Chapter 1

INTRODUCTION

Irrigation scheduling is the process used by irrigation system managers to determine the correct frequency and duration of watering. The goal of irrigation scheduling is to apply enough water to fully wet the plant's root zone as well as minimizing overwatering. In recent years, more sophisticated irrigation controllers have been developed that receive evapotranspiration (ET) input from either a single on-site weather station or from a network of stations and automatically adjust the irrigation schedule accordingly.

1.1 Importance of Irrigation Scheduling

Some irrigation water is stored in the soil to be removed by crops and some is lost by evaporation, runoff, or seepage. The amount of water lost through these processes is affected by irrigation system design and irrigation management. Prudent scheduling minimizes runoff and percolation losses, which in turn usually maximizes irrigation efficiency by reducing energy and water use. (Of course, in situations where not enough water was being applied, proper irrigation scheduling will increase energy and water use.)

You can save energy by no longer pumping water that was previously being wasted. When water supplies and irrigation equipment are adequate, irrigators tend to overirrigate, believing that applying more water will increase crop yields. Instead, overirrigation can reduce yields because the excess soil moisture often results in plant disease, nutrient leaching, and reduced pesticide effectiveness. In addition, water and energy are wasted.

The quantity of water pumped can often be reduced without reducing yield. Studies have shown that irrigation scheduling using water balance methods (to be discussed later) can save 15 to 35 percent of the water normally pumped without reducing yield. Maximum yield usually does not equate to maximum profit. The optimum economic yield is less than the maximum potential yield. Irrigation scheduling tips presented in popular farm magazines too often aim at achieving maximum yield with too little emphasis on water and energy use efficiencies. An optimum irrigation schedule maximizes profit and optimizes water and energy use.

Irrigation scheduling requires knowledge of:

- Soil
- Soil-Water Status
- Crops
- Status of Crop Stress
- Potential Yield Reduction(if the crop remains in a stressed condition)

Irrigation scheduling offers several advantages:

- It enables the farmer to schedule water rotation among the various fields to minimize crop water stress and maximize yields.
- It reduces the farmer's cost of water and labor through fewer irrigations, thereby making maximum use of soil moisture storage.
- It lowers fertilizer costs by holding surface runoff and deep percolation to a minimum.
- It increases net returns by increasing crop yields and crop quality.
- It minimizes water-logging problems by reducing the drainage requirements.
- It assists in controlling root zone salinity problems through controlled leaching.
- It results in additional returns by using the "saved" water to irrigate non-cash Crops that otherwise would not be irrigated during water-short periods.

Keeping the above mentioned facts and information in view, the present study and project is taken up with the following objectives and utility.

1.2 Objectives

(1) To develop an android application for irrigation scheduling.
(2) To test the developed application for irrigation scheduling.

1.3 Utility of the Project

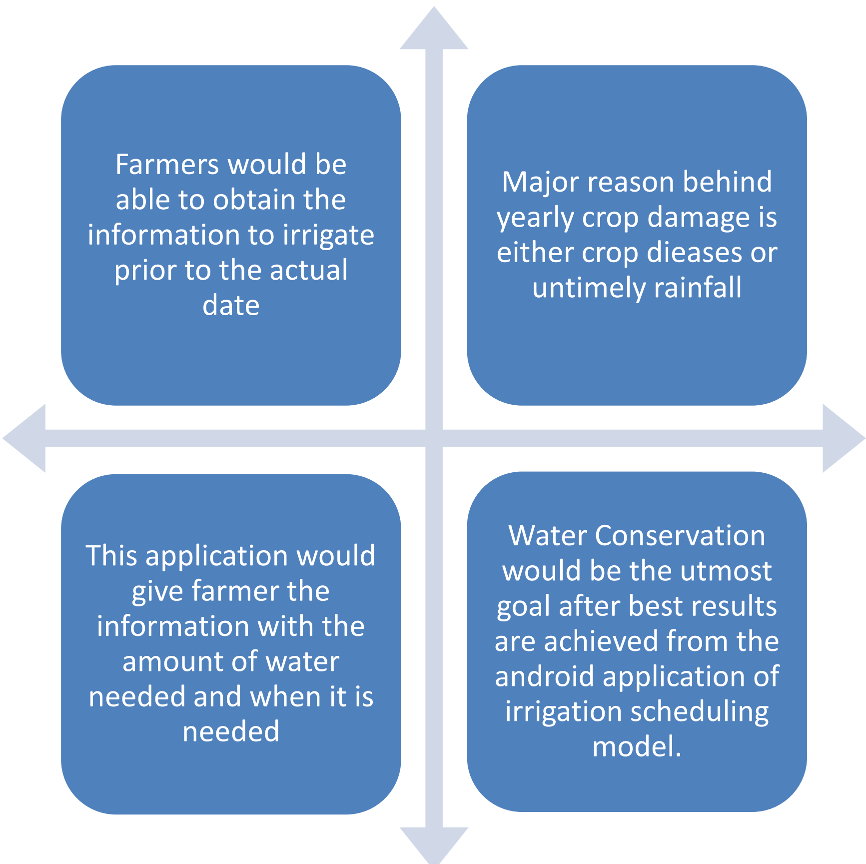


Fig 1.1 Utility of the Project

Chapter 2

REVIEW OF LITERATURE

This Chapter deals with review of literature on various irrigation scheduling techniques based on soil water measurement, weather data and water balance approach.

Irrigation scheduling is the process of answering two basic questions. Firstly, the need to irrigate the field and secondly, the volume of water to be applied.

2.1 Measuring Soil-Water

There are many methods or devices available for measuring soil water. These include the feel method, gravitational method, tensiometers, electrical resistance blocks, neutron probe, and time domain reflectometer. These methods differ in reliability, cost, and labor intensity. Tensiometers are best suited for sandy, sandy loam, and loamy soil textures, while electrical resistance blocks work best in silt or clayey soils. For best results, all soil-water measuring devices should be calibrated for the major soils in each field being irrigated.

Evans et al.(1996) stated about shallow tensiometers to determine when to irrigate, but irrigation must be started sooner so that the last portion to be irrigated does not become too dry. Deeper tensiometers should be located near the midpoint of the travel cycle. They should be monitored as the system passes to determine whether the proper amount of water is being applied. If no change in the tensiometer reading is observed as the system passes, too little water is being applied and the travel speed should be reduced. Likewise, if the tensiometer reading decreases before the system is 90 percent past the tensiometer, too much water is being applied and the travel speed should be increased. With mechanical-move systems, soil-water measurements are used in conjunction with the checkbook approach to schedule irrigation properly and account for the additional soil-water depletion that will occur while the system travels.

Evans et al. (1996) put forward the need of irrigation scheduling along with its need for efficient water and energy use for irrigation where they emphasized on relationship between soil water and plant stress. Irrigation should begin when the crop comes under water stress severe enough to reduce crop yield or quality. The level of stress that will cause a reduction in crop yield or quality depends on the kind of crop and its stage of development; the level varies during the growing season as the crop matures. Thus, determining when to irrigate is a scheduling decision that should take into account the crop's sensitivity to stress.

Use of Meteorological Data

Allen et al. (1998) compiled the efforts put in irrigation scheduling and thereby, presenting an updated procedure for calculating reference and crop evapotranspiration from meteorological data and crop coefficients. The effect of the climate on crop water requirements is given by reference evapotranspiration ETo while the effect of crop is given by crop coefficient Kc. For the estimation of ETo many methodologies came forward which were FAO Penman method and Blaney-Criddle method but these methods overestimated the value of ETo. The use of meteorological data to evaluate ETo led to the discovery of two important methods which were Penman-Monteith method and Hargreaves method which formed the basis to estimate the reference evapotranspiration.

Table 2.1 Compare different methods of irrigation scheduling by monitoring soil moisture content or tension. The methods described in the table measure or estimate the irrigation criterion (Source: Broner et al., 2005)

Method	Measured parameter	Equipment needed	Irrigation criterion	Advantages	Disadvantages
Hand feel and appearance of soil.	Soil moisture content by feel.	Hand probe.	Soil moisture content.	Easy to use; simple; can improve accuracy with experience.	Low accuracies; field work involved to take samples.
Gravimetric soil moisture sample.	Soil moisture content by taking samples.	Auger, caps, oven.	Soil moisture content.	High accuracy.	Labor intensive including field work; time gap between sampling and results.
Tensiometers	Soil moisture tension.	Tensiometers including vacuum gauge.	Soil moisture tension.	Good accuracy; instantaneous reading of soil moisture tension.	Labor to read; needs maintenance; breaks at tensions above 0.7 atm.
Electrical resistance blocks	Electric resistance of soil moisture.	Resistance blocks AC bridge (meter).	Soil moisture tension.	Instantaneous reading; works over larger range of tensions; can be used for remote reading.	Affected by soil salinity; not sensitive at low tensions; needs some maintenance and field reading.
Water budget approach.	Climatic parameters: temperature, radiation, wind, humidity and expected rainfall, depending on model used to predict ET.	Weather station or available weather information.	Estimation of moisture content.	No field work required; flexible; can forecast irrigation needs in the future; with same equipment can schedule many fields.	Needs calibration and periodic adjustments, since it is only an estimate; calculations cumbersome without computer.
Modified atmometer	Reference ET.	Atmometer gauge.	Estimate of moisture content.	Easy to use, direct reading of reference ET.	Needs calibration; it is only an estimation.

2.2 Developed Software on Irrigation Scheduling

Over the years many mathematical models have been developed in the field of irrigation scheduling design and management. Only few of the developed ones are user friendly and working without any glitch. Some of the early software packages and applications developed include CROPWAT, Irrigation Scheduling Model (ISM), InSite, Irris Scheduler and Smart Irrigation Applications.

CROPWAT is a decision support tool developed by the Land and Water Development Division of FAO. CROPWAT 8.0 for Windows is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. CROPWAT 8.0 can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rainfed and irrigated conditions. It is based on FAO Penman-Monteith Combination method as result it requires more information like humidity, sunshine hours, altitude, etc as input which is difficult for the farmers to enter. CROPWAT has all the advantages but the disadvantages being it calculates monthly data for evapotranspiration. Secondly, the complexity of the output for the farmers or farming agents and it doesn't suffice them with the notification for the need of irrigation along with duration.

George et al. (2000) developed **Irrigation Scheduling Model (ISM)** comprising of a database management system (DBMS), model base and graphical user interface (GUI) which could be used for irrigation scheduling for both single and multiple fields. The ISM used climatological, crop and soil data to estimate evapotranspiration (ETo) by giving options to choose methods for its calculation depending on the availability of climatological data. The ISM based on soil water balance approach also allows user to give options for calculating the root depth, crop stress factor and effective rainfall. The output displayed by ISM consists of the details of irrigation schedules and daily soil water balance.

InSite is a water manager tool to generate accurate irrigation schedules. InSite provides a printout of the schedule including watering days, program start times and station run times. Use it to program the controller. Schedules are saved on your computer for future reference.

InSite is a computer software, where the output obtained are in graphical formats from which information could be deduced by doing further calculations. Therefore, as a result output cannot be comprehended by normal farmers without any help.

Irris Scheduler estimates irrigation water needs for corn, soybean, established alfalfa, dry bean, potato and other crops, as well as soil nitrogen losses and availability. It was developed by the Purdue University Department of Agronomy as an easy-to-use tool to assist crop producers with irrigation scheduling and nitrogen application decisions. The model is based on the workflow based on “FAO Irrigation and Drainage Paper No. 56: Crop Evapotranspiration”. Again, it follows the same drawback like that of InSite that is being a computer application and providing charts of soil moisture, weather, evapotranspiration and soil nitrogen in Excel sheets.

Smart Irrigation Applications project focuses on the development of smartphone apps for citrus, cotton, strawberry, and urban lawn. These free apps provide real-time and forecasted information that can be used for more efficient irrigation and water conservation. Apps are currently being tested in experimental plot studies throughout Florida and Georgia. The application runs on android smartphones and have good scope being portable and provides output which could be easily comprehended. Only drawback being that they are still focusing on Florida and Georgia and haven’t considered uneducated farmers in Asia and Africa for whom the implementation of the application will require much simplified outputs for their easy understanding.

Chapter 3

DATA AND METHODOLOGY

One of the most commonly used methods for irrigation scheduling is water balance approach. This Chapter deals with the description of water balance method for irrigation scheduling along with methodology for developing android based irrigation scheduling application.

3.1 Irrigation Scheduling: The Water Balance Approach

Basic facts regarding the water balance approach are:

- The water balance approach to irrigation scheduling keeps track of the soil water deficit by accounting for all water additions and subtractions from the soil root zone.
- Crop water consumption or crop evapotranspiration accounts for the biggest subtraction of water from the root zone while precipitation and irrigation provide the major additions.
- Crop evapotranspiration can be calculated from the data provided by the weather stations and crop coefficients.
- The soil in the root zone has an upper as well as a lower limit of storing water that can be used by crops.
- As the crop grows and extracts water from the soil to satisfy its ETc requirement, the stored soil water is gradually depleted.

The water requirement of a crop must be satisfied to achieve potential yields. The crop water requirement is also called crop evapotranspiration and is usually represented as ETc. Evapotranspiration is a combination of two processes – evaporation of water from the ground surface or wet surfaces of plants; and transpiration of water through the stomata of leaves. The water requirement can be supplied by stored soil water, precipitation, and irrigation. Irrigation is required when ETc (crop water demand) exceeds the supply of water from soil water and precipitation.

As ETc varies with plant development stage and weather conditions, both the amount and timing of irrigation are important. The water balance (accounting) method of irrigation scheduling is one method of estimating the required amount and timing of irrigation for crops. This method can be used if initial soil water content in the root zone, ETc, precipitation, and the available water capacity of the soil are known.

The soil in the root zone has an upper as well as a lower limit of storing water that can be used by crops. The upper limit is called the field capacity (FC), which is the amount of water that can be held by the soil against gravity after being saturated and drained; typically attained after 1 day of rain or irrigation for sandy soils and from two to three days for heavier-textured soils that contain more silt and clay. The lower limit is called permanent wilting point (PWP), which is the amount of water remaining in the soil when the plant permanently wilts because it can no longer extract water.

The available water capacity (AWC), or total available water, of the soil is the amount of water between these two limits (AWC = FC - PWP) and is the maximum amount of soil water that can be used by the plants. The AWC of soil is typically expressed in terms of cm of water per cm of soil depth.

MAD (maximum allowable depth) is the maximum depth by upto which moisture content is allowed to fall after which irrigation is done.

General values of AWC are provided in Table 3.1 below.

Table 3.1 AWC of different soil texture (Source: Andales et al.,2011)

Soil Texture	Available Water Capacity		
	Low	**High**	**Average**
	cm of water/cm of soil		
Coarse sands	0.05	0.07	0.06
Fine sands	0.07	0.08	0.08
Loamy sands	0.07	0.08	0.08
Sandy loams	0.10	0.13	0.12
Fine sandy loams	0.13	0.17	0.15
Sandy clay loams	0.13	0.18	0.16
Loams	0.18	0.21	0.20
Silt loams	0.17	0.21	0.19
Silty clay loams	0.13	0.17	0.15
Clay loams	0.13	0.17	0.15
Silty Clay	0.13	0.14	0.13
Clay	0.11	0.13	0.12

3.2 Water Balance Accounting

Calculations following the water balance approach are mainly done to obtain the soil water depth through soil water balance. With the assumptions involved in the project the soil water balance has been summarized as follows:

$$SW(n) = SW(n-1) + P + I - ETc - DP \tag{1}$$

where:

SW(n) = Soil water depth of the n-th day, cm
SW(n-1) = Soil water depth of the (n-1)-th day, cm
P = Rain (Precipitation), cm
I = Irrigation, cm
ETc = Crop Evapotranspiration = Kc*ETo, cm
DP = Deep Percolation, cm

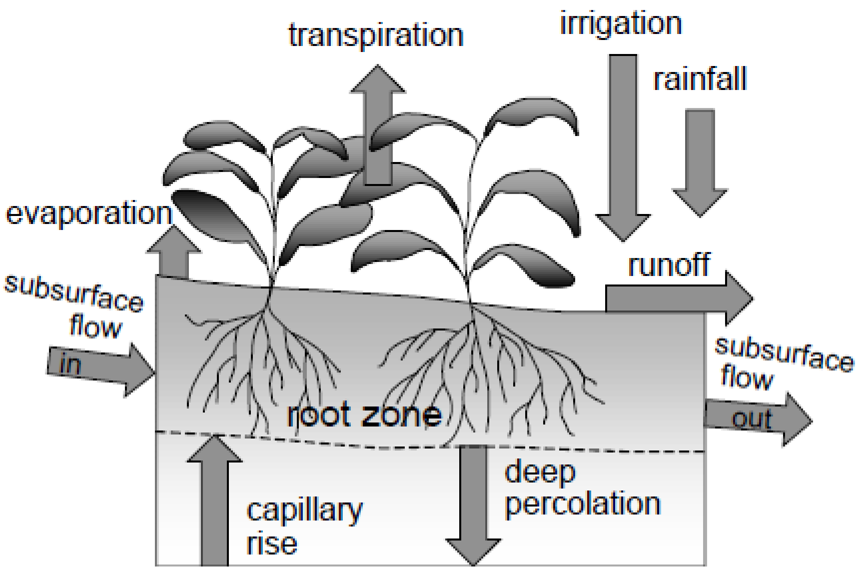


Fig. 3.1 Soil Water Balance Components (Source: Allen et al., 1998)

3.3 Evapotranspiration Process

The combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is referred to as evapotranspiration (ET).

Evaporation is the process whereby liquid water is converted to water vapour (vaporization) and removed from the evaporating surface (vapour removal). Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation.

Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapour removal to the atmosphere. Crops predominately lose their water through stomata.These are small openings on the plant leaf through which gases and water vapour pass. The water, together with some nutrients, is taken up by the roots and transported through the plant. The vaporization occurs within the leaf, namely in the intercellular spaces, and the vapour exchange with the atmosphere is controlled by the stomatal aperture. Nearly all water taken up is lost by transpiration and only a tiny fraction is used within the plant. Transpiration, like direct evaporation, depends on the energy supply, vapour pressure gradient and wind. Hence, radiation, air temperature, air humidity and wind terms should be considered when assessing transpiration. The soil water content and the ability of the soil to conduct water to the roots also determine the transpiration rate, as do waterlogging and soil water salinity. The transpiration rate is also influenced by crop characteristics, environmental aspects and cultivation practices. Different kinds of plants may have different transpiration rates. Not only the type of crop, but also the crop development, environment and management should be considered when assessing transpiration.

Factors Affecting Evapotranspiration
Weather parameters, crop characteristics, management and environmental aspects are factors affecting evaporation and transpiration.

Weather parameters
The principal weather parameters affecting evapotranspiration are radiation, air temperature. The evaporation power of the atmosphere is expressed by the reference crop evapotranspiration (ETo). The reference crop evapotranspiration represents the evapotranspiration from a standardized vegetated surface.

Crop factors
The crop type, variety and development stage should be considered when assessing the evapotranspiration from crops grown in large, well-managed fields. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop rooting characteristics result in different ET levels in different types of crops under identical environmental conditions.

Reference crop evapotranspiration (ETo)
The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The use of other denominations such as potential ET is strongly discouraged due to ambiguities in their definitions.

Crop evapotranspiration under standard conditions (ETc)

The crop evapotranspiration under standard conditions, denoted as ETc, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions.

ET computed from meteorological data

Owing to the difficulty of obtaining accurate field measurements, ET is commonly computed from weather data. A large number of empirical or semi-empirical equations have been developed for assessing crop or reference crop evapotranspiration from meteorological data.
Some of the methods are only valid under specific climatic and agronomic conditions and cannot be applied under conditions different from those under which they were originally developed.

FAO Penman-Monteith and Hargreaves method are now recommended as the standard method for the definition and computation of the reference evapotranspiration, ETo. The ET from crop surfaces under standard conditions is determined by crop coefficients (Kc) that relate ETc to ETo. The ET from crop surfaces under non-standard conditions is adjusted by a water stress coefficient (Ks) and/or by modifying the crop coefficient.

3.4 Reference evapotranspiration (ETo) by Hargreaves Method

ETo can be computed from meteorological data. ETo can be estimated using the Hargreaves ETo equation where:

$$\mathrm{ET_o} = 0.0023\ \mathrm{R_a}\sqrt{(T_{max} - T_{min})}\ (\mathrm{T_{mean}} + 17.8) \qquad (2)$$

ET_o is reference evapotranspiration [mm/day]

R_a is extraterrestrial solar radiation [MJ m^{-2} d^{-1}]

***T_{max}* is daily maximum air temperature** [°C]

***T_{min}* is daily minimum air temperature** [°C]

***T_{mean}* is daily mean air temperature** [°C] = (T_{max} + T_{min}) / 2

R_a is computed from information on location of the site and time of the year. Therefore air temperature is the only parameter that needs to be measured continuously in order to use this equation. R_a can be computed as follows:

$$R_a = \frac{24\ (60)}{\pi} G_{sc} d_r [w_s \sin(\phi) \sin(\delta) + \cos(\phi) \cos(\delta) \sin(w_s)] \qquad (3)$$

Where G_{sc} is solar constant (0.0820 MJ m^{-2} min^{-1}), d_r is inverse relative distance Earth-Sun, w_s is sunset hour angle, ϕ is latitude (rad) and δ is solar radiation (rad). d_r, δ and w_s can be calculated as follows:

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) \qquad (4)$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right) \qquad (5)$$

$$w_s = \arccos[-\tan(\phi) \tan(\delta)] \qquad (6)$$

Where *J* is the number of the day in the year.

Adjusted ET_o = ET_o / (2.501 – 0.002361* *T_{mean}*)

3.5 Crop evapotranspiration (ETc)

In the crop coefficient approach the crop evapotranspiration, ET_c, is calculated by multiplying the reference crop evapotranspiration, ET_o, by a crop coefficient, K_c:

$$ET_c = K_c\ ET_o \qquad (7)$$

where, ET_c crop evapotranspiration [mm d^{-1}],
K_c crop coefficient [dimensionless],
ET_o reference crop evapotranspiration [mm d^{-1}].

Most of the effects of the various weather conditions are incorporated into the ET_o estimate. Therefore, as ET_o represents an index of climatic demand, Kc varies predominately with the specific crop characteristics and only to a limited extent with climate. This enables the transfer of standard values for Kc between locations and between climates. This has been a primary reason for the global acceptance and usefulness of the crop coefficient approach and the K_c factors developed in past studies. The reference ET_o is defined and calculated using the Hargreaves equation. The crop coefficient, Kc, is basically the ratio of the crop ET_c to the reference ETo, and it represents an integration of the effects of four primary characteristics that distinguish the crop from reference grass.

These characteristics are:

- Crop height: The crop height influences the aerodynamic resistance term, Ra in Hargreaves equation and the turbulent transfer of vapour from the crop into the atmosphere.
- Albedo (reflectance) of the crop-soil surface. The albedo is affected by the fraction of ground covered by vegetation and by the soil surface wetness. The albedo of the crop-soil surface influences the net radiation of the surface, which is the primary source of the energy exchange for the evaporation process.
- Canopy resistance. The resistance of the crop to vapour transfer is affected by leaf area (number of stomata), leaf age and condition, and the degree of stomatal control. The canopy resistance influences the surface resistance.
- Evaporation from soil, especially exposed soil.

A typical crop coefficient curve is shown in Fig. 3.2.

Factors determining the Crop Coefficient:

- Crop Type
- Climate
- Soil Evaporation
- Crop Growth Stages:
    - Initial Stage
    - Crop Development Stage
    - Mid Season Stage
    - Late Season Stage

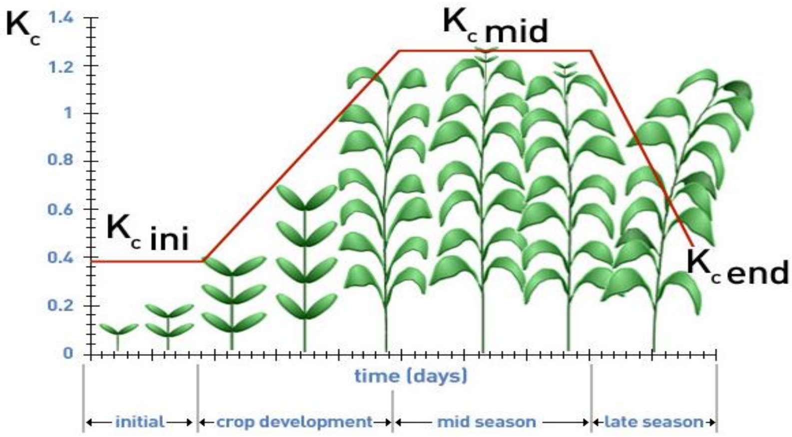


Fig. 3.2 Crop Coefficient Curve (Source: Allen et al., 1998)

Once the Reference ETo has been calculated using Hargreaves method, the crop coefficient curve formation is the next task required to obtain crop coefficient i.e. Kc value for different days in the crop stages. This is done by selecting the values of Kc ini, Kc mid and Kc end related to the particular crop and construct the crop coefficient curve as shown in Fig. 3.2 above. Once the curve is created then the product of the Kc value obtained for a day and the reference evapotranspiration ETo calculated for that day gives the value of crop evapotranspiration, ETc of that particular day. Flowchart for the procedure regarding calculation of ETc has been shown in Fig. 3.3.

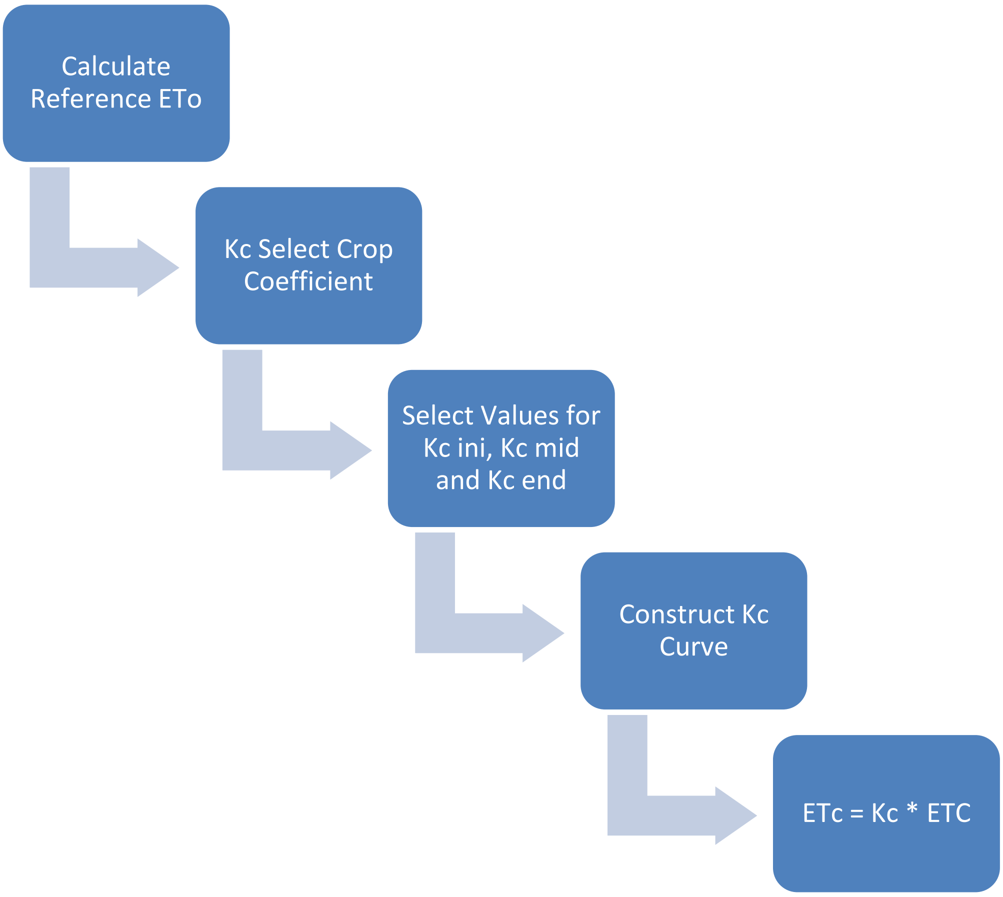


Fig 3.3 General procedure for calculating ETc

3.6 Project Workflow

Although machine generated values can never beat what nature delivers but still the irrigation scheduling application is going to help the users to a reasonably large extent. Weather Data is collected from worldweatheronline.com which serves as a standard for weather information with which the user-fed data done by using the application (stored in the database server) is used to calculate the soil water percentage on a daily basis. The application processes the data and provides useful information mainly hours required to irrigate and project rainfall of four days to the users in the form of timely notifications a day before. Next the application generated data is verified against the field values i.e. the real time data. Full workflow of the project has been shown in Fig. 3.4 below.

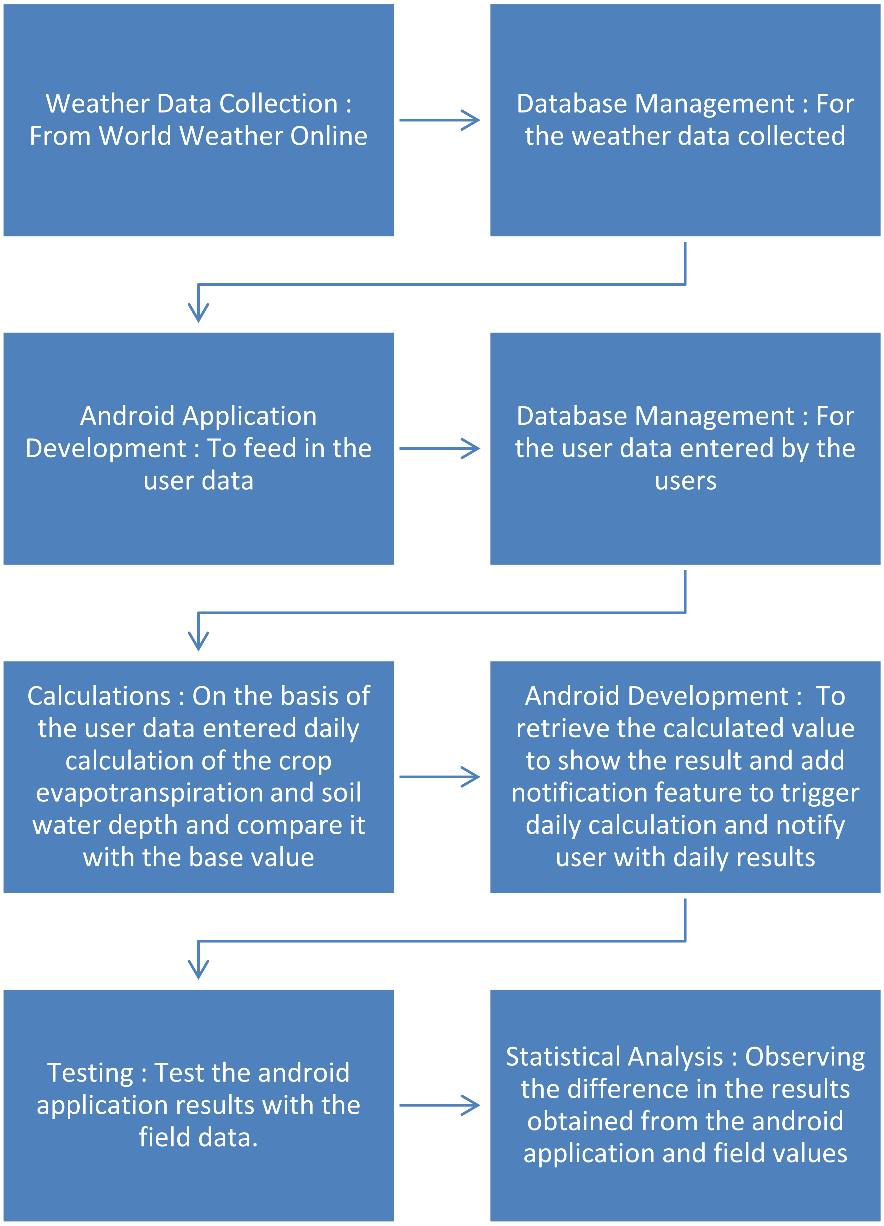


Fig. 3.4 Flowchart of Project Workflow

3.7 Data Used

Weather Data Retrieval

Daily weather data has been obtained from the application program interface of World Weather Online. World Weather Online provide weather for over 232 countries around the world. They cover approximately 3 million worldwide cities and towns and provide detailed weather forecast. The data provided by World Weather Online comprised of daily as well as forecasted data of future four days. These data included date, precipitation i.e. rainfall(in mm), maximum and minimum temperature(in °C and °F), wind direction, wind direction degree(in °), wind speed(in kmph and mph).

Data is being retrieved from www.worldweatheronline.com. The response provided by them is in json which is being parsed in php to number and string format. The sample view of the data provided by www.worldweatheronline.com is shown in Fig. 3.5:


```
[{"id":"41","place_name":"Asansol","fulldata":"{\"meta\":{\"version\":1,\"status_code\":429},\"results\":{\"error\":
{\"type\":\"QpsExceededError\",\"message\":\"Queries per second exceeded: Queries exceeded (5 allowed).\"}}}"},
{"id":"1","place_name":"Asansol","fulldata":"{ \"data\": { \"current_condition\": [ {\"cloudcover\": \"88\",
\"humidity\": \"92\", \"observation_time\": \"05:51 PM\", \"precipMM\": \"0.0\", \"pressure\": \"1004\", \"temp_C\":
\"28\", \"temp_F\": \"83\", \"visibility\": \"10\", \"weatherCode\": \"113\",  \"weatherDesc\": [ {\"value\": \"Clear\" }
],  \"weatherIconUrl\": [ {\"value\":
\"http:\/\/cdn.worldweatheronline.net\/images\/wsymbols01_png_64\/wsymbol_0008_clear_sky_night.png\" } ],
\"winddir16Point\": \"WSW\", \"winddirDegree\": \"244\", \"windspeedKmph\": \"6\", \"windspeedMiles\": \"4\" } ],
\"request\": [ {\"query\": \"Asansol, India\", \"type\": \"City\" } ],  \"weather\": [ {\"date\": \"2014-09-24\",
\"precipMM\": \"2.9\", \"tempMaxC\": \"37\", \"tempMaxF\": \"98\", \"tempMinC\": \"25\", \"tempMinF\": \"77\",
\"weatherCode\": \"113\",  \"weatherDesc\": [ {\"value\": \"Sunny\" } ],  \"weatherIconUrl\": [ {\"value\":
\"http:\/\/cdn.worldweatheronline.net\/images\/wsymbols01_png_64\/wsymbol_0001_sunny.png\" } ], \"winddir16Point\":
\"WSW\", \"winddirDegree\": \"247\", \"winddirection\": \"WSW\", \"windspeedKmph\": \"6\", \"windspeedMiles\": \"4\" },
{\"date\": \"2014-09-25\", \"precipMM\": \"0.4\", \"tempMaxC\": \"36\", \"tempMaxF\": \"96\", \"tempMinC\": \"24\",
\"tempMinF\": \"75\", \"weatherCode\": \"113\",  \"weatherDesc\": [ {\"value\": \"Sunny\" } ],  \"weatherIconUrl\": [
{\"value\": \"http:\/\/cdn.worldweatheronline.net\/images\/wsymbols01_png_64\/wsymbol_0001_sunny.png\" } ],
\"winddir16Point\": \"WNW\", \"winddirDegree\": \"288\", \"winddirection\": \"WNW\", \"windspeedKmph\": \"6\",
\"windspeedMiles\": \"4\" }, {\"date\": \"2014-09-26\", \"precipMM\": \"0.0\", \"tempMaxC\": \"36\", \"tempMaxF\":
\"97\", \"tempMinC\": \"24\", \"tempMinF\": \"76\", \"weatherCode\": \"113\",  \"weatherDesc\": [ {\"value\": \"Sunny\" }
],  \"weatherIconUrl\": [ {\"value\":
\"http:\/\/cdn.worldweatheronline.net\/images\/wsymbols01_png_64\/wsymbol_0001_sunny.png\" } ], \"winddir16Point\":
\"WNW\", \"winddirDegree\": \"287\", \"winddirection\": \"WNW\", \"windspeedKmph\": \"8\", \"windspeedMiles\": \"5\" },
{\"date\": \"2014-09-27\", \"precipMM\": \"0.0\", \"tempMaxC\": \"36\", \"tempMaxF\": \"98\", \"tempMinC\": \"25\",
\"tempMinF\": \"76\", \"weatherCode\": \"113\",  \"weatherDesc\": [ {\"value\": \"Sunny\" } ],  \"weatherIconUrl\": [
{\"value\": \"http:\/\/cdn.worldweatheronline.net\/images\/wsymbols01_png_64\/wsymbol_0001_sunny.png\" } ],
\"winddir16Point\": \"WSW\", \"winddirDegree\": \"254\", \"winddirection\": \"WSW\", \"windspeedKmph\": \"10\",
\"windspeedMiles\": \"6\" }, {\"date\": \"2014-09-28\", \"precipMM\": \"0.0\", \"tempMaxC\": \"37\", \"tempMaxF\":
\"98\", \"tempMinC\": \"25\", \"tempMinF\": \"76\", \"weatherCode\": \"113\",  \"weatherDesc\": [ {\"value\": \"Sunny\" }
],  \"weatherIconUrl\": [ {\"value\":
\"http:\/\/cdn.worldweatheronline.net\/images\/wsymbols01_png_64\/wsymbol_0001_sunny.png\" } ], \"winddir16Point\":
\"WSW\", \"winddirDegree\": \"237\", \"winddirection\": \"WSW\", \"windspeedKmph\": \"10\", \"windspeedMiles\": \"6\" } ]
}}"}]
```


Fig. 3.5 Sample data provided by www.worldweatheronline.com

Crop and Soil Data

Crops used for the testing purpose were wheat and potato for which the crop coefficient along with crop stage intervals are the only requirement in terms of data. Crop Coefficients associated with crop development stages of important crops have been mentioned in the Tables 3.2 and 3.3.

Soil data consist of FC(field capacity), PWP(permanent wilting point) and MAD(Maximum Allowable Depth) which helps in the calculation of AWC(Available Water Content). These values are in percentages and are fixed w.r.t. a particular soil. FC and PWP of all soils have been mentioned in the Table 3.4.

Table 3.2 Lengths of crop development stages for various planting periods and climatic regions (days) (Source: Allen et al., 1998)

Crop	Init. (Lini)	Dev. (Ldev)	Mid (Lmid)	Late (Llate)	Total	Plant Date	Region
Wheat	15	25	50	30	120	November	Central India
Potato	25	30	45	30	130	January/ November	(Semi)Arid Region
Soybeans	15	15	40	15	85	December	Tropics

Table 3.3 Single (time-averaged) crop coefficients, Kc (Source: Allen et al., 1998)

Crop	Kc ini	Kc mid	Kc end
Wheat	0.30	1.15	0.40
Potato	1.05	1.20	0.90
Soybeans	0.50	1.15	0.50

Table 3.4 Field Capacity and Permanent Wilting Point of different Soil Types (Source: Allen et al., 1998)

Soil Type/Texture	FC(in %)	PWP(in %)
Sand	10	5
Loamy Sand	12	5
Sandy Loam	18	8
Sandy Clay Loam	27	17
Loam	28	14
Sandy Clay	36	25
Silt Loam	31	11
Silt	30	6
Clay Loam	36	22
Silty Clay Loam	38	22
Silty Clay	41	27
Clay	42	30

3.8 Development of Online Server and Android Application

Steps involved in setting up of online server and storage of data is shown in Fig. 3.6.

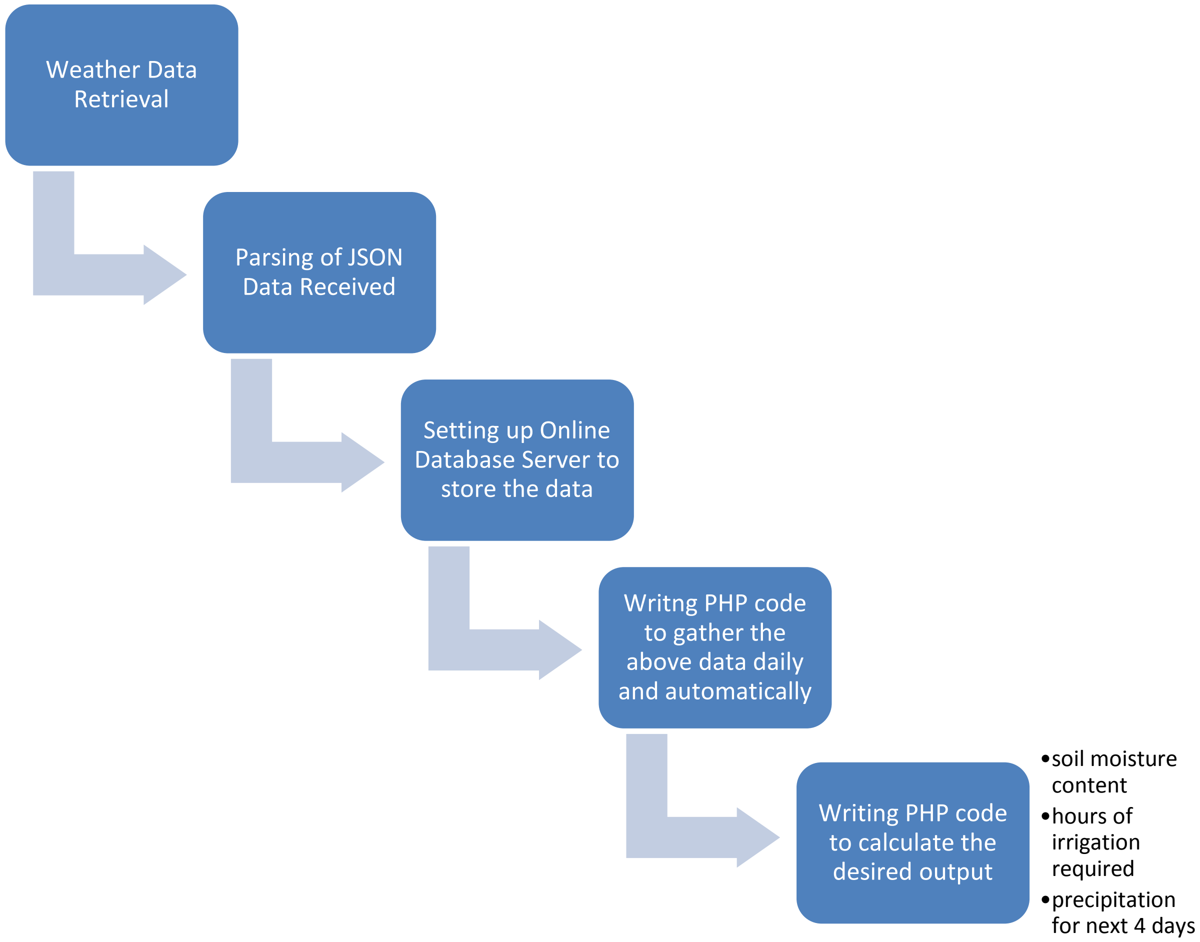


Fig. 3.6 Flowchart of Data Storage and Calculation of the desired output by accessing stored data from Online Server

Output of parsed data with calculated value of Reference Evapotranspiration (ETo) is shown in Fig. 3.7.

```
Kanchrapara - 22.9339115
2015-05-04 - 1.1 - 41 - 28 - 124 - 35.514119136662 - 6.3660266853879
2015-05-05 - 0.0 - 43 - 29 - 125 - 35.444521311005 - 6.7924366398891
2015-05-06 - 0.0 - 45 - 29 - 126 - 35.375107855856 - 7.389126882728
2015-05-07 - 0.0 - 47 - 29 - 127 - 35.305945143852 - 7.9725660408201
2015-05-08 - 0.1 - 47 - 29 - 128 - 35.237099248063 - 7.9570196944873

Kharagpur - 22.3304
2015-05-04 - 17.3 - 40 - 27 - 124 - 35.514119136662 - 6.2382180613268
2015-05-05 - 0.0 - 44 - 29 - 125 - 35.444521311005 - 7.09965127037
2015-05-06 - 0.0 - 46 - 29 - 126 - 35.375107855856 - 7.6897926481791
2015-05-07 - 0.0 - 47 - 29 - 127 - 35.305945143852 - 7.9725660408201
2015-05-08 - 0.0 - 47 - 29 - 128 - 35.237099248063 - 7.9570196944873

Khardaha - 22.7186
2015-05-04 - 9.3 - 41 - 28 - 124 - 35.514119136662 - 6.3660266853879
2015-05-05 - 0.0 - 43 - 29 - 125 - 35.444521311005 - 6.7924366398891
2015-05-06 - 0.0 - 45 - 29 - 126 - 35.375107855856 - 7.389126882728
2015-05-07 - 0.0 - 46 - 29 - 127 - 35.305945143852 - 7.6747581522713
2015-05-08 - 0.0 - 48 - 29 - 128 - 35.237099248063 - 8.2523539702651

Krishnanagar - 23.4008744
2015-05-04 - 0.0 - 42 - 29 - 124 - 35.514119136662 - 6.4940849851865
2015-05-05 - 0.0 - 44 - 29 - 125 - 35.444521311005 - 7.09965127037
2015-05-06 - 0.0 - 46 - 29 - 126 - 35.375107855856 - 7.6897926481791
2015-05-07 - 0.0 - 47 - 30 - 127 - 35.305945143852 - 7.8211965609402
2015-05-08 - 0.0 - 47 - 29 - 128 - 35.237099248063 - 7.9570196944873
```

Fig. 3.7 Output of parsed data with last values of each line displaying calculated ETo

In the study, JAVA and XML programming language was used in the software named Android Studio for the development of the android application. For the development at the server end PHP and MYSQL programming languages were used.

The design of the user interface is worked out so that it is suitable for the users, mainly farmers who must find it easy to operate. The interface has been created using XML and JAVA in the Android Studio environment. Next, the user interface is connected to the online server to complete the application. Finally, the complete android application is debugged and verified by validating the application generated values with the actual field data. Flowchart related to the workflow of the android application development is shown in Fig 3.8.

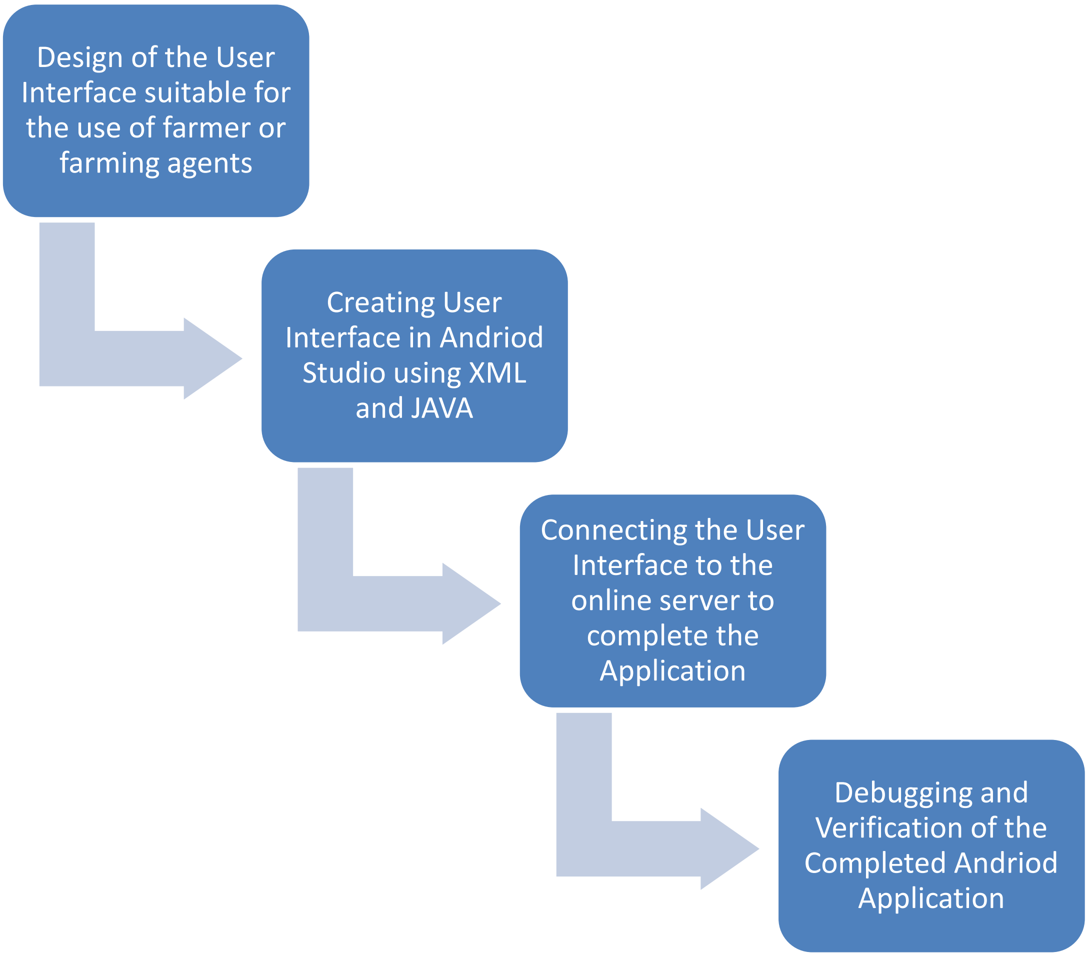


Fig. 3.8 Flowchart of Development of Irrigation Scheduling Android Application

3.9 Workflow of Android Application

The application workflow deals with one time us sign-up which generates a unique passphrase of 20 alphanumeric values giving a unique identity to one user. The create field button allows farmer to enter the required details of the field namely field name, location, crop type, soil type, date of sowing and irrigation type. User would be able to generate multiple field and keep a track of all the fields created displayed in the lists of fields screen. Each field listed would have two options. Firstly, field info button providing information about water balance and precipitation for next four days associated the respective field and other data entered by the user. Timely notifications would be generated for those fields whose soil water percentage would fall below the maximum allowable depth (MAD) the next day. The flowchart of the workflow has been shown in Fig. 3.9

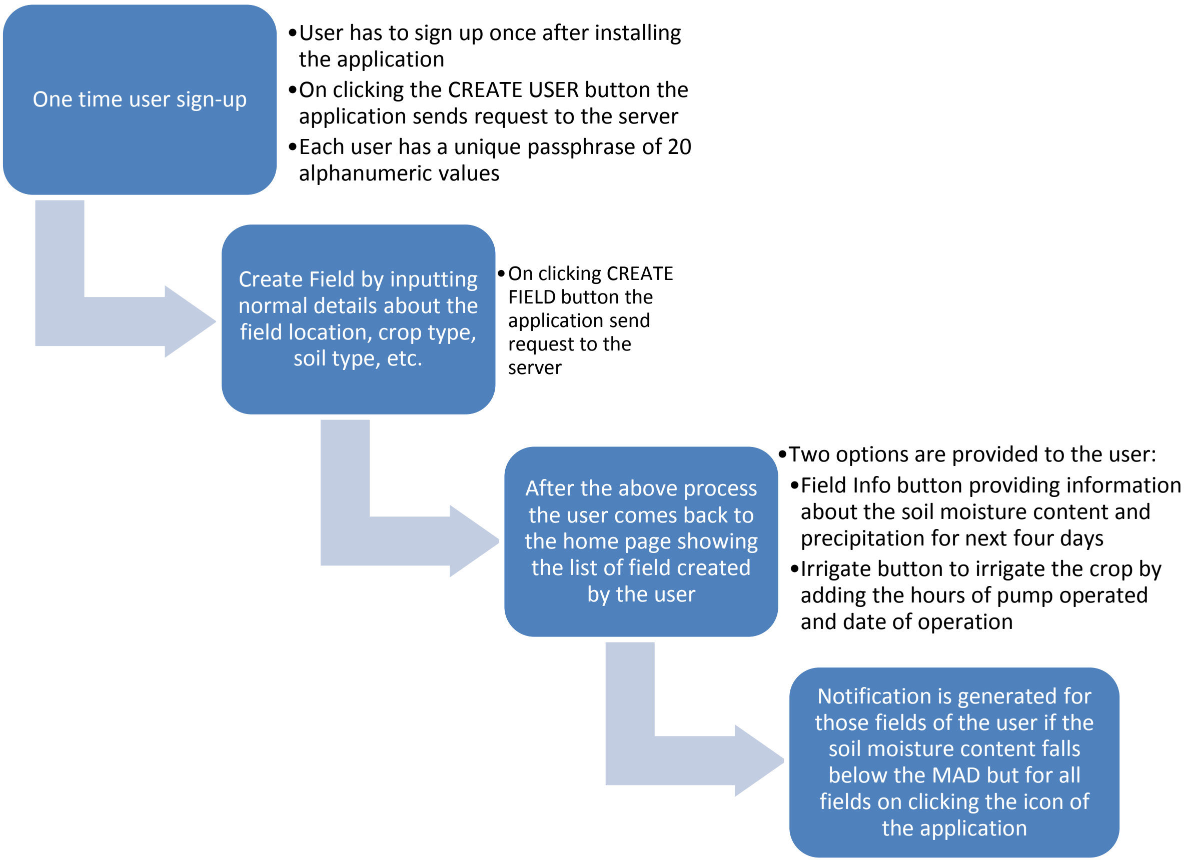


Fig. 3.9 Flowchart of the workflow of Irrigation Scheduling Android Application

Chapter 4

RESULTS AND DISCUSSION

This chapter deals with the details of the developed application which includes the design of the user interface. The developed application is verified against the certain datasets and results are presented here.

4.1 Developed Software and Its Salient Features

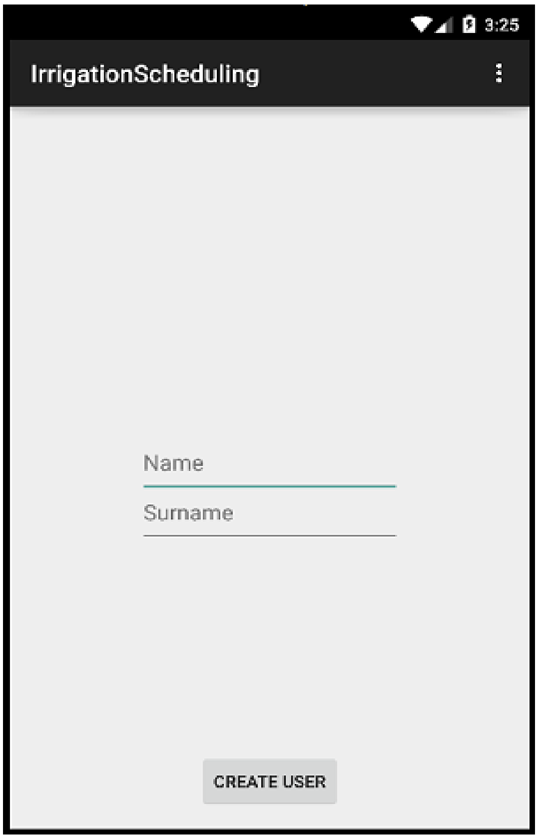


Fig 4.1 One time sign-up (CREATE USER) screen

Fig 4.1 shows the sign-up screen which will open for the first time when the user installs the application in their android smartphones. The application has one time sign-up feature, i.e., the user has to sign-up (create user profile) for once and he would remain logged in forever. There are two advantages, no problem of password as for one unique user there has been a unique passphrase id generated by the application and passed on to the server. The second advantage is, one smartphone set with the application will act as one user.

Fig 4.2 First home screen on signing-up

Fig 4.2 shows the first time display of home screen which user witnesses after signing-up for the first time. Here in Fig. 4.2 it shows “List of fields” with an empty list, which is because no field has been created. In order to create a new field, the user has to click on “CREATE FIELD” button on the home screen.

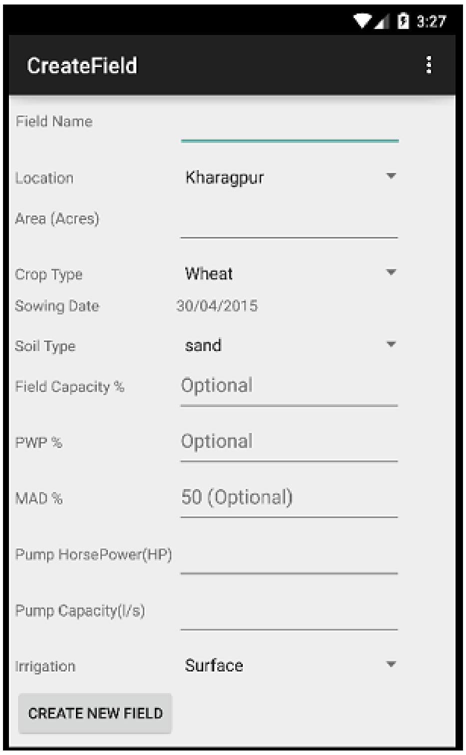


Fig 4.3 Create Field screen

Fig 4.3 shows the Create Field screen which gets displayed on clicking the “CREATE FIELD” button on the home screen. Here in Fig 4.3 shows the inputs required to be filled by the user in order to create new field. The input variables include field name, location, area(in acres), crop type, sowing date, soil type, FC, PWP, MAD, pump horsepower(in HP), pump capacity(in l/s) and irrigation type(i.e. surface or sprinkler). Out of these inputs there are certain variable which farmer might not know like FC, PWP and MAD of the soil they are using therefore these values have been made optional depending upon whether users want to enter those values or want the calculations to be done with standard values.

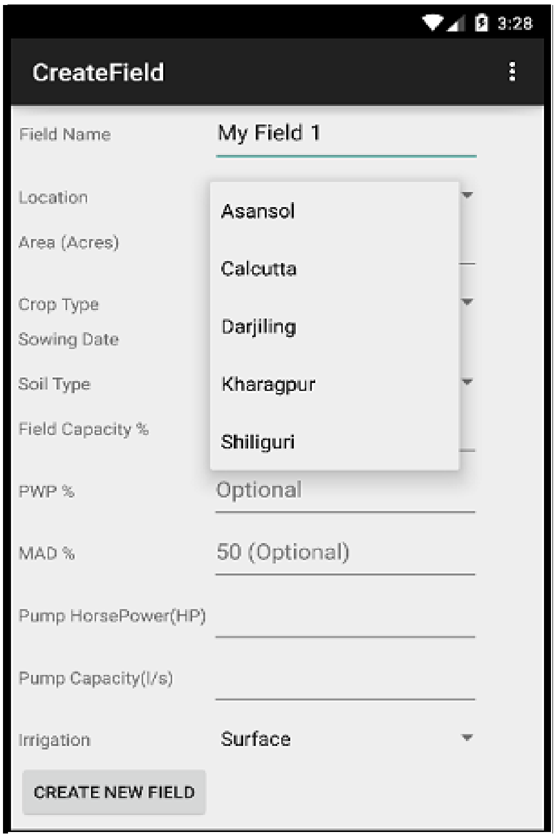


Fig 4.4(a)

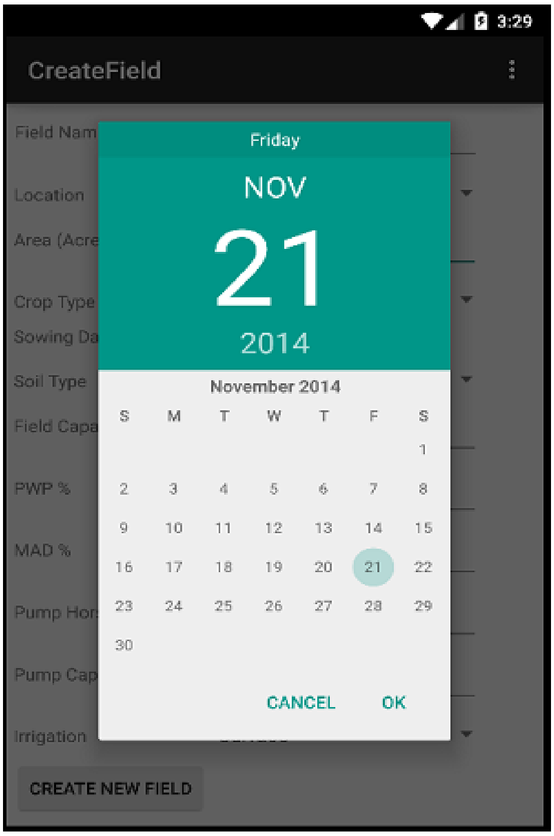
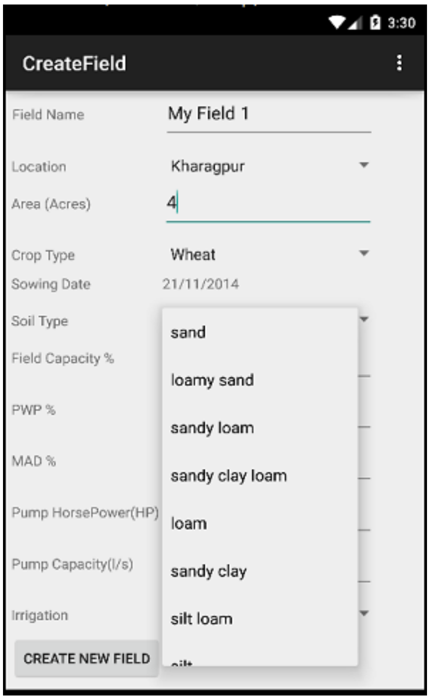


Fig 4.4(b)

Fig 4.4 (a) and (b) both are the features in the Create Field Screen. Left image of the application is showing the drop down list of the locations while right is showing the calendar to input the sowing date

Fig 4.4(a) shows the drop down list of locations. The feature of dropdown list would avoid wrong spelling entry during typing. Similarly in the case of entering dates which might get wrong while typing as users are not properly aware with the format being dd/mm/yyyy or mm/dd/yyyy, etc. Therefore Fig 4.4(b) shows the calendar feature which makes it easy for the user to enter dates without any typing.

Similar features can be seen in Fig 4.5 (a)&(b), where the drop down list of 12 soils and 2 irrigation types have been displayed making it simple for the users in entering data related to the fields.



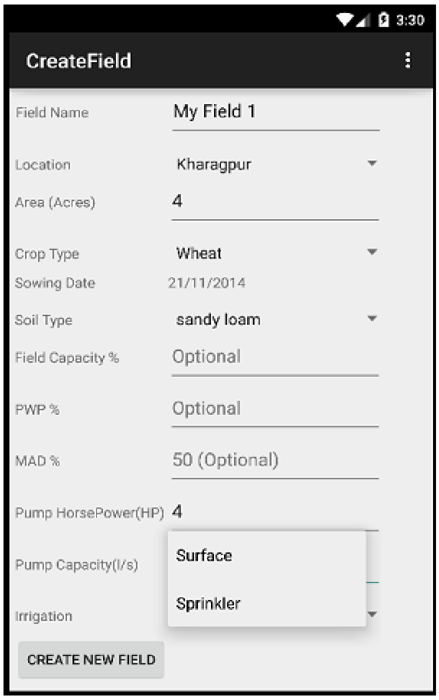


Fig 4.5 (a) **Fig 4.5 (b)**

Fig 4.5 (a) and (b) both are the features of the Create Field Screen providing drop down list of Soil Types, optional entry of FC,PWP and MAD values as well as drop down list for Crop Types and Irrigation Types

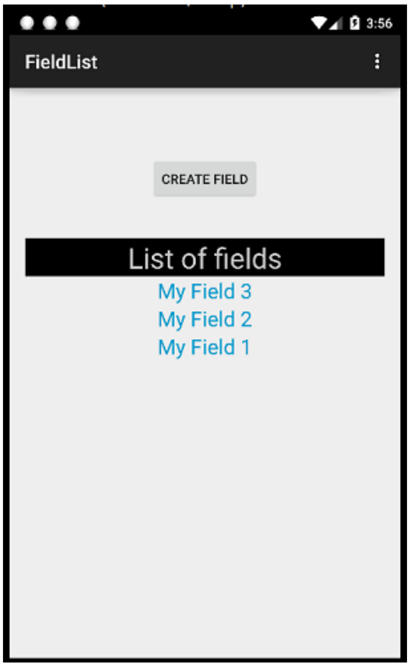


Fig. 4.6 (a) **Fig. 4.6 (b)**

Fig 4.6 (a) Home Screen after user has created numerous fields. (b) On clicking any field name from the List of fields users gets two options namely, FIELD INFO and IRRIGATE

Fig. 4.6(a) shows the home screen after creating couple of fields using CREATE FIELD option. On clicking “CREATE NEW FIELD” button present in the Create Field screen after entering the values, the user is redirected to the home screen displaying the list of fields of the user. On clicking any of the fields from the list, a dialogue box opens shown in Fig 4.6(b) providing two options to the user i.e., whether he wants to get the field information or he wants to irrigate the field by giving information about the hours and minutes of pump operation as well as the date of operation.

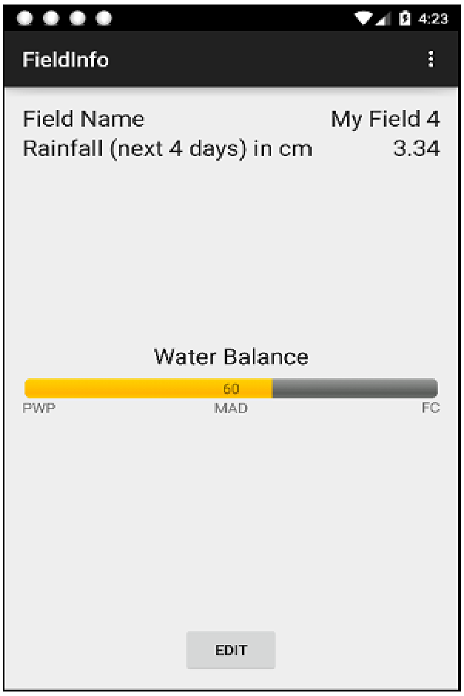


Fig. 4.7 On clicking the FIELD INFO button user is directed to the FieldInfo screen displaying the “Field Name”, “Rainfall(next 4 days) in cm” and Water Balance in a progress bar mode

Fig 4.7 shows the Field Information screen which is displayed on clicking the “FIELD INFO” button. Here, as you can see the information for a particular field has been displayed with the information of rainfall projected for next four days(in cm) as well as the water balance related to the field data of the user along with the name of field. The value of water balance in cm/day might not be comprehended properly by the farming agents. Therefore, the progress bar with pointers showing the PWP,MAD and FC values associated with the field.

In Fig 4.7 there is an "EDIT" button which gives the opportunity to the farmer/user to change the crop type associated with the field after the earlier crop is harvest or any other reasons. As a result he or she has to only enter the new crop type and its date of sowing. This feature has been shown in Fig 4.8 (a)&(b) showing the input variables with the drop down list feature for the crop types and calendar feature for the date of sowing.

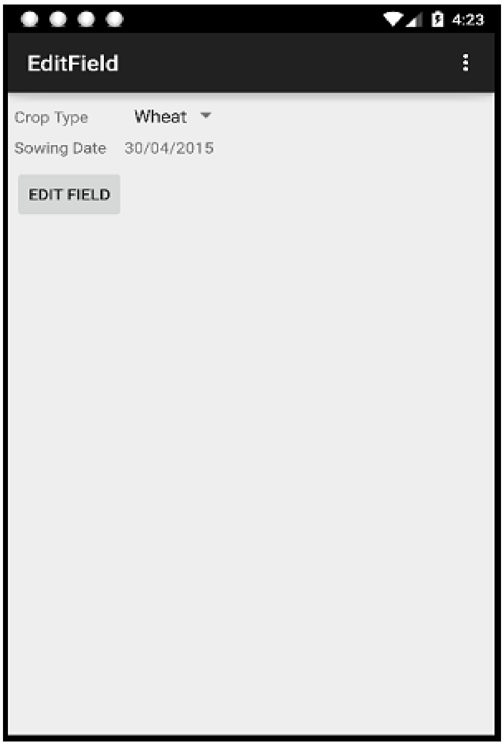


Fig. 4.8 (a)

Fig. 4.8 (b)

Fig. 4.8 (a) On clicking the EDIT button in the FieldInfo Screen, user can change the crop in the existing field. (b) Shows the drop down list of the crop types and sowing date entry field

Most important of all feature of this application being the notification feature shown in Fig 4.9, which will keep the farmer well equipped with the information that which of their listed fields require irrigation, for how many hours they need to operate their pump and the rainfall information for next four days(in cm).

These info would be provided in the form of notification only when the soil water percentage fall below the maximum allowable depth. This condition will trigger the alarm and send the notification to the user with the much needed information. The notification will also be generated for all the fields of the user once he/she click on the application icon. Therefore, two types of notification would be there but both would provide the same information.

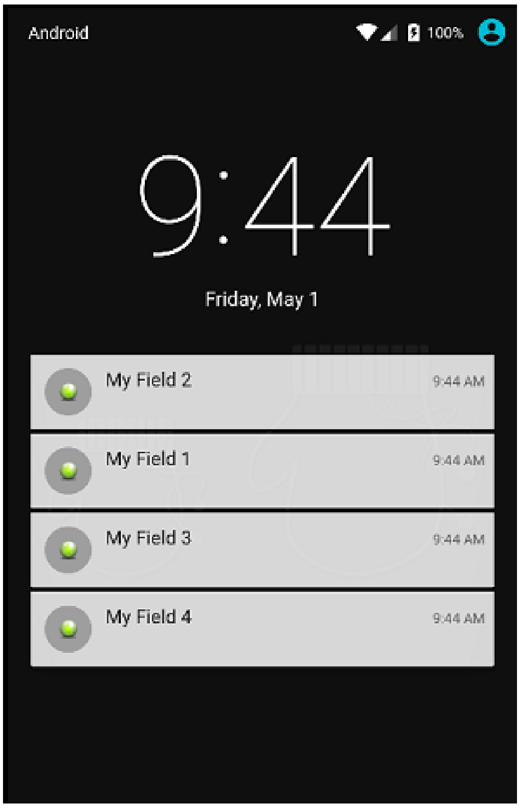


Fig. 4.9 (a)

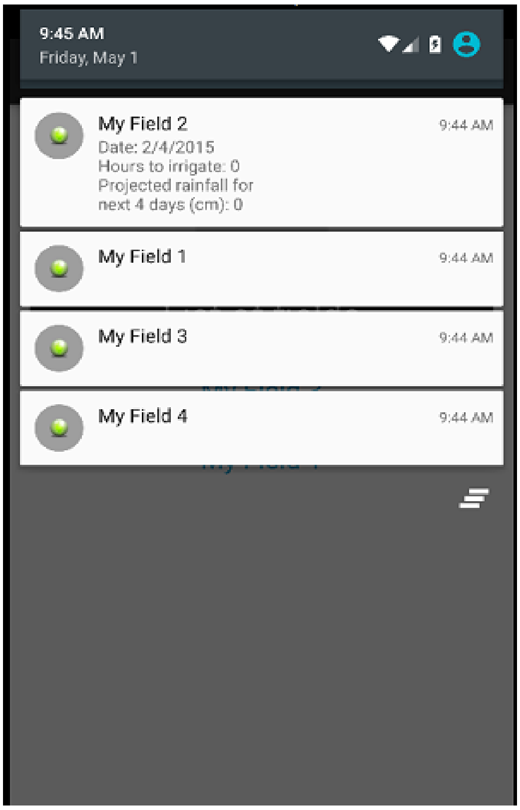


Fig. 4.9 (b)

Fig 4.9 (a) Shows the list of notifications for each field of the user. (b) Shows the Information provided by the notifications for each field of the user

4.2 Verification of the Software

The developed application for irrigation scheduling was tested against the available datasets from the sensors data of wheat crop cultivation with the date of sowing being 21st November, 2014 and date of harvest being 21st March, 2015.

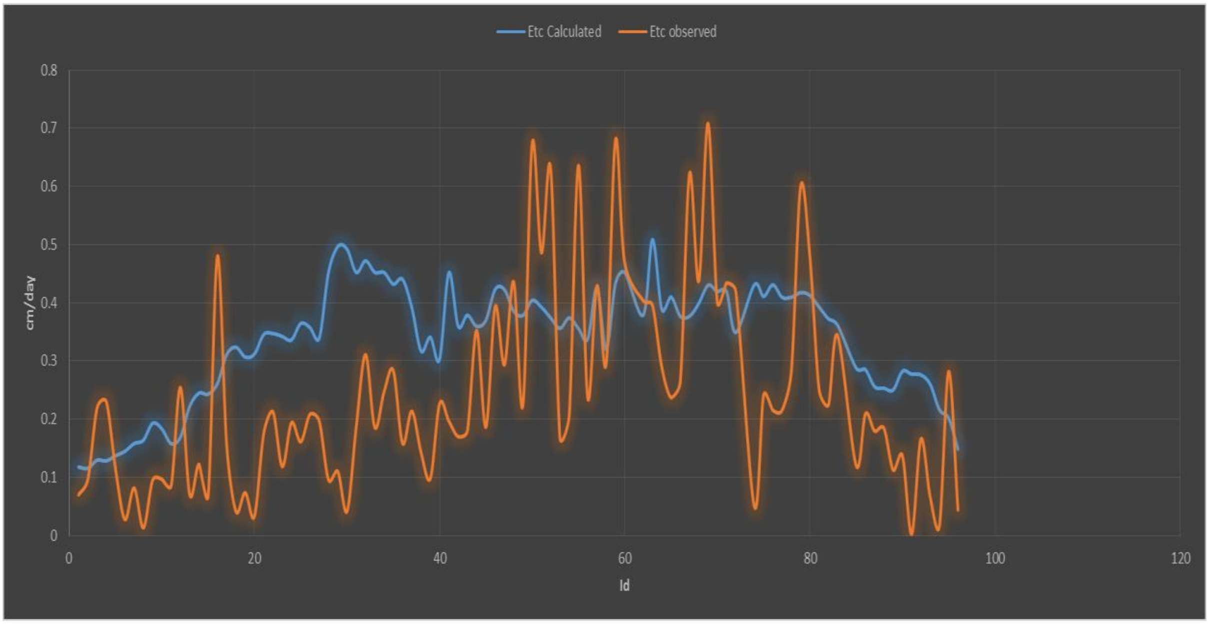


Fig 4.10 ETc (Crop Evapotranspiration) values calculated (blue) and from sensors (orange)

The values of both the calculated and observed values of crop evapotranspiration have been shown in Fig. 4.10. The variations between both the data have been analyzed and the RMSE (root mean square error) between both sets of values is 0.17879 cm/day. The temperature data from both the sources i.e. from weather station in Kharagpur and from World Weather Online have been plotted against each other for particular days, as shown in Fig. 4.10 (a) and (b).

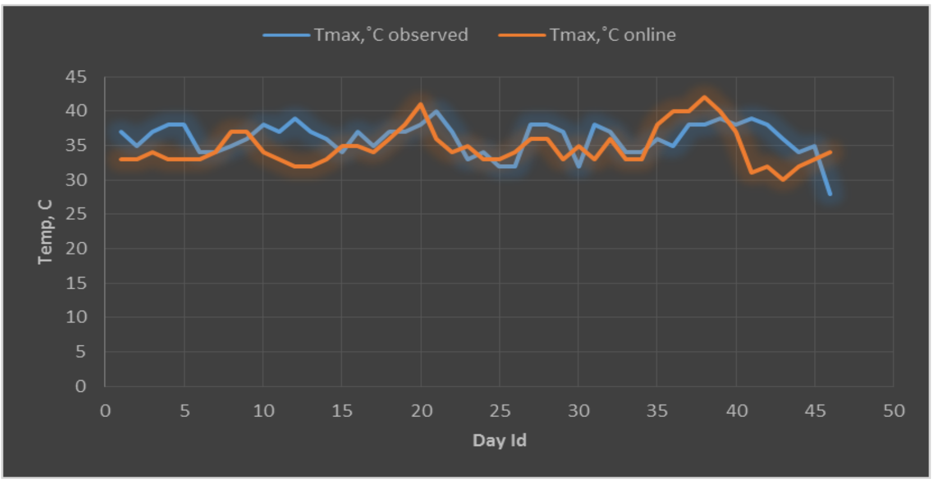


Fig. 4.11 (a) Variation between maximum temperature values

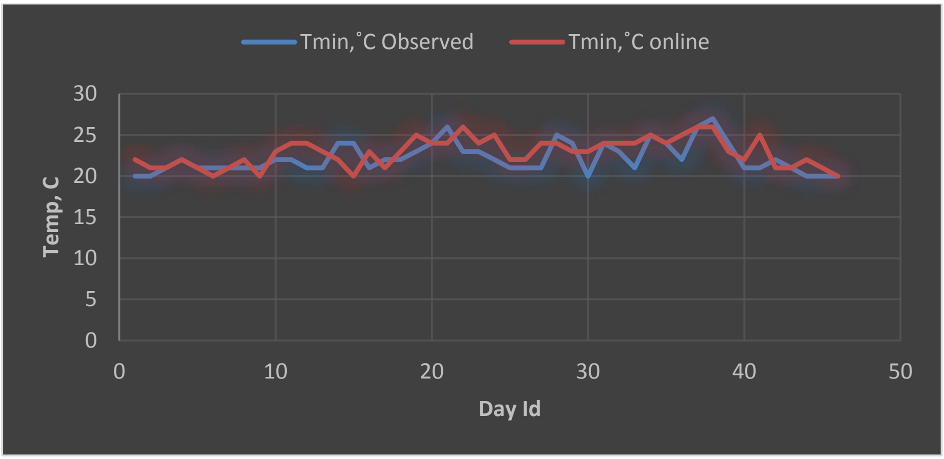


Fig. 4.11 (b) Variation between minimum temperature values

The variation obtained in the temperature values from both the sources were analyzed and the RMSE (root mean square error) in case of maximum temperature was 3.138 °C and in case of minimum temperature was 1.775 °C.

The analysis of the observed AWC (in cm/day) and the calculated AWC (cm/day) is shown in Fig. 4.12

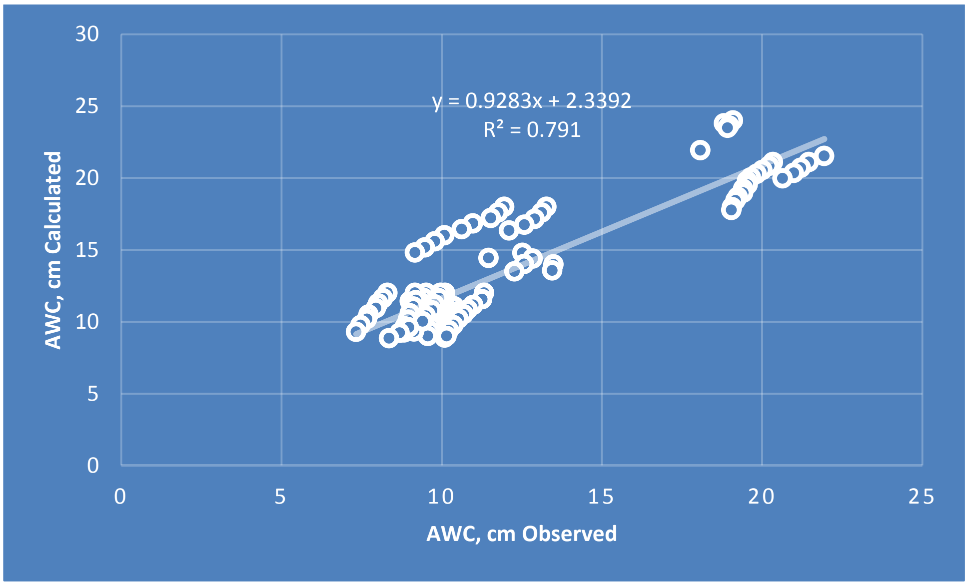


Fig 4.12 Available Water Content (AWC) observed vs calculated

Further the data obtained from worldweatheronline.com and data obtained from weather station were separately used to calculate the value of ETo (pan evapotranspiration). As a result, the RMSE(root mean square error) of 0.718 mm/day was obtained between the two sources. The variations of ETo from both the sources are shown in the Fig. 4.13.

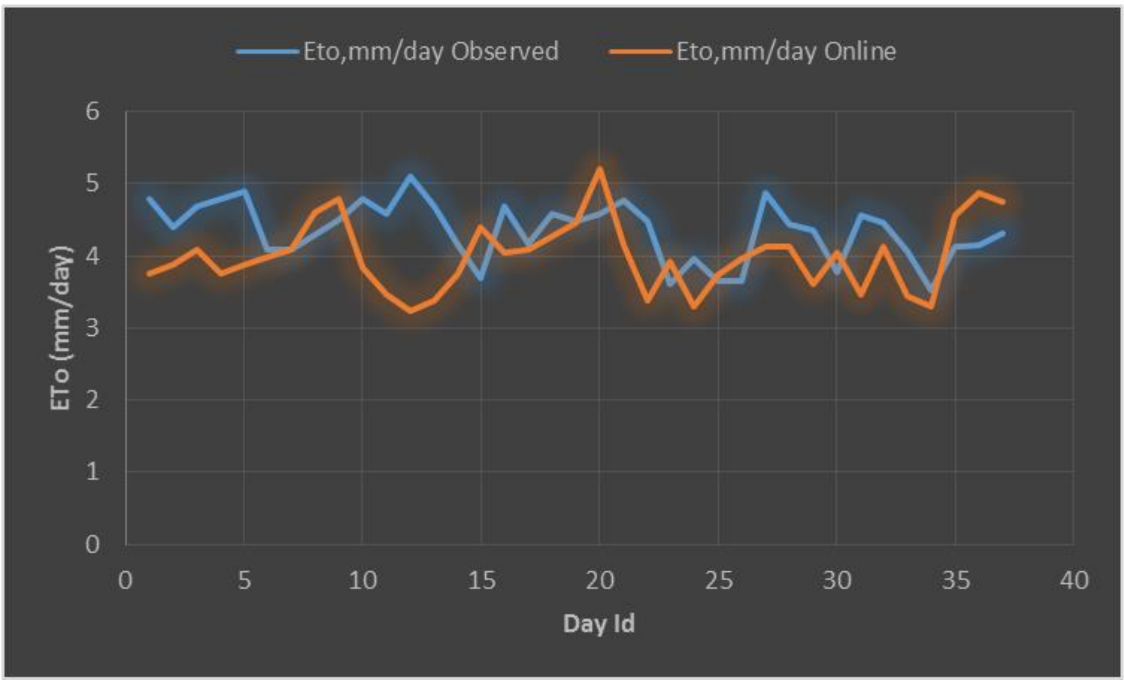


Fig. 4.13 ETo from weather station (blue) and ETo from worldweatheronline.com (orange)

Considering the effective root zone depth being 80 cm, analysis was done to check the variations in AWC (available water content) obtained from the calculations from the application and the observed value from the sensors for different days of crop stages. These variations are showing in Fig. 4.14 below.

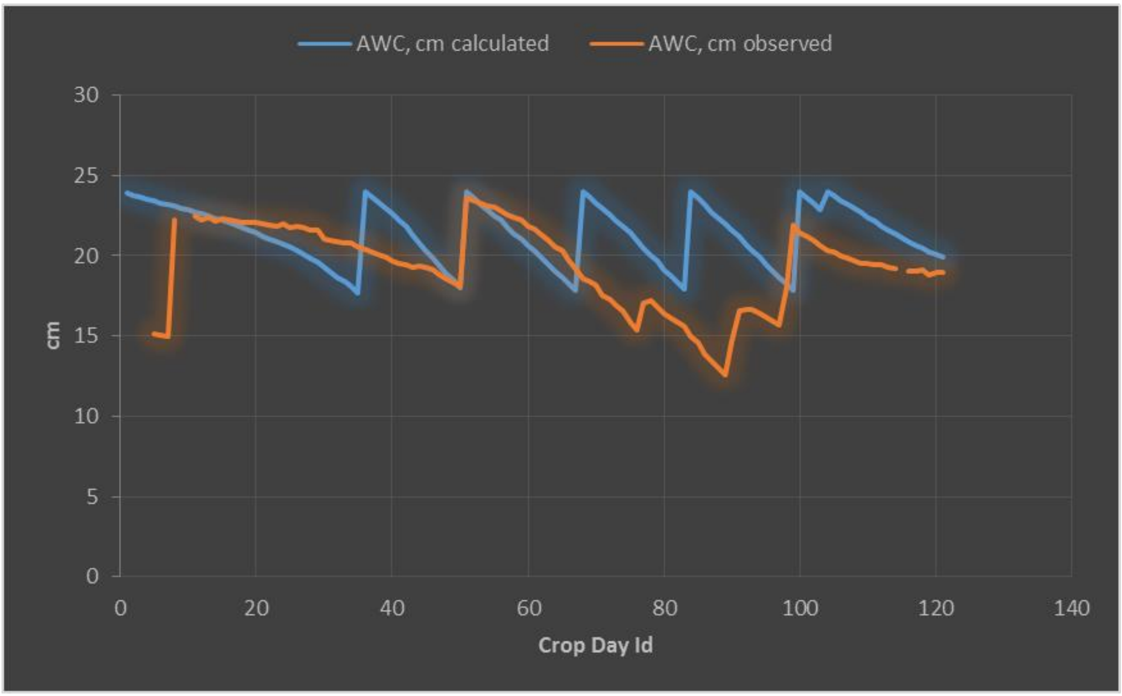


Fig. 4.14 Variations in AWC calculated (blue) and AWC observed (orange) w.r.t. different days of crop stages

Chapter 5

SUMMARY AND CONCLUSIONS

It is difficult to manage the irrigation systems and calculate the water required by the crop along with the information of when to irrigate. The developed application comprises of the features of less and genuine inputs from the farmer and can map the field on their mobile. As a result the calculations would run accordingly in the server and would generate notifications for those fields where the soil moisture content is going to fall below the maximum allowable depth the next day. Thereby, farmers get to know beforehand when they need to irrigate and how much.

The calculations have been tested against the sensors data from the field and the weather data have been checked against the data obtained from the weather station. The developed android application was found to be efficient in many of the cases but there are small glitches which required to be removed by testing the calculated data against varied data obtained from other stations and fields.

More scope is there for further changes by cross-checking with the real pan evapotranspiration values and switching to better online resource with wide range of reliable data. Moreover, the application can be made available to regional languages to increase the users. Internet of things can be applied by connecting the result of the application to the pumps with precision timing and duration.

REFERENCES

Allen, R.G.; Perrera, L.S.; Raes, D.; Smith, M. (1998). Crop Evapotranspiration (guidelines for computing crop water requirements). FAO Irrigation and Drainage Paper No. 56.

Andales, A.A.; Chavez, J.L.; Bauder, T.A. (2011). Irrigation Scheduling: The Water Balance Approach. Fact Sheet No. 4.707.

Broner, I. (2005). Irrigation Scheduling. Fact Sheet No. 4.708.

Brouwer, C.; Prins, K.; Kay, M.; Heibloem, M. (1989). Irrigation Water Management: Irrigation Water Needs. Training Manual 4.

Evans, R.; Sneed, R. E.; Cassel, D.K. (1996). Irrigation Scheduling to Improve Water and Energy-Use Efficiencies. North Carolina Cooperative Extension Service.

George, B. A.; Shende, S.A.; Raghuwanshi, N.S. (2000). Development and Testing of an Irrigation Scheduling Model. Agricultural Water Management 46 (2000) 121-136.