.4	165.7	168.9	164.8	167.4	237.3
November	104.4	50.9	30	30.9	30	30	5.8
December	16.1	42.7	63	69	64	63	68.2
Total	**1508.8**	**1794.7**	**1644**	**1845.4**	**1613.5**	**1736.3**	**1973.4**

At present the monthly rainfall distribution is high in the month July and having a rainfall of 412 mm. and the base is 0.9 mm. during January. As per RCP 4.5 and 8.5, in projected climate July and august will be the months having maximum rainfall. And there will be an extreme decline in rainfall during February and September. In May the projected climate shows an expanding pattern of rainfall distribution compared with the current condition. In the case of annual rainfall, in projected climate there will be a growing pattern contrast with the present condition.

The monthly rainy days of Palakkad eastern plains (AEU23) for the present and projected climate (RCP 4.5 and 8.5) were analyzed and represented in table 21.

Table.21. Monthly rainy days of Palakkad eastern plains (AEU23) and the projected climate in Palakkad district

Rainy days		RCP 4.5			RCP 8.5		
Month	Present	2030	2050	2080	2030	2050	2080
January	1	0	2	1	0	0	0
February	1	0	0	0	0	0	0
March	1	2	2	3	3	2	3
April	3	2	1	1	1	2	2
May	4	10	12	13	12	11	12
June	15	19	21	22	21	21	21
July	21	25	28	27	28	28	26
August	15	14	14	14	14	16	19
September	8	0	0	0	0	0	0
October	10	10	10	10	10	10	9
November	5	3	2	2	2	2	1
December	1	5	6	6	6	6	9
Total	**85**	**90**	**98**	**99**	**97**	**98**	**102**

In the current condition, July has the maximum number of rainy days and it is 21 days. January, February, March and December showed the lowest number of rainy days.

According to RCP 4.5 and 8.5, the maximum rainy days will be 28 days in July and the minimum number of rainy days will be in February. As per RCP 4.5 and 8.5 the projected climate shows an increasing trend in the annual rainy days. The annual rainy days of projected climate will be higher than that of the present condition.

For the current condition and projected climate, the seasonal rainy days of Palakkad eastern plains (AEU23) were examined and given in table 22.

Table.22. Seasonal rainy days of Palakkad eastern plains (AEU23) and the projected climate in Palakkad district

RCP	Season	Winter		Summer		South West		North East	
	Year	Rainy Days	Rainfall	Rainy Days	Rainfall	Rainy Days	Rainfall	Rainy Days	Rainfall
	Present	1	14.79	9	173.28	59	1037.57	16	283.22
4.5	2030	0	0	14	279.2	58	1251.5	18	264
	2050	2	14.5	16	174.6	63	1196.2	18	258.7
	2080	1	5.3	17	153.4	63	1417.9	18	268.8
8.5	2030	0	0	16	170.8	63	1183.9	18	258.8
	2050	0	0	15	204.4	65	1271.5	18	260.4
	2080	0	0	17	288	66	1374.1	19	311.3

At the present climate the maximum number of rainy days are getting in south west monsoon trailed by north east monsoon, summer and winter season. In projected climate based on RCP 4.5 and 8.5 there will be least variations in the amount of rainfall during south west, north east and summer season compared with the present climate. In the case of winter season, there will be a drastic decrease in the rainfall but as per RCP 4.5 during 2050 the rainfall shows an increment which is comparable to the present condition.

4.5.2. High rainfall events of Palakkad eastern plains (AEU23) in Palakkad district

For the present condition and projected climate, the high rainfall events of Palakkad eastern plains (AEU23) were studied and given in table 23.

Table.23. High rainfall events of Palakkad eastern plains (AEU23) and the projected climate in Palakkad district

Year	Rainfall (mm)	RCP 4.5					RCP 8.5				
		10 <25	25 <50	50 <75	75 <100	>= 100	10 <25	25 <50	50 <75	75 <100	>= 100
	Season	Days	Days	Days	Days	Days	Days	Days	Days	Days	Days
Present	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	2	2	0	1	0	2	2	0	1	0
	SWM	20	10	7	2	0	20	10	7	2	0
	NEM	6	3	0	0	0	6	3	0	0	0
	Total	**28**	**15**	**7**	**3**	**0**	**28**	**15**	**7**	**3**	**0**
2030	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	5	3	1	0	0	2	2	0	0	0
	SWM	24	13	4	0	0	30	12	1	0	1
	NEM	6	1	0	1	0	6	1	0	1	0
	Total	**35**	**17**	**5**	**1**	**0**	**38**	**15**	**1**	**1**	**1**
2050	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	2	2	0	0	0	2	2	1	0	0
	SWM	30	12	1	0	1	33	12	2	0	1
	NEM	7	0	0	1	0	7	0	0	1	0
	Total	**39**	**14**	**1**	**1**	**1**	**42**	**14**	**3**	**1**	**1**
2080	Winter	0	0	0	0	0	0	0	0	0	0
	Summer	7	0	0	0	0	5	2	0	1	0
	SWM	26	15	4	0	1	25	17	4	1	0
	NEM	7	0	0	1	0	6	2	0	1	0
	Total	**40**	**15**	**4**	**1**	**1**	**36**	**21**	**4**	**3**	**0**

As compared with present condition, in projected climate as per RCP 4.5 and 8.5 there will be an increase in the low rainfall events and in the case of high rainfall events there will be least variation happens. As per RCP 4.5, the low rainfall events show an increasing trend but in RCP 8.5 there will be a decrease from 2050 to 2080.

4.6. The lengths of growing period of various AEUs of Palakkad district

The lengths of growing period of various AEUs were calculated for the four districts viz. Ernakulam, Thrissur, Palakkad, Malappuram comprises central Kerala and represented in table 24.

Table.24. The lengths of growing period of various AEUs of Palakkad district

LGP (Weeks)		RCP 4.5			RCP 8.5		
	Present	2030	2050	2080	2030	2050	2080
				Palakkad			
AEU10	22	20	19	21	19	20	21
AEU13	22	21	20	23	21	23	28
AEU15	24	20	23	21	24	25	22
AEU22	18	19	20	19	19	20	19
AEU23	19	19	17	21	17	20	23

Considering the AEUs of Palakkad districts such as North central laterites (AEU10), Northern foothills (AEU13), Southern high hills (AEU14), Northern high hills (AEU15), Attappady hills (AEU18), Attappady dry hills (AEU19), Palakkad central plains (AEU22) and Palakkad eastern plains (AEU23) at current condition these AEUs have a length of growing periods 22, 22, 31, 24, 14, 9, 18 and 19 weeks respectively.

4.7. Water balance of various rice growing AEUs of Palakkad

4.7.1. Monthly Potential evapotranspiration, Deficit and Surplus of North central laterites (AEU10) in Palakkad district

The monthly potential evapotranspiration of North central laterites (AEU10) for the present and projected climate (RCP 4.5 and 8.5) were studied and given in table 25.

Table.25. Monthly potential evapotranspiration of North central laterites (AEU10) and the projected climate in Palakkad district

PET (mm)	Present	RCP 4.5			RCP 8.5		
Month		2030	2050	2080	2030	2050	2080
January	150.8	147.6	151.6	155.6	149.2	153.2	164.8
February	170.4	150	153.2	156.8	150.4	157.2	166.4
March	231.3	194	196	201	193.5	200	210.5
April	183.2	163.6	163.6	168	161.2	166	175.6
May	202.1	209.5	212.5	217.5	209.5	214	223.5
June	140.2	162.8	172.8	176.4	170.4	175.6	181.2
July	177.2	203.5	206.5	211.5	203	218.5	226
August	149.1	165.2	164.8	169.2	162.4	166.8	180.8
September	181.7	195	206	210.5	203	206.5	222
October	134.8	156.4	154.4	158	152	162.8	167.6
November	134.8	154.8	155.6	158.8	153.6	154.4	165.2
December	134.8	151.6	156	159.2	154	156.8	165.6
Total	**1990.4**	**2054.1**	**2093.1**	**2142.2**	**2062.4**	**2131.3**	**2248.7**

At the present condition, the maximum potential evapotranspiration occurring is 231.3 mm. during March and the minimum is 134.8 mm. during October, November and December. In projected climate based on RCP 4.5 and 8.5 the potential evapotranspiration shows an increasing trend from the present value. The maximum values will occur in May and July. And the minimum will be in January.

The monthly Deficit of North central laterites (AEU10) for the current and projected climate (RCP 4.5 and 8.5) were considered and arranged in table 26.

Table.26. Monthly Deficit of North central laterites (AEU10) and the projected climate in Palakkad district

Deficit (mm)	Present	RCP 4.5			RCP 8.5		
Month		2030	2050	2080	2030	2050	2080
January	150.8	146.6	150.6	154.6	148.2	152.2	163.8
February	170.4	150	153.2	156.8	150.4	157.2	166.4
March	231.3	187.4	182.4	176.5	183.2	186.9	199.6
April	159.6	132.4	156.9	140.1	154.1	162.1	166.3
May	89.3	65.5	67.4	79.1	74	54.8	75.5
June	1.5	0	0	0	0	0	0
July	16.9	0	0	0	0	0	0
August	19	16.6	18.8	25.8	24.7	17	26.8
September	58.6	152.1	160.8	167.5	161.6	174	121.1
October	0.5	56.9	55.8	49.6	47.1	51.8	61.4
November	109.1	127.8	127.6	113.3	115.5	119.1	159
December	113.3	125.6	128.6	111.3	142.1	142	147.7
Total	**1120.3**	**1160.7**	**1202.5**	**1174.5**	**1200.9**	**1216.7**	**1287.3**

In the current climate all the months shows deficit and the maximum amount of deficit occurs in March and it is about 231.3 mm. June and October have a deficit below 10 mm. In the projected climate as per RCP 4.5 and 8.5 the maximum deficit will occur during March. Based on projections every month shows deficit except in June and July. In the case of September and October in projected climate there will be a drastic increase in deficit compared to the present climate. Annually the deficit shows an increasing trend from the present condition.

The monthly Surplus of North central laterites (AEU10) for the present and projected climate (RCP 4.5 and 8.5) were studied and given in table 27.

Table.27. Monthly Surplus of North central laterites (AEU10) and the projected climate in Palakkad district

Surplus (mm)	Present	RCP 4.5			RCP 8.5		
Month		2030	2050	2080	2030	2050	2080
January	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0
May	235.8	283.9	151.5	182	191.4	193.3	118.1
June	290.6	802.8	969.3	776.8	883.3	743	680.6
July	773.2	990.6	1115.8	913.4	1045.5	895.7	1021.5
August	344.8	135.5	159.8	193.2	199.7	186.1	157.6
September	62.9	53.7	49.7	71.5	70.5	0	0
October	175.1	44.1	55.3	52.8	53.3	130.2	127.4
November	0	0	0	2.5	0	0	0
December	0	0	0	0	0	0	0
Total	**1882.4**	**2310.3**	**2501.3**	**2192.5**	**2443.5**	**2148.4**	**2105.3**

In the present condition the surplus occurring during January, February, March, April, November and December is zero. The maximum amount of surplus is occurring in July and it is about 773.2 mm. As per RCP 4.5 and 8.5 in projected climate, during the months January, February, March, April, November and December the amount of surplus will be zero. The maximum amount of surplus will occur in July followed by June. Yearly surplus value shows an increasing trend in projected climate.

4.7.2. Monthly Potential evapotranspiration, Deficit and Surplus of Northern foothills (AEU13) in Palakkad district

The monthly potential evapotranspiration of Northern foothills (AEU13) for the present and projected climate (RCP 4.5 and 8.5) were studied and given in table 28.

Table.28. Monthly potential evapotranspiration of Northern foothills (AEU13) and the projected climate in Palakkad district

PET (mm)	Present	RCP 4.5			RCP 8.5		
Month		2030	2050	2080	2030	2050	2080
January	150.4	150.4	151.6	155.2	148.4	156.8	167.6
February	151.6	151.6	155.6	159.2	153.2	157.2	168.4
March	195	195	197.5	203	195	203	214.5
April	162.4	162.4	164	167.6	161.6	167.2	175.6
May	211.5	211.5	211.5	216.5	208.5	213.5	226
June	171.6	171.6	174	177.6	171.6	174.4	182.4
July	205	205	216.5	220.5	214	219.5	226.5
August	163.6	163.6	165.2	169.2	162.4	174	180.4
September	204.5	204.5	204	208.5	201	206.5	223
October	153.2	153.2	161.6	164.8	159.2	161.6	173.2
November	154.8	154.8	152.8	156.4	150.4	160.8	165.6
December	154.8	154.8	155.6	158.8	153.6	154.4	164.8
Total	**2077.8**	**2077.8**	**2109.4**	**2157.1**	**2078.1**	**2148.5**	**2268.5**

In the current condition, the maximum amount of potential evapotranspiration is occurring in May (211.5 mm.) and the minimum in January (150.4 mm.). In projected climate every month will show potential evapotranspiration greater than 150 mm. In the annual value it shows an increasing trend compared to the present condition. The maximum amount will occur in May, July and September and the minimum will occur in January and February.

The monthly Deficit of Northern foothills (AEU13) for the current and projected climate (RCP 4.5 and 8.5) were considered and arranged in table 29.

Table.29. Monthly Deficit of Northern foothills (AEU13) and the projected climate in Palakkad district

Deficit (mm)	Present	RCP 4.5			RCP 8.5		
Month		2030	2050	2080	2030	2050	2080
January	150.4	149.4	150.6	154.2	147.4	155.8	166.6
February	151.6	151.6	155.6	159.2	153.2	157.2	168.4
March	159.5	159.5	187.2	184	167.2	162.4	185.9
April	158	158	153.8	137.3	145.1	131.6	170.5
May	70.5	70.5	31.9	25.9	56.9	28	55.7
June	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0
August	22.6	22.6	15.7	19.3	14.8	22.3	1.7
September	162.9	162.9	171.9	174.2	169.9	176.7	162
October	45.1	45.1	48.9	51.3	47.5	49.6	69.7
November	119.9	119.9	109.4	111.8	107.8	116.2	120.4
December	141.3	141.3	116.9	107.6	114.5	113.6	100.4
Total	**1181.4**	**1180.4**	**1141.7**	**1124.7**	**1124**	**1112.9**	**1201.7**

At present the maximum deficit occurs during the month September (162.9 mm.) and the deficit during June and July is zero. As per RCP 4.5 and 8.5 in projected climate every month will show a deficit except in June and July. In the projected climate March and September will be the months having maximum deficit. Annually the deficit shows a decreasing trend except in 2080 as per RCP 8.5.

The monthly Surplus of Northern foothills (AEU13) for the present and projected climate (RCP 4.5 and 8.5) were studied and given in table 30.

Table.30. Monthly Surplus of Northern foothills (AEU13) and the projected climate in Palakkad district

Surplus (mm)	Present	RCP 4.5			RCP 8.5		
Month		2030	2050	2080	2030	2050	2080
January	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0
May	66.6	66.6	91.7	146.5	177.1	71.4	175.5
June	585.7	585.7	705.1	768.9	573.4	477.8	450.4
July	958.1	958.1	959.9	1000.5	912.9	945.4	884.6
August	195.3	195.3	183.7	189.4	184.3	241.9	184.3
September	62.3	62.3	0	0	0	0	0
October	50.1	50.1	126.8	133.4	123.8	140.2	177.3
November	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0
Total	**1918.2**	**1918.2**	**2066.7**	**2238.8**	**1971.6**	**1876.7**	**1872**

Currently, there is surplus in all the months except January, February and March, April, November and December. The maximum amount of surplus is occurring in July and it is about 958.1 mm. As per RCP 4.5 and 8.5, in projected climate there will be surplus during May, June, July, August and October whereas in remaining months the surplus will be zero. In projected climate the maximum surplus will occur during the month July.

4.7.3. Monthly Potential evapotranspiration, Deficit and Surplus of Northern high hills (AEU15) in Palakkad district

The monthly potential evapotranspiration of Northern high hills (AEU15) for the present and projected climate (RCP 4.5 and 8.5) were studied and given in table 31.

Table.31. Monthly potential evapotranspiration of Northern high hills (AEU15) and the projected climate in Palakkad district

PET (mm)		RCP 4.5			RCP 8.5		
Month	Present	2030	2050	2080	2030	2050	2080
January	141.2	124.8	127.2	142	135.2	138.8	152.8
February	153.2	138	139.2	141.2	127.6	139.2	155.2
March	209.6	163.5	175	187.5	177.5	183	196
April	163.4	127.6	150.8	150	136.4	148.8	161.2
May	184.4	158	186	186	165.5	197	202.5
June	135	122	137.6	140.8	128.8	154.8	168
July	166.9	146.5	165	166	151.5	185.5	205.5
August	138.5	111.2	124.4	128.8	116.8	136.4	166.8
September	164.6	141.5	149	151	137	159	199
October	122.4	108.8	110.4	122	110.4	121.6	150.8
November	123.6	107.2	112.8	118.4	107.2	113.2	145.6
December	123.6	108	110	117.6	106.8	117.2	141.2
Total	**1826.4**	**1556.9**	**1687.3**	**1750.3**	**1601.2**	**1795**	**2045.7**

At current situation, the maximum monthly potential evapotranspiration is during March (209.6 mm.) and the base value is 122.4 mm. in October. In projected climate based on RCP 4.5 and 8.5, the maximum values will occur during March, May, July and September and the minimum will be in November and December. The yearly potential evapotranspiration during projected climate will be less as compared to the present condition.

The monthly Deficit of Northern high hills (AEU15) for the current and projected climate (RCP 4.5 and 8.5) were considered and arranged in table 32.

Table.32. Monthly Deficit of Northern high hills (AEU15) and the projected climate in Palakkad district

Deficit (mm)	Present	RCP 4.5			RCP 8.5		
Month		2030	2050	2080	2030	2050	2080
January	141.2	123.8	115	138.5	134.2	126.8	133
February	124.3	130.8	122.3	125.5	117.7	122.4	142.6
March	199.4	145.3	159.1	169	152.3	166.4	179
April	80.2	125.2	128.4	89.5	136	114.5	150.7
May	40.3	48.9	88.9	72.5	6.2	85.5	98
June	0	2.7	0	0	0	4	0
July	30.1	0	0	0	0	0	0
August	0	0	0	0	0	0	0
September	17.9	97.5	56.2	67.2	95	47.8	135.3
October	50.6	16.9	0.1	0.6	13.6	20.4	45.2
November	104.3	95.2	68.6	77.1	88.6	62	77.5
December	108.5	80.5	54.7	92.3	74.5	62.7	92.5
Total	**896.8**	**866.5**	**793.4**	**831.8**	**818.4**	**813.1**	**1054.6**

At present the maximum deficit occurs during the month March and it is about 199.4 mm. and the deficit is zero during June and August. As per RCP 4.5 and 8.5 in projected climate every month will show a deficit except in June, July and August. In projected climate the maximum amount of deficit occurs during March.

The monthly Surplus of Northern high hills (AEU15) for the present and projected climate (RCP 4.5 and 8.5) were studied and given in table 33.

Table.33. Monthly Surplus of Northern high hills (AEU15) and the projected climate in Palakkad district

Surplus (mm)	Present	RCP 4.5			RCP 8.5		
Month		2030	2050	2080	2030	2050	2080
January	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0
May	28.9	141.2	0	0.4	172.7	11.3	58
June	247.5	144.7	161.2	285.3	293.4	167.9	120.3
July	120.7	559.9	392.7	247.5	436.2	376.5	438.1
August	596.9	142.3	206.6	206.9	196.6	196	192.7
September	69.4	0	16.4	17.2	0	14	0
October	0	144.8	120.6	122.3	121.4	136.9	98.3
November	0	0	108.6	108.9	0	106.5	25.4
December	0	0	0	0	0	0	0
Total	**1063.4**	**1132.9**	**1006.1**	**988.9**	**1220.1**	**1009.1**	**932.4**

Currently, there is surplus from May to September whereas in remaining months the surplus is zero. The maximum amount of surplus is occurring in August. As per RCP 4.5 and 8.5, in projected climate there will be surplus from May to November and during the remaining months the surplus will be zero. In projected climate the maximum surplus will occur during the month July. Annually the surplus shows a decreasing trend in projected climate except in 2030s.

4.7.4. Monthly Potential evapotranspiration, Deficit and Surplus of Palakkad central plains (AEU22) in Palakkad district

The monthly potential evapotranspiration of Palakkad central plains (AEU22) for the present and projected climate (RCP 4.5 and 8.5) were studied and given in table 34.

Table.34. Monthly potential evapotranspiration of Palakkad central plains (AEU22) and the projected climate in Palakkad district

PET (mm)	Present	RCP 4.5			RCP 8.5		
Months		2030	2050	2080	2030	2050	2080
January	150.4	151.2	152.8	156.4	152	158	168.8
February	170	152.8	156.8	160.4	153.6	158	168.8
March	229.9	195.5	199.5	203.5	196.5	204.5	215.5
April	225.7	205.6	207.7	212.6	206.6	211.1	221.8
May	158.2	169.6	170	173.6	170.4	172.4	181.6
June	141	172.4	174.8	178.4	173.2	175.6	182.8
July	177.9	205.5	217.5	222	206.5	220.5	227.5
August	149.2	164.4	166.4	170	165.2	175.6	181.2
September	180.9	206	205.5	210	207	208	223.5
October	133.6	154.4	162.8	165.6	154.8	162.8	174
November	134	155.6	154.4	157.6	156.4	162	166.4
December	134	156	156.8	160	156.4	155.6	165.6
Total	**1984.8**	**2089.3**	**2124.5**	**2170.6**	**2098.8**	**2164.1**	**2276.9**

At present condition, the maximum potential evapotranspiration occurring is 229.9 mm. during March and the minimum is 133.6 mm. during October. In projected climate based on RCP 4.5 and 8.5 the annual potential evapotranspiration shows an increasing trend from the present value. The maximum values will occur in March, April, July and September and the minimum will be in January.

The monthly Deficit of Palakkad central plains (AEU22) for the current and projected climate (RCP 4.5 and 8.5) were considered and arranged in table 35.

Table.35. Monthly Deficit of Palakkad central plains (AEU22) and the projected climate in Palakkad district

Deficit (mm)	Present	RCP 4.5			RCP 8.5		
Months		2030	2050	2080	2030	2050	2080
January	14.2	142.1	147.6	154.4	150.5	153.1	167.8
February	23.4	152.8	156.8	160.4	153.6	158	168.8
March	104	186.8	176.3	191	179.3	197	196.6
April	119.7	160.8	140.4	124.7	160.6	143	159
May	159.8	82	78.4	60.5	81.9	76.7	127.3
June	141	0	0	0	0	0	0
July	173.1	0	0	0	0	0	0
August	186.9	63.6	58.5	62.8	65	64.2	35
September	107	123.6	136.4	137.8	124.2	141.6	178.1
October	66.7	53.5	53	55.2	52.5	53.6	73.2
November	6.4	122	122.5	112.9	121.6	133.8	124.2
December	26.8	140.2	141.9	111.7	145.9	136.3	111.8
Total	**1129**	**1227.4**	**1211.5**	**1171.7**	**1235.1**	**1257.7**	**1341.5**

In the current climate there is deficit in every month and maximum amount of deficit occurs in August and it is about 186.9 mm. Only November have a deficit below 10 mm. In the projected climate as per RCP 4.5 and 8.5 there will be deficit in every month except

June and July. In the projected climate maximum deficit will occurs in March and annual deficit shows an increasing trend.

The monthly Surplus of Palakkad central plains (AE22) for the present and projected climate (RCP 4.5 and 8.5) were studied and given in table 36.

Table.36. Monthly Surplus of Palakkad central plains (AEU22) and the projected climate in Palakkad district

Surplus (mm)	Present	RCP 4.5			RCP 8.5		
Months		2030	2050	2080	2030	2050	2080
January	386.4	0	0	0	0	0	0
February	67.2	0	0	0	0	0	0
March	119	0	0	0	0	0	0
April	292.9	0	0	9.8	0	0	0
May	0	167.5	150.6	101.9	96.9	98.5	77.7
June	0	798.2	706.4	456.2	856.9	624	646.6
July	0	815.7	844.5	992	826.1	922.3	926.1
August	0	193.3	182.7	187.8	187.9	224.8	182.5
September	0	51.4	0	0	53.3	0	0
October	26	40.8	105.8	112.3	42	118.8	155
November	212.9	0	0	0	0	0	0
December	347.2	0	0	0	0	0	0
Total	**1451.6**	**2066.6**	**1990.2**	**1859.8**	**2062.9**	**1988.5**	**1988**

In the present condition the surplus is zero from May to September and the maximum amount of surplus is occurring in January (386.4 mm.). As per RCP 4.5 and 8.5 in projected climate, during the months January, February, March, April, November and December the amount of surplus will be zero. The maximum amount of surplus will occur in July and the annual value shows an increasing trend in the projected climate.

4.7.5. Monthly Potential evapotranspiration, Deficit and Surplus of Palakkad eastern plains (AEU23) in Palakkad district

The monthly potential evapotranspiration of Palakkad eastern plains (AEU23) for the present and projected climate (RCP 4.5 and 8.5) were studied and given in table 37.

Table.37. Monthly potential evapotranspiration of Palakkad eastern plains (AEU23) and the projected climate in Palakkad district

PET (mm)	Present	RCP 4.5			RCP 8.5		
Months		2030	2050	2080	2030	2050	2080
January	151.2	148.8	154.4	158	152	160.8	173.6
February	169.2	152.8	154.4	158.4	178.4	160.8	188
March	229.9	195	199.5	204.5	196.5	204	219.5
April	182.3	161.2	164	167.6	187.2	166.4	196.8
May	201.2	207	210	215	207	215	227.5
June	140.6	171.2	171.6	175.2	196.4	172.8	202
July	177.9	213	216	220.5	213	214.5	225
August	149.2	162.8	171.6	174.8	193.2	171.2	198
September	181.3	201	203	207.5	200	213	219.5
October	134.4	159.6	159.6	162.4	182.8	165.6	188
November	134	151.2	159.2	162	156.8	157.6	167.6
December	134	153.6	152.4	156	172.8	156.8	182.4
Total	**1985.2**	**2076.9**	**2115.5**	**2162.2**	**2236.4**	**2158.7**	**2387.2**

In the current condition, the maximum amount of potential evapotranspiration is occurring in March (229.9 mm.) and the minimum is in November (134 mm.) and December (134 mm.). In projected climate, the yearly value shows an increasing trend compared to the present condition. The maximum amount will occur in May, July and September and the minimum will be in January.

The monthly Deficit of Palakkad eastern plains (AEU23) for the current and projected climate (RCP 4.5 and 8.5) were considered and arranged in table 38.

Table 38. Monthly Deficit of Palakkad eastern plains (AEU23) and the projected climate in Palakkad district

Deficit(mm)	Present	RCP 4.5			RCP 8.5		
Months		2030	2050	2080	2030	2050	2080
January	151.2	147.8	138.9	151.7	151	159.8	172.6
February	169.2	152.8	154.4	158.4	178.4	160.8	188
March	229.9	173.4	186.6	187	183.5	187.5	192.7
April	155.3	154.2	152.1	161.6	176	153.3	187
May	103.8	35.6	85.1	79.1	84.8	84.3	33
June	49.8	2	5	0	9.1	0.8	1.3
July	26.8	0	0	0	0	0	0
August	20.2	17.3	30.4	31.2	35.8	3.3	6.1
September	35.1	165.6	178.1	182.2	173.3	207.8	216.5
October	13.8	91.4	87.9	90.3	106.9	85.3	43.5
November	104.1	107.5	113.4	115.5	111.6	127.6	161.9
December	127	104.4	106.2	103.6	124.9	93.8	114.2
Total	**1186.2**	**1151.6**	**1238**	**1261**	**1335.5**	**1264.4**	**1316.3**

At present there is deficit in every month and maximum deficit occurs during March (229.9 mm.) whereas October shows the least amount of deficit. As per RCP 4.5 and 8.5 in projected climate every month will show a deficit except July. In June there will be a deficit below 10 mm. In the projected climate March and September will be the months having maximum deficit. Annually the deficit shows an increasing trend in projected climate compared to the current condition.

The monthly Surplus of Palakkad eastern plains (AEU23) for the present and projected climate (RCP 4.5 and 8.5) were studied and given in table 39.

Table.39. Monthly Surplus of Palakkad eastern plains (AEU23) and the projected climate in Palakkad district

Surplus(mm)	Present	RCP 4.5			RCP 8.5		
Months		2030	2050	2080	2030	2050	2080
January	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0
May	62.1	67	19.7	0	19.1	84.5	65.5
June	160.7	150.5	193.5	393.3	169.9	178	123.8
July	566	470	346.1	339.5	339.5	369.6	428.9
August	124	115.7	137.7	139.5	122	123.8	192.6
September	27.9	0	0	0	0	0	0
October	40.9	67.6	70.6	72.8	63.2	87.2	92.9
November	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0
Total	**981.6**	**870.4**	**767.5**	**945.3**	**713.6**	**843**	**903.5**

Currently, there is surplus in every month except January, February, March, April, November and December. The maximum amount of surplus is occurring in July and it is about 566 mm. As per RCP 4.5 and 8.5, in projected climate there will be surplus during May, June, July, August and October and there will be no surplus occurs during in the remaining months. In projected climate the maximum surplus will occur during the month July and there will be a severe decline in surplus during September from the current condition. Yearly surplus shows a decreasing trend in the projected climate.

4.8. Fertility status of rice growing AEUs of Palakkad District

The soil fertility status of major rice growing AEUs are shown in Table 40. As per the soil test results the majority of soils in Palakkad districts are highly acidic in nature. Except in AEU 10 all other ecological units are deficit in organic carbon. Availability of phosphorus is low in AEUs of eastern Palakkad (AEU 22 and 23). It can be also noticed that majority of soils are deficit in boron.

Table.40. Soil Fertility Status of Major Rice Growing Agro-Ecological Units of Palakkad

	AEU 10	AEU 13	AEU 15	AEU 22	AEU 23
pH	5.99 (Mac)	5.23(HAc)	5.69 (HAc)	5.17 (HAc)	5.84(HAc)
EC	0.09 (N)	0.10 (N)	0.10 (N)	0.097 (N)	0.13 (N)
OC	1.10 (H)	0.41 (L)	0.51 (L)	0.71 (M)	0.38 (L)
P	49.25 (M)	23.79 (M)	25.86 (M)	18.82(L)	19.837(L)
K	276.63 (M)	179.82 (M)	220.25 (M)	143.23(M)	162.28 (M)
S	5.49 (D)	11.88 (S)	10.77 (S)	27.69(S)	13.03 (S)
Zn	2.56 (S)	3.18 (S)	3.50 (S)	2.95 (S)	3.33 (S)
Fe	142.04 (S)	48.61 (S)	57.83 (S)	75.25 (S)	62.33 (S)
Cu	2.97 (S)	3.01 (S)	2.98 (S)	2.93 (S)	3.29 (S)
Mn	112.59 (S)	35.92 (S)	41.01 (S)	36.84 (S)	34.94 (S)
B	0.43 (D)	0.51 (S)	2.38 (S)	0.36 (D)	0.44 (D)

L - Low, VL- Very Low, M - Medium, H - High, VH - Very High, D - Deficient, S - Sufficient, AS - Acid Sulphate, SrAc- Strongly acidic, HAc - Highly Acidic, MAc - Moderately Acidic, SlAc - Slightly Acidic, N - Neutral, MAl – Moderately Alkaline, SlAl - Strongly Alkaline

4.9. Agro Ecological Unit wise Production of Rice in Palakkad District

The area, production and productivity of the rice growing areas are given in table 41 to 49 and from those table it can be clearly seen that the area under rice cultivation in Palakkad district declining at an alarming rate.

4.9.1. Area under rice during the first crop season in various Agro-Ecological Units of Palakkad

It can be inferred from the below table that as per the latest statistics, the highest area under rice cultivation during the first crop season was 14728.8 hectares in Palakkad central plains (AEU 22) and the lowest area (0 ha.) was in Northern high hills (AEU 15). It can be also noted that total area under rice production has shown a decline in all of the 5 AEUs in Palakkad over a period from 2009 – 2017.

Table.41. Area under rice during the first crop season in various Agro-Ecological Units of Palakkad

Year	AEU 10	AEU 13	AEU 15	AEU 22	AEU 23	Total
2009	2766.1	7513.5	1.0	18020.9	7228.0	35529.5
2010	3072.3	7896.7	0.5	18513.6	5484.7	34967.7
2011	1804.7	6252.2	7.3	15725.4	5832.3	29621.9
2012	1231.4	3522.8	0.4	15870.7	8554.5	29179.8
2013	1126.0	2971.6	2.7	16260.7	7462.8	27823.7
2014	962.4	3162.1	0.0	15350.5	6948.7	26423.8
2015	864.5	3374.9	0.0	15904.2	8322.6	28466.3
2016	537.7	3284.8	0.0	15241.3	8699.8	27763.6
2017	666.9	3051.9	0.0	14728.8	8479.6	26927.2

4.9.2. Area under rice during the second crop season in various Agro-Ecological Units of Palakkad

It can be seen from the below table that as per the latest statistics, the highest area under rice cultivation during the second crop season was 10664.8 hectares in Palakkad central plains (AEU 22) and the lowest area (0 ha.) was in Northern high hills (AEU 15). It can be also perceived that total area under rice production has shown a decline in all of the 5 AEUs in Palakkad over a period from 2009 – 2017.

Table.42. Area under rice during the second crop season in various Agro-Ecological Units of Palakkad

YEAR	AEU 10	AEU 13	AEU 15	AEU 22	AEU 23	Total
2009	6560.4	6979.8	9.3	16632.9	1170.3	31352.6
2010	6078.0	8644.0	8.0	18957.4	4533.4	38220.8
2011	6206.0	6201.0	1.7	17202.6	3006.8	32618.0
2012	5108.3	4540.9	2.1	16439.9	5741.4	31832.5
2013	4820.4	2660.0	2.4	16444.0	5096.2	29023.0
2014	5128.0	4055.9	13.9	16555.2	5693.9	31446.9
2015	5059.6	4064.3	1.5	17704.5	5385.0	32214.7
2016	5362.3	3626.0	0.2	16517.7	4977.7	30484.0
2017	4620.0	3141.7	0.0	10664.8	3594.5	22020.9

4.9.3. Area under rice during the third crop season in various Agro-Ecological Units of Palakkad

It can be noticed from the below table that as per the latest statistics, the highest area under rice cultivation during the third crop season was 300.8 hectares in Palakkad eastern plains (AEU 23) and the lowest area (0 ha.) was in Northern high hills (AEU 15). It can be also observed that total area under rice production has shown a decline in all of the 5 AEUs in Palakkad over a period from 2009 – 2017.

Table.43. Area under rice during the third crop season in various Agro-Ecological Units of Palakkad

YEAR	AEU 10	AEU 13	AEU 15	AEU 22	AEU 23	Total
2009	147.3	666.5	12.0	1379.7	6015.7	8221.2
2010	275.0	411.7	20.5	752.6	4994.3	6454.2
2011	205.9	737.7	8.9	10692.4	4193.3	15838.1
2012	98.1	301.6	1.0	933.1	2323.4	3657.1
2013	103.6	198.3	2.5	434.6	1930.3	2669.2
2014	154.4	323.2	2.2	1371.1	2777.8	4628.7
2015	123.6	298.7	0.0	235.0	2024.7	2682.1
2016	184.8	269.7	0.0	479.9	2891.5	3825.9
2017	91.9	18.7	0.0	33.7	300.8	445.0

4.9.4. Production and Productivity of rice in various rice growing AEUs of Palakkad

4.9.4.1 Rice production during the first crop season in various Agro-Ecological Units of Palakkad

It can be inferred from the below table that as per the latest statistics, highest Production under rice during the first crop season was 42666.21 T hectares in Palakkad central plains (AEU 22) and the lowest production under rice during the first crop season was (0 T) was in Northern high hills (AEU 15). It can be also observed Production under rice during the first crop season has shown a decline in all of the 5 AEUs in Palakkad over a period from 2009 – 2017.

Table.44. Rice production during the first crop season in various Agro-Ecological Units of Palakkad

YEAR	AEU 10	AEU 13	AEU 15	AEU 22	AEU 23	Total
2009	4408.719	16776.36	1.0	47625.6	18322.0	87133.7
2010	4841.932	20033.91	1.2	47211.1	16249.8	88337.9
2011	3344.227	14486.36	0.0	39560.8	15632.2	73023.6
2012	2201.352	8524.33	1.4	39711.3	20546.8	70985.2
2013	2079.968	6532.08	9.5	39798.5	18391.8	66811.9
2014	2014.514	7160.799	0.0	42458.0	18834.1	70467.4
2015	1738.053	6731.47	0.0	40236.1	21615.9	70321.5
2016	1188.768	8022.993	0.0	38935.0	22882.6	71029.4
2017	1407.579	8614.521	0.0	42666.21	24070.7	76759.0

4.9.4.2. Rice production during the second crop season in various Agro-Ecological Units of Palakkad

It can be inferred from the below table that as per the latest statistics, highest Production under rice during the second crop season was 15172.8 T hectares in Palakkad central plains (AEU 22) and the lowest production under rice during the first crop season was (0 T) was in Northern high hills (AEU 15). It can be also noticed Production under rice during the second crop season has shown a decline in all of the 5 AEUs in Palakkad over a period from 2009 – 2017.

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Table.45. Rice production during the second crop season in various Agro-Ecological Units of Palakkad

YEAR	AEU 10	AEU 13	AEU 15	AEU 22	AEU 23	Total
2009	12997.3	17468.9	19.4	42571.1	2764.4	75821.1
2010	12511.5	23897.9	16.9	55077.6	12200.2	103704.2
2011	13604.3	14846.6	16.1	42183.9	7872.7	78523.5
2012	11441.2	12649.3	5.6	47861.5	15090.6	87048.2
2013	9968.7	5810.1	3.9	36614.7	10249.4	62646.8
2014	12479.2	11048.6	36.9	52083.5	15797.6	91445.8
2015	13826.7	11224.1	3.9	54237.4	15160.0	94452.0
2016	14587.5	9292.2	0.4	49902.4	14357.7	88140.2
2017	9705.5	5093.7	0.0	15172.8	3334.8	33306.9

4.9.4.3. Rice production during the third crop season in various Agro-Ecological Units of Palakkad

It can be inferred from the below table that as per the latest statistics, highest Production under rice during the third crop season was 603.7 T in Palakkad eastern plains (AEU 23) and the lowest production under rice during the first crop season was (0 T) was in Northern high hills (AEU 15). It can be also noticed Production under rice during the third crop season has shown a decline in all of the 5 AEUs in Palakkad over a period from 2009 – 2017.

Table.46. Rice production during the third crop season in various Agro-Ecological Units of Palakkad

YEAR	AEU 10	AEU 13	AEU 15	AEU 22	AEU 23	Total
2009	445.1	1900.9	30.0	3770.3	17396.8	23543.0
2010	619.2	990.5	56.5	1427.8	13732.1	16826.1
2011	298.0	2257.5	4.3	905.3	11819.4	15284.5
2012	236.2	885.8	2.9	2664.5	6895.8	10685.1
2013	220.8	136.8	7.0	763.2	4140.8	5268.7
2014	455.1	919.0	7.1	4127.8	7627.4	13136.4
2015	377.7	1107.8	0.0	632.8	6782.2	8900.5
2016	540.2	751.7	0.0	1013.2	8821.5	11126.7
2017	156.7	56.4	0.0	59.8	603.7	876.5

4.9.4.4. Rice productivity during the first crop season in various Agro-Ecological Units of Palakkad

It can be inferred from the below table that as per the latest statistics, highest Productivity under rice during the first crop season was 2.9 T hectares^{-1} in Palakkad central plains (AEU 22) and the lowest productivity under rice during the first crop season was (0 T hectares^{-1}) was in Northern high hills (AEU 15). It can be also noticed Production under rice during the first crop season has shown a decline in all of the 5 AEUs in Palakkad over a period from 2009 – 2017.

Table.47. Rice productivity during the first crop season in various Agro-Ecological Units of Palakkad

YEAR	AEU 10	AEU 13	AEU 15	AEU 22	AEU 23	Average
2009	1.6	2.2	0.0	2.6	2.5	1.8
2010	1.6	2.5	2.4	2.6	3.0	2.4
2011	1.9	2.3	0.0	2.5	2.7	1.9
2012	1.8	2.4	3.6	2.5	2.4	2.5
2013	1.8	2.2	3.5	2.4	2.5	2.5
2014	2.1	2.3	0.0	2.8	2.7	2.0
2015	2.0	2.0	0.0	2.5	2.6	1.8
2016	2.2	2.4	0.0	2.6	2.6	2.0
2017	2.1	2.8	0.0	2.9	2.8	2.1

4.9.4.5. Rice productivity during the second crop season in various Agro-Ecological Units of Palakkad

From the below table that as per the latest statistics, highest Productivity under rice during the second crop season was 1.4 T ha^{-1} in Palakkad central plains (AEU 22) and the lowest productivity under rice during the second crop season was (0 T hectares^{-1}) was in Northern high hills (AEU 15). It can be also noticed Production under rice during the first crop season has shown a decline in all of the 5 AEUs in Palakkad over a period from 2009 – 2017.

Table.48. Rice productivity during the second crop season in various Agro-Ecological Units of Palakkad

YEAR	AEU 10	AEU 13	AEU 15	AEU 22	AEU 23	Average
2009	2.0	2.5	2.1	2.6	2.4	2.3
2010	2.1	2.8	2.1	2.9	2.7	2.5
2011	2.2	2.4	9.7	2.5	2.6	3.9
2012	2.2	2.8	2.6	2.9	2.6	2.6
2013	2.1	2.2	1.7	2.2	2.0	2.0
2014	2.4	2.7	2.6	3.1	2.8	2.7
2015	2.7	2.8	2.6	3.1	2.8	2.8
2016	2.7	2.6	2.0	3.0	2.9	2.6
2017	2.1	1.6	0.0	1.4	0.9	1.2

It can be inferred from the below table that as per the latest statistics, highest Productivity under rice during the second crop season was 2.3 T hectares^{-1} in Palakkad eastern plains (AEU 23) and the lowest productivity under rice during the second crop season was (0 T hectares^{-1}) was in Northern high hills (AEU 15). It can be also noticed Productivity under rice during the first crop season has shown a decline in all of the 5 AEUs in Palakkad over a period from 2009 – 2017.

Table.49. Rice productivity during the third crop season in various Agro-Ecological Units of Palakkad

YEAR	AEU 10	AEU 13	AEU 15	AEU 22	AEU 23	Average
2009	3.0	2.9	2.5	2.7	2.9	2.8
2010	2.3	2.4	2.8	1.9	2.7	2.4
2011	1.4	3.1	0.5	0.1	2.8	1.6
2012	2.4	2.9	2.9	2.9	3.0	2.8
2013	2.1	0.7	2.8	1.8	2.1	1.9
2014	2.9	2.8	3.2	3.0	2.7	2.9
2015	3.1	3.7	0.0	2.7	3.3	2.6
2016	2.9	2.8	0.0	2.1	3.1	2.2
2017	1.7	3.0	0.0	1.8	2.0	1.7

4.10. MODELING OF RICE PRODUCTION USING DSSAT MODEL

Sixteen dates of transplanting in three seasons (*Virippu*, *Mundakan* and *Puncha*) has been used for for validating CERES –Rice (DSSAT 4.7). The Genetic coefficients of the varieties were developed and presented in the Table 50.

Table.50. Genetic coefficients of major rice varieties

Variety	Genetic coefficients							
	P1	P2R	P5	P20	G1	G2	G3	G4
Jyothi	556.8	29.7	423	10.4	49.8	0.0235	1	1
Kanchana	465	149.1	404.9	12.1	9	0.23	1	1
Athira	895	55.1	270	10.8	46	0.0222	0.98	0.9
Uma	630	62.8	270	10.8	54	0.02	1	1.1

The observed and simulated yields of rice under varied agro ecological situations were presented in the table 52 to 56 and figure 2 to 6. The highest yields were recorded at Palakkad central plains (AEU 23) followed by Northern foothills (AEU 13) and the lowest were recorded under North central laterites (AEU 10). It can be inferred from the tables and figures below that CERES rice model can be used a decision support tool for estimating rice production under the varied agro ecological situations of Palakkad district. The RMSE values for DSSAT prediction showed good fit and presented in table 51.

Table 51. RMSE for DSSAT prediction

Season	Alathur	Chittur	Palakkad	Mannarkkad	Pattambi
I crop season	447.5	289.5	565.6667	101.5	66
II crop Season	585.4	591	490	820.2	195.8
III crop Season	308.8	216	213	291.4	194.8
Total	447.25	360.75	431.8125	385.4375	146.8125

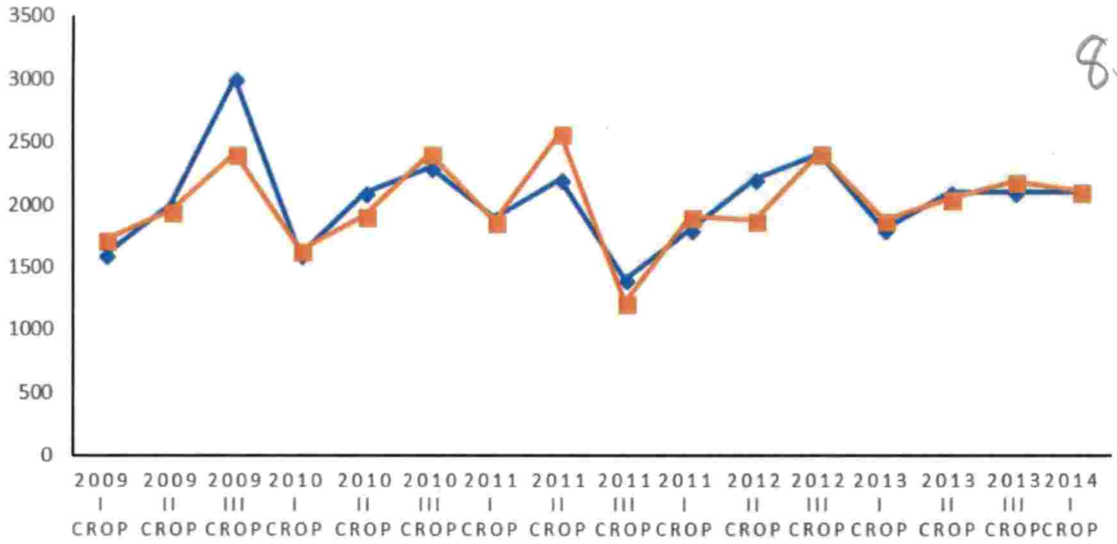

Figure.2. Observed and Predicted Yield of North central laterites (AEU10)

Table.52. Observed and Predicted Yield of North central laterites (AEU10)

Season	Pattambi	
	Observed	Predicted
2009 I Crop	1600	1726
2009 II Crop	2000	1949
2009 III Crop	3000	2411
2010 I Crop	1600	1642
2010 II Crop	2100	1916
2010 III Crop	2300	2413
2011 I Crop	1900	1870
2011 II Crop	2200	2570
2011 III Crop	1400	1216
201 I Crop	1800	1909
2012 II Crop	2200	1878
2012 III Crop	2400	2407
2013 I Crop	1800	1881
2013 II Crop	2100	2048
2013 III Crop	2100	2181
2014 I Crop	2100	2108

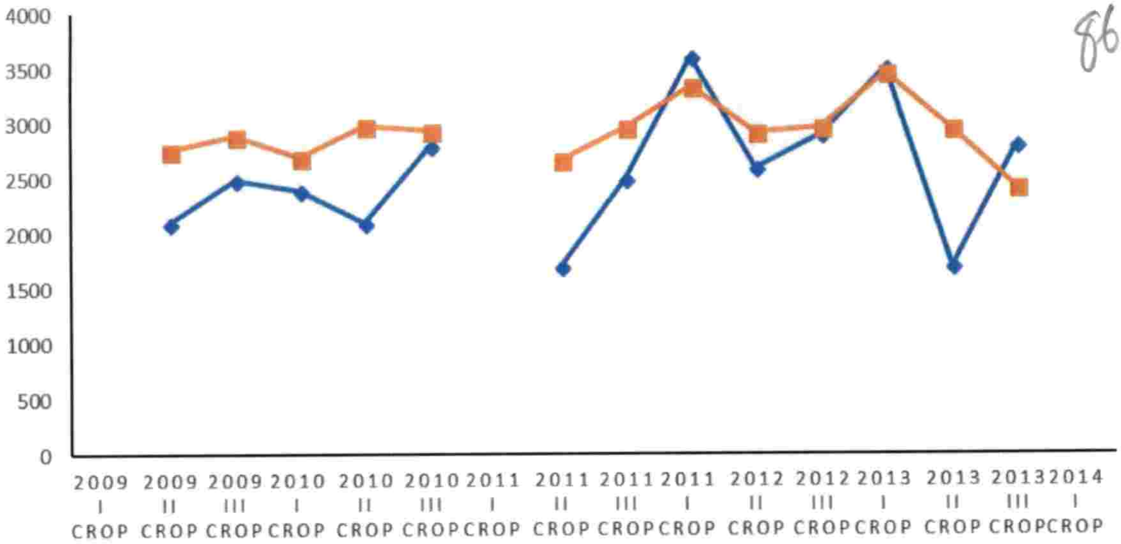

Figure 3. Observed and Predicted Yield of Northern foothills (AEU13)

Table.53. Observed and Predicted Yield of Northern foothills (AEU13)

Season	Mannarkkad	
	Observed	Predicted
2009 I Crop	0	0
2009 II Crop	2100	2769
2009 III Crop	2500	2901
2010 I Crop	2400	2707
2010 II Crop	2100	2984
2010 III Crop	2800	2941
2011 I Crop	0	0
2011 II Crop	1700	2669
2011 III Crop	2500	2965
201 I Crop	3600	3339
2012 II Crop	2600	2927
2012 III Crop	2900	2966
2013 I Crop	3500	3459
2013 II Crop	1700	2952
2013 III Crop	2800	2416
2014 I Crop	0	0

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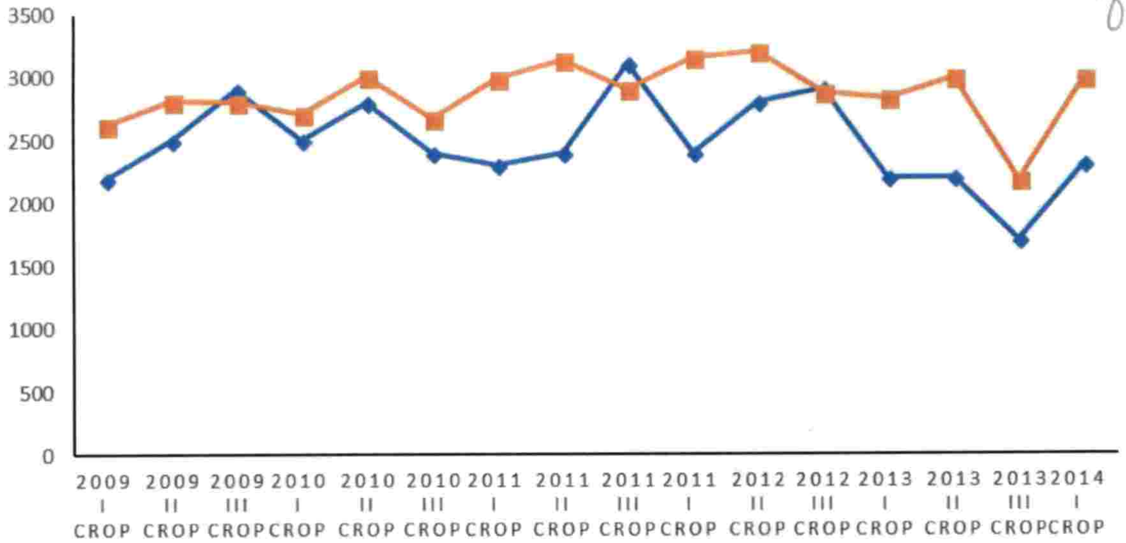

Figure 4. Observed and Predicted Yield of Northern high hills (AEU15)

Table.54. Observed and Predicted Yield of Northern high hills (AEU15)

Season	Palakkad	
	Observed	Predicted
2009 I Crop	2200	2627
2009 II Crop	2500	2821
2009 III Crop	2900	2812
2010 I Crop	2500	2717
2010 II Crop	2800	3009
2010 III Crop	2400	2672
2011 I Crop	2300	2986
2011 II Crop	2400	3135
2011 III Crop	3100	2903
201 I Crop	2400	3153
2012 II Crop	2800	3198
2012 III Crop	2900	2872
2013 I Crop	2200	2828
2013 II Crop	2200	2987
2013 III Crop	1700	2180
2014 I Crop	2300	2983

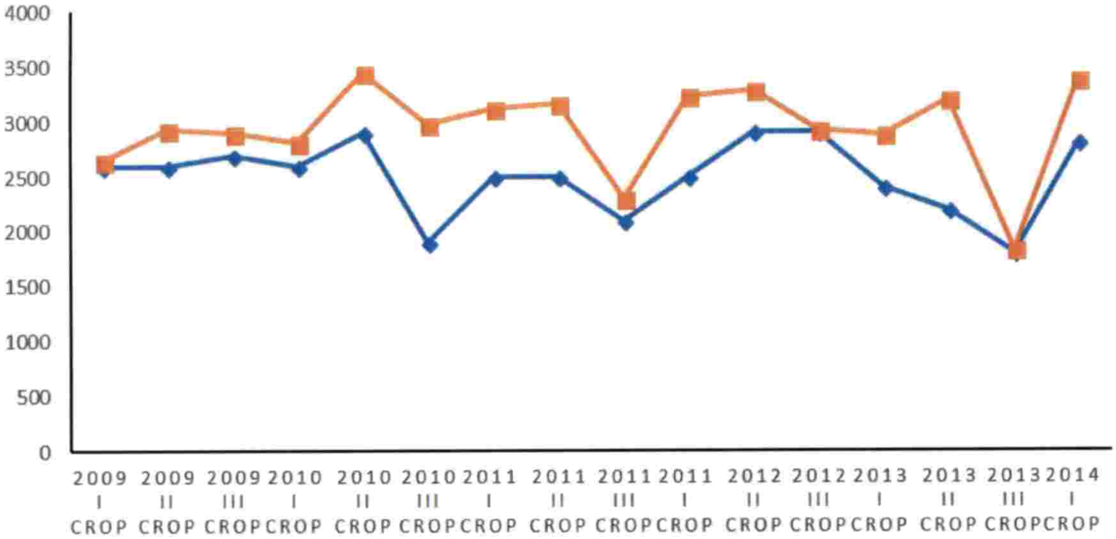

Figure 5. Observed and Predicted Yield of Palakkad central plains (AEU -22)

Table.55. Observed and Predicted Yield of Palakkad central plains (AEU -22)

Season	AEU -22	
	Observed	Predicted
2009 I Crop	2600	2658
2009 II Crop	2600	2936
2009 III Crop	2700	2908
2010 I Crop	2600	2817
2010 II Crop	2900	3453
2010 III Crop	1900	2975
2011 I Crop	2500	3126
2011 II Crop	2500	3164
2011 III Crop	2100	2300
201 I Crop	2500	3233
2012 II Crop	2900	3281
2012 III Crop	2900	2925
2013 I Crop	2400	2884
2013 II Crop	2200	3193
2013 III Crop	1800	1836
2014 I Crop	2800	3367

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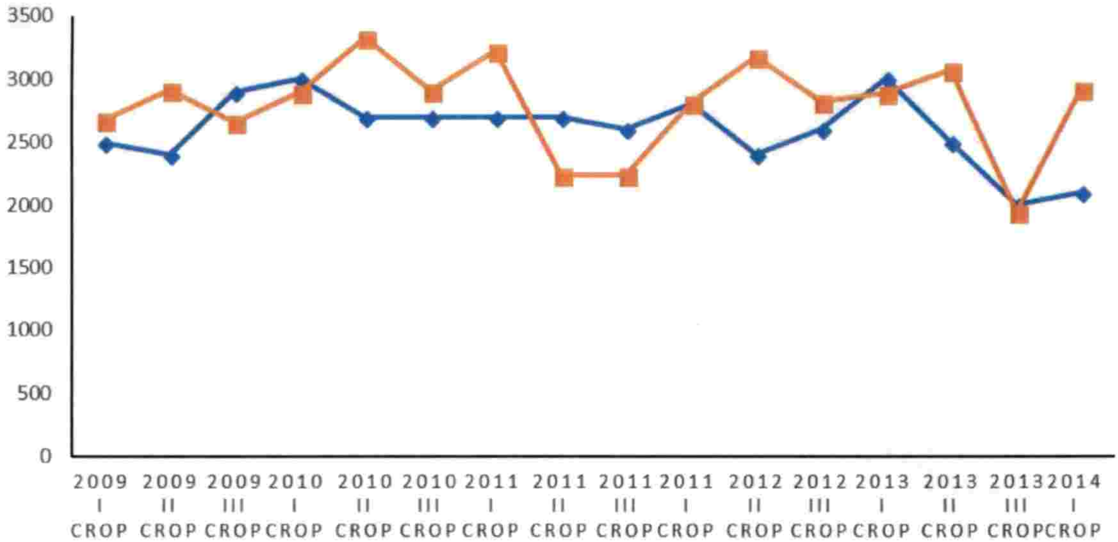

Figure 6. Observed and Predicted Yield of Palakkad eastern plains (AEU -23)

Table.56. Observed and Predicted Yield of Palakkad eastern plains (AEU -23)

Season	Chittur	
	Observed	Predicted
2009 I Crop	2500	2674
2009 II Crop	2400	2913
2009 III Crop	2900	2664
2010 I Crop	3000	2897
2010 II Crop	2700	3330
2010 III Crop	2700	2903
2011 I Crop	2700	3218
2011 II Crop	2700	2240
2011 III Crop	2600	2237
201 I Crop	2800	2813
2012 II Crop	2400	3178
2012 III Crop	2600	2823
2013 I Crop	3000	2889
2013 II Crop	2500	3074
2013 III Crop	2000	1945
2014 I Crop	2100	2918

4.11. CLIMATE CHANGE IMPACT ON RICE PRODUCTION

The future climatic projections have taken from Ensemble of 17 General Circulation Models (GCMs). The future carbon dioxide concentrations and climate data has been incorporated into crop simulation model-DSSAT and predicted the future yield for the years 2030 and 2050. The observed and predicted yield for the years 2030 and 2050 under RCPs 4.5 has been presented in the table 57.

Table.57. Impact of Projected Climate on Rice yield

AEU	Scenario	I Crop	II Crop
AEU 22	Present	2566	2620
	2030	2156	2443
	2050	2233	2364
AEU 23	Present	2800	2540
	2030	2624	2680
	2050	2896	2534
AEU 13	Present	2320	2540
	2030	3644	2652
	2050	3422	2423
AEU 15	Present	2533	2266
	2030	3107	2185
	2050	2977	2208
AEU 10	Present	1740	2120
	2030	1335	1540
	2050	1301	1635

In general, as per the projections under RCP 4.5, in the first crop season production of rice will reduce by 2030s and 2050s. By 2030s the maximum temperature is decreasing 0.4°C and minimum temperature will increase 0.7°C. The Period also showed an increase in the rainfall (674mm) which resulted in decrease yield due to flooding and low solar radiation. In the second crop season, yield will be reduced by about 10 per cent and 12 per cent by 2030s and 2050s respectively. This can be due to increase in the minimum temperature (Fig. 32) during the flowering and grain filling period of the second crop season which will increase the respiration thereby reduces the yield (Peng *et al.,* 2004).

These results are in confirmation with Wassman *et al.,* (2009) Barnwal *et al.,* (2013) Auffahammer *et al.,* (2012).

It can be also noticed from the projection results that the reduction was more in AEU 10 (23.3%), AEU 15 (16.0%) and AEU 22 (16.0%) during the first crop season in 2030s and 25.2%, 17.3% and 13.0% respectively in 2050s. The reduction in yield followed almost same trend during the second crop season also. It is interesting to notice that the reduction in yield will be comparatively less for AEU 13 and AEU 23 and even slight increase in yield will be also expected during the second crop season. The climate diagram of projected climate of the major rice growing AEUs of Palakkad is shown below (fig 7 to 11)

So, it can be concluded from the study that crop modelling is becoming a valuable tool to understand and mimic climatic constraints and yield gaps. So, it is more appropriate and can be parameterized to simulate crop growth under changing climatic scenarios to select suitable genotypes, sowing time, cropping pattern, fertilizer and weed management strategies enabling crop to cope with environmental hazards. Therefore, studies have clearly depicted crop simulation model as potential agronomic and decision-making tool to understand heat crop bio-dynamism under variable climatic conditions of agriculture (Mukhtar Ahmeda and Fayyaz-ul-Hassana. 2011).

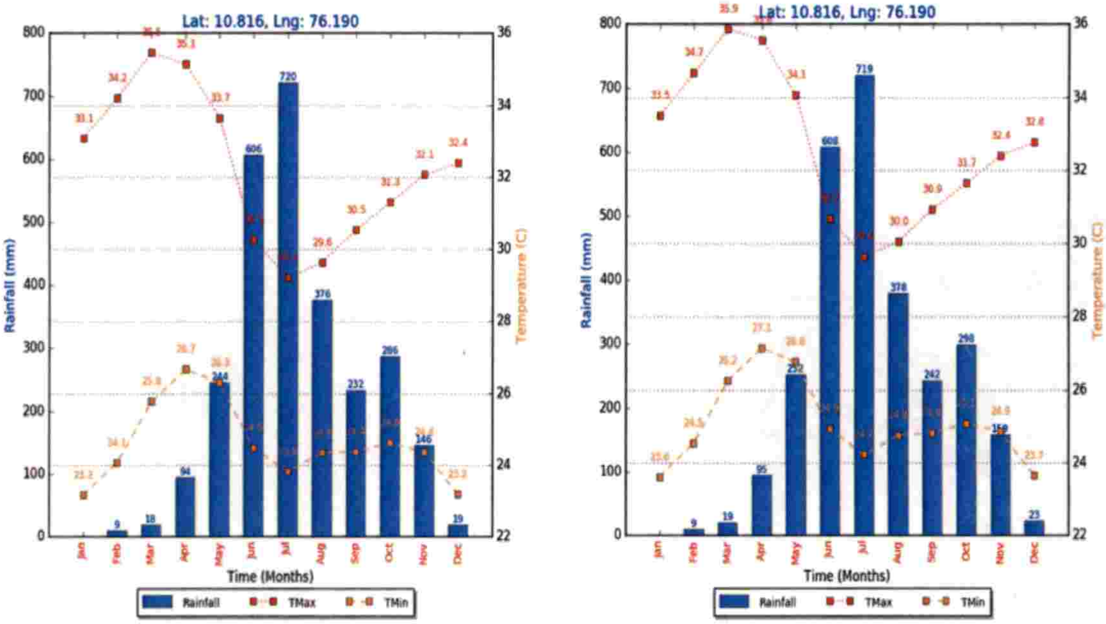

Fig 7. Projected Climate map of North central laterites (AEU10)

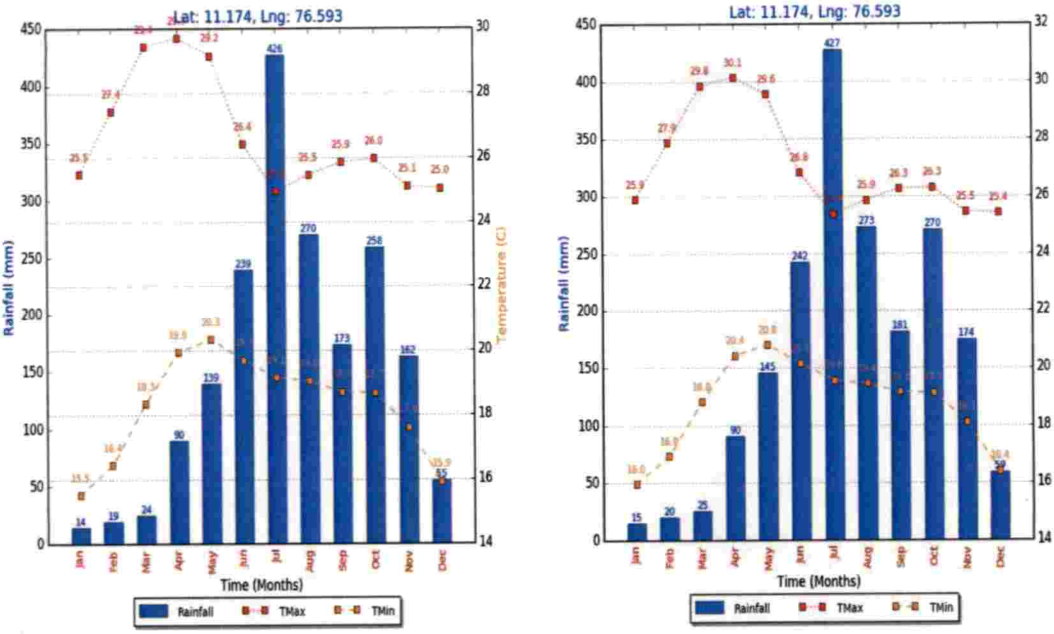

Fig 8. Projected Climate map of Northern foothills (AEU13)

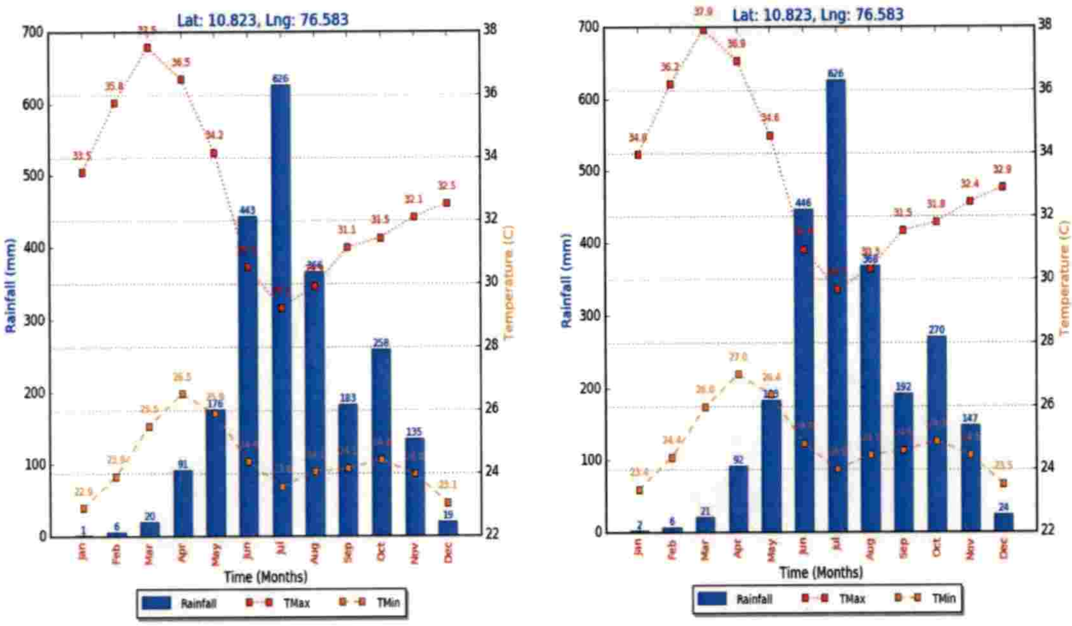

Fig 9. Projected Climate map of Northern high hills (AEU 15)

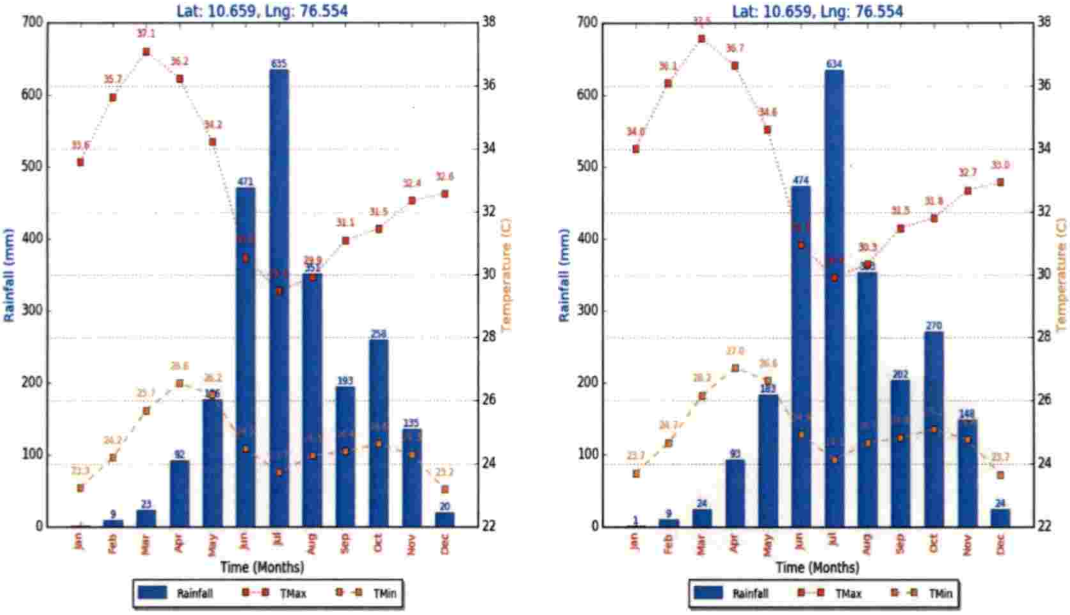

Fig 10. Projected Climate map of Palakkad central plains (AEU22)

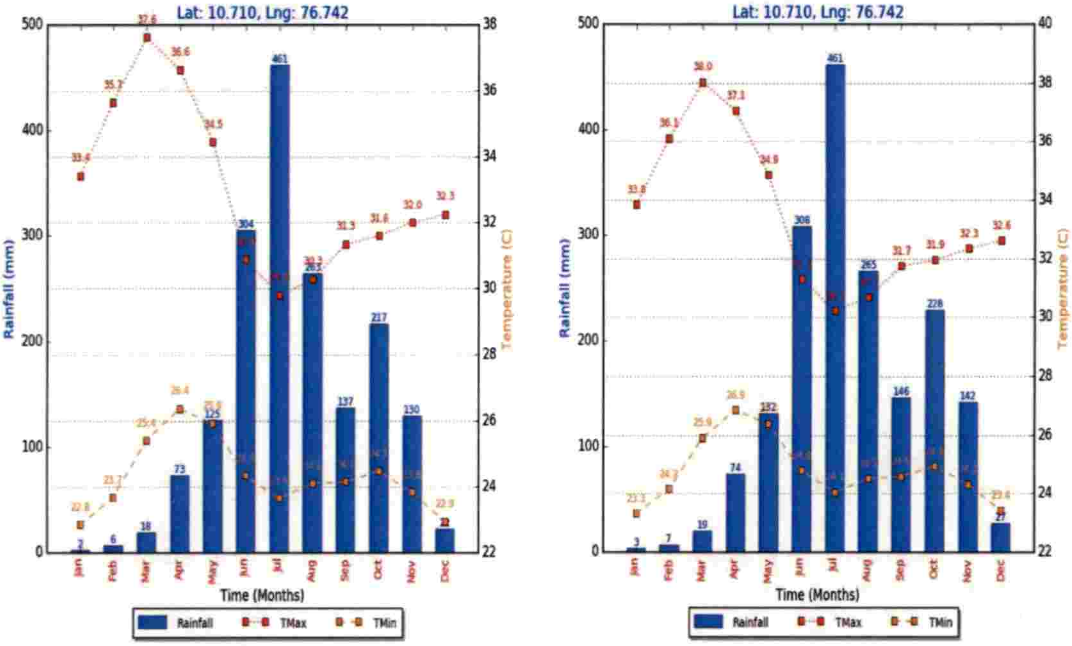

Fig 11. Projected Climate map of Palakkad eastern plains (AEU23)

Chapter 5. Summary

A study was conducted at Academy of Climate Change Education and Research to model the rice production under varied Agro-Ecological Situations of Palakkad district and its vulnerability to climate change and to study the impact of climate change by the periods 2030s and 2050s under different climate change scenarios of IPCC 2013 report.

The observations on weather factors were recorded daily to workout crop weather relationship. DSSAT model was validated and impact of climate change on rice production was studied. The salient findings are summarized as follows:

- The monthly rainfall of various Agro ecological units of Palakkad district indicate an increased rainfall during the months June, July and August in Projected climate as per RCP 4.5
- A weakening in rainfall can be noticed during the months January, February, September and December in projected climate
- Annually, the number of rainy days indicates a declining trend in projected climate. In nut shell, the wet months will be wetter and dry periods will be drier
- The south west monsoon and summer season shows an increasing tendency in the number of rainy days and amount of rainfall in projected climate
- Most of the agro-ecological units in Palakkad district showed a decreasing pattern in the length of growing period in projected climate as per RCP 4.5
- In projected climate, the maximum amount of potential evapotranspiration can be observed during the months May, July and September whereas the minimum will be in January, November and December
- The yearly potential evapotranspiration shows an increasing trend in projected climate as per RCP 4.5
- The number of periods where deficit will happen indicate a decreasing trend whereas the annual amount of deficit shows an increasing pattern in projected climate
- As per the projections maximum amount of water deficit will happen during the month March in most of the agro ecological units of central Kerala
- Annually the amount of water surplus indicates an increasing trend in projected climate based on RCP 4.5.

- DSSAT model was validated and it was given good RMSE values for important varieties of Palakkad district
- In RCP 4.5, which is the most likely scenario for India, the yield reduction will be 10 per cent and 12 per cent by 2030s and 2050s respectively.
- It can be observed from the study that the impact of climate change on rice production varied widely under different agro ecological situations
- The major rice growing tracts of Palakkad district except Palakkad eastern plains (AEU23) showed decline in productivity.

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MODELING THE RICE PRODUCTION UNDER VARIED AGRO-ECOLOGICAL SITUATIONS OF PALAKKAD DISTRICT AND ITS VULNERABILITY TO CLIMATE CHANGE

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ABSTRACT OF THE THESIS

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ABSTRACT

The research project entitled “Modeling the rice production under varied Agro-Ecological Situations of Palakkad district and its vulnerability to climate change.” was carried out at RARS Pattambi and the daily rainfall data for the period 1991-2014 was collected from the India Meteorological Department, Thiruvananthapurm.

The weather data from General Circulation Models based on RCP 4.5 and 8.5 were used for the analysis and projections were made up to 2050. Weather cock v.1.5 was used for converting the daily weather data into standard week, month and seasonal formats. The rainfall parameters or indices like seasonal and monthly rainfall, rainy days and high rainfall events were calculated. It is also used to compute PET and Thornthwaite water balances. The crop simulation model DSSAT –developed by IBSNAT was used for studying the impact of climate change on these ecosystems.

The monthly rainfall of various Agro ecological units of Palakkad district indicate an increased rainfall during the months June, July and August in Projected climate as per RCP 4.5.A weakening in rainfall can be noticed during the months January, February, September and December in projected climate, annually, the number of rainy days indicates a declining trend in projected climate. In a nut shell, the wet months will be wetter and dry periods will be drier. The south west monsoon and summer season shows an increasing tendency in the number of rainy days and amount of rainfall in projected climate.

Most of the agro-ecological units in Palakkad district showed a decreasing pattern in the length of growing period in projected climate as per RCP 4.5 In projected climate, the maximum amount of potential evapotranspiration can be observed during the months May, July and September whereas the minimum will be in January, November and December.

The yearly potential evapotranspiration shows an increasing trend in projected climate as per RCP 4.5. The number of periods where deficit will happen indicate a decreasing trend whereas the annual amount of deficit shows an increasing pattern in projected climate. As per the projections maximum amount of water deficit will happen during the month March in most of the agro ecological units of central Kerala.

Annually the amount of water surplus indicates an increasing trend in projected climate based on RCP 4.5. In RCP 4.5, which is the most likely scenario for India, the

yield reduction will be 10 per cent and 12 per cent by 2030s and 2050s respectively. It can be observed from the study that the impact of climate change on rice production varied widely under different agro ecological situations. The major rice growing tracts of Palakkad district except Palakkad eastern plains (AEU23) showed decline in productivity.