CLIMATE VARIABLITY IMPACT ON WATER RESOURCES IN THE COMMAND AREA OF A RIVER DIVERSION SCHEME

by

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(2012-20-105)

THESIS

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DECLARATION

I hereby declare that the thesis entitled **"Climate variability impact on water resources in the command area of a river diversion scheme"** is a bonafide record of research work done by me during the course of research and the thesis has not 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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SYMBOLS AND ABBREVIATIONS

Abbreviation	Expansion
CRDS	Chalakudy River Diversion Scheme
LBMC	Left Bank Main Canal
LBC	Left Bank Canal
CWR	Crop water requirement
IWR	Irrigation water requirement
CGWB	Central Ground water board
IPCC	Intergovernmental Panel on Climate Change
FAO	Food and Agricultural Organisation
Kc	Crop coefficient
Eto	Reference crop evapotranspiration
Etc	Crop evapotranspiration
AEU	Agro Ecological Units
Peff	Effective Rainfall
RF	Rainfall
DWR	Domestic water requirement
CS	Canal supply
ENSO	El Ni-no Southern Oscillation
RCP	Representative concentration pathways
FSD	Full Supply Depth
ARS	Agronomic Research Station

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INTRODUCTION

CHAPTER I

INTRODUCTION

The availability of water is the key for development of any sector. As the entire globe is moving in the path of development, the scarcity of water is a curb in this path. Water scarcity is the lack of timely availability of sufficient water resources to meet water needs within a region. Physical water scarcity results from inadequate natural water resources to supply a region's demand, and economic water scarcity results from poor management of the sufficient available water resources. The latter is found more often to be the cause of countries or regions experiencing water scarcity, as most countries or regions have enough water to meet household, industrial, agricultural, and environmental needs, but lack the means to provide it in an accessible manner. Water scarcity results from variation in climatic variables as well as the overuse of available water. The rising population and growing food demands is creating an additional stress on the existing water resources.

Water is available as surface as well as groundwater resources. The climatic variables such as precipitation and temperature of a geographical area influence the water availability of the region. Climate change and climatic variability are the major concerns regarding the availability of water resources. The rise in temperature due to global warming has resulted in drying up of surface water resources and increased water demand for different sectors including agriculture. As the changes in climatic condition of an area occurs over a longer time period the adaptation strategies can be planned, but the variability in climate is of more concern as it has an impact on seasonal water availability of a region.

Monsoon rainfall is the important source of water in India. The South West and North East monsoon together account for about 86 per cent of the annual rainfall. Variation in the monsoon rainfall affects the water availability and agricultural production of the country. The decline in monsoon rainfall will lead to increased irrigation demand and extreme water shortage in most parts of the

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nation. Most of the south Indian rivers are fed by monsoon rainfall and dries if monsoon fails. The agriculture along the command area of the irrigation systems in these rivers is also affected.

Kerala, located in the southern tip of the country is the gateway of South West monsoon and receives abundant rainfall of 3000mm on an annual average. The state is blessed with 44 rivers which are mostly fed by monsoonal precipitation. Even with this much surplus of water in rainy season the state is facing extreme shortage of water during summer, even for drinking water. The topography of the state is the major reason for the fast draining of showers as runoff, through streams to the sea, within a short span of time. Due to these reasons, agriculture and domestic uses are mainly dependent on groundwater supplies during summer. The decline in precipitation will affect the groundwater recharge and subsequently result in further exploitation of available water. It has been observed that groundwater levels have gone down beyond viable limits in many regions. In these circumstances, the most feasible solution is the diversion of water available in rivers and the proper management of available water.

The major portion of water available for development by man is met from water in streams, rivers, fresh water lakes and about 44 per cent of the quantity of groundwater which occurs at depths less than 800m from ground surface (Michael, 2008). The canal system of water supply can be used to supply water from river diversions to a vast area far away from water sources. The supply of water through canals is not only beneficial for irrigation but also for recharging wells which replenish the groundwater levels as well as contribute to domestic water requirements. Even though the river diversions are intended to supply water continuously through canals, due to the scarce availability of water caused by climatic variability as well as excess of diversion structures and projects in the same river the water is supplied through 'turn system' in branch canals. Disputes may arise regarding the time of supply of water and disparities are observed in water availability. The tail ends of many canals most often do not get any water. The irregularity in supply of water may adversely affect agricultural production if

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crops do not get water during critical periods. The present canal systems do not cater to the spatial variability in water availability. Regions with water scarcity may not have sufficient supply, whereas regions with alternate sources of water may still end up with additional water which is left in excess.

For efficient water management and equitable water distribution, the water demand has to be worked out for command area of individual branch canals. The irrigation supplies reach the fields through a hierarchical network of main canals, branch canals (secondary canals) and distributaries (tertiary canals). The distributary is usually the last point of control for main irrigation system management as down-stream of this level, irrigation is either field-to-field or under the direct control of the farmers. The water supply into each distributary has to be decided based on the estimated water demands of the crops in the area irrigated by it, after accounting for field-application losses. The demand depends on soil, weather and crop conditions in the irrigated area. Further, the total area irrigated by different distributaries also varies. The irrigation demand estimation for each distributary is therefore independent of other distributaries. The individual distributary-level water demands are aggregated to assess irrigation supply requirements at higher levels (branch canals and main canals) of the irrigation system after accounting for transmission losses. In addition, the groundwater level estimation is an important parameter to be estimated as the water sufficient and water insufficient regions can be identified. The domestic demand based on population of each command area is also to be estimated. Thus the real time monitoring of the total demand of individual commands will be helpful in water distribution in an optimum manner. The operational efficiencies depend on the extent to which the irrigation supplies match the demands at each hierarchical level of the network. Thus estimating periodically and in real time, the water demands of individual distributaries of the canal network are critical for improving the overall operational efficiencies of large irrigation systems.

A water balance model in canal commands based on cropping pattern, weather parameters, domestic demand as well as water availability will be helpful

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to provide demand based water release strategies. This will help reduce the gap between canal supplies and demands and will help irrigation engineers, agronomists and agro-meteorologists in planning, operation and management of irrigation systems efficiently.

The command area of left bank canal of Chalakudy river diversion scheme is selected for the present study. The command area comprises of 11 panchayaths, among which four are in Thrissur and seven are in Ernakulam district. This area is a major belt of crops such as nutmeg, coconut and paddy. The Chalakudy river is facing water scarcity due to many diversions and hydroelectric projects along with the decline in monsoonal precipitation. In this context, for the efficient and proper management of available water this study was undertaken.

The objective of the present research work is to study the impact of climate variability on water availability for the cropping systems and domestic demand in the left bank canal of Chalakudy River Diversion Scheme

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REVIEW OF LITERATURE

CHAPTER II

REVIEW OF LITERATURE

A study on impact of climate variability on water availability for the cropping systems and domestic demand was done in the command area of Left bank canal of Chalakudy River Diversion Scheme in Thrissur district. The study was a real time analysis of the situations of the command area considering the crop water demands, domestic and drinking water needs. The availability of water through canals and the groundwater supply was analysed. The study was aimed at proposing a model for optimum allocation of water resources during scarce situations mainly due to variability of rainfall. Earlier studies conducted on these aspects are reviewed in this chapter.

2.1 CLIMATE CHANGE AND CLIMATE VARIABILITY

Climate change emerged as the major threat affecting the environment and water resources. Increased emission of greenhouse gases like carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) is the main reason behind this drastic change in the global climate. In addition to this population explosion also plays an important role in the climate change (FAO, 2013). As per IPCC Representative Concentration Pathways 8.5 projections global mean surface temperature may experience an increase by 2.6°C to 4.8°C by the end of 21st century (IPCC, 2014). Accelerated warming of the atmosphere can jeopardize the global economy through ecosystem changes. Further, elevated ambient temperature can also alter the evapotranspiration and the form of precipitation thereby variably impacting monthly stream flow patterns (Chien *et al.*, 2013). Additionally, coupled effects of climate and land use changes can amend the average monthly stream flow, ultimately lower base flow and cause higher surface runoff. (Wang, *et al.*, 2014). Besides, elevated ambient temperature can also increase the frequency and intensity of drought events. Furthermore, climate change can also reduce the ground water flow and river flows. All these factors can together culminate in the shrinkage of water resources and increased need of water.

Conservation and development of the water resources is the need of the hour. Concerted efforts are to be taken in order to develop proper adaptation, mitigation and modelling strategies.

2.2 IMPACT OF CLIMATE CHANGE ON WATER RESOURCES

Under the conditions of Green house warming domination over the world's policy agenda the major concern is regarding the impact of climate change on water supply (Watson *et al.,* 1996). Climate change is considered to affect water resources through increased/ unusual spatio- temporal variability long term temperature and water balance changes which would in turn affect the water and food security, human health and their livelihood and ecosystem (Vorosmarty *et al.*, 2000). Increasing water stress has been anticipated from the global assessment of water resources in many parts of the world under the projected climate change and population growth scenarios (Arnell *et al.,* 2001).

According to the third assessment Report (IPCC, 2004) annual stream flow changes are having robust links with the changes in precipitation. The comparison of continental scale runoff during 20th century in Asia, North America and South America as well as Africa and Europe clearly relates to the statement. An increase in runoff was found for Asia, North America and South America while the Africa had shown a decrease in runoff and Europe doesn't had significant change. The rainfall pattern was also found clearly according to the runoff. The net precipitation had shown an increasing trend for Asia, North America and South America and precipitation decrease was observed almost over the entire Africa and a combination of both increases and decreases of Europe.

Rising temperature as well as declining precipitation levels would guide to reduced water supplies and increased water demands and this might affect the quality of water in freshwater bodies which will impulse a further strain on the already fragile balance between supply and demand in many countries (Milly *et al.,* 2005). According to IPCC, by 2020 severe water stress had been predicted in some parts of India due to rise in temperature and depletion in summer rainfall by the influence of climate variability on Indian subcontinent (Cruz *et al.,* 2007).

Heejun and Won (2010) stated that, changes in runoff is mainly influenced by precipitation than temperature, in most basins, except those in higher elevations with snow melt dominated regimes, which are responsive to temperature than precipitation. For the effective management of water resources and planning of optimum allocation the assessment of climate change/ variability is inevitable. Water availability and water demand are influenced by climate. The quantitative estimation of hydrological effects of climate change will be useful in understanding potential water resource problems and formulation of planning strategies (Raneesh and Thampi, 2011). They concluded that climate change is likely to have impacts on hydrological effects due to changes in primary inputs like precipitation, temperature and evapotranspiration for the terrestrial part of hydrological cycle.

Climate change may have direct impact on stream flow and groundwater recharge due to its influence on hydrological processes such as precipitation, and evapotranspiration (Thampi and Raneesh, 2012). A significant impact on global water cycle by climate change with greater disparity between wet and dry regions was predicted by Intergovernmental panel on climate change (Stocker *et al.*, 2013). Twenty first century is concerned with a serious issue of the effect on water availability due to changes and or fluctuations in the hydrological cycle (Pal and Al-Tabbaa., 2011; Suryavanshi *et al.,* 2014). According to Rao *et al.* (2014), global climate change can affect precipitation patterns which in turn affect water availability besides the increase in flood and droughts. Increase in the frequency of more intense precipitation and decrease in number of rainy days as well as total annual precipitation was predicted in many parts of Asia. Climate change and climate variability influence the stream hydrology to a greater extent. Under the

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projected climate scenario the stream flow will rise drastically in monsoon but will decrease much during the non-monsoon season.

Nair (2015) studied the rainfall pattern over Western Ghats and in particular the stream flow in *Sita river* in Karnataka and *Karamana* river in Kerala. Both river basins have undergone changes in the land use pattern and it altered the water balance of the basins. *Karamana* basin suffered a deficit in available water due to low rainfall in the basin and increased demand of water. *Sita* basin received abundant rainfall to cater the needs of the basin and no water deficit was observed during the period from 1990 to 2010.

2.3 RAINFALL VARIABILITY IN INDIA

Rainfall is a characteristic feature, which helps in resolving uncertainties (Singh, 2012) and making decisions on a broad series of local issues related with agriculture, industry, irrigation, generation of electricity and other human activities by analysing its trends and changes (Singh and Sontakke, 1999).

Significant inter annual and decadal variability is observed in north east monsoon rainfall. The trend analysis of rainfall data of homogenous regions of India, obtained for a period from 1871-2002, had shown a declining trend in summer monsoon rainfall for Kerala while the coastal Karnataka, Goa and Konkan had shown an increasing trend (Dash *et al.*, 2007). About 80 per cent of the total rainfall in India is contributed from summer monsoon from June to September (Ghosh *et al.*, 2009).

Krishnakumar *et al.* (2009) observed that the mean annual rainfall is having an insignificant decreasing trend for a period of 1871-2005 but the trend was noticed to be significantly increasing in mean annual rainfall when observed from 1951-2005. Significant trends of increase and decline in rainfall over Kerala was found during the recent rainfall trend analysis in post monsoon and monsoon rainfall respectively over Kerala. The months of June and July had shown

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maximum decline in rainfall and the months of August and September had shown slight augment in rainfall.

According to Pal and Al-Tabba (2011), the variation in seasonal precipitation in India could be resulted either or due to cumulative effect of the multiple factors such as changes in rainy days, intensity of rainfall, sea surface temperature and El Nino–Southern Oscillation.

From the study of 32 years of rain gauge data from 1979 to 2010 (Prakash *et al.*, 2013) stated that a significant increase in north east monsoon rainfall over equatorial Indian ocean, Peninsular India and Sri Lanka endorsed to the increased frequency of cyclone in Bay of Bengal in November and increasing warming of Indian ocean. Subash and Sikka (2014) analysed the rainfall over India using monthly time series rainfall data and found that maximum decreasing trend in rainfall occurred in Kerala region during 1904 to 2003 and maximum increasing trend in coastal Karnataka.

The study conducted by Nair *et al.* (2014) using monthly precipitation data obtained the results of maximum seasonal coefficient of variation in precipitation during winter preceded by pre monsoon and post monsoon periods, while the monsoon precipitation had shown minimum seasonal coefficient of variation for the entire districts of Kerala. The month of January, July and November had shown a declining trend in rainfall from 1901-2000 in most districts. The districts of Kannur, Kozhikode, Malppuram, Palakkad and Alappuzha of Kerala exhibited a decreasing trend in annual rainfall. The districts of Thrissur, Kottayam, Wayanad, Idukki and Pathanamthitta exhibited an increasing trend in rainfall based on seasonality index. This revealed that the rainfall has become less seasonal in those districts over the years.

The results of Mondal *et al.* (2014) revealed a non-significant negative trend in monsoon rainfall of Kerala from the rainfall data analysis over a period of 1871-2011 and the Konkan, Goa and Coastal Karnataka had a significant positive trend.

Ajithkumar and Sreekala (2015) studied the recent trends in rainfall of different districts of Kerala. Detailed investigation of the spatial and temporal variation in seasonal and annual rainfall was done for a period from 1992-2012. Annual mean rainfall of all districts as well as their coefficient of variation was determined and Mann Kendall trend test was used to find out the significance of the trend. The result had shown that the mean annual rainfall was about 2956.4 ± 391.9 mm with coefficient of variation (CV) of 13.3 per cent. A significant decreasing trend was observed in south west monsoon rainfall. All districts except Palakkad had shown a declining trend in south west monsoon. A decreasing trend in North East monsoon was also observed with a trend value of -1.1 but summer rainfall had shown a positive trend with a trend value of 1.6 at 10per cent significance level. An increasing trend was observed in winter rainfall also.

2.4 GROUND WATER

Groundwater is an important natural resource on which about 2 billion people relies upon for their daily supply worldwide (Kemper, 2004). Any variation in the regime and quantity of precipitation apart from the variation in temperature and evapotranspiration affect groundwater recharges (Labat *et al.*, 2004).

Efficient management of groundwater has to be implemented to cope up with climate change so as to make use of the advantage of groundwater as an important source of sustainable development and also as a reserve freshwater resource. Agricultural requirements cannot be fulfilled depending only on rainfall; as such it is necessary to pump groundwater to meet the crop water requirements so as to ensure food security by increasing crop production with respect to scarcity in water availability under projected climatic and population scenario. Groundwater has received only meagre attention compared to surface water resources, considering the climate change impacts, and most Asian countries have not yet responded to the effect of climate change on their water management strategies (Kundzewicz *et al.*, 2007).

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India, home to 17 per cent of the world's population, is facing acute water scarcity .The country is ranked highest in groundwater use globally; its groundwater use is 250 billion m^3 per year (FAO, 2010; Shah *et al.*, 2007). About 80 per cent of the available water of the country was used for irrigation (Mall *et al.*, 2006) and 65 per cent of irrigation supply is provided by groundwater (Siebert *et al.*, 2010). Increase in the number of irrigation wells equipped with diesel or electric pumps were the main reasons for large scale groundwater withdrawal; there has been a 130 fold increase in the irrigation wells from 0.15 million in 1960 to nearly 20 million by 2000 (Shah, 2009). Such groundwater development has caused groundwater depletion and several other environmental problems in many regions of India (Ambast *et al.*, 2006; CGWB, 2006; Rodell *et al.*, 2009; Singh and Singh, 2002; Tiwari *et al.*, 2009)

Focused research and study based on a good set of meteorological and hydrological data are a necessity to overcome the present and future water and environmental problems which at present are far from satisfactory. It is an urgent need to reduce the gap between water supply and demand with more efficient irrigation systems, training of farmers, recycling of waste waters, water conservation through public awareness and groundwater legislation for better ground water management (Dragoni and Sukhilija, 2008)

Guhathakurta and Saji, (2013) conducted a study on rainfall pattern of Maharashtra for the period of 1901-2006 and found that monsoon rainfall had shown an increase in different areas of the state, while the period of January to May showed a decline in precipitation and concluded that the soil moisture depletion and reduction in groundwater levels are contributed by increased heating due to reduction in rainfall of initial five months of the year.

2.4.1 Groundwater level analysis

Groundwater levels of selected observation wells was analysed in the south coastal region of British Columbia, Canada by Allen (2010) for better understanding of historical trends in groundwater levels. Groundwater level had shown a domination of negative trend during a common period (1976-1999) and appears to be related to longer term negative regional trends in precipitation, although variable trends are evident at the shorter time periods used for this study. The sensitivity of recharge to changes in precipitation and temperature was studied by using the Projections for future climate from one global climate model.

Zhou *et al.* (2010) stated that, not only water resources but also water demand for irrigation are influenced by climate change. A large proportion of the world's agriculture depends on groundwater. In several regions, aquifer resources face depletion. Groundwater recharge has been viewed as a by-product of irrigation return flow, and with climate change, aquifer storage of such flow will be vital.

Rani and Elangovan (2012) assessed the impact of irrigation delivery on groundwater in Parambikulam Aliyar Project in Tamil Nadu. They collected monthly water level observations of 17 observation wells along the sub basins of the project. The impact on groundwater levels due to introduction of Alternative sluice method of irrigation was studied. The sluice method was introduced in 1999. The groundwater level of 17 observation wells and the monthly rainfall of 28 rain gauge stations from 1971-2010 are used for analysis and hydrographs are prepared. The results indicate that there is an increase in the ground water level in the 50per cent of the observation wells located in the area due to the sluice method of irrigation, even though the rainfall in this area is reduced in some parts.

2.5 WATER AVAILABILITY AND AGRICULTURE

Serious water shortages are developing in many countries particularly in India and water for agriculture is becoming increasingly scarce in the light of growing water demands from different sectors (IWMI, 2010). Agriculture the largest user of water resources worldwide (Hoekstra and Mekkonnen, 2012), is strongly affected by water shortages.

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Agriculture is the largest consumer of water in India and hence more efficient use of water in agriculture needs to be top most priority (Surendran *et al.* 2013). Fresh water availability seriously limits the expansion of agricultural irrigation activities. Continued or extended fresh water withdrawals by the agricultural sector impair seriously the sustainability of global freshwater resources. Moreover, climate change scenarios are investigated regarding a potential boost in water scarcity (Sivakumar *et al.*, 2014; Lehmann, 2013).

Water supply and availability directly affect food production through agricultural practices. Sufficient water supply is vital to ensure crop growth and livestock survival, and agriculture accounts for approximately 70 per cent of global freshwater use (UN DESA, 2014). Irrigated land accounts for about 20 per cent of the total cultivated land worldwide but it contributes 40 per cent of the global food production. This states the potential contribution which irrigated agriculture might make to raise food security. On the other hand, fresh water withdrawal by the agricultural sector represents about 70 per cent of the total global fresh water consumption, estimated to exceed the value of 80 per cent till 2050 (UN FAO, 2014). According to Estave *et al.* (2015), the crop yield changes are a consequence of climate conditions as well as effective water availability (driven by climate and management conditions) and explains water as the limiting factor for crop production.

To achieve effective planning on water resources, accurate information is needed for crop water requirements and irrigation withdrawal as a function of crop, soil type and weather conditions. The rainfall and evapotranspiration ultimately determine water balance, crop water and irrigation requirements of different crops of the region. Scientific crop water requirements are required for efficient irrigation scheduling, water balance, canal design capacities, regional drainage, water resources planning, reservoir operation studies, and to assess the potential for crop production (Surendran *et al.*, 2015). Regional planning of water resources could be achieved, only if we have precise scientific data about the crop water requirements at different stages, quantity of water needed for producing targeted yields specific to crops and information on soil physical characteristics and weather conditions of specified regions (Surendran *et al.,* 2017). Crop water requirement can be calculated by several methods. CROPWAT is a computer based model which is used to work out crop water requirements from weather and crop data inputs.

2.5.1 CROPWAT

CROPWAT model developed by FAO, Rome is simple, robust and accurate, and has been extensively used for estimating crop water balance (Smith, 1992). Penman-Monteith method, used in CROPWAT, based on crop coefficient approach calculates reference evapotranspiration in a relatively simpler manner (Allen *et al*., 2005; Maeda *et al*., 2011; Shen *et al*., 2013). FAO Penman-Monteith method, using decision support software CROPWAT 8.0 developed by FAO, based on FAO Irrigation and Drainage Paper 56 (FAO 1998). The FAO CROPWAT program (FAO, 2009) incorporates procedures for calculating reference crop evapotranspiration and crop water requirements and allow the simulation of crop water use under various climate, crop and soil conditions.

Surendran *et al.* (2015) computed crop water requirements of crops in agro-ecological units (AEUs) of Palakkad district of humid tropical Kerala with CROPWAT 8.0 using meteorological parameters. The net irrigation demand, the gross irrigation demand and irrigation interval for the various crops grown in different AEUs have been computed. Water balance analysis was done for the current scenario and future demand for agriculture, domestic and industrial demand.

Surendran *et al.* (2017) estimated the crop water need and appraisal of water resources for sustainable water resource management in Kollam district by using CROPWAT model. The gross water required for important crops such as rice, coconut, rubber, pepper, banana, brinjal, tomato, tapioca, cardamom, tea, etc has been computed in various AEUs using meteorological parameters. Using

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evapotranspiration and effective rainfall in each unit, a water balance has been worked out.

2.6 CANAL ALLOCATION OF WATER

The unreliable supply of water through canal system results in water excess in upstream and water shortage in the downstream ends of canal. Efficient management of water has to be done for optimum use of available water resources.

One of the greatest concerns in irrigation by the engineers, irrigation managers and planners is regarding the equitable distribution of canal waters (Abernethy 1986; Suryavanshi and Reddy 1986; Makin 1987; Steiner and Walter 1992) .In India canals are the major sources of irrigation water as majority of farmers cannot afford to build their own irrigation system (Imtiyaz *et al.*, 2007). Canal water is the main source of water in an irrigation command (Mane *et al.*, 2008).

Imtiyaz *et al.* (2007) investigated the variation in water demand and supply in nine branch canals of a major canal system in Uttar Pradesh. Controversies existed between canal authorities and farmers regarding the fact that the water supply was insufficient to meet the irrigation demands in canal commands. But the canal authorities claimed that there was enough supply through the system. The study was conducted during 2003-2004 for Silodhi, Sirher, Khunta, Sinki, Hanokwar, Dhareta, Gulalpur, Pachauna and Dasauti minors of Hardia distributary (Mejabranch canal) of state of Uttar Pradesh. The study revealed that water supply was inadequate to meet the crop water requirement in all branches except Silodhi minor where supply was in excess of demand. Detailed investigation was done for Sinki minor and found that critical period of crops which falls in month of February and March experienced shortage in irrigation water which resulted in decline in production of crops in the command. During rabi season water demand varied due to variations in evaporative demand and supply was insufficient to meet demand. During kharif season the water supply requirement was increased considerably as paddy cultivation started. Apart from these the tail ends of the Sinki minor was unable to produce marketable yield for paddy due to short supply of irrigation water and the tail ends of most canals are of the same situation.

Cordery (2009) found that a rigid water allocation based on very limited criteria such as farm size does not maximize the socio-economic benefits gained from the use of scarce water. This study was based on a survey conducted among 124 farmers located on five water courses in the Indus river basin of Pakistan. According to their findings, canal water allocation should be based on the distribution of fresh groundwater resources along with other critical variables. A framework is to be developed, including consideration of the gross area of a tertiary canal, sensitivity of crop growth stage to water shortage, crop value, and bias of allocation towards most water use efficient areas.

Shahdany *et al.* (2015) formulated a model predictive control system which aimed at fair distribution of water at upstream and downstream users in main canals suffering from water shortages. It was a method of water level difference error sharing mechanism by using model predictive controls. According to the method in the condition in which the total demand exceeds the canal inflow, downstream and upstream users equally suffer from this water shortage i.e in period of water shortage in downstream, stored water in upstream will be allocated equally to both upstream and downstream by using controllers. This latest configuration of the water level difference control method, referred to as DE-MPC, is proposed to speed up a fair sharing of errors among all pools in a main canal.

2.7 NEED FOR WATER MANAGEMENT

The quantity and quality of available water resources have been recognized as the limiting factors in development of most of the arid and semi-arid regions (Khare and Jat, 2006). Irrigation engineers are being challenged by the competition for water among irrigation sector, industrial, urban, recreational, and environmental sectors, and the need for increasing agricultural water productivity (Molden, 2007) for water saving and to provide more flexible water allocation system (Merriam *et al.*, 2007).

Canal water supply based on the daily or weekly supply requirements of the command area has to be followed to ensure the productive and optimum utilisation of our expensive and scarce water resource (Imtiyaz *et al.*, 2007). Scheduling is a function of flow rate, duration of irrigation, and frequency of irrigation. Assuming that each of these components can be either constant or variable, a number of different types of irrigation schedules may be made. Broadly, the scheduling can be categorized into three types: continuous (a constant or variable flow rate is maintained without interruption), rotational (a constant or variable flow rate is supplied intermittently with fixed or variable duration and frequency), and on-demand (flow rate, duration, and frequency, all are variable; water is supplied as per demand and availability (Bhadra *et al.*, 2009).

Patil *et al.* (2014) assessed the irrigation scheduling for command area of *Wadi Adampur* distributory of *Wan* River Project. The software CROPWAT and CRIWAR were used for obtaining crop water requirement of the crops in the command. From the estimation it was found that water applied during 2006-2007 to 2010-2011 except for 2009-2010 varied between 2.56 to 16.93 mm which accounts about an annual average of about 9.23 Mm^3, while the results from CROPWAT and CRIWAR revealed that crop water requirement varied between 4.89 to 6.92 and 9.80 to 12.90 Mm^3 respectively which was far less compared to actual application. The discharge required was found to be 2.05 l/s/ha and 4.59 l/s/ha respectively from CROPWAT and CRIWAR. Actual applied water was estimated to be about 53.06 per cent more and 14.77 per cent less compared to CROPWAT and CRIWAR. Although the actual applied amount of water was more and the area irrigated was less compared to CROPWAT schedules. The findings of the study concluded to use CROPWAT schedule for irrigation.

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Anjana *et al.* (2015) studied the water availability in the Right Bank Main canal of Chalakudy river diversion scheme and an irrigation schedule has been done for the Right Bank canal. They found that the water supply through the canal was sufficient to meet the water needs of the command area even though water deficit was observed in most branches under the existing supply system and arrived at the conclusion that the losses and unscientific management of canals are the reasons behind the deficit in water availability.

Ansu (2017) has conducted a study in Left Bank canal of CRDS with an objective to estimate the transmission losses in the Left Bank canal. The study was conducted for a selected section canal from Ezhattumugam to Palissery. The study was also aimed to estimate the demand, supply and deficit of Thumboormuzhy left bank canal system depending on the type of crops cultivated and the crop water requirement. A maximum loss of 29.4 per cent was obtained between Ezhattumugham and signboard which was at a distance of 0 .8 km from the main weir at Ezhattumugham. A minimum loss of 0.7 per cent was observed between Karamttom junction and Karamattom main. They arrived at the conclusion that probable reasons for the loss of water in specific areas of canal includes unauthorised usage, seepage loss, conveyance loses and deteriorated lining of the canal slopes and canal bed. They observed that the efficiency of canal conveyance was minimal with about 60 per cent efficiency in the initial reaches of main canal. They observed water deficit for canal branches selected for the study.

2.8 OPTIMISATION MODEL FOR CANAL WATER ALLOCATION

Majority of the mathematical models of canal operation and automation (Loof *et al.*, 1991; Malaterre, 1995; Islam *et al.*, 2008) developed over the years exclusively concentrate on hydraulic aspects of canal system and do not consider the hydrology of reservoir catchment and irrigated command. Such simulation models could simulate time and space dependent changes in water surface profiles in canals as well as flow under complex canal flow conditions (operation of gates, presence of control and drop structures, etc.) and they are developed for steady flow or gradually varying flow. As such they are highly data intensive and cannot adequately account for actual flow conditions which involves frequent canal filling and dewatering, as required for the rotational irrigation practiced in many schemes in India. Several attempts for using such models in India provided unsatisfactory results.

Kemachandra and Murty (1992) developed a water balance model for low land paddy and one based on soil moisture approach for upland crops for estimation of water deliveries at tertiary and secondary canals. Through researches, Mandavia and Acharya (1995) recommended that simple models that use available data be used under Indian conditions. One such simple canal flow model had been developed by Vyas and Sarma (1992) based on uniform flow in the irrigation distributaries which used an iterative procedure for accounting gradually varying flow conditions.

Attempts made by Singh *et al.* (1997) in Mahanadi reservoir irrigation scheme and Mishra *et al.* (2005) in Right Bank Main Canal (RBMC) of Kangsabati irrigation project considered hydraulic and hydrologic simulation of canal command but failed to consider reservoir component. A multi-criteria rotational schedule has been developed by Santhi and Pundarikanthan (2000) for an irrigation system in India which practiced a rotation based distributary level canal distribution.

Khepar *et al.* (2000) have formulated a model for equitable distribution water along the canal considering the seepage loss through the length of the branch canal. The model was applied to a watercourse of Kotakpura distributary in Punjab. The study revealed that existing distribution system follows an inequitable distribution pattern and the tail end users are greatest sufferers of water stress. The strategy developed provided equitable distribution of water from a common water course irrespective of the location of the holdings from water course outlet.

Khare and Jat (2006) developed a mathematical model for optimisation of conjunctive use planning in Sapon irrigation command area of Indonesia. Evaluation of water demand and available surface and groundwater resources was done in the study. The simple economic and engineering optimization model developed was based on linear programming, with various hydrological and management constraints, to explore the possibilities of conjunctive use of surface and groundwater and to arrive at an optimal cropping pattern for optimal use of water resources for maximization of net benefits. The LINDO 6.1, optimization package has been used to arrive at optimal allocation plan of surface water and groundwater.

A model developed by Mishra *et al.* (2008) for Phulnakhara distributary of the Puri main for achieving irrigation efficiency during summer saved about 10.31 per cent of water over prevailing water supplies by the best alternative delivery schedule proposed by the model created favourable water regime and better crop evapotranspiration. The IRCIM model developed by Bhadra *et al.* (2009) integrated all the components (catchment, reservoir, canal and command) responsible for the efficient management of reservoir-based irrigation projects.

Mankar (2009) formulated a conjunctive use model for optimum utilization of water resources in the command area of Som Kadgar irrigation project. Linear programming optimization technique was used to suggest optimal cropping pattern for available surface and groundwater resources. Both the surface water resources as well as groundwater resources were considered in the study. The objective of the study was to allocate a limited quantity of water in the most appropriate manner to maximize productivity A user friendly software was developed with Visual Basic 6.0 for optimum crop area allocation with various hydrological and management constraints.

RIMIS a GIS- integrated tool for equitable irrigation supply to tertiary canals was developed by Rowshon *et al.* (2009). It characterised the irrigation delivery performance with the advancement of season in Tanjung Karang irrigation scheme in Malaysia. A field irrigation demand prediction model was dynamically linked with the RIMIS for the area irrigated by the canal and was capable for simulating and evaluating recommended irrigation supplies in tertiary canals. This matched the available discharge at the system with crop water demand for actual field conditions and ensured equal sharing of water for the tail end users.

Kilic and Anac (2010) developed a multi-objective planning model and applied on the Menemen Left Bank Irrigation System of the Lower Gediz Basin in Turkey. The model aimed at increasing the area irrigated, maximising benefit from production as well as reducing the water loss. The model was applied to an open channel system consisting of 44 tertiary channels receiving water from three secondaries, serving an area of 3,606 ha. About 20.63per cent increase in income and 29.26per cent decrease in total irrigation water requirements was predicted by the model according to projected change in cropping pattern which caused a reduction in water loss by about 26per cent for the whole network.

Montazar *et al.* (2010) formulated a model for optimum allocation of water resources in the Qazvin irrigation command area a semi-arid region in Iran. In the study, a blending of integrated soil water algorithm with a non-linear optimisation model for efficient water allocation was done in complex deficit agricultural water resource system, considering the criteria of economic efficiency. Various possible operational scenarios of branch canals of the command area was suggested for dry and common condition in the study and would be helpful for irrigation engineers in water allocation plans within different irrigation districts.

Devi *et al.* (2013) used linear programming technique and formulated the conjunctive use optimization model for the optimal allocation of surface and groundwater, to maximize the benefits within the framework of given constraints and designed cropping pattern. The model was run for the present scenario with the existing cropping pattern and several cases of projected cropping patterns are also analysed and yielded five alternatives of surface and groundwater allocation.

MATERIALS AND METHODS

CHAPTER III

MATERIALS AND METHODS

A real time study was conducted to understand the impact of climate variability on water resources in the command area of Chalakudy river diversion scheme. The materials and methods deployed for data collection and analysis is discussed here.

3.1 LOCATION

The command area of Left Bank Canal (LBC) of Chalakudy River Diversion Scheme (CRDS) which extends between 10.17° to 10.31° North latitude and 76.30° to 76.49° East longitude was selected for the study. This area is located in Thrissur and Ernakulam districts of Kerala. A variety of crops including paddy, nutmeg, coconut, banana and tapioca are grown in this region. The area is a major belt of Nutmeg in central Kerala.

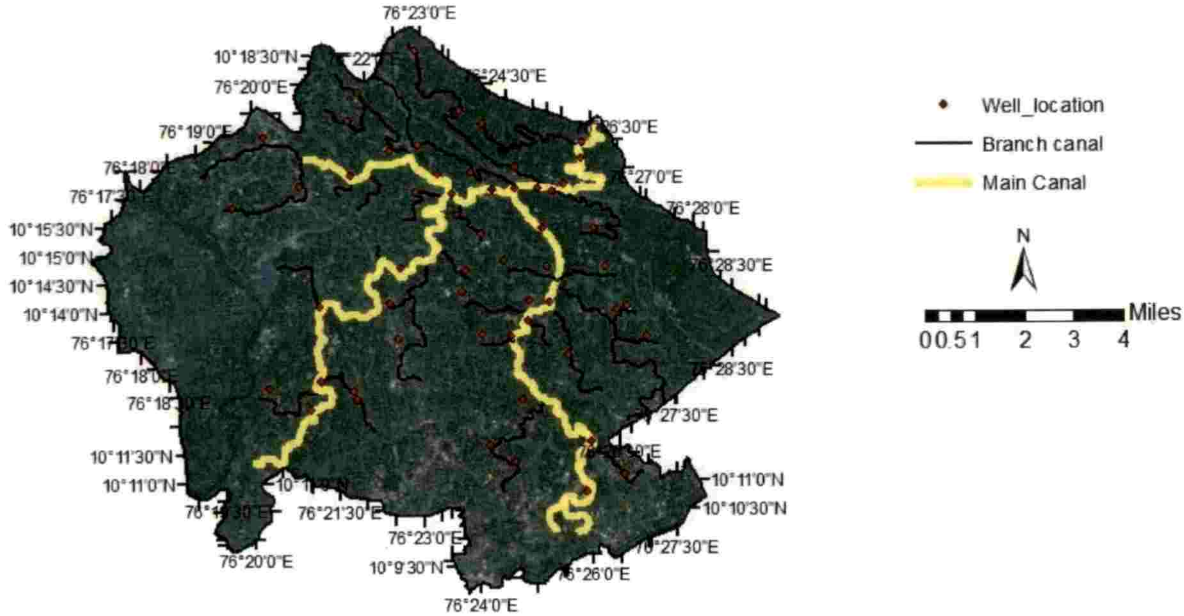

Figure 1. Command area of LBC of CRDS

Fig 1 and 2 shows the entire canal system and the command area.

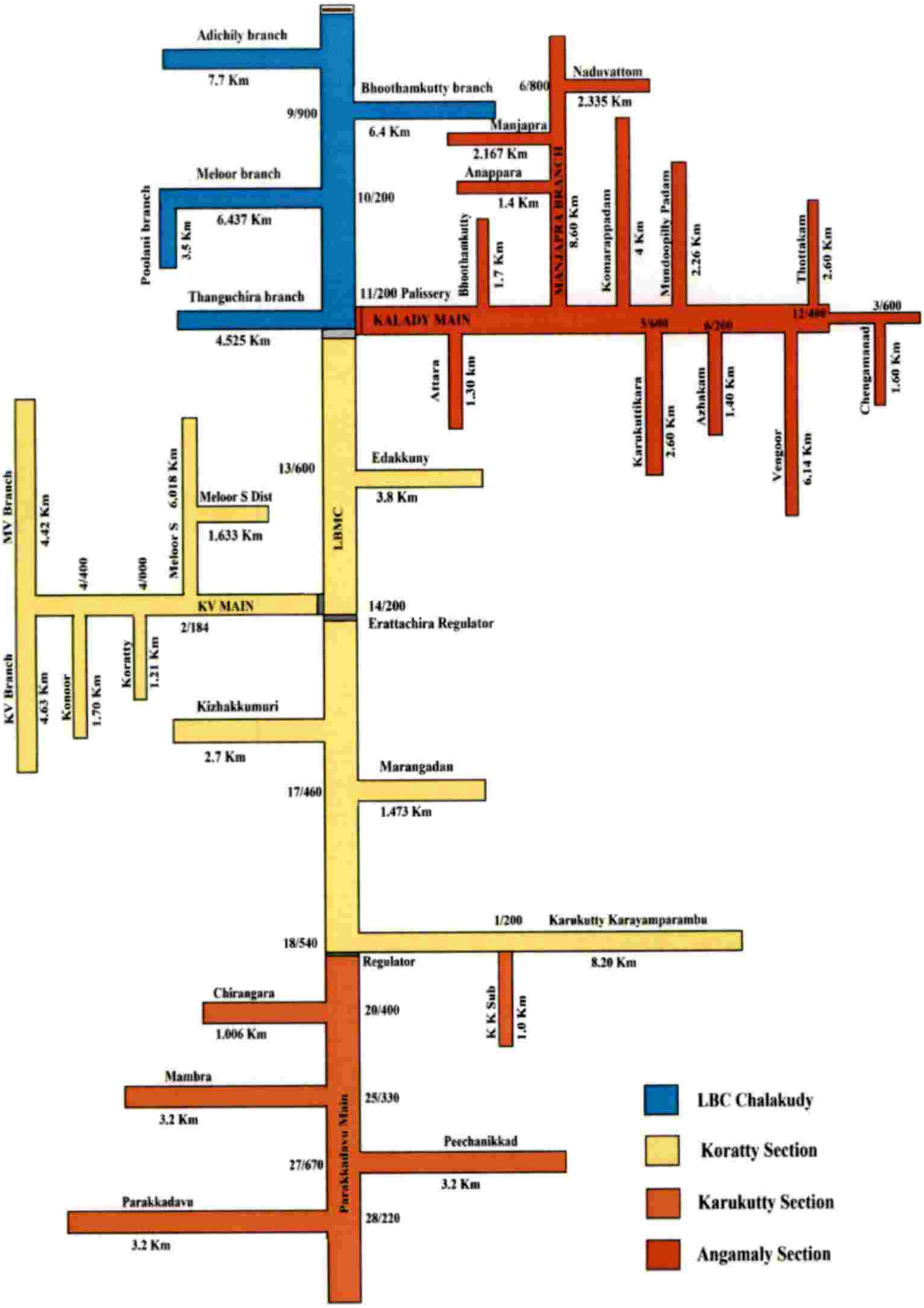

Figure 2. LBC System under different sections

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3.1.1. Chalakudy river diversion scheme

A major irrigation project in the river, Chalakudy River Diversion Scheme (CRDS) at Thumboormuzhi, commissioned in 1957, diverts the water in the river by a weir of height 3.96m constructed as a barrier across the river to both right bank main canal (48.2km) and left bank main canal (33.2km), to cater to the drinking and irrigation needs. It was meant for the irrigation of 14,000 hectares of land in the command area. As there is no storage facility in the weir the scheme completely depends on water flow through the river and the scheme was designed to provide continuous supply of water through the canals in summer. Initially it was able to fulfil the requirements of the command area but later after the construction of six dams in the river on the upstream portion of the weir, water availability has been reduced. Since the river is an inter-state river, the discharge from dams of Tamil Nadu was unavailable due to several disputes and only the discharges from projects of Kerala namely Peringalkuthu and Kerala Sholayar were available. This was too less for proper operation of the scheme and irrigation officials were compelled to introduce turn system of water supply.

The Left Bank Main Canal (LBMC), branching off from Thumboormuzhi, passes through hill slopes in the first 4 km and its first branch is at Adichily. Afterwards the main canal flows through midlands and lowlands and branches to two at Palissery into Kalady main branch and Koratty main branch. The Koratty main again branches at Erattachira as Koratty branch and *Parakkadavu* main. After several branching and sub branching Kalady branch ends at Mattoor in Ernakulam district and Parakkadavu main ends at Parakkadavu. The LBMC passes through three panchayaths of Thrissur district namely Koratty, Annamanada and Kadukutty and seven panchayaths in Ernakulam district including Mookannur, Manjapra, Thuravoor, Kalady, Meloor, Parakkadavu and Karukutty as well as Angamaly municipality. The canals have a total ayacut of 7794.23 ha. There are 31 branches for the canal starting from Adichily branch. The branches constitute a total length of 130.884 km and the distributaries have a length of 4.13km.The entire length of the canal consists of 4 regulators and 889 spouts. The hydraulic particulars of LBC are given in Table 1.

Table 1. Hydraulic particulars of LBC

Name of Canal	**Branches at**	**Length (km)**	**Bed Width (m)**	**Side Slope**	**F.S.D (m)**	**Velocity (m/s)**	**Discharge m^3/s**
LBMC Main		11.20	6.10		2.00	0.97	12.75
Adichily Branch	4/100 of LBMC	7.70	1.37		0.52	0.24	0.24
Bhoohamkutty Branch	9/100 of LBMC	6.40	1.37		0.61	0.34	0.18
Meloor Branch	10/100 of LBMC	6.44	1.83	01:0.5	0.61	0.31	0.42
Poolani Branch	6/500 of LBMC	3.22	1.37	01:0.5	0.53	0.34	0.22
Thanguchira Branch	11/200 of LBMC	4.52	1.07	01:0.5	0.53	0.17	0.14
LBMC		7.20	6.10	01:0.5	1.22	0.70	3.22
K.V. Main	14/1000 of LBMC	6.60	6.10	01:0.5	0.90	0.47	1.53
Kizhakkumuri Branch	14/200 of LBMC	2.82	0.90	01:0.5	0.61	0.28	0.18
Chirangara Branch	20/400 of LBMC	1.01	0.90	01:0.5	0.46	0.18	0.11
Meloor South Branch	2/184 of KV Main	4.97	1.27	01:0.5	0.60	0.10	0.45
Meloor South 1st	3/324 of Meloor	1.61	0.90	01:0.5	0.61	0.20	0.18

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Name of Canal	Branches at	Length (km)	Bed Width	Side Slope	F.S.D	Velocity (m/s)	Discharge m^3/s
Koratty Branch	4/0 of KV Main	1.21	0.90	01:0.5	0.40	0.18	0.11
Konoor Branch	4/400 of KV Main	1.55	0.75	01:0.5	0.30	0.10	0.30
K.V. Branch	6/630 of KV Main	4.63	1.37	01:0.5	0.61	0.52	0.41
M.V Branch Canal	5/630 of KV Main	4.42	1.37	01:0.5	0.61	0.30	0.49
Edakunny Branch	13/600 of LBMC	3.60	1.27	01:0.5	0.46	0.49	0.38
Marangadam Branch	17/640 of LBMC	1.40	0.90	01:0.5	0.46	0.37	0.23
Parakkadavu Main 1st reach	18/400 of LBMC	6.80	2.50	01:0.5	1.05	0.70	1.48
Parakkadavu 2nd reach	25/200 of LBMC	3.20	2.50	01:0.5	0.75	0.45	0.62
Parakkadavu 3rd reach	28/4 of LBMC	4.80	1.20	01:0.5	0.45	0.45	0.62
Karukutty-Karayamparambu branch	18/40 of Parakkadavu main	6.20	1.37	01:0.5	0.61	0.33	0.53
Mambra Branch	25/330 of Parakkadavu main	2.97	1.22	01:0.5	0.61	0.55	0.56
Peechanikkad Branch	27/670 of Parakkadavu main	3.22	1.20	01:0.5	0.46	0.45	0.35

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Name of Canal	Branches at	Length (km)	Bed Width (m)	Side Slope	F.S.D (m)	Velocity (m/s)	Discharge m³/s
Parakkadavu Branch	28/220 of Parakkadavu main	3.32	1.20	01:0.5	0.38	0.48	0.35
Attara Branch	3/600 of Kalady main	1.80	0.90	01:0.5	0.56	0.43	0.35
Azhakam Branch	6/200 of Kalady main	1.40	0.90	01:0.5	0.38	0.41	0.20
Karukutty kara Branch	5/600 of Kalady main	2.60	0.90	01:0.5	0.53	0.54	0.41
Kalady main		12.40	6.10	01:01	1.07	0.71	3.84
Manjapra branch	4/200 of Kalady main	8.60	1.67	01:01	0.90	0.72	0.90
Anappara branch	2/600 of Manjapra main	1.30	0.90	01:01	0.46	0.22	0.14
Naduvattam branch	6/800 of Manjapra main	2.34	0.90	01:01	0.46	0.39	0.19
Poothamkutty branch	3/600 of Kalady main	1.70	2.80	01:01	0.46	0.30	0.19
Kalady branch	12/400 of Kalady main	5.20	0.90	01:01	0.46	0.29	0.30
Manjapra distributary	3/200 Manjapara main	2.17	0.90	01:01	0.46	0.30	0.19
Komarappadam Branch	5/00 of Kalady main	4.00	0.90	01:01	0.53	0.54	0.41

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Name of Canal	Branches at	Length (km)	Bed Width (m)	Side Slope	F.S.D (m)	Velocity (m/s)	Discharge m^3/s
Vengoor Branch	9/400 of Kalady main	6.00	1.5	01:01	0.61	0.31	0.47
Thottakam Branch	12/400 of Kalady main	2.60	0.90	01:01	0.46	0.35	0.22
Chengamanad branch	3/600 of Kalady main	1.60	1.83	01:01	0.46	0.20	0.21
Karukutty-Karayamparambu sub branch		1.00	0.90	01:01	0.38	0.21	0.24

(Source: Idamalayar Irrigation Division, Chalakudy)

3.2 WEATHER DATA

The investigation was conducted from December 2016 to May 2017. Data on climate variables such as precipitation, temperature etc. from 1987 to 2017 was obtained from Agronomic Research Station (ARS), Chalakudy. The precipitation during the period was important for the study. The weather data is given in the Appendix.

3.2.1 Rainfall variability

One of the most highly variable meteorological parameter is rainfall (Singh, 2013). The rainfall data is quite important for the study as it is the basis of water availability. The rainfall data collected from ARS Chalakudy for a period of 30 years ranging from 1987 to 2017 was used for analysis. The data had been analysed for the understanding the trend in monthly, seasonal as well annual rainfall. Trend analysis of annual rainfall using linear regression was done for the time period from 1987 to 2016. The standard deviation and coefficient of variation of rainfall for different periods were also worked out to explain the variability of rainfall. Rainfall trend analysis was done by using TREND, a statistical tool for analysis of time series data. In TREND, the variability of rainfall can be analysed by using rainfall data over years saved in .csv format.

The climatological data were pooled season wise, which is classified by IMD as shown in Table 2.

Table 2. Classification of seasons

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

Apart from the parametric test, Non parametric Mann-Kendall (MK) test has been used together with the Sen's slope Estimator for the determination of trend and slope magnitude.

Mann- Kendall test was used for analysing spatial variation and temporal trends of hydro climatic series. "TREND" a statistical software which was developed by e water community, Melbourne and available through e water toolkit was used for Mann Kendall trend test of the rainfall. TREND is designed to facilitate statistical testing for trend, change and randomness in hydrological and other time series data.

3.2.1.1 ***Mann Kendall trend***

The Mann-Kendall test is the rank based nonparametric test and is applicable to the detection of a monotonic trend in a time series with no seasonal or other cycle, as described in Kundzewicz and Robson (2004). The test is based on the statistic S, which is calculated using the formula

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sign}(x_j - x_k)$$

$$\operatorname{sign}(x_j - x_k) = \begin{Bmatrix} +1 & \text{if} & x_j - x_k > 0 \\ 0 & \text{if} & x_j - x_k = 0 \\ -1 & \text{if} & x_j - x_k < 0 \end{Bmatrix}$$

Where n is the number of observed data series, x_j and x_k are the values in periods j and k, respectively, j > k. It has been documented that when n ≥ 8, the statistic S is approximately normally distributed with the mean.

$E(S) = 0$

The variance statistic is given as

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(i)(i-1)\ (2i+5)\right]$$

Where t_i is considered as the number of ties up to sample i. The test statistics Z_C is computed as

$$Z = \begin{Bmatrix} \dfrac{S-1}{\sqrt{VAR(S)}} & \text{if} & S > 0 \\ 0 & \text{if} & S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} & \text{if} & S < 0 \end{Bmatrix}$$

Z_C follows the standard normal distribution. Z_C here follows a standard normal distribution. A positive value of Z indicates an upward trend while a negative value of Z indicates a downward trend. A significance level α is also utilised for testing either an upward or downward monotone trend (a two-tailed test). If Z_C appears greater than $Z_{\alpha/2}$ where α depicts the significance level, then the trend is considered as significant.

3.2.1.2 *Sen's slope Estimator Test*

The magnitude of trend is predicted by the Sen's estimator. Here, the slope (Ti) of all data pairs is computed as (Sen, 1968)

$$\mathbf{T_i = (X_j - X_k) / (j\text{-}k)} \quad \text{for } i = 1,2,3......,N$$

where $\mathbf{x_j}$ and $\mathbf{x_k}$ are considered as data values at time j and k (j>k) correspondingly.

The median of these N values of $\mathbf{T_i}$ is represented as Sen's estimator of slope which is given as:

$$Qi = \mathbf{T}_{(N+1)/2} \text{ (N is odd)}, \quad \mathbf{(1/2) * (T_{N/2} + T_{(N+1)/2})} \text{ (N is even)}$$

Sen's estimator is computed as **Q med=T(N+1)/2** if N appears odd, and it is considered as

Q med = [TN/2+ T (N+2)/2]/2 if N appears even.

At the end, Q med is computed by a two sided test at 100 (1-α) per cent confidence interval and then a true slope can be obtained by the non-parametric test. Positive value of Qi indicates an upward or increasing trend and a negative value of Qi gives a downward or decreasing trend in the time series.

3.3. WATER REQUIREMENT

The water demand of the area comprises of irrigation water demand and domestic water demand. The allocation of water is based on demand and supply. The weekly water requirements were worked out for the command area including irrigation water requirements of major crops and domestic water requirements of the area for 26 weeks from December 1st 2016 to 31st May 2017, which is the irrigation season. The irrigation season starts from December and supply is done for 6 months till May.

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3.3.1 Crop area

The area of major crops namely nutmeg, banana, tapioca, vegetables, and paddy was obtained by analysing the land use map of the area in ARCGIS and the comparison with ground truth obtained from surveys and from Krishibhavans. The data regarding the area occupied by major crops are given in Table 3.

Table 3. Area under major crops in the command area

Sl. No	Branch	Area under each crop (ha)				
		Nutmeg	Banana	Tapioca	Vegetables	Paddy
1	Adichily	70.17	29.66	19.79	9.82	0.00
2	Bhoohamkutty	4.56	7.64	7.64	6.13	7.64
3	Meloor Poolani	70.90	29.97	19.99	9.93	7.09
4	Poolani	34.54	14.60	9.74	4.84	3.45
5	Thanguchira	85.78	36.26	24.19	12.01	8.58
6	Kizhakkumuri	17.38	23.24	2.31	1.74	13.25
7	Chirangara	8.58	11.47	1.14	0.86	6.54
8	Meloor South	96.32	40.71	27.16	13.48	9.63
9	Koratty	13.35	17.85	1.77	1.34	10.18
10	Konoor	9.81	13.12	1.30	0.98	0.00
11	K.V	29.14	38.97	3.87	2.92	22.22
12	M.V	227.72	37.92	7.58	4.05	8.85
13	Edakunny	78.86	11.47	5.74	3.35	0.00
14	Marangadam	68.06	9.90	4.95	2.89	4.74
15	Anappara	10.23	2.51	1.16	0.77	1.55
16	Karukuttikkara	47.97	9.59	1.92	1.92	1.92
17	Mundoopilly	19.60	3.92	0.78	0.78	0.78
18	Mambra	122.63	18.02	10.80	18.02	46.87
19	Peechanikkad	56.83	21.30	7.14	2.84	4.96
20	Parakkadavu	53.20	19.94	6.68	2.66	4.64
21	Attara	34.74	6.95	1.39	1.39	1.39
22	Azhakam	30.15	6.03	1.21	1.21	1.21
23	Karukutty Karayamparambu	217.54	31.64	15.82	9.23	15.16
24	Manjapra	42.41	10.40	4.80	3.20	6.41
25	Naduvattam	11.64	2.85	1.32	0.88	1.76
26	Poothamkutty	33.18	13.15	1.33	1.33	1.33
27	Manjapra Distributary	11.95	2.93	1.35	0.90	1.81
28	Komarappadam	63.30	12.66	2.53	2.53	2.53
29	Vengoor	46.42	11.38	5.26	3.50	7.01

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3.3.2 Crop water requirement

CROPWAT 8.0 carries out calculations for reference crop evapotranspiration, crop water requirements and irrigation requirements in order to calculate irrigation water demand and to schedule water supply in accordance with requirement. CROPWAT 8.0 uses the FAO (1992) Penman-Monteith method for calculating reference crop evapotranspiration. CROPWAT is an irrigation management and planning model simulating the complex relationships of on-farm parameters like climate, crop and soil.

In this study, CROPWAT model was used for the computation of crop water requirement and irrigation water demand of different terrains for rice and other crops (nutmeg, areca nut, coconut, tapioca, pepper, vegetables and plantain). There are eight input and output modules in CROPWAT. They are

- ET_0 /Climate
- Rain
- Crop
- Soil
- Crop Water Requirement
- Schedule
- Crop Pattern
- Scheme

3.3.2.1 *ET_0 /Climate Data*

The module is primary for data input, requiring information on the meteorological station (country name, altitude, latitude and longitude) together with climatic data. CROPWAT 8.0 calculates reference crop evapotranspiration using maximum and minimum temperature, sunshine hour, rainfall, relative humidity and wind speed. The daily data of climate variables for the season (2016-2017) collected from ARS Chalakudy was given as input. The monthly average of climate variables like maximum and minimum temperature and other estimated values of sunshine hour, relative humidity and wind speed are appended. The output of this module gives reference crop evapotranspiration in mm/day.

3.3.2.2 *Rainfall data*

The rain module includes calculations for effective rainfall. The daily rainfall data collected for 2016-2017 of the river basin were used as input data and are given in the Table 4.

Effective rainfall was calculated for 10 day period in the model. Fixed percentage method was used to calculate effective rainfall. Effective rainfall is considered as 80 per cent of the total rainfall.

$$P_{eff} = P_{week} * 0.8$$

3.3.2.3 *Crop data*

In this module crop name, planting date, crop coefficient (K_C), stage of crop, rooting depth, critical depletion fraction (p) and yield response factor (K_Y) are necessary. Details about the planting date were collected from farmers. The crop coefficient values used for the computation of ETc are given in the Table 5.

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Table 4. Daily rainfall data in mm for the period from August 2016- July2017

Day	August	September	October	November	December	January	February	March	April	May	June	July
1	5.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	4.6	0.0
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	13.0	42.2
3	5.0	1.9	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	2.8	5.6
4	4.6	0.0	0.0	0.0	23.4	0.0	0.0	0.0	0.0	0.0	23.2	29.8
5	14.8	0.0	1.2	10.2	0.0	0.0	0.0	0.0	0.0	0.0	26.4	7.4
6	6.0	3.0	0.0	0.0	0.0	0.0	0.0	26.2	5.1	0.0	44.0	4.6
7	8.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.0	4.0	31.0	7.0
8	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.0	2.4	18.2
9	14.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	1.4
10	22.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.4	73.6
11	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.6	52.0	19.2
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.8	0.0
13	2.0	0.0	4.1	0.0	2.0	0.0	0.0	0.0	0.0	29.5	41.8	0.6
14	0.0	0.2	12.0	0.0	20.0	0.0	0.0	0.0	2.6	22.4	17.8	34.0
15	9.0	9.0	0.4	2.0	6.4	0.0	0.0	0.5	0.0	0.0	6.6	7.2
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.1	0.0	0.0	1.8	6.0
17	3.0	0.0	0.2	0.0	0.0	0.0	0.0	0.4	0.0	0.0	18.4	11.2
18	7.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	18.4
19	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.0	3.5	9.4
20	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	23.4
21	0.0	8.4	0.0	0.0	0.0	0.0	0.0	0.0	12.2	0.0	39.2	29.8
22	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.0	11.8
23	0.0	6.8	0.0	0.0	0.0	0.0	0.0	7.2	0.0	3.6	51.6	1.2
24	2.0	2.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.4	47.2	0.5
25	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	49.2	2.0
26	9.5	7.0	12.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6	44.0	5.4
27	1.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	27.0	3.8
28	24.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	6.6	29.6	45.8
29	20.0	0.0	73.2	0.0	0.0	0.0		0.0	0.0	15.6	23.0	1.8
30	3.0	1.6	0.0	0.0	0.0	0.0		0.0	0.0	50.4	25.4	0.0
31	23.0		28.4		0.0	0.0		0.0		35.6		0.0

Table 5. Crop coefficient of annual/seasonal crops

Crops	K_c		
	Initial	**middle**	**Late**
Rice	1.1	1.2	1.05
Tapioca	0.3	1.1	0.5
Banana	0.5	1.1	1
Vegetables	0.7	1.05	0.95
Coconut	0.75	0.75	0.75
Nutmeg (coconut-nutmeg)	0.87	0.87	0.87

(Source: Surendran *et al.*, 2017)

3.3.2.4 ***Soil data***

The soil module requires general soil data like total available water (TAW), maximum infiltration rate, maximum rooting depth and initial soil moisture depletion. In case of rice, additional soil data are required like drainable porosity, critical depletion for puddle cracking, water availability at planting, maximum water depth etc. are required. The soil type was identified from agro ecological unit map. Fig.3 and Fig.4shows the AEU map of Ernakulam and Thrissur. The data on soil type was collected from the National Bureau of Soil Survey and Land use Planning.

The area was found to fall under AEU9 and AEU10. The input soil data are given in Table 6.

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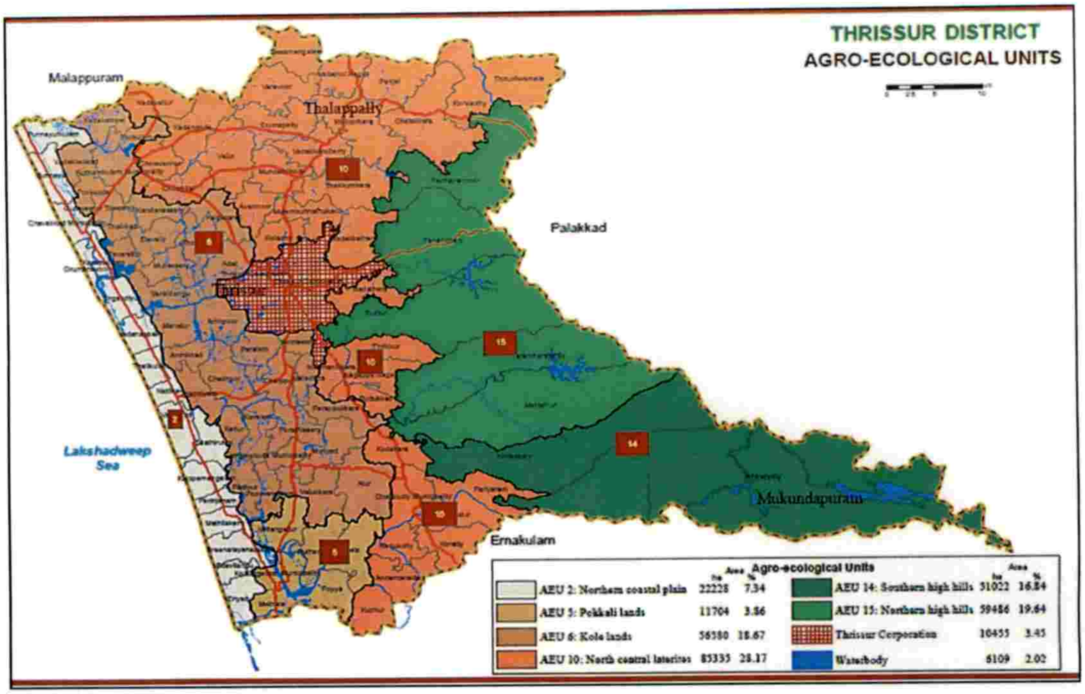

Figure 3. AEU map of Thrissur

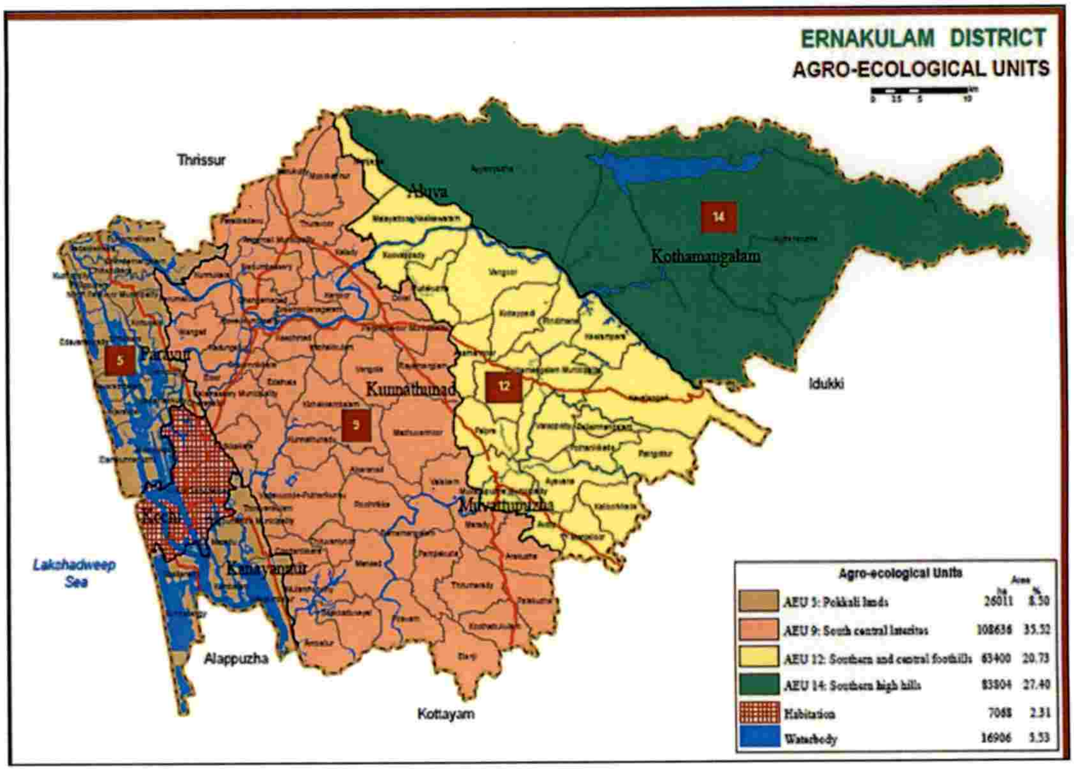

Figure 4. AEU Map of Ernakulam

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Table 6. Input soil data

General soil data	Soil Type	
	North Central Laterites (AEU 9)	**South Central Laterites (AEU 10)**
Total Available Soil moisture (FC-WP)	86.0 mm/meter	110.0 mm/meter
Maximum rain infiltration rate	187 mm/day	34 mm/day
Maximum rooting Depth	200 cm	95 cm
Initial Soil moisture depletion (as per cent TAM)	0	0
Initial available soil moisture	86 mm/meter	110 mm/meter
Additional data for rice		
Drainable porosity (SAT-FC)	22 %	11%
Critical depletion for puddle cracking	0.8	0.8
Maximum percolation rate after puddling	5.7 mm/day	3.2 mm/day
Water availability at planting	50 mm WD	50 mm WD
Maximum water depth	50 mm	50 mm

3.3.2.5 *Crop water requirement*

Crop water requirement (CWR) refers to the amount of water required to compensate the evapotranspiration loss from the cropped field also synonymously known as crop evapotranspiration (ETc). Data on climate/ETo, rainfall, crop and soil are required.

The CWR module includes calculations producing the irrigation water requirement of the crop on a daily basis depending on the crop coefficient approach. Although the values of CWR and ETc are identical, CWR refers specifically to the amount of water to be supplied, whereas ETc refers to the amount of water that crop has lost through evapotranspiration.

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ETc is calculated at daily time step according to the following method:

$$ETc = Kc \times ET_0.$$

The effects of characteristics that distinguish field crops from reference grass crop are integrated into the crop coefficient (Kc) and due to variations in the crop characteristics throughout its growing cycle Kc for a given crop changes from sowing till harvest. Irrigation requirement is calculated on a daily basis using the following formula. It refers to the amount of water required to be supplied to the crop so as to meet the CWR.

$$\text{Irrigation Requirement} = ETc - Peff$$

The CWR is calculated for a decade (a period of 10 days) in the CROPWAT.

3.3.2.6 *Calculation of weekly irrigation water requirements*

The crop water requirement is obtained on a decade basis in CROPWAT. The decade wise CWR is added up to obtain the monthly CWR. The daily CWR is worked out for the month by dividing total monthly crop water requirement by the total number of days. The weekly CWR is calculated from the daily CWR. The weekly irrigation water requirement is worked out by subtracting the weekly effective rainfall from the CWR.

3.3.2.7 *Penman-Monteith equation*

In 1948, Penman combined the energy balance with the mass transfer method and derived an equation to compute the evaporation from an open water surface from standard climatologically records of sunshine, temperature, humidity and wind speed. This so called combination method was further developed by many researchers and extended to cropped surfaces by introducing resistance factors (FAO, 1998).

$$\lambda ET = \Delta(Rn - G) + \rho a\, CP\ (\ (es - ea) / ra\ )\ \Delta + \gamma\ (1 + rs / ra)$$

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Where,

Rn- The net radiation [MJ m^{-2} day^{-1}]

G - The soil heat flux [MJ m^{-2} day^{-1}]

ρa - The mean air density at constant pressure [kg m^{-3}]

C_p - The specific heat of the air [MJ kg^{-1} $°C^{-1}$] rs- The surface resistance describes the resistance of vapour flow through stomata openings, total leaf area and soil surface

ra - The aerodynamic resistance, describes the resistance from the vegetation upward and involves friction from air flowing over vegetative surfaces [s m^{-1}]

(es - ea) - The vapour pressure deficit of the air [kPa]

Δ -The slope of the saturation vapour pressure temperature relationship [kPa $°C^{-1}$]

γ - The psychometric constant [kPa $°C^{-1}$]

The Penman-Monteith approach as formulated above includes all parameters that govern energy exchange and corresponding latent heat flux (evapotranspiration) from uniform expanses of vegetation. The equation can be utilized for the direct calculation of any crop evapotranspiration as the surface and aerodynamic resistances are crop specific.

3.3.3 Domestic water requirement

The number of houses in the canal commands was obtained through survey along the command area. An assumption of four persons per house was done and domestic water requirement as per. IS Code 1172: 1993 was used for calculating water requirement for domestic needs. About 120 litres was taken as the basic water requirement for domestic need per day.

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Domestic water requirement of a branch canal = (No. of houses) * 4* (Standard domestic water requirement)

3.4 GROUNDWATER OBSERVATIONS

The allocation of water should be based on availability of water in an area. For the better understanding of water availability and water table groundwater observations were taken by monitoring observation wells along the entire canal system.

Sixty observation wells were selected along the entire length of canal. Two to three observation wells were taken in each branch, based on the length of the branch canal. The wells were taken at an interval of two to three kilometres. Observation of water levels was done on a weekly basis for a period of six months from December to May. The wells about a distance of 80 to 100m from canals are selected. Analysis of observed groundwater levels for variations in water levels during supply and non-supply periods was done for different branch canals.

The coordinates of the selected wells were marked using a GPS system and it was incorporated in a base map of the area using ArcGIS. The marked wells are shown in Figure 5.

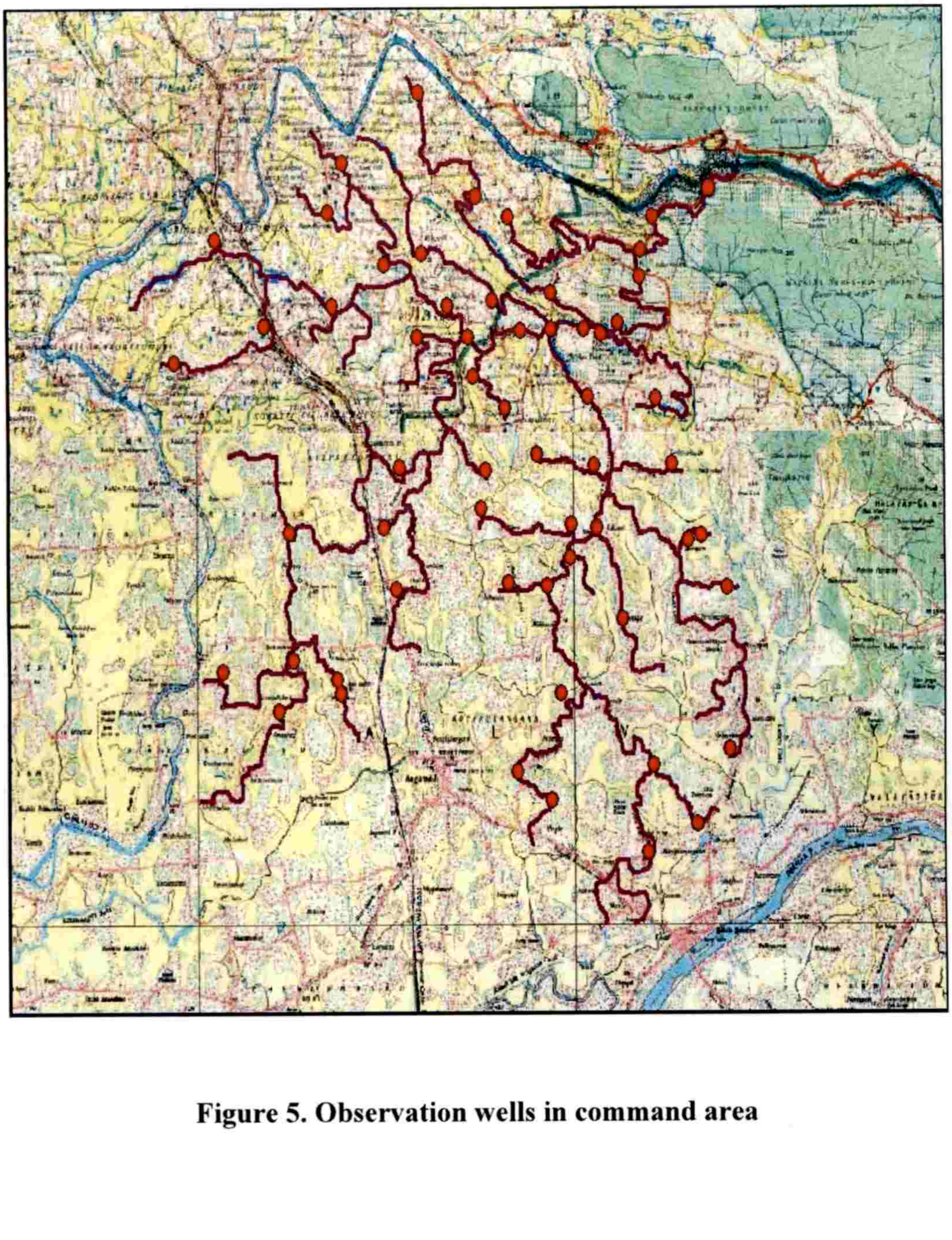

Figure 5. Observation wells in command area

Table 7. Geographical co - ordinates of the selected observation wells

Well No.	Latitude (degrees)	Longitude (degrees)	Elevation (m)
1	10.29	76.45	29.2
2	10.29	76.43	25.9
3	10.28	76.43	29.7
4	10.29	76.4	38.5
5	10.28	76.43	40.7
6	10.27	76.43	42.3
7	10.27	76.42	40.4
8	10.26	76.43	39.9
9	10.28	76.41	36.6
10	10.29	76.39	34.6
11	10.31	76.38	24.4
12	10.27	76.42	39.7
13	10.27	76.41	36
14	10.27	76.4	42.7
15	10.28	76.38	33
16	10.27	76.4	38
17	10.26	76.39	31.2
18	10.26	76.4	32.8
19	10.27	76.39	37.6
20	10.27	76.39	45.2
21	10.28	76.37	48.2
22	10.3	76.36	26.2
23	10.29	76.36	28.1
24	10.27	76.36	25.6
25	10.27	75.32	17.3
26	10.26	76.33	18.8
27	10.28	76.34	18.4
28	10.27	76.38	31.5
29	10.25	76.4	25.2
30	10.23	76.38	22.6
31	10.24	76.37	37.7
32	10.25	76.38	27

Table 7 continued

Well No.	Latitude (degrees)	Longitude (degrees)	Elevation (m)
33	10.25	76.37	24.6
34	10.23	76.35	27.9
35	10.21	76.36	23
36	10.21	76.36	28.5
37	10.21	76.34	18.1
38	10.21	76.35	32.2
39	10.2	76.35	24
40	10.26	76.42	35.2
41	10.25	76.42	35.6
42	10.25	76.41	27.6
43	10.25	76.44	42.2
44	10.23	76.44	28.4
45	10.23	76.44	31.1
46	10.23	76.45	28.6
47	10.2	76.45	20.6
48	10.24	76.42	35.2
49	10.22	76.43	23.3
50	10.24	76.42	28.5
51	10.24	76.4	16
52	10.23	76.41	35.8
53	10.23	76.41	32
54	10.23	76.4	29.7
55	10.21	76.41	17.4
56	10.19	76.4	21.9
57	10.19	76.41	19
58	10.2	76.43	19.4
59	10.19	76.44	25.5
60	10.18	76.43	27.1
61	10.27	76.34	18.9
62	10.25	76.35	23.3

3.5 WATER SUPPLY DATA

Canal water supply data for the period December 2016 to May 2017 was collected from the Department of Irrigation, Govt. of Kerala. Daily discharge data from Thumburmuzhi weir was available. The information on rotation wise supply system, the number of days of supply was obtained from the four sections of LBC namely Chalakudy, Koratty, Karukutty and Angamaly.

The details on days and duration of water supply through individual branch canals obtained from the irrigation section was used to work out the amount of supply through the branches by using Manning's formula.

$$Q = A * (1/n) * R^{(2/3)} * S^{(1/2)}$$

Where, n = Manning's roughness coefficient (0.04) (s/[$m^{1/3}$])

R=Area/ Wetted perimeter (m)

A=Area of Cross section of canal (m^2)

S= bed slope of the canal 1/3000 (y/x)

Q = Discharge rate (m^3/s)

t = time of operation (s)

Amount of water supply = Q*t (m^3)

The depth of flow was measured for different canals which were used to work out wetted perimeter and area of flow. The total flow through the branch canal was obtained by multiplying discharge rate with the hours of operation.

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3.6 DEVELOPMENT OF MODEL FOR EFFECTIVE WATER SUPPLY

A computer based model was developed for the optimum allocation of water based on supply and demand. The supply consists of canal supply and rainfall while the demand comprised of irrigation requirement and domestic water requirement.

$$CS+RF = IWR+DWR$$

The model was developed in programming language .net. The Opening screen of the model was designed in such a way that the menu bar consists of five options

- Rainfall
- Canal Supply
- Water requirement
- Groundwater
- Water management

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RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

The observed results of the analysis done on weather data, ground water regime and estimates of water demand against the supply of different branches so as to depict the existing conditions of the system as well as the water allocation models evolved are discussed in the chapter.

4.1 WEATHER DATA ANALYSIS

Rainfall is the major climatic variable that determines the water availability of a region. Rainfall trend analysis has been done for Chalakudy river basin with 30 years of rainfall data. Fig.6 represents the variation in annual rainfall over 30 years. From the graph, the year 2007 had maximum precipitation of 4112.40 mm and the year 2016 had minimum rainfall of 1693.66 mm during this period. The average annual rainfall was 3044.81 mm during the period.

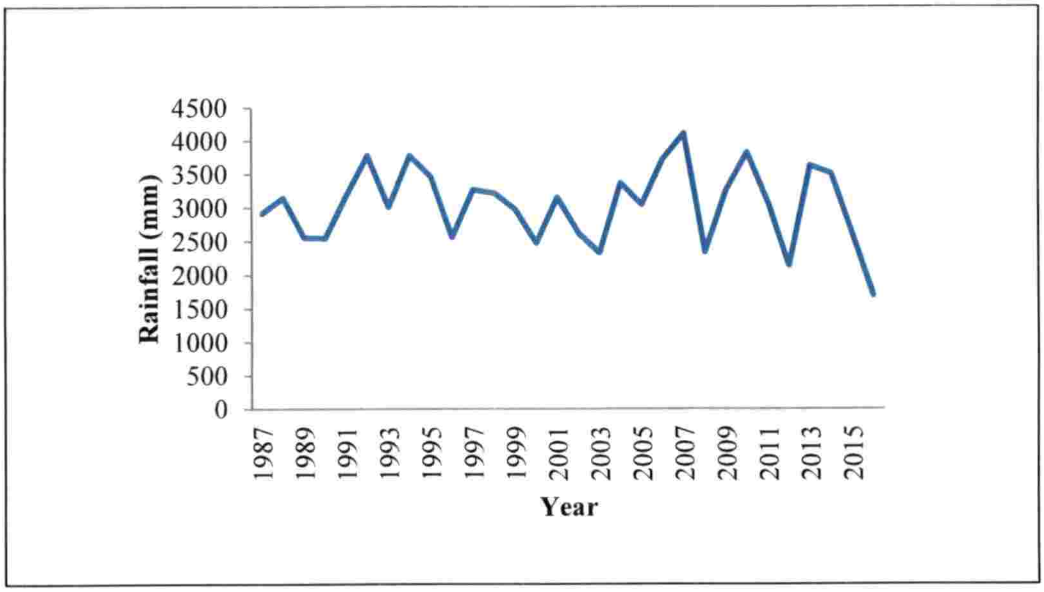

Figure 6. Distribution of annual rainfall for 30 years

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4.1.1 Seasonal variation of rainfall

Fig.7 illustrates the distribution of South West monsoon from the year 1987 to 2016. The year 2007 had maximum amount of precipitation of 3123.20 mm and in the year 2016 the minimum amount of precipitation of 1282.60 mm was observed. Average precipitation during the entire period was about 2149.10 mm.

Distribution of North East monsoon for the period is represented in Fig.8. The maximum amount of precipitation during North East monsoon season was found in 2010 with a total of 1161.10mm and minimum of about 65.45mm during 2012. The average precipitation of about 550.25mm was received during North East monsoon. A steady increase in rainfall was observed from 1990 to 1993 and a steady decline from 1993 to 1996 and it again followed an increasing trend from 1996 to 1999. After 1999 the rainfall shows a fluctuating pattern.

Winter rainfall is represented in Fig.9. The maximum amount of precipitation was about 92.90 mm during 1994 while no rainfall was observed in winter during years of 1987, 1989, 1990, 1991, 1992, 1997, 1998, 2004, 2007, 2009, 2012, 2014 and 2016. An average precipitation of about 15.45 mm was got during the period.

Variation of summer rainfall can be understood from Fig. 10. The summer rainfall had its minimum value of about 46.50 mm during 1987 and a maximum value in 2004 with a precipitation of 729.90 mm. The average rainfall during summer was about 330.00 mm. An overall decline in rainfall was observed from 2006 to 2016.

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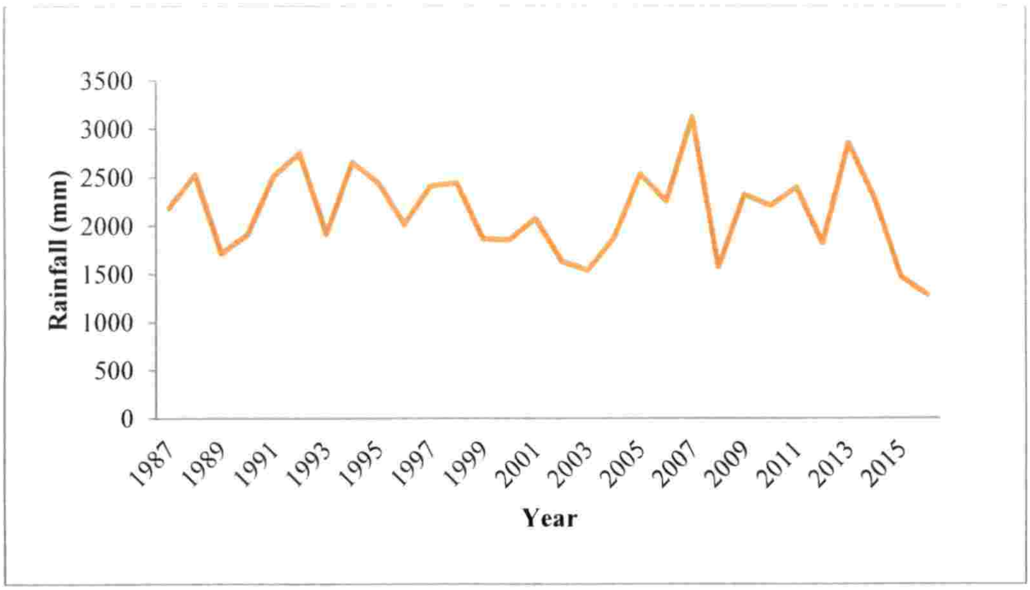

Figure 7. Distribution of South West monsoon rainfall

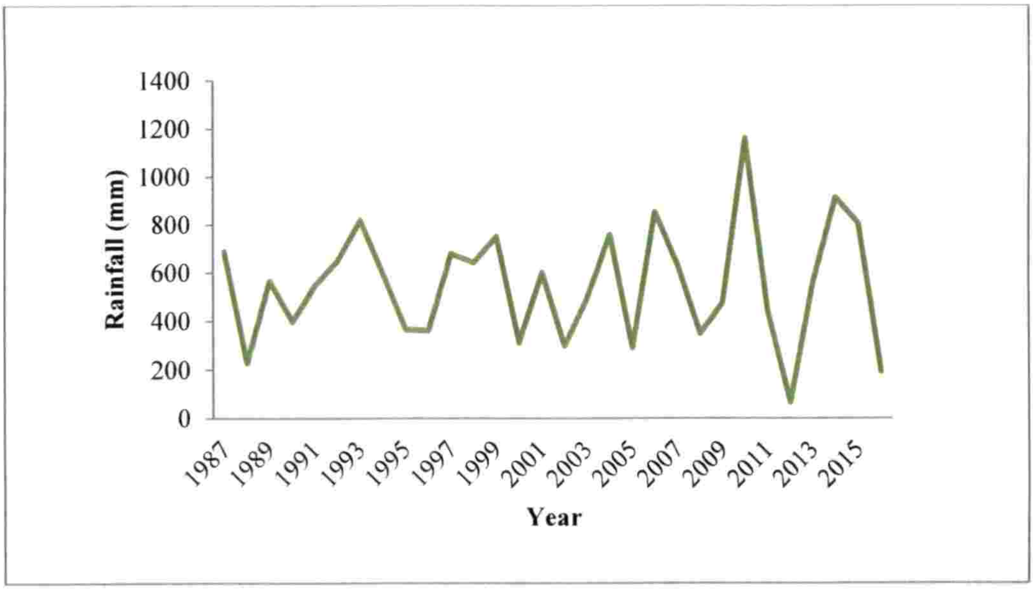

Figure 8. Distribution of North East Monsoon Rainfall

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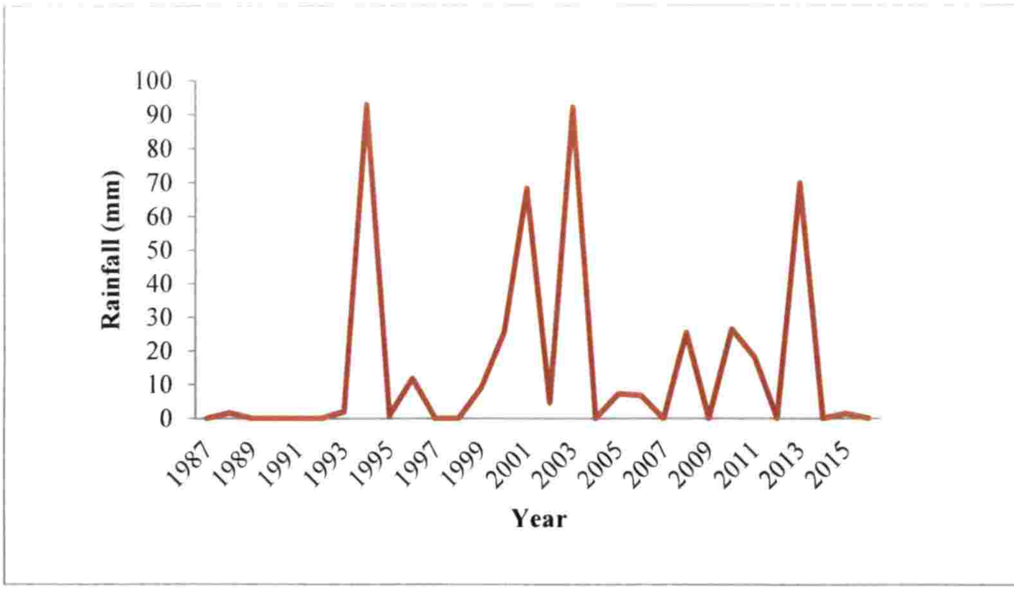

Figure 9. Distribution of Winter Rainfall

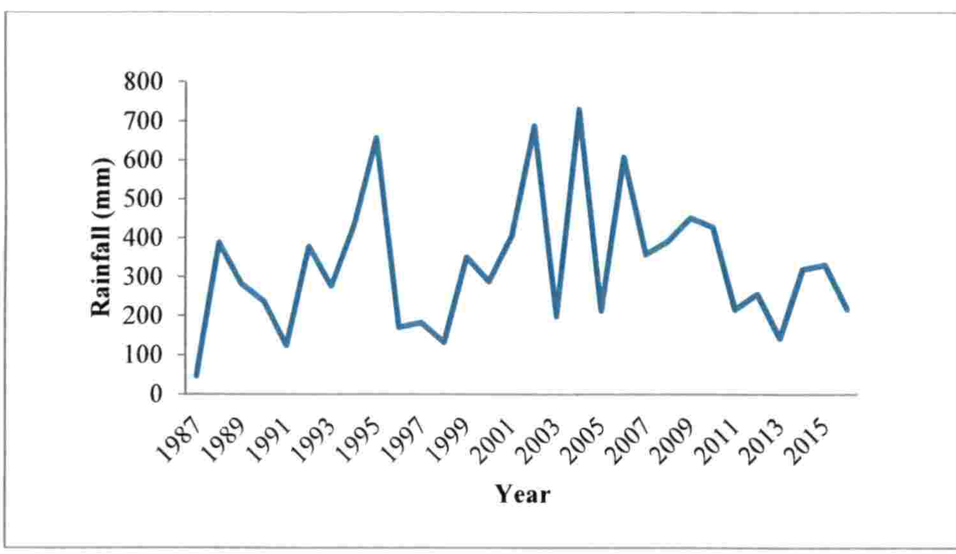

Figure 10. Distribution of Summer Rainfall

4.1.2 Rainfall trend analysis

The rainfall data for the period was analysed using *Weathercock* software. The percentage deviation of annual rainfall from the normal was obtained (Table 8). Considering a ten years interval the deviation and the years having higher deviation of rainfall was found to be higher over the years from 1987 to 2016. During three years of the first decade (1987 to 1996) a negative deviation up to

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-15 per cent of annual rainfall was seen. But for the second decade (1997-2006) the deviation was found to have increased up to -20 to -25 per cent. For the last decade (2007-2016) the deviation was found to be higher, which crossed -40 per cent. Not only the per cent deviation but also the number of years that exhibited the deviation was also increased from three to four. For the last decade during 2012 and 2016 a moderate drought was noticed. From the analysis it was clear that the rainfall of the basin was showing greater deviation over the years and the region is gradually moving towards a drought condition. The percentage deviations of annual rainfall over the years from normal are shown in Fig. 11.

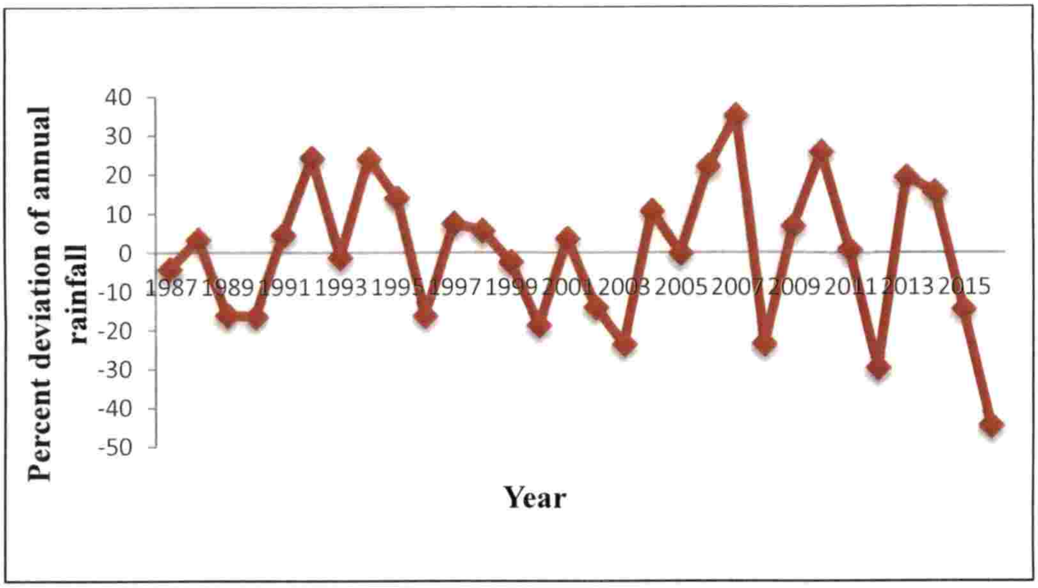

Figure 11. Percentage deviation of annual rainfall

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Table 8. Percentage deviation of annual rainfall

Sl. no	Year	Annual RF (mm)	Deviation	Drought condition
1	1987	2918.60	-4.14	No Drought
2	1988	3147.70	3.38	No Drought
3	1989	2559.70	-15.93	No Drought
4	1990	2549.54	-16.27	No Drought
5	1991	3184.80	4.60	No Drought
6	1992	3784.50	24.29	No Drought
7	1993	3010.20	-1.14	No Drought
8	1994	3779.30	24.12	No Drought
9	1995	3470.75	13.99	No Drought
10	1996	2559.84	-15.93	No Drought
11	1997	3273.00	7.49	No Drought
12	1998	3219.90	5.75	No Drought
13	1999	2976.00	-2.26	No Drought
14	2000	2478.90	-18.59	No Drought
15	2001	3153.40	3.57	No Drought
16	2002	2623.86	-13.83	No Drought
17	2003	2331.42	-23.43	No Drought
18	2004	3369.40	10.66	No Drought
19	2005	3044.26	-0.02	No Drought
20	2006	3721.21	22.22	No Drought
21	2007	4112.00	35.05	No Drought
22	2008	2338.01	-23.21	No Drought
23	2009	3252.26	6.81	No Drought
24	2010	3826.70	25.68	No Drought
25	2011	3072.00	0.89	No Drought
26	2012	2142.05	-29.65	Moderate
27	2013	3630.40	19.23	No Drought
28	2014	3511.40	15.32	No Drought
29	2015	2609.40	-14.30	No Drought
30	2016	1693.66	-44.38	Moderate

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4.1.3 Rainfall Variability

The monthly as well as seasonal rainfall was analysed to find out mean, standard deviation and coefficient of variation. The maximum mean monthly rainfall was observed for June (702.45mm) and July (667.01mm) and minimum was observed for January (5.09mm). Maximum standard deviation of rainfall was observed in July followed by the month of June. But the rainfall of June and July was found to be most assured as indicated by lower value of Coefficient of variation (Table 9) and the larger variation in rainfall was observed in January and March. The mean number of rainy days was higher for July followed by June and was least during January and February.

Among the seasons mean rainfall was maximum during South West monsoon (2149.10mm) and was minimum during winter (15.45mm). The standard deviation was higher for South West monsoon and North East monsoon (444.36 and 241.48) compared to rainfall during summer and winter (170.88 and 27.62). But the South West monsoon and north east monsoon was highly dependent with a coefficient of variation of about 20.68 percent and 43.89 percent. The winter rainfall was noted to be highly variable with 178.73 percent of coefficient of variation (Table 10). The mean number of rainy days was higher during South West monsoon (81.07) and least during winter (0.80).

Table 9. Variability of Monthly rainfall

Month	Rainfall			Rainy days		
	Mean	SD	CV	Mean	SD	CV
January	5.09	16.67	327.64	0.33	0.80	240.69
February	10.37	23.37	225.39	0.47	0.90	192.76
March	20.72	47.78	230.62	1.40	2.04	146.02
April	101.81	67.70	66.50	6.33	4.60	72.69
May	207.47	167.68	80.82	8.73	5.18	59.30
June	702.45	185.83	26.45	23.47	3.00	12.80
July	667.01	209.85	31.46	24.30	3.58	14.74
August	453.65	170.53	37.59	19.50	3.07	15.75
September	326.00	186.16	57.11	13.80	6.09	44.16
October	358.99	179.55	50.02	14.60	5.37	36.80
November	155.75	120.59	77.42	7.27	3.86	53.11
December	35.52	53.79	151.44	1.90	2.25	118.38

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Table 10. Variability of seasonal rainfall

Season	Rainfall			Rainy days		
	Mean	SD	CV	Mean	SD	CV
Winter	15.45	27.62	178.73	0.80	1.24	155.36
Summer	330.00	170.88	51.78	16.47	6.20	37.63
South West Monsoon	2149.10	444.36	20.68	81.07	8.37	10.32
North East Monsoon	550.25	241.48	43.89	23.77	8.21	34.53

4.2.1. Mann-Kendall Trend analysis test

In the non parametric Mann-Kendall test, trend of rainfall for the four seasons and monthly rainfall had been calculated individually. The magnitude of trend was found using Sen's slope. The Z_c statistics revealed the trend of the rainfall. Fig. 12 provides information about the trends in rainfall during different seasons. The Z_c statistic is plotted for the different seasons. A negative trend was observed for South West monsoon and winter rainfall while the summer rainfall as well as North East monsoon showed a positive trend. But no significant trend was observed for any of the seasons. The trend value was about -1.32, 0.5, 0.321, and 1.035 for Southwest, North East monsoons and winter and summer rainfall respectively.

The Sen's slope was computed for the four seasons. The magnitude of trend is indicated by the Sen's slope. The result is quite significant as the season's having negative trend according to Mann Kendall trend analysis shown negative Sen's slope and those with positive trend value had positive Sen's slope. Table .11 represent Sen's slope, mean, median and standard deviation for the respective seasons.

Fig. 13 shows the trend values of rainfall over different months from 1987 to 2016. Table 12 exhibits the values of Sen's slope, mean, median and standard deviation for the individual months. The trend analysis of monthly rainfall by Mann Kendall trend analysis shows negative trend of rainfall for April, May, June, July and August with trend values of -0.731,-2.105,-2.105,-0.749,-0.892 and

-0.071 respectively. But only May and June show significant trend. The months of January, February, March, September, November and December exhibit positive trend in rainfall with trend values 0.321, 0.589, 0.999, 0.963, 1.195 and 0.25. Even though the trend is positive there is no significance in the trend. Only significant negative trend is in rainfall of the months May and June.

Mondal *et al.* (2012) had analysed the rainfall trend by using Mann Kendall trend test and Sen's slope estimator in North eastern part of Cuttack in Orissa. The analysis of rainfall for 40 years had shown decreasing trend in some months and increasing trend in certain others. As above the study also had obtained trends in which the Mann Kendall Zc statistic and Sen's slope estimator had indicated same trend.

Ajithkumar and Sreekala (2015) observed the rainfall trend analysis over Kerala using Mann Kendall trend test and found a decreasing trend for South West monsoon over Kerala which was identical with observed results, Even though the significance in trend was not observed for this study the South West monsoon had shown a decreasing trend. They had spotted a negative trend for North East monsoon also over entire Kerala which was different from the present study which showed an insignificant slight increase in North East monsoon rainfall may be as it consider the Chalakudy basin only while compared to the other considering whole state. But the summer rainfall had similar trends for both the studies. The winter rainfall got a slight decline as per present study while it had a positive trend from the above mentioned.

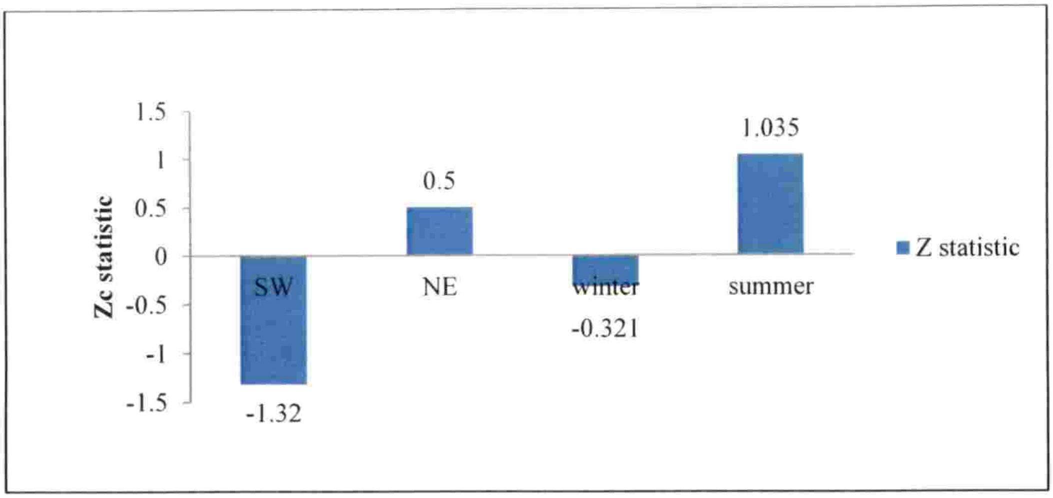

Figure 12. Trend of seasonal rainfall by Mann-Kendall trend analysis

Table 11. Sen's slope values of rainfall over different seasons from 1987 to 2016

Season	Sen's slope
South West monsoon	-9.250
North East monsoon	2.375
winter	-0.658
summer	2.375

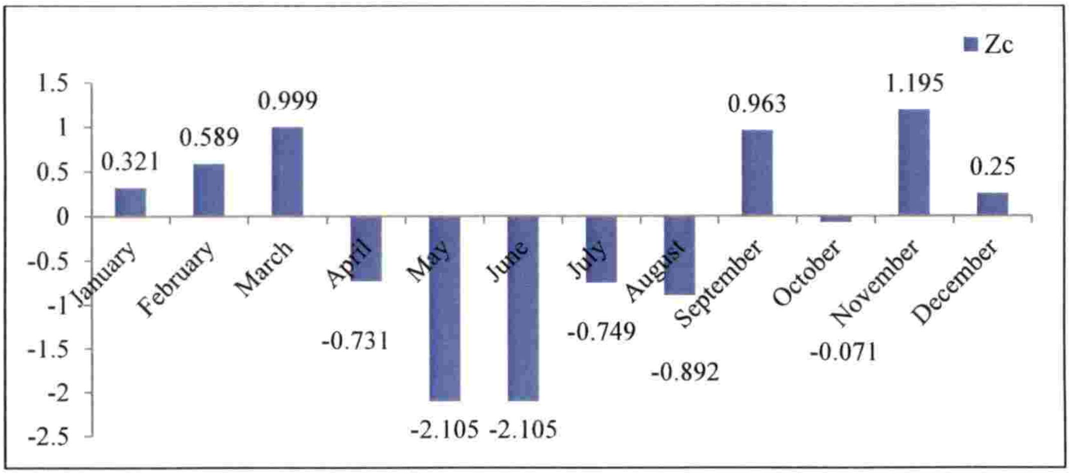

Figure 13. Trend of Monthly rainfall by Mann Kendall trend analysis

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Table 12. Sen's slope values of the monthly rainfall from 1987 to 2016

Month	Sen's slope
January	-0.27
February	0.22
March	1.04
April	-1.29
May	0.48
June	-5.96
July	-3.47
August	-2.12
September	2.58
October	-0.58
November	3.32
December	-1.61

4.2. WATER REQUIREMENT

Weekly water requirement was computed for the command area of all the branch canals of LBC of Chalakudy River Diversion Scheme. The irrigation water requirement was calculated considering major crops in the command area. The domestic water requirement for the commands was also worked out.

4.2.1 Crop irrigation water requirement

Weekly irrigation water requirement for crops which occupied major areas of the command area is presented in Table 13. It could be inferred that among the crops, nutmeg had maximum weekly irrigation water requirement. The maximum irrigation water requirement for nutmeg was about 34.67 mm in 13th week. Nutmeg has a mean weekly irrigation requirement of about 24.09 mm during the entire irrigation season and mean irrigation requirement was found minimum for tapioca with a value of about 1.91 mm per week. Vegetables were cultivated in the command area during the weeks 9 to 23.

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Table 13. Weekly irrigation water requirement of major crops

Weeks (01/12/2016 to 31/05/2017)	Weekly irrigation water requirement of crops (mm)				
	Nutmeg	Banana	Tapioca	Vegetables	Paddy
1	8.87	0.00	_	_	15.55
2	9.99	0.00	_	_	16.67
3	22.47	9.40	_	_	29.15
4	27.59	14.52	_	_	34.27
5	29.81	15.71	_	_	29.09
6	31.48	16.60	_	_	25.22
7	31.48	16.60	_	_	25.22
8	31.48	16.60	_	_	25.22
9	31.93	17.50	_	_	_
10	34.65	22.93	_	26.03	_
11	34.65	22.93	_	26.03	_
12	34.65	22.93	_	26.03	_
13	34.67	24.11	_	27.17	_
14	9.70	6.13	_	8.95	_
15	34.42	30.85	_	33.67	_
16	12.82	9.25	_	12.07	_
17	29.06	25.49	_	28.31	_
18	34.20	34.05	7.77	34.87	_
19	29.87	31.08	6.79	31.11	_
20	31.87	33.08	8.79	33.11	_
21	24.19	25.40	1.11	25.43	_
22	27.69	28.81	11.31	14.03	_
23	14.33	15.33	6.88	0.00	_
24	0.00	0.00	0.00	_	_
25	14.33	15.33	6.88	_	_
26	0.00	0.00	0.00	_	_

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The mean water requirement was highest for nutmeg which was followed by banana, vegetables, paddy and tapioca with 17.48, 17.46, 13.31, 6.84 and .91 mm respectively on a weekly basis.

4.2.2 BRANCH WISE IRRIGATION WATER DEMAND

Branch wise irrigation water demand was worked out for each branch of the canal system. The irrigation water demand of crops was multiplied with their respective area in each canal command to work out the volumetric water demand.

Weekly irrigation water demands of the individual canal commands are presented in Table. 14. The highest amount of irrigation water requirement was obtained for MV branch (1633.27 million litres) and the lowest amount of irrigation water requirement was found for Anappara branch (81.68 million litres). Figure.14 depicts the graphical representation of net irrigation water demand of all the branches of CRDS. The irrigation requirement of the MV branch was followed by Karukutty-Karayamparambu, Mambra, Meloor south and Thanguchira branch. The net irrigation requirement of Parakkadavu, Peechanikkad and Komarappadam had almost identical irrigation water requirements the branches Poothamkutty, Kizhakkumuri, Attara, Azhakam and Poothamkutty had similar irrigation water requirements.

Figure.15 illustrates the weekly irrigation water requirement for the whole CRDS system. The peak water requirement was found to be about 781.20 million litres which was noticed in the 18^{th} week. The next highest requirement was noted for 15^{th} week. The minimum value of irrigation water requirement for the system was zero during the 24^{th} and 26^{th} weeks due to heavy rainfall in the week. The next minimum was observed in week 1^{st}, 2^{nd} and the 14^{th} weeks which also attributed to heavy rainfall events. The lower water requirement in 1^{st} and second weeks was due to lack of seasonal crops tapioca and vegetables in the field as well as sufficient rainfall. While the 14^{th} week had more rainfall compared to 1^{st} and 2^{nd} weeks even though more crops were present in the field during 14^{th} week compared to 1^{st} and second and the irrigation water requirement was less.

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Table 13. Irrigation water requirement of branch canals in the commands

Week (1/12/16 to 31/5/17)	Branch name										
	Adichily	Bhoohamkutty	Meloor poolani	Poolani	Thanguchira	Kizhakkumuri	Chirangara	Meloor South	Koratty	Konoor	K.V
	Irrigation water requirement (in million litres)										
1	6.23	1.59	7.39	3.60	8.95	3.60	1.78	10.04	2.77	0.87	6.04
2	7.01	1.73	8.27	4.03	10.00	3.95	1.95	11.23	3.03	0.98	6.61
3	18.56	3.97	20.82	10.14	25.19	9.95	4.91	28.28	7.65	3.44	16.69
4	23.67	4.98	26.34	12.83	31.88	12.71	6.27	35.79	9.76	4.61	21.31
5	25.58	4.78	27.90	13.59	33.77	12.68	6.26	37.91	9.74	4.99	21.27
6	27.01	4.63	29.08	14.17	35.18	12.67	6.25	39.50	9.73	5.27	21.24
7	27.01	4.63	29.08	14.17	35.18	12.67	6.25	39.50	9.73	5.27	21.24
8	27.01	4.63	29.08	14.17	35.18	12.67	6.25	39.50	9.73	5.27	21.24
9	27.96	3.02	28.25	13.76	34.18	9.68	4.78	38.38	7.44	5.47	16.23
10	33.67	4.93	34.02	16.57	41.16	11.80	5.83	46.22	9.07	6.66	19.79
11	33.67	4.93	34.02	16.57	41.16	11.80	5.83	46.22	9.07	6.66	19.79
12	33.67	4.93	34.02	16.57	41.16	11.80	5.83	46.22	9.07	6.66	19.79
13	34.15	5.09	34.51	16.81	41.75	12.10	5.97	46.88	9.30	6.83	20.29
14	9.50	1.46	9.60	4.68	11.62	3.27	1.61	13.05	2.51	1.84	5.48
15	36.61	5.99	36.99	18.02	44.76	13.74	6.78	50.25	10.55	7.76	23.03
16	12.93	2.03	13.06	6.36	15.80	4.59	2.26	17.74	3.52	2.59	7.69
17	30.73	5.01	31.05	15.13	37.57	11.47	5.66	42.18	8.81	6.47	19.23
18	39.06	6.89	39.46	19.22	47.75	14.64	7.23	53.61	11.25	8.27	24.55
19	34.58	6.16	34.94	17.02	42.27	13.11	6.47	47.46	10.07	7.40	21.99
20	37.17	6.68	37.55	18.29	45.44	14.01	6.91	51.02	10.76	7.91	23.49
21	27.23	4.69	27.51	13.40	33.29	10.58	5.22	37.37	8.12	5.97	17.73
22	31.59	5.19	31.92	15.55	38.62	12.01	5.93	43.36	9.23	6.78	20.14
23	15.96	2.35	16.13	7.86	19.52	6.21	3.07	21.91	4.77	3.51	10.41
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	15.96	2.35	16.13	7.86	19.52	6.21	3.07	21.91	4.77	3.51	10.41
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	616.54	102.63	637.10	310.38	770.90	247.93	122.38	865.55	190.46	124.97	415.70

Table 13 continued

Week (1/12/16 to 31/5/17)	Branch name									
	M.V	Edakunny	Marangadam	Anappara	Karukuttikkara	Mundoopilly	Mambra	Peechanikkad	Parakkadavu	Attara
	Irrigation water requirement (million litres)									
1	21.58	7.00	6.78	1.15	4.56	1.86	18.17	5.81	5.44	3.30
2	24.23	7.88	7.59	1.28	5.11	2.09	20.07	6.51	6.09	3.70
3	57.32	18.80	17.61	2.99	12.24	5.00	42.92	16.22	15.18	8.87
4	71.37	23.43	21.84	3.72	15.29	6.25	52.52	20.47	19.16	11.07
5	76.42	25.31	23.23	3.89	16.37	6.69	53.02	21.73	20.34	11.85
6	80.21	26.73	24.26	4.03	17.18	7.02	53.41	22.68	21.22	12.44
7	80.21	26.73	24.26	4.03	17.18	7.02	53.41	22.68	21.22	12.44
8	80.21	26.73	24.26	4.03	17.18	7.02	53.41	22.68	21.22	12.44
9	79.50	27.31	23.57	3.73	17.07	6.98	42.98	21.98	20.57	12.36
10	88.65	30.82	26.61	4.32	19.32	7.90	51.31	25.31	23.70	13.99
11	88.65	30.82	26.61	4.32	19.32	7.90	51.31	25.31	23.70	13.99
12	88.65	30.82	26.61	4.32	19.32	7.90	51.31	25.31	23.70	13.99
13	89.20	31.02	26.77	4.36	19.47	7.96	51.76	25.61	23.98	14.10
14	24.77	8.65	7.47	1.22	5.41	2.21	14.61	7.07	6.62	3.92
15	91.44	31.81	27.45	4.55	20.12	8.22	53.83	27.09	25.36	14.57
16	33.19	11.57	9.99	1.64	7.27	2.97	19.56	9.60	8.99	5.26
17	76.99	26.79	23.12	3.83	16.93	6.92	45.33	22.75	21.29	12.26
18	92.79	32.49	28.04	4.71	20.49	8.37	55.19	28.23	26.43	14.84
19	81.58	28.55	24.64	4.15	18.04	7.37	48.57	24.97	23.37	13.06
20	87.13	30.54	26.36	4.45	19.27	7.87	51.96	26.73	25.02	13.95
21	65.83	22.90	19.77	3.32	14.55	5.95	38.94	19.96	18.68	10.54
22	75.41	26.26	22.66	3.79	16.53	6.76	42.90	23.08	21.60	11.98
23	38.97	13.45	11.61	1.93	8.48	3.46	21.08	11.90	11.14	6.14
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	38.97	13.45	11.61	1.93	8.48	3.46	21.08	11.90	11.14	6.14
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	1633.27	559.86	492.73	81.68	355.16	145.15	1008.65	475.59	445.17	257.23

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Table 13 continued

Week (1/12/16 to 31/5/17)	Branch name							
	Azhakam	Karukutty karayamparambu	Manjapra	Naduvattam	poothamkutty	Manjapra distributory	Komarappadam	Vengoor
	Irrigation water requirement (million litres)							
1	2.86	21.66	4.76	1.31	3.15	1.34	6.01	5.21
2	3.21	24.27	5.31	1.46	3.54	1.50	6.75	5.81
3	7.69	56.28	12.38	3.40	9.08	3.49	16.15	13.55
4	9.61	69.82	15.41	4.23	11.52	4.34	20.17	16.86
5	10.29	74.24	16.14	4.43	12.34	4.55	21.60	17.67
6	10.79	77.55	16.69	4.58	12.96	4.70	22.67	18.27
7	10.79	77.55	16.69	4.58	12.96	4.70	22.67	18.27
8	10.79	77.55	16.69	4.58	12.96	4.70	22.67	18.27
9	10.73	75.34	15.48	4.25	12.94	4.36	22.52	16.94
10	12.14	85.04	17.91	4.92	14.85	5.05	25.50	19.61
11	12.14	85.04	17.91	4.92	14.85	5.05	25.50	19.61
12	12.14	85.04	17.91	4.92	14.85	5.05	25.50	19.61
13	12.24	85.57	18.08	4.96	15.03	5.09	25.69	19.79
14	3.40	23.87	5.04	1.38	4.14	1.42	7.14	5.51
15	12.64	87.75	18.88	5.18	15.92	5.32	26.55	20.67
16	4.57	31.93	6.78	1.86	5.63	1.91	9.59	7.43
17	10.64	73.90	15.88	4.36	13.37	4.47	22.34	17.38
18	12.88	89.62	19.53	5.36	16.39	5.50	27.04	21.38
19	11.34	78.76	17.22	4.73	14.50	4.85	23.80	18.85
20	12.11	84.25	18.44	5.06	15.48	5.20	25.42	20.18
21	9.14	63.19	13.77	3.78	11.72	3.88	19.20	15.07
22	10.39	72.44	15.73	4.32	13.31	4.43	21.82	17.22
23	5.33	37.12	8.00	2.20	6.86	2.25	11.19	8.76
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	5.33	37.12	8.00	2.20	6.86	2.25	11.19	8.76
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	223.20	1574.88	338.63	92.96	275.23	95.42	468.68	370.66

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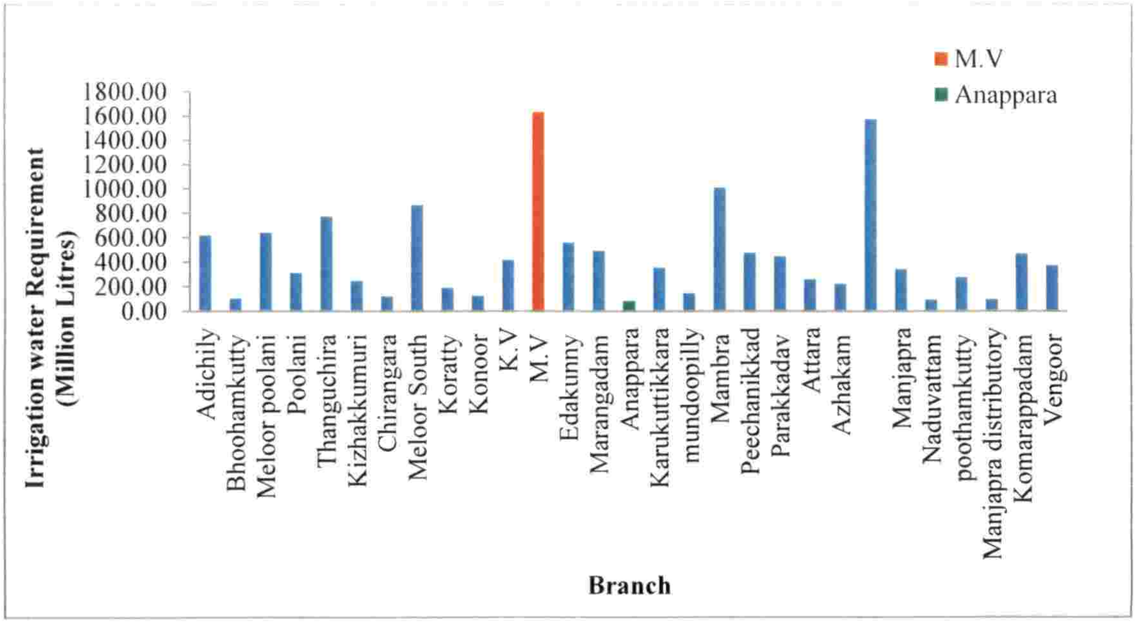

Figure 14. Total Irrigation water requirement for individual branch canal commands

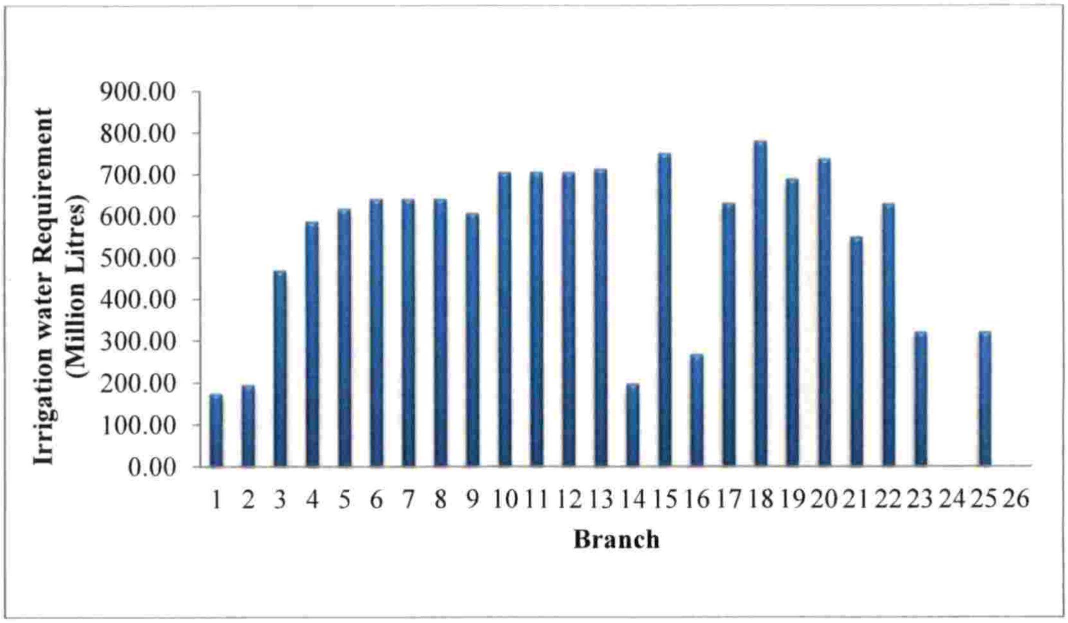

Figure 15. Weekly irrigation water requirement of the entire canal system

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4.2.3 Domestic water requirement

The information regarding number of houses in the influential area of canal for groundwater and the total weekly domestic water requirement are provided in Table 15. The maximum number of houses was found along the banks of Karukutty -Karayamparambu and KV branches.

From the graphical representation of weekly domestic water requirement in Fig.16 maximum domestic needs were spotted for Karukutty-Karayamparambu branch followed by KV branch with weekly requirements of about 12.77 and 10.75 lakh litres per week respectively. The minimum requirements were found for Azhakam branch with a requirement of about 0.74 lakh litres of water per week.

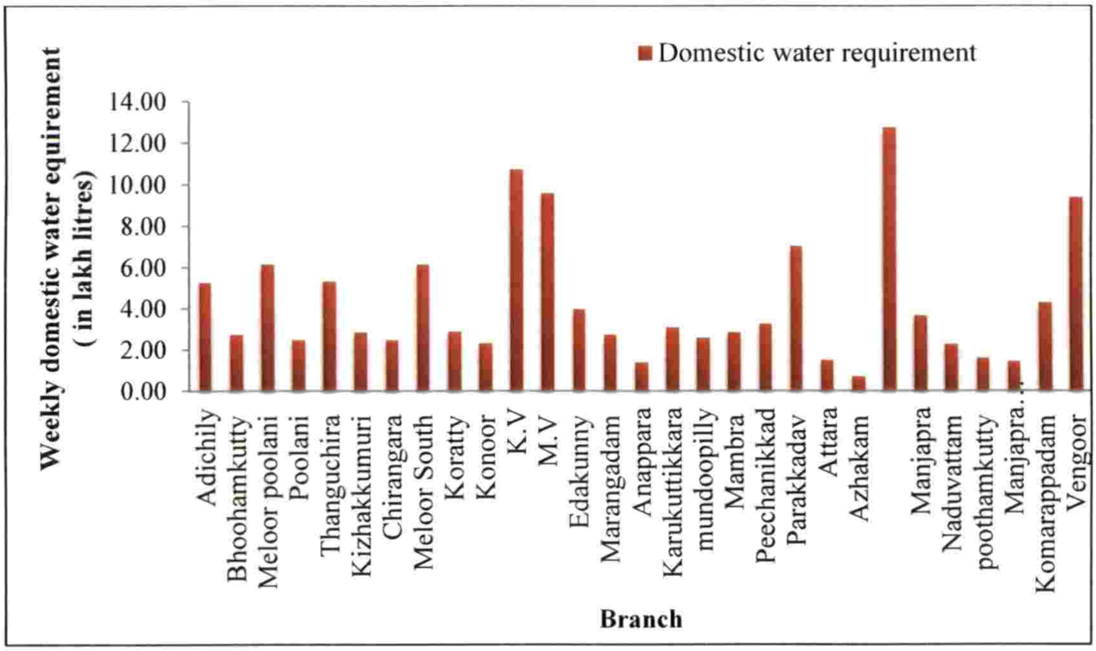

Figure 16. Weekly domestic water requirement for branch commands

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Table 15. Domestic water requirement in the commands of branch canals

Sl. No	Branch name	Number of houses	Domestic water demand (lakh litres/week)
1	Adichily	158	5.30
2	Bhoohamkutty	82	2.76
3	Meloor-Poolani	184	6.18
4	Poolani	75	2.52
5	Thanguchira	160	5.38
6	Kizhakkumuri	85	2.86
7	Chirangara	75	2.52
8	Meloor South	184	6.18
9	Koratty	87	2.92
10	Konoor	70	2.35
11	K.V. B	320	10.75
12	M.V	286	9.61
13	Edakunny	120	4.03
14	Marangadan	83	2.79
15	Anappara	42	1.41
16	Karukuttikkara	93	3.13
17	Mundoopilly	78	2.62
18	Mambra	86	2.89
19	Peechanikkad	98	3.29
20	Parakkadavu	210	7.06
21	Attara	46	1.55
22	Azhakam	22	0.74
23	Karukutty Karayamparambu	380	12.77
24	Manjapra branch	110	3.70
25	Naduvattam branch	68	2.28

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Table 15 Continued

Sl. No	Branch Name	Number of Houses	Domestic water demand (lakh litres/week)
26	Poothamkutty branch	48	1.61
27	Manjapra distributary	44	1.48
28	Komarappadam Branch	128	4.30
29	Vengoor Branch	280	9.41

4.2.4 Total water requirement

Total water requirements were computed by adding irrigation water requirement with the domestic water requirements for the weeks during the irrigation season.

Fig. 17 shows the graphical representation of total water requirement in different branch commands of CRDS. The maximum water requirement was observed for MV branch with a requirement of 1658.23 million litres of water for the entire irrigation period. It is followed by Karukutty-Karayamparambu branch with a requirement of about 1608.16 million litres. The cropped area was higher in the command area of Karukutty-Karayamparambu branch (289.40 ha) and the next was for the command of MV branch (286.11 ha), but the larger value of water requirement of the MV branch was due to the difference in area of nutmeg. The MV branch had 227.72 ha of nutmeg while the Karukutty Karayamparambu branch had about 217.54 ha. Area of banana was also found higher along the MV branch (37.92) the Karukutty Karayamparambu (31.64).

The minimum water requirement was also was observed for Anappara branch canal with a need of 85.12 million litres. The Anappara branch had the minimum water requirement as it had the minimum cropped area along the command.

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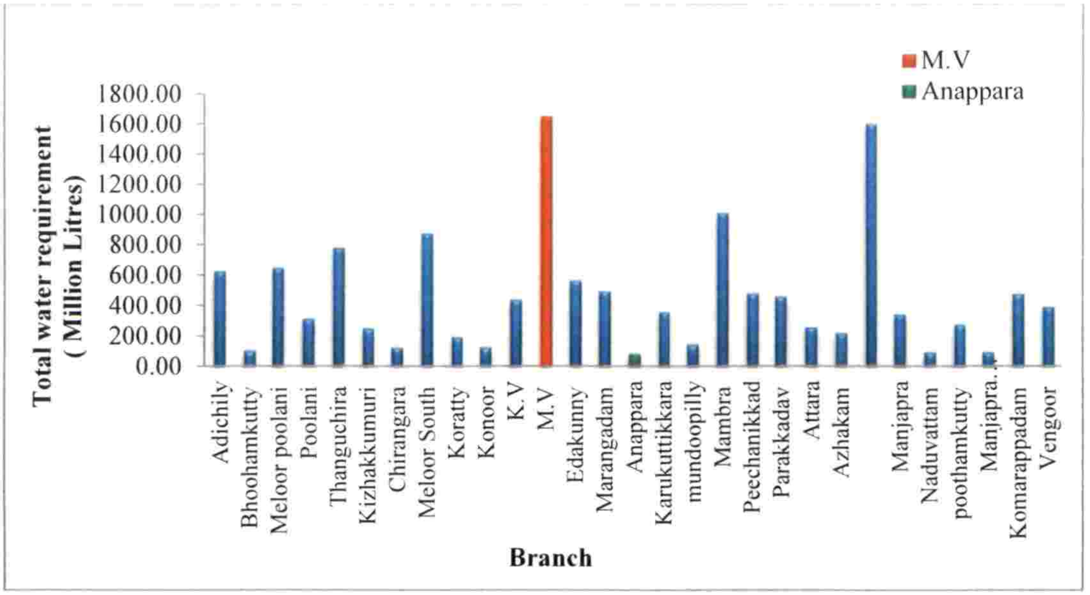

Figure 17. Branch wise total water requirement of CRDS System

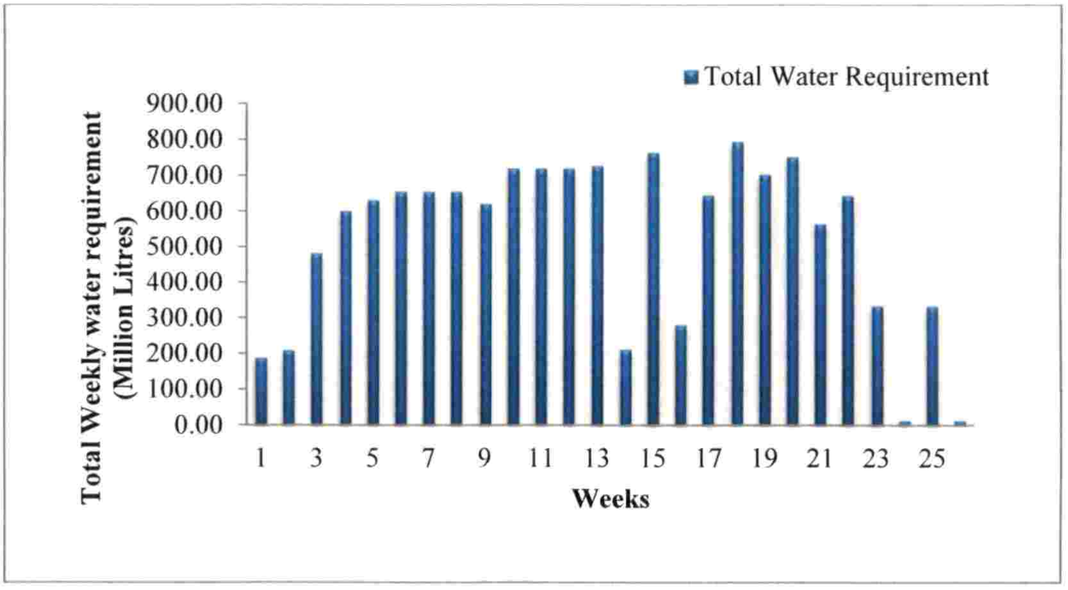

Figure 18. Total weekly water requirement for the whole CRDS system

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4.3 GROUNDWATER LEVEL ANALYSIS

The groundwater levels along the different branches are analysed by comparing with the supply through the branch canals. Groundwater level variations along three selected branches of the area are discussed here. The graphical representation of variation in depth to water table of wells along three selected branches of the CRDS system is represented in the Figures 19, 20 and 21 respectively.

Fig. 19 illustrates the variation in depth to water table for selected observation wells along Meloor branch canal. Two wells are selected on the command of Meloor branch, one at the head reaches of the canal and the other at the tail end. From the graph it was clear that during the supply periods the depth to water table decreases as the water level rises due to recharge from canals. A maximum fluctuation in depth to water table of about 2.44 m was observed in the well at the head portion and about 1.71m in the well at tail end during supply and off periods. The rainfall also influenced the groundwater recharge. The lower depth to water table during first two weeks and an increased depth to water table observed for the following weeks attributed to the rainfall during initial weeks and the decline in rainfall for the following weeks. The maximum recharge in well at the head portion was observed for the 12th week which had the largest supply. The recharge to the wells at the tail end was a minimum as there was no sufficient flow of water in the canals at the tail reach. The wells at the tail end got recharged only due to rainfall. Lower discharge through the branch was observed during 6th, 9th, 16th, 18th and 22nd weeks. The recharge in tail end wells during 16th and 22nd weeks is due to water from rainfall. Meloor is one of the long branches of CRDS system and the supply was given once in 3-4 weeks.

Fig. 20 depicts the variation of depth to water table data for MV branch. The maximum depth to water table was found to be in 8th week about 6.23m and minimum was 2.96 m during 9th week. The water table fluctuated by 3m during canal supply and lean periods. The reduction in depth to water table during first

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week can be observed due to higher rainfall compared to the following weeks. A noticeable recharge cannot be observed for a minimum supply. It's because the recharge rate was much lower for the area. But continuous supply resulted in good recharge which was noticed for 8th and 9th week. The higher supply during 15th, 21st and 23rd has resulted in higher water recharge. The rainfall also had `a considerable impact on water levels. The recharge was found to be higher in week in which rainfall occurred in addition to the water supply in the canal.

The depth to water table over weeks for the wells along Anappara branch of CRDS is given in Fig. 21. The variation in depth to water table could be observed in weeks having supply. A variation of about 2m was observed for water levels in wells at head reach and about 3.5m was observed for wells in tail reach due to groundwater recharge. Anappara branch had water supply once in three weeks from 11th week onwards. As Anappara branch canal was smaller in length compared to other branches the water supply had similar influence on wells at the head reach as well as tail ends.

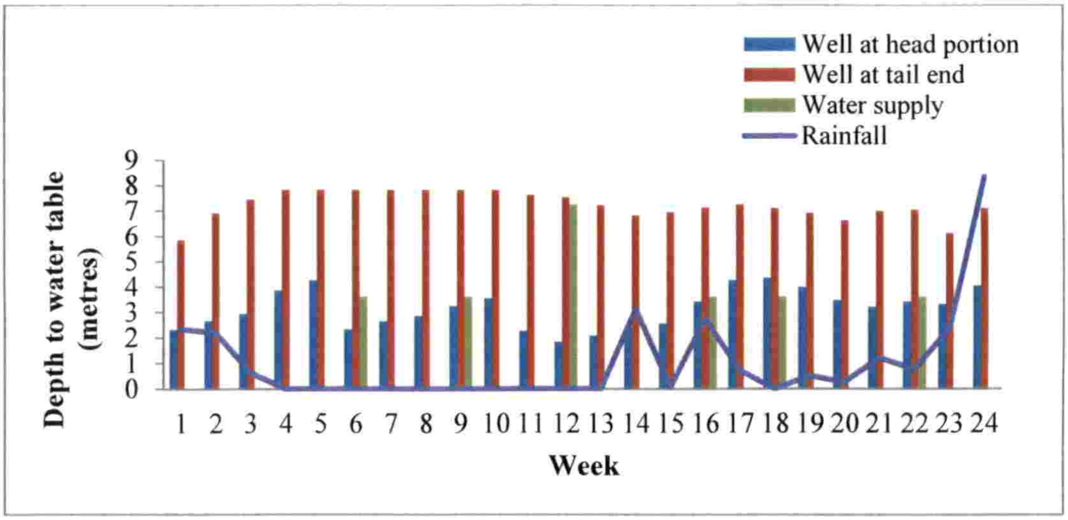

Figure 19. Depth to water table of wells along Meloor branch

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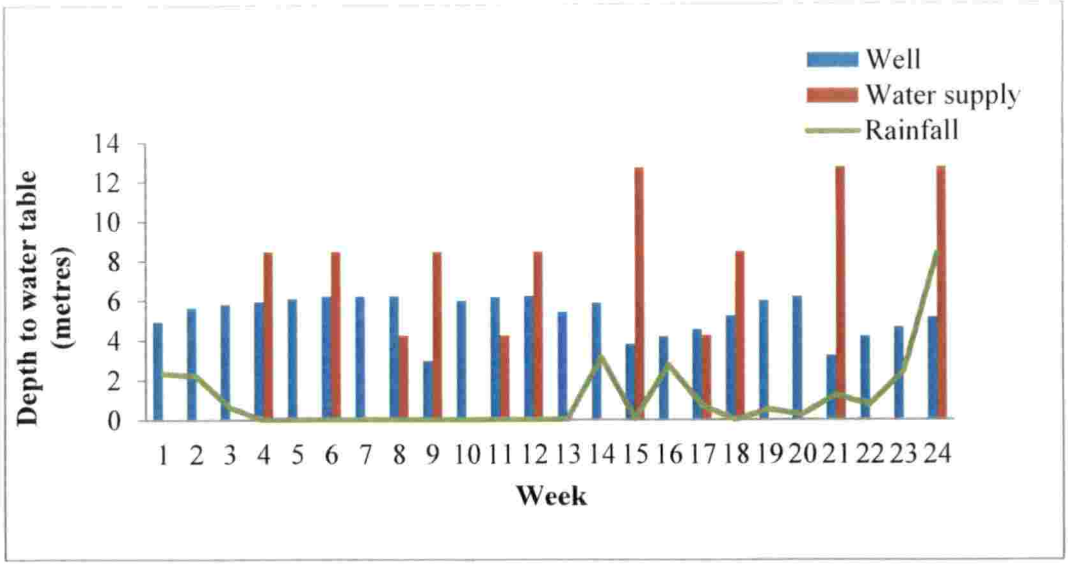

Figure 20. Depth to water table for wells along MV branch

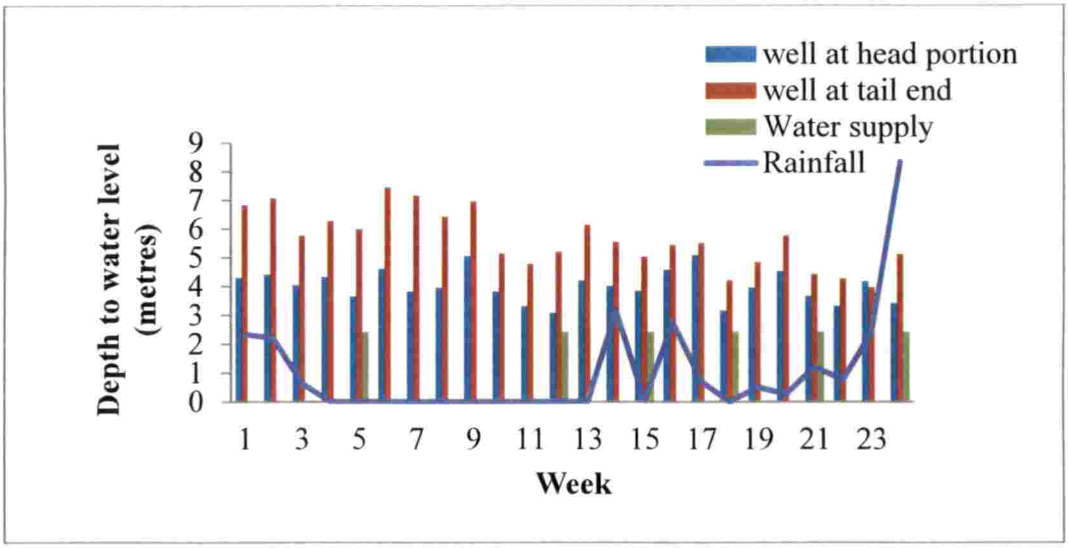

Figure 21. Depth to water table for wells along Anappara branch

Noticeable fluctuation could be observed in the water levels due to canal supply. The lower depth to water table observed in wells during periods of canal supply was found to be increasing till the next supply. Increase in groundwater levels were observed in almost all observation wells. The wells at the tail end did not get recharged as there was no appreciable flow at the tail ends of the canal. In some cases the rise in water supply may be observed in the weeks next to the weeks of supply as the supply may be in the last days of the week or depending upon soil characteristics. For the longer branches the wells in tail ends would not be recharged for lower discharges as sufficient amount of water would not be available at the tail ends. The wells in the tail portion might not have obtained sufficient water during the entire 26 weeks of supply. The withdrawal of groundwater for irrigation will be much higher in tail reaches as canal water is not available or insufficient for irrigation. This further aggravates the groundwater depletion.

(Rani and Elangovan, 2012) also found the positive relation between groundwater recharge and seepage from irrigation. From their study, groundwater levels of about 50 percent of wells selected in a basin are influenced by seepage from irrigation. Mankar (2009) also have done similar analysis of groundwater along command area of Som Kagdar irrigation project. Similar results were obtained for wells at the tail and head reaches.

4.4 WATER SUPPLY

Weekly water supply was computed for all the branches of CRDS. Fig. 22 renders information on total water supply through different branch canals over the entire irrigation season. From the analysis of the graph maximum water supply was through MV branch with 710.81 million litres and minimum water supply was through Azhakam branch with a supply of 32.40 million litres. The water supply of MV main was followed by Manjapra branch and Meloor south.

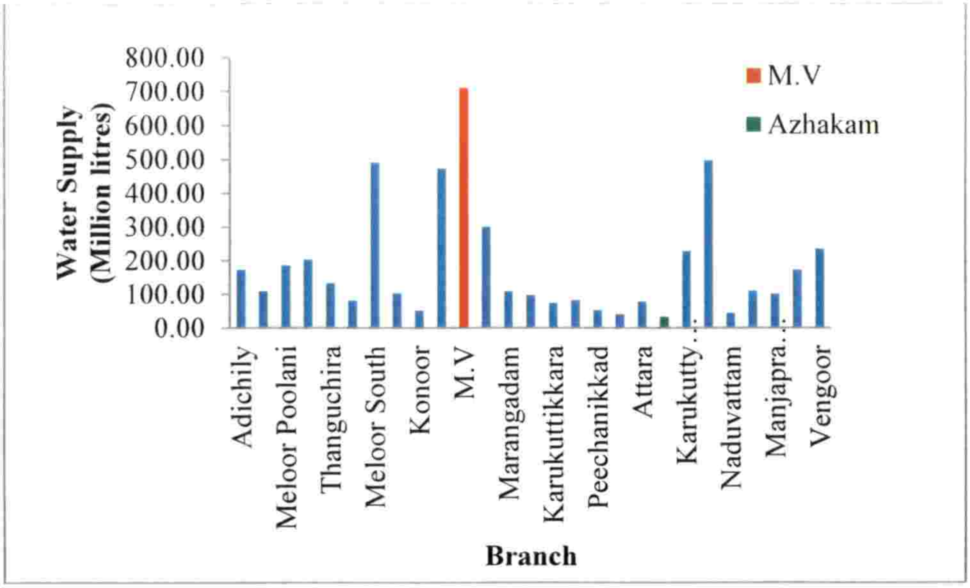

Figure 22. Total water supply through different branches of canal

4.4.1 Demand supply gap

Total demand and supply has been worked out for all the branches and water deficit was observed in most of the branches. Table .16 depicts the demand supply gap as well as the amount of water deficit or surplus in million litres. A net surplus was observed for KV, Bhoothamkutty, Mundoopilly, Anappara, Manjapra and Manjapra distributary and all other branches had a deficit of water.

Even though these branches had a net surplus, but on a weekly basis several weeks are devoid of water supply while certain weeks are of excess or over supply. Water deficit was found higher in Karukutty Karayamparambu branch with a deficit of 1379.20 million litres, it was followed by MV and Mambra branches.

Three branches were selected for the analysis of weekly demand of the branches with the weekly supply to analyse the effectiveness of the existing supply system. Fig. 23 shows the graphical representation of weekly water demand and weekly water supply of Adichily branch. Adichily branch had 6 weeks of supply for the irrigation season from December 1st to May 31st. The time interval between the supply periods can be understood from the graph which

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indicates an irregular supply system. The supply was almost enough to meet the requirements in four weeks while in the 6th and 7th it was insufficient. From the graph it is clear that the supply can meet the requirement during the supply periods but irregular water distribution cannot meet the weekly water requirement.

Fig. 24 pictures the demand supply graph for Anappara branch. Anappara was one of the shorter branches and it had a total supply which was excess. From the graph it could be seen that the supply was in excess during the supply periods. It would be better if the supply is based on the demand and requirement. There had been so many weeks devoid of any supply. This can be avoided and sufficient water can be provided on a weekly basis by reducing the wastage of water by excess supply, if the proper water demand was considered during the supply periods.

The weekly demand and supply through the Karukutty Karayamparambu branch is given in Fig. 25. The branch had supply only for four weeks and the two weeks among them were able to provide sufficient supply. But the supply during 13th and 22nd were not enough to meet the water demand for the respective weeks. Most of the weeks were devoid of any water. Though the demand was met in the weeks of supply, there is a large deficit for several weeks.

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Table 16. Demand-supply gap in the CRDS branches

Branch	Demand (million litres)	Supply (million litres)	Surplus/ Deficit (million litres)	Status
Adichily	630.32	172.77	-457.55	Deficit
Bhoohamkutty	109.91	108.86	-1.05	Surplus
Meloor Poolani	653.22	185.49	-467.73	Deficit
Poolani	316.88	203.14	-113.74	Deficit
Thanguchira	784.94	133.06	-651.88	Deficit
Kizhakkumuri	255.47	210.43	-45.04	Deficit
Chirangara	128.88	80.9	-47.98	Deficit
Meloor South	881.67	491.34	-390.33	Deficit
Koratty	198.00	103.19	-94.81	Deficit
Konoor	131.21	52.29	-78.92	Deficit
K.V	443.78	474.14	30.36	Surplus
M.V	1658.23	710.81	-947.42	Deficit
Edakkuny	570.26	300.64	-269.62	Deficit
Marangadam	500.01	108.76	-391.25	Deficit
Anappara	85.32	97.07	11.75	Surplus
Karukuttikkara	363.22	73.41	-289.81	Deficit
Mundoopilly	151.91	174.95	23.04	Surplus
Mambra	1016.19	82.59	-933.6	Deficit
Peechanikkad	484.17	52.38	-431.79	Deficit
Parakkadavu	463.63	40.27	-423.36	Deficit
Attara	261.13	78.55	-182.58	Deficit
Azhakam	225.02	32.4	-192.62	Deficit
Karukutty Karayamparambu	1608.16	228.96	-1379.2	Deficit
Manjapra	348.25	498	149.75	Surplus
Naduvattam	98.94	44.72	-54.22	Deficit
Poothamkutty	279.39	109.41	-169.98	Deficit
Manjapra distributory	99.32	100.99	1.67	Surplus
Komarappadam	479.86	172.18	-307.68	Deficit
Vengoor	395.1	235.62	-159.48	Deficit

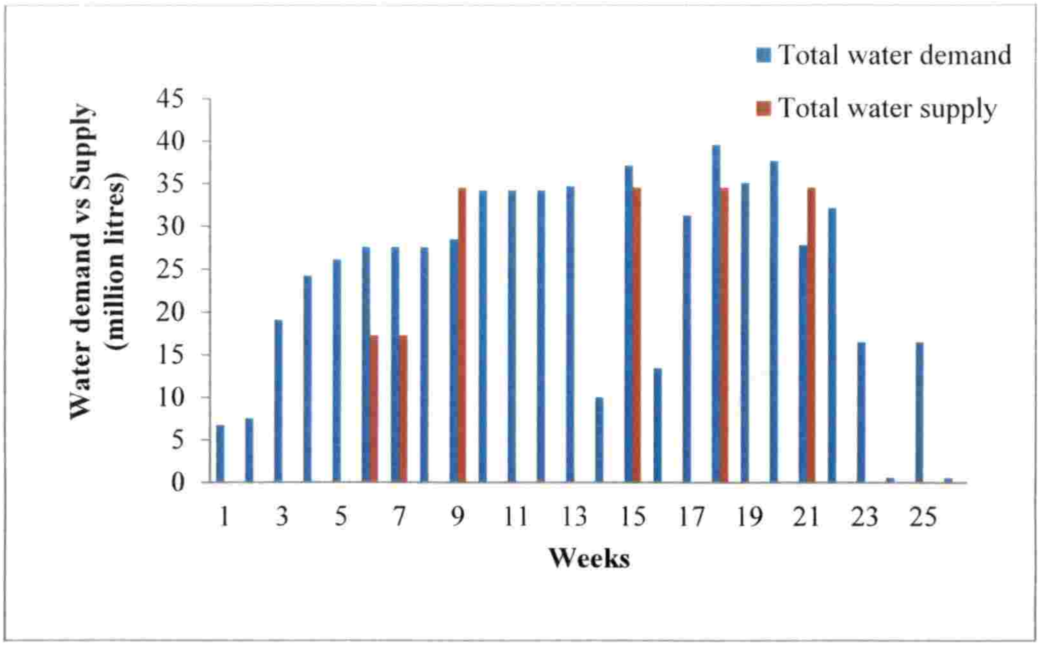

Figure 23. Weekly demand and supply of Adichily branch

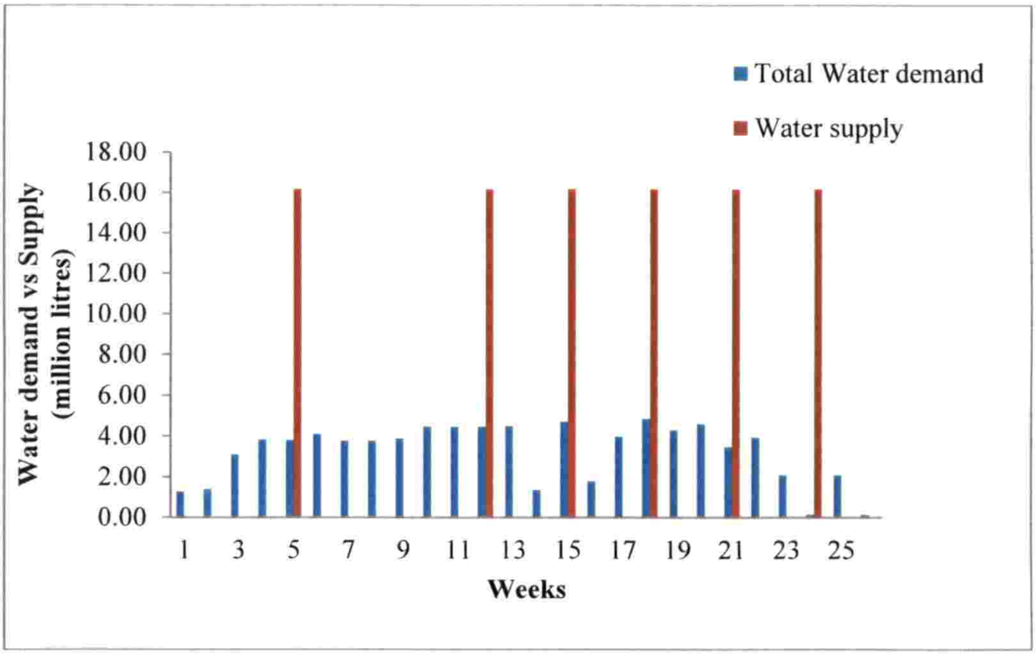

Figure 24. Weekly demand and supply of Anappara branch

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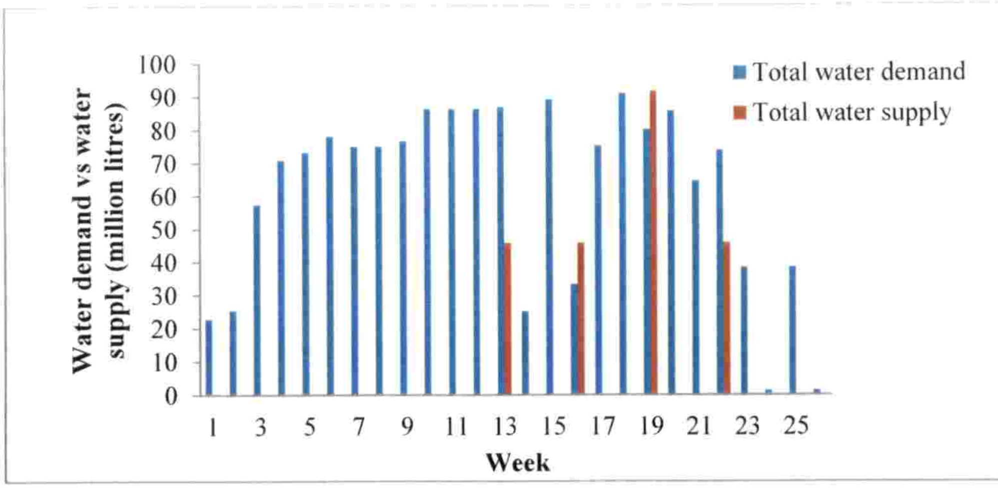

Figure 25. Weekly demand and supply of Karukutty Karayamparambu branch

4.4.2 Gross supply at CRDS

The monthly discharge at the diversion point in litres is given in Table. 17. The total release for the entire irrigation season was about 73990 million litres and from analysis total branch wise water demand availability is 13622.38 million litres. The seepage losses at the head reach accounts for the inadequacy of water to meet the demand. The released water at the head reach was found to be 5 times more than the actual demand. Even though the release from the starting point is higher compared to the water requirement, water deficit is observed in most branches. This could be due to heavy water loss which is about 29.4 per cent in the initial stretches of the canal (Ansu, 2017). Supply based on demand and proper management can improve the efficiency of irrigation in the command. The illegal drain of water from spouts for water diversion also causes loss of large amount of water. In several places water has been diverted through spouts from main canal and they operate for the entire irrigation season. Proper control of this misuse can also reduce water loss to a great extent.

From the details of total release from the weir it is clear that the supply was enough to meet the demand, but the issues in the supply system are improper management of canals, losses from main canals due to the breaks in canals,

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improper diversion of water through the spouts, unscientific supply system without considering the water demand etc. Anjana *et al.* (2015) from the study of water resources in the command area of Right Bank main canal have also found that the supplies through the canals were sufficient but the problems in the management were the major reasons for inefficiency in water allocation.

These examples imply that in the scenario of decreasing rainfall, proper management of available water resources has become inevitable. The domestic and agricultural demands are essentially to be met as life in a region and economy are dependent on these. Availability of water in the CRDS depends on release from the hydro-electric projects situated upstream and hence the control is not with the Department of Irrigation. But, proper communication between the departments and intelligent management can help to overcome the present gaps in demand and supply. Climate change and the resulting rainfall variability create a precarious situation in terms of water availability. If the water deficit continues for more years the cropping pattern of the region may have to be changed, especially when paddy and nutmeg are the major crops.

Table 17. Monthly water release

Month	Discharge (million litres)
Dec	12890
Jan	10100
Feb	10670
Mar	14550
Apr	12890
May	12890
Total	73990

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Figure 26. Leakage from main canal

Figure 27. Blocking the canal flow and illegal usage of canal water

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Figure 28. Improper maintenance of branch canals

4.5 MODEL FOR EFFICIENT WATER ALLOCATION

A computer based model has been developed for water allocation for the command area of CRDS. The model with different options, menus and modules can be used to work out the water requirement for all the branches of the system. The calculations are done on a weekly basis. The options and modules of the model are discussed here. The model can provide the amount of water required for efficient supply through the different branches on a weekly basis.

Fig. 29 shows the opening window of the model and Fig. 30 displays main window of the model. The main window consists of options Rainfall, Canal system, Water management, Water allocation model. Each Main menu consists of separate submenus. Four submenus are provided under the menu Rainfall. They are Rainfall Data, Rainfall report, Trend and weekly rainfall. The rainfall report and weekly rainfall options are used for data entry while TREND is an existing model for rainfall trend analysis and the rainfall report is the output window.

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In the rainfall data window (Fig. 31) the month and season (South West monsoon, North East monsoon, winter, summer) has to be entered and in the table the year as well as the monthly rainfall of the selected month can be entered.

The rainfall data report window is shown in Fig. 32. The report gives the details on rainfall in different years over a season which was entered as rainfall data. The season and file name has to be entered.

The option TREND opens the model which is used for analysis of time series data. The monthly or weekly rainfall data over years entered in an excel data sheet can be analysed in the model.

Fig. 33 displays the window for entering weekly rainfall. The weekly rainfall has to be entered in the table against week number. The entered data is used for calculation of irrigation water requirement from effective rainfall. To add new values enter the data in table and click add data.

The option of canal system consists of sub menus canal map, branch details and weekly water supply. The options branch details and weekly water supply are for data entry and canal map is for data display. Opening screen for canal map is illustrated in Fig. 34. The entered data of a branch canal can be seen by selecting the branch, year and by clicking show button. The map of the command area, cropping pattern and weekly water supply will be displayed.

The option branch details consists of sub menus, add new branch and edit branch. The option add new branch is provided to add details of a new branch. Fig. 35 shows the opening window screen for adding a new branch. The branch name, image of command area, no of houses in the influential area of branch canal, cropping pattern and year can be entered here.

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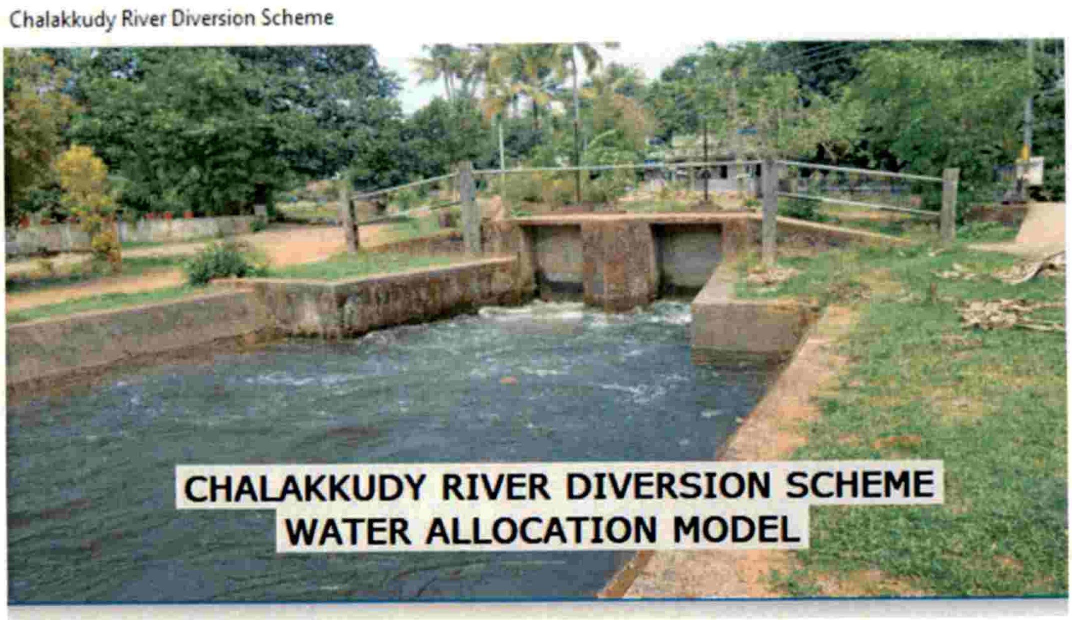

Figure 29. Opening screen of the water allocation model

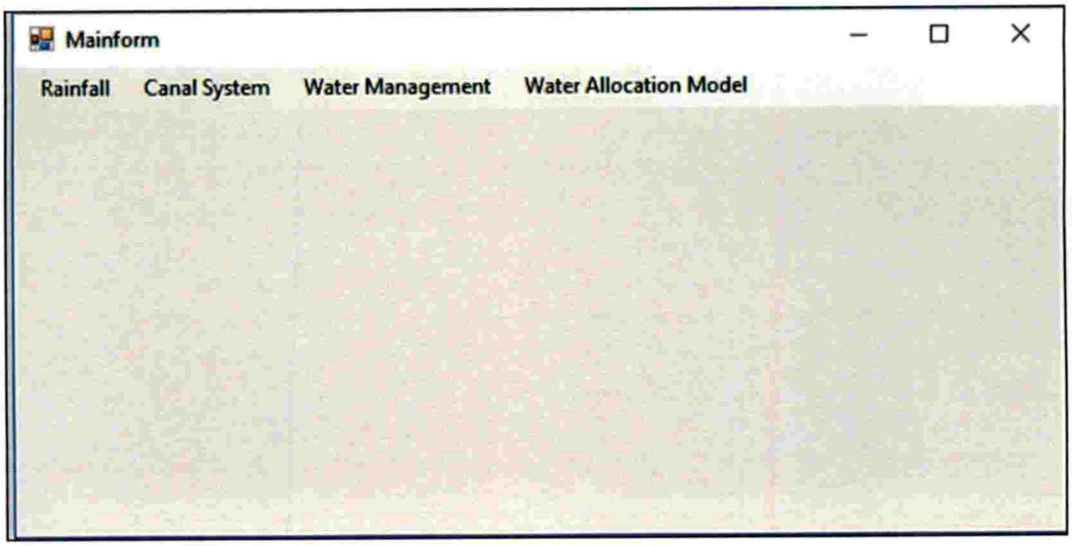

Figure 30. Main window of the model

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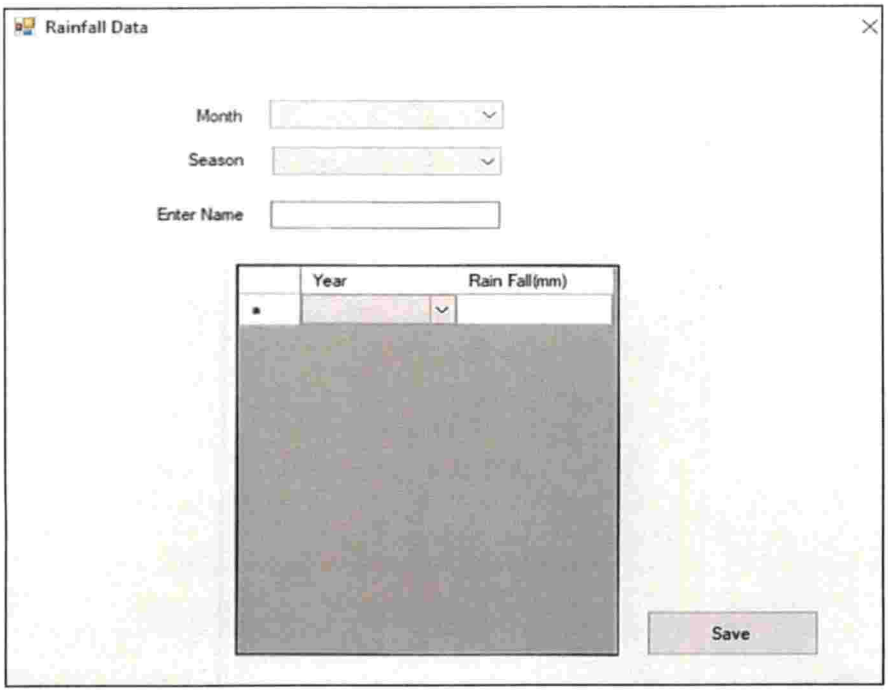

Figure 31. Rainfall Data window

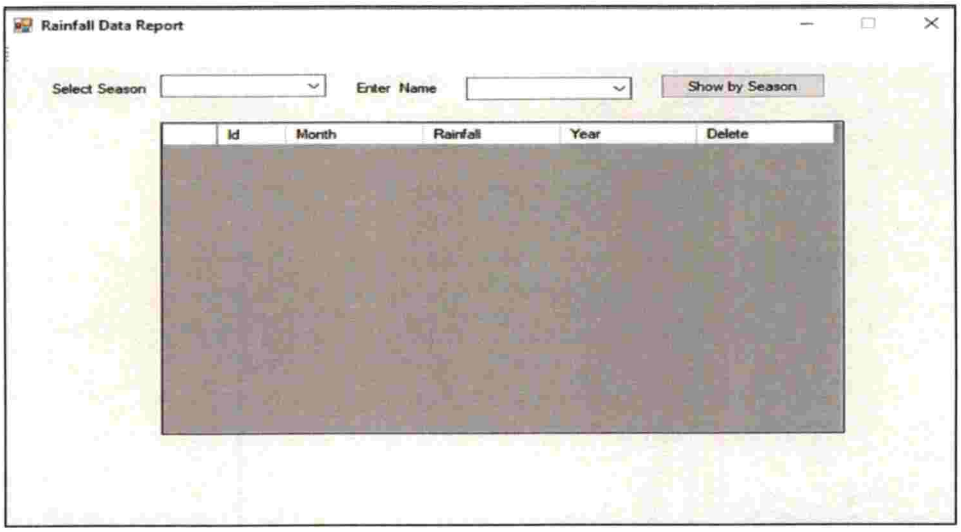

Figure 32. Rainfall data report window

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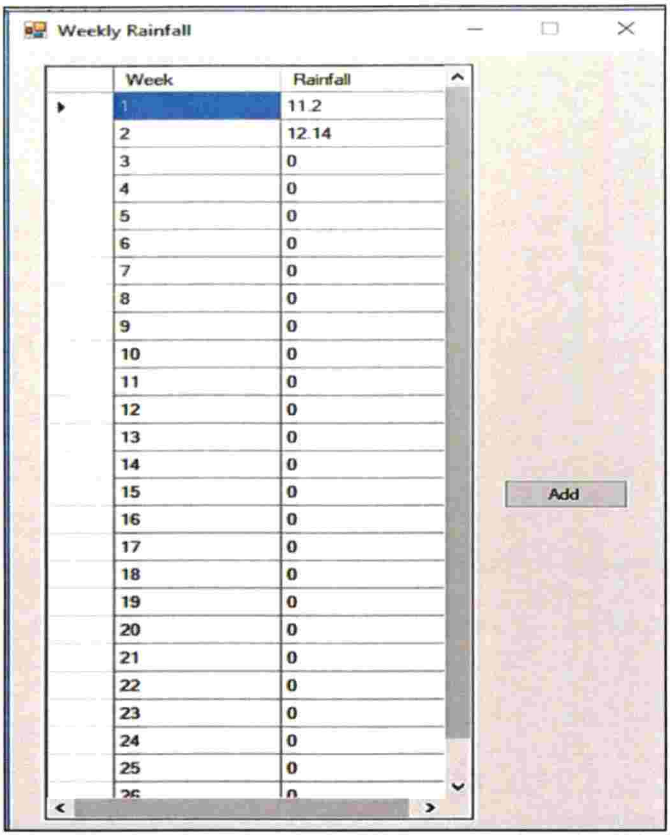

Figure 33. Weekly rainfall window

The window for editing an existing branch details is shown in Fig. 36. The modifications of the entered details can be done by using this option. The branch name and year of the branch to be edited has to be selected. The options are provided for deleting and updating an entered data by clicking change button.

The weekly water supply through different branches can be entered in the window given in Fig. 37.

The option for water management consists of sub menus CROPWAT, domestic water requirement, crop irrigation requirement and total irrigation requirement.

The sub menu CROPWAT is used to open the CROPWAT model linked with the model which can be used to calculate crop water requirements. The submenu domestic water requirement is used for calculation of domestic water requirement. Fig. 38 shows the screen for calculation of domestic water requirement. The branch name has to be selected. The number of houses will be displayed automatically from the data entered earlier. Then the number of persons per house and per capita water requirements also has to be entered. Domestic water requirement will be calculated and auto saved.

The sub menu crop irrigation requirement opens a window to workout irrigation requirement. The window for the same is given in Fig. 39. The canal name, crop name and year have to be entered and the monthly crop water requirement has to be given in table. The weekly irrigation water requirement for the crop is displayed in the table.

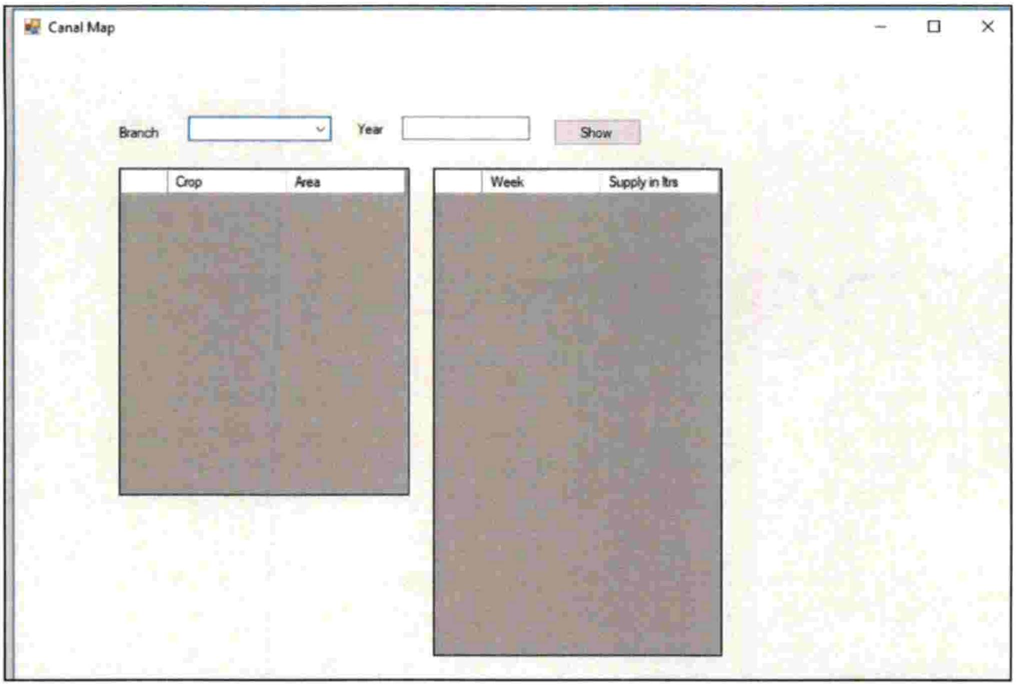

Figure 34. Opening screen for canal map

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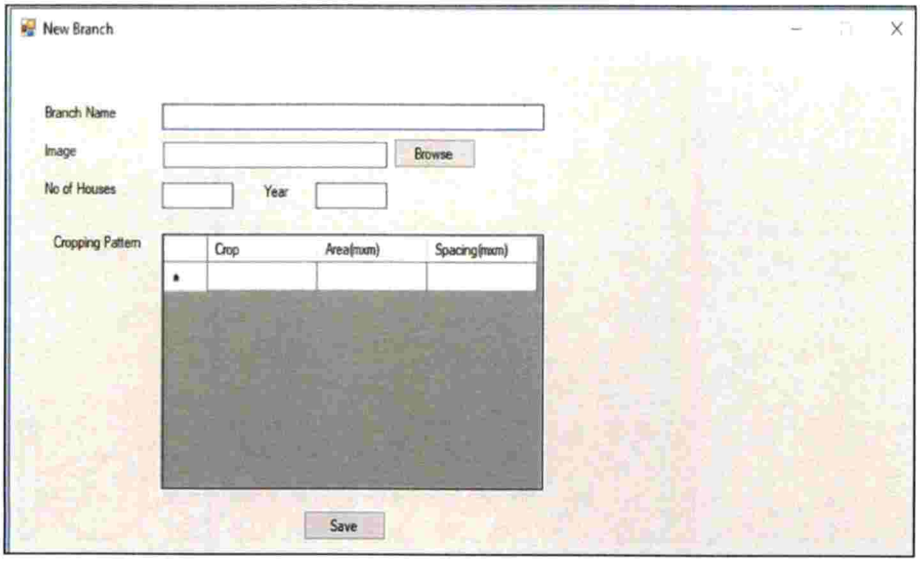

Figure 35. Screen for adding new branch

The submenu total irrigation requirement displays the total irrigation requirement of the selected branch for the year and also separately irrigation requirement of different crops. Fig. 40 shows the window for displaying total irrigation requirement. The name of the canal and year has to be entered.

Water allocation model consists of two submenu water management model and weekly water allocation. The submenu water management model shows whether the supply is in excess or deficit. If the data regarding water loss is available it can also be given. The supply, requirement, status of supply (Surplus or Deficit) and the quantity of water which is surplus or deficit will be displayed. The Fig. 41 shows the window for water management model.

The submenu weekly water allocation displays the weekly status of the entire CRDS system. Year has to be entered in the field. The show button can be used to go through different weeks. Fig. 42 displays the window for water allocation model.

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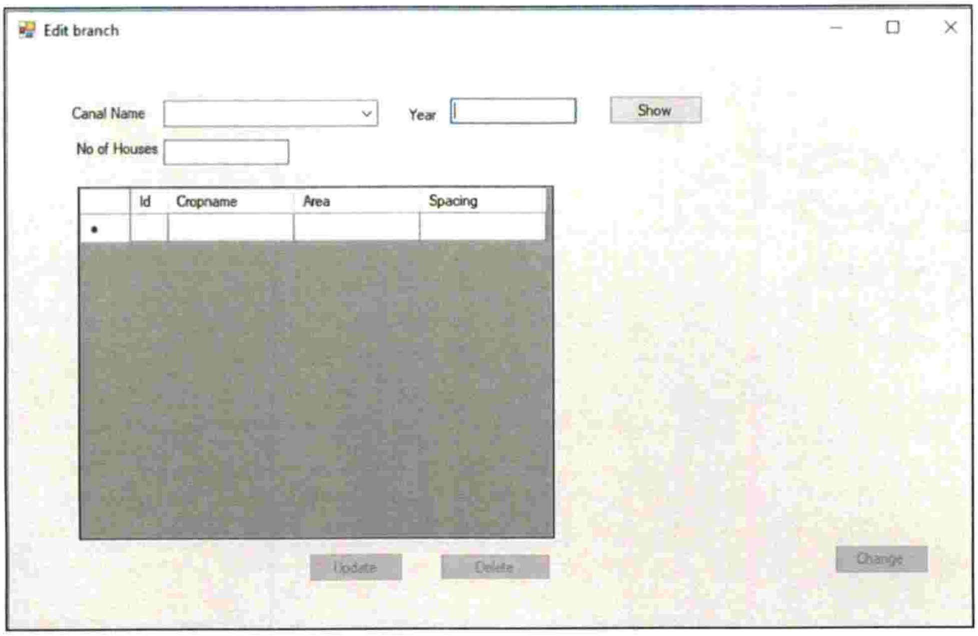

Figure 36. Window for editing an existing branch

Santhi and Pundarikanthan (2000) developed a model considering equity, adequacy and timeliness of the water supply. The model output provides the canal delivery schedule for the crop season. But the present model provides the situations of existing delivery system and the statistics of water deficit or supply through individual branches. Mankar (2009) developed a similar but rather complex model for optimum utilization of water resources in command area of Som-Kagdar irrigation project. It was a conjunctive use model developed using computer programming. The analysis of groundwater level fluctuations similar to the present study was also conducted.

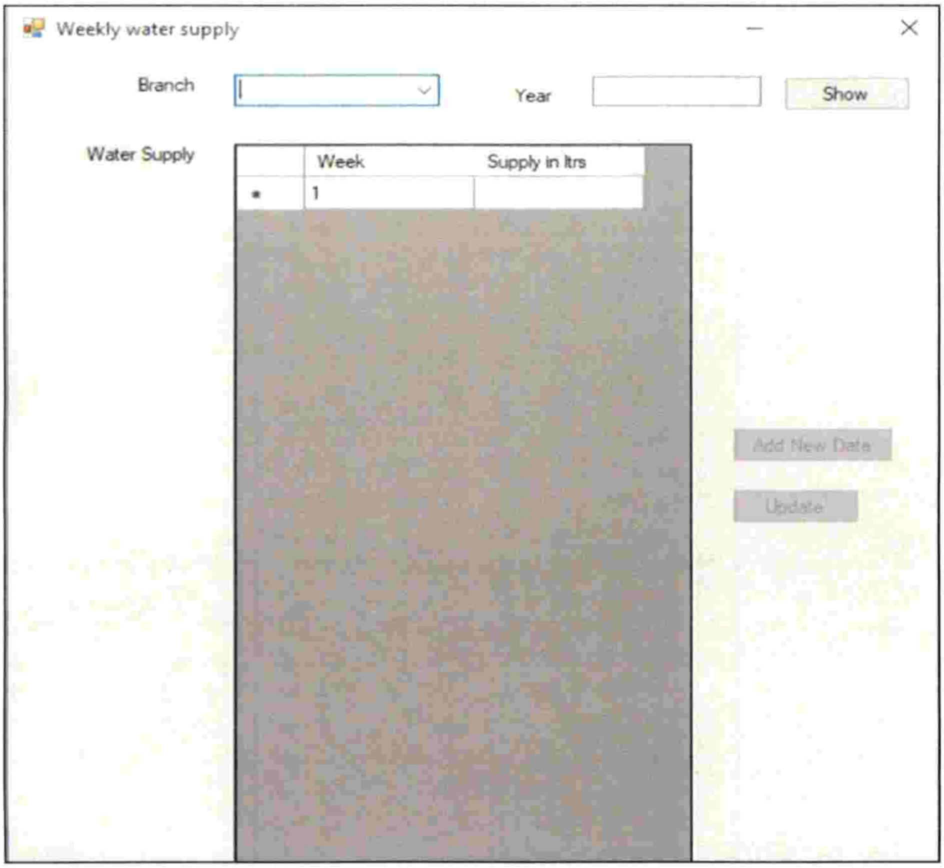

Figure 37. Window for entering water supply

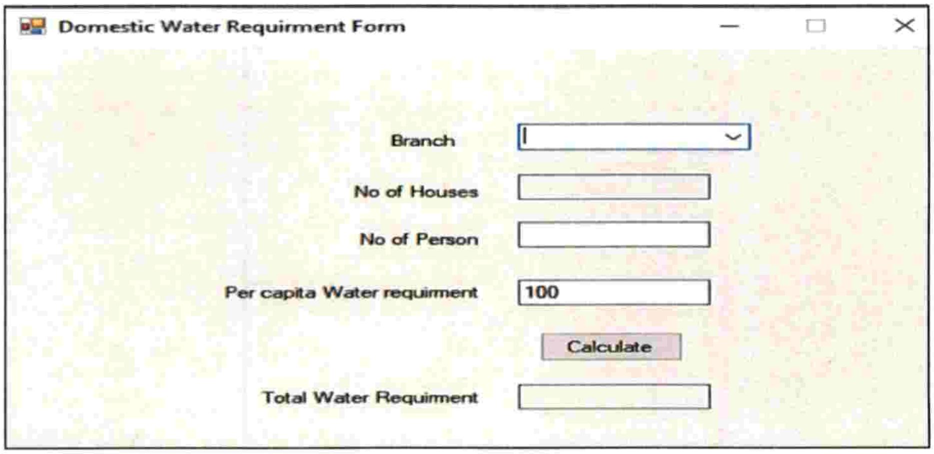

Figure 38. Screen for calculation of domestic water requirement

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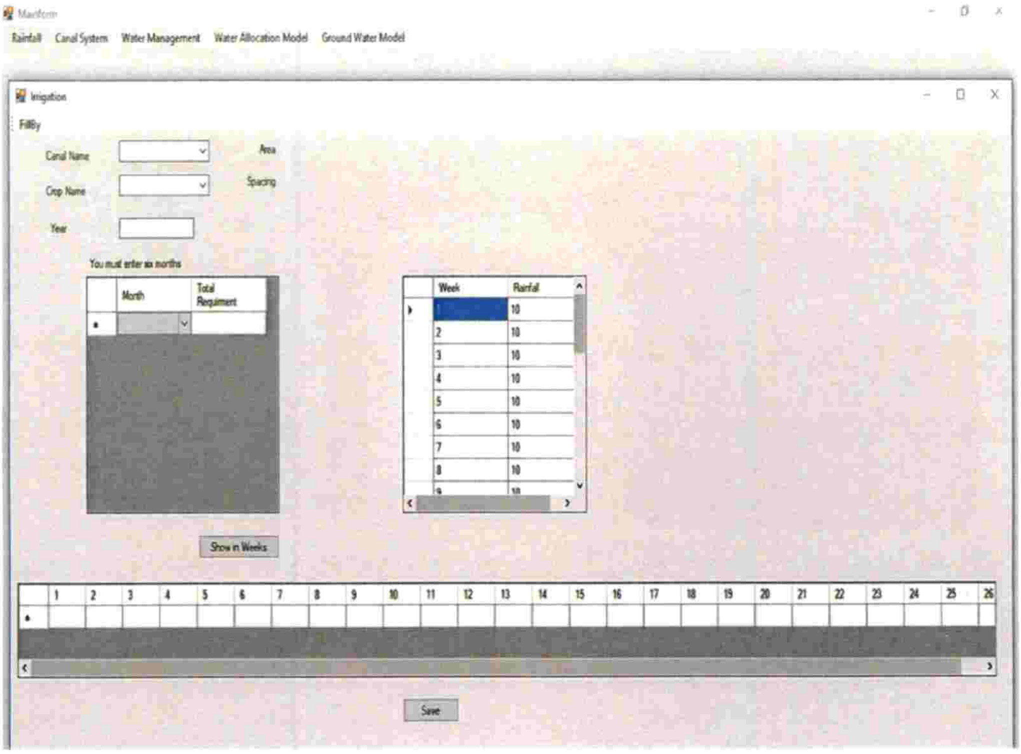

Figure 39. Window for calculation of crop irrigation requirement

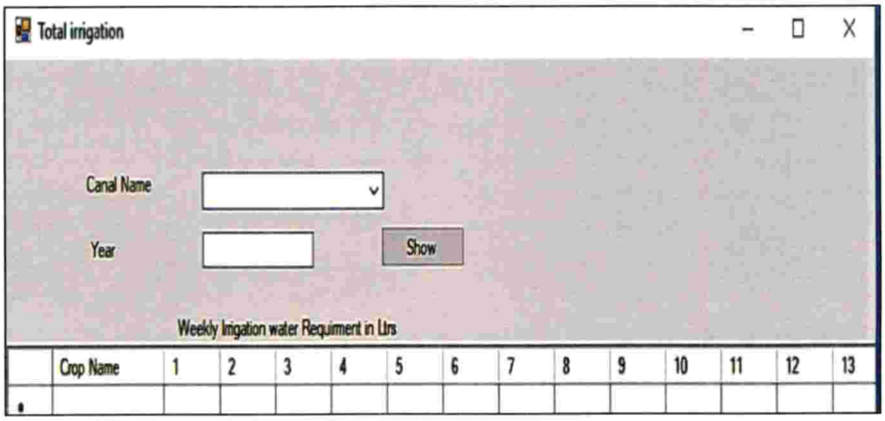

Figure 40. Window for Calculation of Total irrigation water requirement

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Figure 41. Window showing water management window

Figure 42. Window for displaying weekly water allocation

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SUMMARY

CHAPTER V

SUMMARY

The salient findings of the study are as follows

- A declining trend was noted in the annual rainfall over the period from 1987 to 2016
- During three years of the first decade (1987 to 1996) a negative deviation up to 15 per cent of annual rainfall was seen, but for the second decade (1997-2006) the deviation was found to have increased up to -20 to -25 per cent and for the last decade (2007-2016) the deviation was found to be higher, which crossed -40 per cent
- For the last decade during 2012 and 2016 a moderate drought was noticed and from the analysis it was noted that the rainfall of the basin was showing negative deviation from normal over the years and the region is gradually moving towards a drought condition
- The maximum mean monthly rainfall was observed for June (702.45mm) and July (667.01mm) and minimum was observed for January (5.09mm)
- Maximum standard deviation of rainfall was observed in July followed by the month of June. But the rainfall of June and July was found to be most assured as indicated by lower value of Coefficient of variation and the larger variation in rainfall was observed in January and March
- Among the seasons mean rainfall was maximum during South West monsoon (2149.10mm) and was minimum during winter (15.45mm)
- The standard deviation was higher for South West monsoon and North East monsoon (444.36 and 241.48) compared to rainfall during summer and winter (170.88 and 27.62). But the South West monsoon and North East Monsoon was highly dependent with a coefficient of variation of about 20.68 percent and 43.89 percent.
- The winter rainfall was noted to be highly variable with 178.73 percent of coefficient of variation

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- The trend of seasonal rainfall exhibited a decline in South West Monsoon and rainfall during winter. But the North East monsoon and summer showers had shown an increasing trend.
- South West monsoon and North East monsoon was highly dependent with a coefficient of variation of about 20.7 percent and 46.9 percent
- The winter rainfall was noted to be highly variable with 109.8 percent of coefficient of variation
- From the Mann Kendall trend analysis test also, a declining trend was observed for South West monsoon and winter rainfall but summer rainfall and North East monsoon had exhibited an increasing trend.
- A significant declining trend was found for the rainfall in May and June from the Mann Kendall trend test
- The highest irrigation water requirement was obtained for MV branch (1633.27 million litres) and the lowest irrigation water requirement was found for Anappara branch (81.68 million litres).
- Maximum domestic needs were spotted for Karukutty Karayamparambu branch followed by KV branch with weekly requirements of about 12.77 and 10.75 lakh litres per week respectively
- The minimum domestic water requirements were found for Azhakam branch with a requirement of about 0.74 lakh litres of water per week.
- From the groundwater level analysis it was clear that noticeable recharge occurred in the wells along the canals during supply periods.
- Wells in the head portion show rise in water level during all supply periods while the wells in tail end doesn't show recharge during all the supply periods as water flow through the canals may be insufficient to reach the tail ends and to have a sufficient recharge
- The withdrawal of groundwater for irrigation will be much higher in tail reaches as canal water is not available or insufficient for irrigation. This further aggravates the groundwater depletion.

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- The entire reach of shorter branches get sufficient water recharge during supply periods while the tail reaches of longer branches are the most deficits.
- Maximum water supply was through MV branch with 743.11 million litres and minimum water supply was through Azhakam branch with a supply of 37.8 million litres.
- Total demand and supply has been worked out for all the branches and water deficit was observed in most of the branches.
- A net surplus was observed for KV, Bhoothamkutty, Mundoopilly, Anappara, Manjapra and Manjapra distributary and all other branches had a deficit of water.
- Even though these branches had a net surplus, on a weekly basis several weeks are devoid of water supply while certain weeks are of excess or over supply.
- From the analysis of total discharge from the Thumboormuzhi weir the water supply was found to be more than enough to meet the demand.
- From the study it was found that the huge loss of water due to improper canal management and illegal withdrawals are the major reason for water deficit.

From the present study the available water for release is sufficient to meet the water demand. Proper management is necessary to efficiently make the available water reach the tail end. Proper lining of canal can cause a large reduction in water loss by seepage. The existing water allocation system has to be changed as it is not based on the actual water demand of individual branches and water has to be supplied through the branch canals at least once in a week to meet the demand, or else sufficient water storage facilities has to be planned along the branches.

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CLIMATE VARIABLITY IMPACT ON WATER RESOURCES IN THE COMMAND AREA OF A RIVER DIVERSION SCHEME

by,

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ABSTRACT OF THE THESIS

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ABSTRACT

Climate change is the major cause that affects water availability mainly due to variability in rainfall and temperature. The rising population and increasing food demands are imposing a further pressure on available water resources. Hence the efficient management of available water resource is of great concern. Irrigation is the largest sector that accounts for water use. In this situation a study was conducted in the command area of Left Bank Canal of Chalakudy River Diversion Scheme to assess the impact of climate variability on the water availability for the cropping systems and domestic demand during the irrigation period from December to May. The variability and trend in the rainfall was studied for the basin for a period from 1987 to 2016 and it is seen that the annual rainfall shows a declining trend. An investigation was done for finding out the cropping pattern of the canal commands. The crop water demand worked out using CROPWAT was used to estimate irrigation water demand. The domestic water demand calculated for the basin along with the irrigation water requirement constituted the net water demand. The total weekly water requirement was computed for all the branch canals for the irrigation period. The groundwater level analysis was done for wells along branch canals. Water recharge was observed in almost all the observation wells during supply periods. But no recharge was observed in wells in tail reaches during certain supply periods due to insufficient supply of water to tail ends. The weekly water supply for the branch canals were compared with the water demand. Most branches show a water deficit while a few exhibits water excess. Water deficit was observed mostly in longer and farther branches. The existing supply system was noted to be inefficient and works without considering proper branch wise water demand. The discharge from the main shutter was also obtained and was found to be almost about five times of the demand. Seepage losses, illegal withdrawal of canal water, and improper management are observed to be the reasons behind the insufficient water supply. Proper management of canals and supply based on demand has to be followed for efficient water management. A computer based model was developed for the

calculation of weekly water demand based on crop and weather data. A comparison of supply with the demand can also be done in the model which indicates the efficiency of supply system on a weekly basis. Proper planning can be done for efficient water management through the canal system, under the given conditions using the model.

APPENDIX

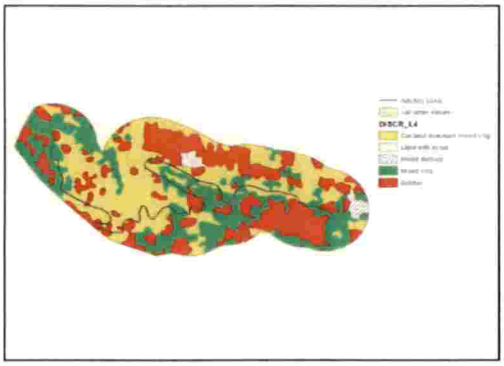
Appendix.1. Maximum Temperature in ^{0}C (August 2016- July 2017)

Day	August	September	October	November	December	January	February	March	April	May	June	July
	Month											
1	31.5	28	32	32	32.5	34	37	39	37	36	32.5	30
2	30.5	30	32	33	31.5	34.5	36	36.5	36.5	37	30	30
3	30	29.5	32	32.5	33	34.5	35.5	37	35	35.5	32.5	30
4	31	30.5	32	32.5	32.5	35	35.5	37	35.5	36	32	28.5
5	30.2	30.5	33	30.5	34	33.5	34.5	36	35	36	33	32
6	29	31	32.5	33	35	34.5	34.5	36	35	36	27	33
7	30.5	31	32	33	34	34	35	30.5	35	36	32.5	29
8	32	31	31	33	33.5	34	35	35	35.5	36	29	30
9	31	30.5	32	33	33.5	34	35.5	35.5	35.5	35	31.5	32
10	30	30.5	32.5	33	33.5	32.5	36.5	35	36	35	30.5	32
11	31	27	32	33	33.5	33.5	35.1	34.5	35	36	29	31.5
12	31.5	30	32	33	33	34	36	34.5	34	36	30	30.5
13	31	31	32	32.5	31.5	32.5	36	34	35	35.5	29	30.5
14	31	29	32	34	27.5	33.5	36	34	36	35	30.5	31
15	31	31	31.5	33	31.5	34	36	36	32.5	35	31	30
16	31	31.2	33	33.5	33	35	37	35	35	35	32.5	31
17	30	31.5	33.5	35	34	34	37	34.5	35	35	32	30
18	30.5	32	33	35	31	34	37	34	34	35	33	30
19	31	31	33.5	34	31	34	37	33.5	35	35	33	30.5
20	32	31.5	33	34	34	33.5	38	35	35	33.5	33	29
21	32	31.5	32	33.5	34.5	34	38	35	35	33.5	30.5	30
22	32	30.5	31.5	34	35	35	38	35	35	33	31	31.5
23	32	30.5	32	35	34	35.5	38	36	35	32	31	31.5
24	32	31	32	34.5	33	36	37.5	34.5	34.5	33.3	29	31.5
25	31.5	31	32	34	33	37	38	36.5	35	35	29	32.5
26	31	30	32	34.5	32.5	37	37	36	35	33.5	29	33
27	31	30.5	32.5	34	32.5	33.5	34.5	37	35.5	33.5	30	32.5
28	30.5	30	32.5	34	35	34.5	37.5	36	35.5	32.5	27	32
29	31	31	33	32.5	33.5	35		35	35.5	32	31	31.5
30	31	30.5	33	31.5	33	35.5		35	36	29	30	32
31	27.5		33		33.5	36		36.5		29.5		32

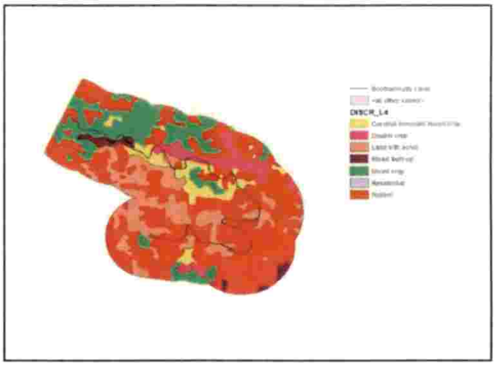
Appendix.2. Minimum Temperature in ^{0}C (August 2016- July 2017)

Day	Month											
	August	September	October	November	December	January	February	March	April	May	June	July
1	24.5	24	24.5	22	21.5	22	22.5	20.5	26.5	27	25	25
2	24.5	24.5	24	22	20	23.5	21.5	21.5	27	23.5	25.5	25
3	24.5	22	22	22	27.5	22.5	20	23	27	25.5	25.5	25
4	24	22.5	22	22	22.5	17	19	23	26	25.5	25.5	25.5
5	23	22.5	24	23	22	22	20	23.5	27	27.5	25	25.5
6	23.5	22.5	23	22	24.5	21.5	20	23.5	27	27.5	25	24.5
7	23.5	22	22	21	20.5	22.5	20	24	26	24	25.5	25.5
8	24.5	22	22	21	20.5	22	19	24.5	27	24.5	25.5	25
9	24	22	23	21	20.5	22.5	19	24.5	27.5	26.5	26	25
10	24	24	23	21	20.5	22	19.5	25.5	27.5	26.5	25.5	24.5
11	23	26	22	21	20.5	21	22.5	25	27	26	25	25
12	24	25	22	21	20.5	21.5	21.5	24.5	26.5	24	25.5	26
13	23	24	22	24	20.5	20	19	24.5	27.5	24.5	25.5	26
14	23	24	22	24	20.5	22	19	26.5	25.5	25	25.5	24.5
15	23.5	24	22	24	20.5	20	19	26.5	26	25	26	25.5
16	24	24	22	23.5	20.5	20.5	18.5	24.5	27	26.5	26.5	25.5
17	24	24	22	23.5	20.5	21	17	24.5	27.5	27.6	25.5	24.5
18	24.5	24	22	24	20.5	17.5	16	26	27	27	25.5	25
19	23	23.5	22	22	20	18	17.5	25.5	26	21	26	25.5
20	23.5	24	22	22.5	24	18	17.5	26	26.5	26.5	26.5	24
21	24.5	24	22.5	22.5	20.5	18	17.5	26	25	26.5	25.5	24
22	25	24	22.5	23.5	20	25.5	17.5	25	25	27	25.5	24.5
23	24.5	24.5	22.5	23	22.5	21	24	26.5	25	25	25.5	26
24	24	24	22.5	23	23	26	24.5	26	27.5	27	24.5	26
25	25	24	22.5	21.5	24	26	18	26	27	27.5	24.5	25.5
26	24.5	24	22.5	21	22	22	23.5	26.5	26.5	25.5	24	26.5
27	24.5	24	22	21	21.5	22.5	24.5	26.5	27	26.5	25.5	26
28	23.5	24	22	21	22	22.5	24.5	26.5	29.5	26	25	25
29	23	25	22	21	22	23.5		26	27	27	25.5	26
30	23.5	25	22	21.5	23	24		26.5	24.5	25	26	26
31	24		22		23.5	23.5		26.5		25		25.5

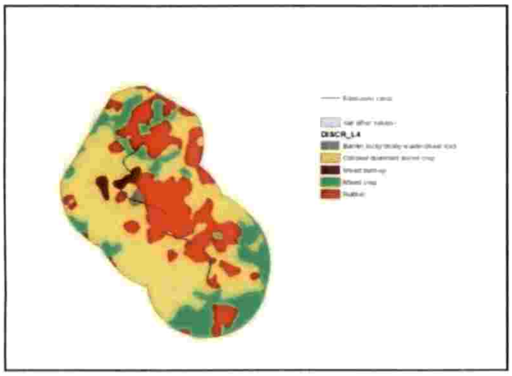
Appendix .3. Command area of branch canals



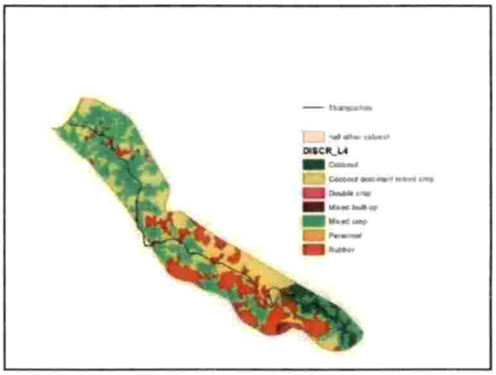
Adichily branch



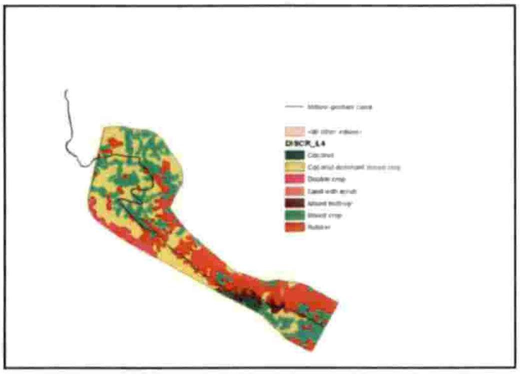
Bhoothamkutty branch



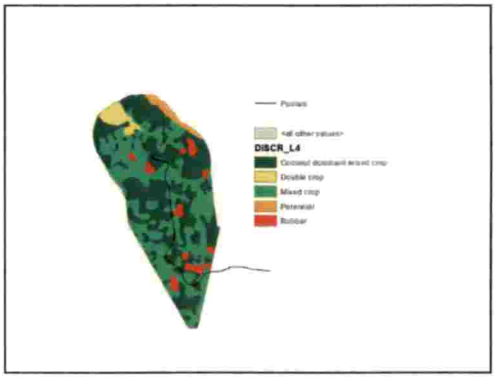
Edakkunnu branch



Thanguchira

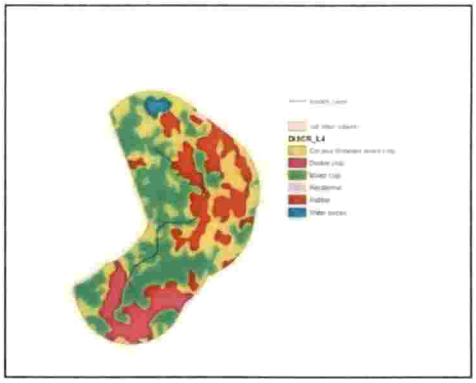


Meloor Poolani

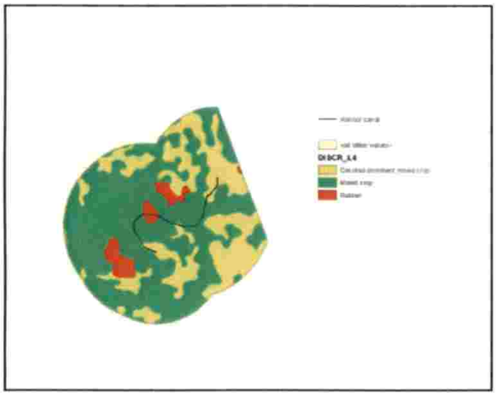


Poolani

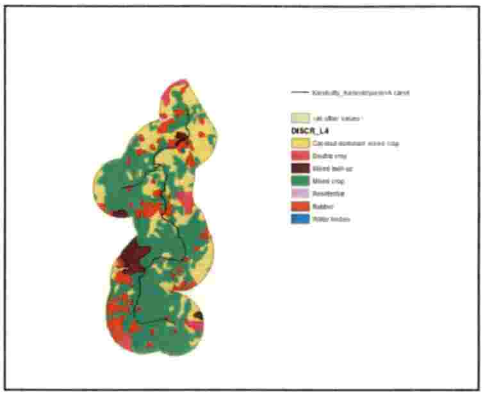
Kizhakkumury



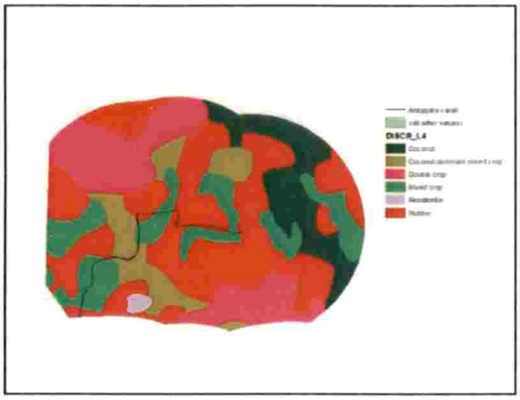
Koratty



Konoor



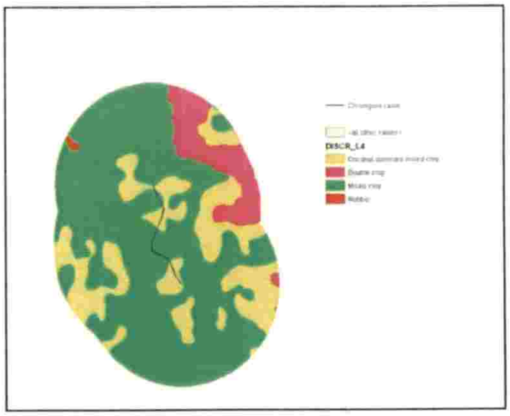
Karukutty Karayamparamb



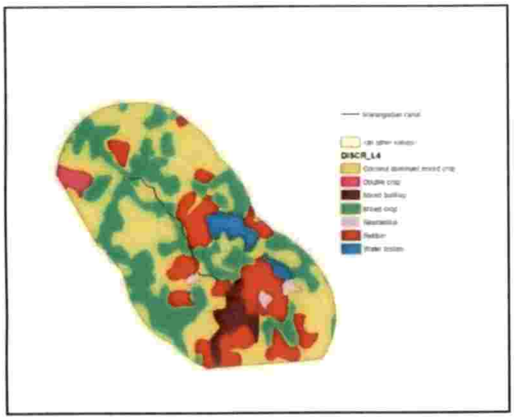
Anappara

Attara

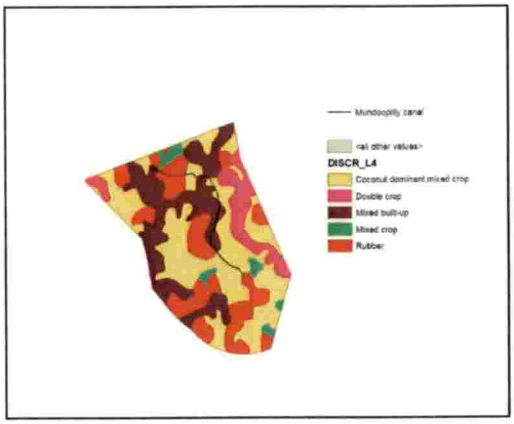
Azhakam



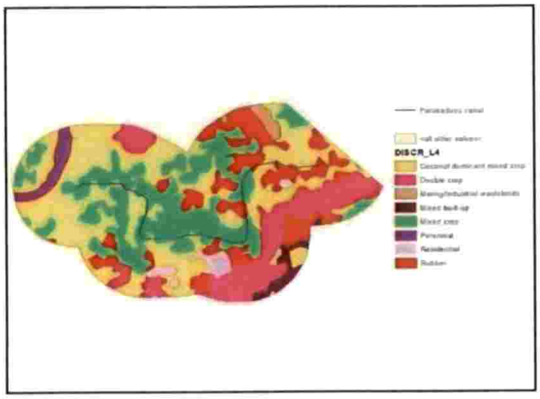
Chirangara



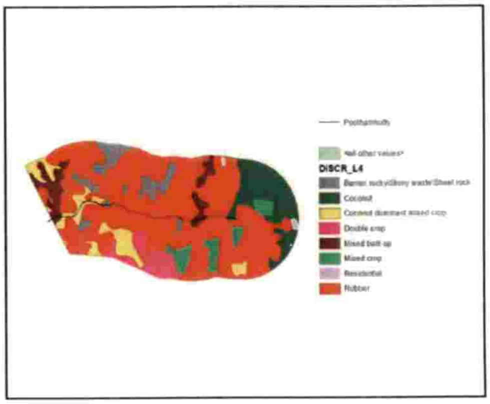
Marangadan



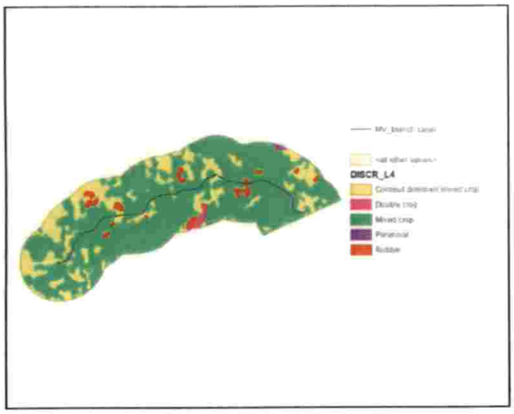
Mundoopilly



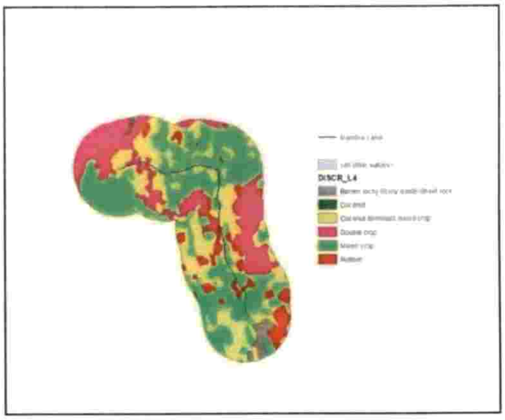
Naduvattom



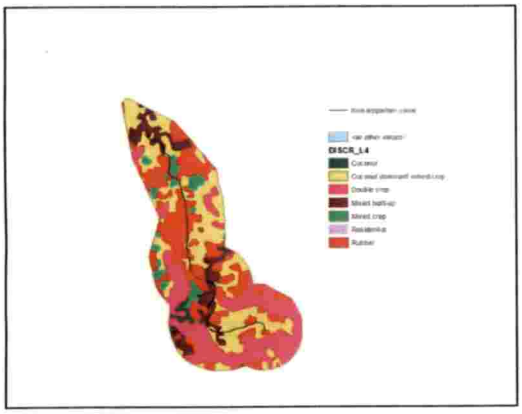
Poothamkutty



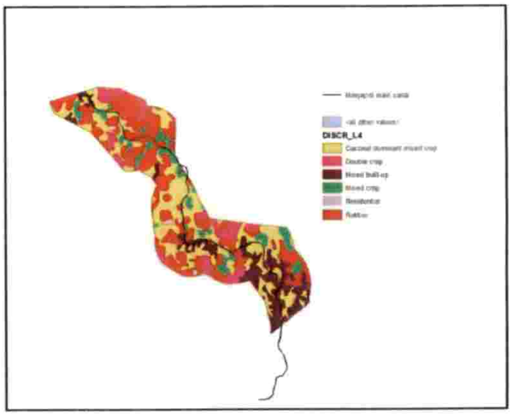
MV branch



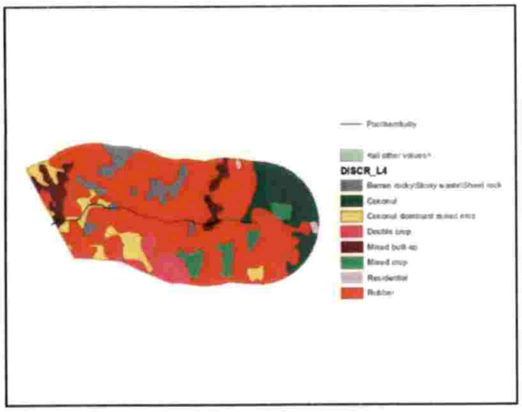
Mambra branch



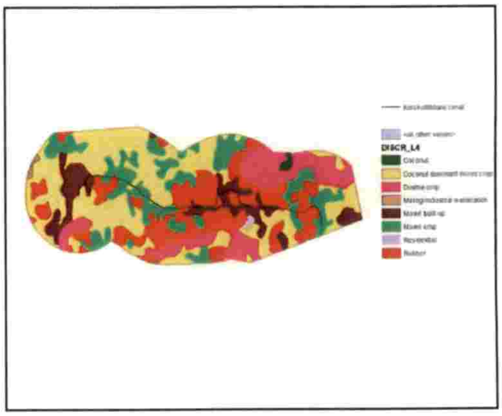
Komarappadam



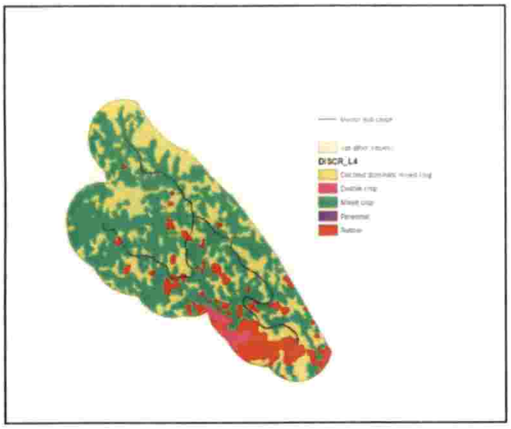
Manajapra main

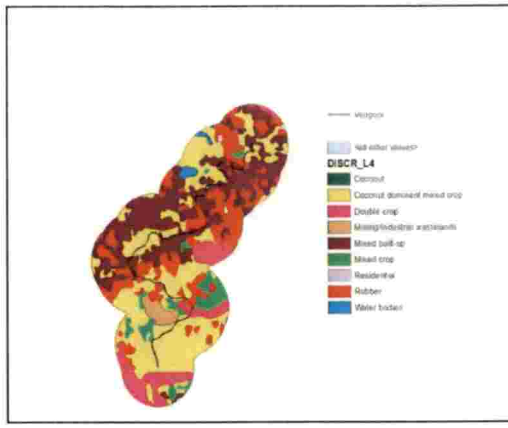


Manjapra branch



Karukuttikkara





Meloor South Vengoor

Apeendix. 4. Depth to water level in observation wells (m)

Weeks (1/12/16 to 31/5/17)	Branch Name										
	Main	Main	Main	Adichily*	Main	Main	Bhoothamkutty	Bhoothamkutty *	Meloor	Meloor *	Poolani
	Well No										
	1	2	3	4	5	6	7	8	9	10	11
1	3.08	3.54	3.77	6.27	0.66	3.05	2.32	9.44	2.33	5.86	4.47
2	3.38	4.38	3.05	6.27	0.725	3.17	2.43	9.59	2.66	6.92	4.63
3	3.16	3.67	2.8	6.27	0.39	3.19	2.32	9.63	2.94	7.46	4.69
4	3.69	2.69	2.74	6.27	0.22	3.28	2.27	9.64	3.86	7.84	4.31
5	3.1	3.16	3.1	6.27	0.29	3.31	2.88	9.69	4.27	7.84	4.33
6	2.6	5.63	4.35	6.27	0.36	3.76	2.86	9.74	2.34	7.84	4.45
7	2.73	7.12	4	6.27	0.44	3.77	2.93	9.77	2.65	7.84	4.58
8	3.1	5.23	2.89	6.27	0.53	3.83	3.03	9.81	2.87	7.84	4.73
9	3.33	5.08	2.85	6.27	0.61	3.97	3.12	9.84	3.26	7.84	4.9
10	3.23	3.19	2.72	6.27	0.91	4.06	3.13	9.83	3.56	7.84	4.62
11	3.3	3.24	3.22	6.27	1.21	4.18	3.08	9.88	2.27	7.63	3.99
12	3.16	5.85	3.24	6.13	1.24	4.24	2.96	9.87	1.84	7.54	4.08
13	3.05	4.2	2.7	6.18	1.26	4.44	3.26	9.23	2.08	7.23	4.23
14	3.08	5.38	2.6	6.27	1.31	4.46	3.83	9.28	2.39	6.83	4.28
15	3.15	4.2	3.42	6.27	0.72	2.97	2.13	9.43	2.57	6.97	4.41
16	3.3	4.74	3.5	6.27	0.76	3.06	2.17	9.65	3.44	7.14	4.58
17	2.43	4.88	2.96	6.27	0.81	3.18	2.17	9.72	4.28	7.27	5.11
18	2.54	4.78	2.9	6.27	1.03	4.31	2.48	2.49	4.37	7.12	5.48
19	3.03	4.53	2.85	6.05	0.93	4.11	2.67	2.81	4	6.93	4.55
20	3.22	4.3	3.4	6.27	0.98	3.81	1.85	4.64	3.48	6.64	4.9
21	3.94	4.24	3.47	6.27	0.67	3.41	1.99	6.16	3.22	7	5.05
22	3.87	4.3	3.62	6.27	0.52	3.01	2.39	6.93	3.44	7.06	5.75
23	3.93	4.8	3.68	6.08	0.58	2.96	3.07	8.24	3.34	6.13	5.55
24	2.9	4.36	3.54	3.64	0.44	4.12	2.64	5.2	4.06	7.12	4.98

* Tail end of the branch

Weeks (1/12/16 to 31/5/17)	Branch Name											
	Main	Junction palissery	Tanguchira	Tanguchira*	Main nalukettu	Edakuunu	Edakkunnu*	koratty main	koratty main	meloor.s	meloor.s right*	Meloor left
	Well No											
	12	13	14	15	16	17	18	19	20	21	22	23
1	2.65	3.56	8.31	6.3	8.2	6.61	6.64	4.58	3.75	2.26	5.57	7.27
2	2.49	3.47	8.52	6.46	8.81	6.03	6.82	4.33	5.12	4.12	6.48	6.43
3	2.77	3.2	8.62	6.69	7.98	6.93	7.01	5.35	5.75	6.26	3.13	7.04
4	2.51	2.13	7.96	6.94	8.05	7.55	6.35	5.24	4.31	2.58	5.95	6.36
5	2.56	2.22	7.51	6.28	8.84	6.78	6.78	5.42	0.9	3.97	3.14	7.02
6	4.32	2.47	6.8	6.36	8.98	7.04	7.11	4.16	4.22	5.99	4.16	6.13
7	4.18	2.38	8.37	6.4	8.17	5.19	7.49	4.52	1.5	4.72	5.27	6.27
8	3.8	2.24	8.57	5.43	8.66	5.92	7.75	4.32	5.5	6.36	3.76	7.35
9	3.61	2.01	8.77	5.57	9.42	5.34	8	3.86	4.25	2.7	4.98	6.52
10	3.74	1.98	8.84	5.88	10.03	6.85	8.34	3.61	5.19	4.05	5.54	7.02
11	3.83	1.9	8.87	6.09	8.82	2.77	8.83	4.02	4.55	5.27	3.43	6.13
12	4.06	1.8	8.75	6.58	8.96	5.34	9.18	4.67	2.44	6.05	4	7.13
13	4.23	1.92	8.96	7.14	8.5	5.38	7.47	4.58	5.13	1.47	4.78	6.47
14	2.56	2.03	9.2	7.43	8.47	3.21	5.5	3.92	4.78	3.65	5.16	6.08
15	2.31	2.2	9.25	6.97	8.62	4.44	3.86	4.14	3.12	5.84	3.41	6.52
16	2.02	2.23	9.24	6.72	8.79	5.3	2.26	4.35	5.31	1.18	4.23	7.02
17	1.88	2.25	9.26	6.2	9.11	3.38	3.69	4.69	2.69	5.22	4.96	7.14
18	3.12	2.44	8.8	6.43	7.29	3.87	4.96	5.27	3.14	6.87	3.03	7.48
19	3.63	3.33	9.19	6.17	8.13	4.16	5.34	5.48	3.51	1.51	3.84	7.52
20	2.37	3.18	9.21	3.45	8.48	4.97	7.2	5.93	4.36	4.61	5.21	6.95
21	2.2	3.37	9.22	4.36	7.96	6.51	7.86	5.32	4.71	6	4.67	7.06
22	1.9	3.54	8.86	5.28	7.47	5.38	5.47	5.58	4.59	6.5	3.56	6.17
23	2.12	3.8	9.07	6.02	8.54	5.55	3.22	5.64	5.77	4.55	5.38	6.48
24	1.17	3.12	8.12	5.14	8.12	4.38	4.12	5.76	4.27	6.06	5.24	6.26

* Tail end of the branch

Weeks (1/12/16 to 31/5/17)	Branch Name										
	Konoor branch*	KV branch	KV branch	KV branch*	MV branch	kizhakkumuri	Marangadan branch	karukutty karayamparamb	karukutty karayamparamb*	Main	Chirangara
	Well No.										
	24	25	61	26	27	28	29	30	31	32	33
1	2.81	3.72	8.18	8.44	4.94	4.92	7.54	3.65	1.7	5.95	6
2	3.14	4.13	8.22	1.94	5.65	3.77	7.56	3.71	2.16	4.28	7.16
3	4.83	4.76	8.67	1.62	5.8	5.16	8.07	3.75	1.85	6.08	3.47
4	5.4	3.24	1.32	4.27	5.93	3.68	7.67	3.84	1.09	2.98	4.19
5	6.74	3.98	5.12	6.27	6.1	4.53	7.62	3.98	0.94	5.28	5.6
6	7.48	4.72	7.28	8.27	6.2	5.69	7.97	3.89	0.94	6.34	6.14
7	5.47	5.23	2.15	8.07	6.2	6.01	7.87	3.94	0.63	6.78	7.27
8	4.36	5.7	6.89	10.27	6.23	3.94	6.53	4.16	0.48	6.08	3.18
9	4.74	4.48	7.16	12.27	2.96	5.47	8.04	4.56	1.09	1.88	4.56
10	5.12	3.87	7.92	4.27	5.98	4.77	8.12	4.95	1.09	5.88	5.78
11	5.48	3.65	1.64	5.27	6.17	4.57	6.14	4.98	0.79	4.38	6.29
12	3.17	4.75	4.18	5.77	6.23	5.56	6.62	4.96	1.02	6.08	7.08
13	4.75	5.16	6.32	6.27	5.4	5.88	7.39	5.03	1.62	4.98	7.52
14	5.76	2.4	1.54	5.27	5.86	3.68	6.71	4.75	2.77	1.93	7.86
15	6.42	4.6	3.86	7.37	3.78	4.07	6.81	4.62	1.47	5.63	8.13
16	7.12	4.71	5.24	5.27	4.17	4.58	7.12	4.42	1.78	4.88	5.75
17	3.98	4.96	7.19	4.27	4.53	3.16	4.68	4.5	2.01	2.18	5.55
18	4.12	5.14	1.57	6.42	5.21	4.19	5.82	4.67	2.14	4.16	5.47
19	4.23	2.54	3.85	7.14	5.98	5.27	6.17	4.98	1.1	5.34	3.92
20	6.17	3.12	4.53	4.24	6.17	3.72	7.27	5.04	1.58	6.16	5.75
21	5.92	4.78	6.41	5.3	3.21	4.45	7.47	4.02	1.92	2.94	5.54
22	4.83	2.33	7.32	6.14	4.17	5.12	7.67	4.16	2.06	4.22	3.1
23	8.33	3.82	7.52	7.23	4.64	4.16	8.17	4.28	2.35	5.16	3.6
24	7.46	4.24	7.41	2.46	5.12	5.78	6.24	4.65	2.4	6.12	7.31

* Tail end of the branch

Weeks (1/12/16 to 31/5/17)	Branch Name									
	Mambra	Mambra*	Peechanikkad*	Pechanikkad	Parakkadavu	Parakkadavu	Parakkadav main	kalady Main	Attara	Attara*
	Well No.									
	34	62	35	36	37	38	39	40	41	42
1	4.14	8.02	6.9	8.2	9.13	6.54	7.03	7.85	4.64	8.25
2	3.93	5.49	6.97	7.9	9.15	5.27	7.13	6.64	5.12	8.4
3	2.64	3.48	7.12	7.59	9.3	5.86	7.18	5.11	3.86	8.56
4	2.88	3.33	7.28	7.44	9.45	6.6	6.95	3.24	3.36	8.28
5	3.71	4.98	7.28	8.96	9.6	6.62	6.91	5.14	4.44	8.55
6	4.34	6.48	7.28	8.98	9.8	6.62	7.04	6.84	5.06	8.17
7	2.97	4.33	7.28	7.75	9.98	6.88	7.12	6.32	5.17	8.36
8	3.18	5.48	7.28	7.52	10.08	7.02	6.97	4.99	5.26	8.56
9	3.67	5.73	7.28	8.04	10.1	7.1	6.43	7.79	5.34	8.66
10	4.34	6.49	7.28	8.34	10.2	7.14	6.83	6.94	5.08	8.25
11	2.21	4.13	7.28	8.79	9.87	7.1	7.04	3.44	4.06	8.16
12	2.89	4.47	7.28	7.23	9.58	6.45	6.24	6.19	4.86	8.28
13	3.68	5.61	7.28	7.56	9.96	6.34	6.37	6.94	5.03	8.55
14	3.83	6.07	7.28	0	10.12	6.22	6.79	4.17	3.14	4.6
15	4.17	7.17	7.28	8.96	4.56	4.88	2.65	5.14	4.36	6.48
16	4.24	7.51	7.28	7.29	5.75	5.37	3.8	5.87	4.64	7.34
17	2.16	6.49	7.28	7.87	6.46	6.14	6.55	3.64	5.3	8.5
18	2.75	7.01	7.28	6.7	7.13	5.48	7.12	5.64	3.18	4.84
19	3.24	7.51	7.28	7.24	8.67	5.91	7.06	7.04	3.48	5.38
20	3.97	7.81	7.28	8.04	9.34	6.13	6.7	4.26	4.24	6.35
21	2.84	6.88	6.98	8.64	8.91	5.12	6.85	4.72	3.74	5.55
22	3.48	7.52	7.18	6.68	8.62	5.88	6.45	5.02	5.12	6.95
23	4.13	7.59	7.28	7.4	8.47	6.21	6.38	5.25	5.34	7.27
24	3.35	7.91	7.28	7.98	9.36	6.29	6.56	5.67	5.4	7.86

* Tail end of the branch

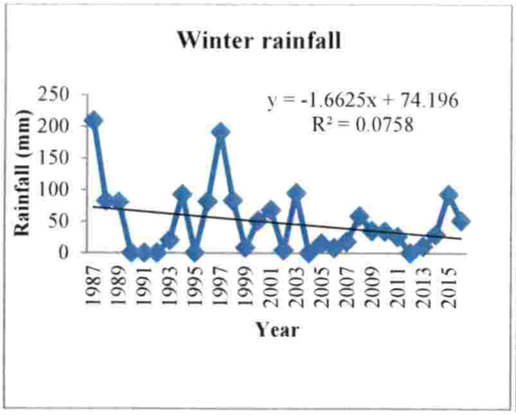
Weeks (1/12/16 to 31/5/17)	Branch Name								
	Poothamkutty	Anappara	Anappara*	manjapra branch	manjapra main	komarappadam	komarappadam*	karukuttikkara	karukuttikkara
	Well No.								
	43	44	45	46	47	48	49	50	51
1	6.28	4.3	6.84	6.51	1.23	6.82	6.74	4.68	8.34
2	6.4	4.41	7.08	6.69	1.83	6.43	7.59	5.07	8.4
3	6.72	4.04	5.77	7.02	2.08	4.42	4.65	2.89	2.87
4	6.93	4.32	6.28	7.24	2.06	5.56	6.38	4.87	4.53
5	5.4	4.64	6.99	6.92	2.14	5.59	7.29	5.2	7.68
6	5.85	4.61	7.46	6.94	1.26	4.96	7.64	4.57	8.34
7	6.15	3.82	7.17	5.7	0.19	6.23	7.84	2.64	2.36
8	3.92	3.96	6.43	4.52	0.22	6.8	8.52	6.13	7.54
9	4.66	5.06	6.97	5.63	0.19	6.96	8.92	2.48	2.57
10	6.38	3.82	5.15	6.29	0.23	3.19	5.82	4.16	5.65
11	3.53	3.31	4.78	4.69	0.34	4.23	8.02	5.83	7.64
12	4.74	4.08	5.2	3.19	0.4716	5.03	8.62	6.14	8.41
13	6	4.2	6.15	4.11	0.66	6.23	9.07	1.72	2.24
14	3.24	3.84	5.54	5.6	1.23	4.73	7.55	3.09	5
15	3.86	4.01	5.03	6.21	1.56	6.2	7.52	5.16	8.04
16	4.4	4.58	5.44	6.47	0.95	6.37	8.42	3.27	6.52
17	5.06	5.09	5.51	6.71	1.22	6.73	8.72	4.55	7.4
18	6.18	3.16	4.21	4.64	1.57	6.84	8.22	5.74	7.76
19	7.23	3.96	4.85	5.71	2.26	3.23	8.46	6.23	8.38
20	8.06	4.52	5.77	6.23	3.29	4.6	8.62	4.45	6.74
21	3.44	5.04	6.42	5.42	3.83	6.87	8.91	4.65	7.42
22	3.98	3.31	4.27	4.17	4.57	6.9	9.04	3.15	4.37
23	3.26	4.17	3.97	4.79	5.25	6.6	7.43	3.25	4.76
24	5.12	4.96	5.12	5.62	5.24	6.67	8.34	4.78	6.96

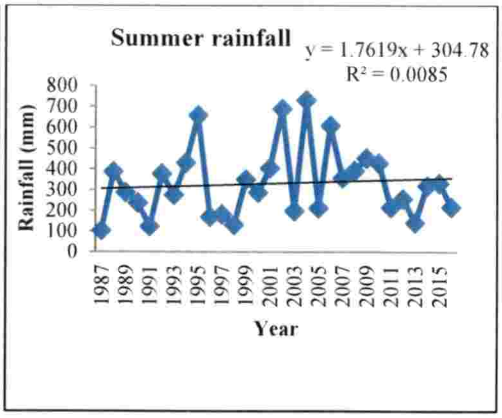
* Tail end of the branch

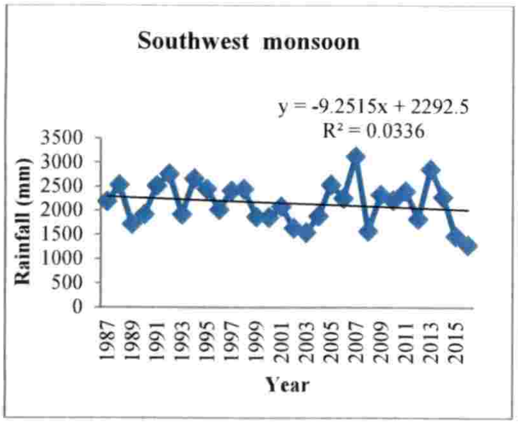
Weeks (1/12/16 to 31/5/17)	Branch Name						
	Mundoopilly padam	Azhakam	Azhakam*	Vengoor	Vengoor	Vengoor*	Thottakam
	Well No.						
	52	53	54	55	56	57	58
1	5.88	6.63	3.4	7.46	4.16	4.66	4.86
2	5.79	5.57	5.02	7.84	7.48	5.21	5.04
3	3.37	4.45	1.51	7.72	7.14	4.86	5.42
4	5.59	2.66	1.8	7.9	6.62	5.15	4.15
5	6.49	3.31	1.84	8.04	5.97	5.17	4.89
6	5.2	4.77	5.1	7.8	6.28	5.08	5.26
7	5.76	5.49	5.2	8.4	6.73	5.82	3.68
8	5.36	3.87	1.93	7.13	4.62	6.14	4.02
9	6.37	5.97	5.14	7.26	5.16	3.37	4.48
10	3.65	5.34	5.27	7.37	3.95	4.28	4.66
11	4.98	4.42	4.57	6.5	6.23	4.84	4.69
12	6.46	6.77	5.86	6.89	7.53	5.18	4.95
13	3.46	1.57	1.28	7.2	3.24	4.53	5.23
14	4.94	4.4	3.56	6.28	5.1	4.56	4.49
15	6.15	2.36	8.68	6.46	5.58	4.31	5.46
16	2.68	3.23	6.14	7.09	3.77	5.12	3.54
17	6.18	4.64	6.47	7.34	6.44	5.98	4.14
18	7.38	5.75	6.78	7.86	7.12	6.12	4.52
19	7.1	6.14	7.12	7.92	7.65	6.73	5.15
20	5.88	3.17	7.95	7.98	8.1	2.33	3.65
21	6.03	3.47	7.05	6.34	7.7	6.8	3.98
22	3.25	1.47	6.85	5.17	7.5	6.9	4.12
23	4.78	3.97	6.95	4.03	7.35	6.58	4.3
24	5.16	4.62	6.14	6.64	7.62	6.84	4.78

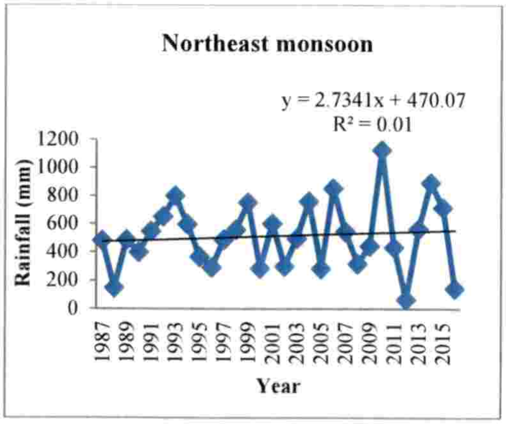
* Tail end of the branch

Appendix.5. Rainfall trend analysis

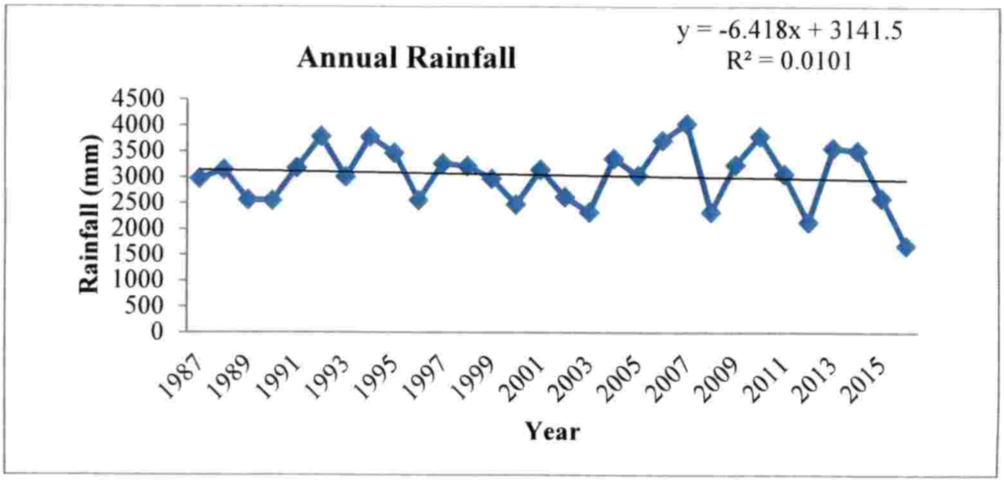




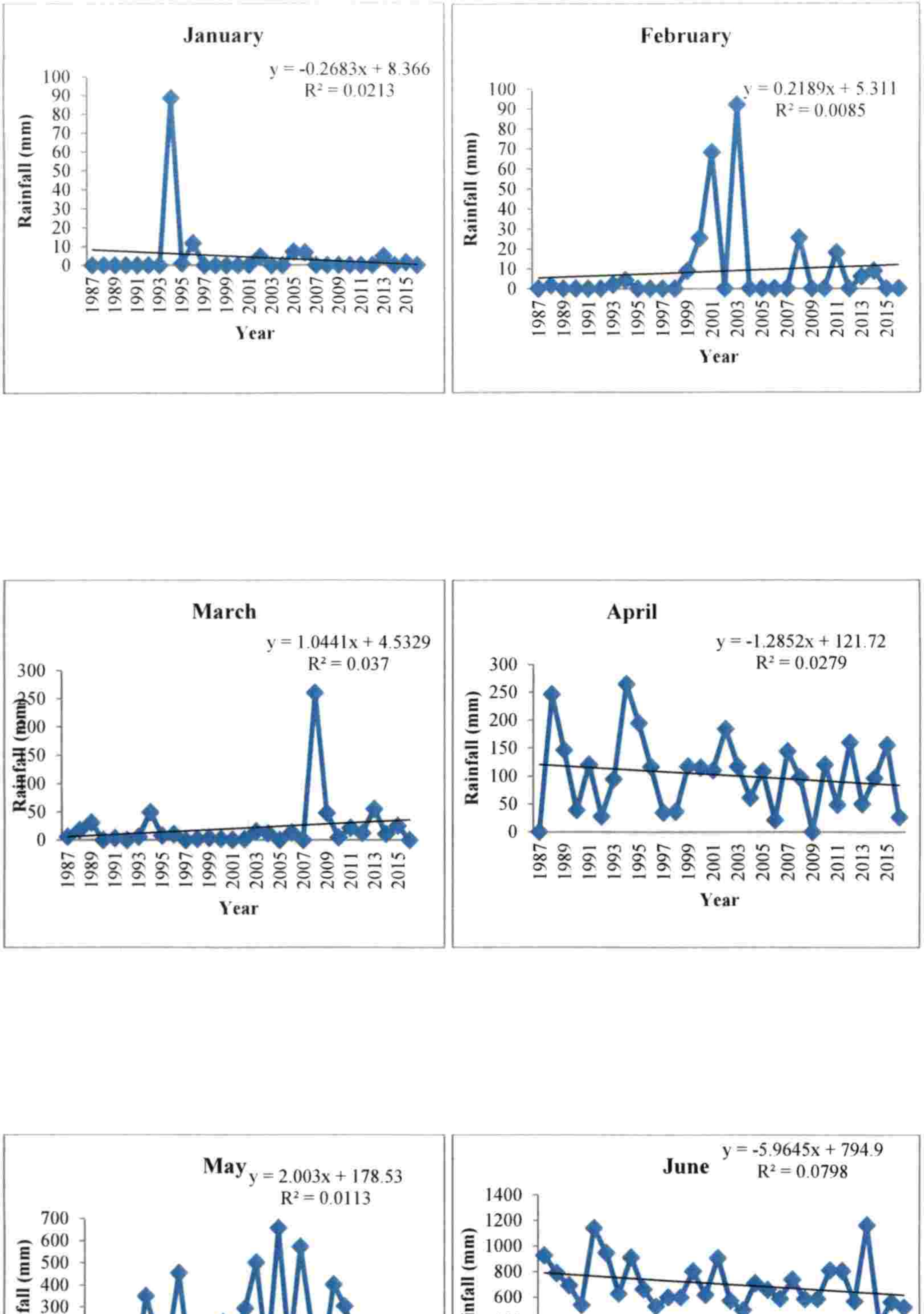




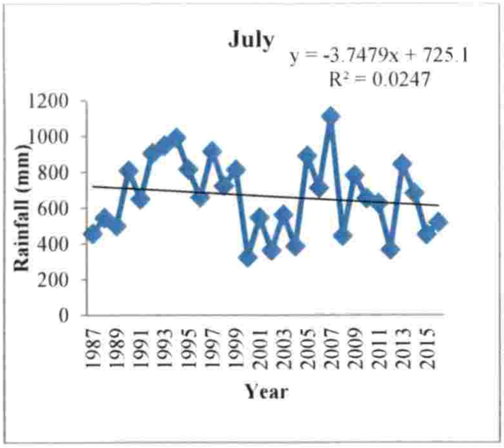
Trend of Seasonal Rainfall

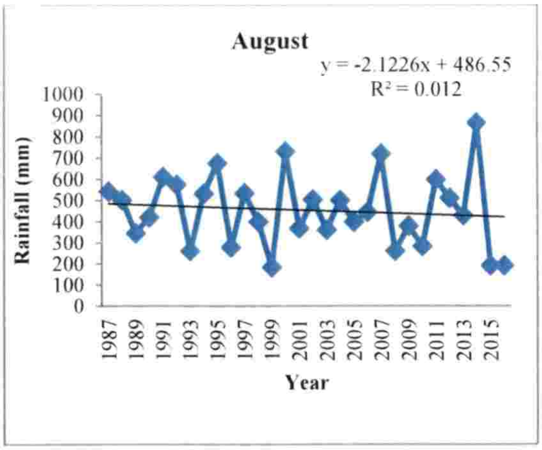


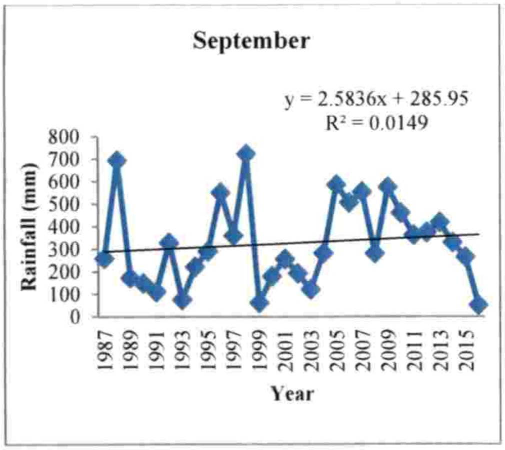
Trend of Annual Rainfall

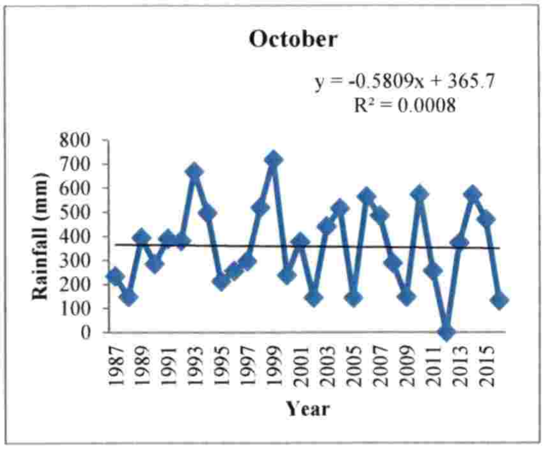


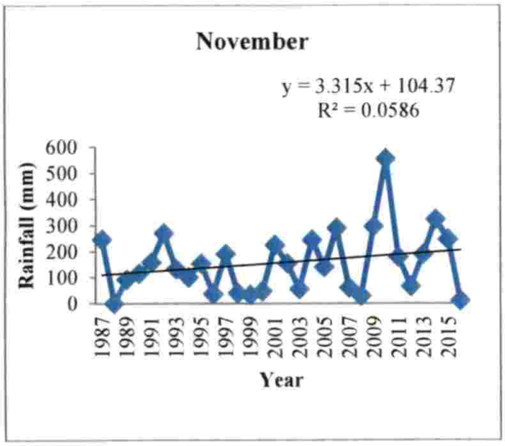
Trend of monthly rainfall (Months January to June)

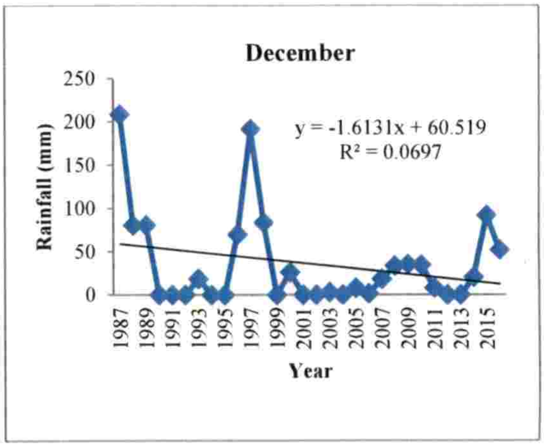












Trends of Monthly Rainfall (Months July to December)

Appendix.6. Water supply through branch canals

Week (1/12/16 t0 31/5/17)	Adichily	Bhoothamkutty	Meloor	Poolani	Thanguchira	Edakkuny	Meloor.South	Koratty	Konoor	KV	MV
	Water supply (million litres/ week)										
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	37.58	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.90	8.04	24.95	64.62
5	0.00	0.00	0.00	0.00	24.19	0.00	0.00	0.00	0.00	24.95	0.00
6	17.28	15.55	26.50	15.63	12.10	0.00	0.00	12.90	4.02	24.95	64.62
7	17.28	0.00	0.00	15.63	0.00	25.05	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	12.53	27.30	6.45	4.02	0.00	32.31
9	34.55	0.00	26.50	15.63	0.00	0.00	54.59	6.45	4.02	24.95	64.62
10	0.00	15.55	0.00	15.63	0.00	25.05	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	12.53	27.30	6.45	4.02	0.00	32.31
12	0.00	0.00	53.00	0.00	24.19	0.00	54.59	6.45	4.02	74.86	64.62
13	0.00	31.10	0.00	31.25	0.00	25.05	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	12.53	0.00	0.00	0.00	0.00	0.00
15	34.55	0.00	0.00	31.25	24.19	0.00	81.89	12.90	4.02	74.86	96.93
16	0.00	15.55	26.50	0.00	0.00	25.05	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	12.53	27.30	6.45	4.02	0.00	32.31
18	34.55	15.55	26.50	31.25	24.19	0.00	54.59	6.45	4.02	74.86	64.62
19	0.00	0.00	0.00	0.00	0.00	37.58	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	34.55	0.00	0.00	15.63	12.10	0.00	81.89	12.90	8.04	74.86	96.93
22	0.00	15.55	26.50	31.25	12.10	12.53	0.00	0.00	0.00	0.00	0.00
23	0.00	0.00	0.00	0.00	0.00	25.05	0.00	0.00	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	81.89	12.90	4.02	74.86	96.93
25	0.00	0.00	0.00	0.00	0.00	12.53	0.00	0.00	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	25.05	0.00	0.00	0.00	0.00	0.00
Total	172.77	108.86	185.49	203.14	133.06	300.64	491.34	103.19	52.29	474.14	710.81

Weekly water supply through branch canals

Week (1/12/16 to 31/5/17)	Branch									
	Kizhakkumuri	Marangadan	chirangara	Karukutty karaymparamb	Mambra	Peechanikkad	Parakkadavu	Poothamkutty	Manjapra branch	Manjapra dist
	Water supply (million litres/ week)									
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	26.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.42	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	71.18	8.42
7	26.30	15.54	8.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	8.09	0.00	20.65	10.48	8.05	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	71.18	8.42
10	26.30	15.54	8.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	8.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.83	71.18	16.83
13	26.30	15.54	0.00	45.79	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	16.18	0.00	0.00	10.48	8.05	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	71.18	16.83
16	26.30	15.54	0.00	45.79	0.00	0.00	0.00	16.83	0.00	0.00
17	0.00	0.00	0.00	0.00	20.65	10.48	8.05	8.42	0.00	0.00
18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	25.25	71.18	16.83
19	26.30	15.54	0.00	91.58	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	20.65	10.48	8.05	0.00	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.83	71.18	16.83
22	13.15	7.77	0.00	45.79	0.00	0.00	0.00	0.00	0.00	0.00
23	13.15	7.77	16.18	0.00	20.65	10.48	8.05	0.00	0.00	0.00
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.83	71.18	16.83
25	13.15	7.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	13.15	7.77	16.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	210.43	108.76	80.90	228.96	82.59	52.38	40.27	109.41	498.27	100.99

Weekly water supply through branch canals								
Week (1/12/16 to 31/5/17)	Branch							
	Anappara	Naduvattom	Komarappadam	Mundoopilly	Vengoor	Attara	Karukuttikkara	Azhakam
	Water supply (million litres/ week)							
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	16.18	7.45	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	10.13	0.00	0.00	11.22	10.49	5.40
7	0.00	0.00	10.13	8.75	18.12	0.00	10.49	5.40
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	10.13	8.75	18.12	0.00	0.00	0.00
10	0.00	0.00	0.00	8.75	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	16.18	0.00	10.13	8.75	0.00	22.44	10.49	5.40
13	0.00	0.00	30.39	34.99	36.25	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	16.18	0.00	0.00	0.00	0.00	22.44	0.00	0.00
16	0.00	0.00	40.51	34.99	72.50	0.00	10.49	5.40
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	16.18	14.91	20.26	17.49	0.00	11.22	10.49	5.40
19	0.00	0.00	10.13	8.75	18.12	0.00	10.49	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	16.18	14.91	0.00	0.00	0.00	11.22	0.00	0.00
22	0.00	0.00	20.26	26.24	18.12	0.00	10.49	5.40
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	16.18	7.45	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	10.13	17.49	54.37	0.00	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	97.07	44.72	172.18	174.95	235.62	78.55	73.41	32.40