CLIMATE CHANGE IMPACT ON CROP WATER REQUIREMENT OF RICE IN THRISSUR DISTRICT

By

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(2010-20-119)

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THESIS

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DECLARATION

I hereby declare that the thesis entitled **'Climate change impact on crop water requirement of rice in Thrissur district'** is a bonafide record of research work done by me during the course of research and the thesis has not been previously formed the basis for the award to me any degree, diploma, fellowship or other similar title, of any other University or Society.

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Certified that this thesis entitled **‘Climate change impact on crop water requirement of rice in Thrissur district’** is a record of research work done independently by Mr. Basil Abraham (2010-20-119) 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.

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SYMBOLS AND ABBREVIATIONS

Agric.	Agriculture/ Agricultural
Agron.	Agronomy
Am.	America/American
APSIM	Agricultural production systems simulator
AR5	Assessment Report 5
ARIMA	Autoregressive integrated moving average
Aust.	Australia/Australian
Biol.	Biology/ Biological
Bot.	Botany/Botanical
Bull.	Bulletin
Chem.	Chemistry
Clim.	Climate
Conserv.	Conservation
Curr.	Current
CWR	Crop water requirement
Drain.	Drainage
Dept.	Department
DSSAT	Decision Support System for Agro technology Transfer
Ecol.	Ecology
Econ.	Economics

Ecosyst.	Ecosystem
Ed.	Edition
Eng.	Engineering
Environ.	Environment/Environmental
ET_0	Reference crop evapotranspiration
ETc	Evapotranspiration
Exp.	Experiment/Experimental
FAO	Food and Agriculture Organization
For.	Forest
GCM	Global Circulation Model
Geol.	Geology/Geological
GHG	Greenhouse Gas
Hydrol.	Hydrology
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
IMD	India Meteorological Department
Inst.	Institute/Institution
Int.	International
IPCC	Inter-governmental Panel on Climate Change
Irrig.	Irrigation
Jpn.	Japan/Japanese
J.	Journal
Kc	Crop coefficient
Ky	Crop yeild
Manag.	Management
Meterol.	Meteorology

Natl.	National
Physiol.	Physiology
Polit.	Political
Proc.	Proceedings
Prod.	Production
Qual.	Quality
Rcp.	Representative concentration pathway
Res.	Research
Rev.	Review
Sci.	Science
Soc.	Society
Technol.	Technology
Trans.	Transactions
Univ.	University

INTRODUCTION

CHAPTER 1

INTRODUCTION

Climate change is a possible threat that will affect agriculture by making reduced availability of natural resources like water and soil. Climate change is regarded as the greatest challenge facing future agriculture. Sustainable agricultural production is possible by making better use of land and water and providing environmental services such as management of watersheds. Climate change is defined as a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods. The enhanced greenhouse gases have already caused an increase in the global surface temperature, rise of sea level and melting of snow cover.

Agricultural production is dependent on climate as crop growth is influenced by solar radiation, temperature and precipitation. Crops are sensitive to climate variability and weather extremes of droughts, floods and severe storms. Climate change is projected to have an effect on agriculture and the net result could be harmful or beneficial.

Each crop has specific temperature range at which the crop growth will proceed at an optimal rate. Exposure of crop to extremely high temperature during the vegetative and reproductive phases will have an impact on the growth and yield. Increased surface and atmospheric temperature will affect evaporation and in turn will increase the water requirement of the crop. Higher temperature during the reproductive stage of development will affect pollen viability, fertilization and grain formation. Warming generally allow plants to grow faster that are below their optimum temperature for cereal crops. Faster vegetative growth makes a less time for the grain to grow itself and the grains do not mature in time and the yield is reduced.

Different varieties of rice could be grown under a range of temperatures where germination is possible from 6° to 47° C. The optimum range of temperature for germination and growth were reported as 26.5°- 37.5° C. Temperatures beyond 41° C are found to be lethal and at the same time low temperatures are found to reduce germination. Other factors of light, radiation, oxygen availability, moisture tension, chemicals all are reported to have an effect on the germination, seedling growth and maturity of rice plant.

Every change on the climate could affect the hydrologic components such as precipitation, temperature, runoff, stream flow, evaporation and this in turn will lead to increased crop water requirements. The industrial and domestic water consumption may also increase.

Water management is of great importance in rice cultivation. Proper water management of rice stimulates better crop growth and increased grain production. Water management involves the manipulation of the hydrologic cycle at various stages to make water available when necessary, and to remove it when there is an excess of water and also maintain the quality. Crop water requirement includes water lost by evaporation from the field, water transpired or metabolically used by the crop, unfavorable water loss during application and also water needed for special field operations such as land preparation and puddling of soil.

Rice (*Oryza sativa*), belongs to the subtribe Oryzineae of the family Gramineae and is one of the leading food crops in the world. It is the staple food of an estimated 3.5 billion people worldwide (Juliano, 1994). Rice is basically a terrestrial plant adapted to aquatic habitat. In general, it is less tolerant to stresses due to drought than other cereals. When the rice crop is stressed, it suffers more rapidly than other cereal crops. Rice, being a major crop of Kerala, an increase in the water requirement may lead more stress on the water resources. High daytime temperature and related heat stress adversely affects rice nearly at all stages of development (Wassmann *et al.*, 2009). According to Satake and Yoshida (1978), temperature beyond the optimum level reduces the photosynthesis, increase the respiration and shorten the vegetation and grain-filling periods. Rice yield is negatively correlated with high temperature during the reproductive phase.

Rice has a wide physiological adaptability and the crop is grown in tropics, sub tropics and temperate regions. A wide variety of the plant with different responses to climatic factors of temperature, rainfall and day length and with varying adaptability to different soil conditions is cultivated. Rice is regarded as the most important staple crop among all the *kharif* cereals in terms of yield. The availability of quick maturing photo insensitive, fertilizer responsive dwarf varieties and increased irrigation facilities could raise the yield of rice crop.

Rice is regarded as a water loving crop and typically they are grown in the puddled condition. The paddy fields are usually kept flooded 7-10 days before harvest. Continuous flooding helps to ensure sufficient water and also to control weed growth. Low land rice required a high quantity of water and on an average, it takes 1432 liters of waters to produce one kilo gram of rice in an irrigated low land production system. The seasonal water requirements of rice is found to vary from 400 mm in heavy clays with shallow ground water table to more than 2000mm in coarse textured soils with deep water tables. The typical water requirement of irrigated rice in Asia varies between 1300 and 1500 mm. Irrigated rice receives an estimated 34 to 43 per cent of the total world's irrigation water. In other words 24 to 30 per cent of the entire world's developed fresh water resources are used for rice production.

Crop models is an important tool to evaluate the agricultural response to climate conditions. Better predictions were possible with ECHAM model and Representative Concentration Pathway (RCP) 4.5. It is a scenario of long-term, global emissions of greenhouse gases, short-lived species, and land use-land cover which stabilizes radiative forcing at 4.5 W/m^{-2} at approximately 650 ppm CO_2 equivalent in the year 2100.

A prediction of the future water needs in terms of crop water requirement of rice is needed under the projected climate change for the future years. This will help in managing the water resources in a sustainable manner and will aid in planning the schedule of operation of irrigation projects and other water distribution systems. A re-structuring of the operation system of major projects may be necessary in the event of major climate changes.

Thus the present research programme is taken up with the objective of assessing the impact of climate change on crop water requirement of rice. Specific objectives of the research project is to generate the climate data for 2030, 2050 and 2080 under IPCC emission scenario RCP 4.5 and to work out the crop water requirement for rice under the predicted climate.

REVIEW OF LITEREATURE

CHAPTER 2

REVIEW OF LITERATURE

Climate change is projected to have an effect on agriculture and the net result could be beneficial or detrimental. On a global basis, climate change may be beneficial for mid to high latitudes for agriculture whereas low latitudes, semi-arid regions and tropical areas will have much reduced crop yields. The associated increase in atmospheric temperature with climate change may enhance the water requirements of crops. Rice being a major crop which loves water the increase in water requirement of rice may have consequences on the water resources utilization. The previous studies relevant to the objectives of this research are presented in this chapter.

2.1 Rice crop and cultivation

The rice plant belongs to the genus Oryza, subtribe oryzineae of the family gramineae. This genus has 24 species of which 22 are wild and two, namely O. *sativa* and O. *glaberrima*, are cultivated (Roy 1985). Rice is indigenous to the humid areas of tropical and subtropical regions. The *Indica* varieties of rice (Oryza sativa) are grown mainly in the tropical countries. These varieties are photosensitive, making the period of maturity variable, depending on the planting (ICAR, 1985).

Rice is generally grown under a wide range of soil and water conditions. Certain optimum soil management practices are essential for obtaining high yields. The critical edafic factors such as soil air, soil water, temperature, define the optimum conditions to obtain maximum yield of rice. The soil physical factors affecting the growth of rice are puddling, soil aeration, soil temperature and soil water plant atmospheric interactions (Ghildyal, 1985). Rice is the second most important crop in the world after wheat with about 522 million tonnes being produced annually. It is grown over a considerable geographic range from 45°N - 40°S to elevations of more than 2500 m, but with average daily temperature in the range of 20-30°C (Oldeman *et al*., 1987).

Rice is the most widely grown of all crops under irrigation. More than 80 per cent of the developed freshwater resources in Asia are used for irrigation purposes and about half of the total irrigation water is used for rice production ((Bhuiyan, 1992; Dawe *et al*., 1998). The abundant water environment in which rice grows best differentiates it from all other important crops. But water is becoming increasingly scarce. Per capita availability of water resources declined by 40– 60 per cent in many Asian countries between 1955 and 1990 (Gleick, 1993).

Based on soil physiographic, bio-climate and length of growing period India is divided into 20 agro-ecological regions and 60 agro-ecological sub regions (Mandal, 1999).

Lourduraj and Bayan (1999) have reported the influence of moisture in lowland rice, rice response to water stress, and water requirements and water use. Studies have shown that continuous land submergence is not essential for optimum rice yields. Reports from different parts of the country indicated that irrigation could be withheld for two to three days after disappearance of ponded water without any yield reduction. Increased water use efficiency with intermittent submergence as compared to continuous submergence could also be obtained. Moisture influences the availability of nutrients, nutrient uptake, plant growth and ultimately yield. The estimated values of water requirement vary with the soil type, rainfall, variety and other climatic variables. For different parts of India, the water requirement ranged between 1500 and 2500 mm water.

Water is a finite resource which our country has from pre historic times widely used. Besides irrigation, water is diverted to other uses like industries and domestic purpose at the cost of share for agricultural purpose. The present scenario at all India level indicated that the supply demand gap amounts to 80 per cent and will further increase to 25 per cent in 2020 AD. It is necessary that every drop of water is to be used judiciously and economically to realize maximum agricultural production per unit of water. Rice crop requires water 2-4 times higher than that of other crops of the same duration because of the water loss by percolation, seepage, and field preparation (Chandrasekharan *et al*., 2007).

There are two systems of rice cultivation mostly based on water availability. They are wet grown or grown as dry rice. Wet grown are under total submergence of land and dry rice grown exclusively under rain fed conditions. The wet system of rice is practiced under direct sown in puddle condition or are transplanted. Direct seeding is advantageous when mechanised seeders are available and also when labour availability is scarce (Chandrasekharan *et al.,* 2007).

Rice cultivation system existed 7000 years ago and now there are 42 rice producing countries in the world ranging from mountainous Himalayas to low delta areas. Rice is grown both as *rabi* (winter crop) and *kharif* (monsoon crop) crop under three conditions: upland rice, medium land rice and lowland rice in India. Rice is the staple food in Asia, Latin America, parts of Africa and Middle East. It is estimated that rice demand in 2025 will be 140 million tonnes in India (Chandrasekaran *et al.,* 2008).

Kumari *et al*. (2013) reported that rice-wheat system is the most important and largest production system in India and occupies 10 million hectares of area extending from Indo-Gangetic plain to foothills of Himalayas. Increase in cropped as well as irrigated area coupled with high cropping intensity and a major shift towards rice-wheat culture has led to over exploitation of groundwater resulting in declining ground water resources. Besides shrinking of water resources, the adoption of irrigation and fertilizer intensive cultivation has invited many environmental problems like water logging, salinity, loss of fertilizers, ground water pollution and eutrophication. The rapidly depleting water resources and agro-environmental health threaten the sustenance of existing levels of agricultural production, and call for efficient use of water over space and time.

In Kerala state, rice is cultivated in an area of 2.34 lakh hectares and the productivity of rice is reported as 2556 kg ha^{-1}. Annual production of rice in Kerala amounts to 5.98 lakh tonnes. Thrissur district occupy a major role in production of rice and have an area of 23098 ha under rice cultivation producing 66390 tonnes per year (Dept. of Agriculture, 2015)

2.2 Water requirements of crops

Crop water requirement is defined as the depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in large field under non-restricting soil conditions including soil water and fertility and achieving full production potential under given growing environment. Crop water demand is calculated as the product of the estimated reference evapotranspiration (ET_0) and the crop factor (k_c) (Doorenbos, 1984).

FAO (1984) has defined ET_0 as "the rate of ET from an extensive surface of 5–15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". ET of a crop is defined as "the rate of ET from a disease-free crop, growing in large fields under no restricting soil water and fertility conditions and achieving full production potential under the given growing environment" (James, 1993).

Water demand for rice during the entire growth period varies from 950 mm to 1050 mm for three month duration crop and 1120 to1250 mm for four month duration crop. It depends on crop growth stage, climatic condition and soil characteristics. For different conditions, it varies from 1000-1500 mm for heavy soils with high water table, short duration variety, Kharif season; 1500-2000 mm for medium soils *Kharif* or early spring season and 2000-2500 mm for light soils, long duration varieties during *Kharif*, medium duration varieties during summer (Indiaagronet, 2005).

Food and Agriculture Organization has predicted a net expansion of irrigated land of about 45 million hectares in 93 developing countries reaching a total of 242 million hectares by 2030. The projected water withdrawals by the agriculture sector will increase by about 14 per cent during 2000 – 2030 to meet food demand (FAO, 2006).

Jadhav et al. (2006) conducted investigations in basmati rice (*Oryza sativa* cv. Basmati-370) to evaluate the water requirement in Maharashtra, India. The consumptive use of basmati rice grown under upland irrigated condition during the *kharif* season of 1998-99 on Vertisol, as estimated by modified Penman, radiation, pan-evaporation and Hargreaves methods showed a variation from consumptive use estimated by the gravimetric methods. The variability was observed in all the growth stages of crop. The variation was highest during flowering and was lowest during grain filling and maturity stage of the crop.

Pedro *et al*. (2007) conducted research to determine the water requirements of the pineapple crop in Brazil, using a sprinkler irrigation system as complementary water supply. Crop evapotranspiration (ETc) was estimated by the Bowen ratio-energy balance and reference evapotranspiration (ET_0) by the Penman-Monteith method. The mean daily crop evapotranspiration was too variable throughout the pineapple crop development cycle, with values decreasing from (ETc = 4.6 mm day^{-1}) in the vegetative growth to 3.5 mm day^{-1} in the fruits harvesting phenological stage. On the overall, ETc was lower in the beginning of the vegetative growth and fruits harvest and higher in the middle of the productive cycle. The cumulative water used during the crop growing cycle was 1421 mm while the cumulative reference evapotranspiration was 1614.9 mm.

2.2.1Crop water estimation

The model CROPWAT for Windows is a decision support system developed by the Land and Water Development Division of FAO, Italy with the assistance of the Institute of Irrigation and Development Studies of Southampton, UK and National Water Research Centre, Egypt. This model carries out calculations for reference evapotranspiration, crop water requirements and irrigation requirements in order to develop irrigation schedules under various management conditions and schemes of water supply.

Doorenbos and Pruitt (1977) presented a method for the prediction of crop water requirement based on Penman evaporation equation. Doorenbos and Pruitt (1977) method used a slightly modified version of the equation with a revised wind function, where the evapotranspiration (ET_0) from reference short grass was determined.

Adam and Farbrother (1984) presented a method for predicting the crop water requirement. The method was based on the calculation of water needed by plants to satisfy evapotranspiration losses measured from soil moisture depletion through daily gravimetric sampling. The sampling was done on 10-20 cm depth intervals up to 1 m. The calculated ET values were related to the original Penman evaporation from free water surface via a crop factor (k_f).

One of the most important aspects of water balance is evapotranspiration (ET); unfortunately this is also one of the most difficult parameters to measure in the field. A lot of research has been undertaken to estimate a kind of reference ET from meteorological data and convert this to the actual ET. The most frequently used in this sense is the so-called FAO-24 concept (Doorenbos and Pruitt, 1977), which is recently updated.

Allen (2000) and Akio *et al.* (1999) used Penman-Monteith reference crop evapotranspiration with derived crop coefficients from the phenomenological stages of cotton to estimate the crop water requirement. The results were compared with the current practice that uses Penman evaporation from free water surface and crop factors. Penman -Monteith equation was found to be better in terms of the total predicted crop water requirement, coefficient of determination (r^2), and the slope of the linear regression line and the standard error of estimate with both basal and derived (Kc) values. The trends of weather examined for the period 1966 -1993 showed an increasing ET_0 during the rainy season due to the recent drought conditions that prevailed in the region.

Kar and Verma (2005) computed the crop water requirement of rice using CROPWAT 4.0 model as 450- 550 mm, 600-720 mm, 775-875 mm for autumn rice, winter rice and summer rice respectively in different agro-ecological sub-regions. Sheng-Feng Kuo (2006) conducted field experiments to calculate the reference and actual crop evapotranspiration, derived the crop coefficient, and collected requirements input data for the CROPWAT irrigation management model to estimate the irrigation water requirements of paddy and upland crops. In the paddy fields, the irrigation water requirements and deep percolation were 962 and 295 mm, respectively, for the first rice crop, and 1114 and 296 mm for the second rice crop. For the irrigated single and double rice cropping patterns the CROPWAT model simulated results indicate that the annual crop water demands are 507 and 1019 mm, respectively, and the monthly water requirements peaked in October at 126 mm and in January at 192 mm, respectively.

Manjunatha *et al*. (2009) conducted a study during the *kharif* season of 2005 in Karnataka, India, to determine the effect of different systems of rice intensification on yield, water requirement and water use efficiency. The grain yield of rice was significantly the highest with modified SRI method (6342 kg/ha)). Crops grown with 9- and 12-day-old seedlings recorded the significant highest grain yields (6017 and 6018 kg/ha, respectively), over the rest of the treatments.

Wenzhi *et al.* (2010) conducted an inter comparison study on crop evapotranspiration (ETc) with six methods for estimating ETc applied to maize crop. The ETc was estimated by the soil water balance and Bowen ratio-energy balance methods while the Priestley–Taylor, Penman, Penman–Monteith and Hargreaves methods were used for estimating the reference evapotranspiration (ET_0). The results of study showed that the trend of ETc was very similar, while the differences were significant among the different methods. The variations of ETc were closely related to the LAI as well as to the meteorological features. The Penman–Monteith method provided fairly good estimation of ETo as compared with the Priestley– Taylor, Penman, Hargreaves methods.

Rakesh *et al.* (2012) used different methods of crop establishment in basmati rice. A field experiment was conducted during *kharif* season of 2009-10. The basic infiltration rate under puddled and unpuddled soil condition was recorded as 0.020 mm/min and 0.049 mm/min, respectively. There was a saving of 8-26 per cent irrigation water under different methods of direct seeded rice (DSR) as compared to puddled manual transplanted rice and different methods of mechanical transplanted rice. There was 19 per cent saving of water under puddled as compared non puddled mechanical transplanted rice, respectively. The grain yield in mechanical transplanting varied from 29.5 to 32.6 q/ha. The grain yield recorded in the range of 31.2 to 32.1 q/ha when crop was sown with DSR techniques.

Falguni and Kevin (2013) cited that reference crop evapotranspiration (ET_0) was determined using mean monthly meteorological data with the help of CROPWAT 8.0 and then crop water requirement (ETc) was determined. Results showed the clear effect of climate change on crop water requirement of *rabi* and hot weather crops. Results showed that crop water requirement of all hot weather crops of millet, ground nut, maize, small vegetables and tomato increased.

Mamta *et al.* (2013) used remote sensing based approach for determining large-area crop water requirement using vegetation indices as proxy indicator of crop coefficient (Kc). This study was an attempt to estimate the reasonably proper Kc for lowland rice and wheat and subsequently crop evapotranspiration (ETc) in rice-wheat system using multi temporal IRS P6-AWiFS data integrated with meteorological data following FAO-56 approach. Monthly biophysical parameters viz., fractional canopy cover (f_c) and water scalar factor (Ws) were derived from spectral indices in order to adjust Kc for the different growth stages in rice-wheat system. The results showed that after including Ws with *fc* for rice, degree of fit (R^2) has been significantly improved from 0.72 to 0.94 for Kc estimation of rice. The estimated crop water requirement was 241.66, 531.34, 440.86 and 192.63 M ha.m for rice and 127.43, 135.77, 305.55, 262.84 and 204.5 M ha.m for wheat at various growth stages.

Kite and Droogers (2000) as part of an inter comparison study on estimating ET used different methods such as field measurements, satellite data and model predictions. Six of the most commonly used reference ET methods were applied in this comparison. Jensen *et al*. (1990) reported a major study where they analyzed the performances of 20 different methods for estimating the ET under different climatic conditions. The impact of climate change on crop evapotranspiration therefore becomes important for water management and agricultural sustainability (Mo et al., 2013).

Babu *et al*. (2014) estimated water requirement of different crops using CROPWAT 8.0 model. The crop water requirement for the groundnut k*harif* and r*abi* crops in the Anantapur region was estimated at 591.3 mm and 443.3 mm, respectively and for the vegetables, cotton, rice, grains and maize in the Anantapur region were estimated to be 594.1 mm, 878.6 mm, 1110.6 mm, 699.9 mm and 679.3 mm, respectively. Efficient water management becomes crucial and critical in normal or deficit rainfall years

Banavath *et al*. (2015) reported that determination of reference crop evapotranspiration (ET_0) by using Penman-Monteith method through the help of CROPWAT model using climatic data of Pichatur Station in Andhra Pradesh, the probability of exceedance functions on rainfall data to obtain the dry year condition for optimal development of irrigation projects, determine crop water requirements by using a CROPWAT model for the present scenario, prediction of climatic data by using ANN-Back Propagation Feed Forward Function to determine the future CWR, prediction of climatic data by using IBM-SPSS model to obtain future CWR, validate models for the predicted data and estimation of future crop water requirements.

2.2.2 Climate change and water requirement

Rapid industrialization over the last century has brought out industrial and agricultural emissions of carbon dioxide (CO_2), Methane (CH_4), chloro fluro carbon (CFC), nitrogen oxide (NOx) and other gases. It resulted in an increase of green house gases in the earth's atmosphere. Carbon di oxide concentration is found to increase at the rate of about 1.5 ppm per year (Keeling *et al.,* 1984). The increase in the atmospheric concentrations of greenhouse gases contributes towards the gradual warming of the earth by retaining more heat within the earth atmosphere (Ogats *et al*., 1992). General circulation models (GCM) describing the dynamic processes in the earth's atmosphere have been used extensively to provide potential climate change scenario (Grotch.1998; Gutowski *et al*., 1988; Smith and Tarpak. 1989; Cohen. 1990).

Saini and Nanda (1987) found that increased temperature hastened the rate of leaf senescence resulting in reduction in leaf area. The model simulation revealed that warming scenarios will have an adverse effect on rice production through the advancement in maturity and reduction of source size coupled with poor sink strength in state of Punjab. Similarly the decrease in crop life span and grain yield with increase in temperature was also reported (Wardlaw *et al.* (1989); Hundal *et al*. (1993).

Climate change scenarios include higher temperatures, changes in precipitation, and higher atmospheric carbon dioxide concentrations which may affect yield, growth rates, photosynthesis and transpiration rates, moisture availability, through changes of water use agricultural inputs such as herbicides, insecticides and fertilizers. Environmental effects such as frequency and intensity of soil drainage leading to nitrogen leaching, soil erosion, land availability, reduction of crop diversity may also affect agricultural productivity. An atmosphere with higher carbon dioxide concentration would result in higher net photosynthetic rates (Cure and Acock 1986; Allen *et al*, 1987).

According to current GCM prediction, a doubling of the current CO_2 level will bring about an increase in average global surface air temperature of between 1.5 and 4°C with accompanying changes in precipitation patterns (Gates *et al*., 1992).

Watson *et al*. (1996) reported that the changing climate may accelerate the hydrological cycle resulting in changes in precipitation, evapotranspiration, run-off, and in the intensity and frequency of floods and droughts. Both changes in rainfall and temperature affect crop growth and development.

Global climate change is a change in the long-term weather patterns that characterize the regions of the world. The term 'weather' refers to the short-term (daily) changes in temperature, wind, and/or precipitation of a region (Merritts *et al.* 1998).

Atmospheric carbon dioxide concentration has risen and the general circulation models have predicted a global temperature rise of 2.8-5.2°C for a doubling of atmospheric carbon dioxide concentration. Doubling of carbon dioxide will decrease leaf stomatal conductance to water vapour to about 40 per cent. Water use efficiency by C_3 crop plants under field conditions has usually seen to be decreased. A yield enhancement of 30-35 per cent for C_3 crops occurred for a doubling of carbon dioxide. Transpiration rates were found to increase for an increase in the atmospheric temperature. Under well-watered conditions evaporation will increase about 4-5 per cent per 1°C rise in temperature (Allen, 2004).

Schmidhubber and Tubiello, (2007) investigated the spatial and temporal variation of the water requirement, water consumption and water deficit as affected by the changing weather patterns in the period from 1976 to 2005. Most agricultural climate change impact studies have focused on the impact on crop productivity. Changes in temperature, radiation and precipitation not only affect productivity but also have an impact on plant water use. Agriculture being the number one water user across the globe, changes in agricultural water use will have large impacts on water availability.

Supit *et al.* (2010) analyzed the trends in European seasonal weather conditions and related crop water requirements, crop water consumption and crop water deficits during the period 1976–2005. The impacts of the changing weather patterns differed per crop and per region. In various European regions, the wheat water requirement showed a downward trend which can be attributed to a shorter growing season as a result of higher temperatures in spring. Changes in these variables can be attributed to the combined effect of variations in crop water requirements and rainfall.

Nguyen (2012) had reported that rainfall pattern is a very important limiting factor for rain-fed rice production. Higher variability in distribution and a likely decrease in precipitation will adversely impact rice production and complete crop failure is possible if severe drought takes place during the reproductive stages. In upland fields, if the rice crop receives up to 200 mm of precipitation in one day and then receives no rainfall for the next 20 days, the moisture stress will severely damage final yields.

Singh *et al.* (2012) reported that the research conducted by Indian Agricultural Research Institute (IARI) has shown that the grain yield of rice was not impacted by a temperature increase less than 1°C. However from an increase of 1-4°C the grain yield reduced on average by 10 per cent for each degree of temperature rise. Thus, higher temperatures accompanying climate change will impact world rice production creating the possibility of a shortfall. Basmati varieties of rice were particularly vulnerable to temperature induced pollen sterility, and thus to lower grain formation.

Vaidhyanathan (2012) studied the impact of night time temperature rise on rice yields. It was reported that the warmer nights have an extensive impact on the yield of rice, every 1°C increase in night time temperature led to a 10 per cent reduction in yield.

According to a study done by the Indian agricultural Research Institute, the impact of climate change with increased temperature and decreased radiation will lead to decrease productivity in rice in the North Eastern region (IARI.2012).

Shakhawat (2013) investigated possible implications of climate change on crop water requirements from 2011 to 2050 in Saudi Arabia. Crop water requirements were predicted for four scenarios: (i) current temperature and rainfall (ii) temperature in 2050 and current state of rainfall (iii) rainfall in 2050 and current state of temperature and (iv) temperature and rainfall in 2050 . On an average, 1^0 C increases in temperature may increase the overall crop water requirement by 2.9 per cent in this region.

Chattaraj *et al.* (2014) reported that the crop water requirement under the projected climate change could be mediated through changes in other weather parameters including the air temperature. Field simulation using temperature gradient tunnels shows 18 per cent higher crop evapotranspiration (ETc) and 17 per cent increase in root water extraction at 3.6^0 C elevated temperature compared to 1.5^0 C increase over the ambient. A time series model (ARIMA) with long-term (1984–2010) weather data of the experimental site and a global climate model (IPCC-SRES HADCM3) were used to simulate the potential ET (ET0) of wheat for 2020–2021 and 2050–2051 years. The CWR and NIR (Net Irrigation Requirement) are likely to be less in projected years even though air temperatures increase. It may be likely that the effect of temperature increase on CWR is manifested mostly through its relation with crop phenophase and not the temperature effect on ET_0 per se.

2.3 Climate change projection

The realistic models of climate which combined atmospheric and oceanic models indicated global warming to the tune of 0.5° to 0.7° K for the period 1850-1980.This warming agrees well with the observed Northern Hemisphere warming of 0.6 K in this period. During next century, average rate increase in global temperature is projected as 0.3°C per decade with a range of 0.2 to 0.5°C (Kellogg 1983).

The increased temperature will lead to forced maturity and poor harvest index due to limited water supply. The water stress during grain filling period may result in decline of grain yield. Higher temperature coupled with increased CO_2 concentration could result in photosynthetic acclimation because of the imbalance in the source/sink ratio (Yadav *et al*. 1987).

The combustion of fuel, biomass burning, production of synthetic chemicals and deforestation are enhancing the greenhouse effect by changing the chemical composition of the atmosphere. The greenhouse gases are found to be increasing at the rate of one per cent for methane, 0.4-0.5 per cent for carbon dioxide and 0.2-0.3 per cent for nitrous oxide At this rate the concentration of carbon dioxide will exceed 370 ppm by the year 2030 (Baker, 1989).

The combined effect of greenhouse gases CH_4, N_2O, CFC_{11}, CFC_{12} and O_3 is equivalent to an additional 40-50 ppm increase of CO_2 (Bach, 1989). The increased level of carbon dioxide from 340 to 680 ppm could increase the yield of major crops by 10- 15 per cent especially in C_3 plants like rice (Allen 1990).The beneficial effects of increased temperature can be negated as the incidence. Photosynthetically Active Radiation (PAR) is likely to decline by one per cent (Hume and Cattle 1990).

During next 60 years the concentration of greenhouse gases will result in a situation equivalent to a CO_2 doubling in the first half of the 21^{st} century which indicates changing trend of the global climate over a longer period. The Intergovernmental Panel on Climate Change (IPCC) has reported that global mean surface air temperature has increased by 0.3-0.6°C over the last century with the warmest year being in 1980 (Martin 1993).

Geethalakshmi *et al.* (2011) reported that the results of the projected climate change over Cauvery basin of Tamil Nadu for A1B scenario using regional climate models showed an increasing trend for maximum, minimum temperatures and rainfall. The yields of ADT 43 rice simulated by decision support system for agricultural technology transfer with CO_2 fertilization effect had shown a reduction of 135 kg ha^{-1} $decade^{-1}$ for providing regional climates for impact studies (PRECIS) output, while there was an increase in yield by 24 kg ha^{-1} $decade^{-1}$ for regional climate model system. Suggested adaptation strategies included, system of rice intensification, use of temperature tolerant cultivars and application of green manures/ bio fertilizers for economizing water and increasing the rice productivity under warmer climate.

In India, it is predicted that, physical impact of climate change will be seen as an increase in the average surface temperature by 2-4° C, changes in rainfall during both monsoon and non-monsoon months, a decrease in the number of rainy days by more than 15 days, an increase in the intensity of rain by 1-4mm/day and an increase in the frequency and intensity of cyclonic storms. Temperature and its associated seasonal patterns are critical components of agricultural production systems. Rising temperatures associated with climate change will have a detrimental impact on crop production, livestock, fishery and allied sectors. It is predicted that for every 2° C rise in temperature, the GDP will reduce by 5 per cent (Anna and Richa, 2012).

IMD (2013) has reported that the state wise averaged annual mean maximum temperature time series is showing an increasing trend over states of India except Bihar, Chhattisgarh, Delhi, Haryana, Jammu and Kashmir, Meghalaya, Punjab, Tripura and Uttar Pradesh. The increasing trends were significant over Andhra Pradesh, Arunachal Pradesh, Assam, Goa, Gujarat, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Lakshadweep, Madhya Pradesh, Maharashtra, Manipur, Mizoram, Odisha, Rajasthan, Sikkim, Tamil Nadu and Uttarakhand. State averaged annual minimum temperature have shown significantly increasing trend over Andhra Pradesh, Arunachal Pradesh, Assam, Bihar, Delhi, Gujarat, Haryana, Kerala, Lakshadweep, Manipur, Meghalaya, Rajasthan, Sikkim, Tamil Nadu and Tripura. The highest increase in annual mean temperature was obtained for Sikkim (+0.05°C/year) followed by Manipur (+0.03°C/year), Goa, Himachal Pradesh, Tamil Nadu (+0.02°C/year). The state of Punjab (-0.01°C/year) has shown significant decrease in annual mean temperature while no trends were observed for Chhattisgarh, Haryana, Meghalaya, Orissa, Uttar Pradesh, and West Bengal, during1951-2010. Annual rainfall over the states of Arunachal Pradesh, Assam, Chhattisgarh, Delhi, Goa, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Nagaland, Punjab, Sikkim and Uttar Pradesh were found to have increased. The highest increase in average rainfall was observed over Meghalaya (+14.6mm/year) and the highest decrease was observed for Andaman and Nicobar (-7.77mm/year). State averaged summer mean maximum temperature have increased over all states of India except Arunachal Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Jammu and Kashmir, Jharkhand, Meghalaya, Punjab, Tripura, Uttar Pradesh, Uttarakhand and West Bengal. The increasing trends were significant over Andhra Pradesh, Goa, Himachal Pradesh, Karnataka, Kerala, Maharashtra, Lakshadweep, Mizoram, Rajasthan, Sikkim and Tamil Nadu.

2.4 Climate change impacts on agriculture

Chakraborty and Maity (2004) conducted a study to determine the water requirements of both paddy and different winter crops (wheat, Indian mustard, groundnut, sesame, sunflower, lentil, gram, potato, sweet potato, chilli, tomato and brinjal) in West Bengal, India. Seasonal water requirement varied widely with the type of crops. Paddy utilized the highest amount of water (1470 mm), while the lowest water use (121 mm) was observed in sunflower. The rest of the crops required water between 155 and 333 mm. The rate of water use of the crops also varied to a great extent. The water consumption rate of paddy was 8.56 mm/day. For the other crops it ranged from 1.42 to 5.27 mm/day. Water use efficiency was a maximum in tomato (79 kg ha^{-1} mm^{-1}) and minimum in paddy (4 kg ha^{-1} mm^{-1}). The water use index was also highest in tomato (Rs. 393.33 ha^{-1} mm^{-1}) and lowest in paddy (Rs. 18.86 ha^{-1} mm^{-1}). Crop yield was highest in tomato (23.17 t/ha) and lowest in sunflower (0.81 t/ha).

Kuo *et al*. (2005) reported that irrigation water requirements and deep percolation in Taiwan were 962 and 295 mm, respectively, for the first rice crop, and 1114 and 296 mm for the second rice crop. Regarding the upland crops, the irrigation water requirements for spring and autumn corn are 358 and 273 mm, respectively, compared to 332 and 366 mm for sorghum, and 350 and 264 mm for soybean.

Dev (2005) reported the use of groundwater for irrigation in crop production particularly for cereal crops in West Bengal, India. The study aimed to bring down the harvest of groundwater through reallocation of agricultural land to cereal crops. Based on water requirement of different crops the study suggested for reallocation of agricultural land to the crops which require relatively low quantity of water. The paddy crop was observed to require the highest quantity of water among the cereal crops using ground water.

Lorenzo *et al*. (2006) found that green-house shading improved the quality of tomato and increased yield of cucumber in Egypt. It reduced crop transpiration and thus water uptake, and improved water use efficiency by 47 per cent and 62 per cent for the crops grown in open fields in a semi-dry climate subjected to direct sunlight, high temperatures and wind resulting in high crop evapotranspiration (ETc). Shade-houses favored plant growth; since plants were less stressful, direct sunlight was avoided, temperature was lower, humidity was higher, wind speed reduced, and ETc was low.

Ambuja (2006) mentioned that rice crop water requirement and water supply was analyzed with the help of meteorological data and irrigation data. The crop water requirement of rice crop was computed with the help of reference evapotranspiration (pan evaporation method) and crop coefficients. It was found that the water demand for rice crop exceeded the irrigation supply.

Morison *et al.* (2008) reported that agriculture accounts for more than 80 per cent of all freshwater used by humans, most of that is for crop production. Currently most of the water used to grow crops is derived from rain fed soil moisture, with non-irrigated agriculture accounting for about 60 per cent of production in developing countries. Though irrigation provides only 10 per cent of agricultural water use and covers just around 20 per cent of the cropland, it can vastly increase crop yields, improve food security and contribute about 40 per cent of total food production since productivity of irrigated land is almost three times higher than that of rain fed land.

Manjunatha *et al*. (2009) conducted a study, during the *kharif* season of 2005 in Karnataka, India, to determine the effect of different system of rice intensification on yield, water requirement and water use efficiency. Treatment combinations comprised:

three methods of planting (M1, normal method; M2, recommended SRI method; and M3, modified SRI method) and five seedling ages (9, 12, 15, 18 and 21 days) laid out in split-plot design with three replications. Data on the effects of planting method and seedling age on the grain and straw yields of rice, water requirement and water use efficiency are tabulated. The grain yield of rice was significantly highest with M3 (modified SRI method (6342 kg/ha)). Crops grown with 9- and 12-day-old seedlings recorded the significant highest grain yields (6017 and 6018 kg/ha, respectively), over the rest of the treatments.

Antle (2010) and Hanjra (2010) conducted a study on the changes in crop production and yield associated with climate change. Climate-induced water scarcity from changes in temporal and spatial distribution of rainfall could lead to increased competition within the agriculture sector and with other sectors.

Lobell (2011) and Nelson (2010) reported that climate change will influence crop distribution and production and increase risks associated with farming. Crop yields have already experienced negative impacts, underlining the necessity of taking adaptive measures.

Mo *et al*. (2013) reported that impact of climate change on crop evapotranspiration becomes important for water management and agricultural sustainability. The warmer climate may increase the ET_0 of crops leading to greater demand for irrigation water. Climatic factors like radiation, humidity, wind speed and rainfall also influence the ET_0. Consequently, any variation in those factors will also modify the ETc.

Kumari *et al*. (2013) reported that remote sensing based approach of large-area crop water requirement using vegetation indices as proxy indicator of crop coefficient (Kc). It was an attempt to estimate the reasonably proper Kc for lowland rice and wheat and subsequently crop evapotranspiration (ETc) in rice-wheat system using multi temporal IRS P6-AWiFS data integrated with meteorological data following FAO-56 approach. Geometrically and radiometrically corrected multi-temporal AWiFS images were classified by rule based classifier to discriminate rice-wheat system from other cropping system.

Falguni and Kevin (2013) reported that climate change is likely to have impact on the hydrological cycle and consequently on the available water resources and agricultural water demand. There were concerns about the impacts of climate change on agricultural productivity. Industrialization and the extended use of fossil fuels have lead to a great increase in the atmospheric concentrations of greenhouse gases. With respect to the relations between the hydrological cycle and the climate system, every change on the climate could affect parameters such as precipitation, temperature, runoff, stream flow and groundwater level. This could lead to changes in the crop water requirement in agriculture and also industrial and domestic water consumption demands will also change.

Surendran *et al*. (2014) reported that rise in temperature is one of the predicted impacts of climate change with significant implications on water resources management. An attempt has been made to calculate the water requirement of crops in different agro-ecological zones of Palakkad district in humid tropical Kerala using the CROPWAT 8.0 model. Sensitivity analysis was done for a simulated rise in temperature from 0.5 to 3.0°C keeping other parameters the same. The analysis showed that the total crop water requirement of all the major crops, like coconut, paddy and banana, increased with rising temperature thereby increasing the simulated irrigation water demand.

Chattaraj *et al.* (2014) conducted a study which was directed to assess the on-farm water requirement in wheat crop in semi-arid Indo-Gangetic Plains of India, through field and computer simulations. Field simulation using temperature gradient tunnels show 18 per cent higher crop evapotranspiration (ETc) and 17 per cent increase in root water extraction at 3.6° C elevated temperature compared to 1.5° C increase over the ambient temperature. Time series model (ARIMA) with long-term (1984–2010) weather data of the experimental site and a global climate model (IPCC-SRES HADCM3) were used to simulate the potential ET (ET_0) of wheat for 2020–2021 and 2050–2051 years.

Banavath *et al.* (2015) reported that the amount of Crop Water Requirement (CWR) for different crops grown in the Araniar reservoir basin command area was calculated by using CROPWAT model. This is a ‘crop-soil-climate’ phenomenon which will facilitate the estimation of the crop evapotranspiration and irrigation schedule, and agricultural water requirements with different cropping patterns for irrigation planning. Estimation of Reference evapotranspiration and CWR are the very important in application such as irrigation design, irrigation scheduling, water resources management, hydrology and cropping system modelling. The model works on the climatic data as inputs such as minimum and maximum temperature, relative humidity, wind speed, sunshine hours, rainfall, soil parameters and crop details.

2.4.1 Climate change impact on Indian agriculture

Naresh *et al.* (2011) reported that Indian agriculture is facing challenges due to several factors such as increased competition for land, water and labour from non-agricultural sectors and increasing climatic variability. The climate variability associated with global warming will result in considerable seasonal or annual fluctuations in food production. Carbon dioxide enrichment experiments had shown that in the field environment, 550 ppm carbon dioxide leads to a benefit of 8–10 per cent in yield in wheat and rice, up to 15 per cent in soyabean, and almost negligible in maize and sorghum; but increase in temperature may alter these results.

Pratap *et al.* (2014) analysed the changes in climate variables, viz. temperature and rainfall during the period 1969-2005 and has assessed their impact on yields of important food crops. A significant rise was observed in mean monthly temperature, but more so during the post-rainy season. The changes in rainfall, however, were not significant. An increase in maximum temperature was found to have an adverse effect on the crop yields. A similar increase in minimum temperature had a favourable effect on yields of most crops, but it was not sufficient to fully compensate the damages caused by the rise in maximum temperature. Pigeonpea, rice, chickpea and wheat were more vulnerable to rise in temperature. Rainfall had a positive effect on most crops, but it could not counterbalance the negative effect of temperature. The projections of climate impacts towards 2100 have suggested that with significant changes in temperature and rainfall, the rice yield will be lower by 15 per cent and wheat yield by 22 per cent.

Surendran *et al.* (2014) reported that, rise in temperature is one of the predicted impacts of climate change with significant implications on water resources management. An attempt has been made to calculate the water requirement of crops in different agro-ecological zones of Palakkad district in humid tropical Kerala using the CROPWAT 8.0 model. Sensitivity analysis was done for a simulated rise in temperature from 0.5 to 3.0°C keeping other parameters the same. The analysis showed that the total crop water requirement of all the major crops, like coconut, paddy and banana, increased with rising temperature thereby increasing the simulated irrigation water demand. The simulated gross water demand for an increase in temperature of 0.5, 1.0, 2.0 and 3.0°C will be 1,523, 1,791, 1,822 and 1,853 Mm^3, respectively.

2.4.2 Climate change impacts on rice

Higher carbon dioxide concentrations may also reduce transpiration as plants reduce their stomatal apertures, the small openings in the leaves through which carbon dioxide and water vapour are exchanged with the atmosphere. The reduction in transpiration could be 30 per cent in some crop plants (Kimball 1983).

Stomata response to carbon dioxide interacts with many environmental factors like temperature, light intensity and plant factors like age, hormones. Therefore, predicting the effect of elevated carbon dioxide on the responsiveness of stomata is still very difficult (Rosenzweig and Hillel, 1995).

Carbon dioxide enrichment have generally shown significant increases in rice biomass (25-40%) and yields (15-39%) at ambient temperature, but those increases tended to be offset when temperature was increased along with rising carbon dioxide (Ziska et al., 1996a,b; Moya et al., 1998). Yield losses caused by concurrent increases in carbon dioxide and temperature were primarily caused by high-temperature-induced spikelet sterility (Matsui et al., 1997a).

Increased carbon dioxide levels may also cause a direct inhibition of maintenance respiration at night temperatures higher than 21°C (Baker et al., 2000). In rice, extreme maximum temperature is of particular importance during flowering which usually lasts two to three weeks. Exposure to high temperature for a few hours can greatly reduce pollen viability and, hence, cause yield loss. Spikelet sterility is greatly increased at temperatures higher than 35°C (Osada et al., 1973; Matsui et al., 1997b).Enhanced carbon dioxide levels may further aggravate this problem, possibly because of reduced transpiration cooling (Matsui *et al.*, 1997a).

A key mechanism of high temperature-induced floret sterility in rice is the decreased ability of the pollen grains to swell, resulting in poor thecae dehiscence (Matsui et al., 2000). Significant genotypic variation in high-temperature induced floret sterility exists. Variation in solar radiation increased maintenance respiration losses or differential effects of night vs. day temperature on tillers.

Chakraborty and Maity (2004) conducted a series of studies during the dry seasons of West Bengal, India, to determine and compare the water requirements of both paddy and different winter crops. Seasonal water requirement varied widely with the type of crops. Paddy utilized the highest amount of water (1470 mm), while the lowest water use (121 mm) was observed in sunflower. The rest of the crops required water between 155 and 333 mm. The rate of water use of the crops also varied to a great extent. The water consumption rate of paddy was 8.56 mm/day, whereas for the other crops it ranged from 1.42 to 5.27 mm/day. Water use efficiency was maximum in tomato (79 kg ha^{-1} mm^{-1}) and minimum in paddy (4 kg ha^{-1} mm^{-1}). The water use index was also highest in tomato (Rs. 393.33 ha^{-1} mm^{-1}) and lowest in paddy (Rs. 18.86 ha^{-1} mm^{-1}).

For every 75 ppm increase in carbon dioxide concentration rice yields will increase by 0.5 t/ha, but yield will decrease by 0.6 t/ha for every 1 °C increase in temperature (Sheehy *et al.,* 2005).

In a climate chamber study, there was first evidence of possible genotypic variation in resistance to high night temperatures high carbon dioxide levels and/or temperature are likely to affect crop development rates(Counce *et a*l., 2005) .

Sheng-Feng Kuo (2006) conducted field experiments to calculate the reference and actual crop evapotranspiration, derived the crop coefficient, and collected requirements for input data for the CROPWAT irrigation management model to estimate the irrigation water requirements of paddy and upland crops. In the paddy fields, the irrigation water requirements and deep percolation were 962 and 295 mm, respectively, for the first rice crop, and 1114 and 296 mm for the second rice crop. For the irrigated single and double rice cropping patterns the CROPWAT model simulated results indicated that the annual crop water demands are 507 and 1019 mm, respectively. The monthly water requirements were peak in October with 126 mm and in January with 192 mm, respectively.

Climate change could affect agriculture in several ways such as quantity and quality of crops in terms of productivity, growth rates, photosynthesis and transpiration rates and moisture availability. Climate change is likely to impact directly food production across the globe. Increase in the mean seasonal temperature can reduce the duration of many crops and hence reduce the yield. In areas where temperatures are already close to the physiological maxima for crops, warming will impact yields more immediately (IPCC, 2007).

Yashvir (2010) conducted crop simulation study and assessed the potential productivity and water requirements of maize peanut rotations for the SAT climatic zone of Australia using the Agricultural Production Systems Simulator (APSIM) model. The simulated mean total yield potential of the dry season maize and wet season peanut rotation (15–19.2 t/ha) was about 28 per cent greater than the wet season maize–dry season peanut (WMDP) rotation because of the higher yield potential of maize in the dry season compared to in the wet season. The overall simulated irrigation water requirement for both rotations, which varied from 11.5 to 13.8 ML/ha on different soils, was similar. The DMWP rotation had 21 per cent higher water use efficiency

Chung (2013) conducted studies to project future irrigation demands of paddy. The results showed that the growing season mean temperature and rainfall for future scenarios were projected to increase. The effect of ET_0 increase due to temperature increase was larger than that of rainfall increase on paddy irrigation requirement. Therefore the paddy irrigation requirement was projected to increase in the future. The total volumetric irrigation water demand was projected to increase by 2.8% (2020's), 4.9% (2050's) and 4.5% (2080's). The temporal and spatial variations were large and should be considered in irrigation water resource planning and management in the future.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

This chapter describes the materials used and methodology adopted for the research.

1 Location

This experiment was conducted in Thrissur district, Kerala (10.69 N, 75.96 E (EN); 10.19 N, 76.15 E (ES); 10.27 N, 76.87 E (WS); 10.74 N, 76.46 E (WN))

2 Climate

The monthly average climatic data of twenty five years (1985-2010) for the research site were used for the research. The data included, maximum and minimum air temperature, relative humidity, wind speed, sunshine duration and rainfall. Climate is humid tropical monsoon type (B2-B4). Mean annual temperature is 27.7 °C. March is the hottest month (35.3 °C) and January the coldest (22.5 °C). Average annual precipitation is 3,000 mm (range: 2,119 3,962 mm).

3 CROPWAT and input data

The model CROPWAT for Windows is a decision support system developed by the Land and Water Development Division of FAO, Italy. In this model, calculations are done for reference evapotranspiration, crop water requirements and irrigation requirements for the development of irrigation schedules under various management conditions and scheme water supply. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules and the assessment of production under rainfed conditions or deficit irrigation. The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-moisture balance using various options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern provided in the program.

The potential evapotranspiration (ETo) was computed by Penman-Monteith Model. In this model, most of the equation parameters are directly measured or can be readily calculated from weather data. The equation can be utilized for the direct calculation of any crop evapotranspiration (ETc).The FAO Penman-Monteith method suggested by Verhoef and Feddes (1991) to estimate ETo is given as

$$ETo = \frac{0.408\Delta\,(Rn - G) + \gamma\frac{900}{T + 273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

Where,

Et_o	- Reference evapotranspiration [mm day^{-1}]
Rn	-Net radiation at the crop surface [MJ m^{-2} day^{-1}]
G	-Soil heat flux density [MJ m^{-2} day^{-1}]
u_2	-Wind speed at 2 m height [m s^{-1}]
T	-Mean daily air temperature at 2 m height [°C]
es	-Saturation vapour pressure [kPa]
ea	-Actual vapour pressure [kPa]
es-ea	-Saturation vapour pressure deficit [kPa]
Δ	-Slope vapour pressure curve [kPa°C^{-1}]
A	-Psychrometric constant [kPa°C^{-1}].

4 Crop and soil data

For this research study, sets of standard rice crop data that are included in the program were used. The crop coefficient (Kc) and crop yield data (Ky) have been updated by FAO CROPWAT. The model simulation requires soil data, such as heavy soil, medium soil and light soil which is fulfilled by CROPWAT automatically utilizing soil data option.

5 Season

Rice crop was usually planted in three seasons, i.e. in January, by planting at fortnightly interval during the third crop season (December-January to March-April), first crop (April-May to September-October) and second crop (September-October to December-January) respectively. Accordingly, crop harvests were done during May, October and January for the above three seasons.

6 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 Report 5 (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 modeling 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 has taken

- Rainfall
- Maximum temperature
- Minimum temperature
- Solar radiation

The regional climate scenarios including radiation, maximum temperature (T_{max}), minimum temperature (T_{min}) and precipitation as inputs of the CROPWAT model to simulate the impacts of climate change on water requirement of rice in Thrissur district, Kerala.

Table 1. Description of representative concentration pathway (RCP) scenarios (Moss, 2010)

RCP	Description
RCP 2.6	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.
RCP 4.5	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.
RCP 6.0	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.
RCP 8.5	It is characterized by increasing GHG emissions over time representative of scenarios in the literature leading to high GHG concentration levels.

7 General Circulation Models (GCMs) Used

The ensembled mean data of seventeen models have been used for the years 2030, 2050 and 2080.

Table 2. General Circulation Models used for the study

No	Model	Institution
1	BCC-CSM 1.1	Beijing Climate Center, China Meteorological Administration
2	BCC-CSM 1.1(m)	Beijing Climate Center, China Meteorological Administration
3	CSIRO-Mk3.6.0	Commonwealth Scientific and Industrial Research Organisation and the Queensland Climate Change Centre of Excellence
4	FIO-ESM	The First Institute of Oceanography, SOA, China
5	GFDL-CM3	Geophysical Fluid Dynamics Laboratory
6	GFDL-ESM2G	Geophysical Fluid Dynamics Laboratory
7	GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory
8	GISS-E2-H	NASA Goddard Institute for Space Studies
9	GISS-E2-R	NASA Goddard Institute for Space Studies
10	HadGEM2-ES	Met Office Hadley Centre
11	IPSL-CM5A-LR	Institut Pierre-Simon Laplace
12	IPSL-CM5A-MR	Institut Pierre-Simon Laplace
13	MIROC-ESM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
14	MIROC-ESM-CHEM	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
15	MIROC5	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
16	MRI-CGCM3	Meteorological Research Institute
17	NorESM1-M	Norwegian Climate Centre

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

The results and discussion of the research project entitled “Impact of climate change on crop water requirement rice in Thrissur district” are presented in this chapter. The effects of climate change on crop and irrigation water requirement were studied. The simulation model CROPWAT. 8.0 developed by FAO was used for studying the impact of climate change based on IPCC projections for the year 2030, 2050 and 2080 based on RCP 4.5, which is the most likely scenario for India.

4.1 Climate of Thrissur

The monthly weather parameters viz., maximum and minimum temperatures, rainfall, relative humidity, wind speed and bright sunshine hours recorded at Agro-meteorological Observatory, College of Horticulture, Vellanikkara were used for the study and are depicted in table 3.

Mean maximum monthly temperature of 35.3°C was observed during the month of March. It was followed by February (34.5°C), April (34.4°C), January (32.8°C) and May (32.6°C) respectively lowest minimum temperature was observed during the month of December and January 22.5° C. The minimum temperature observed during the months which reported highest maximum temperatures were March (24.1°C), February (22.7°C), April (24.9°C), January (22.5°C), May (24.7°C) respectively.

4.1.1 Rainfall

The normal annual rainfall of Thrissur is 2637.1mm. The highest monthly rainfall was recorded in the month of July (577.3 mm) and the lowest was observed during the month of January (0.7 mm). The average annual rainfall for the district is 2637.7mm and months of June, July received rainfall of 533.5mm and 577.3mm respectively. During the third crop season (summer), January to April the average amount of 148.5mm rainfall will be occurring. Non availability of rainfall during the critical stages of rice crop necessitates the application of irrigation water.

Table 3. Monthly climatic data of Thrissur district

Month	Temperature (°C)		Radiation (MJ/m^2/day)	Rain (mm)
	Minimum	Maximum		
January	22.5	32.8	20.4	0.7
February	22.7	34.5	22.0	19.0
March	24.1	35.3	21.8	42.4
April	24.9	34.4	20.5	86.4
May	24.7	32.6	18.6	234.3
June	23.4	30.0	13.9	533.5
July	22.9	29.2	12.8	577.3
August	23.1	29.5	15.0	414.4
September	23.1	30.3	17.1	307.4
October	23.0	30.9	16.5	334.4
November	23.2	31.5	16.9	79.1
December	22.5	31.6	18.5	8.2
Average	23.3	31.9	17.8	Total 2637.1

The weather parameters of temperature and radiation being higher during the third crop season, the situation demands assured irrigation to meet the evapotranspiration requirement.

4.1.2 Temperature

The mean monthly maximum temperature of the district is 31.9°C and March is the hottest month (35.3°C). The mean monthly minimum temperature is 23.3°C and December (22.5°C) is the coldest month.

4.1.3 Solar radiation

The solar radiation during the entire year revealed that the maximum available solar radiation was recorded during the month of February and the lowest was observed during the month of July. The average annual solar radiation was to the tune of 17.8 $MJ/m^2/day$. The months of February, March, April, January receive higher values of solar radiation which were recorded as 22.0, 21.8, 20.5, 20.4 $MJ/m^2/day$ respectively.

4.2 Impact of climate change

The variations in the climatic parameters viz, maximum and minimum temperature, rainfall and solar radiation as per RCP 4.5 were modeled using the general circulation models.

4.2.1 Minimum temperature

The impact of climate change on monthly minimum temperature is shown in table 4.and figure.1.

From the fig, it was very clear the minimum temperature will increase from present (2015) to 2080 and the month of May will become the hottest month of the year during the periods 2030, 2050 and 2080.

The predicted minimum temperature for the future years of 2030, 2050 and 2080 are presented in table 4. Predicted mean minimum temperatures for the months of 2030, 2050 and 2080 are depicted in fig.1. It could be seen that the minimum temperatures are likely to increase during the future years. Months of March, April, May and June may remain as the hot period with May as the hottest month. The minimum temperatures observed at present for the period June to November is almost uniform

Table 4. Minimum temperature

Month	Temperature (°C) at present and during future period			
	Present	**2030**	**2050**	**2080**
January	22.5	22.0	22.9	24
February	22.7	24.2	24.9	25.8
March	24.1	25.8	26.5	27.4
April	24.9	26.3	27.0	27.7
May	24.7	28.4	29.0	29.6
June	23.4	26.4	27.1	27.7
July	22.9	24.3	25.0	25.6
August	23.1	25.8	26.4	27.0
September	23.1	24.9	25.6	26.2
October	23.0	26.5	27.1	27.7
November	23.2	23.9	24.8	25.5
December	22.5	23.5	24.3	25.2
Average	23.3	25.2	25.9	26.6

but the trend is likely to vary during the predicted years of 2030, 2050 and 2080. The minimum temperatures during the summer season are found to be showing an increasing trend during the predicted years of 2030, 2050 and 2080. The predicted mean temperatures are found to increase during the future periods.

4.2.2 Maximum temperature

The impact of climate change on monthly maximum temperature is shown in table 5.and fig.2.

From the Fig.2 it was very clear the maximum temperature will show an increasing trend from present (2015) to 2080 and the month of May will become the hottest month of the year during the periods 2030, 2050 and 2080. Unlike the minimum temperature, the increase in maximum temperature is moderate.

The maximum temperatures observed at present during the months of June to November remained uniform but the predicted maximum temperature during the periods is found to be varying with higher values than the present. Highest maximum temperatures during the future years are predicted during the month of May. The summer months January to March will also remain as the hot months during the predicted years.

The maximum and minimum temperature showed a continuous increase as compared to present climate mainly due to radiative forcing as a result of increased atmospheric carbon dioxide concentration according to RCP 4.5.The results are in agreement with the findings reported by IMD (2013) and Prathap *et al*. (2014).

4.2.3 Solar radiation

The impact of climate change on monthly solar radiation is presented in table 6 and fig.3.

From the results, it was very clear that the monthly solar radiation will increase during summer months i.e., from February to May and during August, September, November and December. It is interesting to notice that unlike temperature, the intensity of solar radiation will not change much during 2030, 2050 and 2080.

Table 5. Maximum temperature

Month	Temperature at present and during future years (°C)			
	Present	2030	2050	2080
January	32.8	31.4	32.2	33.0
February	34.5	34.8	35.3	35.9
March	35.3	35.7	36.2	36.8
April	34.4	35.1	35.7	36.4
May	32.6	36.6	37.2	37.9
June	30.0	32.0	32.7	33.2
July	29.2	29.8	30.5	31.3
August	29.5	31.6	32.2	32.8
September	30.3	30.0	30.8	31.3
October	30.9	33.0	33.6	34.2
November	31.5	30.8	31.3	31.8
December	31.6	33.5	34.2	34.8
Average	31.9	32.9	33.5	34.1

Table 6. Solar radiation

Month	Solar radiation at present and during future years (MJ/m²/day)			
	Present	**2030**	**2050**	**2080**
January	20.4	18.2	18.2	18.3
February	22.0	22.8	22.8	21.7
March	21.8	24.6	24.6	24.9
April	20.5	26.2	26.2	25.9
May	18.6	21.7	21.7	22.2
June	13.9	13.5	13.5	13.8
July	12.8	11.8	11.8	12.7
August	15.0	19.4	19.4	20.3
September	17.1	23.5	23.5	23.7
October	16.5	15.9	15.9	16.3
November	16.9	19.9	19.9	19.9
December	18.5	15.9	15.9	16.5
Average	17.8	19.4	19.4	19.7

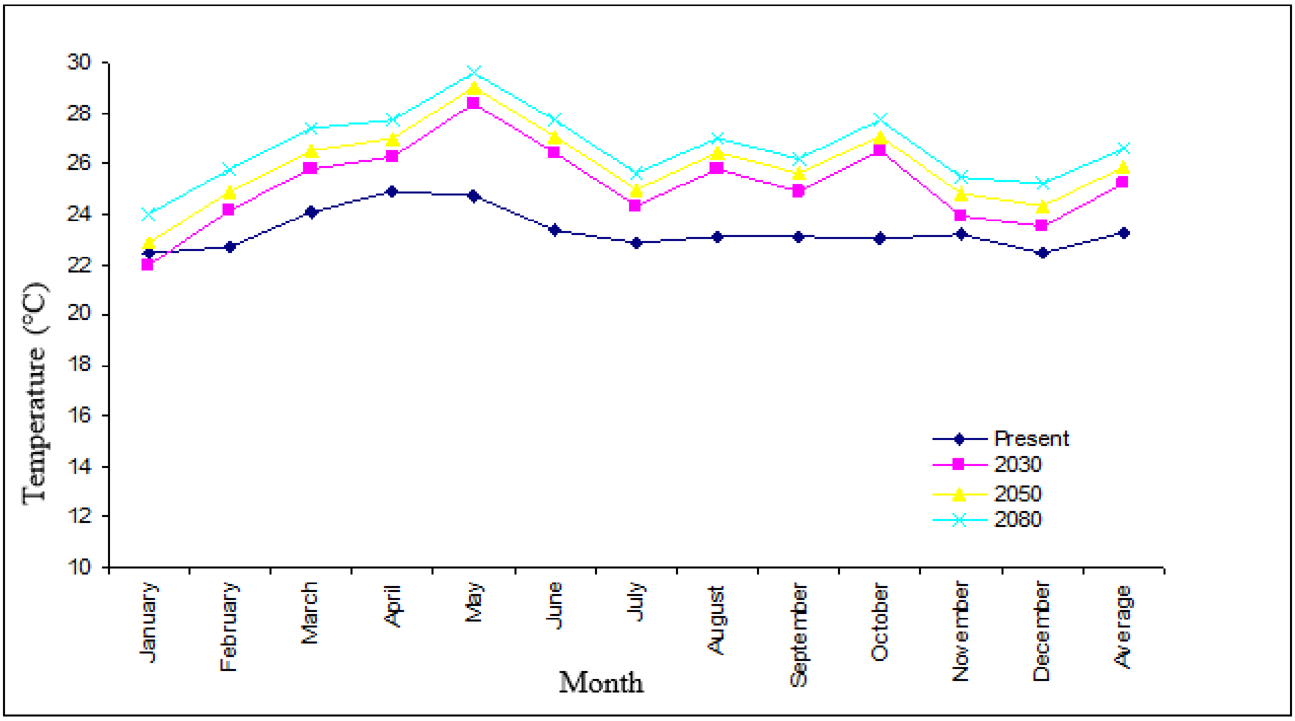

Fig. 1. Minimum temperature

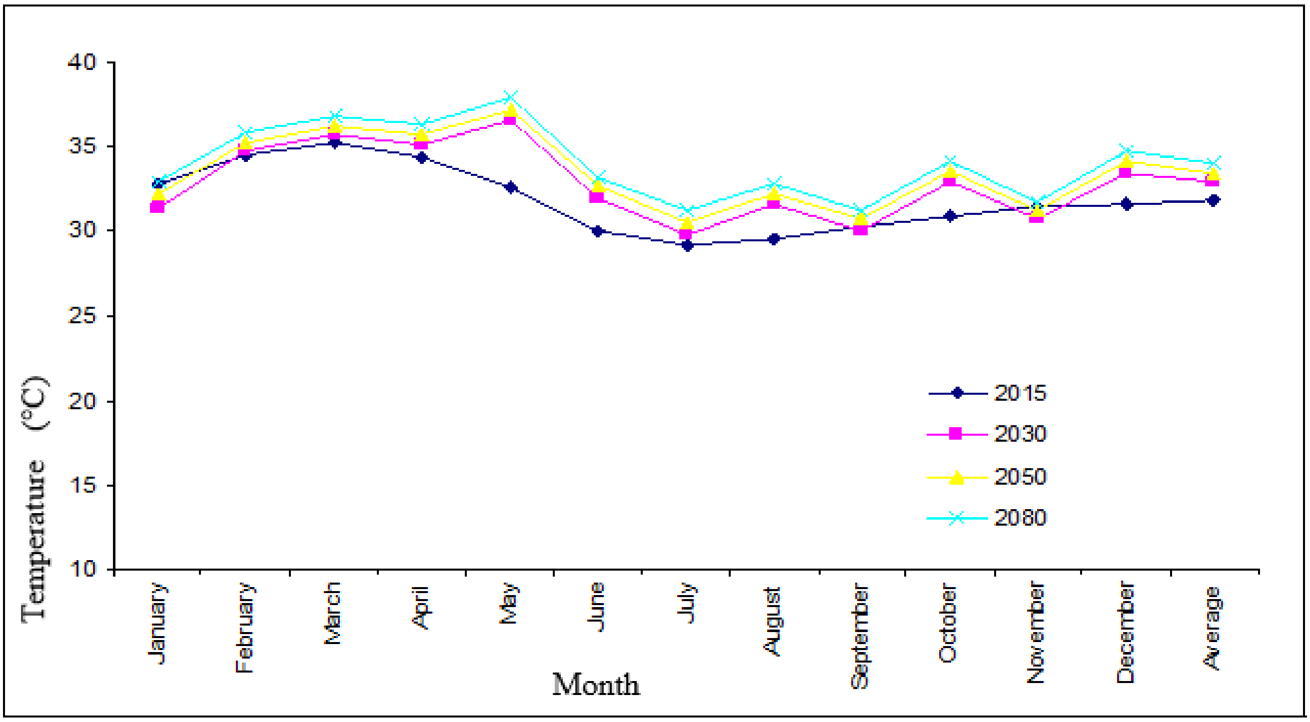

Fig. 2. Maximum temperature

In general, the solar radiation showed an increasing trend. But during rainy season there will be considerable reduction in the amount of insolation particularly during the month of June-July. It may be mainly because of increased cloudiness associated with increase in rainfall activities during that period. The productivity of rice may decrease due to decreased radiation as reported by IARI (2012).

4.2.4 Rainfall

The impact of climate change on monthly rainfall is presented in table 7 and fig.4.

From the results, it was very clear that the total amount of rainfall is going to increase in the future. June and July months will continue to be the months receiving highest amount of rainfall. The rainfall activity during the south west monsoon period will increase. It is worth to notice that the amount rainfall after south west will drastically reduce under climate change projections and the summers will be drier compared to present day conditions. The future climate change projections showed poor rainfall distribution and predisposes the district to frequent floods and droughts.

The predicted average rainfall for the future years of 2030, 2050 and 2080 will increase from the present value of 2637.1mm to 3139.1, 3089.8 and 3307.6mm respectively. It is likely that the onset of south west monsoon may become early or the summer rains may continue to give a good amount of rainfall during April and May. The period November to March will continue to remain dry during the future years also. This may affect crops and possible shifts in the cropping season may also occur as reported by Anna and Richa (2012).According to Ngugyen (2012), rainfall pattern is a limiting factor in rice production and variability in rainfall pattern will affect the rice production.

4.3 Impact of climate change on crop water requirement in rice

The growth of rice plant in relation to water management can be divided into four periods viz., seedling, vegetative, reproductive and ripening. Less water is consumed during seedling stage. Water requirements are worked out for different stages of growth.

Table 7. Predicted rainfall

Month	Rainfall at present and during future years (mm)			
	Present	**2030**	**2050**	**2080**
January	0.7	0	0	0
February	19	0	0	1.7
March	42.4	7.1	15.4	26.6
April	86.4	13.1	11.5	75.7
May	234.3	336.5	277.1	409.5
June	533.5	918.6	982.5	909.9
July	577.3	1019.6	996.2	1083.1
August	414.4	479.3	488.5	485.5
September	307.4	77.1	3.9	3.9
October	334.4	222.2	236.2	238.9
November	79.1	23.1	39.3	27.5
December	8.2	42.5	39.2	45.3
Total	**2637.1**	**3139.1**	**3089.8**	**3307.6**

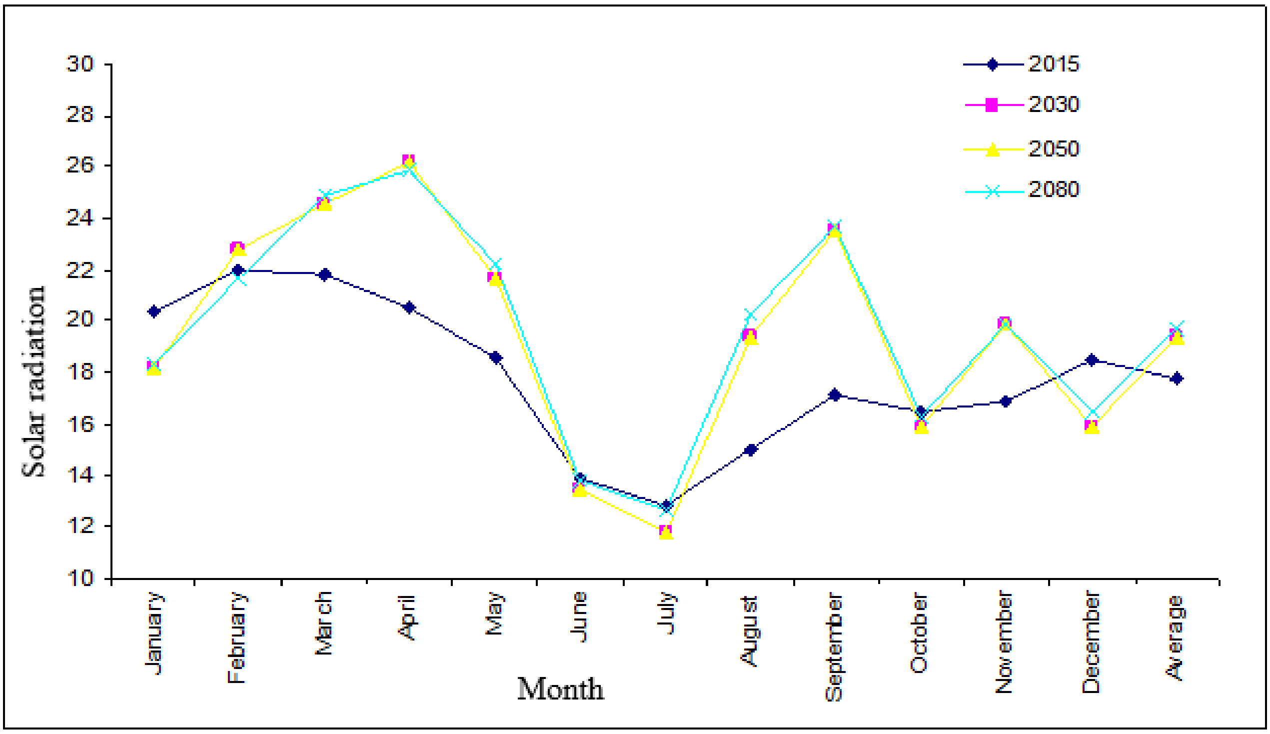

Fig. 3. Solar radiation

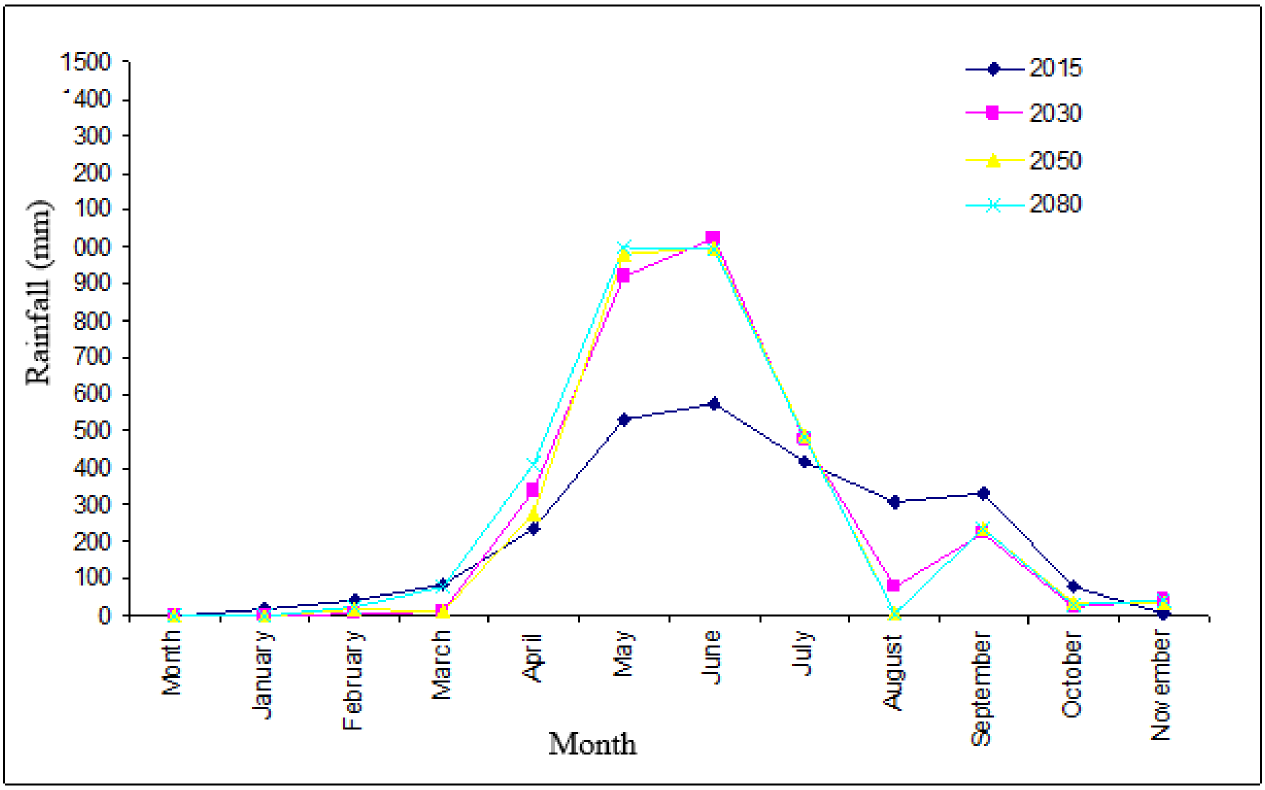

Fig. 4. Rainfall during predicted years

4.3.1 Reference crop evapotranspiration (ET_0)

The impact of climate change on reference crop evapotranspiration in rice is presented in Table 8.

It is clear from the table that the total annual reference crop evapotranspiration is showing an increasing trend. As per the RCP 4.5 scenario, 2080s will have the highest average annual reference crop evapotranspiration (4.6 mm a day) where as in the present day conditions it was 4.06 mm.

The increase in reference crop evapotranspiration is mainly associated with increase in atmospheric temperature and incoming solar radiation. This result was on par with the findings of Chung (2013).

4.3.2 Crop evapotranspiration (ET_c)

The impact of climate change on crop evapotranspiration in rice is presented in tables 9, 10 and 11.The results showed that the crop evapotranspiration in all the three rice growing seasons will increase as per the projected climate change scenario based on RCP 4.5. The total crop evapotranspiration was found to be increasing from 49.99 mm during 2015 to 61.27 mm during 2080 in first crop season, whereas during second and third crop seasons, it was 56.53 mm to 82.17 mm and 77.16 mm to 83.17 mm respectively. Among the different seasons, irrespective of the future periods first crop season showed the lowest crop evapotranspiration.

As mentioned in the case of ET_0, the increase in atmospheric temperature increased the crop evapotranspiration from the field. The increase in atmospheric temperature eventually increased the water holding capacity of the atmosphere and thus required more water to become saturated. The changes in crop evapotranspiration will be more prominent during first and second crop seasons. This is mainly because of the reduction in the number of days with assured rainfall during the season. During the third crop season, the ET_0 was found to increase from the present value of 77.16 mm to 79.67, 81.2 and 83.7 mm for the future years of 2030, 2050 and 2080 respectively. Although the ET_0 recorded higher values during the third crop season, the increase recorded for future years were nominal. The increase in ET_0 for future years in the first and second crop seasons was more predominant and likely to affect the crop production. Climatic

Table 8. Reference crop evapotranspiration (ET_0)

Month	Reference crop evapotranspiration (ET_0) (mm/day)			
	Present	**2030**	**2050**	**2080**
January	5.2	4.66	4.76	4.89
February	5.36	5.48	5.56	5.5
March	5.02	5.58	5.65	5.81
April	4.75	5.82	5.91	5.96
May	4.18	5.16	5.24	5.42
June	3.11	3.24	3.28	3.37
July	2.8	2.64	2.68	2.88
August	3.22	4.16	4.22	4.46
September	3.6	4.72	4.81	4.91
October	3.45	3.55	3.6	3.73
November	3.72	4.06	4.13	4.19
December	4.25	3.9	3.97	4.11
Average	**4.06**	**4.41**	**4.48**	**4.60**

Table 9. Crop evapotranspiration at present and during future years in first crop season

Month	Stage	Evaporation during first crop season (mm/day)			
		Present	2030	2050	2080
May	Nurs	0.52	0.66	0.66	0.68
May	Nurs/LPr	4.05	5.14	5.18	5.36
May	Nurs/LPr	4.07	4.91	4.95	5.12
Jun	Init	3.81	4.20	4.25	4.39
Jun	Init	3.42	3.45	3.50	3.60
Jun	Deve	3.30	3.24	3.31	3.45
Jul	Deve	3.18	2.92	3.00	3.18
Jul	Deve	3.07	2.60	2.70	2.92
Jul	Mid	3.22	3.23	3.33	3.56
Aug	Mid	3.37	4.01	4.11	4.35
Aug	Mid	3.53	4.61	4.70	4.96
Aug	Late	3.66	4.69	4.87	5.08
Sep	Late	3.69	4.65	4.98	5.13
Sep	Late	3.65	4.56	4.99	5.08
Sep	Late	3.45	4.03	4.31	4.41
Total		**49.99**	**56.9**	**58.84**	**61.27**

Table 10. Crop evapotranspiration at present and during future years in second crop season

Month	Stage	Evaporation during second crop season (mm/day)			
		Present	**2030**	**2050**	**2080**
Aug	Nurs	0.37	0.45	0.45	0.5
Aug	Nurs/LPr	3.12	4.14	4.2	3.99
Aug	Nurs/LPr	3.56	4.7	4.78	4.65
Sep	Init	3.82	5.13	5.22	5.09
Sep	Init	3.96	5.41	5.51	5.37
Sep	Deve	3.92	4.91	4.99	5.64
Oct	Deve	3.89	4.19	4.26	5.94
Oct	Deve	3.85	3.69	3.74	6.24
Oct	Mid	3.96	3.95	4.00	6.38
Nov	Mid	4.06	4.29	4.35	6.49
Nov	Mid	4.16	4.48	4.54	6.61
Nov	Late	4.35	4.42	4.48	6.66
Dec	Late	4.44	4.20	4.26	6.55
Dec	Late	4.46	3.97	4.03	6.28
Dec	Late	4.61	4.14	4.21	5.78
Total		**56.53**	**62.07**	**63.02**	**82.17**

Table 11. Crop evapotranspiration at present and during future years in third crop season

Month	Stage	Evaporation during third crop season(mm/day)			
		Present	**2030**	**2050**	**2080**
Dec	Nurs	0.49	0.47	0.47	0.5
Dec	Nurs/LPr	4.12	3.69	3.75	3.99
Dec	Nurs/LPr	4.86	4.35	4.43	4.65
Jan	Init	5.37	4.85	4.95	5.09
Jan	Init	5.72	5.12	5.24	5.37
Jan	Deve	5.84	5.47	5.57	5.64
Feb	Deve	6	5.85	5.94	5.94
Feb	Mid	6.15	6.24	6.32	6.24
Feb	Mid	6.06	6.3	6.38	6.38
Mar	Mid	5.93	6.34	6.42	6.49
Mar	Mid	5.8	6.38	6.45	6.61
Mar	Mid	5.7	6.47	6.55	6.66
Apr	Late	5.44	6.38	6.54	6.55
Apr	Late	5.07	6.15	6.35	6.28
Apr	Late	4.61	5.61	5.76	6.78
Total		**77.16**	**79.67**	**81.12**	**83.17**

factors like radiation, humidity, wind speed and rainfall also influenced the ET_0 and led to consequent changes as reported by Mo et al. (2013).

4.3.3 Irrigation water requirement

The effect of climate change on irrigation water requirement of rice are depicted in tables 12, 13 and 14.

The impact of climate change on irrigation water requirement is very much evident and will increase up to 2050 and then start to decrease. During first crop season, the amount of irrigation water will increase till 2050s (319.6 mm) and then start decreasing and will reach 265.6 mm during 2080s. During the second crop season, the irrigation water requirement will increase considerably i.e., 485.3 mm in 2030s, 549.1 mm in 2050s and 571.5 in 2080s as compared to 368.1 mm during 2015. During the third crop season, the increase in irrigation water requirement will be marginal and it will get back to the present day irrigation water requirement during 2080s. The total irrigation water requirement during the third crop season will be 982.3 mm in 2030s, 994.8 mm in 2050s and 933.4 mm in 2080s. The present day irrigation water requirement during the third crop season was 931.9.

From the above results in can be inferred that the irrigation water requirement variations will be high during the second crop season and it will require more than 100 mm water for success cultivation in the future as per RCP 4.5 scenario.

The irrigation water showed a high variation with cropping season. The variation will be high during second crop season where the expected rainfall will be less compared to the present climate whereas during the third crop season, the variation will be less. This will be mainly because of the reduced rainfall from August to December as per RCP4.5 scenario. The results are supported with the findings of Kar and Verma (2005).

4.3.4 Effective rainfall

The effective rainfall showed considerable seasonal variations (Table 15,16 and 17). The maximum effective rainfall was recorded during the first crop season followed by second crop season, whereas it was very less during third crop season. In the first crop season, the effective rainfall will be high compared to present climatic conditions during 2030s (831.6 mm) where as it is going to reduce during second and third crop seasons.

As the effective rainfall is the function of the rainfall available during the particular season, it was more in kharif season as compared to rabi and summer but it is interesting to notice that in general the amount of effective rainfall is going to decrease as per the future climate projections. This may be mainly due to the increase in the intensity of rainfall which leads to more runoff under Kerala climate.

4.4 Impact of climate change on water use efficiency

Water use efficiency (WUE) is quantified by the ratio of crop production to crop evapotranspiration (ETc), which can provide insight into the ecological functioning of the land surface and ecosystem resilience. The improvement in our understanding of how climatic and agronomic factors influence crop WUE is essential to develop sustainable management strategies for future climate change mitigation and adaptation. In order to find out the water use efficiency of rice under climate change, the study conducted by Subramaniam (2015) on impact of climate change on rice production was used. According to him the reduction in yield due to climate change as per RCP 4.5 will be as follows (Table No 18).

4.4.1 Field water use efficiency

The impact of climate change on field water use efficiency i.e., the ratio of yield of the crop to total water requirement in the field (WR = irrigation requirement + Effective rainfall). The results showed that the field water use efficiency showed a declining trend as per the projected climate change (RCP 4.5 scenario) (Table 19).

4.4.2 Crop water use efficiency

Crop water use efficiency is the yield of the crop (y) per unit of water lost through evapotranspiration of the crop (ETc). It was calculated and it was depicted in table 20.

It can be seen from the table that crop water efficiency in the purview of climate change will go on to decrease drastically up to 2080. Only in the case of third crop

Table 12. Irrigation Water Requirement at present and during different years in first crop season

Month	Stage	Irrigation Water Requirement during crop season(mm)			
		Present	**2030**	**2050**	**2080**
May	Nurs	0	0	0	0
May	Nurs/LPr	65.6	66.1	66.1	66.2
May	Nurs/LPr	135.3	67.8	112.6	53.1
Jun	Init	0	0	0	0
Jun	Init	0	0	0	0
Jun	Deve	0	0	0	0
Jul	Deve	0	0	0	0
Jul	Deve	0	0	0	0
Jul	Mid	0	0	0	0
Aug	Mid	0	0	0	0
Aug	Mid	0	0	0	0
Aug	Late	0	5.1	10.8	13
Sep	Late	0	20.4	47.6	49.1
Sep	Late	0	35	49.9	50.8
Sep	Late	0	8.6	32.6	33.4
Total		**200.9**	**203.1**	**319.6**	**265.6**

Table 13. Irrigation Water Requirement at present and during future years in second crop season

Month	Stage	Irrigation Water Requirement during second crop season(mm)			
		Present	2030	2050	2080
Aug	Nurs	0	0	0	0
Aug	Nurs/LPr	65.3	65.7	65.7	65.8
Aug	Nurs/LPr	124.1	140.7	147.7	150.4
Sep	Init	0	22.8	50.1	51.7
Sep	Init	0	40.2	55.1	56.2
Sep	Deve	0	23.9	48.1	49.3
Oct	Deve	0	0	1.5	2.2
Oct	Deve	0	0	0	0
Oct	Mid	0	3	0	1.2
Nov	Mid	8.5	26.4	22.4	26.4
Nov	Mid	19.9	43.9	38.3	43.8
Nov	Late	28.2	39.2	36	39.5
Dec	Late	36.6	29	29.2	30.4
Dec	Late	44.4	23.9	26.4	26.1
Dec	Late	41.3	26.7	28.6	28.5
Total		**368.1**	**485.3**	**549.1**	**571.5**

Table 14. Irrigation Water Requirement (mm) at present and during future years in third crop season

Month	Stage	Irrigation Water Requirement during third crop season (mm)			
		Present	**2030**	**2050**	**2080**
Dec	Nurs	0	0	0	0
Dec	Nurs/LPr	106.7	86.5	89.1	88.8
Dec	Nurs/LPr	282.4	204.8	208.2	208.9
Jan	Init	53.5	48.4	49.3	50.8
Jan	Init	57.2	51.2	52.4	53.7
Jan	Deve	63.6	60.2	61.3	62.0
Feb	Deve	55.9	58.5	59.4	59.4
Feb	Mid	55.5	62.4	63.2	62.4
Feb	Mid	40.1	50.3	50.9	49.2
Mar	Mid	48.9	61.9	60.3	59.6
Mar	Mid	45.4	61.4	58.7	58.4
Mar	Mid	46.0	68.2	66.9	60.8
Apr	Late	34.7	63.3	64.4	49.7
Apr	Late	27.7	61.5	63.5	43.4
Apr	Late	14.5	43.8	47.2	26.4
Total		**931.9**	**982.3**	**994.8**	**933.4**

Table 15. Effective rainfall at present and during different years in first crop season

Month	Stage	Effective rainfall during first crop season (mm)			
		Present	**2030**	**2050**	**2080**
May	Nurs	37.8	35.5	33.7	41
May	Nurs/LPr	50.7	57	54.3	57.2
May	Nurs/LPr	53.6	62.1	61	63.1
Jun	Init	56.7	67.4	68.7	70.5
Jun	Init	60.7	74.6	77.7	78
Jun	Deve	60.8	74.7	76.8	76.4
Jul	Deve	61.1	75.9	76.5	74.9
Jul	Deve	61.9	77.8	77.5	74.8
Jul	Mid	59.7	71.1	71	69.2
Aug	Mid	57.1	65.1	67.4	66.8
Aug	Mid	55.2	60.1	63.5	63.7
Aug	Late	54.1	47.6	42.8	42.9
Sep	Late	52.7	28.5	2.2	2.2
Sep	Late	51.3	13.9	0	0
Sep	Late	41.5	20.2	1.5	1.5
Total		**814.9**	**831.6**	**774.4**	**782.3**

Table 16. Effective rainfall at present and during different years in second crop season

Month	Stage	Effective rainfall during second crop season (mm)			
		Present	**2030**	**2050**	**2080**
Aug	Nurs	51.4	58.6	60.6	60.1
Aug	Nurs/LPr	55.2	60.1	63.5	63.7
Aug	Nurs/LPr	54.1	47.6	42.8	42.9
Sep	Init	52.7	28.5	2.2	2.2
Sep	Init	51.3	13.9	0	0
Sep	Deve	51.8	25.2	1.8	1.8
Oct	Deve	55.4	45.5	41.1	41.6
Oct	Deve	57.2	57	61	61.8
Oct	Mid	45.8	40.5	44.7	44.1
Nov	Mid	32.1	16.5	21	17.9
Nov	Mid	21.7	0.9	7.1	2.3
Nov	Late	15.4	5	8.8	6.2
Dec	Late	7.8	13	13.4	14.1
Dec	Late	0.2	15.9	13.9	16.7
Dec	Late	0.2	8.6	7.6	9.1
Total		**552.3**	**436.9**	**389.6**	**384.6**

Table 17. Effective rainfall at present and during different years in third crop season

Month	Stage	Effective rainfall during third crop season (mm)			
		Present	**2030**	**2050**	**2080**
Dec	Nurs	7	11.7	12.1	12.7
Dec	Nurs/LPr	0.2	15.9	13.9	16.7
Dec	Nurs/LPr	0.2	10.6	9.3	11.1
Jan	Init	0.3	0.1	0.1	0.1
Jan	Init	0	0	0	0
Jan	Deve	0.6	0	0	0
Feb	Deve	4.1	0	0	0
Feb	Mid	6	0	0	0
Feb	Mid	8.4	0.1	0.1	1.8
Mar	Mid	10.4	1.6	3.9	5.3
Mar	Mid	12.6	2.3	5.9	7.7
Mar	Mid	16.7	3	5.2	12.5
Apr	Late	19.8	0.6	1	15.8
Apr	Late	23.1	0	0	19.4
Apr	Late	31.7	12.4	10.4	31.4
Total		**141**	**58.2**	**61.9**	**134.5**

Table 18. Per cent change in the yield of rice as per RCP 4.5 scenario

Season	Present yield (t ha^{-1})	Change in the yield (%)		
		2030	2050	2080
1st Season	5.70	0.0 (5.7)	-7.0 (5.3)	-22 (4.4)
2nd Season	5.70	-35 (3.7)	-38 (3.5)	-43 (3.2)
3rd Season	5.60	-26 (4.1)	-26 (4.1)	-23 (4.3)

Table 19. Field water use efficiency

Season	**Field water use efficiency**			
	Present	**2030**	**2050**	**2080**
I Crop	5.6	5.5	4.8	4.2
II Crop	6.2	4.0	4.9	3.3
III Crop	5.2	3.9	3.9	4.0

season, the crop water use efficiency was consistent throughout the projected climate change periods.

The field water use efficiency and crop water use efficiency in rice will be going to decline as an impact of climate of climate change mainly due to reduction in yield as a result of elevated temperature and increase in the evaporative demand of the atmosphere.

4.4.3 Impact of climate change on irrigation water requirement of Thrissur district

The impact of climate change on irrigation water requirement was depicted in table 21. It can be clearly observed from the table that the irrigation water of Thrissur district will increase tremendously as per the climate change projections (RCP 4.5). An additional amount of about 200 billion litres of water will be required for meeting increased demand in future during the second crop season, during which the area under cultivation is maximum. The second important rice growing season of Thrissur is third crop season and the area under cultivation is about 7881 ha. The irrigation water requirement during the third crop season will be very high (about 750 billion litres) and the expected rainfall will be lesser compared to these days. Considering the above conditions, it can be concluded that rice production in Thrissur district will be difficult during the second and third crop seasons.

Table 20. Crop water use efficiency

Season	Crop water use efficiency			
	Present	2030	2050	2080
I Crop	11.3	9.9	8.9	7.1
II Crop	10.0	5.9	5.5	4.9
III Crop	7.2	5.1	5.0	5.2

Table 21. Irrigation water requirement

Season	Area	Irrigation water requirement			
		Present	2030	2050	2080
First Crop	1810	36.4	36.8	57.8	48.1
Second Crop	12580	463.1	610.5	690.8	718.9
Third Crop	7881	734.4	774.2	784.0	735.6

SUMMARY AND CONCLUSION

CHAPTER 5
SUMMARY AND CONCLUSION

Rice is indigenous to humid areas of tropical and subtropical regions. It is grown under wide range of soil and water conditions. The critical factors such as soil air, soil water and temperature define the optimum condition to obtain maximum yield. The water requirement for the rice crop generally varies from 950 mm to 1250 mm depending on the season and crop growth conditions. It is reported that the present climate is likely to vary in future years. The likely change in the weather parameters and associated climate change will affect the crop water requirement of rice. This study has been taken up with objective of generating the climate for 2030, 2050 and 2080. Under emission scenario, RCP 4.5 and to work at the crop water requirement of rice under the predicted climate.

The climate of Thrissur district during the present day was analysed based on the weather parameters and data available from the Department of Agricultural Meteorology, College of Horticulture, Vellanikkkara The mean monthly maximum temperature of the district is 31.9°C and March is the hottest month (35.3°C). The mean monthly minimum temperature is 23.3°C and December (22.5°C) is the coldest month. Mean maximum monthly temperature of 35.3°C was observed during the month of March. It was followed by February (34.5°C), April (34.4°C), January (32.8°C) and May (32.6°C) respectively. Lowest minimum temperature of 22.5°C was observed during the month of December and January. The normal annual rainfall of Thrissur is 2637.1mm. The highest monthly rainfall was recorded in the month of July (577.3 mm) and the lowest was observed during the month of January (0.7 mm). Months of June and July receive rainfall of 533.5mm and 577.3mm respectively. During the third crop season (summer) January to April the average amount of 148.5mm rainfall will be occurring. Non availability of rainfall during the critical stages of rice crop necessities the application of irrigation water. The average annual solar radiation was to the tune of 17.8 $MJ/m^2/day$. The months of February, March, April, January receive higher values of solar radiation which were recorded as 22.0, 21.8, 20.5, 20.4 $MJ/m^2/day$ respectively. Maximum available solar radiation was recorded during the month of February and the lowest was observed during the month of July. The weather parameters of temperature and radiation being higher during the third crop season, the situation demands assured irrigation to meet the evapotranspiration requirements.

The variations in the climatic parameters viz, maximum and minimum temperature, rainfall and solar radiation as per RCP 4.5 were analyzed and modelled using the General Circulation Models and the ensemble results were used for the study.

The minimum temperatures are likely to increase during the future years of 2030, 2050 and 2080. Months of March, April, May and June may remain as the hot period with May as the hottest month. The minimum temperatures observed at present for the periods June to November is almost uniform but the trend is likely to vary during the predicted years of 2030, 2050 and 2080. The minimum temperatures during the summer season are found to be showing an increasing trend during the predicted years of 2030, 2050 and 2080.

The maximum temperature will show an increasing trend from present (2015) to 2080 and the month of May will become the hottest month of the year during the periods 2030, 2050 and 2080. Unlike the minimum temperature, the increase in maximum temperature is moderate. The maximum temperatures observed at present during the months of June to November remained uniform but the predicted maximum temperature during the periods is found to be varying with higher values than the present. Highest maximum temperatures during the future years was predicted as the month of May. The summer months January to March will also remain as the hot months during the predicted years. The monthly solar radiation will increase during summer months i.e., from February to May and during August, September, November and December. In general, the solar radiation showed an increasing trend. But during the rainy season there will be considerable reduction in the amount of insolation particularly during the month of June-July. It may be mainly because of increased cloudiness associated with increase in rainfall activities during that period.

The predicted average rainfall for the future years of 2030, 2050 and 2080 will increase from the present value of 2637.1mm to 3139.1, 3089.8 and 3307.6mm respectively. It is likely that the onset of south west monsoon may become early or the summer rains may continue to give a good amount of rainfall during April and May. The period November to March will continue to remain dry during the future years also. This may affect crops and possible shifts in the cropping season may also occur. The rainfall is found to increase in future years based on the predictions attempted in the study. Months of June and July will continue to receive highest amount of rainfall. The rainfall activity during the south west monsoon period will increase. It is worth to notice that the amount of rainfall after south west monsoon period will drastically reduce under climate change projections and the summers will be drier compared to present day conditions. The future climate change projections showed poor rainfall distribution and predisposes the district to frequent floods and droughts.

As per the RCP 4.5 scenario, 2080s will have the highest average annual reference crop evapotranspiration (4.6 mm a day) where as in the present day conditions it was 4.06 mm. It is clear from the table that the total annual reference crop evapotranspiration is showing an increasing trend.

The impact of climate change on crop evapotranspiration in rice was analysed. The results showed that the crop evapotranspiration in all the three rice growing seasons will increase as per the projected climate change scenario based on RCP 4.5. The total crop evapotranspiration was found to be increasing from 49.99 mm during 2015 to 61.27 mm during 2080 in first crop season, whereas during second and third crop seasons, the variations were from 56.53 mm to 82.17 mm and 77.16 mm to 83.17 mm respectively. Among the different seasons, irrespective of the future periods first crop season showed least crop evapotranspiration.

The impact of climate change on irrigation water requirement was found to be very evident and will increase up to 2050 and then start to decrease during the predicted years of 2050 and 2080. During first crop season, the amount of irrigation water will increase till 2050s (319.6 mm) and then start to decrease reaching to 265.6 mm during 2080s. During the second crop season, the irrigation water requirement will increase considerably i.e., 485.3 mm in 2030s, 549.1 mm in 2050s and 571.5 in 2080s as compared to 368.1 mm during 2015s. During the third crop season, the increase in irrigation water requirement will be marginal and it will get back to the present day irrigation water requirement during 2080s. The total irrigation water requirement during the third crop season will be 982.3 mm in 2030s, 994.8 mm in 2050s and 933.4 mm in 2080s.The results of the study indicate that the irrigation water requirement variations will be high during the second crop season and it will require more than 100 mm water for successive cultivation in the future as per RCP 4.5 scenario.

The availability of effective rainfall showed considerable seasonal variations. The maximum effective rainfall was recorded during the first crop season followed by second crop season, whereas it was very less during third crop season. In the first crop season, the effective rainfall will be high compared to present climatic conditions during 2030s (831.6 mm) where as it is going to reduce during second and third crop seasons.

Crop water use efficiency is the yield of the crop (y) per unit of water lost through evapotranspiration of the crop (ETc) was worked out in the present study. It was seen that crop water use efficiency in the purview of climate change will decrease drastically up to 2080.

It can be clearly observed from the study that the demand for irrigation water will increase tremendously in Thrissur District as per the climate change projections (RCP 4.5). An additional amount of about 200 billion litres of water will be required for meeting increased demand in future during the second crop season, during which the area under cultivation is maximum. The second important rice growing season of Thrissur is third crop season and the area under cultivation is about 7881 ha. The irrigation water requirement during the third crop season will be very high as about 750 billion litres. Considering the above conditions, it can be concluded that rice production in Thrissur district will be affected due to increased irrigation water demand.

In this research work, the ability of CROPWAT model is exploited for decision making in irrigation water use in response to climate change. The model has many realistic features that can be used as a decision tool for applied research of water management. The optimal water use policies were derived for the system, with an objective function, using CROPWAT model, and simulated the optimal rules of water use for climate change scenarios. Optimal long term water allocation decisions for irrigation projects are affected by several agronomic, hydrologic, climatic and economic factors. This study provides a framework for long term water allocation decisions considering the climate change scenarios.

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APPENDICES

Appendix-1

Cropwat model run for 2010

Monthly ETo Penman-Monteith data

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sun (hours)	Rad (MJ/m?/day)	ETo (mm/day)
January	22.5	32.8	57	183	8.9	20.4	5.2
February	22.7	34.5	58	143	9.1	22	5.36
March	24.1	35.3	66	88	8.2	21.8	5.02
April	24.9	34.4	73	90	7.1	20.5	4.75
May	24.7	32.6	79	72	6.1	18.6	4.18
June	23.4	30	85	68	3.2	13.9	3.11
July	22.9	29.2	85	49	2.4	12.8	2.8
August	23.1	29.5	84	72	3.7	15	3.22
September	23.1	30.3	81	62	5.1	17.1	3.6
October	23	30.9	79	51	5.2	16.5	3.45
November	23.2	31.5	71	84	6.3	16.9	3.72
December	22.5	31.6	61	120	7.9	18.5	4.25
Average	23.3	31.9	73	90	6.1	17.8	4.05

Monthly rain data

Month	Rain (mm)	Effective rain (mm)
January	0.7	0.7
February	19	18.4
March	42.4	39.5
April	86.4	74.5
May	234.3	146.5
June	533.5	178.3
July	577.3	182.7
August	414.4	166.4
September	307.4	155.7
October	334.4	158.4
November	79.1	69.1
December	8.2	8.1
Total	2637.1	1198.4

Rice data

Stage	nursery	land preparation		growth stage				total
		total	puddling	initial	develop	mid	late	
Length (days)	30	20	5	20	30	40	30	150
Kc dry	0.7		0.3	0.5	-->	1.05	0.7	
Kc wet	1.2		1.05	1.1	-->	1.2	1.05	
Rooting depth (m)				0.1	-->	0.6	0.6	
Puddling depth (m)			0.4					
Nursery area (%)	10							
Critical depletion	0.2			0.2	-->	0.2	0.2	
Yield response f.				1	1.09	1.09	1.09	1.09
Crop height (m)						1		

Soil data

General soil data:

Total available soil moisture (FC - WP)	80.0 mm/meter
Maximum rain infiltration rate	26 mm/day
Maximum rooting depth	100 centimetres
Initial soil moisture depletion (as % TA)	10%
Initial available soil moisture	72.0 mm/meter

Additional soil data for rice calculations:

Drainable porosity (SAT - FC)	15%
Critical depletion for puddle cracking	0.60 mm/day
Water availability at planting	10 mm WD
Maximum water depth	100 mm

Crop water requirements

Month	Decade	Stage	Kc coeff	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr. Req. (mm/dec)
Dec	1	Nurs	1.2	0.49	4.4	7	0
Dec	2	Nurs/LPr	1.08	4.12	41.2	0.2	106.7
Dec	3	Nurs/LPr	1.06	4.86	53.5	0.2	282.4
Jan	1	Init	1.1	5.37	53.7	0.3	53.5
Jan	2	Init	1.1	5.72	57.2	0	57.2
Jan	3	Deve	1.11	5.84	64.2	0.6	63.6
Feb	1	Deve	1.13	6	60	4.1	55.9
Feb	2	Mid	1.15	6.15	61.5	6	55.5
Feb	3	Mid	1.16	6.06	48.5	8.4	40.1
Mar	1	Mid	1.16	5.93	59.3	10.4	48.9
Mar	2	Mid	1.16	5.8	58	12.6	45.4
Mar	3	Mid	1.16	5.7	62.7	16.7	46
Apr	1	Late	1.12	5.44	54.4	19.8	34.7
Apr	2	Late	1.07	5.07	50.7	23.1	27.7
Apr	3	Late	1.01	4.61	46.1	31.7	14.5
					775.6	141	931.9

Rice irrigation schedule

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Puddl (state)	Percol. (mm)	Depl. (mm)	SMNet Gif (mm)	Loss (mm)	Depl.SA (mm)
12-Dec	-19	PrePu	0	1	100	Prep	0	4	65.6	0	60
23-Dec	-8	PrePu	0	1	100	Prep	0	8	60	0	60
27-Dec	-4	Puddl	0	1	100	Prep	3	0	107.4	0	57.4
31-Dec	0	Puddl	0	1	100	OK	4.6	0	58.6	0	8.6
06-Jan	6	Init	0	1	100	OK	3	0	99.9	0	-0.1
18-Jan	18	Init	0	1	100	OK	3	0	102.8	0	2.8
29-Jan	29	Dev	0	1	100	OK	3	0	96	0	-4
10-Feb	41	Dev	0	1	100	OK	3	0	103	0	3
22-Feb	53	Mid	0	1	100	OK	3	0	103.1	0	3.1
06-Mar	65	Mid	0	1	100	OK	3	0	97.6	0	-2.4
19-Mar	78	Mid	0	1	100	OK	3	0	101.2	0	1.2
02-Apr	92	End	0	1	100	OK	3	0	102.4	0	2.4
18-Apr	108	End	0	1	100	OK	3	0	97.3	0	-2.7
30-Apr	End	End	0	1	0	OK	0	0			

Totals			
Total gross irrigation	1707.2 mm	Total rainfall	149.0 mm
Total net irrigation	1195.1 mm	Effective rainfall	128.7 mm
Total irrigation losses	0.0 mm	Total rain loss	20.3 mm
Total percolation losses	487.6 mm		

Actual water use by crop	671.8 mm	Moist deficit at harvest	0.0 mm
Potential water use by crop	671.8 mm	Actual irrigation requirement	543.1 mm
Efficiency irrigation schedule	100.00%	Efficiency rain	86.40%
Deficiency irrigation schedule	0.00%		

Yield Reduction					
Stage label	A	B	C	D	Season
Reductions in ETc	0	0	0	0	0.00%
Yield response factor	1	1.09	1.32	0.5	1.1
Yield reduction	0	0	0	0	0.00%
Cumulative yield reduction	0	0	0	0	%

Appendix-2

Cropwat model run for 2030

Monthly ETo Penman-Monteith data

Month	Min Temp (°C)	Max Temp(°C)	Humidity (%)	Wind (km/day)	Sun (hours)	Rad (MJ/m?/day)	ETo (mm/day)
January	22	31.4	61	183	7.3	18.2	4.66
February	24.2	34.8	59	143	9.6	22.8	5.48
March	25.8	35.7	67	88	10	24.6	5.58
April	26.3	35.1	74	90	10.8	26.2	5.82
May	28.4	36.6	79	72	8.2	21.7	5.16
June	26.4	32	86	68	2.9	13.5	3.24
July	24.3	29.8	88	49	1.7	11.8	2.64
August	25.8	31.6	86	72	6.6	19.4	4.16
September	24.9	30	83	62	9.3	23.5	4.72
October	26.5	33	85	51	4.8	15.9	3.55
November	23.9	30.8	81	84	8.4	19.9	4.06
December	23.5	33.5	70	120	6	15.9	3.9
Average	25.2	32.9	77	90	7.1	19.4	4.41

Monthly rain data

Month	rain (mm)	EFF rain (mm)
January	0	0
February	0	0
March	7.1	7
April	13.1	12.8
May	336.5	158.7
June	918.6	216.9
July	999	224.9
August	479.3	172.9
September	77.1	67.6
October	222.2	143.2
November	23.1	22.2
December	42.5	39.6
Total	3118.5	1065.8

Rice data

Stage	nursery	land preparation		growth stage				total
		total	puddling	initial	develop	mid	late	
Length (days)	30	20	5	20	30	40	30	150
Kc dry	0.7		0.3	0.5	-->	1.05	0.7	
Kc wet	1.2		1.05	1.1	-->	1.2	1.05	
Rooting depth (m)				0.1	-->	0.6	0.6	
Puddling depth (m)			0.4					
Nursery area (%)	10							
Critical depletion	0.2			0.2	-->	0.2	0.2	
Yield response f.				1	1.09	1.09	1.09	1.09
Crop height (m)						1		

Soil data

General soil data:	
Total available soil moisture (FC - WP)	80.0 mm/meter
Maximum rain infiltration rate	26 mm/day
Maximum rooting depth	100 centimetres
Initial soil moisture depletion (as % TA	10%
Initial available soil moisture	72.0 mm/meter

Additional soil data for rice calculations:	
Drainable porosity (SAT - FC)	15%
Critical depletion for puddle cracking	0.60 mm/day
Water availability at planting	10 mm WD
Maximum water depth	100 mm

Crop water requirements

Month	Decade	Stage	Kc coeff	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr. Req. (mm/dec)
May	1	Nurs	1.2	0.65	5.9	35.5	0
May	2	Nurs/LPr	1.08	5.11	51.1	57	66.1
May	3	Nurs/LPr	1.06	4.89	53.7	62.1	67.8
Jun	1	Init	1.1	4.19	41.9	67.4	0
Jun	2	Init	1.1	3.45	34.5	74.6	0
Jun	3	Deve	1.1	3.26	32.6	74.7	0
Jul	1	Deve	1.09	2.96	29.6	75.9	0
Jul	2	Deve	1.09	2.66	26.6	77.8	0
Jul	3	Mid	1.09	3.28	36.1	71.1	0
Aug	1	Mid	1.09	4.05	40.5	65.1	0
Aug	2	Mid	1.09	4.64	46.4	60.1	0
Aug	3	Late	1.09	4.8	52.7	47.6	5.1
Sep	1	Late	1.05	4.89	48.9	28.5	20.4
Sep	2	Late	1	4.9	49	13.9	35
Sep	3	Late	0.95	4.23	33.8	20.2	8.6
					583.3	831.6	203.1

Totals			
Total gross irrigation	472.0 mm	Total rainfall	2742. mm
Total net irrigation	330.4 mm	Effective rainfall	906.0 mm
Total irrigation losses	0.0 mm	Total rain loss	1836. mm
Total percolation losses	626.9 mm		
Actual water use by crop	468.3 mm	Moist deficit at harvest	0.0 mm
Potential water use by crop	468.3 mm	Actual irrigation requirement	-437. mm
Efficiency irrigation schedule	100.00%	Efficiency rain	33.00%
Deficiency irrigation schedule	0.00%		

Yield reductions					
Stage label	A	B	C	D	Season
Reductions in ETc	0	0	0	0	0%
Yield response factor	1	1.09	1.32	0.5	1.1
Yield reduction	0	0	0	0	0%
Cumulative yield reduction	0	0	0	0	%

Rice irrigation schedule

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Puddl (state)	Percol. (mm)	Depl. (mm)	SMNet Gif (mm)	Loss (mm)	Depl.SA (mm)
12-May	-19	PrePu	0	1	100	Prep	0	5	66	0	60
28-May	-3	Puddl	0	1	100	OK	16.8	0	67.1	0	17.1
02-Jun	2	Init	0	1	100	OK	3	0	101.3	0	1.3
14-Sep	106	End	0	1	100	OK	3	0	96	0	-4
28-Sep	End	End	0	1	0	OK	0	0			

Appendix-3

Cropwat model run for 2050

Monthly ETo Penman-Monteith data

Month	Min Temp (°C)	Max Temp(°C)	Humidity (%)	Wind (km/day)	Sun (hours)	Rad (MJ/m?/day)	ETo (mm/day)
January	22.9	32.2	61	183	7.3	18.2	4.76
February	24.9	35.3	59	143	9.6	22.8	5.56
March	26.5	36.2	67	88	10	24.6	5.65
April	27	35.7	74	90	10.8	26.2	5.91
May	29	37.2	79	72	8.2	21.7	5.24
June	27.1	32.7	86	68	2.9	13.5	3.28
July	25	30.5	88	49	1.7	11.8	2.68
August	26.4	32.2	86	72	6.6	19.4	4.22
September	25.6	30.8	83	62	9.3	23.5	4.81
October	27.1	33.6	85	51	4.8	15.9	3.6
November	24.8	31.3	81	84	8.4	19.9	4.13
December	24.3	34.2	70	120	6	15.9	3.97
Average	25.9	33.5	77	90	7.1	19.4	4.48

Monthly rain data

Month	rain (mm)	EFF rain (mm)
January	0	0
February	0	0
March	15.4	15
April	11.5	11.3
May	277.1	152.7
June	982.5	223.3
July	999.9	225
August	488.5	173.8
September	3.9	3.9
October	236.2	146.9
November	39.3	36.8
December	39.2	36.7
Total	3093.5	1025.5

Rice data

	nursery	land preparation		growth stage				
Stage		total	puddling	initial	develop	mid	late	total
Length (days)	30	20	5	20	30	40	30	150
Kc dry	0.7		0.3	0.5	-->	1.05	0.7	
Kc wet	1.2		1.05	1.1	-->	1.2	1.05	
Rooting depth (m)				0.1	-->	0.6	0.6	
Puddling depth (m)			0.4					
Nursery area (%)	10							
Critical depletion	0.2			0.2	-->	0.2	0.2	
Yield response f.				1	1.09	1.09	1.09	1.09
Cropheight (m)						1		

Soil data

General soil data:	
Total available soil moisture (FC - WP)	80.0 mm/meter
Maximum rain infiltration rate	26 mm/day
Maximum rooting depth	100 centimetres
Initial soil moisture depletion (as % TA	10%
Initial available soil moisture	72.0 mm/meter

Additional soil data for rice calculations:	
Drainable porosity (SAT - FC)	15%
Critical depletion for puddle cracking	0.60 mm/day
Water availability at planting	10 mm WD
Maximum water depth	100 mm

Crop water requirements

Month	Decade	Stage	Kc coeff	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr. Req. (mm/dec)
May	1	Nurs	1.2	0.66	6	33.7	0
May	2	Nurs/LPr	1.08	5.18	51.8	54.3	66.1
May	3	Nurs/LPr	1.06	4.95	54.5	61	112.6
Jun	1	Init	1.1	4.25	42.5	68.7	0
Jun	2	Init	1.1	3.5	35	77.7	0
Jun	3	Deve	1.1	3.31	33.1	76.8	0
Jul	1	Deve	1.09	3	30	76.5	0
Jul	2	Deve	1.09	2.7	27	77.5	0
Jul	3	Mid	1.09	3.33	36.6	71	0
Aug	1	Mid	1.09	4.11	41.1	67.4	0
Aug	2	Mid	1.09	4.7	47	63.5	0
Aug	3	Late	1.09	4.87	53.6	42.8	10.8
Sep	1	Late	1.05	4.98	49.8	2.2	47.6
Sep	2	Late	1	4.99	49.9	0	49.9
Sep	3	Late	0.95	4.31	34.5	1.5	32.6
					592.4	774.4	319.6

Rice irrigation schedule

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Puddl (state)	Percol. (mm)	Depl. (mm)	SMNet Gif (mm)	Loss (mm)	Depl.SA (mm)
12-May	-19	PrePu	0	1	100	Prep	0	5	66	0	60
27-May	-4	Puddl	78.4	1	100	Prep	26	0	52.7	0	2.7
31-May	0	Puddl	0	1	100	OK	4.6	0	58.9	0	8.9
08-Sep	100	End	0	1	100	OK	3	0	100	0	0
20-Sep	112	End	0	1	100	OK	3	0	95.4	0	-4.6
28-Sep	End	End	0	1	0	OK	0	0			

Totals			
Total gross irrigation	532.9 mm	Total rainfall	2703. mm
Total net irrigation	373.1 mm	Effective rainfall	861.6 mm
Total irrigation losses	0.0 mm	Total rain loss	1841. mm
Total percolation losses	593.5 mm		
Actual water use by crop	475.8 mm	Moist deficit at harvest	0.0 mm
Potential water use by crop	475.8 mm	Actual irrigation requirement	-385. mm
Efficiency irrigation schedule	100.00%	Efficiency rain	31.90%
Deficiency irrigation schedule	0.00%		

Yield reductions					
Stage label	A	B	C	D	Season
Reductions in ETc	0	0	0	0	0%
Yield response factor	1	1.09	1.32	0.5	1.1
Yield reduction	0	0	0	0	0%
Cumulative yield reduction	0	0	0	0	%

Appendix-4

Cropwat model run for 2080

Monthly ETo Penman-Monteith data

Month	Min Temp (°C)	Max Temp(°C)	Humidity (%)	Wind (km/day)	Sun (hours)	Rad (MJ/m?/day)	ETo (mm/day)
January	24	33	61	183	7.4	18.3	4.89
February	25.8	35.9	59	143	8.9	21.7	5.5
March	27.4	36.8	67	88	10.2	24.9	5.81
April	27.7	36.4	74	90	10.6	25.9	5.96
May	29.6	37.9	79	72	8.5	22.2	5.42
June	27.7	33.2	86	68	3.1	13.8	3.37
July	25.6	31.3	88	49	2.3	12.7	2.88
August	27	32.8	86	72	7.2	20.3	4.46
September	26.2	31.3	83	62	9.4	23.7	4.91
October	27.7	34.2	85	51	5.1	16.3	3.73
November	25.5	31.8	81	84	8.4	19.9	4.19
December	25.2	34.8	70	120	6.4	16.5	4.11
Average	26.6	34.1	77	90	7.3	19.7	4.6

Monthly rain data

Month	rain (mm)	EFF rain (mm)
January	0	0
February	1.7	1.7
March	26.6	25.5
April	75.7	66.5
May	409.5	165.9
June	999.9	225
July	993.1	224.3
August	485.5	173.6
September	3.9	3.9
October	238.9	147.6
November	27.5	26.3
December	45.3	42
Total	3307.6	1102.3

Rice data

	nursery	land preparation		growth stage				
Stage		total	puddling	initial	develop	mid	late	total
Length (days)	30	20	5	20	30	40	30	150
Kc dry	0.7		0.3	0.5	-->	1.05	0.7	
Kc wet	1.2		1.05	1.1	-->	1.2	1.05	
Rooting depth (m)				0.1	-->	0.6	0.6	
Puddling depth (m)			0.4					
Nursery area (%)	10							
Critical depletion	0.2			0.2	-->	0.2	0.2	
Yield response f.				1	1.09	1.09	1.09	1.09
Crop height (m)						1		

Soil data

General soil data:	
Total available soil moisture (FC - WP)	80.0 mm/meter
Maximum rain infiltration rate	26 mm/day
Maximum rooting depth	100 centimeters
Initial soil moisture depletion (as % TA	10%
Initial available soil moisture	72.0 mm/meter
Additional soil data for rice calculations:	
Drainable porosity (SAT - FC)	15%
Critical depletion for puddle cracking	0.60 mm/day
Water availability at planting	10 mm WD
Maximum water depth	100 mm

Crop water requirements

Month	Decade	Stage	Kc coeff	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr. Req. (mm/dec)
Aug	1	Nurs	1.2	0.48	4.3	60.5	0
Aug	2	Nurs/LPr	1.08	4.43	44.3	63.4	65.8
Aug	3	Nurs/LPr	1.06	4.98	54.8	42.7	151.1
Sep	1	Init	1.1	5.38	53.8	2.2	51.7
Sep	2	Init	1.1	5.62	56.2	0	56.2
Sep	3	Deve	1.1	5.11	51.1	1.8	49.3
Oct	1	Deve	1.1	4.39	43.9	41.6	2.2
Oct	2	Deve	1.1	3.88	38.8	61.8	0
Oct	3	Mid	1.1	4.12	45.3	44.1	1.2
Nov	1	Mid	1.1	4.43	44.3	17.9	26.4
Nov	2	Mid	1.1	4.6	46	2.3	43.8
Nov	3	Late	1.1	4.57	45.7	6.2	39.5
Dec	1	Late	1.08	4.45	44.5	14.1	30.4
Dec	2	Late	1.04	4.28	42.8	16.7	26.1
Dec	3	Late	1.01	4.4	39.6	9.1	28.5
					655.5	384.4	572.3

Rice irrigation schedule

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Puddl (state)	Percol. (mm)	Depl. (mm)	SMNet Gif (mm)	Loss (mm)	Depl.SA (mm)
12-Aug	-19	PrePu	0	1	100	Prep	0	5	65.7	0	60
27-Aug	-4	Puddl	53.8	1	100	Prep	24.5	0	79.3	0	29.3
31-Aug	0	Puddl	0	1	100	OK	4.6	0	59	0	9
06-Sep	6	Init	0	1	100	OK	3	0	98.7	0	-1.3
18-Sep	18	Init	0	1	100	OK	3	0	102	0	2
30-Sep	30	Dev	0	1	100	OK	3	0	96.6	0	-3.4
12-Nov	73	Mid	0	1	100	OK	3	0	101.3	0	1.3
25-Nov	86	Mid	0	1	100	OK	3	0	96	0	-4
11-Dec	102	End	0	1	100	OK	3	0	101.7	0	1.7
28-Dec	119	End	0	1	100	OK	3	0	95.8	0	-4.2
29-Dec	End	End	0	1	0	OK	0	0			

Totals			
Total gross irrigation	1280.4 mm	Total rainfall	583.7 mm
Total net irrigation	896.3 mm	Effective rainfall	526.2 mm
Total irrigation losses	0.0 mm	Total rain loss	57.5 mm
Total percolation losses	656.1 mm		
Actual water use by crop	547.7 mm	Moist deficit at harvest	0.0 mm
Potential water use by crop	547.7 mm	Actual irrigation requirement	21.5 mm
Efficiency irrigation schedule	100.00%	Efficiency rain	90.20%
Deficiency irrigation schedule	0.00%		

Yield reductions					
Stage label	A	B	C	D	Season
Reductions in ETc	0	0	0	0	0%
Yield response factor	1	1.09	1.32	0.5	1.1
Yield reduction	0	0	0	0	0%
Cumulative yield reduction	0	0	0	0	%

ABSTRACT

CLIMATE CHANGE IMPACT ON CROP WATER REQUIREMENT OF RICE IN THRISSUR DISTRICT

By

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ABSTRACT OF THE THESIS

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ABSTRACT

Rice crop occupies a major position in the agricultural production in Kerala State. Under the present climate change scenarios the climatic parameters are subject to variations and that in turn will affect the water requirement of the crop. A great stress on the irrigation reservoirs and projects for additional water to be released will be effected. It was attempted to generate the climate data for 2030, 2050, 2080 under IPCC emission scenarios RCP.45.The crop water requirement for rice was calculated under the predicted climate for Thrissur district using CROPWAT model.

The minimum temperature in the district were found to increase during the future years. The maximum temperature also showed an increasing trend through the future years. The summer months January – March were found to remain as the hot months during the predicted years. The solar radiation was also found to increase.

The average annual rain fall for Thrissur district was found to vary as 3139.1, 3089.8 and 3307.6 mm for the future years of 2030, 2050, 2080. The onset of south west monsoon may become early. The summer rains will continue to give a good amount of rain fall through the future years. There will be a reduction in the post monsoon rain fall and a poor distribution of rain fall over the district.

The crop evapotranspiration in all the three rice growing seasons of *virippu, mundakan and punja* was found to increase under the predicted scenario. Crop evapotranspiration was found to increase from 49.99 mm during 2015 to 61.27 mm during 2080 in the first crop season (*virippu*). During the second and third crop season (*mundakan* and *punja*) crop evapotranspiration varied from 56.53 mm to 82.17 mm and 77.06 mm to 83.17 mm respectively. When compared to the year 2050 the irrigation water demand was found to decrease during the year 2080. During the first crop season the irrigation water demand will increase to 319.6 mm in the year 2050 and later during 2080 it was found to decrease to 265.6 mm. There will be a considerable increase in the water requirement during the second crop season during 2050's and 2080's when compared with the present day demand. It was also indicated that under RCP 4.5 scenario the water demand to the rice crop during second crop season will be more by 100 mm of water.

The crop water use efficiency was found to decrease during future years. An additional amount of 200 billion litres of water will be required for meeting increased water requirement during the second crop season for irrigating rice. The requirement for the third crop season will be high as 750 billion litres.