IMPACT OF CLIMATE CHANGE ON WATER BALANCE OF AGRO ECOLOGICAL UNITS OF KERALA

By

ATHUL KRISHNA, K. S

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THESIS

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ACADAMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

DECLARATION

I hereby declare that the thesis entitled **"Impact of Climate Change on Water Balance of Agro Ecological Units of Kerala"** 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.

Date: 28.03.2017
Vellanikkara

Athul Krishna K.S.
(2010-20-113)

CERTIFICATE

Certified that this thesis entitled **"Impact of Climate Change on Water Balance of Agro Ecological Units of Kerala"** is a record of research work done independently by **Mr. Athul Krishna, K.S.** (2010-20-113) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship with any other person.

Vellanikkara
28.03.2017

Dr. K.M. Sunil
(Chairman, Advisory Committee)
Assistant Professor (Agril. Meteorology)
Krishi Vigyan Kendra-Palakkad
KAU, Pattambi

CERTIFICATE

We, the undersigned members of the advisory committee of Mr. Athul Krishna, K.S. (2010-20-113), a candidate for the degree of **BSc-MSc (Integrated) Climate Change Adaptation** agree that the thesis entitled **"Impact of Climate Change on Water Balance of Agro Ecological Units of Kerala"** may be submitted by Mr. Athul Krishna, K.S. (2010-20-113), in partial fulfilment of the requirement for the degree.

Dr. K.M. Sunil
(Major advisor, Advisory Committee)
Assistant professor, Agricultural meteorology
Krishi Vigyan Kendra-Palakkad
Pattambi

Dr. E.K. Kurien
(Member, Advisory Committee)
Special Officer
ACCER, KAU
Vellanikkara, Thrissur.

28/03/2017
Dr. P. Suresh Kumar
(Member, Advisory Committee)
Professor and Head,
Radiological Safety Officer,
Radiotracer Laboratory,
College of Horticulture
Vellanikkara, Thrissur

Dr. S. Sandeep
(Member, Advisory Committee)
Scientist- B
Kerala Forest Research Institute
Peechi, Thrissur

28/3/17
EXTERNAL EXAMINER

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Weather and its associated seasonal patterns are critical components of agricultural production systems. Rising temperatures linked with climate change will likely have a detrimental impact on crop production, livestock, fishery and allied sectors. With the ever increasing need for food, shelter and energy, the subject of maximizing the produce from land by agriculture has become the most important problem for the entire human race. The problem is all the more important and perhaps, belongs to priority number one for an agricultural country like India. Because of climate change, Indian agriculture is doubly vulnerable. First as around 60 percent of India's total agricultural areas are rain-fed, it is highly vulnerable to climate change impacts on monsoon. Secondly, more than 80 percent of farmers in India are small and marginal (having less than 1 ha of land) thus having less capacity to cope with climate change impacts on agriculture.

The full potential of climate as an agricultural resource has not been used or ever realized. As a result, several crops are grown traditionally in areas without any consideration for the suitability of climate. Thus, on the one hand, poor yields of crops are obtained and on the other, much of the production potential of this vast resource is left unutilized. It is impossible to tame the weather on a large scale, or even be in complete harmony with it. However, it is inevitable to make adjustment with the weather to extract the maximum benefit from this resource. In this context knowledge on agro-climatology of a region is a valuable tool in crop planning.

The concept of agro-ecological delineations was developed by FAO (1976, 1978) with strong emphasis on comparable agro-climatic parameters to delineate agriculturally potential areas suitable for particular crops or combination of crops so that optimum production potential is achieved. The significance of homogeneous agricultural environment, as realized in the agro-ecological unit is of particular importance in effective and sustainable land use to enhance agricultural output for meeting the increasing demand for food, fodder, fiber and other products.

The Planning Commission, consequent to a mid-term appraïsal of the planning targets of the VII Plan (1985-1990), divided the country into 15 broad agro-climatic zones based on physiography and climate.

In this scheme entire state of Kerala formed a part of zone 12, West Coast Plains and Ghat region. Later National Agricultural Research Project (NARP) delineated India into 127 Agro ecological subzones based primarily on rainfall, existing cropping patterns and administrative units and Kerala State was delineated into 8 subzones viz., Northern zone, Southern zone, Central zone, High altitude zone, Onattukara zone, Kuttanad and Kole zone, Pokkali zone, and Low rainfall zone. Kerala Agricultural University revised the NARP delineation the agro-ecological subzones and created an Agro-ecological Zones Map of the state (Kerala Agricultural University, 2007).

The basis of spatial delineations was the variability in altitude, rainfall pattern, soil type and topography. The revision resulted in delineation of 13 agro-ecological zones for the state. Off late, the researchers of NBSS&LUP characterized the agro-ecological variability in the state and generated an agro-ecological unit map of the state with the funding of the Kerala State Planning Board during 2008.

Kerala state is blessed with rich biodiversity. Forest covers nearly 29 per cent of the state's total land area. The mountain ranges in Kerala consisting of the highland area of the Western Ghats, display an exotic charm. Rising to an average height of 1520 m, the tropical forests of the Ghats house rich and unique flora and fauna.

The Western Ghats are home for major plantations like tea, coffee, cardamom, pepper and various spices. The midlands and lowlands are areas of intensive cultivation under a variety of plantation and annual crop production systems. Coconut, rubber, cashew and areca nut are the major plantation crops and rice, banana, tapioca and vegetables are the major annual crops.

The Intergovernmental Panel on Climate Change (IPCC) reported that if the projected doubling of atmospheric CO_2 occurs within the next century it is likely to cause significant changes in global and regional climates, and that this will have a significant impact on ecosystems and natural resources (Houghton *et al.,* 1990). Agricultural productivity and agro-biodiversity of an area are largely governed by the overhead climate and qualities of land and soil.

In the tropics and subtropics, where sunlight and temperature are not limiting, it is often the precipitation and the capacity of the land and soil to retain water that control biological productivity. An agro-ecological delineation is characterized by distinct ecological responses to the macro-elements, which are reflected in the vegetation, soils and agricultural land use. In order to understand how the climate change will affect the crop production in Kerala, the present investigation was taken up with the following objectives:

1. To study rainfall variability and to determine water availability periods of 23 Agro ecological units of Kerala under different climate change scenarios.
2. To determine weekly Moisture Adequacy Index (MAI) for various AEU in the state in the purview of climate change.
3. To study the effect of climate change on water balance and length of growing period of Agro ecological Units of Kerala

An agro ecological zone (AEZ) is a land resource mapping unit, defined in terms of climate, landform, and soils, and has a specific range of potentials and constraints for cropping. The future climate change will lead to significant local changes of AEZs and the overall pattern of AEZs. Climate change alters weather conditions considerably which is sufficiently evident from observations all around the world. Climate change alters weather variables and there by affect the production of rice. General Circulation Models (GCM's) are very useful in predicting the future climate. In this chapter we are going to review the effect of climate change on water balance and its components under various agro ecological units of Kerala state is being reviewed.

2.1. CLIMATE CHANGE

The atmosphere acts like the glass of a hot house, because it lets through the light rays of the sun but retains the dark rays from the ground (Fourier, 1824). The diurnal and annual variations of the temperature were lessened by the absorption of atmosphere (Tyndall, 1861). Water vapour, hydrocarbons like methane (CH_4), and carbon dioxide (CO_2) strongly block the radiation (Tyndall, 1872).

The air retains heat (light or dark) in two different ways. The heat suffers a selective diffusion on its passage through the air. On the other hand, some of the atmospheric gases absorb considerable quantities of heat. These two actions are very different. The selective diffusion is extra ordinarily great for the ultra-violet rays, and diminishes continuously with increasing wave-length of the light, so that it is insensible for the rays that form the chief part of the radiation from a body of the mean temperature of the earth (Langley, 1884).

Cutting CO_2 in half would suffice to produce an ice age. A doubling of atmospheric CO_2 would give a total warming of 5.0 to 6.0 °C (Arrhenius, 1896).

A systematic variation with season and latitude in the concentration and isotopic abundance of atmospheric carbon dioxide has been found in the northern hemisphere. In Antarctica, a small but persistent increase in concentration has been found (Keeling, 1960).

A doubling of carbon dioxide from the current level would result in approximately 2.0°C increase in global temperature (Manabe and Wetherald, 1967). In 1975, Manabe (1975) had developed a three-dimensional global climate model that gave a roughly accurate representation of the current climate. Doubling CO_2 in the model's atmosphere gave a roughly 2.0°C rise in global temperature.

Chlorofluorocarbons (CFCs) could have a global warming effect (Lovelock *et al.*, 1973). A CFC molecule could be 10,000 times more effective in absorbing infrared radiation than a carbon dioxide molecule, making CFCs potentially important despite their very low concentrations in the atmosphere (Ramanathan, 1975). After 1980, scenarios become main stream in futures research (Hafele *et al.*, 1981, Robertson, 1983, Svedin, 1987)

IPCC was established in 1988 by two United Nations organizations, the World Meteorological_Organization and the United_Nations_Environment Programme. In first report, they predict that under a "business as usual" scenario, global mean temperature will increase by about 0.3°C per decade during the 21st century. They judge that global mean surface air temperature has increased by 0.3 to 0.6 °C over the last 100 years, broadly consistent with prediction of climate models, but also of the same magnitude as natural climate variability.

The greenhouse gases (GHGs) are presently increasing at the rate of one percent for CH_4, 0.4-0.5 percent CO_2 and 0.2-0.3 percent for N_2O (Baker 1989). General Circulation Models (GCMs) used to study climate changes project variable magnitude of change particularly on a regional basis (Mitchell *et al.*, 1990).

Giorgi *et al.*, (1998) showed for most regions of the world, the inter-GCM model range of simulated temperature increase for a doubling of CO_2 was about 3.0-5.0°C. For South-east Asia different GCMs predicted an increase of 0.8 to 3.2°C for doubling of CO_2.

The globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85°C, over the period 1880 to 2012. Global surface temperature change for the end of the 21st century is likely to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP 2.6. It is likely to exceed 2.0°C for RCP 6.0 and RCP 8.5, and more likely than not to exceed 2.0°C for RCP 4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP 2.6. Warming will continue to exhibit inter annual-to-decadal variability and will not be regionally uniform (IPCC, 2013).

2.2. CLIMATE CHANGE AND AGRO ECOLOGICAL ZONES

Dickinson, (1983) and Schlesinger, (1997) concluded that Climate change will affect the terrestrial biosphere through changes in the regional energy balance and play a primary role in determining the ecology of a region. Gunderson *et al.*, 2000 commended that the terrestrial

Ecosystems are the first sectors where climate change impacts can be recognized and 'value' of impact is difficult to be quantitatively assessed.

A critical examination of the AEZ classification and its applicability to a climate change impact analysis has never been conducted, albeit its popularity in climate literature (Easterling *et al.*, 2007).

The impact of climate change on water resources seems apparent since it alters precipitation and temperature, factors such as population growth and land use change often have a more substantial impact (IPCC, 2007)

Several agricultural researchers identified most vulnerable agricultural zones to climate change and weather factors using the AEZ concept (Butt *et al.*, 2005, Kazianga and Udry, 2006; Thornton *et al.*, 2008; Seo, 2012).

Studies conducted by Fischer *et al.*, 2005 and Tubiello *et al.*, 2007 found that Agro Ecological Zone classification has proved to be useful in the impact analysis of climate change on agriculture and it also turned out to be a useful concept in explaining adaptation behaviors to climate change.

According to Naik and Sastry (2001) precision in research in agriculture could be much accurate and extension recommendations would be much successful as one moves from macro level to micro level approaches for classification of agro ecological zones.

Griffin *et al.*, (2013) used the water stress indicators to categorize the sub-watersheds as water rich, water stressed, or water scarce and concluded that scenarios incorporating regional predictions of climate change indicate a decrease in summer soil moisture minima and increases in summer water deficit and also there is a shift toward water stress in the Lower Cape Fear River basin, due to a warming climate as well as increased demand.

According to Seo, N.L. (2013) the Agro Ecological Zones classification identifies the land's suitability for crop farming and adaptive decisions such as diversification and risk management are difficult to capture by the Agro Ecological Zone methods.

Ecological conditions in turn have profound impacts on the types and scales of various economic activities performed therein. Economic activities lead to greenhouse gas emissions or reductions which have consequences on the earth's climate (Keeling *et al.*, 2005; Nordhaus, 2006; Hansen *et al.*, 2006; IPCC, 2007; Seo, 2012).

The agronomists who studied Africa have shown that climate factors play a substantial role in African agricultural activities They classified African geography into the Agro-Ecological Zones (AEZs) based on temperature, precipitation, and soil moisture conditions (Ford and Katondo, 1977).

According to Fischer *et al.*, (2005) and Tubiello *et al.*, (2007) this AEZ classification has proved to be useful in the impact analysis of climate change on agriculture and it also turned out to be a useful concept in explaining adaptation behaviors to climate change.

The concept of growing seasonal crops is applied to the statistical examination of an individual crop's yield vulnerability to climatic change and agricultural researchers also identified most vulnerable agricultural zones to climate change and weather factors using the AEZ concept (Butt *et al.*, 2005, Kazianga and Udry, 2006; Thornton *et al.*, 2008).

The shifts in the AEZs under different climate change scenarios were modeled using statistical methods. However, a critical examination of the AEZ classification and its applicability to a climate change impact analysis has never been conducted, albeit its popularity in climate literature (Easterling *et al.*, 2007; Kala *et al.*, 2012).

According to Seo and Mendelsohn,(2008) the characterization of the Africa's ecosystems using the AEZ concept is a good indicator of a variety of farming activities that are actually performed on the ground by the African farmers and is a useful tool for the study of climate change.

Yingzhi Lin *et al.*, (2013) found that the future climate change would lead to significant local changes of AEZs in China and the overall pattern of AEZs in China is stable.

The shifting patterns of AEZs were be characterized by northward expansion of humid AEZs to sub-humid AEZs in south China, eastward expansion of arid AEZs to dry and moist semiarid AEZs in north China, and southward expansion of dry semiarid AEZs to arid AEZs in southwest China.

2.3. CLIMATE CHANGE AND WATER BALANCE

The concepts of water balance was put forth by Thornthwaite in 1948. Thornthwaite evolved a book keeping procedure from which it is possible to calculate actual evapotranspiration (AET), water surplus (WS) and water deficit (WD), by comparing PET and rainfall.

Thornthwaite and Mather (1955) revised assumptions and methods of computations of the book keeping procedure. The water balance of India according to these modified concepts was discussed by Subrahmanyam (1956).

Subramaniam (1964) in an attempt to use the knowledge of applied climatology in order to examine as to what extent Thornthwaite's scheme could be used for explaining the natural vegetation of the Mysore state, observed that, despite the scarcity of stations and scantiness of data, the correspondences were so marked and convincing that they justified the applicability of water balance concepts to practical problems and thus there established the rationality of the approach.

Pinto and Preuss (1975) prepared a computer program in FORTRAN for the evaluation of water balance according to the method proposed by Thornthwaite and Mather. The maximum water storage term can be modified according to the crop considered. Monthly values of soil water retention were calculated on a mathematical basis.

Queiroz and Correa (1979) calculated the water balance for 10-day periods in Ponta Grossa using the method of Thornthwaite and Mather. Several periods of water deficiency and excess were identified.

Subramaniam and Rao (1979 and 1980) studied the broad scale patterns of water balance for Rajasthan with particular reference to its latitudinal and longitudinal variation. Subramaniam *et al.*, (1980) presented the climatic water budget for Andhra Pradesh as a whole. Subramaniam and Rao (1981) compared the spatial distribution of annual IMA with crop combination maps of Maharashtra.

Subramaniam and Murthy (1982) calculated the climatic water balances of five stations of Kerala state. They also classified climates of Kerala both on thermal and moisture regimes following Thornthwaite's scheme. Subramaniam and Rao (1982) presented the water balance and crops in Karnataka. They calculated climatic water balance elements and water balance indices for all the meteorological stations in the state. They compared the general distribution of crops and IMA to identify the limits for certain crops.

For studying about water balance of any region, invented by Thornthwaite (1948), is the climatic water balance approach, and later it was modified by Thornthwaite and Mather in 1955 (Subramanyam, 1982).

Franco (1983) presented five programs for computing water balance by Thornthwaite-Mather method using TEXAS TI 59/PC-100C equipment. Hanna (1983) discussed the following (a) the water balance of crops, (b) the measurement of soil water in the field, (c) relationships between the environment and growth, (d) statistical models of climate and yield, (e) moisture indices, (f) application of statistical models and (g) models of the soil-plant-atmosphere.

Swaminadhan and Shanthakumari (1983) studied water balance for selected stations in Madurai district of Tamil Nadu to find out the water surplus/deficit and to suggest the cropping season. They proposed to suggest suitable cropping seasons for the district.

Vinayak (1983) computed water balance and indices for six stations in Kerala for finding the impact of soil moisture conditions on crop yields.

Subramaniam and Rao (1985) presented monthly and weekly water balances of a dry subhumid coastal station of Andhra Pradesh. They used the concept of aridity to identify the drought years with different intensities and also delineated water availability periods.

Donker (1987) prepared a computer program (WTRBLN) to calculate water balance based on the basis of long-term average monthly precipitation, potential evapotranspiration and combined soil and vegetation characteristics, according to the method proposed by Thornthwaite and Mather. Three additions to the original method are implemented (1) direct runoff can be taken into account (2) reference potential evapotranspiration can be adjusted to crop potential evapotranspiration by the factors and (3) a successive approximation method can be selected by the user if the climate is so dry that the soil never reaches field capacity.

Amorirn and Silva (1989) defined the water balance according to Thornthwaite and Mather. Its calculation was described and examples of its application to different regions of Brazil were presented with the help of tables and graphs.

Agnese *et al.*, (1989) computed water balance using Eagleson water balance model and a comparison with the more simplified Thornthwaite model showed marked differences in results.

Chakraborty and Chakraborty (1990) used daily rainfall data during 1976-85 for estimating assured rainfall pattern, conditional probability analysis and water balance analysis for the Berhampore region in the Murshidabad district of West Bengal. Water balance analysis was made for different soil types in the region with available water capacity of 200, 250 and 300 mm/m soil depth. The use of the information obtained from those analyses for crop planning in the region was discussed.

Zahler (1991) determined moisture deficiencies for C. *arabia* in the Distrito Federal, Brazil, using 1931-1960 meteorological data. The water balance was calculated by Thornthwaite and Mather's method, considering a soil moisture retention of 125 mm.

Victor *et al.*, (1991) observed that crop water use estimated from the FAO water balance model which can be used to quantify the crop yields. Their analysis can permit evaluation of the suitability of a given crop for production at the planting site.

Kerkides *et al.*, (1997) calculated water balance, for 31 locations in Greece on the basis of long-term average monthly precipitation, evapotranspiration and combined soil and vegetation characteristics, using the method of Thornthwaite and Mather.

Urgent action is required for understanding and solving potential water resources problems for human's existence and well-being, especially, quantitative estimates of hydrological effects of climate change are essential (Guo *et al.*, 2002).

The term 'water balance' expresses overall mass conservation for all rain falling in any given period. However, the water potential can never be assessed from precipitation alone. To assess such potentiality, it is essential to have reliable information on the balance between inflows and outflows of water for each situation and analysis of water balance for the study area was done according to Thornthwaite book keeping technique (Sudhishri, 2007)

Water balance is a concept used to understand the availability and the overall state of water resources in a hydrological system which forms the basis of the principle of mass conservation applied to exchanges of water and ensures the magnitudes of the various water exchange processes (Das, 2015)

2.3.1. Precipitation

On globally average basis, precipitation over land increased by about 2% over the period from 1900–1998 (Dai *et al.,* 1997 and Hulme *et al.,* 1998).

Hurd *et al.,* (1999), reported that in the southern United States may see an overall increase in precipitation, but will also see alteration in the yearly distribution, such that the increase will likely come more in the form of intense precipitation events, causing water quality and flooding problems.

According to Katz, 1999, the probability of occurrence of substantially more extreme precipitation events could increase dramatically if there are increases in both the mean and the variance of precipitation amounts.

In a warming climate, this could result in increased moisture content in the atmosphere, likely increasing the intensity and/or frequency of precipitation events, often referred to as the intensification of the hydrologic cycle. At the same time, increased temperature and energy content of the atmosphere could drive increases in evaporation that could also increase the moisture content of the atmosphere and enhance precipitation events (Trenberth, 1999).

According to the IPCC report on Climate Change (2001), precipitation has been inhibited due to subsidence in areas like Kalahari and Sahara deserts almost throughout the year. In equatorial and tropical areas however, moderate to heavy precipitation known to be associated with the Inter-Tropical Convergence Zone (ITCZ) is experienced.

It is now well established that surface air temperatures and precipitation over land have increased during the 20th century Results from recent simulations using one of about 20 coupled ocean–atmosphere–land models based on the IS92A mid-range emission scenario indicate that global mean surface air temperature, precipitation, evaporation, and runoff will increase 2.3 °C, 5.2, 5.2, and 7.3%, respectively, by 2050 (Wetherald and Manabe, 2002).

Karl and Trenberth, 2003 reported the increases in precipitation intensity with increasing mean annual surface air temperature for a fixed precipitation amount.

Air temperature is a determining factor for many hydrologic processes and variables, so fluctuations in temperature should be expected to alter the hydrologic cycle. This is due in large part to the sensitivity of saturation vapor pressure, which increases with an increase in temperature (Milly *et al.*, 2005)

Huntington (2006) analyzed historical data to see if trends exist supporting the hypothesis of intensification of the hydrologic cycle with warming. While results indicated intensification, the analyses showed some spatial and temporal uncertainty that relates to incomplete data and some contradictory results.

Climate change is expected to affect precipitation and evapotranspiration patterns (Tsanis *et al.*, 2011)

2.3.2. Dependable precipitation

The best method to determine the rainfall probability is to fit the data to incomplete gamma distribution (Stern and Coe, 1982; Mondel *et al.*, 1983; Chan, 1984; Sarker *et al.*, 1978). However, the simple ranking method described by Doorenbos and Pruitt (1977) and Frere and Papov (1982) does not involve complicated statistics and hence, is used for computing rainfall probabilities for all the stations in the central zone. Use of probabilities of monthly total rainfall for agronomic purpose has been reported by Manning (1956); Baliga and Sridharan (1968).

Hargreaves (1975) defined dependable precipitation as the amount that is normally equaled or exceeded three-fourths of the time. It is the 75 percentage statistical probability of occurrence. Mean rainfall data has little value in rainfed agriculture. It gives only trends of certain climatic patterns and can be useful as a tool to indicate agro climatic homogeneous zones, to some extent, but do not give any information on rainfall variability (Hargreaves, 1977; Neuwolt, 1981). In rainfed agriculture, for understanding the probability of success in cropping, one must consider the assured rainfall received in three out of four years, which is otherwise known as dependable precipitation (DP), dependable rainfall or 75 percent probability rainfall.

Virmani (1975) considered crop growth period for three different available water storage capacities and worked out length of growing season at different probabilities of assured rainfall. Virmani *et al.*, (1978) reported the use of initial and conditional rainfall probabilities for obtaining agronomically relevant information.

Month is a fairly long period for critical crop growth phases which are usually of a week or ten days duration. The soil water holding capacity can usually 7 buffer moisture availability for one week or more, so that weekly rainfall models can be used (Sarker, 1978).

Sarker *et al.*, (1978) have analyzed weekly rainfall in the dry farming tract of Karnataka by fitting gamma distribution probability model. Khambete and Kanade (1980) also made weekly rainfall analysis of dry farming tract of Karnataka.

Dickinson, (1983) concluded that Climate change will affect the terrestrial biosphere through changes in the regional energy balance.

Hargreaves *et al.*, (1985) determined precipitation probabilities from the monthly values of precipitation for the 30 years period (1931-60) ranked by the World Meteorological Organization and stated that the accuracy of the analysis depends more on the length of record than on the method used.

The regional water balance is distributing the precipitation to runoff and evapotranspiration from the land surface, and soil moisture storage. Seasonal shifts in water balance occur as a function of precipitation and other climate conditions. Climatic factors, such as temperature, humidity, and wind, affect the water balance by influencing evaporation and transpiration (Eagleson, 1986)

According to Pisharoty (1986), annual rainfall over the plains of India based on the data of 2800 stations is 117 cm and this is the highest value anywhere in the world for a country of the same size of India.

Santhosh and Prabhakaran (1988) applied a first order Markov chain model to daily rainfall data to characterize the rainfall pattern of five selected stations of northern Kerala. Suitable probability distributions were fitted to estimate the rainfall probabilities.

According to Brubaker *et al.*, (1993) alterations in precipitation recycling, the redistribution of water locally that was evaporated from the surface, will increase the frequency of localized precipitation and also the contribution of regional evaporation to regional precipitation varies substantially with location and season.

Analysis of the lowest assured weekly rainfall at different probability levels using the incomplete gamma distribution was found suitable for planning rainfed crops and related rainwater conservation measures for hilly regions of Himachal Pradesh (Verma, *et al.*, 1994).

Biswas and Phadtare (1995) computed rainfall probability at different levels of 16 stations of Konkan region by fitting gamma distribution model to weekly rainfall and suggested a suitable cropping pattern based on rainfall probabilities, soils and existing cropping pattern of the region.

Subudhi *et al.,* (1996) computed dependable rainfall at 40, 50, 60 and 75 per cent probability levels for Bhadrak and Balasore districts of Orissa by using monthly rainfall data. Variation of mean annual rainfall, coefficient of variation and standard error were calculated. They reported that rainfall probability at 60 percent and 70 percent may assist crop planning and irrigation planning, respectively.

According to Guo and Yin, 1997 in the hydrological cycle, the runoff is more sensitive to variation in precipitation than to variation in temperature.

Decreases in pan evaporation have been observed over most of the USA and the former USSR between 1950 and 1990 and such decreases are generally thought to be inconsistent with observed trends towards increasing temperature and precipitation, resulting in an 'evaporation paradox' (Brutsaert and Parlange, 1998).

Rao *et al.*, (1998) assessed the probability of receiving adequate rain for successful crop establishment by using daily rainfall data for Anantapur, Nandyal and Lam from 1969-1984. The implications for crop production were discussed and the probability of receiving a minimum monthly rainfall of 50, 75 and 100 mm at each location was calculated.

2.3.3. Potential evapotranspiration (PET)

There are many methods developed from time to time by various workers to estimate PET. Some of them are by Thornthwaite (1948), Penman (1948), Montieth (1965), Van Bavel (1966), Linacre (1967), Taylor (1972) and Hargreaves (1977). The widely accepted concept of potential evapotranspiration was put forth by Thornthwaite (1948) and Penman (1948) independently. Thornthwaite (1948) de ned potential evapotranspiration as 'the maximum amount of water that would evaporate and transpire from a thickly vegetated extensive territory with no de ciency of water for full use at any time'. Thornthwaite (1948) described the biological and physical importance of evapotranspiration in climatic delineation. He developed an equation for estimating potential evapotranspiration.

Sanderson (1950) reported that measurements of daily evaporation at Toronto over a vegetated soil surface were favourably compared with the PET estimated by the Thornthwaite formula.

Penman *et al.*, (1956) defined PET as the 'evaporation from an extended surface of short green crop, actively growing, completely shading the ground, of uniform height and not short of water'.

Thermal efficiency (same as PET) for several Indian stations according to Thornthwaite formula were first reported by Subrahmanyam (1956a). Palmer and Havens (1958) provided a graphical solution for Thornthwaite's equation.

Matejka (1972) mapped and tabulated Thornthwaite's potential evapotranspiration estimates calculated for 141 meteorological stations throughout Czechoslovakia, discussing their distribution in relation to bioclimatic zones and altitudinal zones of forest associations.

Deo and Amissah (1973) estimated potential evapotranspiration rates over a grass sward at Guelph, Canada using the methods of (a) Penman and (b) Thornthwaite. There was no difference between the two methods, if annual totals were considered, but when using monthly totals, estimates using (a) were higher than when using (b) from May to July; from July onwards estimates with (b) were higher than with (a).

Coulter (1973) compared the estimates of potential evapotranspiration by the Penman formulae with estimates based on evaporation tank data and found to agree well at a number of stations, but tank estimates were greater when the aerodynamic term was large. Potential evapotranspiration values calculated for months and for five day periods were closely correlated with corresponding tank evaporation values. Except when ET was near that corresponding to wet conditions over a wide area, Thornthwaite's estimates were considerably lower than those derived from combination formulae or tank estimates.

Tarsia (1975) reviewed the commonest methods of measuring potential evapotranspiration, with special reference to the formulae of Thornthwaite, Turc and Penman, and provided evidence for concluding that Penman's formula gives the best results.

Ulehla and Smolik (1975) simplified the Thornthwaite method for estimating potential evapotranspiration using the linear relationship between monthly totals of potential

Evapotranspiration and the respective monthly mean temperatures. Data from Pohorelice during 1952-69 were used as an example.

Thermal efficiency values for thirteen stations in Andhra Pradesh have been reported by Subrahmanyam and Hemamalini (1977).

Subramaniam and Rao (1980) reported that the PET values computed using the Thornthwaite formula were in better agreement in per humid (in Vengurla), humid (in Bombay) and sub humid (in Chanda) climate whereas the deviations were more from and arid climates.

Dumario and Cattaneo (1982) used Penman's equation for estimating potential evapotranspiration for data from 186 Sites in Argentina. Charts for the whole year were presented and compared with values obtained by the methods of Thornthwaite, Papadakis and Grassi- Christiansen and with estimations of ETo (reference crop evapotranspiration) obtained from evaporation measurements corrected for variable zonal factors according to the probable magnitude of the oasis effect.

Franco (1983) presented simplifications of the Thornthwaite, Penman and Turc methods of calculating evapotranspiration. The method involved replacing daily values for some parameters by values for a hypothetical mean day value. Values for the parameters are given for N and S latitudes in the different months of the year.

Bosnjak (1986) developed regression equations and correlation indices for converting calculated potential evapotranspiration using the formulae of Penman Blaney and Criddle, Thornthwaite and Alpat'ev into potential evapotranspiration of maize. The results gave fairly reliable simulations for Vojvodina province an analogous areas in Yugoslavia.

Stone (1988) developed a BASIC computer programme for calculating daily potential evapotranspiration by the method of Thornthwaite and Mather.

Changes in soil moisture and evapotranspiration are likely to have large impacts on water and forest resources, since the distribution and abundance of these resources are controlled to a large extent by the volume and seasonality of available moisture (Neilson *et al.*, 1992).

Roth and Gunther (1992) measured the water consumption of winter wheat, spring barley, potatoes and sugar beet in weighable lysimeters, situated in farm fields in Germany.

The results obtained with the lysimeters are compared with the pan-evaporation (two different pans) and the results of four evapotranspiration equations.

Global climate change will affect the terrestrial biosphere primarily through changes in regional energy and water balance Changes in soil moisture and evapotranspiration particularly affect water and forest resources (Marks *et al.*, 1993).

According to Mulholland *et al.*, 1997, warming trends in the climate will increase evapotranspiration in the region which will decrease runoff.

A warming climate can change precipitation and evapotranspiration rates while also altering the frequency, intensity, and location of precipitation (Arnell, 1999).

According to Shaw and Riha (2010) temperature is not the fundamental driver of PET and because the relationship between temperature and net radiation underlying temperature based equations will shift with climate change, temperature-based equations in their current state will likely exaggerate PET in a changing climate.

2.4. WATER AVAILABILITY PERIODS

Though, rainfall is the main source of water, the actual availability does not depend on rainfall alone as it should be balanced against the amounts due to evapotranspiration. Based on this, Cocheme and Franquin (1967) classified water availability periods. George and Krishnan (1969) and Raman and Murthy (1971) attempted for assessing the water availability periods based on climatic and soil conditions. Krishnan (1971) and Murthy (1973, 1976) determined water availability periods using actual evapotranspiration (AET) and potential evapotranspiration (PET), All these methods utilized monthly or weekly mean rainfall.

Gadre and Umrani (1972) used monthly rainfall data for various tahsils in Sholapur district, Maharashtra, and balanced against potential evapotranspiration values of Jeur and Sholapur for the Western and Eastern regions respectively and the water availability periods for each tahsil were delineated. The cropping pattern for each tahsil based on these periods was indicated.

Oswal and Saxena (1980) presented the analysis of rainfall data in the dry land districts of Haryana and revealed that only one crop is possible yearly on rainfall alone. The meteoric water availability period was found to be twelve, nine, seven and four weeks respectively at Mohindergarh, Hissar. Biwani and Sirsa.

Subramaniam and Rao(1981) assessed the water availability periods for crop planning in Rajasthan on the basis of monthly rainfall and monthly potential and actual evapotranspiration during 1901-77.

Subramaniam and Rao(1983) presented a method using PET and dependable rainfall to determine water availability for optimization of crop growth in Karnataka.

2.5. MOISTURE AVAILABILITY INDEX (MAI)

Hargreaves (1971) defined the MAI as the dependable precipitation divided by potential evapotranspiration. He gave equations and methods for its computation.

Hargreaves (1975) suggested an agroclimatic classification considering the length of growing season based on MAI which is the ratio of 75 per cent probability rainfall to the potential evapotranspiration (PET).

Sarker and Biswas (1986) suggested that MAI may be calculated on weekly basis and dependable rainfall be considered at 50 per cent probability level. Further, they considered different values of MAI and duration as appropriate to various crop phases for agroclimatic classification of dry farming tract of India.

Khambete (1992) devised a water availability index and applied it to the dry farming tract of Karnataka. Using this index along with information on soils and crop water requirements, cropping pattern in each agro-climatic zone was assessed.

Prabhakaran *et al.*, (1992) grouped 77 rain gauge stations in Kerala into nine clusters based on MAI and principal component analysis technique.

2.6. MOISTURE ADEQUACY INDEX (IMA)

Subrahmanyam *et al.*, (1963) studied for the first time the relationship of the moisture adequacy index in relation to the distribution of some important crops in the Indian region and observed that the IMA values could explain the crop distribution.

Bishnoi (1980) studied the behavior of moisture adequacy index and its utilization for exploiting the agricultural potential in Punjab and Haryana. The moisture adequacy indices, the ratios of actual evapotranspiration to the potential evapotranspiration, have been found to follow closely the Beta distribution.

The goodness of fit of the Beta distribution to the moisture index frequency distribution was tested using the Kolmogorov-Smirnov test for 144 station months and 36 seasonal curves. Twenty five moisture adequacy curves failed the K-S tests. The probability distribution of moisture adequacy indices has been further used to assess irrigation requirement, optimum evapotranspiration, water management, land use pattern and crop planning aspects for optimum utilization of available natural resources in the region.

Victor *et al.,* (1982) computed monthly values of moisture adequacy index for groundnut during 1941-72. The frequency distribution closely followed a beta distribution. The probabilities at threshold values of moisture adequacy index (actual evaporation/potential evaporation) less than or equal to 0.5 and more than or equal to 0.9 were evaluated. For 44 per cent of the time, the top soil layer (0-15 cm) remained dry continuously for more than two weeks. They reported that damage to groundnut in the Delhi region from severe dry weather may occur on an average once in four years.

Subramaniam (1983) has classified agro-ecological zones of India on the basis of index of moisture adequacy instead of mere rainfall, because rainfall never fully reflects the moisture status of a region and plants do not depend on rainfall alone. In addition to this, he pointed out that the significant role played by soil for the storage water should not be overlooked.

Subramaniam and Rao (1984) have calculated climatic water balance elements and moisture adequacy over Karnataka. The result of the analysis of moisture adequacy were compared with the distribution of crops to identify the limits of moisture adequacy for high productivity.

2.7. CROP PLANNING

Bhatia *et al.,* (1975) analyzed 20 years data on distribution of rainfall at Rehmankhera (Lucknow), Uttar Pradesh. They reported that data on weekly rainfall are more important than data on monthly and yearly rainfall for selection of suitable crops and their cultivars for cultivation in the monsoon season. The probability of drought occurrence was once in 10 years. Sastry (1976) presented the interaction of the rice crop with climate and discussed with particular reference to both rainfed and irrigated rice crops in South and South East Asia.

Venkataraman (1979) analyzed the probabilities of weekly rainfall amounts for 16 district level stations covering the dry farming tract of Maharashtra to find out station wise, the time and duration of rainy season, crop growth periods and mid-seasonal dry spells.

Information on the *kharif* and *rabi* season crops of different maturity that can be grown in these districts was given.

Saksena *et al.*, (1979) made an attempt to study the distributions of dry and wet spells and the pattern of occurrence of rainfall in short intervals of 5, 10 and 15 day periods. Expected lengths of dry and wet spells for various levels of conditional probabilities were obtained through empirical relations. The use of these expected lengths and pattern of occurrence of rainfall in crop planning was shown with the Jowar crop for Jalgaon district, Maharastra.

Krishnan *et al.,* (1980) used systems analysis approach for crop planning in Jodhpur district of Rajasthan. The analysis of rainfall data during 1901-70 showed the presence of 3 main subsystems (early, normal and late) in the rainfall pattern. Information on crops suitable for cultivation in these subsystems in Bilara and Shergarl regions was given.

Bhattacharya and Parikh (1987) analyzed daily rainfall data for 54 years (1927-80) of the Navsari region, Gujarat, to, find the weekly expected rainfall at different percentages of chance of being exceeded for crop planning and irrigation scheduling.

Budhar and Gopalaswamy (1988) suggested improved cropping system for Barur tract of Dharmapuri district in Tamil Nadu on the basis of rainfall data from 1947-83.

Rao *et al.*, (1988) carried out the rainfall probability analysis of three stations in Andhra Pradesh for crop planning. Daily rainfall data for Anantapur, Nandyal and Lam from 1969-1984 were used to assess the probability of receiving adequate rain for successful crop establishment.

Chakraborty *et al.*, (1990) studied rainfall and its impact on cropping pattern in Hoogly district of West Bengal. Assured rainfall analysis, probability of having a specified amount of 20 mm rainfall/week (one-third the potential evapotranspiration ratio of the region) and a water balance approach were found quite effective to assess the water availability period for crop planning under rainfed condition.

Maliwal and Chatrola (1991) studied the rainfall pattern for crop planning in Bhal zone. Gujarat. Maraviya *et al.*, (1991) analyzed rainfall data for crop planning under dry land agriculture at Rajkot, Gujarat.

Budhar *et al.*, (1991) suggested rainfall based cropping system in Palacode Taluk of North Western region of Tamil Nadu, Kulandaivelu and Jayachandran (1992) classified drought and developed a crop plan for Tamil Nadu. The severity of drought was determined by the prevalent soil type in various regions. Drought prone areas were classified based on precipitation (P), potential evapotranspiration (PET) and soil type to provide more precise information in rainfall and to develop suitable crop plan. The P/PET ratio provides a measure of whether certain crops can be grown at a place or not. Based on the ratio, a climatic index was developed and the values were super imposed on a soil map to identify local drought prone areas, and to classify them as mild, moderate or severe.

Shranker *et al.*, (1992) analyzed rainfall data for 1981-89 recorded at Jabalpur, Madhya Pradesh to suggest strategies for crop planning during the rainy season. Budhar and Gopalaswamy (1992) presented annual, seasonal, monthly and weekly rainfall data and suitable cropping systems for the Uthangarai taluk of Dharmapuri district in Tamil Nadu.

Kavi (1992) studied rainfall characteristics in relation to crop planning at Raichur in Karnataka. Data were presented on seasonal rainfall and its percentage contribution to annual rainfall from 1961 to 1990.

Sehgal *et al.*, (1993) presented generalized ranges of moisture availability periods for average deep soils in India, for cereal, cotton, legume, oil and fibre crops which is very useful in crop planning.

Krishnasamy *et al.*, (1994) carried out rainfall analysis and presented rainfall pattern and cropping system for dry land areas of Avanashi block of Coimbatore district.

Rout *et al.*, (1994) studied rainfall pattern and suggested cropping system for sustainable production in Umerkote block of Koraput in Orissa. Chaudhary (1994) suggested a crop plan through rainfall analysis in Bastar district of Madhya Pradesh. The probability of rainfall occurrence and the consequences for crop production are studied with particular reference to rice.

Singh *et al.*, (1994) studied rainfall variability and its relationship with rainfed crop planning at Rewa, Sidhi, Satna and Shahdol districts in Madhya Pradesh. Rainfall and number of rainy days recorded for the period from 1968 to 1990 were analyzed with respect to monthly, seasonal and annual variations and drought, normal and abnormal months were calculated using frequency analysis. It is concluded that rabi cereals and pulses are more suited to Rewa and Satna districts, whereas oilseeds and pulses and rabi oil seed crops are more suited to Shahdol and Sidhi districts.

2.8. GENERAL CIRCULATION MODELS

Gleick (1987) used his water balance model to investigate the potential impacts of climate change on the Sacramento River Basin, using hypothetical GCM based climate scenarios. His results for the GFDL based scenarios show decreases in summer soil moisture by between 33 and 36%, depending on the scenario, and a shift in the seasonality of runoff from spring to winter.

Traditionally, hydrologic models have considered the watersheds as homogeneous against the complex terrain in which they are applied (Kilgore, 1997). These processes are sometimes described by differential equations based on simplified hydraulic laws with other processes, which may be expressed by empirical algebraic equations (Arnold *et al.*, 1998).

Currently general circulation models (GCMs) are considered to be the most comprehensive models for investigating the physical and dynamic processes of the earth surface-atmosphere system and they provide plausible patterns of global climate change. However, it is not yet possible to make reliable predictions of regional hydrologic changes directly from climate models due to the coarse resolution of GCMs and the simplification of hydrologic cycle in climate models (Arora, 2001).

As suggested by Singh and Woolhiser (2002), mathematical models such as WaSiM and geospatial analysis tools are needed to comprehensively study the various processes due to the complexity of the spatial and temporal variations in soils, vegetation and land-use practices of the large Agro ecological zones.

According to GCMs have flaws for events of heavy rainfall in respect to their exceeding thresholds and frequencies. It is also evident that local or regional climates are influenced not only by the atmospheric processes, but are also greatly influenced by land-sea interaction, land use and the topography, which are poorly presented in GCMs due to their coarse spatial resolutions (Sintondji, 2005; Busche *et al.*,2005)

In a study conducted by Galvincio *et al.*, 2008, to assess the impact, of climate change on hydrological cycle and water resources planning a semi-distributed monthly water balance model was proposed and developed to simulate and predict the hydrological processes.

GIS techniques were used as a tool to analyze topography, river networks, land-use, human activities, vegetation and soil characteristics.

A warming climate can change precipitation and evapotranspiration rates while also altering the frequency, intensity, and location of precipitation and also a modeling approach utilizing Hadley Centre (HadCM2 and HadCM3) climate projections indicates that North Carolina would see increased precipitation due to a warming climate, but it will come in the form of more intense precipitation events (Arnell, 1999).

The present work was undertaken with the objective to determine the water balance, weekly Moisture Adequacy Index (MAI) and water availability periods for various Agro Ecological Units (AEU) of Kerala and to examine the impact of climate change on the above mentioned parameters. Agro-Ecological Units Maps of Kerala shows the location of the stations in the State (Fig. 1).

Fig. 1. Agro-Ecological Units Maps of Kerala

3.1 COLLECTION OF DATA

3.1.1. Land use data

The land use and the area under major crops in the state are presented in tables 1 and 2.

Table 1. Land use pattern of Kerala (2012-13)

Classification of land	Area (ha)	Per cent of TGA
Total Geographical Area (TGA)	3886300	100
Forest	1081509	27.82
Land put to non-agricultural uses	402577	10.35
Barren and uncultivated land	16354	0.42
Permanent pastures and grazing land	118	-
Land under miscellaneous tree crops	2799	0.072
Cultivable waste	96596	2.48
Fallow other than current fallow	55835	1.43
Current fallow	76744	1.97
Net area sown	2048109	52.7
Area sown more than once	543625	13.98
Total Cropped area	2591734	66.68

Table 2. Area, Production and Productivity of Principal Crops of Kerala

Crops	Area (ha)		Production (MT)		Productivity (kg/ha)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Rice	208161	197277	568990	564325	2733	2827
Pulses	3668	2989	3128	3246	853	1100
Pepper	85335	84065	37989	29408	445	350
Ginger	6908	4538	37130	21521	5375	4742
Turmeric	2970	2430	7946	6253	2675	2573
Cardamom	41600	39730	10222	14000	246	352
Arecanut	104548	10008	121623	100018	1163	1000
Banana	59069	62261	514054	531299	8703	8533
Other Plantains	48747	54512	330634	362395	6783	6648
Cashew nut	54052	49105	36743	33375	680	680
Tapioca	74498	67589	2567953	2479070	34470	36679
Coconut **	820867	808647	5941	5921	7237	7322
Coffee	85359	85359	68175	66645	799	781
Tea	37028	30205	57904	62938	1564	2084
Rubber	539565	548225	798940	648220	1481	1182

*** Production in million nuts and Productivity in nuts/ha.*

Source: Farm Guide, 2016. Facts and figures of Agriculture in Kerala, 2013

3.1.2 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 3. Weather stations taken for the study

Sl.No	District	Station / Location	Latitude	Longitude
01	Alappuzha	Alappuzha	09°33’N	76°25’E
02		Chengannur	09°19’N	76°37’E
03		Cherthala	09°42’N	76°20’E
04		Haripad	09°15’N	76°25’E
05		Kayamkulam(RARS)	09°30’N	76°20’E
06		Mancompu	09°05’N	76°05’E
07		Mavelikkara /	09°14’N	76°31’E
08	Ernakulam	NAS Kochi	09°57’N	76°16’E
09		Aluva	10°07’N	76°21’E
10		CIAL Kochi	10°09’N	76°24’E
11		Ernakulam (S)Rly	09°19’N	76°37’E
12		Perumbavur	10°05’N	76°25’E
13		Piravom	10°09’N	76°13’E
14	Idukki	Devikulam	10°04’N	77°06’E
15		Idukki	09°50’N	76°55’E
16		Munnar	10°00’N	77°09’E
17		Peermede	09°34’N	76°59’E
18		Thodupuzha	09°50’N	76°40’E
19	Kannur	Irikkur	11°58’N	75°33’E
20		Kannur	11°50’N	75°20’E
21		Thalassery	11°45’N	75°32’E
22		Thaliparamba	12°03’N	75°23’E
23	Kasaragode	Hosdurg	12°12’N	75°06’E
24		Kasaragode	12°31’N	74°59’E
25		Kudulu	12°30’N	75°00’E
26	Kollam	Aryankavu	08°59’N	76°10’E
27		Kollam	08°53’N	76°37’E
28		Punalur	09°00’N	76°55’E
29	Kottayam	Kottayam	09°35’N	76°31’E
30		Kozha	12°03’N	76°34’E
31		Kumarakom	09°40’N	76°30’E
32		Kanjirappally	09°33’N	76°47’E
33		Vaikom	09°46’N	76°24’E
34	Kozhikode	Kozhikode	11°15’N	75°47’E
35		Quilandy	11°25’N	75°40’E
36		Vadakara	11°35’N	75°30’E
37	Malappuram	Karipur AP	11°08’N	75°57’E
38		Angadipuram	10°58’N	76°13’E
39		Manjeri	11°07’N	76°07’E
40		Nilambur	11°20’N	76°15’E
41		Perinthalmanna	10°58’N	76°13’E
42		Ponnani	10°47’N	75°54’E
43	Palakkad	Palakkad	10°46’N	76°39’E
44		Alathur	10°38’N	76°33’E

45		Chittur	10°42’N	76°45’E
46		Kollengode	10°37’N	76°43’E
47		Mannarkkad	10°09’N	76°34’E
48		Ottappalam	11°40’N	76°15’E
49		Parambikulam	10°20’N	76°45’E
50		Pattambi	10°48’N	77°12’E
51		Trithala	10°50’N	76°06’E
52		Konni	09°15’N	76°50’E
53		Thiruvalla	09°24’N	76°35’E
54	Pathanamthitta	Thiruvananthapuram AP	08°28’N	76°57’E
55		Nedumangad	08°36’N	77°00’E
56		Neyyattinkara	08°23’N	77°05’E
57		Chalakkudy	10°18’N	76°20’E
58		Enamackel	10°50’N	76°06’E
59		Irinjalakkuda	10°22’N	76°14’E
60		Kodungallur	10°03’N	76°22’E
61	Thrissur	Kunnamkulam	10°38’N	76°00’E
62		Thrissur	10°31’N	76°13’E
63		Vadakkancherry	10°35’N	76°10’E
64		Vellanikkara	10°31’N	76°13’E
65		Ambalavayal	11°37’N	76°12’E
66		Kuppady	11°41’N	76°16’E
59	Wayanad	Mananthavady	11°50’N	76°00’E
60		Vythiri	11°33’N	76°02’E

3.1.3 Crop and Soil data

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

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 data on maximum temperature and minimum temperature, while totals were computed for rainfall for all the years. Seasons have been identi ed 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 December

3.2.1 Rainfall

Mean weekly, monthly, seasonal and annual rainfall were worked from the totals obtained as above. Coef cient of variation for the above periods were also worked out. Spatial variation mean rainfall and coef cient 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 Probability level Fa (m) which is expressed as,

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

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 speci ed amount, it is called a Wet week (W) otherwise called a Dry week (D).

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

Where

P (Wj) is the probability of receiving a certain amount of rainfall during the j^{th} week

N (Wj) is the Number of occurrence of W during the j^{th} 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 were 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:

$$ET_o = c\ [W.Rn + (1\text{-}w).\ f(u).\ (ea\text{-}ed)]$$

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 eld 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 de cit over the state is presented.

3.2.3.1. Thornthwaite's Method of Water-Balance Computation

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

*The negative sign of *S* is not considered.

It means that *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* and *AE* i.e., $D = PE - AE$

Step 10. Moisture surplus (*S*)

1) Surplus exists when storage (*St*) is 300 or 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 S of 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 quanti es 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 de ned as follows:

Humid period: $AET \geq PET/2$

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. SOFTWARES

Weather cock v.1.5 developed by Central Research Institute for Dry land Agriculture (CRIDA) has been used for converting 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.

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.

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

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.

Table 4. 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.

The results and discussion of the present study " The impact of climate change on water balance of Agro ecological units of Kerala" conducted at the Academy of Climate Change Education and Research, Vellanikkara are presented in this chapter. The present work was undertaken with the objective to determine the water balance, weekly index of moisture adequacy (IMA) and water availability periods for various Agro Ecological Units (AEU) of Kerala and to examine the impact of climate change on the above mentioned parameters.

4.1 Area of the Study

Twenty three agro-ecological units (AEU's) have been delineated for the state based on climatic variability, landform and soils. The spatial bounding limits (external) of the agro-ecological units have been made to correspond to the administrative boundaries of panchayats.

4.1.1 AEU 1: Southern Coastal Plain

The Southern Coastal Plain agro-ecological unit is delineated to represent the nearly level coastal lands where sands are the dominant soil type. The unit comprises 42 panchayats along the coast from Thiruvananthapuram to Ernakulam district.

4.1.2 AEU 2: Northern Coastal Plain

The Northern Coastal Plain agro-ecological unit represents the coastal plain north of Ernakulam district and comprises 77 panchayats along the coast from Thrissur till the northern end of the state.

4.1.3 AEU 3: Onattukara Sandy Plain

The special agro-ecological unit Onattukara Sandy Plain is delineated for the sandy plains extending into the midlands from coast and covering 43 panchayats in Kollam and Alappuzha districts.

4.1.4 AEU 4: Kuttanad

Kuttanad is a special agro-ecological unit delineated to represent the waterlogged lands spread over 69 panchayats of Alappuzha, Kottayam and Pathanamthitta districts. Large parts of these lands are below, at or just above sea level.

4.1.5 AEU 5: Pokkali Lands

Pokkali Lands, another special agro-ecological unit, is delineated for the lowlands, often below sea level, in coastal areas of Ernakulam district and extending to parts of Thrissur and Alappuzha districts. The unit covers 34 panchayats.

4.1.6 AEU 6: Kole Lands

The Kole Lands agro-ecological unit, spread over the coastal part of Thrissur district and extending to southern coastal parts of Malappuram district covers 40 panchayats.

4.1.7 AEU 7: Kaipad Lands

The Kaipad Lands agro-ecological unit occurs along the coast of Kozhikkode, Kannur and Kasaragod districts as isolated stretches of waterlogged lands. The unit covers only 16 panchayats.

4.1.8 AEU 8: Southern Laterites

The Southern Laterites agro-ecological unit spread over 24 panchayats in south-western part of Thiruvananthapuram district is delineated to represent the uniqueness of climate and soils.

4.1.9 AEU 9: South Central Laterites

The South Central Laterites agro-ecological unit is delineated to represent midland laterite terrain with typical laterite soils and short dry period. The unit covering 161 panchayats of midlands extends from Thiruvananthapuram to Ernakulam district.

4.1.10 AEU 10: North Central Laterites

The North Central Laterites agro-ecological unit is delineated to represent midland laterite terrain with longer dry period than its southern counterpart, but less than the one in the north. The unit is spread over 62 panchayats, 3 municipalities and a corporation in Thrissur and Palakkad districts.

4.1.11 AEU 11: Northern Laterites

The Northern Laterites agro-ecological unit is delineated to represent midland laterites from Malappuram to Kasaragod districts experiencing long dry period. It is spread over 163 panchayats and 6 municipalities.

4.1.12 AEU 12: Southern and Central Foothills

The Southern and Central Foothills agro-ecological unit is delineated to represent the undulating lands with low hills, between midland laterites and the high hills of Western Ghats. It covers 90 panchayats from Thiruvananthapuram to Thrissur districts.

4.1.13 AEU 13: Northern Foothills

The Northern Foothills agro-ecological unit represents foothills from Thrissur to Kasaragod and differs from its southern counterpart for longer dry period. It covers 27 panchayats of Palakkad, Malappuram, Kannur and Kasaragod districts.

4.1.14 AEU 14: Southern High Hills

The Southern High Hills agro-ecological unit extending from Thiruvananthapuram to Nelliyampathy in Palakkad district has elevation more than 600 metres. Besides elevation, the steep slopes of the terrain and lower temperatures distinguish the high hills from the foothills and midlands. Thirty panchayats in Thiruvananthapuram to Palakkad district constitute this unit.

4.1.15 AEU 15: Northern High Hills

The Northern High Hills agro-ecological unit extending from Thrissur to Kannur is similar to its southern counterpart except for the longer dry period. The unit comprises 61 panchayats spread over the northern districts.

4.1.16 AEU 16: Kumily High Hills

The Kumily High Hills agro-ecological unit is delineated to represent low-rainfall parts of the High Hills zone. The unit differs from Southern High Hills not only in the lower rainfall, but also the extensive occurrence of very deep, non-gravelly clay soils. Thirteen panchayats distributed in Peerumedu and Udumbanchola taluks of Idukki district constitute this unit.

4.1.17 AEU 17: Marayur Hills

The Marayur Dry Hills agro-ecological unit is delineated to represent the low rainfall region (rain-shadow) of the high hill zone and comprises only three panchayats of Idukki district.

4.1.18 AEU 18: Attappady Hills

The agro-ecological unit Attappaddy Hills spatially distributed as a narrow strip of land along the valley in central part of the hills in North Palakkad, represents land areas of comparatively low rainfall. It comprises parts of Sholayur and Agali panchayats.

4.1.19 AEU 19: Attappady Dry Hills

The Attappady Dry Hills unit represents land areas of very low rainfall and dry period around eight months in a year. This unit in the north-eastern corner of Palakkad district comprises parts of Puthur, Agali and Sholayur panchayats.

4.1.20 AEU 20: Wayanad Central Plateau

The Wayanad Central Plateau agro-ecological unit represents highland plateau with low temperature and high rainfall. The unit covers 11 panchayats in Wayanad district.

4.1.21 AEU 21: Wayanad Eastern Plateau

The Wayanad Eastern Plateau agro-ecological unit represents parts of the high land plateau with lower rainfall. The unit comprises 6 panchayats, one in Mananthavady taluk and rest in Sulthan Bathery taluk of Wayanad district.

4.1.22 AEU 22: Palakkad Central Plain

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). The unit comprises 37 panchayats spread over Alathur, Chittur and Palakkad taluks and the Palakkad Municipality.

4.1.23 AEU 23: Palakkad Eastern Plain

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.

4.2 Agro climatology of Kerala

The State falls in the region of tropical climate. The coastal location of the State and a high variation in relief from the coast to the Western Ghats influence the climatic characteristics to a large extent. While most of the areas are under tropical dry and wet conditions with high maritime influence, certain areas in the eastern parts experience subtropical type of climate.

Kerala receives the highest annual rainfall among the States of India - about 300 cm in a year which is three times the average rainfall of India. The State receives rainfall for almost ten months in a year from both monsoons and local systems though most of the rainfall occurs during the southwest monsoon period. Mean rainfall for the whole Kerala was calculated annually and seasonally by taking the data of 62 rain gauge stations.

4.3. Rainfall

The analysis of past and future rainfall variability and trend is conducted after the quality control is done, missed data is filled. The rainfall data did not show heterogeneity during 1991-2014 at 23 AEUs in study area (Figure 1) and hence, the rainfall data is used for further analysis in the present study.

4.3.1 Spatial distribution of mean rainfall

Spatial distribution of mean rainfall is shown in Table 6. The annual mean rainfall increases from east to west. AEUs in the coastal areas i.e., AEU 2, AEU 5, AEU 7 and AEU 11 were receiving more than 3000 mm rainfall. The eastern part of the Kerala receives less rainfall compared to the western part and AEU receives less than 1500 mm.

During southwest monsoon season also, the same trend is seen. An increase in rainfall is found from east to west. The rainfall does not change considerably as one moves from south to north. The distribution of rainfall is found parallel lines in the north south direction.

Table No 5. Seasonal Normal Rainfall (mm) as per present climate

SEASON	Agro Ecological Units											
	1	2	3	4	5	6	7	8	9	10	11	12
Winter	63.7	7.9	53.6	22.2	65.1	14.9	1.8	44.6	37.8	15	8.2	42.3
Summer	478	338	448	416	1113	364	220	359	399	264	317	252
SW monsoon	1733	2310	1640	1578	2170	2092	2925	730	2249	1890	2214	2062
NE monsoon	597	472	561	621	428	474	336	599	565	410	516	465
TOTAL	2871	3129	2702	2636	3775	2945	3482	1732	3252	2578	3054	2821

SEASON	Agro Ecological Units										
	13	14	15	16	17	18	19	20	21	22	23
Winter	13	62.1	21.4	28.9	131	58.8	145	7.9	17.8	4.8	14.8
Summer	313	370	288	200	450	352	330	220	21.6	234	173
SW monsoon	1686	1286	1653	1163	1014	736	1134	1930	717	1850	1038
NE monsoon	548	761	435	488	706	346	706	247	74.4	241	283
TOTAL	2560	2480	2398	1880	2301	1493	2315	2404	831	2330	1509

Summer Season

The maximum rainfall during the summer season (Table 6) is received at AEU 5-Pokkali land (1113 mm). From this region, the rainfall showed a decreasing trend towards south and north direction. The lowest rainfall (21.6 mm) during summer season was recorded at AEU 21-Wayanad eastern plateau.

SW monsoon Season

The rainfall distribution during the southwest monsoon season is similar to that of the annual pattern. Rainfall increases from 717 mm in the AEU 21-Wayanad eastern plateau to 2925 mm in the AEU 7-Kaippad land. AEUs of heavy rainfall are AEU 2- Northern coastal plain (2310 mm), AEU 5-Pokkali land (2170 mm), AEU 7-Kaippad land (2925 mm) and AEU 9-South central laterite (2249 mm) AEU 11-Northern laterite (2214) and AEU 12-Southern and central foothills (2062). The lowest rainfall region are AEU 8 Southern laterite (730 mm), AEU 18- Attappady hills (763 mm) and AEU 2-Wayand eastern plateau (717 mm)

NE monsoon Season

During this period the eastern slopes of the Ghats towards the south and central Kerala received fairly good amounts of rainfall, comparable to the northern sides. The Ghats region receives about 25% of its total annual rainfall in this season. AEU 14-Southern high hills (761 mm), AEU 17-Marayoor hills (706 mm) AEU 19-Attappady dry hills (706 mm) received high rainfall during NE monsoon season and AEU 20-Wayanad central plateau (247), AEU 21-Wayayand eastern plateau (74.4 mm), AEU 22-Palakkad central plain (241 mm) and AEU 23-Palakkad eastern plain (283 mm) received the lowest amounts. In general NE monsoon is more prevent in southern Kerala compared northern Kerala.

Winter Season

Winter is a period of very low rainfall for the whole State. Rainfall ranges from 145 mm at AEU 19-Attappady dry hills to 1.8 mm in the AEU 7-Kaippad land. The state average rainfall during this period is only 38.3 mm. The AEUs adjoining Tamil Nadu areas receive comparatively more amount of rainfall during this season.

4.3.2 Spatial distribution of mean rainfall as per climate change projections

To project future climate conditions, the simulation outputs for 2030s, 2050s, and 2080s from seventeen general circulation models (GCMs) were extracted under Intergovernmental

Panel on Climate Change (IPCC) greenhouse gases emissions scenarios (RCP 4.5) to consider the uncertainty.

4.3.2.1 Spatial distribution of mean rainfall during 2030s

The results of the climate change projections on the spatial distribution of rainfall as per RCP 4.5 for the period 2030 is presented in Table –7

Table No 6. Seasonal Normal Rainfall (mm) as per 2030 RCP 4.5 scenario

SEASON	Agro Ecological Units											
	1	2	3	4	5	6	7	8	9	10	11	12
Winter	33	0	16	16	24	0	16	63	22	0	7	30
Summer	649	317	378	364	633	277	525	232	478	390	216	266
SW monsoon	2146	3431	2046	2049	2596	2831	2182	1192	2985	3012	2596	1785
NE monsoon	407	331	458	461	523	408	411	285	509	410	298	396
Total	3235	4079	2898	2890	3775	3517	3134	1771	3994	3812	3117	2478

SEASON	Agro Ecological Units										
	13	14	15	16	17	18	19	20	21	22	23
Winter	1	2	48	0	37	45	8	13	0	4	1
Summer	462	197	287	198	509	223	558	261	412	292	286
SW monsoon	2296	2389	1853	2118	2257	1883	3134	2275	2137	1634	1600
NE monsoon	300	290	373	329	518	387	365	127	263	427	276
Total	3059	2877	2561	2645	3320	2537	4065	2676	2812	2357	2163

It can be observed from the table 7. Except in AEU 7, and 12 the total annual rainfall is showing an increasing trend during 2030s as per RCP 4.5. It can be also seen that the AEUs adjoin to Tamil Nadu expected to receive more amount of rainfall during 2030s.

Summer Season

According to the projected climate change scenario for 2030 based on RCP 4.5 showed an increased rainfall activity during the summer months. Out of 23 AEUs 12 AEUs are expected an increase in rainfall during 2030s. The maximum expected positive deviation is about 390 mm (AEU 21-Wayanad eastern plateau) and the negative deviation of 480 mm in AEU 5-Pokkali land.

SW monsoon Season

The rainfall distribution during the southwest monsoon season is almost similar to that of the annual pattern. A huge increase in rainfall is anticipated during the SW monsoon season throughout the State except in AEU 7-Kaippad land, AEU 12-Southern and central foot hills and AEU 22-Palakkad central plain. It is interesting to notice that the state annual average rainfall will expected to increase by about 675 mm during the SW monsoon season in 2030 as per RCP 4.5.

NE monsoon Season

In contrast to the SW monsoon season the rainfall activity during the NE monsoon season expected to decrease by 2030 as per RCP 4.5 scenario. The AEUs 7-Kaippad land, AEU 5-Pokkali land, AEU 18-Attappady hills, AEU 21-Wayanad central plateau and AEU 22-Palakkad central Plain is anticipated an increased precipitation of about 100 mm during 2030 as per RCP 4.5 scenario.

Winter Season

As per the RCP 4.5 scenario the winter rainfall will expect to decrease by an average of 30 mm except in AEU 7-Kaippad land, AEU 8-Southern laterite, AEU 15-Northern high hills and AEU 20-Wayanad central plateau which will showed an increasing trend.

4.3.2.2 Spatial distribution of mean rainfall during 2050s

The results of the spatial distribution of rainfall as per RCP 4.5 for the period 2050 are presented in Table 8. From the table it can be inferred that the rainfall activity will continued to increase during 2050s also. On an average an average annual rainfall of about 575 mm is expected to increase during 2050. Among the various AEUs 18 out of 23 anticipated an increased rainfall ranging from 71 mm in AEU 16-Kumali hills to 2765 mm in AEU 21-Wayand eastern plateau. In AEU 5-Pokkali land, AEU 7-Kaippad land, AEU 9-South central laterite, AEU 11-Northern laterite and AEU 20-Wayand central plateau the projections predicted a decreased rainfall.

Table No 7. Seasonal Normal Rainfall (mm) as per 2050 RCP 4.5 scenario

SEASON	Agro Ecological Units											
	1	2	3	4	5	6	7	8	9	10	11	12
Winter	38	0	40	10	15	0	15	36	38	104	286	16
Summer	513	384	537	258	184	331	184	215	537	869	83	370
SW monsoon	2241	3388	2215	2851	1570	3227	1570	1772	2045	1829	1054	2082
NE monsoon	471	310	471	399	262	375	262	360	471	350	1471	475
Total	3262	4082	3262	3518	2031	3934	2031	2382	3090	3152	2895	2942
SEASON	Agro Ecological Units											
	13	14	15	16	17	18	19	20	21	22	23	
Winter	0	17	41	22	0	0	0	3	22	0	9	
Summer	408	1159	596	362	113	196	103	257	633	424	822	
SW monsoon	2452	1986	2578	1114	2601	2333	3119	1176	2426	2598	2504	
NE monsoon	356	49	404	453	448	112	676	378	516	473	160	
Total	3216	3211	3618	1951	3162	2641	3898	1814	3596	3496	3496	

Summer Season

In accordance with the projected climate change for the period 2050 based on RCP 4.5 showed an increased rainfall activity as compared to present day climate, whereas 9 out of 23 AEUs (AEU 4- Kuttanad, AEU 5- Pokkali, AEU 6- Kole land, AEU 7- Kaippad land, AEU 8- Southern laterites, AEU 11-Northern laterites, AEU 17-Marayoor hills, AEU 18-Attappady hills and AEU 19-Attappady dry hills) showed a decreasing trend. It is interesting to notice that most of the costal AEUs and high range AEUs expected a decrease in summer showers.

SW monsoon Season

An average annual rise of rainfall is noticed as per the projected climate for 2050 during SW monsoon season throughout the state. It is can be noticed that the state annual average rainfall will expect to increase by about 562 mm. It can also inferred that the rainfall activity is a bit reduced as compared to 2030s. It is interesting to notice that AEUs (AEU 5-Pokkali land, AEU 7-Kaippad land, AEU 9-South central laterite, AEU 10-North central laterite, AEU 11-Northern laterite, AEU 16-Kumali hills and AEU 20-Wayanad central plateau) in the mid lands and rain shadow regions expected a decrease in SW monsoon.

NE monsoon Season

The rainfall activity during the NE monsoon season expected an average annual decrease of about 50 mm by 2050 as per RCP 4.5 scenario. The AEU 11-Northern laterites, AEU 12-Southern and central foothills, AEU 20-Wayanad central plateau, AEU 21-Wayanad eastern plateau and AEU 22-Palakkad central plain are anticipated an increased precipitation. It is significant to notice that in the AEU 11-Northern laterites where the SW monsoon season anticipated a decrease in rainfall of 1159 mm will get an increased rainfall during the NE monsoon season (956 mm).

Winter Season

As per the RCP 4.5 scenario the winter rainfall will expect to decrease except in AEU 7-Kaippad land, AEU 9-South central laterites, AEU 10-North central laterites, AEU 11-Northern laterites, AEU 15-Northern high hills and AEU 21-Wayanad eastern plateau, which will showed an increasing trend. It is interesting to notice that an increase of 277 mm rainfall will be expected in AEU 11-Northern laterites during winter season.

4.3.2.3 Spatial distribution of mean rainfall during 2080s

The spatial distribution of rainfall as per RCP 4.5 for the period 2080 is given in Table 9 From the table it can be concluded that the rainfall activity will be less during 2080s. Compared to the present climate conditions an average annual rainfall of about 330 mm is expected to increase during 2080. 18 out of 23 AEUs expected an increased precipitation. In AEU 7-Kaippad, AEU 9-South central laterite, AEU 12-South and central foot hills, AEU 13-Northern foot hills and AEU 20-Wayanad central plateau the projections anticipated a decreased rainfall.

Table No 8. Seasonal Normal Rainfall (mm) as per 2080 RCP 4.5 scenario

SEASON	Agro Ecological Units											
	1	2	3	4	5	6	7	8	9	10	11	12
Winter	36.4	23.8	15.6	16.1	18.4	57.2	0	29	16.4	366	8.5	66.7
Summer	597	328	346	345	515	104	0	662	484	466	386	158
SW monsoon	2247	2988	2133	2144	2822	2781	2138	2189	2380	2010	2512	1004
NE monsoon	354	326	503	503	588	453	81.6	418	354	477	347	433
Total	3234	3666	2997	3007	3943	3395	2220	3298	3234	3318	3254	1662

SEASON	Agro Ecological Units										
	13	14	15	16	17	18	19	20	21	22	23
Winter	36.1	42.3	19.5	34.6	35.4	16.5	37.8	46.6	72	514	0.5
Summer	396	298	927	357	216	387	318	227	158	1580	233
SW monsoon	763	1933	2236	2413	1325	2010	1791	1252	1004	300	1773
NE monsoon	473	403	96.9	401	1741	477	336	278	433	300	297
Total	1668	2676	3279	3206	3317	2890	2482	1804	1667	2694	2303

Summer Season

The projected climate change for the period 2080 based on RCP 4.5 showed an increased rainfall activity as compared to today's climate. 13 out of 23 AEUs showed an increasing trend. An average annual increase of about 250 mm will be expected during 2080s. Most of the costal AEUs (AEU 2-Northern coastal plain, AEU 3-Onattukara sandy plain, AEU 4-Kuttnad, AEU 5-Pokkali land, AEU 6-Kole land, and AEU 7-Kaippad) and high range AEUs (AEU 14-Southern high hills, AEU 17-Marayur hills and AEU 19-Attappady dry hills) projected a decrease in summer showers.

SW monsoon Season

An average annual rise in rainfall is noticed as per the projected climate for 2080 during SW monsoon season throughout Kerala.

It is can be observed that the state annual average rainfall will likely to increase by about 270 mm. It can also conclude that the rainfall activity is reduced as compared to 2050s.

It is interesting to notice that AEU 7-Kaippad, AEU 12-Southern and central foot hills, AEU 13-Northern foot hills, AEU 20-Wayanad central plateau and AEU 22-Palakkad central plain expected a reduction in SW monsoon. The average rate of 1000 mm decrease in SW monsoon is expected in these areas.

NE monsoon Season

The average annual rainfall during the NE monsoon season likely to decrease by 35 mm by 2080 as per RCP 4.5 scenario whereas the AEUs 5- Pokkali lands, AEU 10- North central laterites, AEU 17- Marayur hills, AEU 20- Wayanad central plateau, AEU 21- Wayanad eastern plateau, AEU 22- Palakkad central plain and AEU 23- Palakkad eastern plain are anticipated a rise precipitation (246 mm).

Winter Season

In line with the RCP 4.5 scenario the winter rainfall will expect to decrease marginally by an average of 33 mm except in AEUs 2- Northern coastal plain, 6 Kole lands, AEU 10- North central laterites, AEU 11- Northern laterites, AEU 12- Southern and central foothills, AEU 13- Northern foothills, AEU 16- Kumily high hills, AEU 20- Wayanad central plateau, AEU 21- Wayanad eastern plateau and AEU 22- Palakkad central plain which will showed an increasing trend. Compared to 2050s more AEUs showed increased rainfall activity during 2080 in the winter season.

4.3.3 Rainfall probabilities of receiving > 40 mm

The initial rainfall probabilities of getting more than 40 mm for all the 23 AEUs are worked out. It is useful in finding the sowing time of crop and irrigation scheduling. Markov chain model was used for this analysis. The results of the analysis are presented and Figure 2 to 4 shows the results for AEUs 1 to 23. It can be seen from the figures the initial probability of getting 40 mm rainfall by first week of June is observed only in AEU 1- Southern coastal plain, AEU 2- Northern coastal plain, AEU 3- Onattukara sandy plain, AEU 4- Kuttanad, AEU 8- Southern laterites, AEU 9- South central laterites, AEU 12- Southern and central foothills, AEU 14- Southern high hills and AEU 15- Northern high hills. It can be also seen form the figures that the SW monsoon extents from 22nd STD week to 36th STD week in most of AEUs of Kerala. A bimodal distribution of rainfall is seen in above AEUs. It is interesting to notice that the AEUs of southern parts of Kerala showed a higher probability of getting >40 mm rainfall.

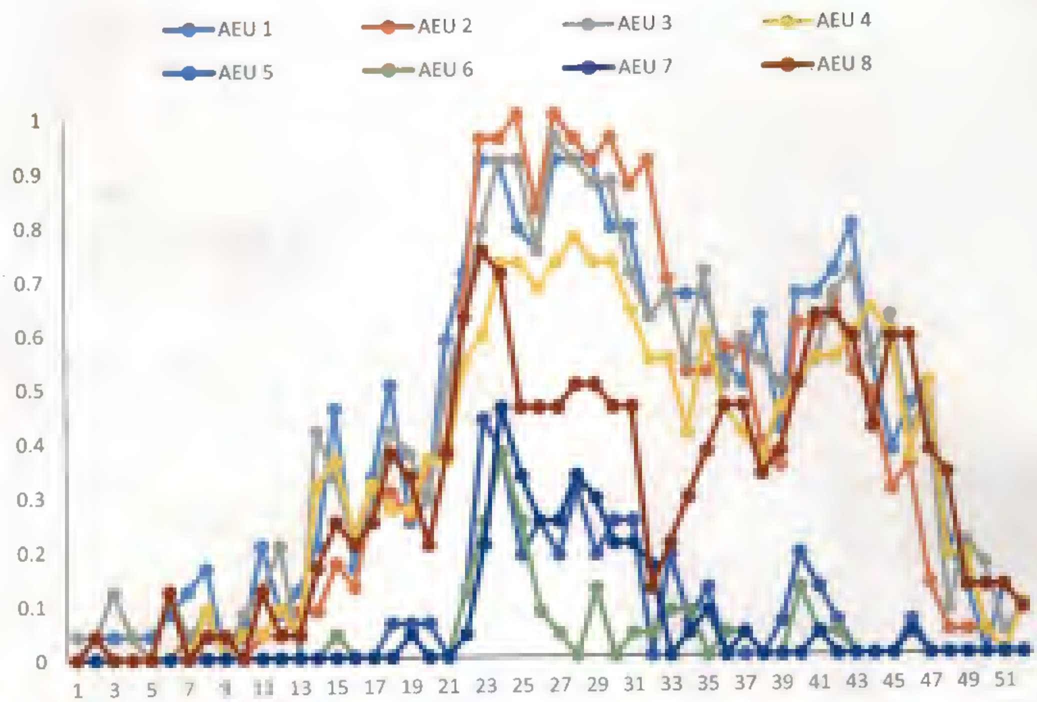

Fig. 2. Initial rainfall probabilities of receiving > 40 mm (1991-2014)

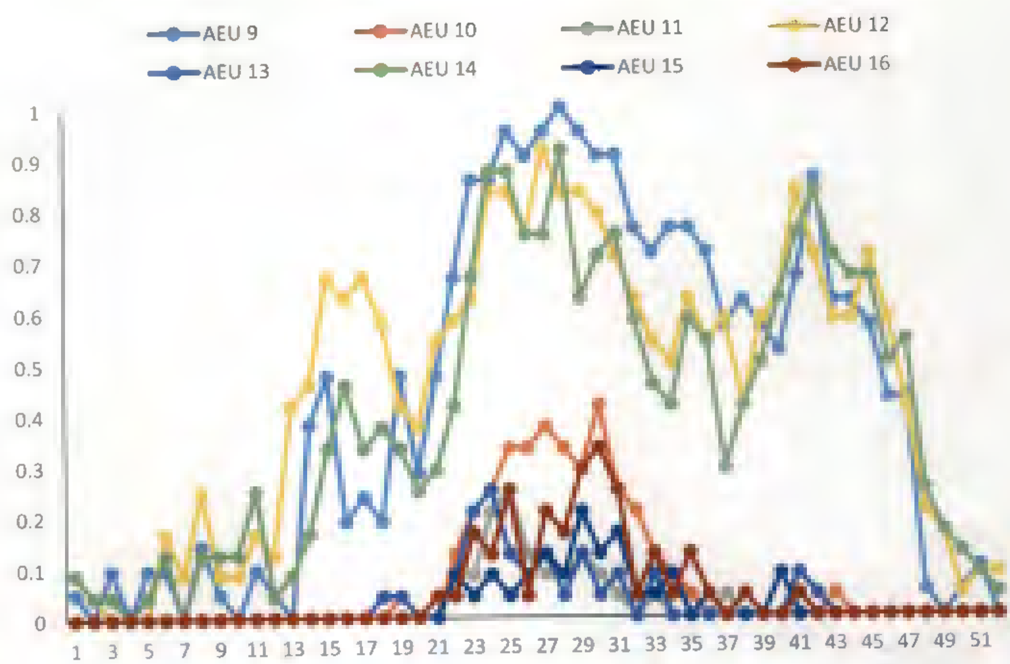

Fig. 3. Initial rainfall probabilities of receiving > 40 mm (1991-2014)

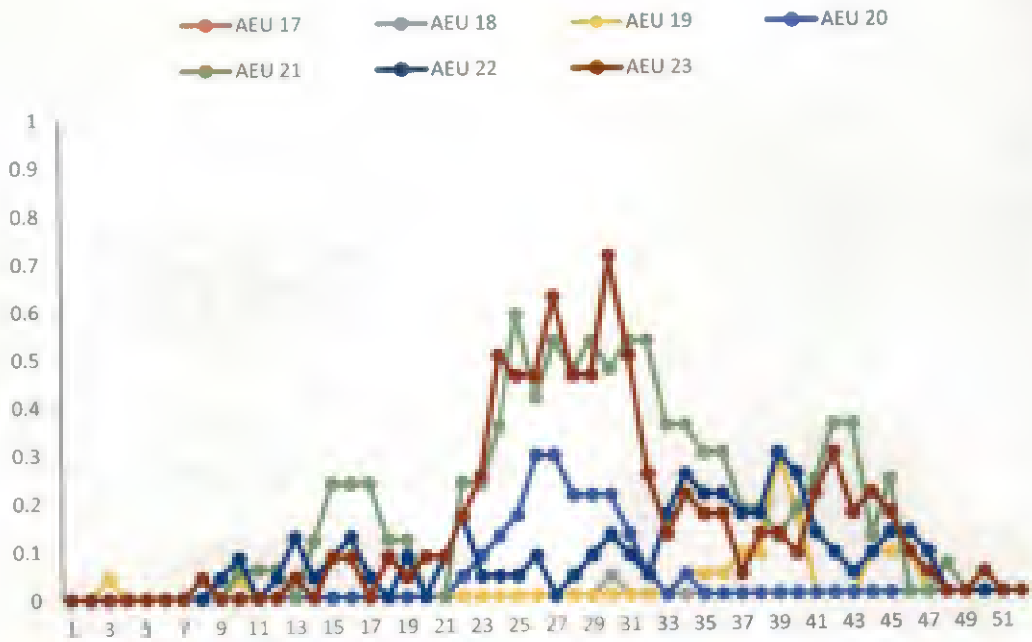

Fig. 4. Initial rainfall probabilities of receiving > 40 mm (1991-2014)

4.3.4 Initial rainfall probabilities of receiving > 40 mm during 2030, 2050 and 2080

It can be seen from the Figure 5 to 10 that the initial probability for getting more than 40 mm of rainfall will be reduced during 2030s. Only AEU 1- Southern coastal plain, AEU 2- Northern coastal plain and AEU 3- Onattukara sandy plain will be receiving assured amount of rainfall during the SW monsoon period. During the 2050s the probability getting an assured amount of rainfall (>40 mm) increased as compared to 2030s. The period of assured rainfall during 2050s expected to recoup to the present climatic conditions. The initial probability of rainfall during 2080s as per RCP 4.5 will be more than that of the present climate. The period of assured rainfall will also expected to extent by 15 days (20 to 34 weeks)

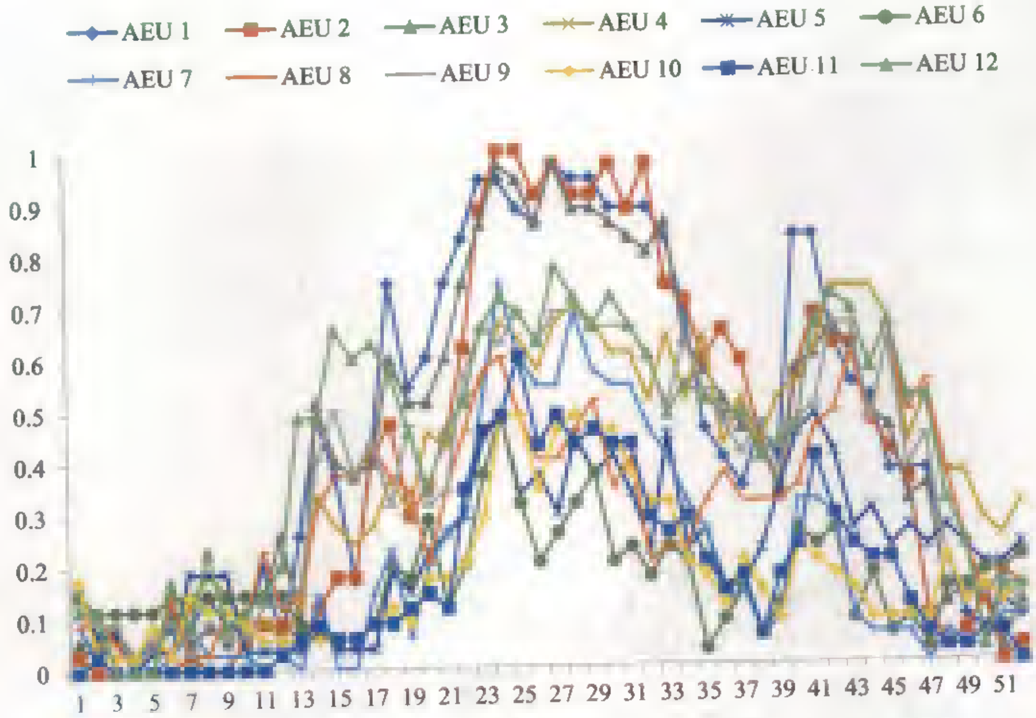

Fig.5. Initial rainfall probabilities of receiving > 40 mm during 2030

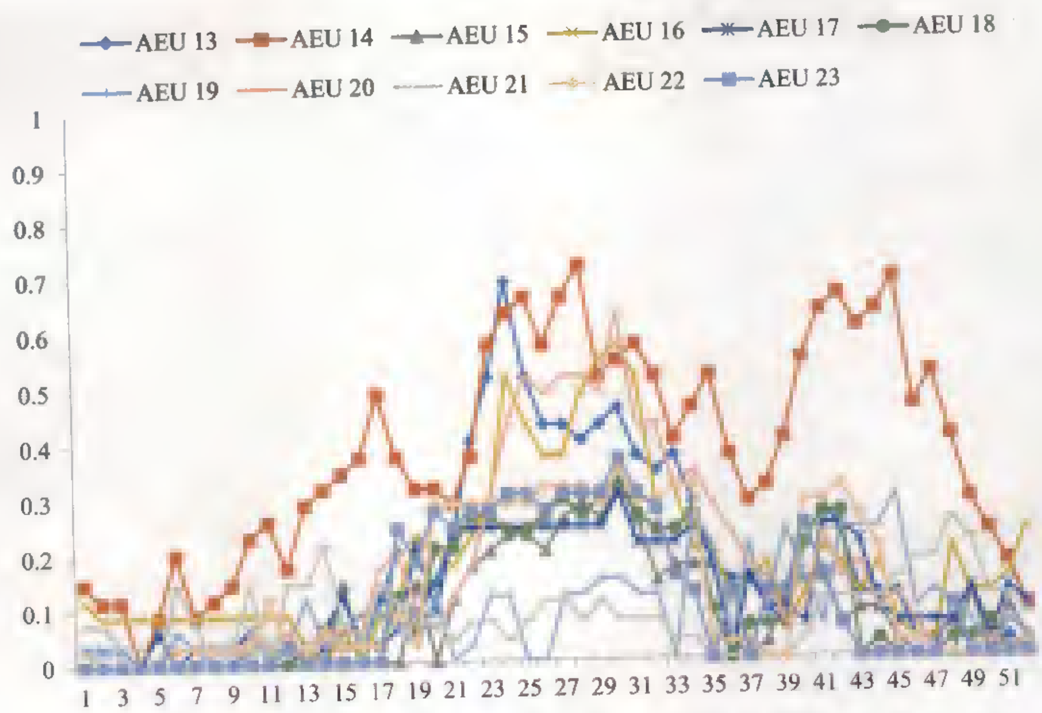

Fig.6. Initial rainfall probabilities of receiving > 40 mm during 2030

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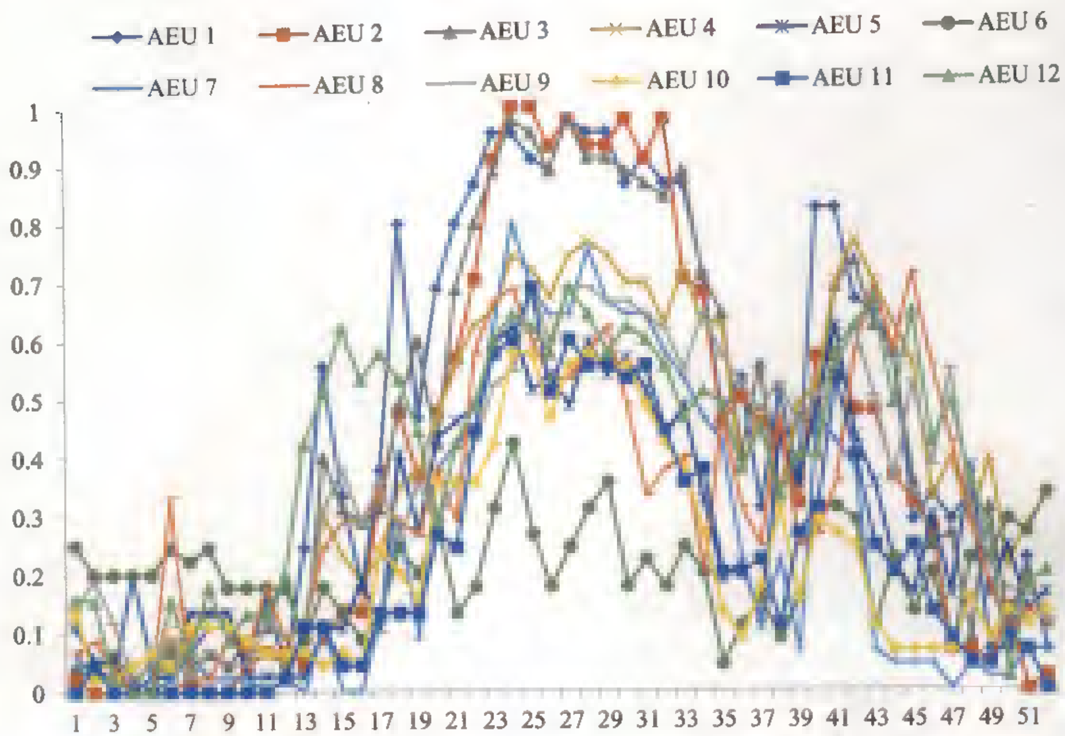

Fig.7. Initial rainfall probabilities of receiving > 40 mm during 2050

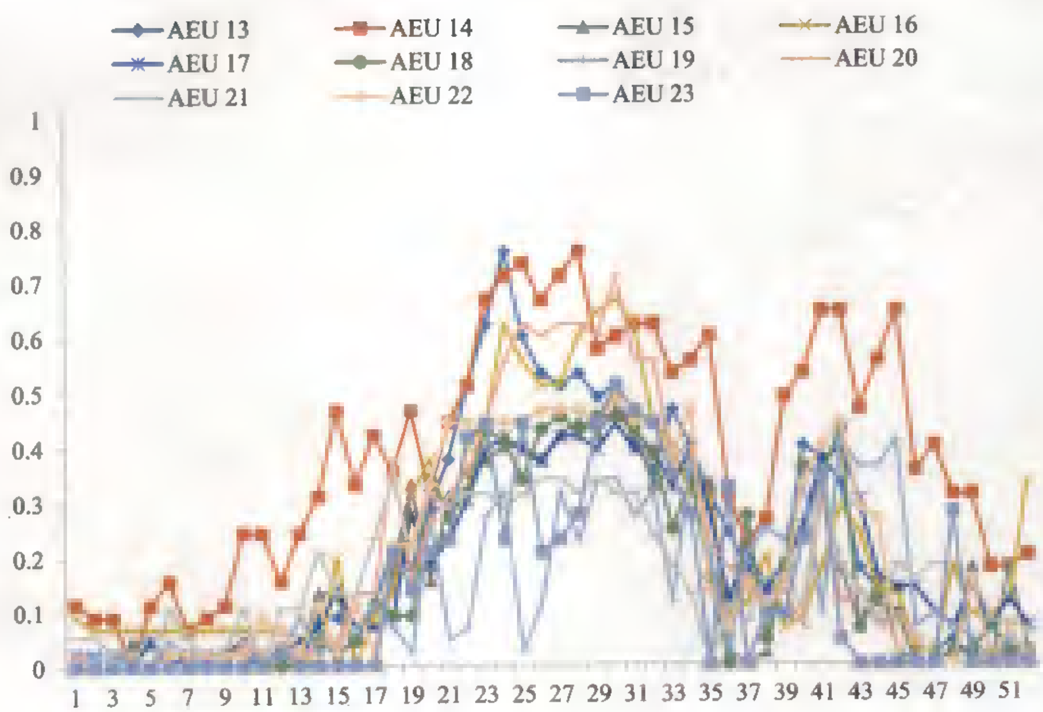

Fig.8. Initial rainfall probabilities of receiving > 40 mm during 2050

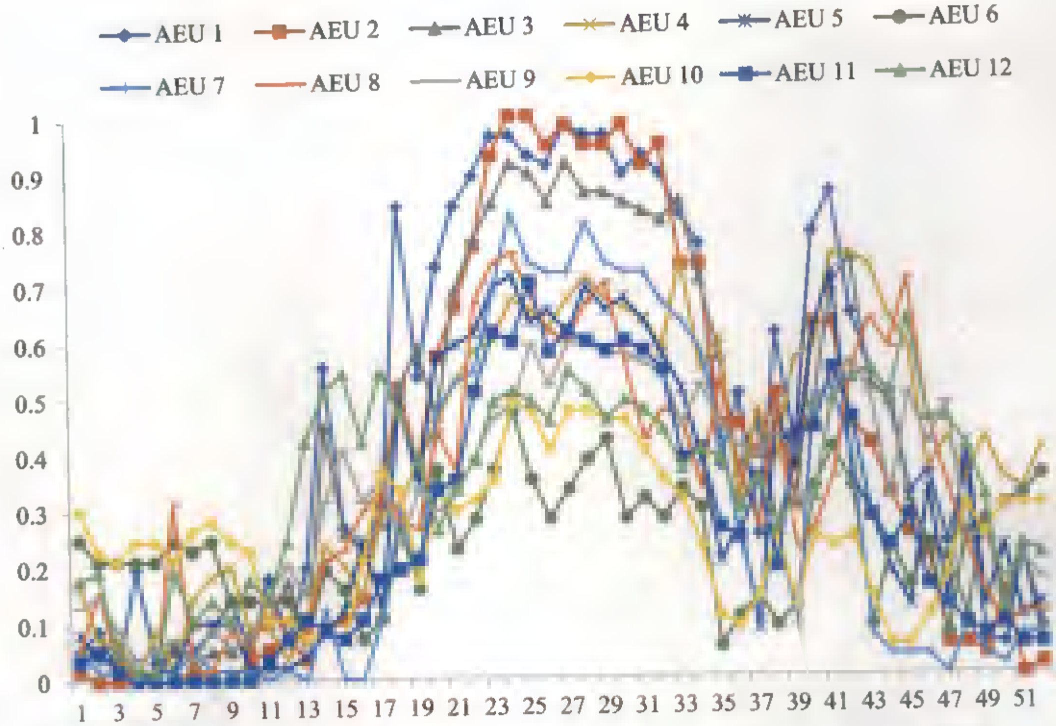

Fig.9. Initial rainfall probabilities of receiving > 40 mm during 2080

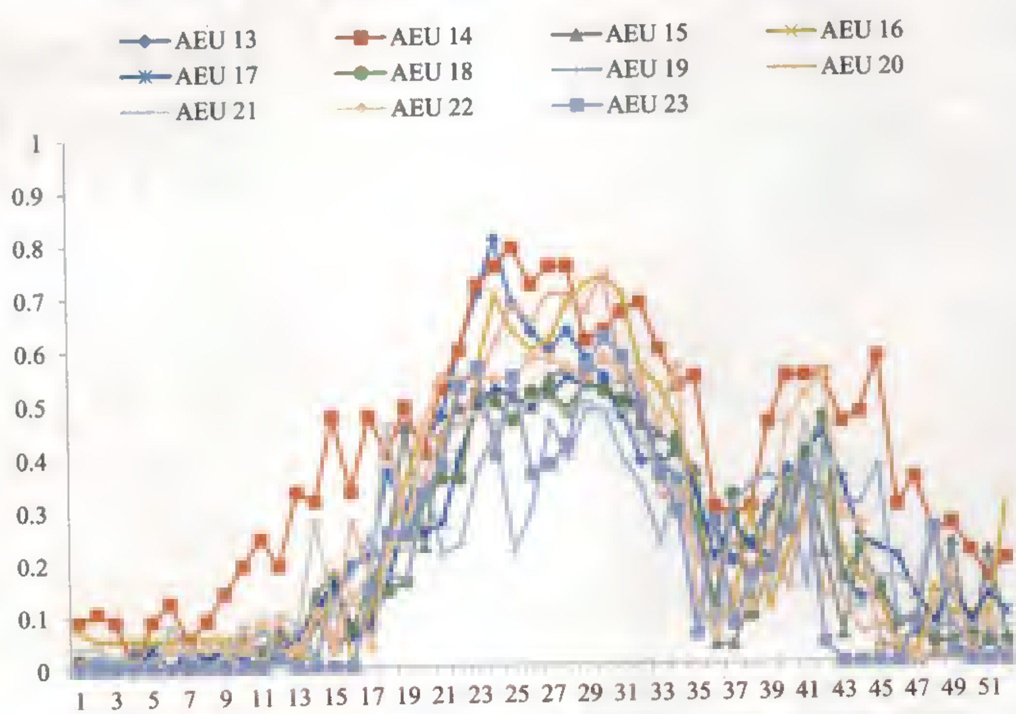

Fig.10. Initial rainfall probabilities of receiving > 40 mm during 2080

4.4. Number of rainy days

The spatial pattern of annual mean rainy days derived observed data (1991-2014) and based on climate change projections as per RCP 4.5 during 2030, 2050 and 2080 are presented in Table 10 and 11. Analysis of number of rainy days during different seasons showed a considerable variation among the AEUs.

Table No 9. Number of rainy days during winter and summer season

Units	Winter				Summer			
	2014	2030	2050	2080	2014	2030	2050	2080
AEU 1	3	3	4	3	22	27	51	26
AEU 2	1	0	0	2	14	17	18	20
AEU 3	3	3	3	3	21	27	27	22
AEU 4	2	3	2	2	23	26	22	30
AEU 5	3	1	2	2	32	27	17	24
AEU 6	1	0	0	3	16	16	16	11
AEU 7	0	2	2	0	9	12	17	12
AEU 8	3	5	3	3	19	11	15	27
AEU 9	2	2	1	4	19	27	23	33
AEU 10	1	0	7	11	13	19	38	24
AEU 11	1	2	12	3	13	17	16	35
AEU 12	6	2	3	5	27	24	12	22
AEU 13	1	0	1	3	16	18	30	23
AEU 14	3	0	3	6	19	15	50	29
AEU 15	2	4	2	1	22	23	28	17
AEU 16	2	4	1	2	13	33	17	24
AEU 17	10	0	0	2	30	17	16	38
AEU 18	5	2	0	1	24	19	19	19
AEU 19	3	0	0	2	14	20	14	23
AEU 20	1	1	3	3	14	13	18	25
AEU 21	1	3	3	6	2	26	27	13
AEU 22	1	2	0	19	9	18	17	60
AEU 23	1	0	1	0	9	20	28	14
Mean	2	2	2	4	17	21	23	25

From the table 10 and 11 It can be observed that the number of rainy days in various AEUs winter and summer season varied differently during winter season. The AEU 17 and 6 recorded the maximum number of rainy days during the winter season. As per the present the climatic conditions the total number of rainy days were ranging from 0 to 10. AEU 1- Southern coastal plain, AEU 4- Kuttanad, AEU 7- Kaipad lands, AEU 8- Southern laterites, AEU 11- Northern laterites, AEU 15- Northern high hills, AEU 16- Kumily high hills, AEU 20- Wayanad central plateau, AEU 21- Wayanad eastern plateau, AEU 22- Palakkad central plain, AEU 23- Palakkad eastern plain showed increased number of rainy days under the projected of climate change conditions as per RCP 4.5 during 2030, 2050 and 2080. But the state average number rainy days remain unchanged up to 2050 and that increased to four during 2080s.

During summer season there is distinct change in number of rainy days. Majority of AEUs expect an increase in number of rainy days during 2030, 2050 and 2080. It is interesting to notice that the number of rainy days (state average) showed continues increase (17 to 25 days) as per projected climate change (RCP 4.5) scenario.

Table No 10. Number of rainy days during SWM and NEM season

Units	South West				North East			
	2014	2030	2050	2080	2014	2030	2050	2080
AEU 1	73	63	55	67	26	16	8	18
AEU 2	79	75	76	68	20	24	17	15
AEU 3	72	65	63	70	26	18	15	21
AEU 4	72	66	75	67	28	17	24	24
AEU 5	71	67	64	71	16	18	16	22
AEU 6	80	67	67	82	21	16	16	16
AEU 7	89	23	64	60	16	15	16	16
AEU 8	46	52	57	63	28	20	21	17
AEU 9	81	75	50	64	25	18	34	15
AEU 10	75	66	46	66	19	16	21	18
AEU 11	79	62	43	65	22	18	45	17
AEU 12	78	63	43	48	40	20	26	28
AEU 13	72	70	65	47	24	15	9	23
AEU 14	66	64	65	70	33	16	1	23
AEU 15	77	77	69	71	28	25	16	26
AEU 16	74	53	70	74	27	12	27	22
AEU 17	52	64	85	57	34	18	20	16
AEU 18	49	65	83	58	23	22	13	23
AEU 19	39	63	86	69	16	18	15	15
AEU 20	77	67	59	59	15	18	21	14
AEU 21	35	63	66	57	4	20	18	19
AEU 22	66	73	67	16	17	12	17	16
AEU 23	59	63	64	65	16	18	8	16
Mean	68	64	64	62	23	18	18	19

The south west monsoon season showed a decreased number of rainy days under future climate change projection. Majority of AEUs except AEU 8- Southern laterites, AEU 17- Marayur hills, AEU 18- Attappady hills, AEU 19- Attappady dry hills, AEU 21- Wayanad eastern plateau, AEU 22- Palakkad central plain and AEU 23- Palakkad eastern plain which occupies a smaller area as compared to other AEUs showed as increased number of rainy days. The AEUs sharing border with Tamil nadu showed increase in number of rainy days as per the future projection.

During the north east monsoon season also the number of rainy days showed a declining trend. The state average declined from 24 to 18 up to 2050 and then increased to 19 during 2080s. AEU 20- Wayanad central plateau, AEU 21- Wayanad eastern plateau and AEU 23- Palakkad eastern plain showed an increase in number of rainy days

The mean annual number of rainy days over Kerala during four different seasons varies between 0 to 12 days in winter, 2 to 32 in summer, 35 to 89 in south west monsoon and 4 to 40 in north east monsoon season.

As per the climate change projections based on RCP 4.5 it can be inferred that the expected rainy days during winter season is in a declining whereas rainy days during summer months showed an increasing trend. The most alarming outcome of the projections is the major rainy seasons of Kerala i.e., SW monsoon season and NE monsoon seasons anticipated a decrease in rainy days.

4.5. Heavy rainfall events

The Number of heavy rainfall events are categorized as 25<50, 50 <75, 75<100 and >=100 and presented in table 12, 13, 14 and 15. The expected number of heavy rainfall during winter season as present as well as climate change projection are considered to be very less. In most of the AEUs it was less than 2. But in AEU 20- Wayanad central plateau, AEU 21- Wayanad eastern plateau, AEU 22- Palakkad central plain, AEU 23- Palakkad eastern plain where the chances of getting heavy rainfall of intensity 25<50 is expected increase under climate change projection.

The number of heavy rains of intensities 25<50 showed an increasing trend up to 2050 during summer season as per the climate change projection and later come back to the present day conditions during 2080s. The heavy rainfall (50-75mm per day) also likely to be increase under projected climate change scenarios. It is also interesting to notice that the number of high rainfall events are expected to be much higher in AEU 21- Wayanad eastern plateau, AEU 22- Palakkad central plain and AEU 23- Palakkad eastern plain as per climate change projections.

Table No 11.Number of rainy days during winter season

AEU	25 <50				50 <75				75 <100				>= 100			
	2014	2030	2050	2080	2014	2030	2050	2080	2014	2030	2050	2080	2014	2030	2050	2080
1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	2	2	0	0	6	1	0	0	1	0	0	0	1	1
11	0	0	3	0	0	0	0	0	0	0	1	0	0	0	0	0
12	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	5	4	0	0	1	1	0	0	0	0	0	0	0	2	0
22	0	3	2	1	0	0	2	6	0	1	1	2	0	0	0	0
23	0	3	3	2	0	1	3	0	0	0	4	0	0	0	1	0
Mean	**0**	**1**	**1**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table No 12.Number of rainy days during summer season

AEU	25 <50				50 <75				75 <100				>= 100			
	2014	2030	2050	2080	2014	2030	2050	2080	2014	2030	2050	2080	2014	2030	2050	2080
1	5	5	13	2	2	0	1	0	1	0	3	1	0	2	2	1
2	2	4	6	2	1	1	1	0	2	0	3	1	0	0	1	0
3	2	1	4	1	1	1	0	1	1	0	0	0	0	0	1	0
4	2	1	3	4	2	1	0	1	0	0	0	1	0	0	0	2
5	17	2	1	1	6	1	0	5	1	0	0	0	0	2	0	0
6	2	1	1	1	1	1	1	0	0	0	0	0	1	0	0	0
7	1	2	1	0	0	0	0	0	1	0	0	0	0	0	0	0
8	7	1	1	5	1	1	0	0	1	0	0	0	0	0	0	2
9	2	3	3	4	2	0	0	1	0	0	0	1	0	1	0	1
10	1	1	8	3	0	4	1	3	1	0	0	0	1	0	0	0
11	0	1	0	5	1	0	0	1	1	0	0	1	0	0	0	3
12	5	0	2	3	1	0	0	1	0	0	0	0	0	0	0	0
13	3	6	7	1	0	2	3	2	0	0	1	0	0	0	0	0
14	4	2	8	4	0	0	3	2	1	0	1	0	0	0	3	0
15	2	1	6	4	0	0	0	2	0	0	0	0	0	0	1	0
16	1	6	4	2	0	3	2	0	0	2	0	0	0	0	0	0
17	1	2	1	8	0	0	1	0	0	0	0	0	0	1	0	0
18	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
19	0	5	1	0	0	2	1	1	1	0	0	0	0	1	0	0
20	2	1	2	3	0	1	0	0	1	0	0	0	0	0	0	0
21	1	14	19	6	0	12	12	4	0	2	5	0	0	2	2	0
22	2	16	18	3	0	7	13	0	0	1	4	1	0	0	3	0
23	2	17	18	16	0	3	14	6	1	3	1	3	0	0	3	1
Mean	**3**	**4**	**6**	**3**	**1**	**2**	**2**	**1**	**1**	**0**	**1**	**0**	**0**	**0**	**1**	**0**

South west monsoon seasons during 2030s expect a huge increase in number of heavy rainfall events except in AEU 21- Wayanad eastern plateau, AEU 22- Palakkad central plain and AEU 23- Palakkad eastern plain which showed a drastic reduction in heavy rainfall events. The expected heavy rainfall events during 2050s and 2080s are on par with the present day conditions. But AEU 12- Southern and central foothills, AEU 13- Northern foothills, AEU 15- Northern high hills, AEU 18- AEU 21- Wayanad eastern plateau, AEU 22- Palakkad central plain and AEU 23- Palakkad eastern plain showed a decrease in number of heavy rainfall events even in 2080s .

Table No 13.Number of rainy days during south west monsoon season

AEU	25 <50				50 <75				75 <100				>= 100			
	2014	2030	2050	2080	2014	2030	2050	2080	2014	2030	2050	2080	2014	2030	2050	2080
1	12	19	14	21	4	10	9	12	2	4	3	3	1	1	2	1
2	23	22	16	22	7	16	9	10	4	4	6	6	2	7	8	6
3	15	23	16	23	1	7	11	8	3	3	3	4	1	2	2	1
4	10	23	17	16	3	7	11	11	1	3	2	1	0	2	2	0
5	15	17	14	19	7	11	7	12	1	4	1	8	2	5	0	3
6	20	25	25	24	5	9	9	13	3	6	6	6	1	3	3	2
7	25	0	14	16	8	0	7	8	5	0	1	3	5	0	0	4
8	9	9	14	19	2	2	11	10	1	3	3	4	0	0	0	1
9	25	22	0	20	7	11	0	11	4	6	0	3	2	5	0	2
10	18	18	0	23	7	14	0	7	2	1	0	2	2	6	0	2
11	23	16	8	18	7	10	2	8	6	5	2	1	1	5	2	1
12	9	17	0	0	5	8	0	0	0	2	0	0	1	0	0	0
13	24	25	19	5	9	7	7	2	1	3	4	0	1	3	4	0
14	14	18	12	18	3	9	6	6	0	2	1	2	1	4	2	0
15	18	17	24	9	4	9	10	0	2	1	3	0	0	0	3	0
16	4	14	9	25	1	3	0	8	0	2	0	3	0	0	0	3
17	15	21	20	14	6	8	6	0	1	4	4	1	1	2	4	0
18	10	24	20	1	0	7	7	0	0	2	5	0	0	0	2	0
19	4	27	20	17	0	9	15	6	0	7	5	3	0	6	5	0
20	19	26	8	9	12	5	3	2	3	4	1	1	2	1	0	0
21	7	2	3	0	2	1	0	3	1	0	0	1	0	0	2	0
22	14	4	1	3	4	1	2	0	2	1	0	1	0	0	1	0
23	10	1	0	1	7	1	0	0	2	0	0	0	0	0	0	1
Mean	**14**	**17**	**12**	**14**	**5**	**7**	**6**	**6**	**2**	**3**	**2**	**2**	**1**	**2**	**2**	**1**

The high rainfall events showed a reverse trend during the north east monsoon season 11 out of 23 AEUs showed decline in heavy rainfall events (25<50). The AEU 21- Wayanad eastern plateau, AEU 22- Palakkad central plain and AEU 23- Palakkad eastern plain showed a drastic increase in heavy rainfall events of all the four categories.

Table No 14.Number of rainy days during north east monsoon season

AEU	25 <50				50 <75				75 <100				>= 100			
	2014	2030	2050	2080	2014	2030	2050	2080	2014	2030	2050	2080	2014	2030	2050	2080
1	4	3	3	2	1	1	0	0	0	0	0	0	0	1	0	1
2	3	1	1	2	1	0	0	0	0	0	0	0	1	1	0	1
3	6	2	1	4	1	2	2	0	1	0	0	1	0	1	1	1
4	3	3	3	3	1	2	1	0	0	0	3	3	0	1	1	1
5	1	3	1	5	0	0	0	1	0	0	1	1	0	2	0	1
6	5	2	2	1	1	1	1	2	0	0	0	0	0	1	1	1
7	3	2	1	1	0	1	0	0	0	0	1	0	0	0	0	0
8	2	1	3	3	1	0	0	1	1	0	1	0	0	1	0	1
9	7	3	5	1	2	0	0	2	0	0	0	0	0	2	0	0
10	3	2	1	3	2	1	3	2	0	0	3	0	0	1	0	1
11	3	3	16	2	1	1	9	0	1	0	2	3	1	0	0	0
12	8	2	3	5	3	1	1	0	1	0	0	0	1	1	0	0
13	2	1	0	0	0	0	0	3	0	0	0	1	1	1	0	0
14	6	2	0	1	1	0	0	0	0	1	0	2	0	0	0	0
15	0	1	3	5	0	1	1	0	0	1	0	0	0	0	1	0
16	5	1	5	3	0	0	0	0	1	0	0	0	0	0	0	1
17	0	4	4	3	1	0	2	0	0	0	1	0	0	2	0	0
18	1	3	0	3	0	0	0	0	0	0	0	0	0	1	0	0
19	1	3	4	3	0	0	1	0	0	0	1	1	0	1	2	0
20	1	0	4	2	0	0	1	1	0	0	0	0	0	0	0	0
21	1	21	26	7	0	14	13	7	1	2	5	1	0	2	6	0
22	3	23	21	25	1	8	17	8	0	3	5	4	0	0	4	1
23	3	21	21	19	0	5	17	6	0	3	5	3	0	0	4	2
Mean	**3**	**5**	**6**	**4**	**1**	**2**	**3**	**1**	**0**	**0**	**1**	**1**	**0**	**1**	**1**	**1**

4.6. Length of Growing Period

The impact of projected climate on total length of growing period (weekly) is presented in table 16 and figure 11 to 14. 11 out of 23 AEUs i.e., AEU 2- Northern coastal plain, AEU 4- Kuttanad, AEU 10- North central laterites, AEU 11- Northern laterites, AEU 16- Kumily high hills, AEU 17- Marayur hills, AEU 18- Attappady hills, AEU 19- Attappady dry hills, AEU 21- Wayanad eastern plateau, AEU 22- Palakkad central plain and AEU 23- Palakkad eastern plain showed an increasing in growing period during 2030s. Whereas all other AEUs showed a decrease in length of growing period. The length of growing period showed a substantial decrease the major rice growing areas (AEU 5- Pokkali lands, AEU 6- Kole lands, AEU 7- Kaipad lands, AEU 8- Southern laterites and AEU 9- South central laterites). Where as in high lands and Palakkad plains expect an increase in growing period. The length of growing period will increase considerably during 2050s in most of the AEUs except in AEUs 2, 3, and 11. A decline growing period in the major rice growing tracts will be expected during 2080s also.

Table No 15. Length of growing period (weeks) as per climate change projections

AEU	2014	2030	2050	2080
AEU 1	29	23	35	26
AEU 2	25	26	22	21
AEU 3	35	30	25	27
AEU 4	23	29	27	27
AEU 5	26	23	33	26
AEU 6	25	14	32	22
AEU 7	25	16	33	18
AEU 8	26	21	37	23
AEU 9	33	25	35	21
AEU 10	22	23	37	29
AEU 11	23	26	21	22
AEU 12	27	22	37	25
AEU 13	22	21	33	33
AEU 14	31	29	33	29
AEU 15	24	23	36	23
AEU 16	23	28	33	29
AEU 17	19	28	34	17
AEU 18	14	24	34	28
AEU 19	9	22	35	10
AEU 20	26	24	35	25
AEU 21	13	23	36	28
AEU 22	21	23	32	22
AEU 23	19	23	32	20
Mean	23	24	32	24

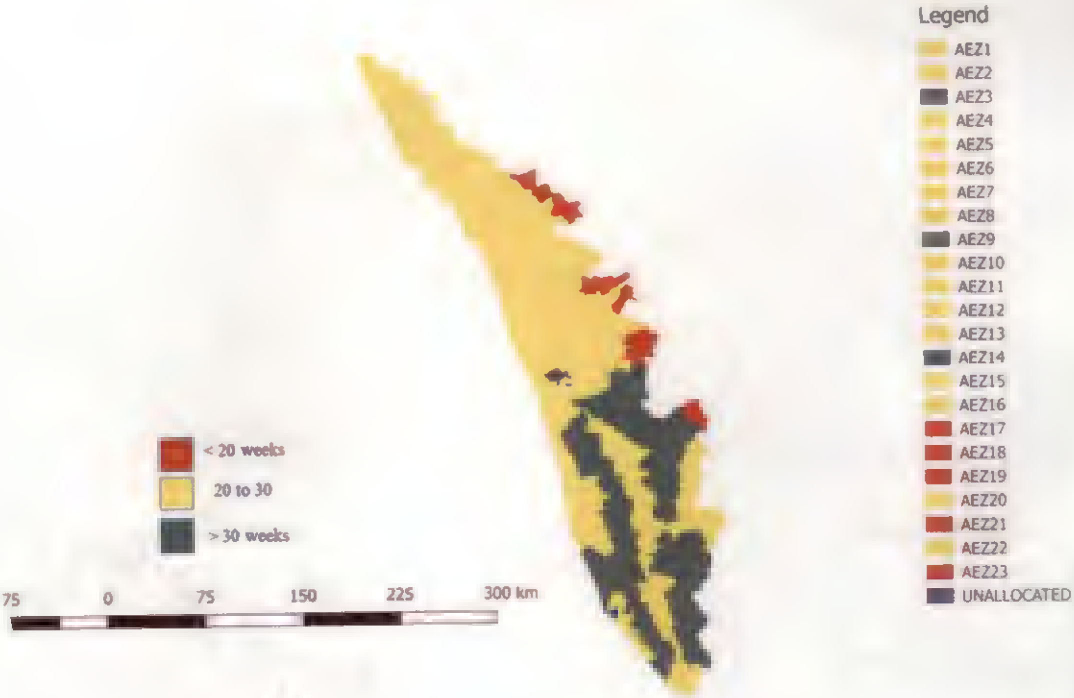

Fig.11. Duration of length of growing period as per present climate

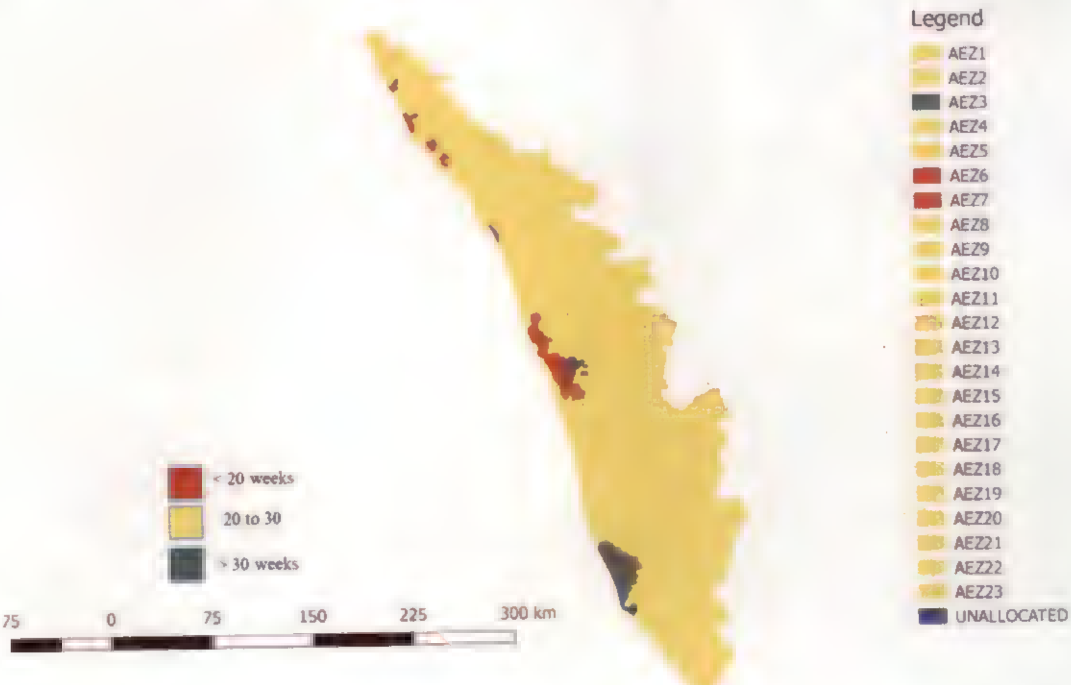

Fig.12 Projected duration of length of growing period during 2030

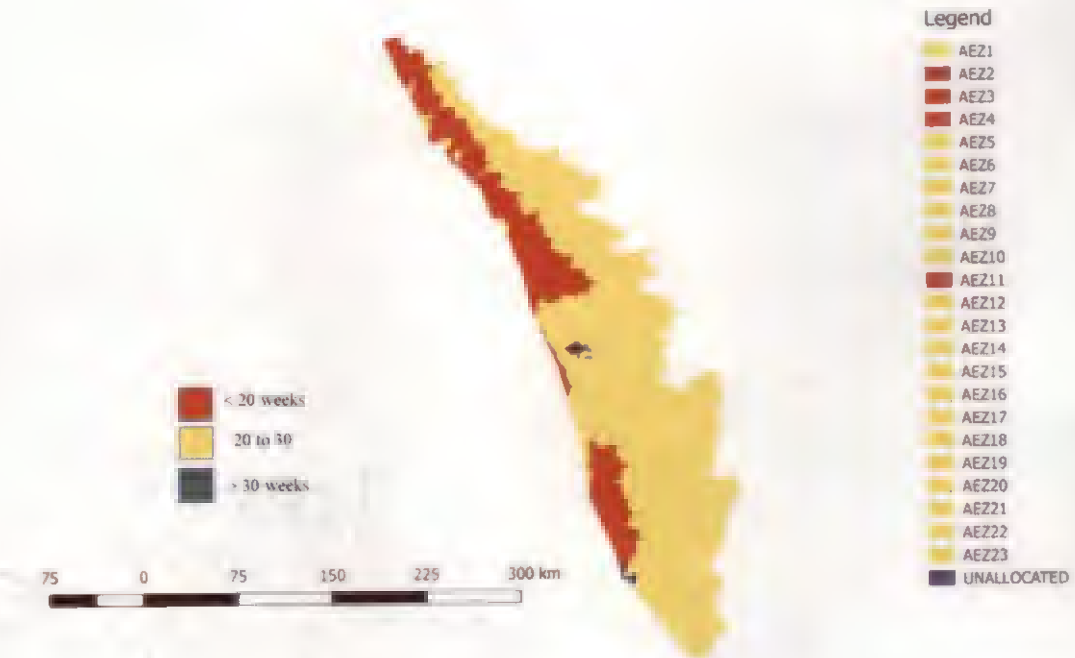

Fig. 13 Projected duration of length of growing period during 2050

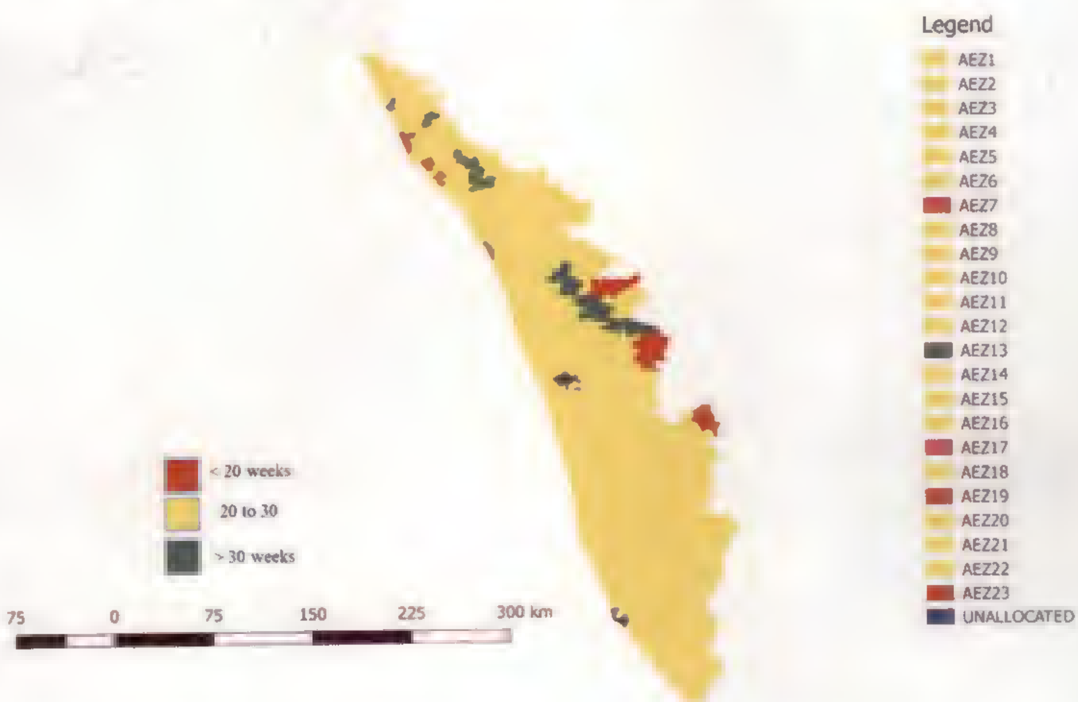

Fig.14. Projected duration of length of growing period during 2080

4.7. Agricultural drought

The chances for the occurrence of agricultural drought and the possible period of droughts are calculated and presented in table 17 and 18 and also in figures 15 to 18. It can be seen from the result that AEUs differ widely in the duration and occurrence of drought.

4.7.1 Kharif season

As per the projected climate change seasons for 2030s the first crop season showed a decrease in duration of agricultural drought in the majorities of AEUs. It can be also seen that the rice growing areas of Kerala except Kole land will experience prolonged drought situation during 2030s. The duration of drought is going to be reduced during 2050s and only AEU 9- South central laterites, AEU 12- Southern and central foothills and AEU 14- Southern high hills will experience a prolonged drought. The situation droughts during 2080s showed an increase in the midlands and foot hills of Kerala. It is also interesting to notice that the Palakkad plain which are highly drought prone during kharif season in the present day conditions showed a much reduced duration of drought during 2050 and 2080.

Table No 16. Agricultural drought during Kharif season

AEU	Period							
	2014	Duration	2030	Duration	2050	Duration	2080	Duration
AEU 1	39 - 42	3	36 - 39	3	29 - 32	3	0	0
AEU 2	35 - 42	7	35 - 40	5	31 - 37	6	35 - 39	4
AEU 3	34 - 39	5	27 - 42	15	36 - 39	3	22 - 42	20
AEU 4	36 - 42	6	22 - 32	10	36 - 40	4	34 - 39	5
AEU 5	22 - 32	10	22 - 34	12	35 - 40	[illegible]	35 - 40	5
AEU 6	30 - 35	5	35 - 39	4	35 - 39	4	39 - 42	3
AEU 7	22 - 34	12	22 - 36	14	35 - 39	4	22 - 25	3
AEU 8	34 - 38	4	22 - 42	20	36 - 40	4	36 - 39	3
AEU 9	35 - 38	3	22 - 42	20	22 - 39	17	33 - 37	4
AEU 10	38 - 42	4	36 - 39	3	34 - 37	3	25 - 37	12
AEU 11	22 - 41	19	36 - 39	3	22 - 31	9	22 - 31	9
AEU 12	36 - 39	3	22 - 42	20	22 - 41	19	22 - 42	20
AEU 13	22 - 42	20	35 - 39	4	33 - 37	4	30 - 34	4
AEU 14	22 - 34	12	22 - 42	20	36 - 39	3	32 - 36	4
AEU 15	25 - 34	9	22 - 42	20	36 - 39	3	32 - 36	4
AEU 16	22 - 32	10	22 - 38	16	33 - 37	4	36 - 40	4
AEU 17	22 - 36	14	22 - 34	12	0	0	36 - 42	6
AEU 18	33 - 37	4	0	0	0	0	0	0
AEU 19	31 - 37	6	0	0	0	0	0	0
AEU 20	23 - 32	9	37 - 40	3	0	0	29 - 35	6
AEU 21	22 - 33	11	22 - 41	19	36 - 39	3	39 - 42	3
AEU 22	22 - 36	14	22 - 35	13	36 - 39	3	36 - 39	3
AEU 23	22 - 35	13	33 - 37	4	26 - 29	3	36 - 39	3

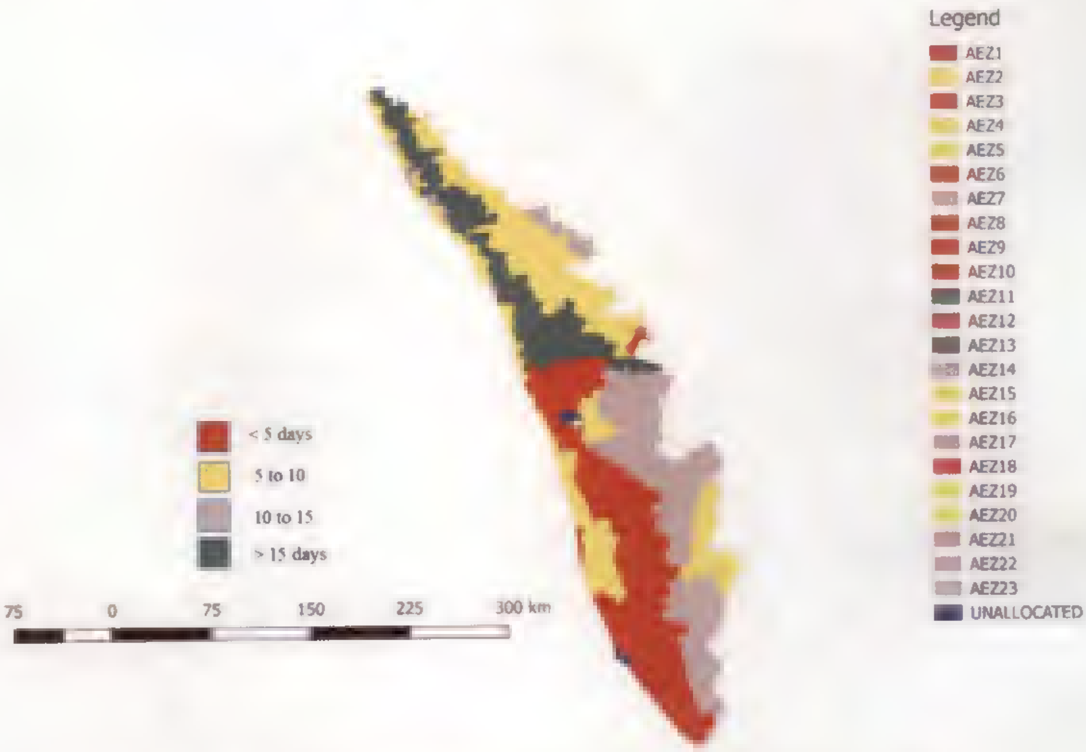

Fig.15. Agricultural Drought during Kharif Season as Per Present Climate

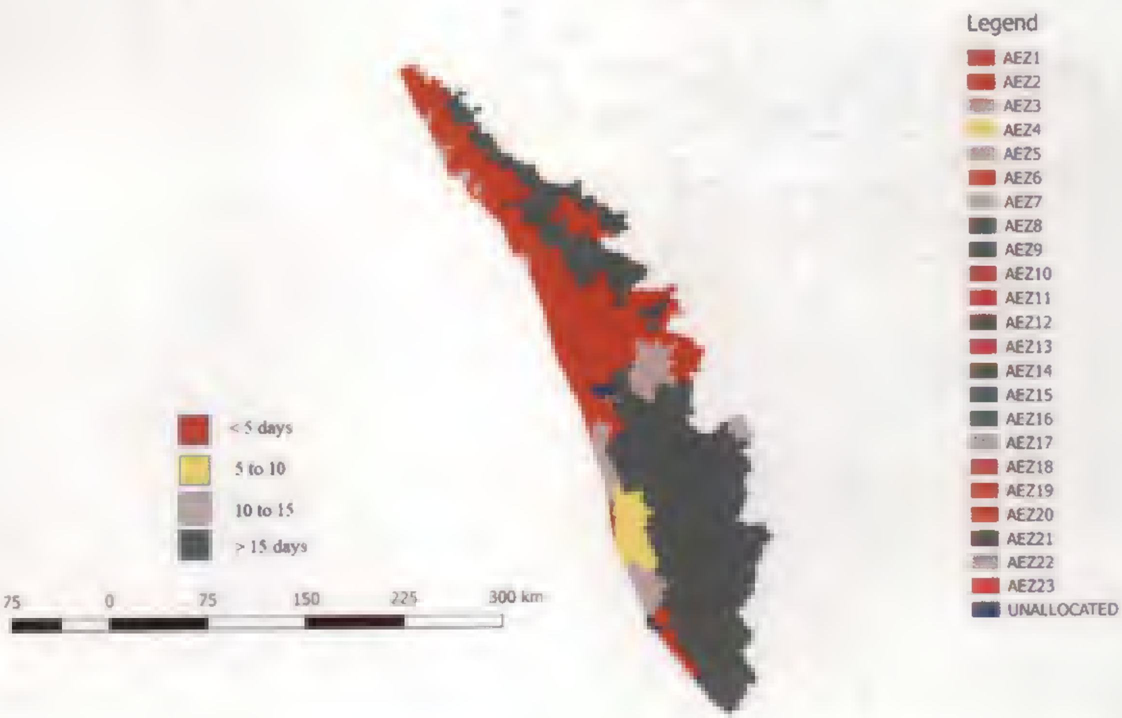

Fig.16. Agricultural Drought during Kharif Season -2030

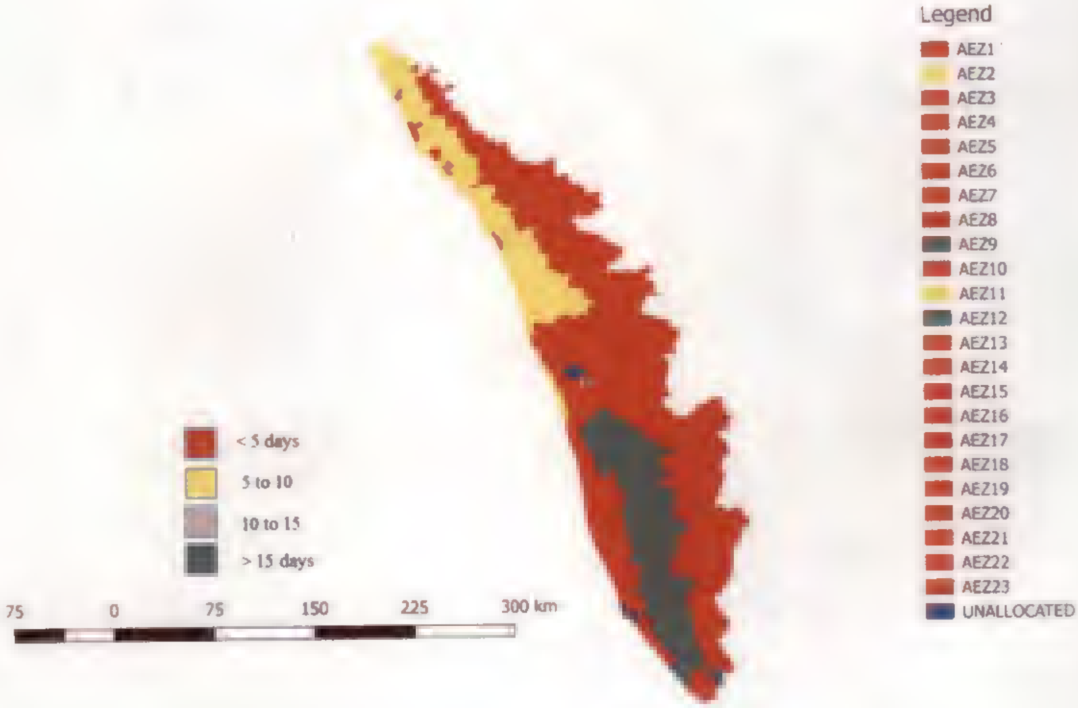

Fig.17. Agricultural Drought during Kharif Season -2050

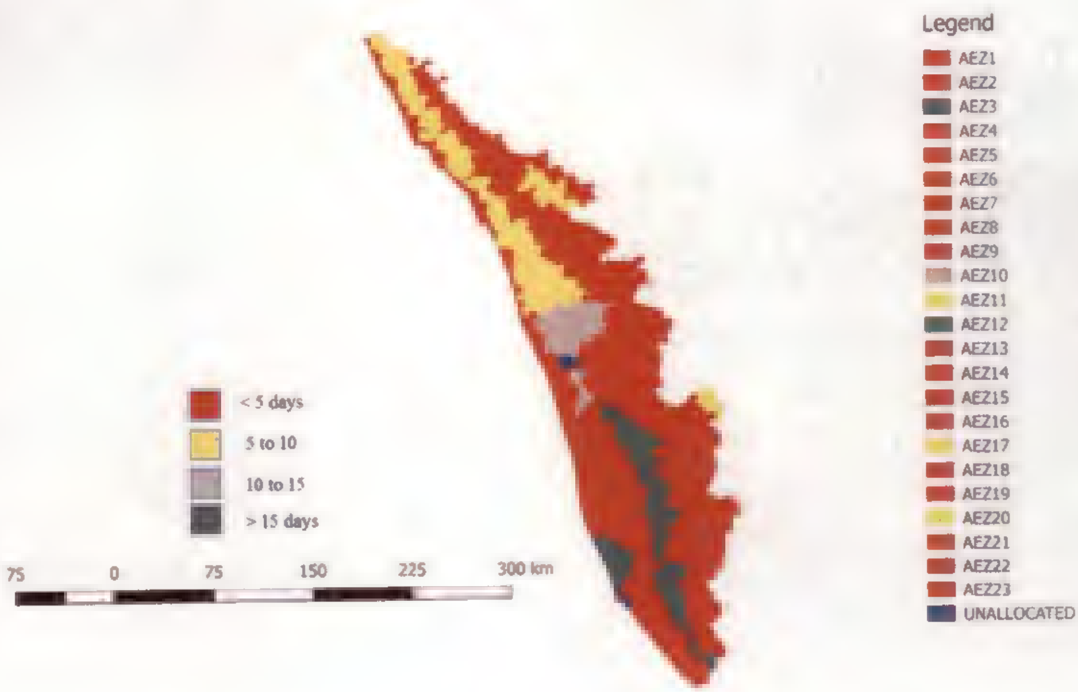

Fig.18. Agricultural Drought during Kharif Season -2080

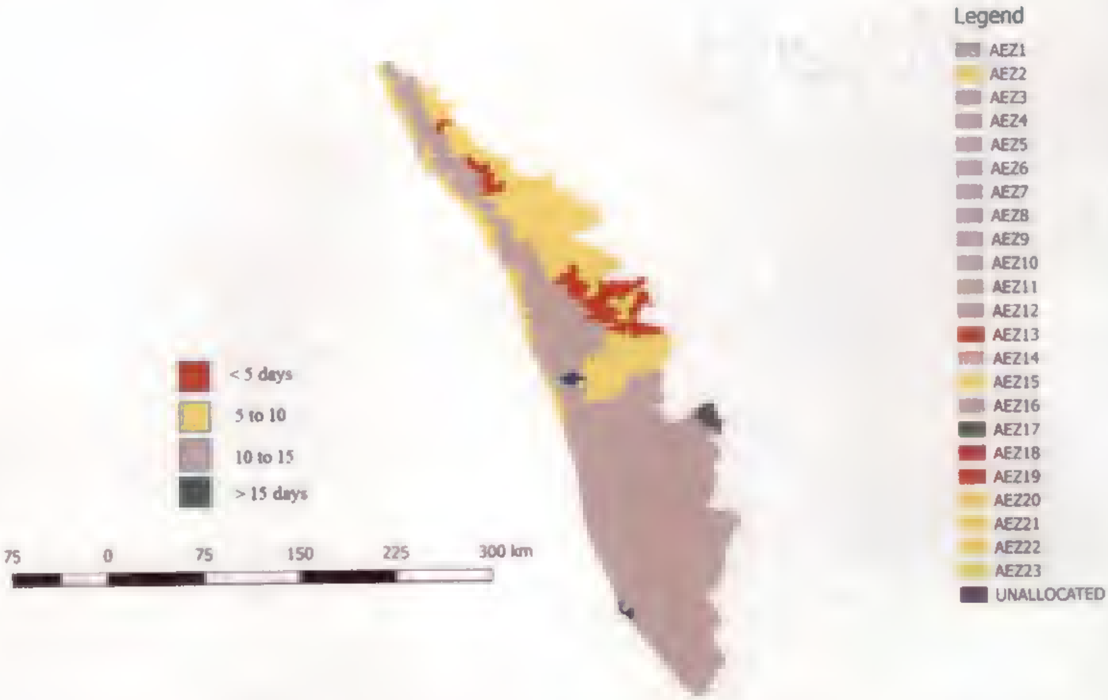

Fig.19. Agricultural Drought during Rabi Season as Per Present Climate

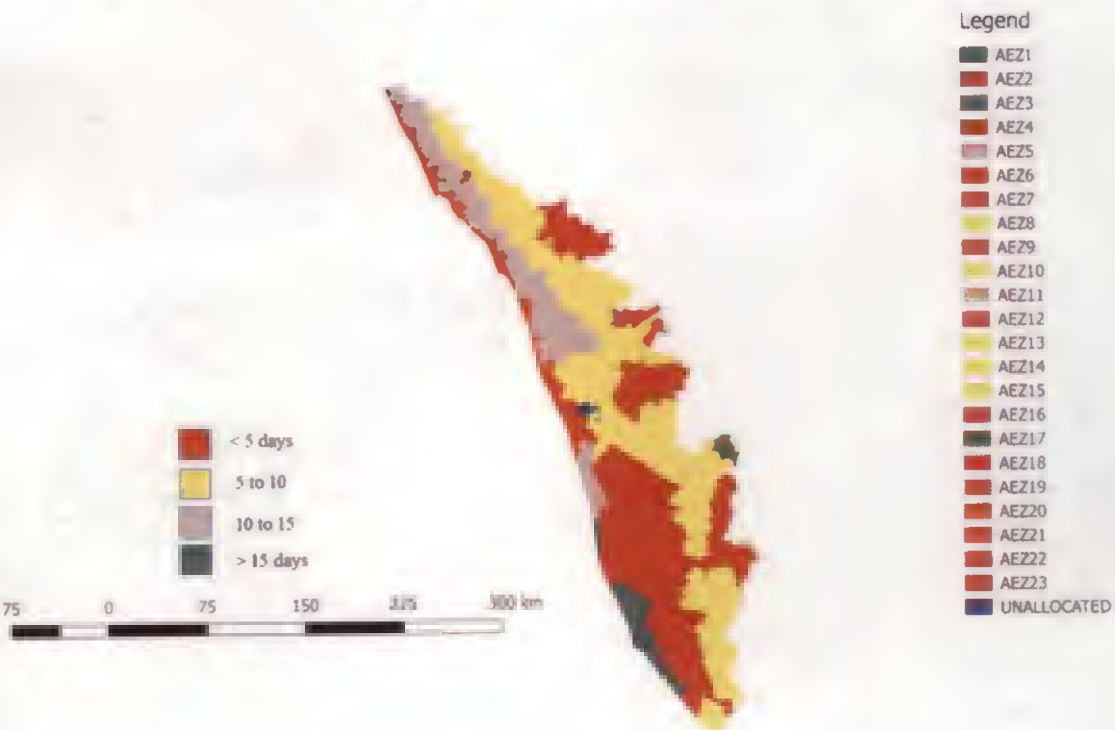

Fig.20. Agricultural Drought during Rabi Season-2030

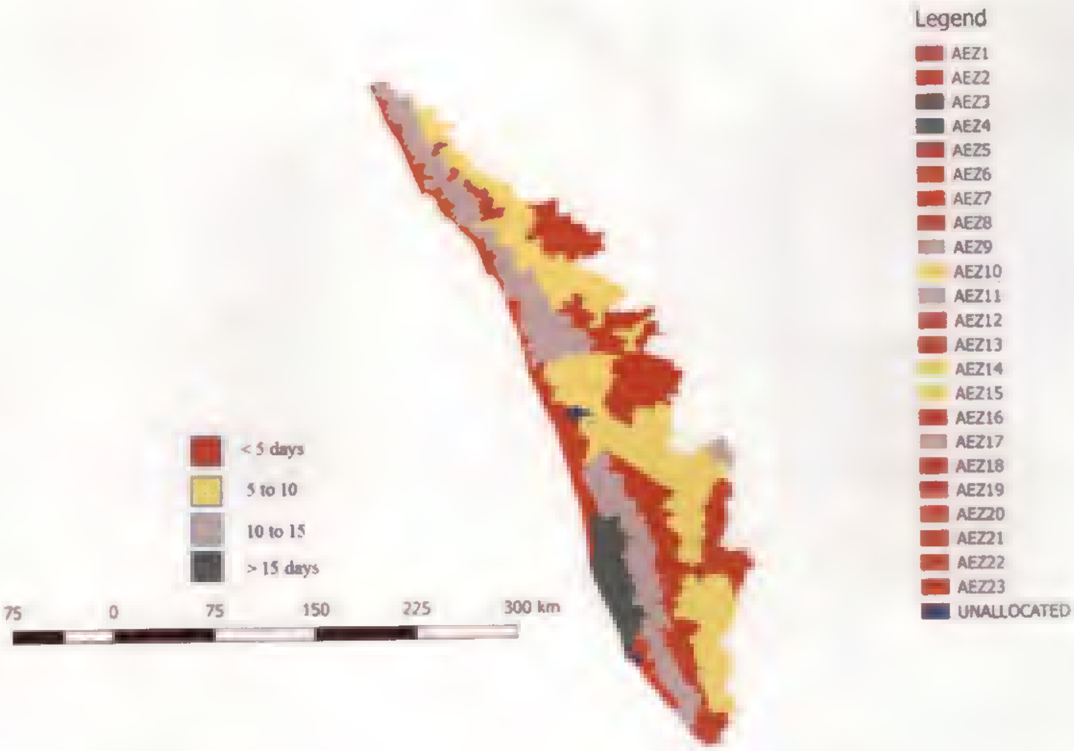

Fig.21. Agricultural Drought during Rabi Season-2050

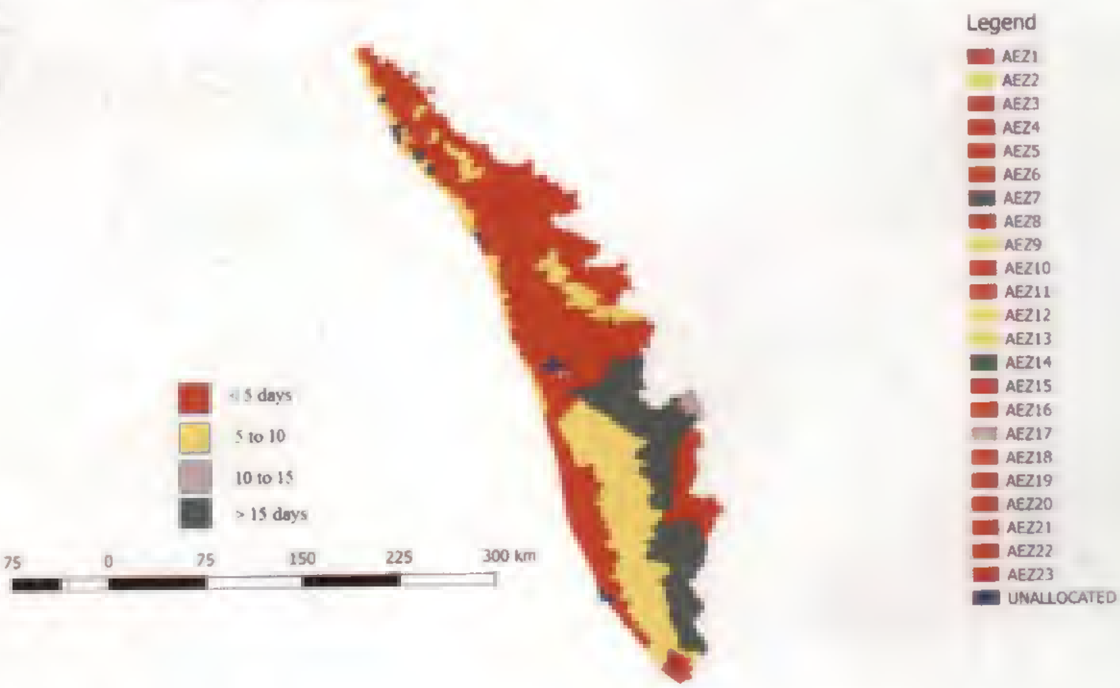

Fig.22. Agricultural Drought during Rabi Season-2080

Considering the drought periods a shift can be observed in the water scarcity periods of majority of AEUs under projected climate change. Most of the AEUs situated in the costal and midlands shows advancing of drought period of about 2 to 13 weeks, whereas AEUs is high hills and foot hills showed earliness in occurrence of drought.

The AEU 2- Northern coastal plain, AEU 5- Pokkali lands and AEU 7- Kaipad lands in the northern costal lands did not show changes in the drought period. Whereas northern high hills and foot hills (AEU 15- Northern high hills and AEU 20- Wayanad central plateau) expected a delay of 13-14 weeks in the occurrence of drought. It can be noticed from the table 17 that Palakkad central plain does not show variations in drought period whereas in eastern plain the drought period reduced considerably. The AEU 18- Attappady hills, AEU 19- Attappady dry hills anticipated a well distribution of rainfall throughout the year during 2030s.

During 2050s majority of the AEUs showed a delay in the commencement of drought period except in AEU 1- Southern coastal plain, AEU 2- Northern coastal plain, AEU 9- South central laterites, AEU 10- North central laterites and AEU 12- Southern and central foothills. The AEU 17- Marayur hills, AEU 18- Attappady hills, AEU 19- Attappady dry hills and AEU 20- Wayanad central plateau will not experience agricultural drought during 2050s.

As per the climate change projection for 2080s AEU 3- Onattukara sandy plain, AEU 4- Kuttanad, AEU 10- North central laterites and AEU 12- Southern and central foothills showed earliness in the occurrence of agricultural drought whereas majorities of AEUs showed a delay in beginning of drought period.

4.7.2. Rabi season

The period and duration of agricultural drought as per present climate conditions and projected climate scenarios are resulted below. It can inferred from the table 18 that most of AEUs experience reduced drought duration as per the climate change projections. The Rabi season will also going to experience earliness in the occurrence of drought in the future.

Table No 17. Agricultural drought during Rabi season

AEU	Period							
	2014	Duration	2030	Duration	2050	Duration	2080	Duration
AEU 1	46 - 60	14	43 - 60	17	0	0	0	0
AEU 2	45 - 51	6	42 - 47	5	41 - 46	5	44 - 51	7
AEU 3	46 - 60	14	40 - 60	20	40 - 60	20	0	0
AEU 4	46 - 60	14	43 - 48	5	42 - 60	18	41 - 46	5
AEU 5	45 - 60	15	45 - 60	15	42 - 47	5	42 - 47	5
AEU 6	45 - 60	15	40 - 45	5	40 - 45	5	43 - 48	5
AEU 7	47 - 60	13	0	0	0	0	44 - 60	16
AEU 8	47 - 60	13	40 - 48	8	46 - 51	5	42 - 47	5
AEU 9	47 - 60	13	0	0	47 - 60	13	43 - 51	8
AEU 10	45 - 60	15	40 - 47	7	40 - 48	8	0	0
AEU 11	47 - 60	13	46 - 60	14	47 - 60	13	45 - 50	5
AEU 12	47 - 60	13	43 - 48	5	43 - 48	5	40 - 46	6
AEU 13	32 - 35	3	32 - 42	10	39 - 42	3	33 - 42	9
AEU 14	47 - 60	13	40 - 46	6	40 - 60	20	40 - 60	20
AEU 15	40 - 46	6	40 - 46	6	40 - 46	6	40 - 45	5
AEU 16	47 - 60	13	0	0	40 - 45	5	42 - 47	5
AEU 17	40 - 60	20	44 - 60	16	46 - 60	14	47 - 60	13
AEU 18	0	0	0	0	0	0	0	0
AEU 19	41 - 46	5	0	0	0	0	0	0
AEU 20	40 - 49	9	42 - 47	5	40 - 45	5	40 - 45	5
AEU 21	44 - 51	7	43 - 48	5	0	0	43 - 48	5
AEU 22	40 - 46	6	0	0	0	0	0	0
AEU 23	45 - 51	6	0	0	0	0	0	0

4.8. Water balance of Kerala

The hydrological potentialities of a region cannot be evaluated by the study of precipitation alone, even though it is the only source of water supply to any region. The transport of water from the earth back to the atmosphere, variously known as water loss, consumptive use, evapotranspiration etc. has also to be considered simultaneously. Thornthwaite and Mather (1955) put forth revised book-keeping procedure of computing water balance. Inadequate water supply and adverse temperature are the universal risks in agricultural production. In tropics, precipitation, thus moisture availability to crops shows relatively wide variations compared to temperature.

The water balance elements for all the 23 AEUs in Kerala were worked out and the annual PET, water surplus, and water deficit is presented in Tables 19 to 34.

Potential Evapotranspiration (PET)

Potential evapotranspiration or the water need is the amount of water that would evaporate from the soil and transpire from the vegetation when there is no water deficiency. The highest monthly PET values were recorded during the month of March (> 200 mm) throughout the state and lowest was recorded during December and October.

The average annual PET of Kerala is 1948 mm. The AEU is recorded (1825) the lowest pet and the AEU 21 recorded (1996) the highest PET. The months showing highest PET are March April and May. The lowest PET was recorded during the month of December (133mm).

Table No 18. Potential Evapotranspiration (1991-2014)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	150	166	222	174	195	140	144	188	145	134	167	134
2	149	166	219	172	192	140	144	188	145	134	166	133
3	148	165	221	173	192	140	144	188	145	134	167	134
4	150	166	221	174	194	140	144	188	145	134	167	134
5	151	169	228	180	199	141	143	186	146	136	168	134
6	150	171	232	184	202	140	141	186	146	138	169	135
7	147	163	214	167	187	138	144	189	144	131	163	131
8	147	163	214	167	187	138	144	189	144	131	163	131
9	143	157	209	162	183	136	140	181	137	126	160	129
10	151	170	231	183	202	140	141	185	146	137	169	135
11	151	170	232	184	204	142	142	186	146	137	168	134
12	150	147	169	132	166	145	161	217	174	163	174	142
13	150	166	221	174	194	140	144	188	145	134	167	134
14	147	163	215	168	188	138	144	187	143	131	163	131
15	141	153	210	163	184	135	133	172	132	124	154	124
16	151	169	228	180	199	141	143	186	146	136	168	134
17	151	170	231	183	202	140	141	185	146	137	169	135
18	149	165	219	171	192	140	144	189	145	133	165	133
19	147	163	214	167	187	138	144	189	144	131	163	131
20	144	162	224	179	197	136	135	175	138	131	159	127
21	150	171	232	187	206	140	139	183	146	139	168	134
22	150	170	230	182	202	141	142	185	145	136	167	134
23	151	169	230	182	201	141	142	185	145	137	168	134

The climate change projections for 2030 showed that is majority of the AEUs the average annual PET showed an increasing trend. Whereas AEUs 3, 7, 12, 17-21 will expect decrease in annual PET.

Table No 19. Potential Evapotranspiration (2030)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	140	156	204	164	221	160	147	199	141	152	195	156
2	116	155	206	168	221	156	145	193	143	165	184	157
3	150	116	198	162	211	166	152	193	159	156	176	94
4	142	154	204	168	214	156	154	187	148	163	183	149
5	118	157	209	171	213	152	151	187	154	154	187	160
6	125	161	214	175	216	150	149	188	161	152	193	160
7	72	86	132	110	142	117	119	150	137	92	104	131
8	150	116	198	162	211	166	152	193	159	156	176	94
9	119	158	207	168	221	160	144	193	144	164	184	158
10	124	160	211	172	214	155	144	206	150	145	196	160
11	122	160	210	171	220	154	144	188	144	164	184	156
12	75	94	138	121	179	144	132	116	114	107	112	80
13	146	164	214	176	225	174	161	189	163	152	202	153
14	141	159	213	175	217	153	152	191	161	152	185	150
15	126	161	214	176	217	149	156	191	162	156	185	152
16	70	70	121	106	172	119	99	125	97	101	110	54
17	70	70	123	115	172	126	98	127	97	90	104	54
18	94	104	171	149	200	146	111	154	115	133	146	74
19	115	117	196	163	205	142	133	178	146	143	143	75
20	66	93	146	132	172	100	97	117	109	97	96	78
21	69	98	153	137	176	103	100	121	104	112	99	82
22	144	162	215	177	223	170	149	188	152	156	196	154
23	142	165	220	175	195	140	158	184	165	150	185	153

During 2050 the number of AEUS showing a decrease in the annual PET increased. AEUs 9, 10, 12, and 14-22 showed a reduced PET. But during 2080 the number of AEUs showing a decreasing trend reduced to 8 (AEU 13, 14, 16-21).

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Table No 20. Potential Evapotranspiration (2050)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	150	158	208	169	219	161	152	194	150	166	189	156
2	123	159	210	171	223	159	149	194	158	168	187	161
3	146	156	207	168	219	165	152	200	146	160	190	151
4	146	156	209	170	217	160	158	191	156	162	189	151
5	147	157	210	171	224	166	154	195	152	155	200	154
6	145	165	214	175	223	158	149	195	154	168	197	162
7	119	158	209	173	218	155	150	192	156	157	187	160
8	151	124	200	167	214	170	159	196	161	157	183	100
9	73	97	154	134	188	116	97	129	84	124	103	80
10	73	97	147	131	190	124	90	145	84	114	103	80
11	145	165	214	175	227	162	145	193	152	163	193	162
12	80	98	150	128	195	133	111	142	105	124	120	80
13	146	164	214	176	225	174	161	189	163	152	202	153
14	140	103	190	159	209	166	157	190	156	149	168	83
15	50	61	96	89	139	92	79	100	76	80	77	54
16	75	76	128	118	175	124	105	134	100	107	107	60
17	70	70	123	115	172	126	98	127	97	90	104	54
18	94	104	171	149	200	146	111	154	115	133	146	74
19	115	117	196	163	205	142	133	178	146	143	143	75
20	76	100	159	141	182	109	104	123	107	117	107	82
21	76	100	159	141	182	109	104	123	107	117	107	82
22	150	166	218	179	225	172	152	192	155	159	191	159
23	148	167	221	177	222	163	143	197	153	163	193	154

Table No 21. Potential Evapotranspiration (2080)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	151	163	211	171	225	166	151	201	150	168	191	160
2	142	163	213	174	230	166	149	200	152	170	192	164
3	150	159	209	171	225	168	155	202	150	168	190	153
4	152	161	213	172	226	169	157	203	151	168	194	155
5	146	165	216	175	228	165	152	200	152	169	193	166
6	149	168	218	175	229	166	150	201	152	170	194	165
7	142	162	212	173	230	166	150	199	149	169	192	164
8	155	148	203	167	218	170	154	198	161	160	184	109
9	151	167	218	175	229	168	153	204	154	170	194	162
10	150	168	218	176	230	166	149	200	151	170	195	164
11	151	168	220	177	231	166	148	201	153	170	194	161
12	149	158	210	171	227	173	161	207	159	167	195	145
13	144	111	194	163	213	169	157	195	159	153	172	87
14	79	80	133	114	189	140	108	140	102	111	112	63
15	154	171	224	180	230	166	148	202	154	170	195	158
16	79	80	133	114	189	140	108	140	102	111	112	63
17	73	73	127	112	182	132	102	132	99	105	105	56
18	100	110	187	153	208	150	118	161	121	142	142	78
19	119	127	201	164	215	161	140	183	147	150	165	82
20	76	100	153	134	197	126	91	137	84	125	105	82
21	73	104	159	141	199	125	92	141	90	128	104	86
22	157	173	226	181	230	166	148	202	154	171	197	162
23	154	171	224	180	230	166	148	202	154	170	195	158

4.8.1. Water Deficit (WD)

Water deficit is a measure of the additional water required for any region to meet the full demands and hence, is a basic criterion for the development of water resources. It provides information on the total volume of water needed at any time and gives a definite measure of droughts.

The annual water deficit of 568 mm to 1438 mm occurs over the State. Seasonally, there exists water deficiency only during the pre-monsoon and winter months and distribution for these periods alone are presented (Table 23 to 26). During January to March period, all most all the AEUs of Kerala exhibit a water deficiency (WD).

The water deficit of present day climate is presented in table 23. It can be observed from the table that an average annual water deficit of 951 mm is recorded in Kerala. The central mid land AEUs (9 and 10) northern foot hills (13) high hills (17-23 no 20) and Palakkad plain experience an annual deficit of more than 1000mm.

Table No 22. Water deficit (1991-2014)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	149	125	193	39	60	2	0	5	40	5	59	100
2	149	166	217	100	45	4	0	10	20	5	86	131
3	148	132	206	8	44	0	0	0	48	20	65	84
4	118	166	202	47	74	0	13	29	43	56	50	103
5	134	153	41	0	3	11	0	16	124	78	147	134
6	150	171	232	136	69	0	1	10	21	15	64	112
7	147	163	214	166	43	0	0	1	7	14	98	73
8	115	163	197	6	59	39	59	0	44	32	36	46
9	143	155	208	61	49	0	0	4	17	0	52	55
10	151	170	231	160	71	1	8	8	40	0	89	113
11	144	169	232	142	76	0	0	6	42	0	69	131
12	87	134	165	40	0	19	61	0	0	14	44	4
13	150	164	194	165	78	0	0	46	12	40	74	116
14	145	141	156	103	44	0	0	2	21	4	11	68
15	141	124	199	80	41	0	18	0	9	25	113	109
16	151	127	168	158	104	0	0	20	84	1	31	85
17	97	110	89	129	165	75	26	8	10	68	148	124
18	129	152	51	114	153	73	54	11	52	84	160	129
19	141	155	128	136	177	109	99	19	83	101	161	129
20	144	162	193	80	26	31	0	5	3	7	140	63
21	150	171	150	187	200	28	8	41	60	70	166	122
22	150	165	230	146	80	20	6.3	0	34	1	147	121
23	151	169	230	155	93	35	24	14	25	4	103	127

As per the climate change projections for the period 2030 the annual water deficit is going increase in majorities of AEUs (1-11) in the coastal plain and midlands. The foothills of southern Kerala showed a decreased water deficit whereas northern foothills record an increase in annual water deficit. High hills and Palakkad plains anticipated a large decrease in water deficit (except AEUs 22) during 2030s.

Table No 23. Water deficit (2030)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	113	156	141	117	0	0	0	4	132	20	162	147
2	106	155	200	129	31	0	0	6	74	31	146	117
3	125	114	174	97	9	0	0	7	102	24	148	44
4	123	147	178	110	27	0	0	0	54	57	167	81
5	86	156	176	126	11	0	0	0	122	14	106	129
6	115	161	206	140	55	0	0	15	152	10	132	150
7	62	84	130	109	122	113	112	139	135	81	87	126
8	133	113	196	151	189	100	111	149	143	129	167	88
9	106	158	202	162	137	36	6	76	127	105	174	154
10	114	160	201	143	42	0	0	2	129	10	135	149
11	112	160	195	163	33	0	0	4	125	17	140	131
12	46	83	110	72	22	0	0	0	85	33	68	20
13	135	164	200	150	19	0	0	9	153	44	176	124
14	129	159	198	158	85	0	0	7	149	13	128	136
15	110	119	188	117	37	0	0	0	80	30	102	67
16	61	69	109	75	42	0	0	2	74	7	56	9
17	34	62	92	79	0	0	0	0	59	3	51	7
18	65	78	133	112	56	0	0	0	86	40	83	19
19	98	117	184	139	18	0	0	6	133	10	87	67
20	57	84	107	112	48	0	0	6	77	38	72	40
21	60	97	130	130	0	0	0	0	69	5	69	41
22	131	162	187	176	83	0	0	4	135	1	95	140
23	131	165	173	173	0	0	0	4	106	32	143	119

The annual water deficit during 2050 almost followed the same trend of 2030. The southern mid land laterites AEUS (9 and 10) which showed an increase water deficit during

2030 showed decreased water deficit in 2050s. Whereas the Palakkad eastern plain (AEU 23) showed an increased in deficit during 2050.

Table No 24. Water deficit (2050)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	104	158	176	134	21	0	0	4	108	16	133	139
2	113	159	202	159	3	0	0	9	82	70	145	127
3	100	155	175	132	7	0	0	1	129	16	135	135
4	136	154	194	136	76	0	0	15	147	11	130	142
5	122	157	193	164	81	0	0	17	148	41	152	112
6	135	165	158	157	71	0	0	15	137	58	168	70
7	94	158	193	166	82	0	0	15	151	38	137	119
8	121	108	172	131	46	0	0	0	123	43	118	32
9	38	87	121	98	1	0	0	0	53	6	43	57
10	0	0	22	28	1	46	64	144	73	111	68	5
11	18	135	169	139	221	139	98	31	12	0	0	123
12	61	91	125	69	18	0	0	0	32	39	99	17
13	136	164	207	102	41	0	0	10	152	13	171	109
14	118	98	43	0	0	0	83	113	136	104	164	83
15	19	44	40	40	0	0	0	0	35	3	37	39
16	66	57	77	3	55	12	0	7	15	9	12	39
17	61	69	96	92	97	0	0	0	23	5	32	18
18	84	103	171	74	57	0	0	2	39	73	92	74
19	105	117	196	163	113	0	0	0	15	8	10	63
20	63	99	119	29	101	42	0	6	6	2	20	39
21	56	99	126	101	6	0	0	6	86	6	52	27
22	140	166	205	152	77	0	0	2	133	14	123	122
23	138	158	214	141	0	0	0	63	78	68	141	131

AEU 4, 10, 13, 14, 16-18, 21, 22 showed decrease in average annual water deficit during 2080. It can be also noticed from the table 23 to 26 that the monthly water deficit in showing a decreasing trend during the summer months.

Table No 25. Water deficit (2080)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	126	161	143	110	0	0	0	6	89	5	147	151
2	109	163	181	150	76	0	0	6	139	58	122	124
3	136	148	179	118	44	0	0	0	28	50	124	74
4	137	149	182	118	47	0	0	0	24	36	116	76
5	132	152	195	129	21	0	0	5	71	18	85	111
6	130	120	197	167	138	19	0	0	16	155	25	113
7	132	162	212	173	230	133	2	95	137	158	192	164
8	133	148	138	117	10	0	0	4	145	32	145	102
9	131	161	166	100	45	0	0	0	74	35	135	143
10	33	102	95	141	71	0	0	4	86	22	161	106
11	132	168	177	141	76	0	0	18	146	20	155	125
12	90	141	173	108	169	4	0	15	70	124	56	104
13	102	109	135	115	54	0	0	54	117	14	83	34
14	46	61	105	41	38	0	0	0	41	11	44	3
15	136	165	184	85	0	0	0	113	49	136	132	130
16	61	55	96	67	12	0	0	0	33	14	45	12
17	45	56	104	63	38	0	8	65	36	0	0	0
18	80	104	160	84	10	0	0	1	64	14	108	26
19	108	122	196	158	170	91	51	98	147	116	164	71
20	65	95	151	108	190	66	64	72	58	110	81	81
21	15	80	122	78	141	0	0	1	11	69	18	43
22	142	17	0	0	61	124	62	164	145	23	144	147
23	144	171	209	126	84	0	0	8	146	43	157	115

4.8.3. Moisture-availability Index (MAI)

It is a relative measure of the adequacy of precipitation in supplying moisture requirements. It is computed by dividing the dependable precipitation by the potential evapotranspiration (MAI = PD/ETP). It indicates the proportion of the crop water supply available from dependable precipitation.

The moisture availability periods based on MAI has been presented in table 27. It can be observed from the table 27 that as per the present climatic conditions in majority of AEUs

(19 out of 23) and Moisture availability index quite moisture availability begins from the month of May and the periods from the June to September is considered as the periods of excessive moisture. The duration of moisture availability periods varied between different AEU. AEU 19 shows lowest moisture availability periods of 2 months, followed by AEU 18 (4month), and AEU 21 (5 months) and AEU 22 (6 months).

Table No 26. Moisture-availability Index (1991-2014)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	0	1	1	3	3	4	4	5	3	4	3	1
2	0	0	0	2	4	4	4	5	3	4	2	0
3	0	1	0	4	4	4	4	5	3	3	3	1
4	1	0	0	3	3	4	4	4	3	2	4	1
5	0	0	4	4	5	4	4	5	1	2	1	0
6	0	0	0	1	3	4	4	5	3	4	3	1
7	0	0	0	0	4	4	4	5	4	4	2	2
8	1	0	0	4	3	3	2	5	3	3	4	3
9	0	0	0	3	4	4	4	5	4	4	3	2
10	0	0	0	1	3	4	4	5	3	4	2	1
11	0	0	0	1	3	4	4	5	3	4	3	0
12	2	0	0	3	5	3	3	5	4	4	4	4
13	0	0	1	0	3	4	4	4	4	3	3	1
14	0	1	1	2	4	4	4	5	3	4	5	2
15	0	1	0	2	4	4	3	5	4	3	1	0
16	0	1	1	0	2	4	4	4	2	4	4	1
17	1	1	3	1	1	2	3	5	4	2	1	0
18	1	0	4	1	1	2	3	5	3	1	0	0
19	0	0	2	1	0	1	1	5	2	1	0	0
20	0	0	1	2	4	3	4	5	4	4	1	2
21	0	0	2	0	0	1	4	4	2	2	0	0
22	0	0	0	1	3	3	4	5	3	4	1	0
23	0	0	0	1	3	3	3	5	3	4	2	0

The moisture availability periods based on MAI during 2030s as per climate change projections showed that majorities of AEUs 1 to 14 (costal and mid lands) showed a decreased in moisture availability whereas AEU 15 to 23 (High lands and Palakkad) showed an increase in moisture availability periods.

Table No 27. Moisture-availability Index (2030)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	0.8	0.0	1.5	1.2	5.0	4.0	4.0	4.9	0.3	3.5	0.8	0.2
2	0.3	0.0	0.2	0.9	4.3	4.0	4.0	4.8	1.9	3.3	1.1	1.0
3	0.7	0.0	0.6	1.6	4.8	4.0	4.0	4.8	1.4	3.4	1.1	2.1
4	0.6	0.2	0.7	1.4	4.4	4.0	4.0	5.0	2.6	2.6	0.5	1.8
5	1.1	0.0	0.8	1.0	4.8	4.0	4.0	5.0	0.9	3.6	2.1	0.8
6	0.3	0.0	0.2	0.8	3.8	4.0	4.0	4.6	0.3	3.7	1.6	0.3
7	0.6	0.1	0.1	0.0	0.7	0.2	0.3	0.4	0.1	0.5	0.9	0.2
8	0.5	0.1	0.1	0.3	0.5	1.6	1.1	1.2	0.4	0.7	0.2	0.2
9	0.4	0.0	0.1	0.1	1.9	3.1	3.8	3.1	0.5	1.4	0.3	0.1
10	0.3	0.0	0.2	0.7	4.1	4.0	4.0	5.0	0.5	3.7	1.6	0.3
11	0.3	0.0	0.4	0.2	4.3	4.0	4.0	4.9	0.5	3.6	1.2	0.6
12	1.5	0.5	1.0	1.6	4.4	4.0	4.0	5.0	1.1	2.9	2.0	3.0
13	0.3	0.0	0.3	0.6	4.6	4.0	4.0	4.8	0.2	2.9	0.6	0.8
14	0.4	0.0	0.4	0.4	3.1	4.0	4.0	4.8	0.3	3.7	1.5	0.4
15	0.5	1.0	0.6	1.4	4.2	4.0	4.0	5.0	2.1	3.2	2.3	2.2
16	0.5	0.0	0.5	1.2	3.8	4.0	4.0	4.9	1.0	3.7	2.5	3.4
17	2.1	0.4	1.3	1.3	5.0	4.0	4.0	5.0	1.5	3.9	2.8	3.5
18	1.2	1.0	1.1	1.0	3.5	4.0	4.0	5.0	1.0	2.8	2.2	3.0
19	0.6	0.0	0.3	0.6	4.6	4.0	4.0	4.8	0.4	3.7	2.3	0.4
20	0.6	0.4	1.4	0.5	3.8	4.0	4.0	4.7	1.4	2.4	1.3	1.9
21	0.5	0.0	0.8	0.2	5.0	4.0	4.0	5.0	1.5	3.8	1.5	2.0
22	0.4	0.0	0.6	0.0	3.1	4.0	4.0	4.9	0.4	4.0	2.6	0.4
23	0.3	0.0	1.1	0.0	5.0	4.0	4.0	4.9	1.4	3.2	1.1	0.9

During 2050s and 2080s the number AEUs showing reduced moisture availability reduced to 6 and 5 representatively. The AEUs 17 and 18 will expect large changes in the moisture availability periods.

Table No 28. Moisture-availability Index (2050)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	1.3	0.0	0.8	0.8	4.5	4.0	4.0	4.9	1.2	3.6	1.5	0.4
2	0.3	0.0	0.2	0.3	4.9	4.0	4.0	4.8	1.9	2.3	1.1	0.9
3	1.3	0.0	0.8	0.8	4.9	4.0	4.0	5.0	0.5	3.6	1.4	0.4
4	0.3	0.1	0.4	0.8	3.3	4.0	4.0	4.6	0.2	3.7	1.6	0.3
5	0.7	0.0	0.4	0.2	3.2	4.0	4.0	4.6	0.1	3.0	1.2	1.1
6	0.3	0.0	1.3	0.4	3.5	4.0	4.0	4.6	0.5	2.6	0.7	2.3
7	0.8	0.0	0.4	0.2	3.2	4.0	4.0	4.6	0.2	3.0	1.3	1.0
8	0.8	0.5	0.7	0.9	3.9	4.0	4.0	5.0	0.9	2.9	1.6	2.7
9	1.9	0.4	1.1	1.1	5.0	4.0	4.0	5.0	1.5	3.8	2.9	1.1
10	4.0	4.0	4.3	3.1	5.0	2.5	1.2	0.0	0.6	0.1	1.7	3.7
11	3.5	0.7	1.1	0.8	0.1	0.6	1.3	4.2	3.7	4.0	5.0	1.0
12	1.0	0.3	0.8	1.9	4.5	4.0	4.0	5.0	2.9	2.7	0.9	3.1
13	0.3	0.0	0.2	1.7	4.1	4.0	4.0	4.8	0.3	3.7	0.8	1.2
14	0.6	0.2	3.9	4.0	5.0	4.0	1.9	2.0	0.5	1.2	0.1	0.0
15	2.5	1.1	2.9	2.3	5.0	4.0	4.0	5.0	2.3	3.8	2.6	1.1
16	0.5	1.0	2.0	3.9	3.5	3.5	4.0	4.7	3.4	3.7	4.4	1.4
17	0.5	0.0	1.0	0.9	2.2	4.0	4.0	5.0	3.0	3.8	3.3	2.7
18	0.4	0.0	0.0	2.0	3.6	4.0	4.0	4.9	2.7	1.8	1.8	0.0
19	0.3	0.0	0.0	0.0	2.3	4.0	4.0	5.0	3.6	3.8	4.6	0.7
20	0.7	0.0	1.2	3.1	2.1	2.7	4.0	4.8	3.8	3.9	4.1	2.1
21	1.1	0.1	1.1	1.2	4.9	4.0	4.0	4.7	0.9	3.7	2.6	2.7
22	0.3	0.0	0.3	0.6	3.3	4.0	4.0	4.9	0.6	3.7	1.8	0.9
23	0.3	0.2	0.2	0.8	5.0	4.0	4.0	3.4	2.0	2.4	1.4	0.6

Table No 29. Moisture-availability Index (2080)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	0.66	0.04	1.63	1.42	5	4	4	4.85	1.63	3.88	1.13	0.25
2	0.95	0	0.76	0.54	3.34	4	4	4.85	0.35	2.65	1.82	0.97
3	0.39	0.28	0.72	1.24	4.01	4	4	5	3.25	2.81	1.75	2.06
4	0.38	0.29	0.73	1.24	3.96	4	4	5	3.37	3.14	1.99	2.05
5	0.39	0.32	0.5	1.04	4.55	4	4	4.87	2.14	3.56	2.79	1.33
6	0.51	1.14	0.48	0.2	1.99	3.55	4	5	3.59	0.33	4.37	1.27
7	0.28	0	0	0	0	0.79	3.96	2.58	0.35	0.28	0	0
8	0.56	0.01	1.6	1.19	4.77	4	4	4.9	0.41	3.21	1.2	0.24
9	0.53	0.15	1.19	1.72	4.03	4	4	5	2.09	3.17	1.52	0.48
10	3.11	1.58	2.83	0.8	3.45	4	4	4.89	1.72	3.48	0.84	1.42
11	0.5	0	0.98	0.82	3.36	4	4	4.52	0.16	3.53	0.98	0.88
12	1.6	0.43	0.87	1.48	1.27	3.9	4	4.62	2.25	1.03	3.52	1.14
13	1.18	0.07	1.51	1.17	3.72	4	4	3.62	1.06	3.65	2.79	2.45
14	1.65	0.98	1.04	2.57	3.99	4	4	5	2.38	3.59	2.95	3.8
15	0.47	0.14	0.9	2.11	5	4	4	2.18	2.74	0.81	1.6	0.69
16	0.95	1.27	1.38	1.67	4.68	4	4	5	2.71	3.5	2.94	3.23
17	1.52	0.95	0.91	1.77	3.97	4	3.68	2.53	2.57	4	5	4
18	0.8	0.22	0.73	1.79	4.76	4	4	4.95	1.88	3.61	1.47	2.68
19	0.36	0.15	0.12	0.14	1.04	1.74	2.56	2.34	0	0.92	0.06	0.54
20	0.55	0.17	0.05	0.79	0.19	1.89	1.22	2.32	1.25	0.5	1.13	0.04
21	3.16	0.91	1.15	1.8	1.45	4	4	4.97	3.5	1.82	4.17	2.02
22	0.39	3.61	4.99	4	3.67	1.01	2.32	0.94	0.23	3.45	1.31	0.37
23	0.26	0	0.33	1.19	3.17	4	4	4.8	0.21	2.99	0.96	1.1

4.8.4. Water Surplus (W.S)

Water surplus represents the excess of rainfall after the demands of water need (P.E.) and that needed to field capacity have been met. This is the water available for runoff and stream flow. By definition, water surplus is the amount of water which does not remain in the surface soil layers but which is available either for overland or surface flow or for deep percolation to the water table contributing to groundwater and subsurface flow.

The monthly water surplus as per the present climatic conditions were worked out and presented in the table 23.

It can be very clearly seen from the table 27 to 31 that under present day climatic conditions, the water surplus periods of more than 80mm is from May to October, July and august are considered as the wetter months. The average annual surplus of Kerala is 1358 mm. The annual water surplus vary widely among AEUs. The AEU is records an average annual surplus of 98 mm whereas AEU 7 records the highest surplus of 2482 mm.

Table No 30.Water Surplus (1991-2014)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	0	0	0	14	178	148	190	504	101	64	38	0
2	0	0	0	21	127	366	743	753	49	224	78	0
3	0	0	0	4	116	203	186	472	36	226	25	20
4	0	0	0	43	57	59	111	322	90	50	19	0
5	0	0	79	629	170	445	382	370	0	0	0	0
6	0	0	0	0	128	444	431	619	50	176	38	0
7	0	0	0	0	79	433	683	1136	99	52	0	0
8	0	0	0	4	246	0	0	314	38	80	0	52
9	0	0	0	0	60	368	461	809	193	208	13	70
10	0	0	0	0	197	291	460	637	33	164	22	0
11	0	0	0	0	85	336	824	596	88	276	67	0
12	0	0	0	7	218	29	0	264	509	178	339	145
13	0	0	0	0	58	489	515	182	348	179	0	0
14	0	0	0	0	138	154	173	397	78	201	60	0
15	0	0	0	0	12	248	115	591	60	1	0	0
16	0	15	0	0	0	85	164	115	0	43	225	0
17	0	0	4	0	0	6	68	689	105	32	0	0
18	0	0	14	0	0	0	0	202	0	0	0	0
19	0	0	23	0	0	0	0	75	0	0	0	0
20	0	0	0	0	59	259	817	733	51	0	0	7
21	0	0	0	0	0	76	153	20	0	66	0	0
22	0	0	0	0	61	141	491	586	77	88	0	0
23	0	0	0	0	41	153	360	314	20	39	0	0

As per the climate change projection it can be early seen that the water surplus periods are reducing drastically during 2030s. The water surplus from December to April is zero whereas during the south west monsoon season the amount of water surplus will be huge. June (552mm) and July (631mm) will be wettest month. The water surplus of September and

November will also be reduced considerably. The average annual water surplus will also increase to 1834. It is interesting notice that the AEU 7-9 there is no water surplus during entire year. The AEU 11, 12 and 22 also record a reduction in water surplus.

Table No 31. Water Surplus (2030)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	0	0	0	0	349	761	516	345	0	233	0	0
2	0	0	0	0	156	1087	1131	444	132	124	0	0
3	0	0	0	0	192	510	563	278	29	245	0	0
4	0	0	0	0	196	456	582	300	14	272	0	0
5	0	0	0	0	572	775	811	269	0	272	0	0
6	0	0	0	0	125	946	938	413	0	195	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	3	0	0	0	0	0
10	0	0	0	0	222	1166	999	279	0	203	0	0
11	0	0	0	0	85	777	917	330	0	82	0	0
12	0	0	0	0	96	308	484	509	0	184	0	7
13	0	0	0	0	191	557	733	505	0	137	0	0
14	0	0	0	0	34	906	645	335	0	80	0	0
15	0	0	0	0	46	288	496	364	74	77	27	0
16	0	0	0	3	40	492	742	501	0	125	0	0
17	0	0	0	0	357	700	567	515	0	316	0	0
18	0	0	0	0	90	351	552	455	0	145	0	4
19	0	0	0	0	385	1007	1122	494	0	168	0	0
20	0	0	0	0	68	481	912	557	0	7	0	0
21	0	0	0	0	190	543	745	504	0	86	0	0
22	0	0	0	0	112	260	626	240	0	95	62	0
23	0	0	0	0	34	329	438	307	0	83	0	0

During 2050 the average annual water surplus will be increased 2150 mm. June (636) and July (667) will be continued to be wettest month. Only AEU 5 and 20 will expect reduction in annual water surplus.

Table No 32. Water Surplus (2050)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	0	0	0	0	373	688	527	356	0	249	0	0
2	0	0	0	0	302	1039	1102	400	118	139	0	0
3	0	0	0	0	359	706	520	357	0	255	0	0
4	0	0	0	0	137	999	883	404	0	179	0	0
5	0	0	0	0	38	237	518	292	0	59	0	0
6	0	0	0	0	95	855	1150	728	0	143	0	0
7	0	0	0	0	45	248	522	291	0	53	0	0
8	0	0	0	0	0	365	540	289	0	93	0	0
9	0	0	0	0	374	755	467	360	0	271	0	0
10	0	0	0	107	147	651	910	294	0	0	0	210
11	140	0	0	0	535	589	514	115	0	0	0	0
12	0	0	0	0	222	530	626	319	31	301	0	0
13	0	0	0	0	120	613	764	573	0	142	0	0
14	0	0	57	589	923	555	8	162	0	0	0	0
15	0	0	0	17	442	664	706	780	9	274	0	0
16	0	0	0	17	38	172	163	272	91	195	50	0
17	0	0	0	0	0	837	958	363	0	210	1	42
18	0	0	0	0	0	881	652	291	0	0	0	0
19	0	0	0	0	24	586	1035	755	117	57	363	0
20	0	0	8	16	0	351	253	132	28	49	102	0
21	0	0	0	0	483	693	818	474	0	280	9	0
22	0	0	0	0	231	822	924	322	0	223	0	0
23	0	0	0	0	676	844	709	80	215	14	0	0

In 2080s the average annual water surplus shows declining trend and reaction to 1629 mm. The average amount of rainfall during June and July will also showed a decreasing trend. It can be also noticed that AEU 7, 19 and 20 showed no water surplus during the entire year and AEU 22 showed a huge shift in water surplus periods.

Table No 33. Water Surplus (2080)

AEU	January	February	March	April	May	June	July	August	September	October	November	December
1	0	0	0	0	272	587	578	407	93	137	0	0
2	0	0	0	0	259	970	917	440	0	103	0	0
3	0	0	0	0	184	350	601	307	112	188	68	0
4	0	0	0	0	170	359	580	328	107	182	59	0
5	0	0	0	0	270	808	1058	232	98	278	0	0
6	0	0	0	0	0	303	638	919	266	0	214	0
7	0	0	0	0	0	0	7	0	0	0	0	0
8	0	0	0	0	380	791	556	284	0	243	0	0
9	0	0	0	0	278	515	566	480	81	168	0	0
10	30	0	235	0	171	505	534	272	30	237	0	0
11	0	0	0	0	156	763	846	394	0	122	0	0
12	0	0	0	0	0	204	123	65	0	48	163	0
13	0	0	0	0	122	153	102	9	0	130	57	0
14	0	0	0	0	101	331	568	399	105	114	50	21
15	0	0	0	0	587	798	724	17	143	0	0	0
16	0	0	0	0	242	431	792	470	90	189	0	9
17	0	0	0	0	9	430	506	0	11	433	695	331
18	0	0	0	0	188	520	565	302	42	255	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	248	193	101	0	59	210	0
22	0	285	494	554	24	78	47	0	0	85	0	0
23	0	0	0	0	12	328	521	415	0	90	0	0

The detailed agro climatic studies of Kerala state in relation to climate change in this investigation has projected the diversity of the various Agro ecological units which significantly influence the land use of the region. The most conspicuous features of the climate of the State is the rich abundance of water resources in the State due to the plentiful monsoon rains. However, the vagaries of the monsoon - the onset, active and weak phases, spatial and temporal variations and the impact of climate change are all very complex.

Kerala state, which depends to a great extent on its agriculture for its welfare a detailed knowledge of the Agricultural potential of the region in relation to the climatology of the area is an essential requirement in agricultural planning. In recent decades the increasing population and the resultant higher demands for food have necessitated for optimal exploitation of the available natural resources, in particular, land and water. As the eastern boundary of Kerala is fully bordered by the Western Ghats, the entire state is under the dominant influence of its orography. This results in heavy monsoon rains and large water surplus during a part of the year. This feature combined with the variety of soil types, vegetation classes and geomorphological features result in a diversity of land use patterns.

This study assessed the potential impacts of climate change on rainfall and its variations across different agro ecological units as per the projected climate change. To project future climate conditions, the simulation outputs for 2030s, 2050s, and 2080s from seventeen general circulation models (GCMs) were extracted under Intergovernmental Panel on Climate Change (IPCC) greenhouse gases emissions scenario RCP 4.5 to consider the range of uncertainty. Thornthwaite water balance model was estimated to the observed and predicted climate data and this was used to estimate different components of water balance for different agro ecological conditions also studied the impact of climate change on drought, length of growing period and intensity of high rainfall events in the future.

The results suggest that future precipitation for the 2030s, 2050s and 2080s are expected to increase based on the multi ensemble GCM outputs. The temporally and spatial distribution of rainfall is like to change significantly throughout Kerala. In nutshell the amount of precipitation during summer and SW monsoon season will expect an increase whereas NE monsoon season and winter season anticipated a decrease in rainfall activity. But the trend is reverse in most of the coastal and high ranges. In general the number of rainy days showed a decrease during all the season and this situation will increase the probability of flood and drought due to the increase in the intensity rainfall and reduced number of rainy days. The number of high rainfall events will also expect an increase in the future.

The total length of growing period is likely to increase in the future due to increased precipitation during summer months. But it can be also noticed that the length of continuous growing period which is a necessity for successful crop production anticipated a decrease. The chances agricultural drought period during kharif season will also likely to increase during 2030s and reduced during 2050s and 2080s. The most interesting observations are the present rain shadow regions of Kerala will be going to have a favourable agricultural environment in the future.

Studies on impact of climatic change on water balance over the state show that the moisture regime of different AEUs of the state undergo wild fluctuations both in the drier and wetter directions. In general the state is going to witness a hike in evapotranspiration due to increase in temperature as a part of global warming. There is high possibility of flood and drought occurrence in the same calendar year. It can also be inferred that the continuous water surplus period over the state is in a declining trend.

It is expected that the results of the present investigation would help in the formulation of climate change adaptive strategies at agro ecological unit level by the judicious management of the available natural resources of land, water and atmosphere. Pointless to say this would enable effective planning for sustainable development of Kerala state

CHAPTER 5 SUMMARY AND RECOMMENDATIONS

The findings of the study "The impact of climate change on water balance of Agro ecological units of Kerala" is summarized as follows.

1. The spatial distribution of mean annual rainfall of Kerala increases from east to west and AEUs in the coastal areas i.e., AEU 2, AEU 5, AEU 7 and AEU 11 were receiving more than 3000 mm rainfall whereas eastern part of the Kerala receives less rainfall (1500 mm).

2. During SW monsoon period, AEU 2- Northern coastal plain (2310 mm), AEU 5-Pokkali land (2170 mm), AEU 7-Kaippad land (2925 mm) and AEU 9-South central laterite (2249 mm) AEU 11-Northern laterite (2214) and AEU 12-Southern and central foothills (2062) recorded highest rainfall. The lowest rainfall region are AEU 8 Southern laterite (730 mm), AEU 18- Attappady hills (763 mm) and AEU 2-Wayand eastern plateau (717 mm).

3. During NE monsoon Season the eastern slopes of the Ghats towards the south and central Kerala received fairly good amounts of rainfall, comparable to the northern sides.

4. Winter is a period of very low rainfall for the whole State. The state average rainfall during this period is only 38.3 mm. The AEUs adjoining Tamil Nadu areas receive comparatively more amount of rainfall during this season.

5. According to the projected climate change scenario for 2030, 2050 and 2080 based on RCP 4.5 showed an increased rainfall activity during the summer months. Out of 23 AEUs 12 AEUs are expected an increase in rainfall during 2030s.

6. A huge increase in rainfall is anticipated during the SW monsoon season throughout the State except in AEU 7-Kaippad land, AEU 12-Southern and central foot hills and AEU 22-Palakkad central plain.

It is interesting to notice that the state annual average rainfall is expected to increase by about 675 mm during the SW monsoon season in 2030, 2050 and 2080 as per RCP 4.5.

7. The rainfall activity during the NE monsoon season is expected to decrease by 2030, 2050 and 2080 as per RCP 4.5 scenario. The AEU 7-Kaippad land, AEU 5-Pokkali land, AEU 18-Attappady hills, AEU 21-Wayanad central plateau and AEU 22-Palakkad central Plain anticipate an increased precipitation of about 100 mm during 2030 as per RCP 4.5 scenario.

8. As per the RCP 4.5 scenario the winter rainfall is expected to decrease by an average of 30 mm except in AEU 7-Kaippad land, AEU 8-Southern laterite, AEU 15-Northern high hills and AEU 20-Wayanad central plateau which shows an increasing trend.

9. During 2050, AEUs (AEU 5-Pokkali land, AEU 7-Kaippad land, AEU 9-South central laterite, AEU 10-North central laterite, AEU 11-Northern laterite, AEU 16-Kumali hills and AEU 20-Wayanad central plateau) in the mid lands and rain shadow regions expected to receive reduced in SW monsoon.

10. The initial probability for getting more than 40 mm of rainfall will be reduced during 2030s. Only AEU 1- Southern coastal plain, AEU 2- Northern coastal plain and AEU 3- Onattukara sandy plain will be receiving assured amount of rainfall during the SW monsoon period.

11. During the 2050s, the probability of getting an assured amount of rainfall (>40 mm) increased as compared to 2030s and during 2080s it will be more than that of the present climate.

12. During summer season, the majority of AEUs expect an increase in number of rainy days during 2030, 2050 and 2080. It is interesting to notice that the number of rainy days (state average) showed continuous increase (17 to 25 days) as per projected climate change (RCP 4.5) scenario.

13. The south west monsoon season showed a decreased number of rainy days under future climate change projection.

14. The AEUs sharing border with Tamil Nadu showed increase in number of rainy days as per the future projection during SW monsoon.

15. During the north east monsoon season also the number of rainy days showed a declining trend. The state average declined from 24 to 18 up to 2050 and then increased to 19 during 2080s.

16. South west monsoon seasons during 2030s expect a huge increase in number of heavy rainfall events except in AEU 21- Wayanad eastern plateau, AEU 22- Palakkad central plain and AEU 23- Palakkad eastern plain which showed a drastic reduction in heavy rainfall events.

17. The length of growing period showed a substantial decrease the major rice growing areas (AEU 5- Pokkali lands, AEU 6- Kole lands, AEU 7- Kaipad lands, AEU 8- Southern laterites and AEU 9- South central laterites). Where as in high lands and Palakkad plains, an increase in growing period is expected.

18. The rice growing areas of Kerala except Kole land will experience prolonged drought situation during 2030s and is going to be reduced during 2050s.

19. Palakkad plain which are highly drought prone during kharif season in the present day conditions showed a much reduced duration of drought during 2050 and 2080.

20. A shift can be observed in the water scarcity periods of majority of AEUs under projected climate change. Most of the AEUs situated in the costal and midlands shows advancing of drought period by about 2 to 13 weeks, whereas AEUs high hills and foot hills shows earliness in occurrence of drought.

21. The climate change projections showed that in majority of the AEUs the average annual PET has an increasing trend. Whereas AEUs 3, 7, 12, 17-21 expect decrease in annual PET.

22. As per the climate change projections the annual water deficit is going to increase in majorities of AEUs.

23. The moisture availability periods based on MAI during 2030s as per climate change projections showed that majorities of AEUs 1 to 14 (costal and mid lands) showed a decreased in moisture availability whereas AEU 15 to 23 (High lands and Palakkad) showed an increase in moisture availability periods.

24. As per the climate change projection the water surplus periods are reducing drastically. There was no water surplus from December to April and during the south west monsoon season the amount of water surplus will be very huge.

Specific impact-based adaptation strategies are essential to reduce the vulnerability of rain fed crop production. To adapt the effect of intra seasonal rainfall variability risk on rain fed crop production, decision makers should take appropriate and available site specific options. The adaptation/mitigation options that the decision maker need to take during the risk time should consider the awareness or understanding level of farmers, availability and accessibility of options, local topography, soil, land use and land coverage. According to (Boyd *et al,* 2013), Governments should invest heavily in early warning systems on drought and climate risk to aid farmers in planning their farming operations. Moreover, effective communication of information on climate adaptation/mitigation is essential for adaptation by households as communication increases understanding and awareness. According to FAO (2011), the crop improvement program system has to concentrate on screening early maturing varieties for drought tolerance. This is a good approach, however even during the short growing period in the dryland areas, the distribution of rainfall is highly variable within the seasons. Therefore, even a short cycle rain fed crop could be exposed to water stress at any time during its life cycle, indicating the need to develop drought resistant crops and varieties. As per the projection Kerala is highly vulnerable to water logging during the SW monsoon season. So efforts should be initiated for proper field level drainage systems. Simultaneously the farmers should have access to supplemental irrigation during periods of less rain. If the dry spell risks can be managed by the use of supplemental irrigation, there may be a possibility to grow long maturing crops in the region.

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IMPACT OF CLIMATE CHANGE ON WATER BALANCE OF AGRO ECOLOGICAL UNITS OF KERALA

By

ATHUL KRISHNA, K. S

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THESIS ABSTARCT

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Faculty of Agriculture

Kerala Agricultural University, Thrissur

ACADAMY OF CLIMATE CHANGE EDUCATION AND RESEARCH

VELLANIKKARA, THRISSUR – 680656

KERALA, INDIA

ABSTRACT

The research project entitled "Impact of climate change on water balance of agro ecological units (AEUs) of Kerala" was carried out in RARS Pattambi and the daily rainfall data for the period 1991-2014 were collected from 60 stations of Kerala state from the India Meteorological Department, Thiruvananthapurm. Agro Ecological Unit wise information on area and production of various crops were collected om Agro Ecology of Kerala, Published by NBSS & LUP and Kerala State Planning Board, 2012.

Kerala state, which depends to a great extent on its agriculture for its welfare a detailed knowledge of the Agricultural potential of the region in relation to the climatology of the area is an essential requirement in agricultural planning. In recent decades the increasing population and the resultant higher demands for food have necessitated for optimal exploitation of the available natural resources, in particular, land and water. As the eastern boundary of Kerala is fully bordered by the Western Ghats, the entire state is under the dominant influence of its orography. This results in heavy monsoon rains and large water surplus during a part of the year. This feature combined with the variety of soil types, vegetation classes and geomorphological features result in a diversity of land use patterns.

This study assessed the potential impacts of climate change on rainfall and its variations across different agro ecological units as per the projected climate change. To project future climate conditions, the simulation outputs for 2030s, 2050s, and 2080s from seventeen general circulation models (GCMs) were extracted under Intergovernmental Panel on Climate Change (IPCC) greenhouse gases emissions scenario RCP 4.5 to consider the range of uncertainty. Thornthwaite water balance model was estimated to the observed and predicted climate data and this was used to estimate different components of water balance for different agro ecological conditions. This project also studied the impact of climate change on drought, length of growing period and intensity of high rainfall events in the future.

The results suggest that future precipitation for the 2030s, 2050s and 2080s are expected to increase based on the multi ensemble GCM outputs. The temporarily and spatial distribution of rainfall like to change significantly throughout Kerala. In nutshell the amount of precipitation during summer and SW monsoon season will expect an increase whereas NE monsoon season and winter season anticipated a decrease in rainfall activity. But the trend is reverse in most of the coastal and high ranges.

The total length of growing period is likely to increase in the future due to increased precipitation during summer months. But it can be also noticed that the length of continuous growing period which is a necessity for successful crop production anticipated a decrease. The most interesting observations are the present rain shadow regions of Kerala will going to have a favourable agricultural environment in the future.

Studies on impact of climatic change on water balance over the state show that the moisture regime of different AEUs of the state undergo wild fluctuations both in the drier and wetter directions. In general the state is going to witness a hike in evapotranspiration due to increase in temperature as a part of global warming. There is high possibility of flood and drought occurrence in the same calendar year. It can also be inferred that the continuous water surplus period over the state is in a declining trend.

It is expected that the results of the present investigation would help in the formulation of climate change adaptive strategies at agro ecological unit level by the judicious management of the available natural resources of land, water and atmosphere. Pointless to say this would enable effective planning for sustainable development of Kerala state.