IDENTIFYING THE BEST LOCATION FOR OPTIMUM YIELD OF COTTON CROP WITH THE HELP OF CLIMWAT AND CROPWAT SOFTWARE

A Dissertation submitted in partial fulfillment of the requirement for the
Award of degree of

MASTER OF TECHNOLOGY

IN

HYDRAULICS AND WATER RESOURCES ENGINEERING

BY

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DECLARATION

I do hereby certify that the work presented is the report entitled “IDENTIFYING THE BEST LOCATION FOR OPTIMUM YIELD OF COTTON CROP WITH THE HELP OF CLIMWAT AND CROPWAT SOFTWARE” in the partial fulfillment of the requirements for the award of the degree of “Master of Technology” in Hydraulics & Water Resources Engineering submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of my own work carried out from January 2017 to July 2017 under the supervision of Dr. MUNENDRA KUMAR (Assistant Professor), Department of Civil engineering. I have not submitted the matter embodied in the report for the award of any other degree or diploma.

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CERTIFICATE

This is to certify that the Major project entitled “IDENTIFYING THE BEST LOCATION FOR OPTIMUM YIELD OF COTTON CROP WITH THE HELP OF CLIMWAT AND CROPWAT SOFTWARE” done by Kuldeep Singh Negi (2K15/HFE/11) is in the partial fulfilment of the requirements for the reward of the degree of Masters of Technology in Hydraulics & Water Resources Engineering, Delhi Technological University (Formerly Delhi College of Engineering, University of Delhi). The information and data enclosed in this thesis is original and has not been submitted elsewhere for honouring of any other degree.

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ABSTRACT

Agriculture is one of major activity in INDIA. Overall development depends on food production in service of existing or growing population with maximum benefits and optimal utilization of water and land resources. Management of this water and land resources is also one of the main financial development. . Since pumping has an effect on the ground water resources availability, effective management of water resources using reliable calculation of historical groundwater balances at local and sub- watershed scales is required (Kendy et al 2004). We used CropWat 8 Window to determine PET of the area and the Crop Water Requirement (CWR) of cotton which are cultivated using irrigation during dry months; T-M and simple water balance equations were used to quantify annual recharge to the water table and water table status under different irrigation scenarios. Although irrigation from the groundwater could ensure the food security of the area, different water management scenarios showed that the ground water table will be declining as a result. Recharge and water table calculations show that irrigation increases the recharge to the water table but at the same time reduces the overall water table depth due to pumping. Water table depth will not be depleted if irrigation follows the CWR of vegetables . Present study includes identifying the best location for optimum yield of cotton crop using Climwat and Cropwat software by taking three study areas of India.

KEY Words: Recharge, water table, ground water balance, irrigation, crop water requirement.

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CHAPTER ONE

1. Introduction

In many areas of the world where extensive irrigation is not possible or practical, the lack of sufficient water in the root zone of the soil can cause great societal disruption, especially to agricultural concerns. Even in areas like the northeastern United States, where mean monthly precipitation is relatively large and consistent throughout the annual cycle, precipitation variability on diverse time-scales characterizes the climate system (Leathers et al, 2000).

Parallel to population growth, food demand of people and consequently the water demand of all sectors are also increasing. Agricultural yield and productivity should be increased to provide a sustainable development and food security of the increasing population. That brings the need for effective and sustainable water resources utilization and enforces the 21st century countries to implement water saving technologies in irrigation practices (Cakmak et at, 2006).

Ground water is the principal source of fresh water for domestic, industrial, and agricultural use in many parts of the world. In addition, ground water supports freshwater ponds, wetlands, streams, and estuary environments, all of which represent specific and important habitats for native flora and fauna. Significant growth in the number of summer and permanent residents over the last 30 years has increased ground water use and placed stresses on ground water resources. In particular, there is concern over the extent of long-term declines in ground water and pond levels and in the quantity of stream flow, as well as about the possibility of saltwater intrusion from the surrounding ocean. The effects of increasing ground water withdrawals depend on the location of wells, local hydro-geologic conditions, the amount and rate of withdrawals and whether or not the water is returned to the aquifer after use. In view of increasing demand of water for various purposes like agricultural, domestic, industrial etc., a greater emphasis is being laid for a planned and optimal utilization of water resources (Kumar, 1993). Due to uneven distribution of rainfall both in time and space, the surface water resources are unevenly distributed. Also, increasing intensities of irrigation from surface water alone may result in alarming rise of water table creating problems of water logging and salinization, affecting crop growth adversely and rendering large areas unproductive. This has resulted in increased emphasis on development of ground water resources. The simultaneous development of ground water especially through dug wells and shallow tube wells will lower water table, provide vertical drainage and thus can prevent water logging and salinization. Areas which are already waterlogged can also be reclaimed. On the other hand continuous increased withdrawals from a ground water reservoir in excess of replenishable recharge may result in regular lowering of water table. In such a situation, a serious problem is created resulting in drying of shallow wells and increase in pumping head for deeper wells and tube wells. This has led to emphasis on planned and optimal development of water resources. An appropriate strategy will be to develop water resources with planning based on conjunctive use of surface water and ground water. For this the first task would be to make a realistic assessment of the surface water and ground water resources and then plan their use in such a way that full crop water requirements are met and there is neither water logging nor excessive lowering of ground water table. It is necessary to maintain the ground water reservoir in a state of dynamic equilibrium over a period of time and the water level fluctuations have to be kept within a particular range over the monsoon and non-monsoon seasons. Water balance techniques have been extensively used to make quantitative estimates

of water resources and the impact of man's activities on the hydrologic cycle. The study of water balance is defined as the systematic presentation of data on the supply and use of water within a geographic region for a specified period. With water balance approach, it is possible to evaluate quantitatively individual contribution of sources of water in the system, over different time periods, and to establish the degree of variation in water regime due to changes in components of the system.

CHAPTER TWO

2. Literature review

Evapotranspiration

The hydrologic cycle is a constant movement of water above, on, and below the earth's surface. It is a cycle that replenishes ground water supplies. It begins as water vaporizes into the atmosphere from vegetation, soil, lakes, rivers, snowfields and oceans-a process called evapotranspiration.

Natural Resources Management and Environment Department, FAO, 2000 Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil transpiration becomes the main process. At sowing nearly 100% of ET comes from evaporation, while at full crop cover more than 90% of ET comes from transpiration.

Verstraeten et al 2008 Evapotranspiration is important in soil water and ground water balances, which require estimating evapotranspiration to determine water storage, which, in turn, can lead to technical measures for the improvement of irrigation drainage and ultimately can be used to increase crop yield . Potential transpiration is defined as the maximum amount of water lost through transpiration by short green vegetables actively growing and fully covering the ground surface with unlimited water supply. The Potential Evapo-Transpiration (PET) at a given place is the total amount of moisture that could be lost at a given place by evaporation and transpiration.

FDRP, IMD Annex I, 1999 Next to rainfall, potential evapotranspiration (PET) is of special importance in a tropical environment. Both rainfall and PET are needed for the computation of the climate water balance in order to have a broad idea regarding the length of the growing season and the characteristics of the crops and their productivity. They also play a significant role in estimating water balance requirements for crop under irrigation. PET is an agro-climatic index and not an evaluation of the evapotranspiration actually taking place in a given area at a given time.

Ziemer 1979 The amount of evaporation actually occurring is largely regulated by the amount of energy supplied. Air temperature provides an indication of the solar energy received and so the potential evapo-transpiration at a given place can be determined from the weather variables which include minimum temperature, maximum temperature, wind speed, relative humidity, and the amount of net radiation (hours of sunshine). The actual evapo-transpiration (AET) at a given place is the total amount of moisture that is actually lost through evaporation and transpiration. It is the quantity of water evaporated by the soil and transpired by plants under existing meteorological and soil moisture conditions.

Effect of irrigation on crop production

Sun et al, 2006 after Yaron and Bresler, 1983; English, 1990; English and Raja, 1996 The effects of irrigation on crop production are usually quantified using crop water production functions which relate crop yield to amounts of water applied. The rational irrigation can significantly increase the grain yield (Hagan et al., 1967; Gajri et al., 1997; Huang et al., 2004).

Hagan et al. (1967) also asserted that excessive irrigation delays the maturity of the plant and the harvesting season and decreases grain yield.

Jin et al. (1999) reported that excessive irrigation led to a decrease of crop water use efficiency and that the effective deficit irrigation may result in higher production and crop water use efficiency.

Kang et al. (2002) indicated that the responses of grain yield and water use efficiency to irrigation varied considerably due to differences in soil water content and irrigation schedules.

Singh et al. (1991) concluded that the impact of limited irrigation and soil water deficit on crop yield or water use efficiency depends on the particular growth stage of the crop.

The relationship between irrigation and ET is linear such that an increase in irrigation increases the ET. ET is driven by meteorological factors, crop factors and soil factors and is not only water consuming process but also an energy consuming process (Sun et al, 2006).

Ground water recharge and discharge

Groundwater recharge is the replenishment of an aquifer with water from the land surface. It is usually expressed as an average rate of inches of water per year, similar to precipitation. Thus, the volume of recharge is the rate times the land area under consideration times the time period. In addition to precipitation, other sources of recharge to an aquifer are stream, lake or pond seepage, irrigation return flow (both from canals and fields), inter-aquifer flows, and urban recharge (from water mains, septic tanks, sewers, drainage ditches). When the sole source of such potential recharge is precipitation, it is usually called potential natural recharge. Potential natural recharge does not consider the other sources of recharge mentioned previously. In contrast to natural recharge (which results from natural causes), artificial recharge is the use of water to artificially replenish the water supply in an aquifer will be done. In many arid and semi-arid regions where surface water resources are limited and ground water is the major source for agricultural, industrial and domestic water supplies, quantitative evaluation of spatial and temporal distribution of ground water recharge is a pre-requisite for operating ground water resources system in an optimal manner. The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon the ground water recharge (Kumar, 1993). Effective management of limited water resources requires reliable calculation of historical groundwater balances at local, sub-watershed scales (Kendy et al 2004). The optimal exploitation of the groundwater requires a previous knowledge on the aquifers potentialities (Benjamin et al 2007).

The withdrawals associated with irrigation from ground water are a negative recharge and will be calculated according to the equation:

Net Recharge (ground water) = Precipitation - (ET x Adjustment Factor).

The ET adjustment factor will be applied according to the geographic location of the irrigated land being calculated and the application method used to apply water

(Contor, 2002).

Crop water use and growth stage

Crop water use, also known as evapo-transpiration (ET), is the water used by a crop for growth and cooling purposes. This water is extracted from the soil root zone by the root system, which represents transpiration and is no longer available as stored water in the soil. Consequently, the term "ET" is used interchangeably with crop water use. Crop water use (ET) at critical growth stages can be used in irrigation scheduling to avoid stressing crops. Water stress during critical growth periods reduces yield and the quality of the crops. Crop water use (ET) is weather dependent as well as soil, water and plant dependent. Periodically check soil water at different depths within the root zone and at different growth stages helps to avoid stressing the crop during critical growth stages (Al-Kaisi et al, 1991). The availability of water to crops depends on both soil properties and root distribution (Meyer et al 1990).

Crop water requirement

Crop water requirement is defined as the depth of water needed to meet the water loss through evapo-transpiration (ET_{crop}) of a disease free crop growing in a large field under non-restricting soil conditions, including soil water and fertility, and achieving full production in a given growing environment.

Water is essential for plant growth. Without enough water, normal plant functions are disturbed, and the plant gradually wilts, stops growing, and dies. Plants are most susceptible to damage from water deficiency during the vegetative and reproductive stages of growth. Also, many plants are most sensitive to salinity during the germination and seedling growth stages.

The investigation of water requirements is the main step in the design and planning of an irrigation system. The irrigation requirement is, in general, the water required to meet the water loss through evaporation, unavoidable application losses and the other water needs of land preparation. The water requirement of crops may be contributed from different sources such as irrigation, effective rainfall, soil moisture storage and ground water contribution (FDRP, KGVDP Annex II, 1999).

Irrigation requirement of the crop

A favorable method for raising the yield per unit area in arid and semi-arid areas is through irrigation (Toda 2005). For effectively and efficiently using the available water sources to meet the possibly variation of cropping pattern, irrigation management plays an important role. To facilitate the management practice, experimental data based the irrigation management model can be applied to estimate the crop water demand and upgrading the capability of irrigation management (Kuo et al 2001). In the case of irrigated agriculture, the irrigation requirement of a crop is defined as the part of the crop water requirement that should be fulfilled by irrigation. In other words, it is the water requirement of the crop that exceeds the sum of effective rainfall carry over soil moisture storage and ground water contribution.

Crop growing period

The growing period is the part of the year during which the moisture supply from precipitation and soil water storage and the temperature are adequate for crop growth.

A normal growing period comprises one or more humid periods besides moist periods.

Intermediate growing periods consist of a transitional moist period only. During an intermediate growing period, it is unlikely that the crop water requirement will be fully met. Yield expectations are therefore smaller than for normal growing period. Growing periods are composed of the different climatic types ; humid (H), moist humid or intermediate (I), moderately dry (D) and very dry periods (VD) which define more accurately the availability of water for plant growth rather than the rainfall alone

(FDRP, KGVDP, Annex I, 1999).

The rate at which vegetation cover develops and the time at which it attains effective full cover are affected by weather conditions in general and by mean daily air temperature in particular. Therefore, the length of time between planting and effective full cover will vary with climate, latitude, elevation and planting date. It will also vary with cultivar (crop variety). Generally, once the effective full cover for a plant canopy has been reached, the rate of further phenological development (flowering, seed development, ripening, and senescence) is more dependent on plant genotype and less dependent on weather.

The end of the mid-season and beginning of the late season is usually marked by senescence of leaves, often beginning with the lower leaves of plants. The length of the late season period may be relatively short (less than 10 days) for vegetation killed by frost (for example, maize at high elevations in latitudes > 40°N) or for agricultural crops that are harvested fresh (for example, table beets and small vegetables). High temperatures may accelerate the ripening and senescence of crops. Long duration of high air temperature (> 35°C) can cause some crops such as turf grass to go into dormancy. If severely high air temperatures are coupled with moisture stress, the dormancy of grass can be permanent for the remainder of the growing season.

Moisture stress or other environmental stresses will usually accelerate the rate of crop maturation and can shorten the mid and late season growing periods periods. (Natural

Resources Management and Environment Department, FAO, 1975).

Crop coefficient (Kc)

The effect of the crop characteristics on crop water requirements is accounted by the crop coefficient (Kc). The Kc value relates to the evapotranspiration of a disease free crop grown in a large field under optimum soil water and fertility conditions, achieving full production potential under a give growing environment. ET crop can be found by

$ET_{crop} = Kc * ETo$,

Where Kc is experimentally derived crop coefficient. Kc values with growing stages for each crop and the distribution of crop coefficient during the growing cycle of the crop is called crop curve (Natural Resources Management and Environment

Department, FAO, 2000).

Available water capacity

Krysanova et al., 2000 The dynamics of soil moisture represent a component of the overall water balance, and may be regarded as the single most important variable defining the fresh water availability. Soil moisture plays a critical role in crop growth and vegetation restoration in semi arid environment, and is also an important factor in hydrological modeling (Fu et. al., 2003).

Available water capacity (AWC) is the amount of water that the soil can store. It is the amount of water that is available for use by plants and is normally expressed as volume fractions or percentage. The soil moisture available to vegetation is the portion of soil moisture that is held between filed capacity and wilting point and hence soils with large differences between field capacity and wilting point generally favor plant growth.

Effective rainfall

Scheduling irrigation based on crop demand requires an estimate of effective precipitation or rainfall. Effective rainfall estimates are also important for planning cropping sequences in both dry-land and irrigation crop production. Effective rainfall is the amount of rainfall stored in the crop root zone. Rainfall that runs off the soil surface or passes through the root zone does not contribute to crop growth and yield. Factors that influence effective rainfall are soil slope, soil texture and structure, plant cover or crop residue, and storm intensity and duration (Tsai et al, 2005)

Effective rainfall is portion of the rainfall that can enter in the soil and support crop evapotranspiration. Effective rainfall can be computed by different methods. Of these, the project (Kobo-Girana valley development project) has adapted the Method developed by USDA Soil Conservation Service. It estimates using the formula:

Effective Rainfall = Total Rainfall / 125 * (125 - 0.2 * Total Rainfall) ... (Total

Rainfall < 250 mm)

Effective Rainfall = 125 + 0.1 * Total Rainfall ………….... (Total Rainfall > 250 mm)

(Feasibility study report for Kobo-Girana Valley Development Program. Volume II:

water resource, Annex F: Irrigation)

Methods of water distribution

There are varieties of methods by which water can be distributed in an irrigation system. In practice three different methods of water delivery are recognized:

Continuous flow

Rotational flow

On demand flow

Continuous flow: in this method, water is d distributed to the delivery point continuously in accordance with established proportion to the service area. This method allows/considers the minimum capacity of the system. The delivery point may be the field or the tertiary unit intake.

Rotational flow: in this method, irrigation supplies are rotated between delivery point (farm, block, field etc) according to pre-arranged schedule. The capacity of water distribution network in this method is much greater than the required for continuous flow.

On demand flow: in this method, irrigation supplies can be continuous or intermittent, it is entirely up to the demand made at the point of delivery. This is a method which gives users freedom to decide when to irrigate and how much to apply (FDRP,

KGVDP, Annex F, 1999).

Irrigation scheduling

Irrigation scheduling is the decision of when and how much water to apply to an irrigated crop to maximize net returns. The maximization of net returns requires a high level of irrigation efficiency. This requires the accurate measurement of the volume of water applied or the depth of application.

It is also important to achieve a uniform water distribution across the paddock to maximize the benefits of irrigation scheduling. Accurate water application prevents over- or under-irrigation. Over-irrigation wastes water, energy and labor, leaches nutrients below the root zone and leads to water logging which reduces crop yields.

Under-irrigation stresses the plant, resulting in yield reductions and decreased returns.

To benefit from irrigation scheduling you must have an efficient irrigation system (FDRP, IMD, Annex F, 1999). Irrigation scheduling has tremendous advantages when environmental, crop production and water use issues are considered. The advantages of irrigation scheduling include:

- The rotation of water amongst paddocks to minimize crop water stress and maximize yields.
- A reduction in energy, water and labor costs through less irrigation.
- A lowering of fertilizer costs through reduced surface runoff and deep drainage.
- Increased net returns through increased yields and improved crop quality.
- A minimization of water-logging problems.
- Assisting control of root zone salinity problems through controlled leaching.
- Additional crops through savings in irrigation water.

Effect of irrigation on ground water table

Schofield et al., 1989; Anderson et al., 1993 Water is the most important limiting factor for agricultural production. To achieve higher grain yields (GY), farmers use water from rivers or pump groundwater to irrigate winter wheat to offset the ET deficit. The excessive exploitation of groundwater resources from shallow and deep aquifers will cause the water table to fall and create many other environmental problems (E. Kendy et al, 2003 and Sun et al 2006). On the other hand indiscriminate use of irrigation water, particularly in existing areas of shallow water table, can result in further water table rise leading to water logging and secondary salinity problems.

Bowman et al 1987 Excess irrigation water builds up on impermeable soil layers forming a water table. If the water table rises into the root zone, plant growth will suffer as a portion of the roots are waterlogged. This is the case when farmers irrigate their field from surface water. If the water table is saline, which is often the case, capillary rise will lift salt into the root zone. This salt accumulates as the water is drawn off, and trees will soon show the symptoms of salt toxicity. Therefore, the water table does not have to reach the root zone to cause a loss in production.

Even though water tables may not presently be causing a problem, it is good practice to monitor their level. If there is a problem, monitoring can help to identify it. Test wells are an inexpensive method of checking the depth to the water table. A test well is a length of slotted PVC pipe installed vertically in the ground to about 2.7 meters.

As the water table rises and falls, the level of water in the test well also rises and falls. This level can be easily read with a tape measure, float or measuring stick. At the beginning of an irrigation season, the water table is usually well below the surface and does not influence tree performance. The test well will show if a water table exists and if so at what depth.

Where water tables are present, test wells should be read before irrigation and one to two days after irrigation. This will assess the effect of irrigation on the table and can help to plan to maintain the depth of the water table below the root zone.

Plant water stress

In many areas of the world where extensive irrigation is not possible or practical, the lack of sufficient water in the root zone of the soil can cause great societal disruption, especially to agricultural concerns (Leathers et al 2000). Plant water stress can be defined in a manner similar to the way stress is defined in the physical sciences. Therefore biological stress is "any change in environmental conditions that might reduce or adversely change a plant's growth or development (its normal functions)" and biological strain is the reduced or changed function.

As water becomes limiting, crop temperatures rise because they cannot transpire enough water to keep themselves cool. Plant leaves open their stomata to admit carbon dioxide for photosynthesis and at the same time water vapor flows out of the leaf, which cools the leaf surface. When soil water becomes limiting, transpiration decreases, thus reducing the leaf cooling effect and causing the crop temperature to rise. This is why when you touch the leaves of a well-watered crop in sunlight on a hot sunny day they are cool, whereas a piece of green cardboard would feel hot.

Khan et al 2004 The effect of soil drying on the transpiration rate requires consideration of the simultaneous interaction of the atmospheric demand, the water potential of the leaf, the resistance to water movement in the plant, and the soil water potential. For years there have been conflicting views about the manner in which transpiration rate responds to the drying of soil. There is increasing, evidence that the form of this relationship can be explained in terms of varying climate, plant, and soil factors. Root density functions are often taken as a function of root biomass, and such data are often difficult to obtain. The development of root systems can be quite dynamic and vary with species, season, and depth.

Plant stress is related to soil water content in two ways.

1. Soil water tension. The drier the soil the harder the plant has to work to extract water from the soil.
2. Void content for gas exchange. Roots need air for respiration. The wetter the
soil, the less air is available.

Sun et al, 2006 The principles of economics should be used to determine the allowable level of stress that results in the best returns on capital and labor. Stress level is monitored by monitoring soil water content in the root zone. Although irrigation is an efficient measure, capable of decreasing water stress, Water use efficiency decreases with increasing in irrigation.

CHAPTER THREE

3. The Study Area

Three study areas of India are taken 1- Kurnool **2-** Veraval 3- Alibag

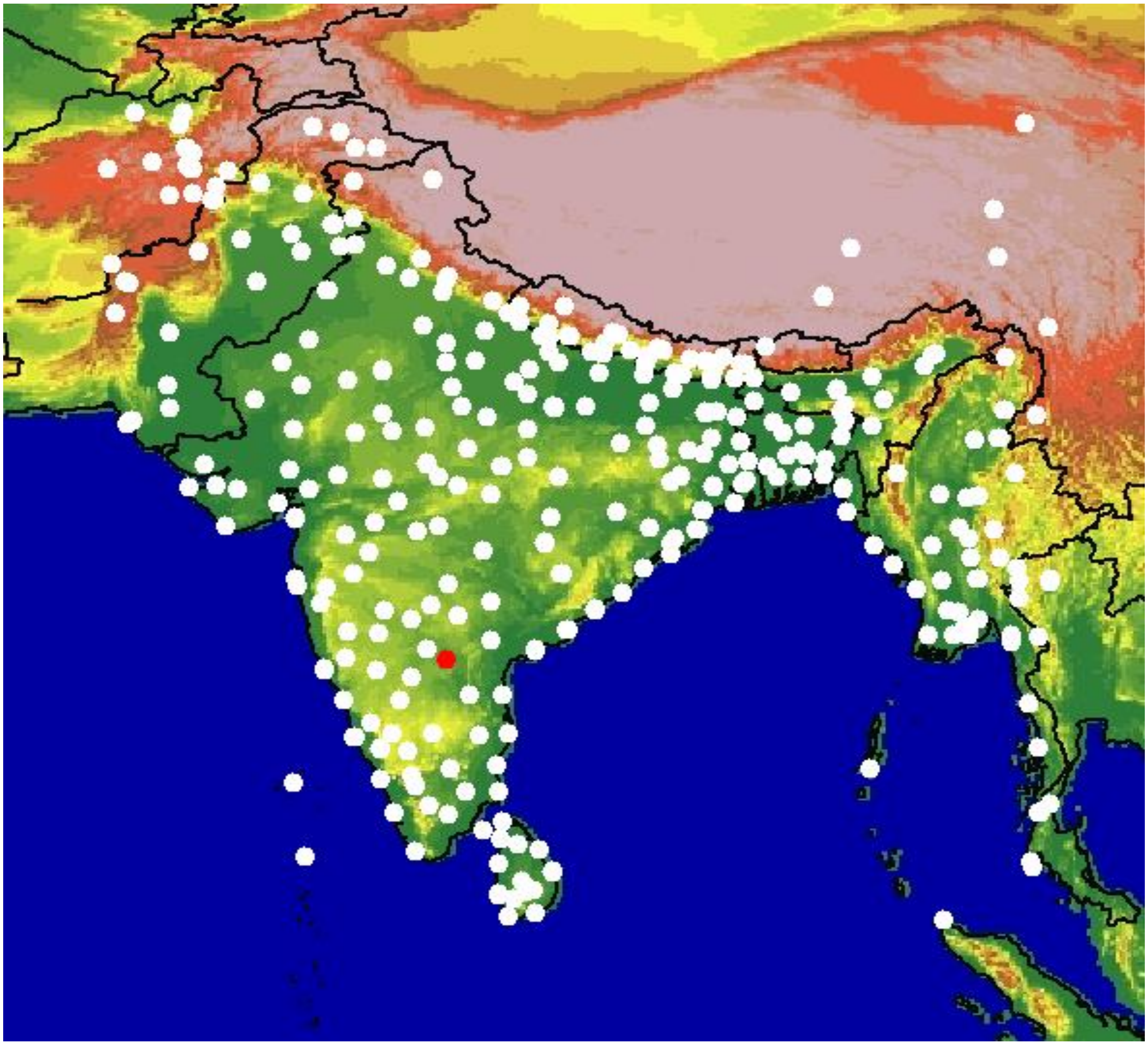


Figure 1 *KURNOOL*

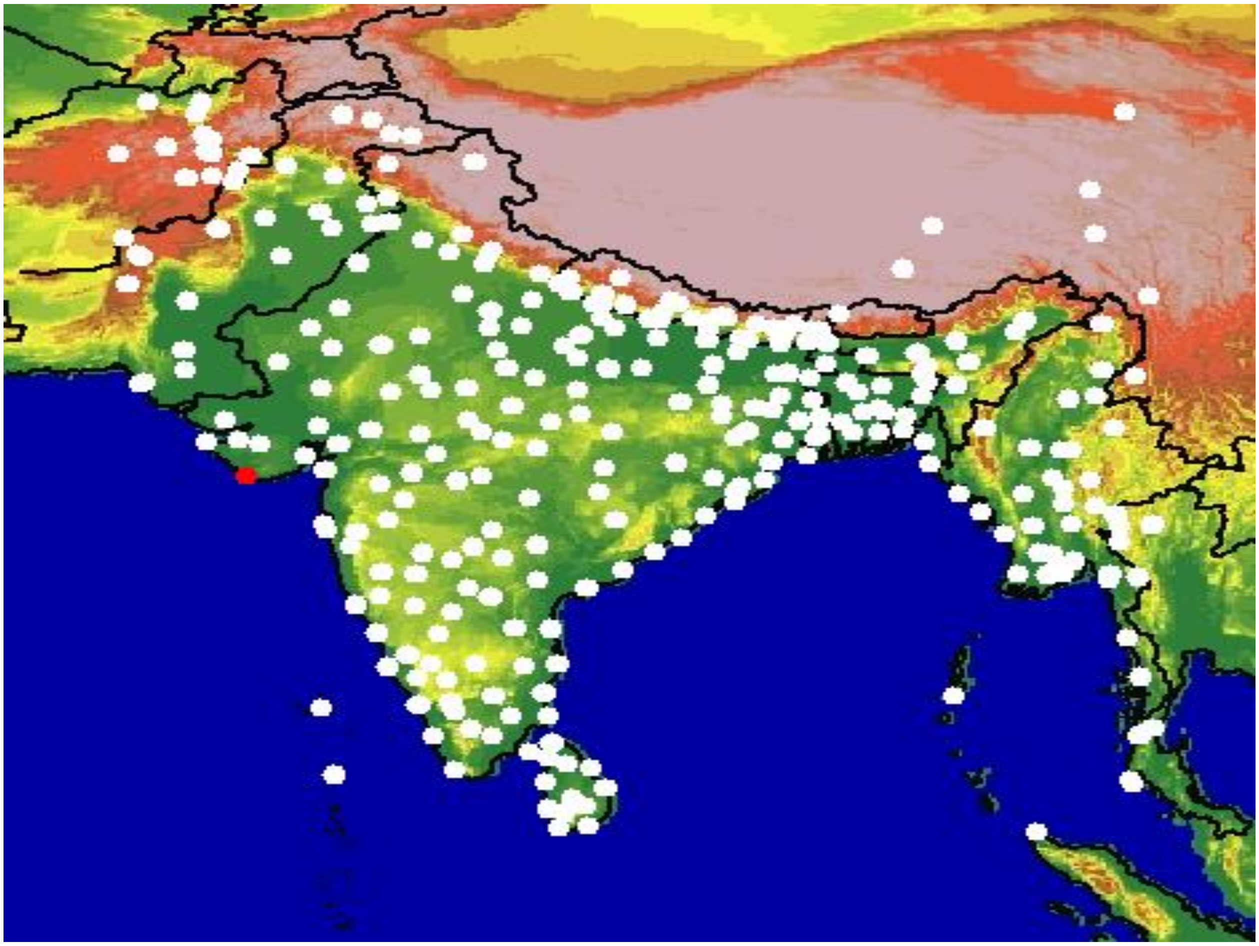


Figure 2 *VERAVAL*

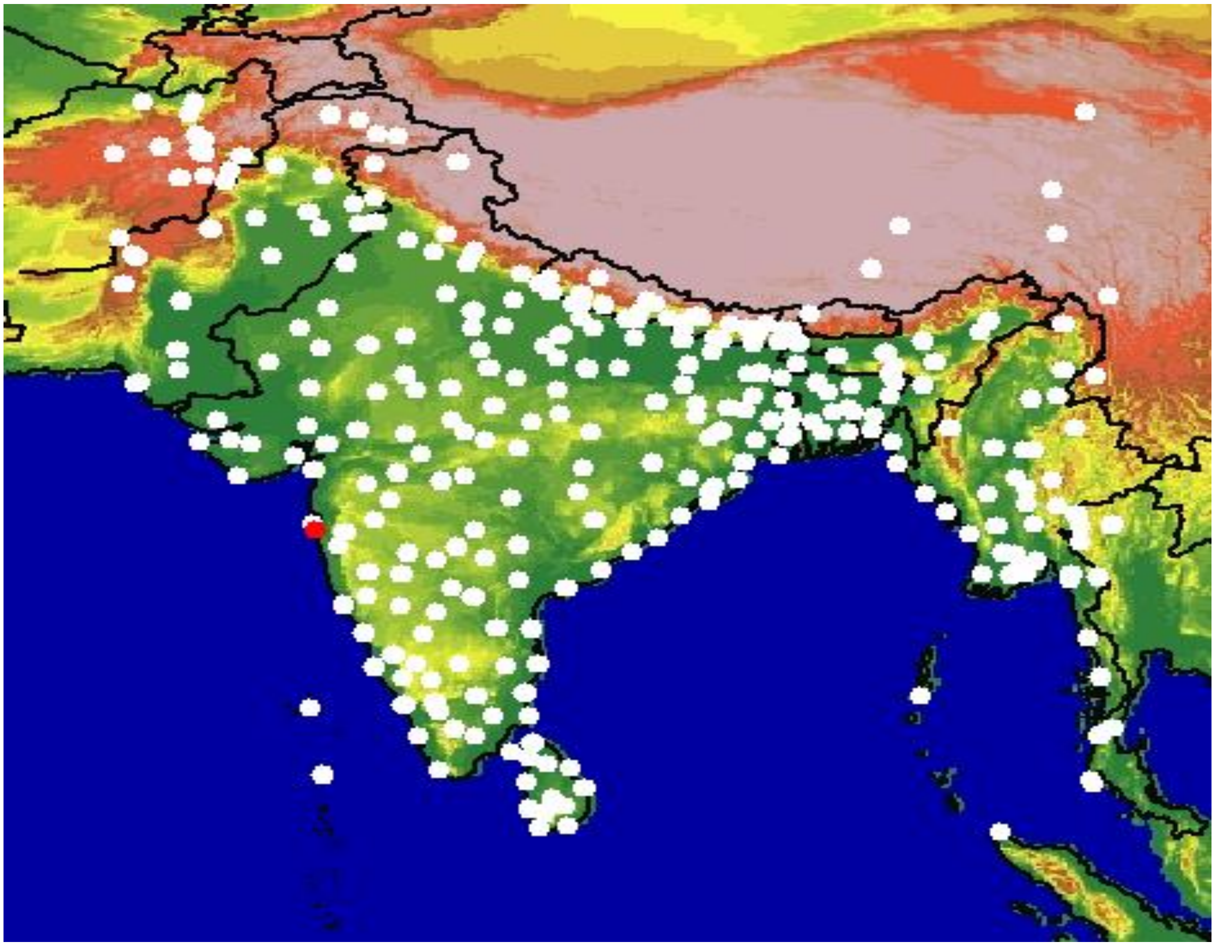


Figure 3 *ALIBAG*

CHAPTER FOUR

4. Data and methods

Data

Mean monthly values of maximum temperature, minimum temperature, precipitation, sunshine hours, relative humidity (RH) and wind speed, as well as soil type, common crops grown in the area and infiltration capacity of the soil are used for the estimation of PET, crop evapotranspiration, CWR, irrigation scheduling, and yield reduction due to water stress by CROPWAT 8 window. Temperature, RH, wind, precipitation and hours of sunshine data were taken from the Indian Meteorological Department (IMD) recorded values. Soil, crop, ground water table level and infiltration capacity data were taken from the previous feasibility study report documents prepared by IMD.

Methods

Calculation of missing precipitation data

Since the normal precipitation of the nearby stations and IMD station is more than 10%, normal ratio method was used to fill the missing precipitation data. The following formula was used:

$$P_x = \frac{N_x}{n}\left(\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} + \cdots \frac{P_n}{N_n}\right) \qquad (1)$$

Where: P_x and N_x are the values of the missing data and the normal precipitation of the station in question, respectively; P_1, P_2, P_3 and P_n are the recorded precipitation values of the nearby stations 1, 2, 3 and n^{th} stations, respectively, for n observation stations; and N1, N2, N3 and Nn are the normal precipitation of 1, 2, 3 and n^{th} stations, respectively.

Potential evapotranspiration, crop water requirement and irrigation scheduling

Potential evapotranspiration (PET) of the area is computed by using the CROPWAT 8 Window model developed by Food and Agriculture Organization (FAO, 1992). The model is also used for the computation of actual and reference crop evapotranspiration, crop water requirement (CWR), irrigation scheduling and total and stage yield reduction due to water stress. The model implements the modified Penman-Monteith equation. Mean monthly maximum and minimum temperature, precipitation, hours of sunshine, relative humidity and wind speed, soil type and infiltration capacity and cover crop were input data for the model. CROPWAT 8 window implements the following empirical formula to calculate PET and other characteristics of the area.

$$ET = \frac{\Delta}{\Delta+\gamma}(R_n - G) + \frac{\gamma}{\gamma+\Delta}15.36(1 + 0.0062V_2)(e_S - e_d) \qquad (2)$$

Where ET is potential evapotranspiration, cal/cm2/day (58 cal/cm2 = 1 mm), Δ is the slope of saturated vapor pressure curve at mean air temperature, γ is Psychometric constant, mb/oC, R_n is the net radiant energy at the earth's surface, cal/cm2/day, G is the soil heat flux, cal/cm2/day, $V2$ is the average wind speed at 2 m, km/day, e_s is the saturated vapor pressure at mean air temperature, mb, ed is the saturated vapor pressure at mean dew point temperature, mb.

Crop evapotranspiration can be calculated from the following equations:

$$ETc = (Kc + Ke)\, ET \qquad (3)$$

$$ETa = (Ksg * Kc + Ke)\, ETo \qquad (4)$$

Where Etc and ETa are crop evapotranspiration standard and adjusted for water stress, respectively, ETo is the reference crop evapotranspiration, Ks is the water stress coefficient, Kc is the crop coefficient, and Ke is the evaporation coefficient. Given the input of the requirement data, the CROPWAT model can be used to calculate crop-related data in every ten days period, such as: (1) crop coefficient, (2) crop leaf index, (3) crop evapotranspiration, (4) percolation, (5) effective rainfall, and (6) crop water requirements. Also, the model can be applied to estimate the irrigation schedule for each crop with 5 different options: in different irrigation management scenarios defined by irrigation manager, irrigation set at below or above critical soil depletion (% RAM), irrigation set at fixed intervals per crop growing stage, irrigation set at deficit irrigation, and no irrigation. Afterwards, the CROPWAT model can simulate the on-farm crop water balance, including: irrigation times, dates and depths.

Growing period and pattern

The growing period and pattern of the area is determined by using the ratio of the average monthly rainfall to the average monthly potential evapo-transpiration. For the determination of the crop growing period and growing pattern, critical ratio values were used as recommended by the FAO. It states that, for rain-fed agriculture, the area is double growing if the ratio has two peaks with a value above one in different periods in the year, single growing if the ratio has one peak with a value above one in a year or no growing period if the ratio has no peaks with a value above one in a year.

Ground water table computation

The ground water recharge and ground water table level are calculated using the application of Thornthwaite Mather (T-M) procedure and a simple water balance equation that balances recharge and pumping. The equation uses monthly /daily potential evaporation and precipitation. The moisture status of the soil depends on the previous day moisture content (AW), the difference between precipitation and potential evapotranspiration and the available water capacity (AWC) of the soil. The AW is calculated by two different methods depending on whether the potential evaporation is greater than or less than the cumulative precipitation.

Case 1:

For the months that the potential evaporation is in excess of the precipitation (i.e., the soil is drying out) the AW at a given time t is given by the formula (Steenhuis and Van

Der Molen. 1986), viz:

$$AW_C = AW_{t-\Delta C} \times exp\frac{P-PET}{AWC} \qquad (5)$$

Where: AW t = the available water at time t (cm); AW $_{t-\Delta t =}$ the available water at time t-Δt (i.e., previous month; cm); PET = cumulative evaporation over time period t (cm); AWC = the available water capacity of the soil (cm) and P = precipitation over time period t (cm).

But in the case of irrigation application, the moisture status of the soil depends on the amount and the time of irrigation applied other than the PET and precipitation. Therefore equation 6 will be modified to account irrigation factor in the soil moisture, viz:

Case 2:

For months when precipitation is in excess of the potential evapotranspiration, (i.e., the soil is wet) the AW at a given time t is given by the formula:

$$AW_C = AW_{t-\Delta C} \times (P - PET) \qquad (6)$$

And again in the case of irrigation application, the moisture status of the soil depends on the amount and the time of irrigation applied other than the PET and precipitation. Therefore equation 6 will be modified to account irrigation factor in the soil moisture, viz

$$AW_C = AW_{t-\Delta C} \times exp(P + I_V - PET) \qquad (7)$$

Therefore the general ground water balance equation for an unconfined aquifer is used to estimate the ground water table level when irrigation is applied. The ground water balance equation is given as:

$$\frac{\Delta S}{\Delta T} = I - Q$$
(8)

Where, I = Inflow (cm) during time Δt, O = Outflow (cm) during time Δt and Δw = change in water level (cm).

Considering the various inflow and outflow components, the ground water balance equation for a time period Δt is given as:

$$\Delta S = R_r + R_T - \left(E_c + T_p + S_e\right) \tag{9}$$

Where; R_i = Recharge from Rainfall, R_r = recharge from field irrigation, E_t= Evapotranspiration, T_p = draft from ground water, S_e =Influent recharge to rivers (Base flow to the river), ΔS = change in ground water storage

Base flow to the river (Se) is estimated by Darcy's law as:

$$Q = KA\frac{\Delta h}{\Delta t} \tag{10}$$

Where Q is the discharge or flow rate (cm3/month), K is hydraulic conductivity (cm/month); A is the cross sectional area (cm2); Δh is the head difference and Δ l is the distance from the well to the river. Hence, the depth of base flow per time is calculated by dividing equation 13 by the area. This gives:

$$S_e = K\frac{(H_t - H_D)}{l} \tag{11}$$

Where, H_t is the height after time t, H_D is the height from the river to water table level and l is the horizontal distance from the river.

Finally, the ground water table height below the ground can be estimated elevation using simple water balance equation that balances the recharge, discharge and pumping of ground water.

$$H_t = H_{t-\Delta t} + \left(1 - \frac{A_i}{A_T}\right) R_t + \frac{A_i}{A_T}(R_t - Pumping) - S_e \tag{12}$$

Where Ht and Ht-Δt are ground water height below the ground at times t and t-Δt respectively. Ai and AT are irrigated and total irrigable areas respectively.

Therefore, equating 14 and 15 gives,

$$H_t = H_{t-\Delta t} + \left(1 - \frac{A_i}{A_T}\right) R_t + \frac{A_i}{A_T}(R_t - Pumping) - K\frac{(H_{t-\Delta t} - H_D)}{l} \tag{13}$$

Equation 16 is used to estimate ground water table level under different scenarios.

Hence the decline of the water table can be calculated by the formula

$$\Delta H = \frac{\Delta S}{Porosity} \tag{14}$$

Where $\Delta S = (H_{t-\Delta t} - H_t)$ (15)

Assumptions

It is assumed that the ground water table level before irrigation was applied was at equilibrium state, i.e. the recharge to the ground water and the base flows are equal. We also take the average ground water table as 18m below the surface of irrigated farm land.

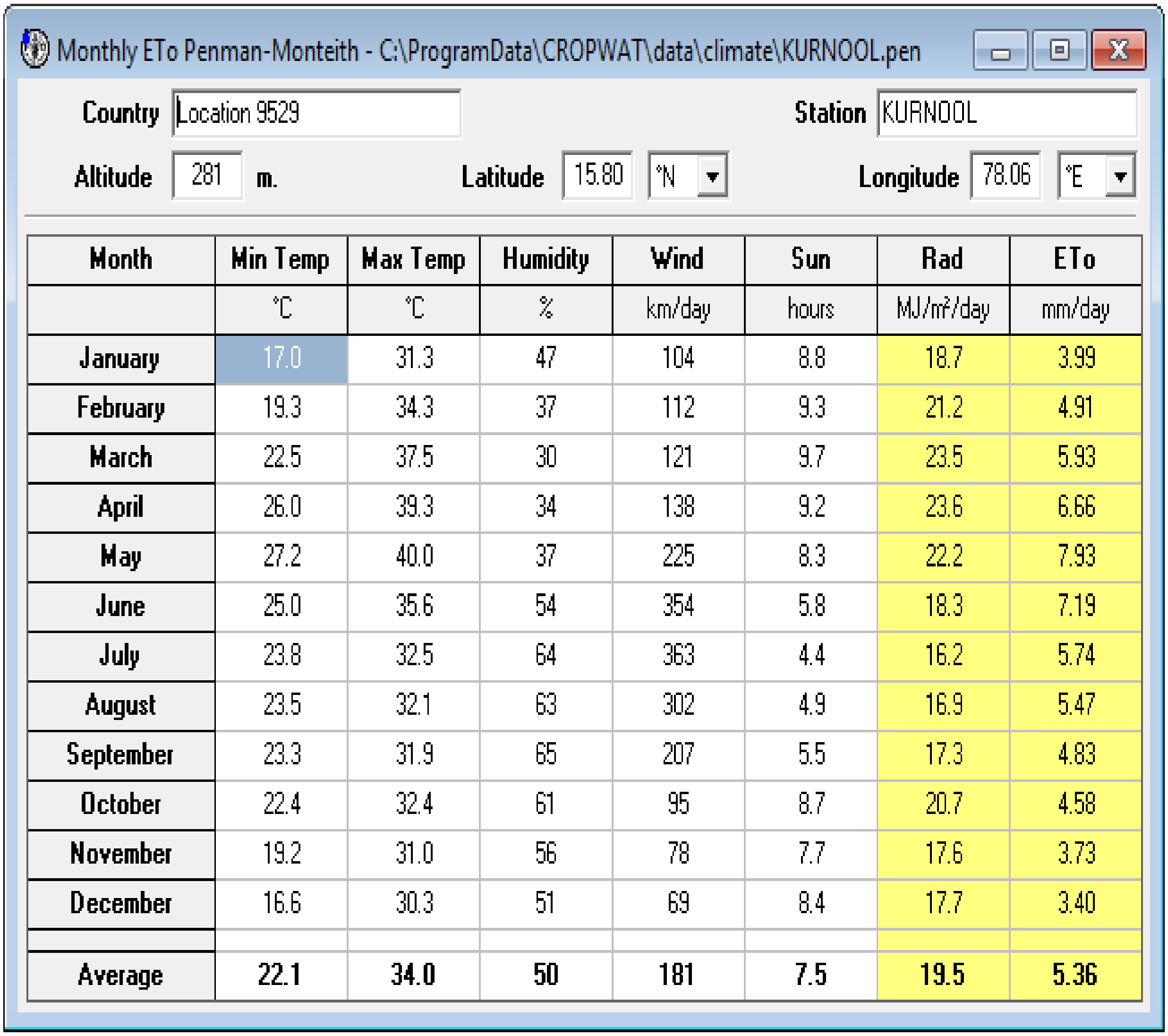
For the development of future water table depth calculations .

CHAPTER FIVE

5. Result and Discussion

The potential evapo-transpiration (ET_O) of the area is computed by CropWat 8 window software, which uses the Penman-Monteith formula calculating ET_O from temperature (minimum & maximum), wind speed at two meters above the surface, solar radiation and relative humidity data. Here with the help of CLIMWAT data is exported to cropwat and then various results and graphs are obtained of our 3 study areas. Here in India as we know base period of cotton crop is july to august so we fixed that time as base period and according to that and data taken by IMD we obtained various results those are -

1- Climate and evapotranspiration graph and table
2- Rain graph and table
3- Crop (cotton)
4- Soil
5- Crop water requirement graph and table



Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\KURNOOL.pen

Country: Location 9529

Station: KURNOOL

Altitude: 281 m.

Latitude: 15.80 °N

Longitude: 78.06 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	17.0	31.3	47	104	8.8	18.7	3.99
February	19.3	34.3	37	112	9.3	21.2	4.91
March	22.5	37.5	30	121	9.7	23.5	5.93
April	26.0	39.3	34	138	9.2	23.6	6.66
May	27.2	40.0	37	225	8.3	22.2	7.93
June	25.0	35.6	54	354	5.8	18.3	7.19
July	23.8	32.5	64	363	4.4	16.2	5.74
August	23.5	32.1	63	302	4.9	16.9	5.47
September	23.3	31.9	65	207	5.5	17.3	4.83
October	22.4	32.4	61	95	8.7	20.7	4.58
November	19.2	31.0	56	78	7.7	17.6	3.73
December	16.6	30.3	51	69	8.4	17.7	3.40
Average	**22.1**	**34.0**	**50**	**181**	**7.5**	**19.5**	**5.36**

Figure 4 *climate and evapotranspiration chart Kurnool*

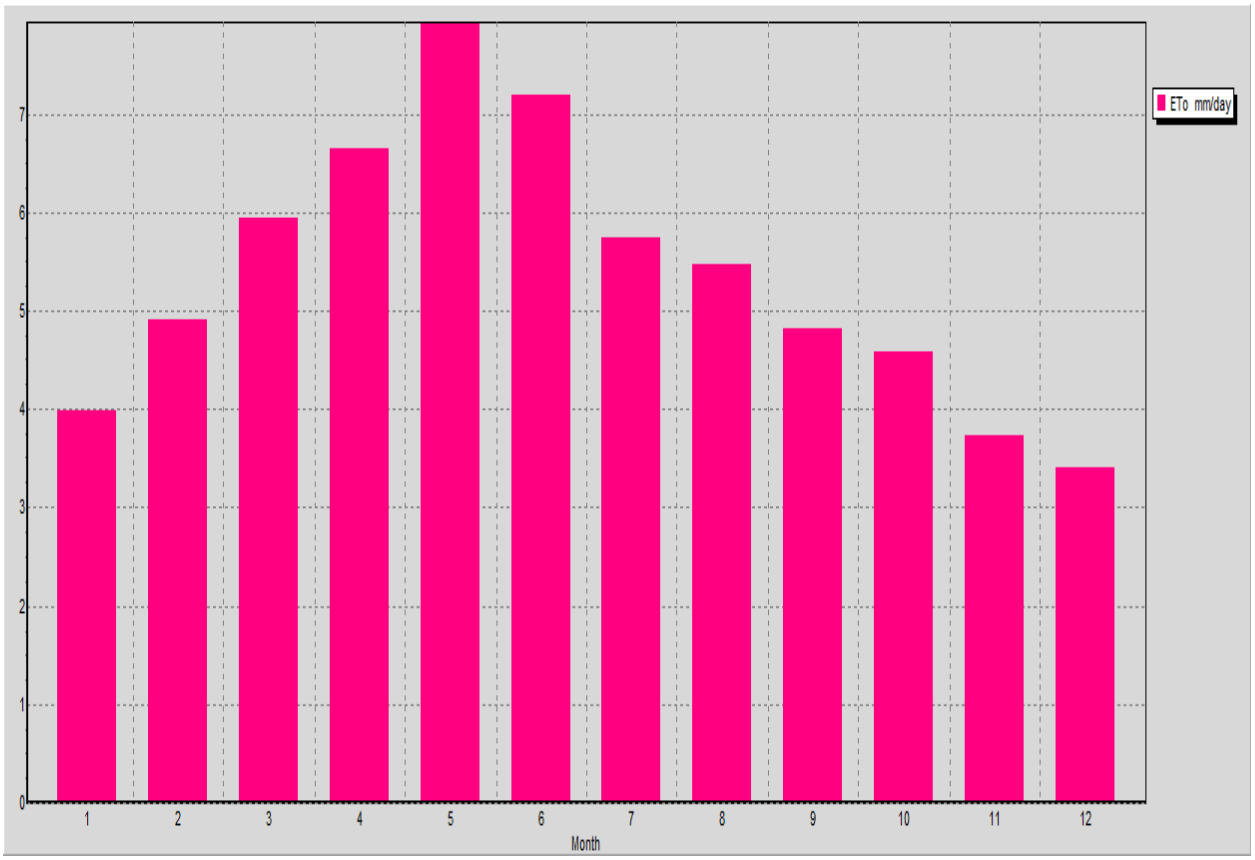
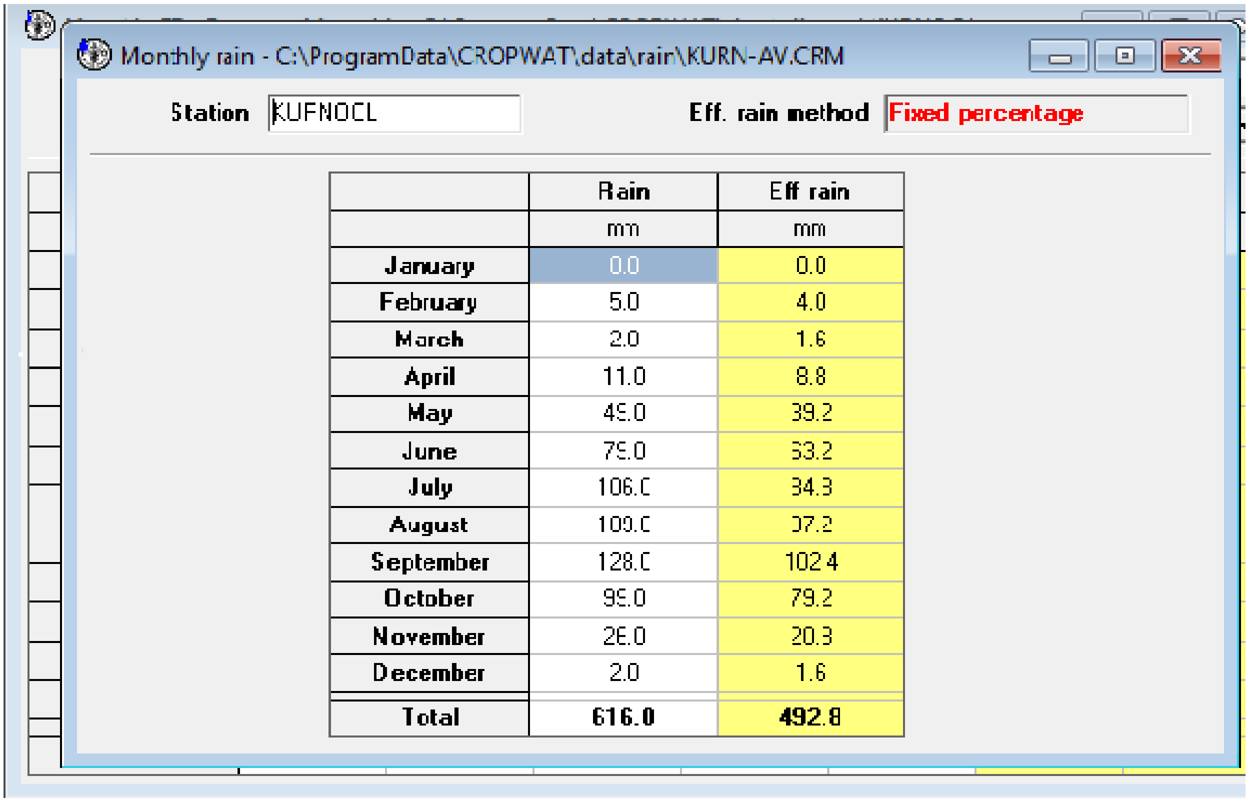


***Figure 5** climate and ET graph Kurnool*



Station KURNOOL

Eff. rain method Fixed percentage

	Rain	Eff rain
	mm	mm
January	0.0	0.0
February	5.0	4.0
March	2.0	1.6
April	11.0	8.8
May	49.0	39.2
June	79.0	63.2
July	106.0	84.8
August	109.0	87.2
September	128.0	102.4
October	99.0	79.2
November	26.0	20.8
December	2.0	1.6
Total	**616.0**	**492.8**

Figure 6 *Rain table kurnool*

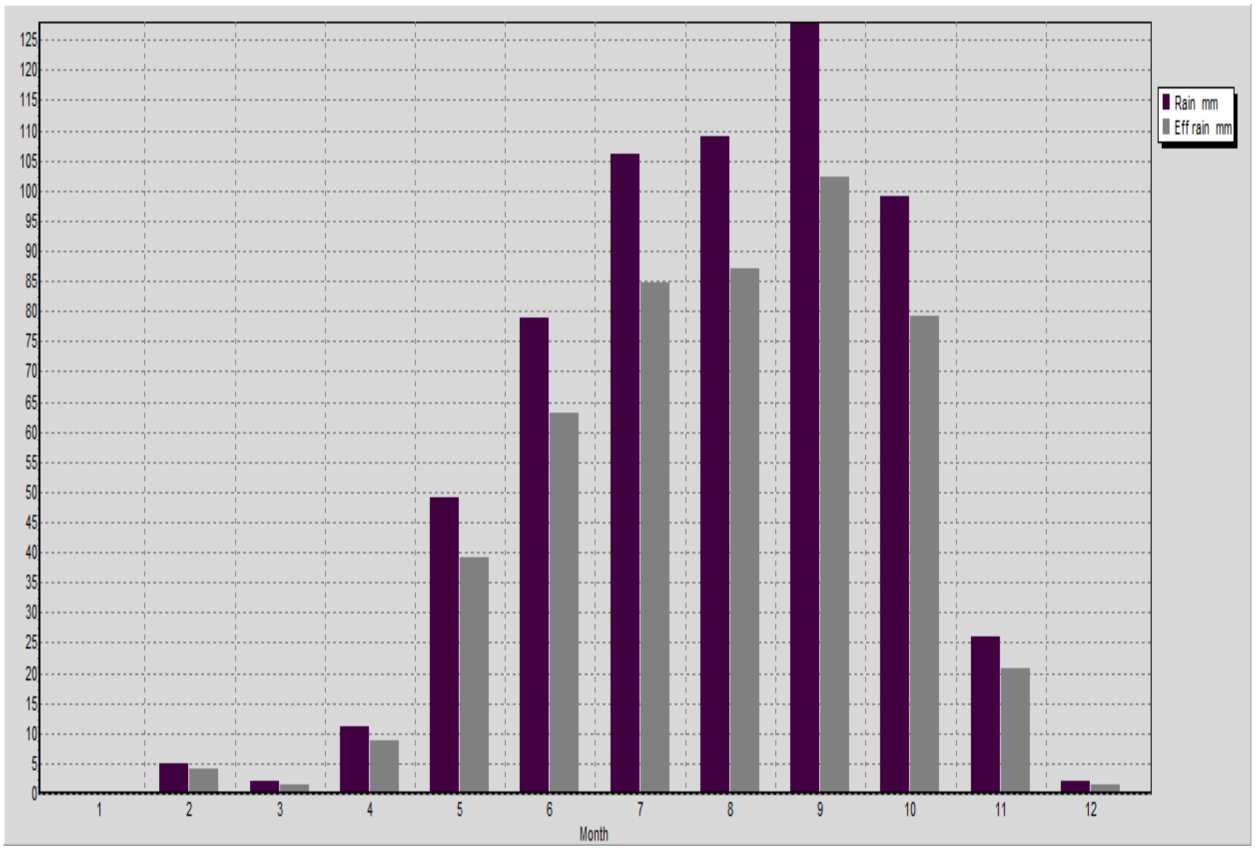
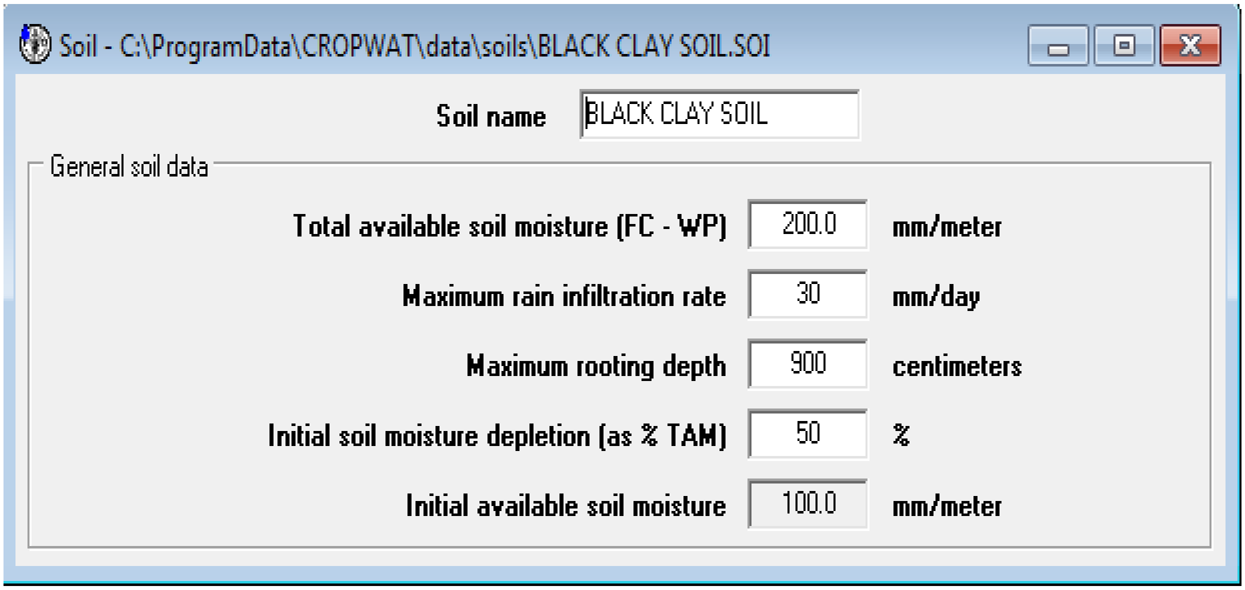


Figure 7 *rain chart kurnool*



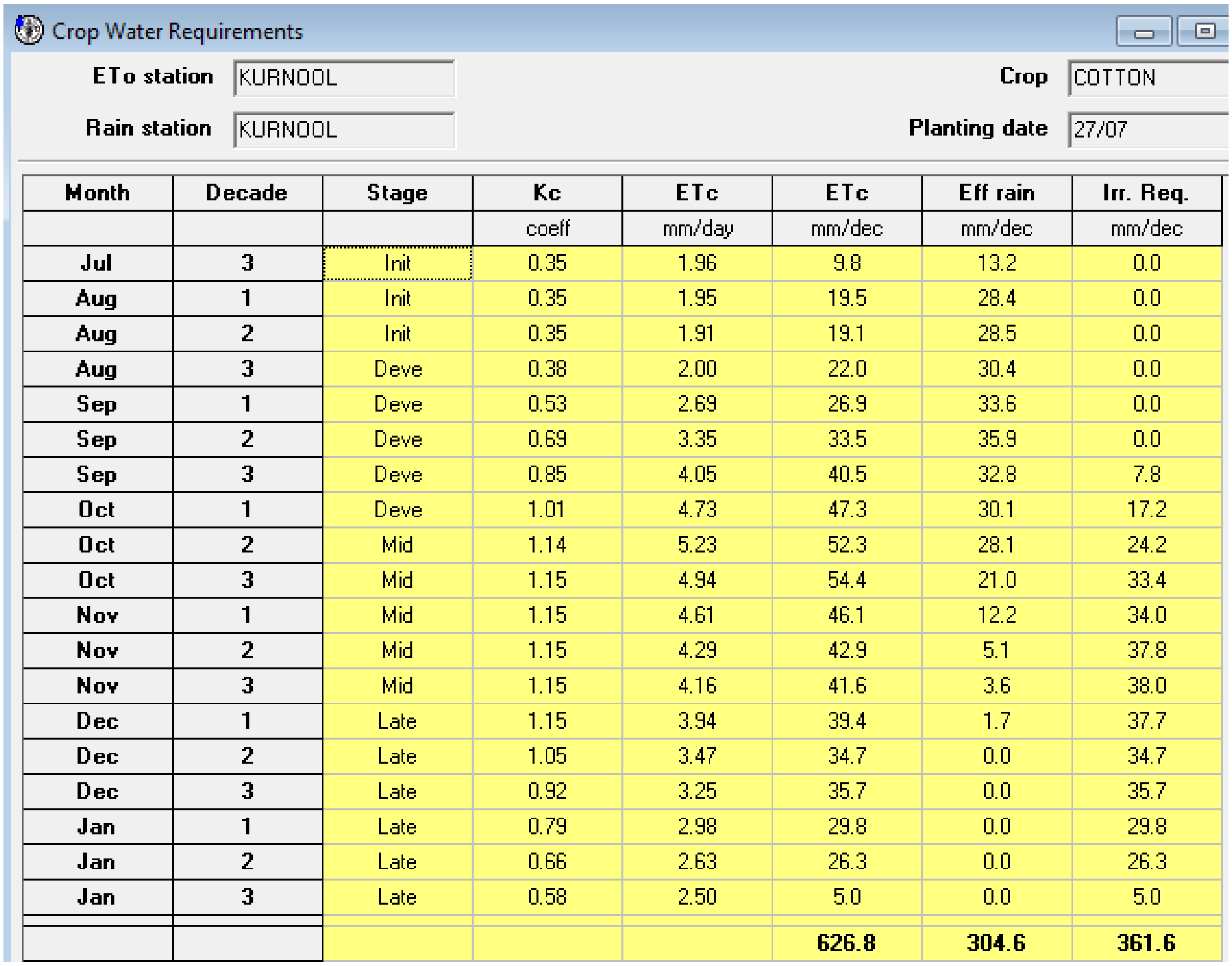
Soil - C:\ProgramData\CROPWAT\data\soils\BLACK CLAY SOIL.SOI

Soil name: BLACK CLAY SOIL

General soil data

Total available soil moisture (FC - WP)	200.0	mm/meter
Maximum rain infiltration rate	30	mm/day
Maximum rooting depth	900	centimeters
Initial soil moisture depletion (as % TAM)	50	%
Initial available soil moisture	100.0	mm/meter

Figure 8 *Soil chart kurnool*



ETo station: KURNOOL

Rain station: KURNOOL

Crop: COTTON

Planting date: 27/07

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	3	Init	0.35	1.96	9.8	13.2	0.0
Aug	1	Init	0.35	1.95	19.5	28.4	0.0
Aug	2	Init	0.35	1.91	19.1	28.5	0.0
Aug	3	Deve	0.38	2.00	22.0	30.4	0.0
Sep	1	Deve	0.53	2.69	26.9	33.6	0.0
Sep	2	Deve	0.69	3.35	33.5	35.9	0.0
Sep	3	Deve	0.85	4.05	40.5	32.8	7.8
Oct	1	Deve	1.01	4.73	47.3	30.1	17.2
Oct	2	Mid	1.14	5.23	52.3	28.1	24.2
Oct	3	Mid	1.15	4.94	54.4	21.0	33.4
Nov	1	Mid	1.15	4.61	46.1	12.2	34.0
Nov	2	Mid	1.15	4.29	42.9	5.1	37.8
Nov	3	Mid	1.15	4.16	41.6	3.6	38.0
Dec	1	Late	1.15	3.94	39.4	1.7	37.7
Dec	2	Late	1.05	3.47	34.7	0.0	34.7
Dec	3	Late	0.92	3.25	35.7	0.0	35.7
Jan	1	Late	0.79	2.98	29.8	0.0	29.8
Jan	2	Late	0.66	2.63	26.3	0.0	26.3
Jan	3	Late	0.58	2.50	5.0	0.0	5.0
					626.8	**304.6**	**361.6**

Figure 9 *CWR table Kurnool*

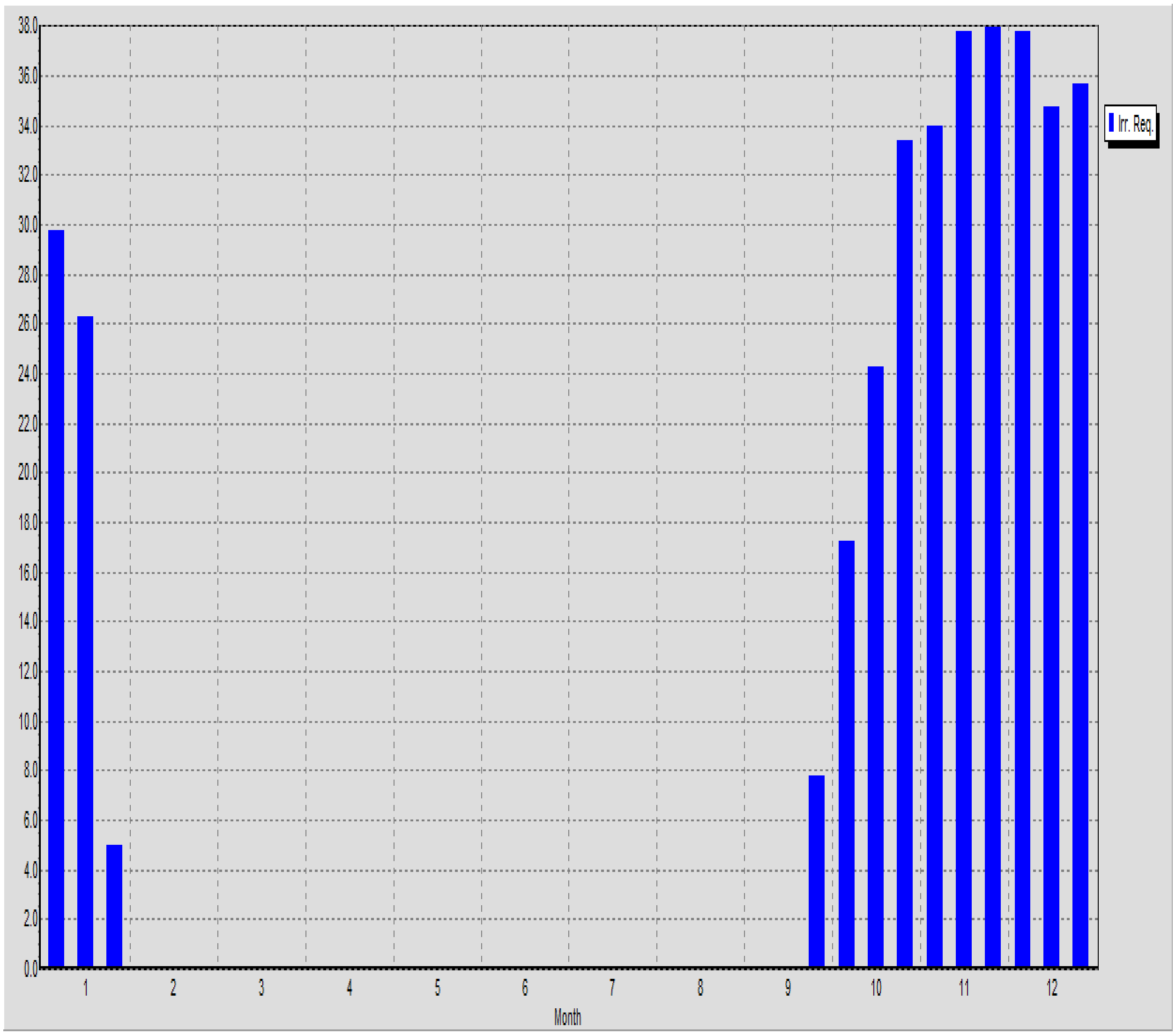
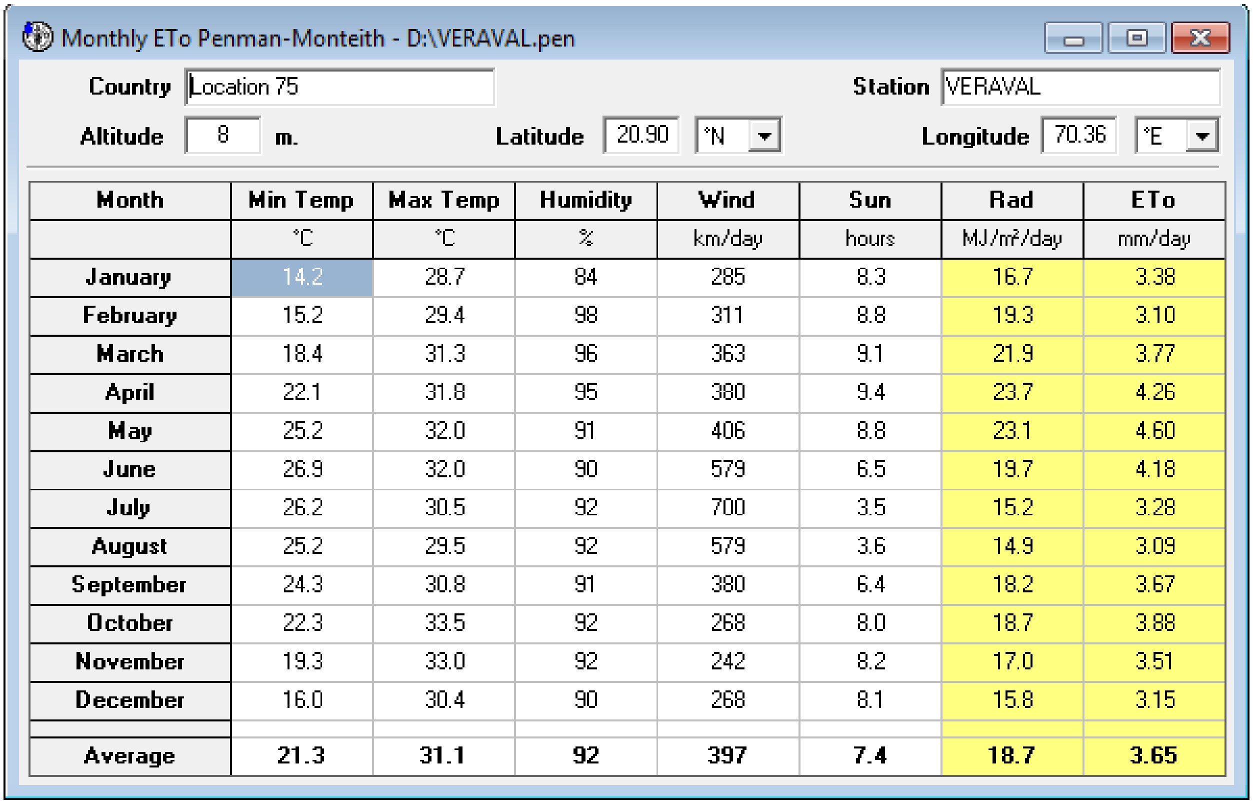


Figure 10 *CWR Graph Kurnool*



Country: Location 75
Station: VERAVAL
Altitude: 8 m.
Latitude: 20.90 °N
Longitude: 70.36 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	14.2	28.7	84	285	8.3	16.7	3.38
February	15.2	29.4	98	311	8.8	19.3	3.10
March	18.4	31.3	96	363	9.1	21.9	3.77
April	22.1	31.8	95	380	9.4	23.7	4.26
May	25.2	32.0	91	406	8.8	23.1	4.60
June	26.9	32.0	90	579	6.5	19.7	4.18
July	26.2	30.5	92	700	3.5	15.2	3.28
August	25.2	29.5	92	579	3.6	14.9	3.09
September	24.3	30.8	91	380	6.4	18.2	3.67
October	22.3	33.5	92	268	8.0	18.7	3.88
November	19.3	33.0	92	242	8.2	17.0	3.51
December	16.0	30.4	90	268	8.1	15.8	3.15
Average	**21.3**	**31.1**	**92**	**397**	**7.4**	**18.7**	**3.65**

Figure 11 *Climate ET chart Veraval*

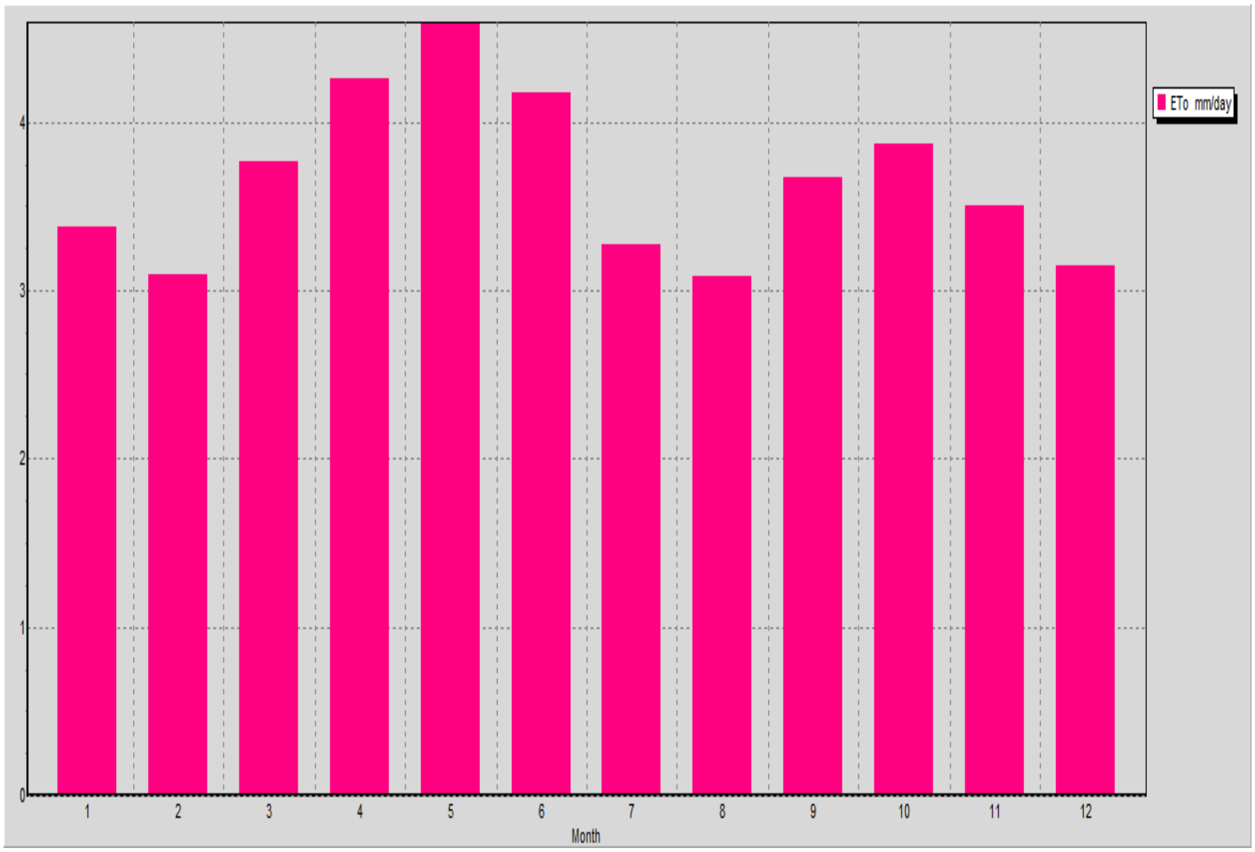
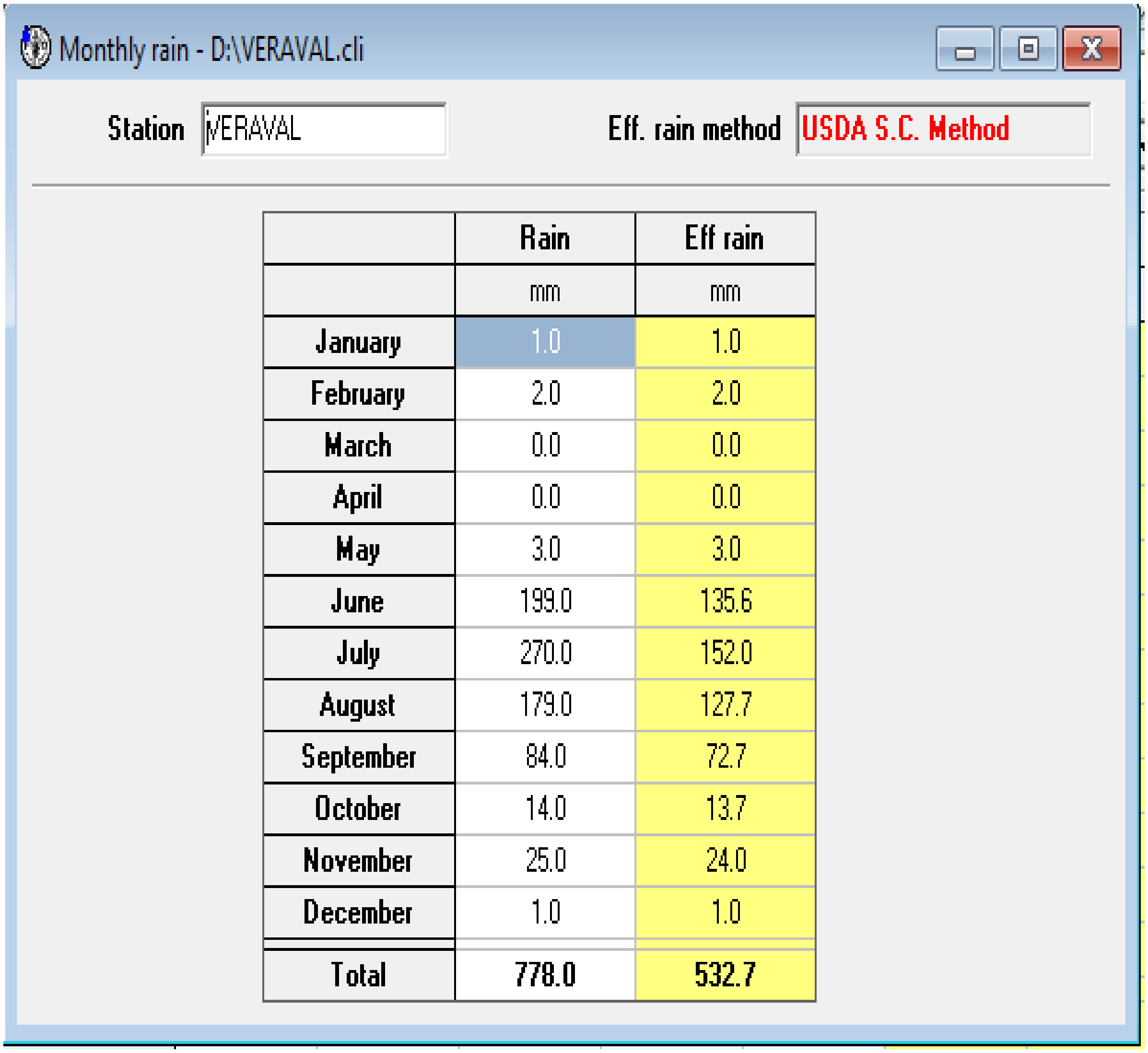


Figure 12 *climate ET graph veraval*

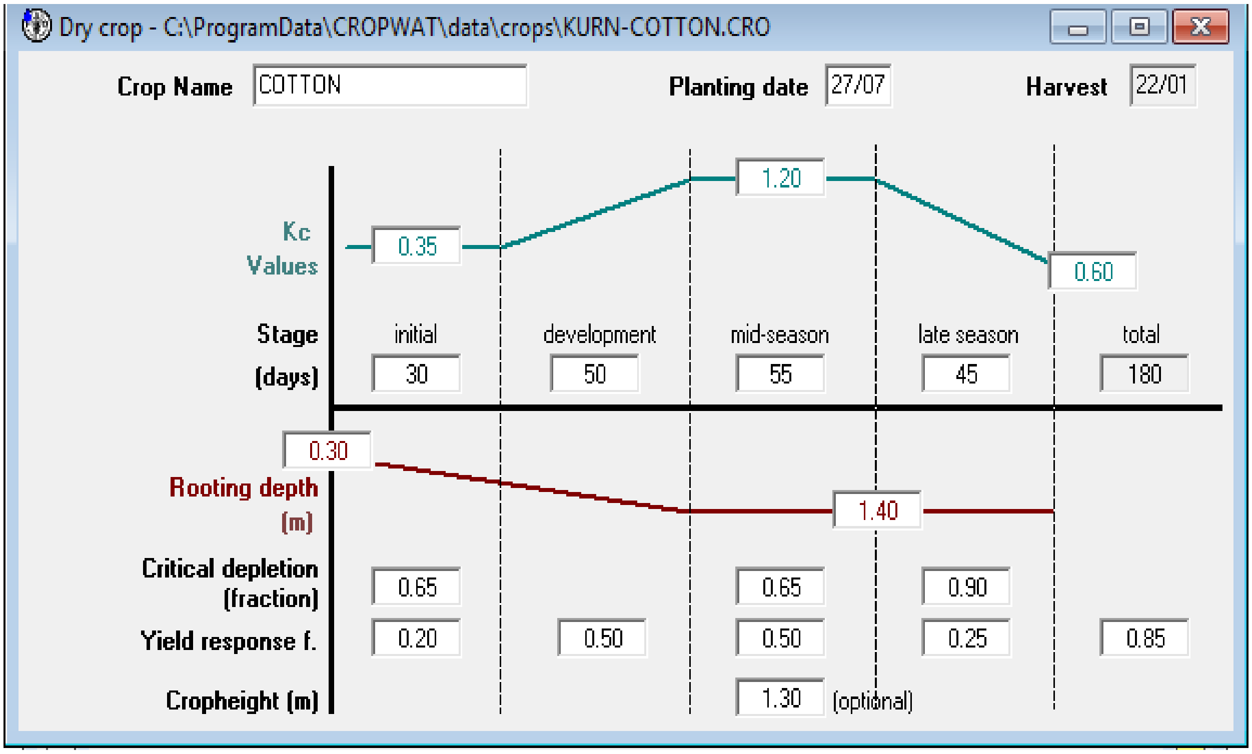


Station VERAVAL

Eff. rain method USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	1.0	1.0
February	2.0	2.0
March	0.0	0.0
April	0.0	0.0
May	3.0	3.0
June	199.0	135.6
July	270.0	152.0
August	179.0	127.7
September	84.0	72.7
October	14.0	13.7
November	25.0	24.0
December	1.0	1.0
Total	**778.0**	**532.7**

Figure 13 *Rain chart veraval*



Crop Name COTTON

Planting date 27/07

Harvest 22/01

Kc Values 0.35 1.20 0.60

Stage (days): initial 30, development 50, mid-season 55, late season 45, total 180

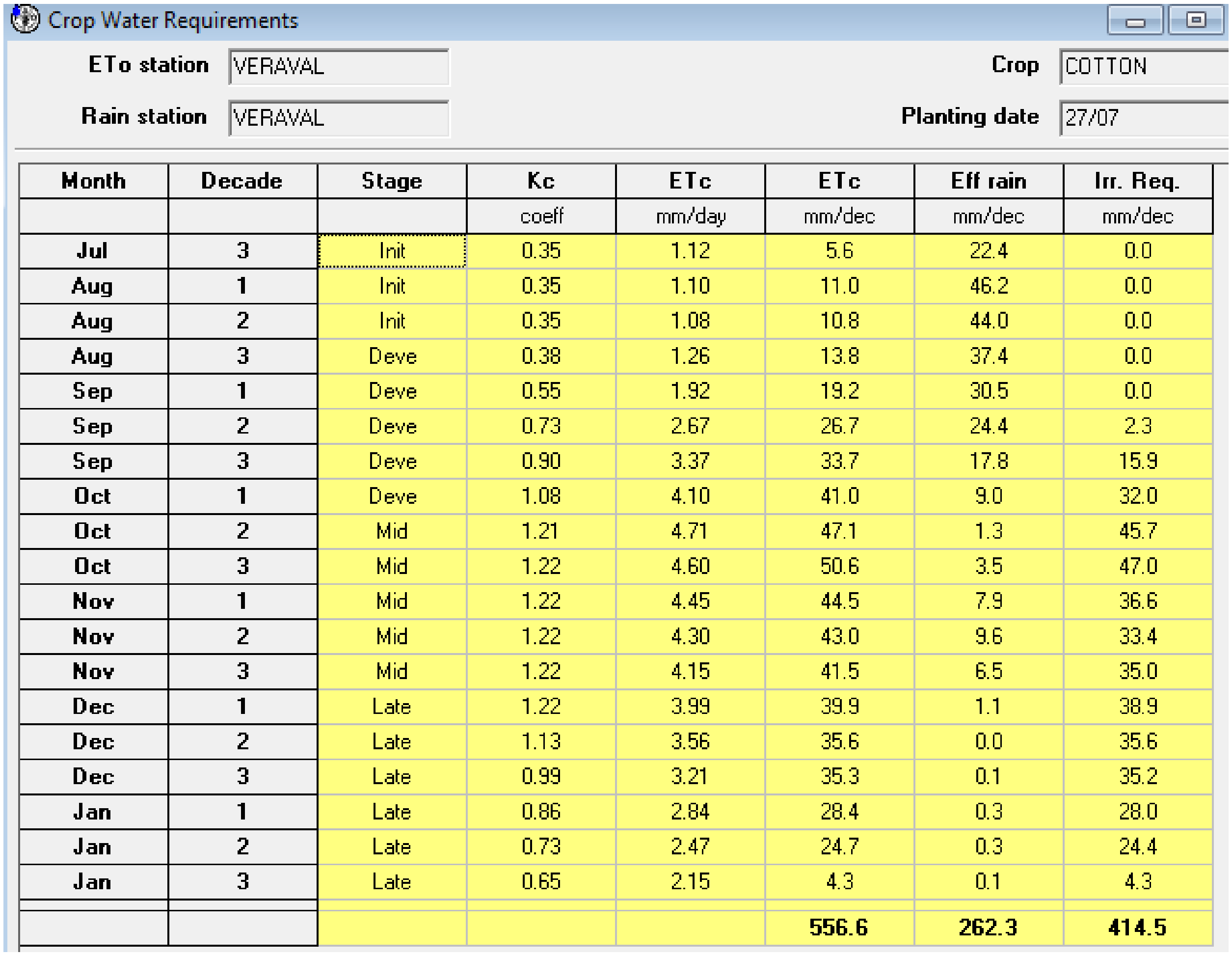
Rooting depth (m) 0.30 1.40

Critical depletion (fraction) 0.65 0.65 0.90

Yield response f. 0.20 0.50 0.50 0.25 0.85

Cropheight (m) 1.30 (optional)

Figure 14 *crop chart veraval*



ETo station VERAVAL

Rain station VERAVAL

Crop COTTON

Planting date 27/07

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	3	Init	0.35	1.12	5.6	22.4	0.0
Aug	1	Init	0.35	1.10	11.0	46.2	0.0
Aug	2	Init	0.35	1.08	10.8	44.0	0.0
Aug	3	Deve	0.38	1.26	13.8	37.4	0.0
Sep	1	Deve	0.55	1.92	19.2	30.5	0.0
Sep	2	Deve	0.73	2.67	26.7	24.4	2.3
Sep	3	Deve	0.90	3.37	33.7	17.8	15.9
Oct	1	Deve	1.08	4.10	41.0	9.0	32.0
Oct	2	Mid	1.21	4.71	47.1	1.3	45.7
Oct	3	Mid	1.22	4.60	50.6	3.5	47.0
Nov	1	Mid	1.22	4.45	44.5	7.9	36.6
Nov	2	Mid	1.22	4.30	43.0	9.6	33.4
Nov	3	Mid	1.22	4.15	41.5	6.5	35.0
Dec	1	Late	1.22	3.99	39.9	1.1	38.9
Dec	2	Late	1.13	3.56	35.6	0.0	35.6
Dec	3	Late	0.99	3.21	35.3	0.1	35.2
Jan	1	Late	0.86	2.84	28.4	0.3	28.0
Jan	2	Late	0.73	2.47	24.7	0.3	24.4
Jan	3	Late	0.65	2.15	4.3	0.1	4.3
					556.6	**262.3**	**414.5**

Figure 15 *CWR chart veraval*

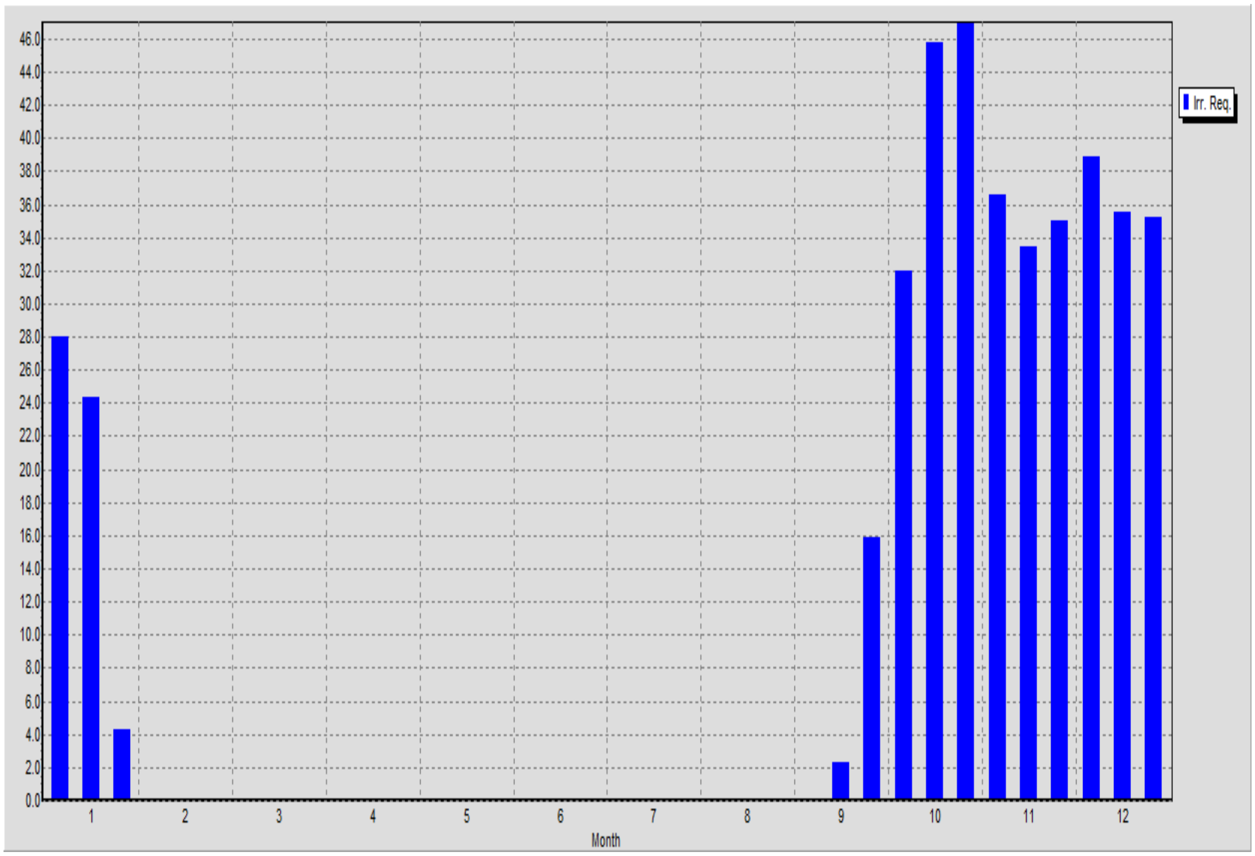
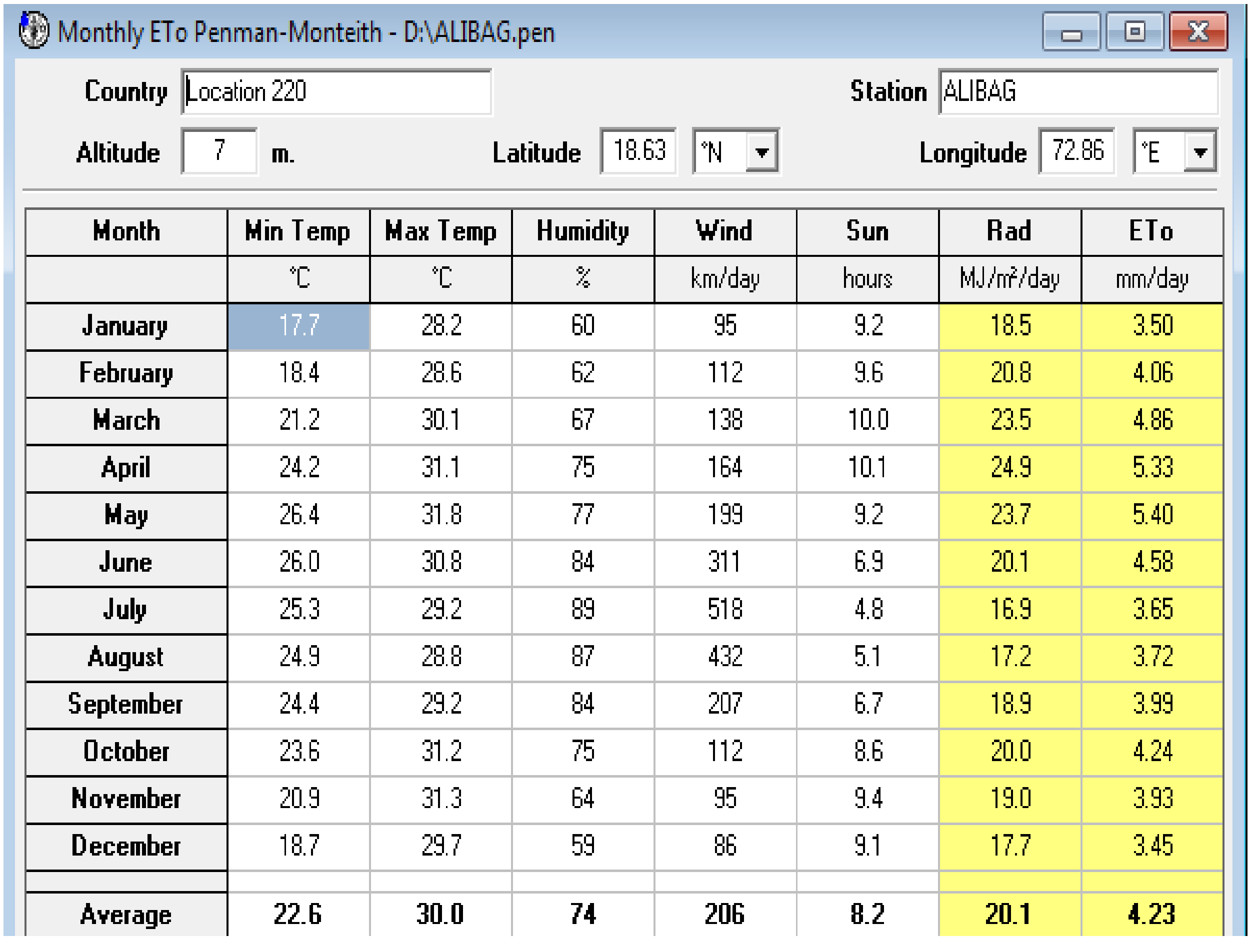


Figure 16 *CWR graph veraval*



Country: Location 220

Station: ALIBAG

Altitude: 7 m.

Latitude: 18.63 °N

Longitude: 72.86 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	17.7	28.2	60	95	9.2	18.5	3.50
February	18.4	28.6	62	112	9.6	20.8	4.06
March	21.2	30.1	67	138	10.0	23.5	4.86
April	24.2	31.1	75	164	10.1	24.9	5.33
May	26.4	31.8	77	199	9.2	23.7	5.40
June	26.0	30.8	84	311	6.9	20.1	4.58
July	25.3	29.2	89	518	4.8	16.9	3.65
August	24.9	28.8	87	432	5.1	17.2	3.72
September	24.4	29.2	84	207	6.7	18.9	3.99
October	23.6	31.2	75	112	8.6	20.0	4.24
November	20.9	31.3	64	95	9.4	19.0	3.93
December	18.7	29.7	59	86	9.1	17.7	3.45
Average	**22.6**	**30.0**	**74**	**206**	**8.2**	**20.1**	**4.23**

Figure 17 *Alibag climate and ET CHART*

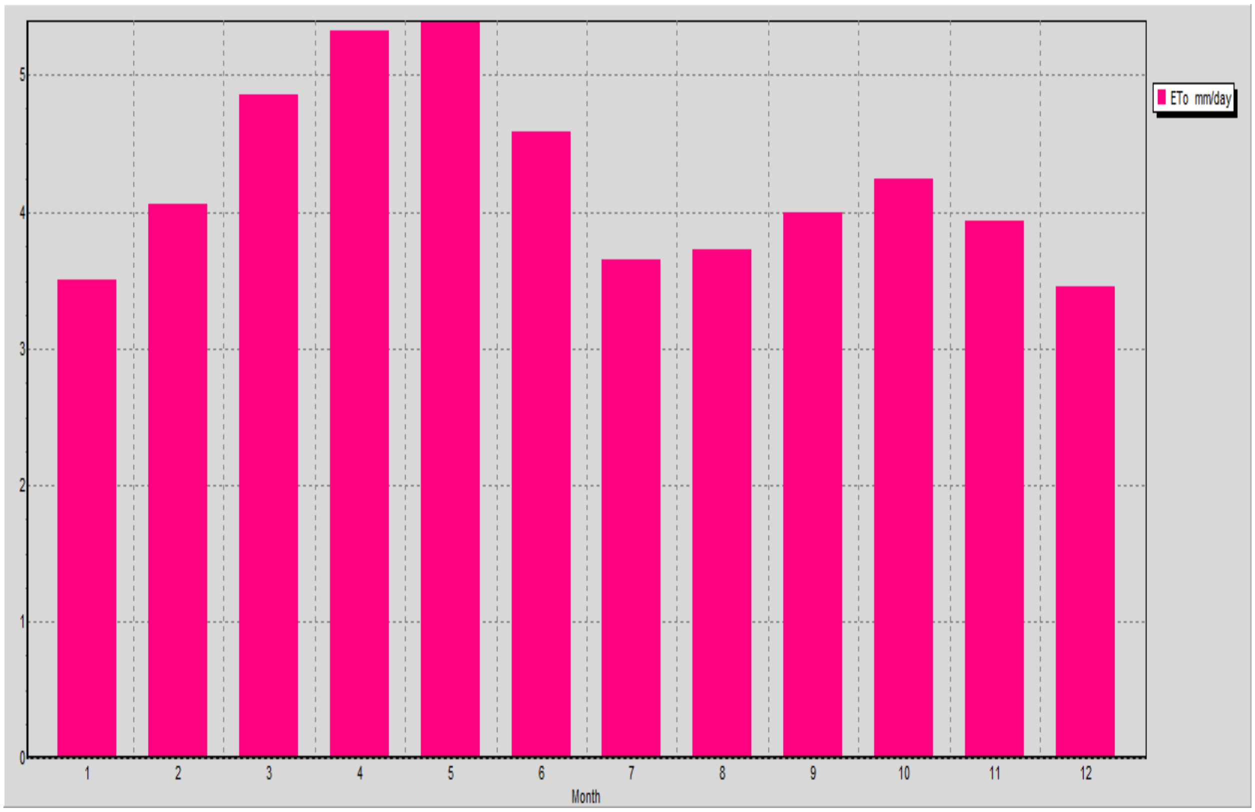
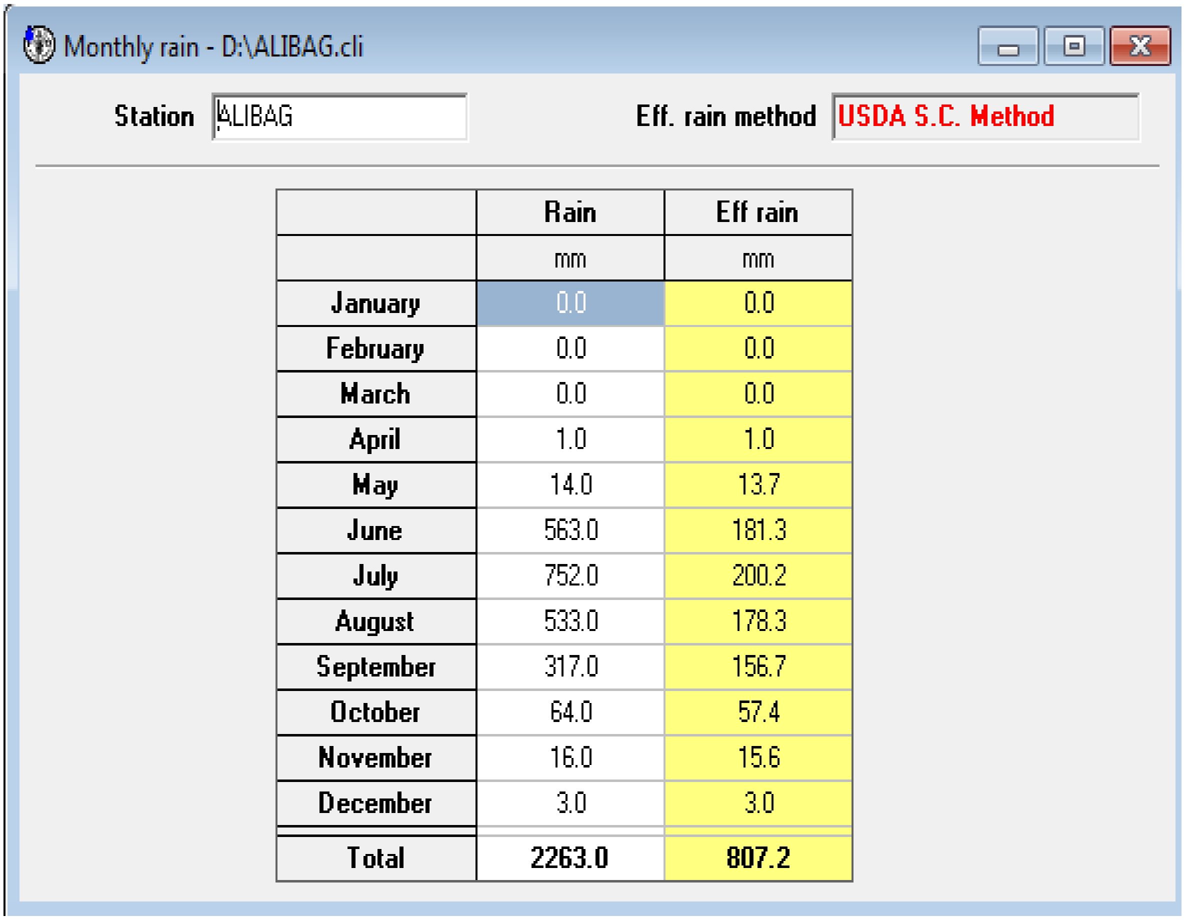


***Figure 18** Alibag Climate and et graph*



Station: ALIBAG

Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	0.0	0.0
February	0.0	0.0
March	0.0	0.0
April	1.0	1.0
May	14.0	13.7
June	563.0	181.3
July	752.0	200.2
August	533.0	178.3
September	317.0	156.7
October	64.0	57.4
November	16.0	15.6
December	3.0	3.0
Total	**2263.0**	**807.2**

Figure 19 *Alibag rain chart*

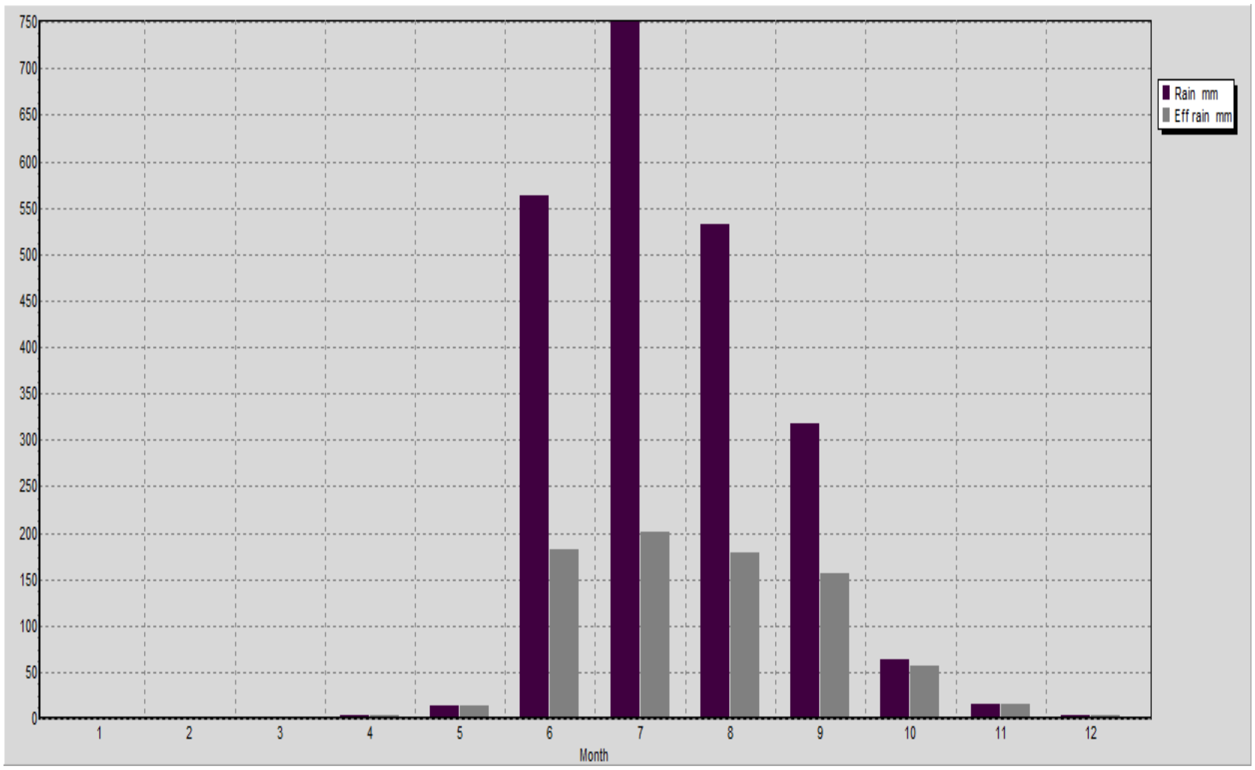
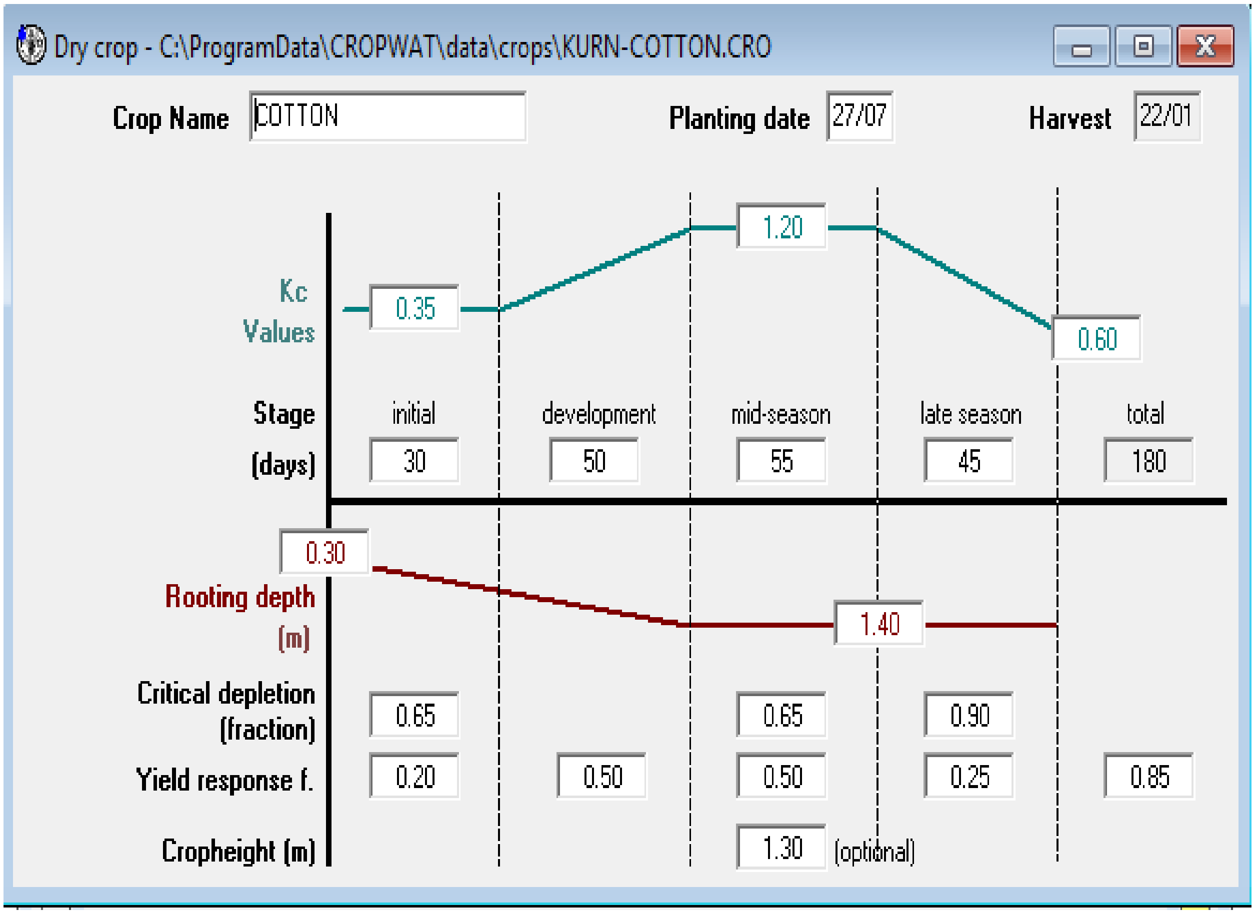


Figure 20 *Alibag rain graph*


Dry crop - C:\ProgramData\CROPWAT\data\crops\KURN-COTTON.CRO

Crop Name COTTON

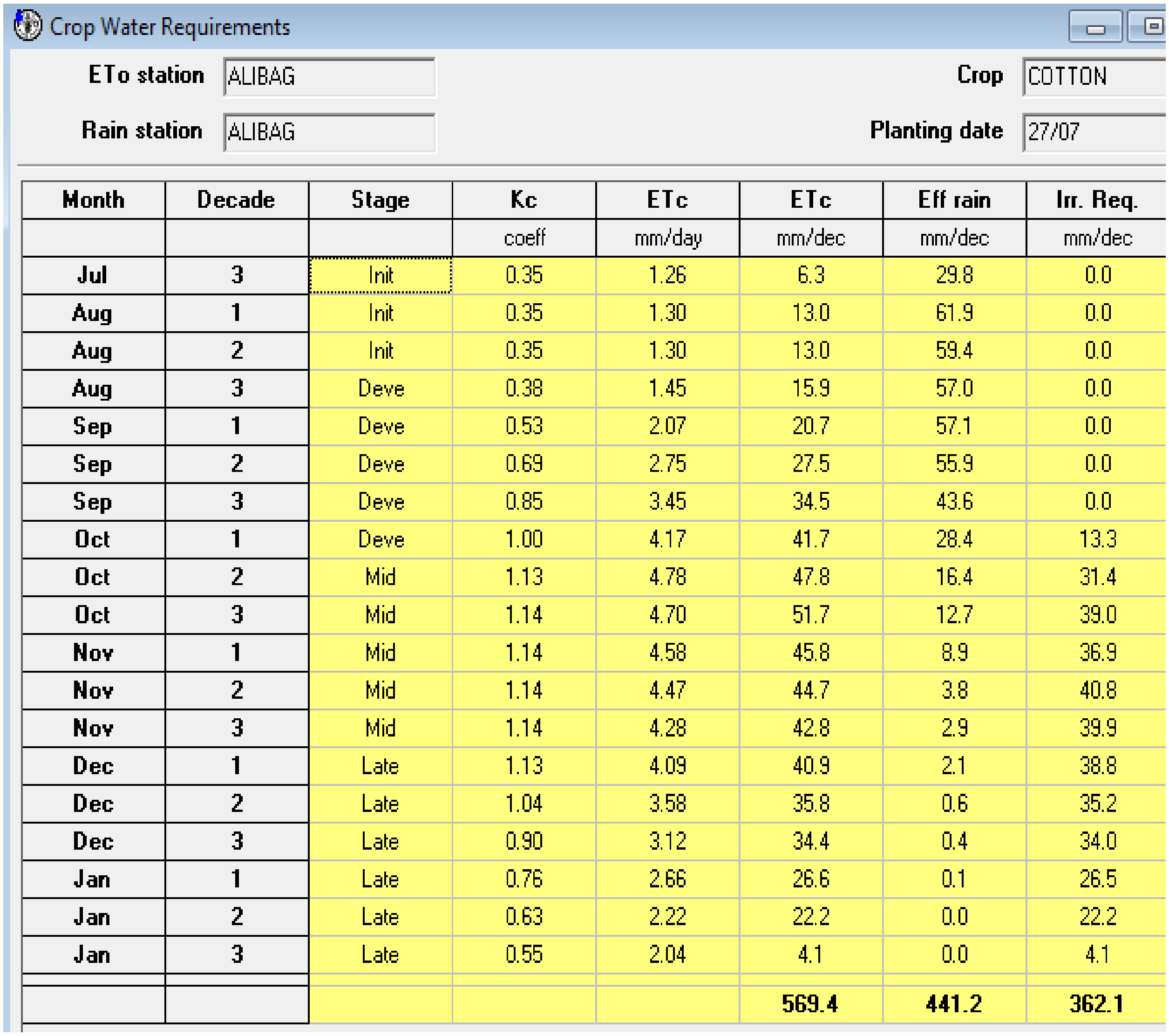
Planting date 27/07

Harvest 22/01

	initial	development	mid-season	late season	total
Kc Values	0.35		1.20		0.60
Stage (days)	30	50	55	45	180
Rooting depth (m)	0.30		1.40		
Critical depletion (fraction)	0.65		0.65	0.90	
Yield response f.	0.20	0.50	0.50	0.25	0.85
Cropheight (m)			1.30		

(optional)

Figure 21 *Alibag crop*



ETo station: ALIBAG

Crop: COTTON

Rain station: ALIBAG

Planting date: 27/07

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	3	Init	0.35	1.26	6.3	29.8	0.0
Aug	1	Init	0.35	1.30	13.0	61.9	0.0
Aug	2	Init	0.35	1.30	13.0	59.4	0.0
Aug	3	Deve	0.38	1.45	15.9	57.0	0.0
Sep	1	Deve	0.53	2.07	20.7	57.1	0.0
Sep	2	Deve	0.69	2.75	27.5	55.9	0.0
Sep	3	Deve	0.85	3.45	34.5	43.6	0.0
Oct	1	Deve	1.00	4.17	41.7	28.4	13.3
Oct	2	Mid	1.13	4.78	47.8	16.4	31.4
Oct	3	Mid	1.14	4.70	51.7	12.7	39.0
Nov	1	Mid	1.14	4.58	45.8	8.9	36.9
Nov	2	Mid	1.14	4.47	44.7	3.8	40.8
Nov	3	Mid	1.14	4.28	42.8	2.9	39.9
Dec	1	Late	1.13	4.09	40.9	2.1	38.8
Dec	2	Late	1.04	3.58	35.8	0.6	35.2
Dec	3	Late	0.90	3.12	34.4	0.4	34.0
Jan	1	Late	0.76	2.66	26.6	0.1	26.5
Jan	2	Late	0.63	2.22	22.2	0.0	22.2
Jan	3	Late	0.55	2.04	4.1	0.0	4.1
					569.4	**441.2**	**362.1**

Figure 22 *Alibag CWR*

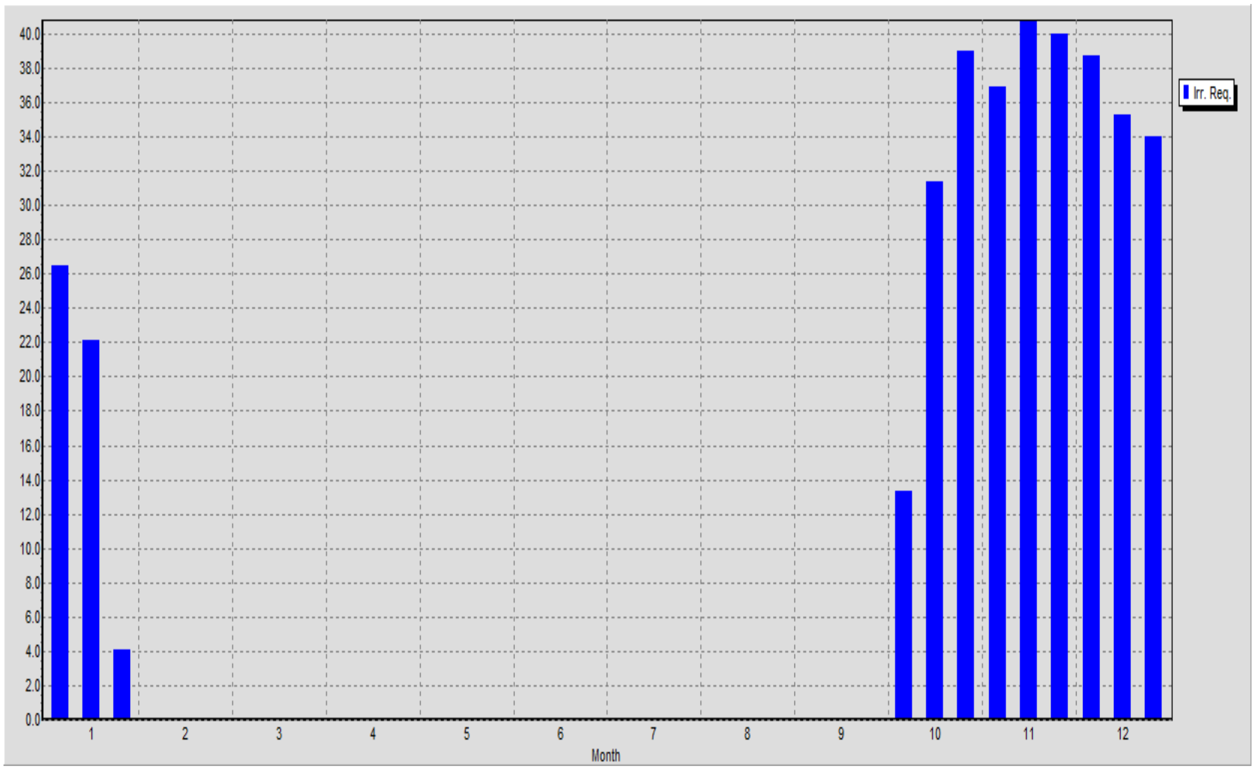


Figure 23 Alibag *CWR chart*

CHAPTER SIX

6. Conclusions

3 things are mainly observed those are

1- Evapotranspiraion per day and mean and maximum Evapotranspiraion
2- Effective rainfall and maximum effective rainfall
3- Maximum irrigation requirement

1-Kurnool

Minimum evapotranspirtion = 3.40 mm/day in the month of December

Maximum evapotranspirtion = 7.93 mm/day in the month of may

In our irrigation period maximum evapotranspiration = 5.74 mm/day

Total effective rain = 492.8 mm

Highest September = 102.4 mm

Minimum Total effective rain = 1.6 mm December

Irrigation requirement maximum = 38 mm/10 day November

Total irrigation requirement = 361.6 mm/10 day

2- Veraval

Minimum evapotranspirtion = 3.09 mm/day in the month of August

Maximum evapotranspirtion = 4.6 mm/day in the month of may

In our irrigation period maximum evapotranspiration = 3.88 mm/day

Total effective rain = 532.7mm

Highest total effective rain = 152mm July

Minimum total effective rain = 1.6 mm December

Irrigation requirement maximum= 38 mm/10 day

Total irrigation requirement = 361.6 mm/10 day

3-Alibag

Minimum evapotranspirtion = 3.40 mm/day in the month of December

Maximum evapotranspirtion = 7.93 mm/day in the month of may

In our irrigation period maximum evapotranspiration = 5.74 mm/day

Total effective rain = 492.8 mm

Highest September = 102.4 mm

Minimum Total effective rain = 1.6 mm December

Irrigation requirement maximum = 38 mm/10 day November

Total irrigation requirement = 361.6 mm/10 day

Based on these results maximum irrigation requirement for Veraval is highest among our 3 selected stations and For Kurnool it is minimum total effective rain for Alibag is maximum but despite that its irrigation requirement is larger then Kurnool because of the fact it lies beside sea coast and humidity there is maximum so based on our results best possible site for growing cotton crop is Kurnool.

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