

**DESIGN OF PIPE DISTRIBUTION NETWORK IRRIGATION SYSTEM
IN COMMAND AREA FOR IMPROVING WATER USE EFFICIENCY
(WUE), LAND AND WATER PRODUCTIVITY AND PREVENTING LAND
DEGRADATION.**

by

Ms. Dhanashri Dipak Patil
(Reg. No. 2020/13)



DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

**DR. ANNASAHEB SHINDE COLLEGE OF AGRICULTURAL
ENGINEERING AND TECHNOLOGY
MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI- 413722, DIST. AHMEDNAGAR,
MAHARASHTRA, INDIA**

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A Thesis submitted to the

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MAHARASHTRA, INDIA**

In partial fulfillment of the requirements for the degree

of

MASTER OF TECHNOLOGY (AGRICULTURAL ENGINEERING)

in

IRRIGATION AND DRAINAGE ENGINEERING



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Approved by

Dr. M. S. Mane

(Chairman and Research Guide)

Dr. N. N. Firake
(Committee Member)

Dr. S. A. Kadam
(Committee Member)

Dr. D. D. Khedkar
(Committee Member)

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

**DR. ANNASAHEB SHINDE COLLEGE OF AGRICULTURAL
ENGINEERING AND TECHNOLOGY**

**MAHATMA PHULE KRISHI VIDYAPEETH,
RAHURI-413 722, DIST- AHMEDNAGAR,
MAHARASHTRA STATE (INDIA)**

2023

Dedication

*This research project
report, affectionately dedicated Parents
and Teachers
To
Our Beloved
Who are continuous sources of
Inspiration for us in every step of life.*

..... Ms. Dhanashri Dipak Patil

CANDIDATE'S DECLARATION

I hereby declare that this thesis or
part thereof has not been submitted
by me or other
person to any other
University or
Institute for Degree
or
Diploma

Place: MPKV, Rahuri

Date: / /2023

(Dhanashri Patil)

Dr. M. S. Mane
Head, Interfaculty,
Dept. of Irrigation Water Management,
Post-Graduation Institute,
Mahatma Phule Krishi Vidyapeeth, Rahuri –
413 722 Dist. Ahmednagar, Maharashtra
State (India)

CERTIFICATE

This is to certify that the thesis entitled. “**DESIGN OF PIPE DISTRIBUTION NETWORK IRRIGATION SYSTEM IN COMMAND AREA FOR IMPROVING WATER USE EFFICIENCY (WUE), LAND AND WATER PRODUCTIVITY AND PREVENTING LAND DEGRADATION**” submitted to the Faculty of Agriculture Engineering, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (Maharashtra) in partial fulfillment of the requirement for the award of degree of **MASTER OF TECHNOLOGY (AGRICULTURE) in IRRIGATION AND DRAINAGE ENGINEERING**, embodies the result of a piece of bonafide research work carried by **MS. DHANASHRI DIPAK PATIL** under my guidance and supervision and that no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged.

Place: MPKV, Rahuri

Date: / /2023

(M.S. Mane)

Dr. S.B. Gadge
Head,
Department of Irrigation and Drainage
Engineering, Faculty of Agricultural
Engineering,
Mahatma Phule Krishi Vidyapeeth, Rahuri -
413 722, Dist. Ahmednagar, Maharashtra
State (India)

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Place: MPKV, Rahuri

Date: / / 2023

(S. B. Gadge)

Dr. D.D. Pawar
Dean,
Faculty of Agricultural Engineering,
Mahatma Phule Krishi Vidyapeeth Rahuri –
413 722, Dist. Ahmednagar, Maharashtra
State (India)

CERTIFICATE

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Place: MPKV, Rahuri

Date: / /2023

(D.D. Pawar)

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“Words provide the wings to our ideas

but sometimes it is very difficult to express feelings in words”.

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(Dhanashri D. Patil)

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LIST OF ABBREVIATIONS

Abbreviations	Description
AICRP	: All India Coordinated Research Project
AV	: Air Valve
B: C ratio	: Benefit cost ratio
CAAST/ CSAWM	: Center for Advanced Agricultural Science and Technology “Climate Smart Agriculture and Water Management”.
CDN	: Canal Distribution Network
cm	: Centimeter
CPE	: Cumulative pan evaporation
CV	: Coefficient of variation
CWR	: Crop water requirement
DAS	: Day after sowing
Dept.	: Department
Dr. A.S.C.A.E & T	: Dr. Annasaheb Shinde College of Agricultural Engineering and Technology
DU	: Distribution uniformity
DV	: Dorot Valve
E	: East
EC	: Electrical conductivity
Eq.	: Equation
ESA	: European space agency
ET	: Evapotranspiration
<i>et al.</i>	: And another
ETc	: Crop evapotranspiration
etc.	: Etcetera
ETo	: Reference evapotranspiration
EVI	: Enhanced vegetation index
FAO	: Food and Agriculture Organization
FCC	: False Composite Color
Fig	: Figure
Fig.	: Figure
GIS	: Geographical Information System
GPS	: Global Positioning System
HDPE	: High Density Poly Ethylene
IDE	: Irrigation and Drainage Engineering
IDW	: Inverse Distance Weighting
IRS	: Indian Remote Sensing

ISODATA	:	International Organization for Standardization Data
IWR	:	Irrigation water requirement
<i>J.</i>	:	Journal
K _c	:	Crop coefficient
LISS	:	Linear Imaging Self Scanning Sensor
lph	:	Litre per hour
LULC	:	Land use / land cover
M.P.K.V	:	Mahatma Phule Krishi Vidyapeeth
NDVI	:	Normalize Difference Vegetation Index
NIR	:	Near Infra-Red
NIWR	:	Net irrigation water requirement
PAR	:	Photosynthetically Active Radiation
PDN	:	Pipe Distribution Network
PE	:	Poly Ethylene
PVC	:	Poly Vinyl Chloride
RH	:	Relative humidity
RS	:	Remote sensing
SOI	:	Survey of India
TM	:	Thematic mapper
USGS	:	United State Geological Survey
<i>viz.</i>	:	Videlicet (Namely)
WUE	:	Water use efficiency

LIST OF SYMBOLS

Symbols	:	Description
%	:	Percent
@	:	at the rate
⁰ C	:	Degree Celsius
3D	:	Three dimension
<i>et al</i>	:	And others
ha	:	Hectare
i.e	:	That is
km ²	:	Square kilometre
lph	:	Litre per hour
m	:	Metre
MCM	:	Million cubic metre
Mha.m	:	Million hectare metre
ml/ha	:	Millilitres per hectare
mm	:	Millimetre
mm d ⁻¹	:	Millimetre per day
T	:	Temperature
TMC	:	Thousands million cubic metres

ABSTRACT

**DESIGN OF PIPE DISTRIBUTION NETWORK IRRIGATION SYSTEM IN
COMMAND AREA FOR IMPROVING WATER USE EFFICIENCY (WUE), LAND
AND WATER PRODUCTIVITY AND PREVENTING LAND DEGRADATION**

by

Ms. Patil Dhanashri Dipak**Master of Technology****(Agricultural Engineering)**

in

Irrigation and Drainage Engineering**Mahatma Phule Krishi Vidyapeeth, Rahuri-413722,****District – Ahmednagar (Maharashtra)****2022**

Research Guide: Dr. M. S. Mane**Department: Interfaculty, Dept. of Irrigation Water Management**

Water is life for all living being on the earth. Water ensures food security, feed livestock, maintain organic life and fulfill domestic and industrial needs. Presently the annual agricultural output is just sufficient to sustain our food grain requirement. To meet the challenge of regular expansion of size of population, the productivity of the land and water has to enhance, as both the resources are limited. Water is a major and vital input to increase agricultural productivity. In the command area, there is unequal distribution of water also water losses due to unlining of canal are more. Thus, the objective of this study is to emphasis on the use of Pipe Distribution Network instead of Canal Distribution Network in the command area of irrigation project to improve water use efficiency.

The growing demand of food for large population can only be met by optimum utilization of available water and appropriate allocation of available land to different crops. Therefore, a study entitled "Design of pipe distribution network irrigation system in the command area for improving water use efficiency (WUE), land and water productivity and preventing land degradation" was taken. For planning of pipe distribution network portion of left bank canal command area of Mula irrigation network was selected for this study. For designing of pipe distribution network, maximum flows required per shift were calculated by using maximum daily crop water requirement and according to that flow mainlines were designed. For each shift 2158 m³/hr flow will be required and to carry that flow 5 mainlines were designed having size 400mm (4 pipes) and 355 mm (1 pipe). The head loss calculated using Darcy- Weisbach equation in IrriCAD software. Pump inlet pressure was given according to required pressure at each outlet of chak. Before designing cropping pattern and yearly crop water requirement and irrigation water requirement were calculated.

Micro irrigation is one of the latest innovations for applying water and represents a definite advancement in irrigation technology. The high initial cost is the major hindrance in popularizing this irrigation system. The main objective of this study is to design pipe networks of micro irrigation subunits. In the research work sample chak design of drip irrigation and sprinkler irrigation were carried out. A chak of 18.3 ha was selected for design of micro irrigation. The pipeline hydraulics and economic parameters related to the costing of the system have been calculated in the software with the help of suitable database and by using appropriate formulae. The use of IrriCAD software result in the economical and efficient design of pipe network and can be easily adopted for designing pipe networks for any conditions of micro irrigation subunits. The yearly crop water requirement of command area is 3.92 MCM. Then by surface irrigation technique, the yearly irrigation water requirement of study area is 6.5 MCM while yearly irrigation water requirement by micro irrigation techniques (Drip/Sprinkler) is 4.4 MCM i.e. nearly 2 MCM water is saved annually by micro irrigation techniques and water saved which can be effectively used for increasing the area under command. The total area of command is 611 ha out of which area irrigated by existing canal network is 491 ha. By adopting pipe network in command area cultural command area will be 575 ha. Therefore about 17 % of area will increase over area under existing canal network. In the *summer* season, cotton crop under drip irrigation gives highest B/C ratio. Similarly, in *kharif* season groundnut under micro sprinkler and in *rabi* season wheat under micro sprinkler gives highest benefit cost ratio.

1. INTRODUCTION

Water is scarce natural resource and also fundamental to our life, livelihood, food security and sustainable development. Also, it is a vital resource of agricultural production on which almost all rural income depends. It is also important to the urban development and industrial growth. Hence accountable water use is imperative.

Throughout the world, irrigation (water for agriculture, or growing crops) is probably the most important use of water. Estimates vary, but about 70 percent of all the world's freshwater withdrawals go towards irrigation uses. Large-scale farming could not provide food for the world's large populations without the irrigation of crop fields by water gotten from rivers, lakes, reservoirs, and wells. Irrigation sector is the biggest consumer of water as more than 80% of available water resources in India are being presently utilized for irrigation purposes. However, the average water use efficiency of Irrigation Projects is assessed to be only of the order of 30-35% (Bhalange *et al*, 2015). There is gap between irrigation potential created and utilized, and it is up most important to minimize the gap. This can be achieved by use of pipe distribution network (Kolhe, 2012).

Role of Remote Sensing and GIS in irrigation water management

Land Use Land Cover

Land is the most important natural resource which consists of soil, water and associated plants and animals involving the total ecosystem. The rapid magnification of population and human activities are increasing the pressure on the limited land and soil resources for energy and numerous other needs. Land Use / Land Cover (LULC) maps describe the vegetation, water and natural features on the land surface. Land use land cover maps play a significant and prime role in planning, management and monitoring programme at local, region and national levels. The term and use relate to the human activity or economic function associated with specific piece of land, while the term land cover relates to the type feature present on the surface of the earth (Lillesand and Kiefer, 2000).

Satellite remote sensing technology has found its acceptance worldwide for rapid resource assessment and monitoring, particularly in the developing world. Satellite remote sensed images have been utilized for land use land cover mapping. The most successful attempt in developing a general-purpose classification scheme compatible with remote sensing data has been by (Anderson, 1971), which is referred to as USGS classification scheme.

Cropping Pattern Map

Cropping pattern is referred to the proportion of the area under various crops at a point of as it changes over the space and time. The cropping patterns of region are closely influenced by the geo-climatic, socio-economic, historical and political factors (Hussain, 1996). Patterns of crop land use of a region are manifestation of combined influence of physical and human environment. Weather plays a decisive role in determining the existing cropping pattern. Cropping pattern is also depending on terrain, topography, slope, soil and availability of water for irrigation use of pesticides, fertilizers and mechanization. In simple word cropping pattern means the production of area under various crops at a point of time. Cropping pattern play a virtual role in determining the level of agricultural production, which in turns would reflect on the agricultural economy of an area. In many countries agricultural activities mostly depends on monsoon. As the monsoon is seasonal, agricultural production requires external water sources for crop yields. It is possible to sustain and utilize water resource completely by adopting the scientific method of agricultural practices. Remote sensing and GIS play an important role in cost effective agricultural applications and implementations.

Estimation of Crop Water Requirement and Irrigation Water Requirement

The term crop water requirement is defined as “amount of water required to the crop from its planting date to harvesting date”. It also refers to the amount of water required to compensate the evapo-transpiration loss from cropped field. It depends on crop type, stage of growth and evaporation demand. The rapidly depleting water resources and agro environmental health threaten the sustenance of existing levels of agricultural production, and call for efficient use of water over space and time (Kumari *et al.*, 2013). Hence estimation of CWR of various crops is necessary which will help in planning an accurate irrigation system to save best possible amount of available water. Accurate quantification of crop water requirements of any crop is essentially required for irrigation scheduling and water management (Yadav *et al.*, 2011). It is "the depth of water needed to meet the water loss through evapotranspiration of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment. It is a function of crop characteristics, management, and environmental demands. Crop water requirement can be calculated from reference evapotranspiration using crop coefficient (K_c). The reference evapotranspiration (ET_r) can be explained as the rate at which readily available soil water is evaporated from specified vegetated surfaces (Jensen *et al.*, 1990). ET is one of the most important variables in the hydrological cycle after rainfall which affects the spatial water requirement of the crops (Mohan and Arumugam, 1996). The FAO experts accepted the FAO Penman-Monteith method as a standard method for definition and computation of reference

evapotranspiration (ET_r) and crop water requirement. The FAO Penman-Monteith method provides consistent ET_r values in all regions and climates (Allen *et al.*, 1998). The estimation of the water requirement of crops is one of the basic needs for crop planning of any irrigation project.

Irrigation Water Management

Irrigation water management is the act of timing and regulating irrigation water application in a way that will satisfy the water requirement of the crop without wasting water, energy, and plant nutrients or degrading the soil resource. This involves applying water according to crop needs in amounts that can be held in the soil and at rates consistent with the intake characteristics of the soil. A primary objective in the field of irrigation water management is to give irrigators an understanding of conservation irrigation principles. This is done by showing them how they can judge the effectiveness of their own irrigation practices, make good water management decisions, or recognize the need to make adjustments in existing systems or to install new systems.

The irrigation system consists of a (main) intake structure or (main) pumping station, a conveyance system, a distribution system, a field application system, and a drainage system. The (main) intake structure, or (main) pumping station, directs water from the source of supply, such as a reservoir or a river, into the irrigation system. The conveyance system assures the transport of water from the main intake structure or main 4 pumping station up to the field ditches. The distribution system assures the transport of water through field ditches to the irrigated fields.

In India, nearly 83% of developed water resources are being used for agriculture (Planning Commission, 2002). Agriculture has been the primary source of livelihood for 75% of the population of India and it contributes to 30% of GDP and 60% employment (Panigrahi and Goyal, 2016). In Maharashtra only 19.64% of the total cultivable area is irrigated. As the productivity of irrigated agriculture is 2 to 3 times higher than rainfed agriculture, it is important that more area is brought under irrigation to meet the food demands of the rising population. This is possible either by the development of additional water resources or efficient management of the available water resources under existing scenarios. It is also observed that the improper irrigation water management in canal commands is responsible for problems of water-logging and soil salinity which affect crop productivity in long-term. If water management in canal command is improved, it will help in reducing deep percolation losses to water table. Ultimately, it can help in reducing water logging and soil salinity. If these plant stresses are controlled, it is expected that land and water productivity may improve. The additional advantage of improving water use efficiency is that there would be saving of irrigation water and it can be used to bring additional land under irrigation.

Ultimate irrigation potential of India is 140 million hectares. Irrigation potential to the tune of about 102 million hectares has been created through major/medium/minor surface water irrigation projects and use of ground water. However, potential utilization is about 87 million hectares only. However, the average water use efficiency of irrigation projects is assessed to be only of the order of 30 - 35%. Thus, there is gap between irrigation potential created and utilized, and it is up most important to minimize the gap. This can be achieved by use of pipe distribution network (Kolhe, 2012). In view of above facts, the present study entitled, 'Design of pipe distribution network irrigation system in command area for improving water use efficiency (WUE), land and water productivity and preventing land degradation' is planned with the following objectives;

- i. To prepare the land use land cover map of the left bank command area of Mula River irrigation network, managed by Water Users' Association (WUA).
- ii. To work out the water requirement of crops in the selected command.
- iii. To design the pipe distribution network irrigation system for the selected command.
- iv. To evaluate economics of pipe distribution network.

2. LITERATURE REVIEW

In order to achieve the objective of this project, we studied different research papers and reviews related to pipe distribution network, crop water requirement and land use land cover.

- To prepare the land use land cover map of the left bank command area of Mula River irrigation network, managed by Water Users' Association (WUA).
- To work out the water requirement of crops in the selected command.
- To design the pipe distribution network irrigation system for the selected command.
- To evaluate economics of pipe distribution network.

The chapter described below, have provided us beneficial knowledge of the objective, which are enlisted in following section.

2.1 Development of Land Use Land Cover and Cropping Pattern Maps

Casasnovas *et al.* (2005) proposed a method that allows long term cropping patterns to be mapped using time-series of crop maps derived from supervised classification of remote sensing data. These maps allow implicit spatial and temporal relationships between the crops grown in an agricultural area. The method was applied to map the multi-year cropping patterns in the Flumen irrigation district (33,000 ha), which is located in the Ebro Valley (northeast Spain). A 7-year time series (1993, 1994, 1996, 1997, 1998, 1999 and 2000) of crop maps derived from Landsat 5 TM and Landsat 7 ETM+ images was used to obtain the yearly crop maps from which to derive the multi-year cropping patterns. To achieve this, the proposed method looks for the spatial and temporal relationships between the main crops present in the study area in their typical locations (areas where the crops are most frequently located) and the alternate crops that have been in these locations in any of the years of the analysed time-series. GIS overlay analysis operations mainly cross-classification operations—are applied to derive the spatial and temporal relationships between crops.

Yuan *et al.*, (2008) developed a methodology to map and monitor land cover change using multi-temporal Landsat TM data in the seven-county twin cities metropolitan area of Minnesota for 1986, 1991, 1998 and 2002. Their result showed that between 1986 and 2002 the amount of urban land increased from 23.7 % to 32.8 % of the total area, while rural cover types of agriculture, forest and wetland decreased from 69.6 % to 60.5 %.

Joshi and Nagare (2009) symbolized a basin which was economically growing fast by converting the fallow lands, woodlands and badlands to agricultural land for the past few decades. The Pravara River basin was selected for the study which is a tributary of Godavari River in Maharashtra. The study area falls in a semi-arid tract of the Western Upland Maharashtra which

is a part of the Deccan trap region, in India. IRS 1 C-LISS III and IRS 1 C PAN, IRS P6 - LISS III and IRS 1 DPAN images were merged to make imageries with resolution matching to the landscape processes operating in the area. The images of the years 1997, 2000, 2004 and 2007 were analysed to detect the changes in the land use and land cover in the past ten years. The analysis revealed that there had been 20 % increase in the agricultural area over the past ten years. Built up area also had increased from 1.35 % to 6.36 % of the area and dense vegetation also had marginally increased. This significant increase in the agricultural area occurred owing to the reclamation of the natural ravines and fallow lands.

Panigrahy *et al.* (2011) carried out the study to delineate the existing cropping systems in the Indo-Gangetic Plains (IGP) using 10-day composite Spot Vegetation (VGT) NDVI data acquired over a crop year (June – May). Results showed that it is feasible to identify the major crops like rice, wheat, sugarcane, potato, and cotton in the dominant growing areas with good accuracy. Double cropping pattern is the most prevalent. Rice-wheat, sugarcane based, cotton- wheat, rice-potato, rice - rice, maize / millet-wheat are some of the major rotations followed. Rice-wheat is the dominant rotation accounting for around 40% of the net sown area. Triple crop rotations were less than 5% of the area and observed in some parts of Uttar Pradesh, Bihar and West Bengal. Single crop rotation of rice-fallow is significant only in West Bengal

Amin and Singh (2012) carried out a study on land use/land cover mapping of Srinagar city in Kashmir valley. They observed that the Srinagar city has experienced significant changes during 1990 to 2007. The analysis also showed that changes in land use pattern have resulted in the loss of forest area and open spaces, etc.

Rahman *et al.* (2012) used Landsat TM and IRS P6 LISS III satellite images to analyse the spatial and temporal change of cropland pattern in Bogra district of Bangladesh over the last 16 years, between 1988-89 and 2004-05. The seasonal cropland maps were derived from object-based classification of satellite images, and then two-date classified image differencing with GIS overlay technique and decision rules were applied. Cropping pattern change was analysed in a spatial and quantitative way using Integrated Land and Water Information System (ILWIS) and Land Change Modular of IDRISI Andes. The results showed that the mono crop cultivation was found in summer, but in winter, areas under different crop cultivation had changed dramatically. The analysis showed that changes occurred mainly in the north northwest and southwest of the areas, and during the time the highest change area was found under the rice-potato pattern.

Vimla *et al.* (2012) developed land use map of Naina-Gorma River basin which is an important source and supplies of water to the living beings of the area. The study was carried out to delineate the land use classes in part of the Rewa district (M.P.), adjoining place of the study

area is Allahabad district (U.P), comprises the North – Eastern and Southern portion of the Rewa district. ERDAS Imagine 8.6 computer software was used to develop land use classification using IRS 1- C, LISS III, image. Unsupervised classification, ISODATA clustering method was used to classify the image and visual image interpretation approach used to delineate the land use classes. The study focused on demarcating boundaries of different land use land cover units from an analysis, with the help of SOI toposheet, and satellite images on 1:50,000 scale, the study divided the area into forest, open scrub, dense scrub, Agriculture Rocky/stony waste land, Sandy soil/land/patches, Settlement, River and other water bodies.

Jwan Al-doski *et al.* (2013) studied in details components related to image classifications process and procedures in image classification techniques and explained in detail two common techniques K – means Classifier and Support Vector Machine. These image classification techniques can be used in the production of land use land cover maps at a regional and global scale.

Wong *et al.* (2014) used high resolution satellite data from IKONOS to perform land use land cover mapping in Johor Bahru city and adjacent areas (Malaysia). Spatial image processing was carried out using the six texture algorithms (mean, variance, contrast, homogeneity, entropy, and GLDV angular second moment) with five difference window sizes (from 3x3 to 11x11). Three different classifiers i.e., Maximum Likelihood Classifier (MLC), Artificial Neural Network (ANN) and Supported Vector Machine (SVM) were used to classify the texture parameters of different spectral bands individually and all bands together using the same training and validation samples. Results indicated that texture parameters of all bands together generally showed a better performance (overall accuracy = 90.10%) for land LULC mapping, however, single spectral band could only achieve an overall accuracy of 72.67%. This research also found an improvement of the overall accuracy (OA) using single-texture multi-scales approach (OA=89.10%) and single scale multi-textures approach (OA=90.10%) compared with all original bands (OA=84.02%) because of the complementary information from different bands and different texture algorithms.

Bharathkumar *et al.* (2015) prepared crop pattern map of the crops grown in Tumkur Taluk located in Southern part of Karnataka, India, using NDVI technique. The cropping pattern includes majorly Coconut plantation, Arecanut plantation, Banana plantation, Ragi, Wheat, Maize, Jowar and other crops, was carried out using the NDVI processing of Landsat 8 data. NDVI result was recorded by taking the training sets in field visit. Finally, the crop pattern map was prepared using ArcGIS tools. The results showed that among current cropping patterns Coconut plantation, Ragi, Rice, Maize, Wheat consumes less water and they are currently

suitable for the area. But Areca nut plantation, Rice and Banana plantation consume large amount of water and were not at all suitable for the regional climatic condition.

Sharma *et al.* (2015) used satellite data to analyse crop rotation and long-term changes monitoring in cropping pattern along with other spatial and non-spatial collateral data at block level of Kurukshetra District of Haryana. Multi-date IRS LISS-III data of different seasons for the year 2007-08 have been used for the study. Cropping pattern maps of Rabi, Kharif and Summer season have been understood to know the spatial distribution and associations between crops or crops and uncultivated land in the same fields (although not in a particular order of sequence). The findings of the study were useful to the Department of Agriculture, Haryana for planning of agricultural strategies in the district and for planning agricultural research and extension activities for crop diversification.

Chaudhary *et al.* (2017) used remote sensing and GIS for land use land cover mapping of Koshalya-Jhajhara watershed, India. The study aimed to analyse the changes in Land Use/ Land Cover (LULC) in Koshalya-Jhajhara (K-J) watershed using remote sensing and GIS. Landsat (7 ETM+ and 8) have been used for LULC mapping and monitoring while Global Positioning System was used for ground truth verification. The classification used was hybrid of unsupervised, supervised and on-screen digitization and comparison. The main categories were dense forest, open forest, scrub forest, built up compact, built up Sparse, Industry, and cropped in 2 seasons, Fallow land and water body. Major change detected in the area under category built up which has increased from 7.12 to 24.84 km² over the study period of 1999-2000 to 2015-2016. The area under forest was found to decrease from 109.35 to 96.78km² and under agricultural land from 12.61 to 7.35km², respectively. This indicates that substantial amount of agricultural land and forest has become under urbanization.

Huynh Vuong Thu Minh *et al.* (2019) generated a rice cropping pattern map using the Support Vector Machine (SVM) classification of Sentinel-1A satellite data. The accuracy of the classification was found to be 80.7% with a 0.78 Kappa coefficient. Therefore, it was concluded that Sentinel-1A satellite data can be used to detect and understand rice phenological changes as well as rice cropping systems using radar backscattering.

Aqil Tariq *et al.* (2022) developed maps of cropland, cropping patterns and crop types by combining optical remote sensing images with decision tree classifier and random forest. This study applied a methodology to identify cropland and specific crop types, including tobacco, wheat, barley, and gram, as well as the following cropping patterns: wheat-tobacco, wheat-gram, wheat-barley, and wheat-maize, which are common in Gujranwala District, Pakistan, the study region. The methodology was subsequently evaluated using Landsat images, crop statistical data

for 2020 and 2021, and field data on cropping patterns. The results highlight the high level of accuracy of the methodological approach presented using Sentinel-2 and Landsat-8 images, together with ML techniques, for mapping not only the distribution of cropland, but also crop types and cropping patterns when validated at the county level.

2.2 Estimation of Water Requirement

Saravan *et al* (2014) studied on determination of Water requirements of Main Crops in the Tank Irrigation Command area using CROPWAT 8.0. A Study was carried out to determine the water requirement of main crops in the perumal tank irrigation command area in cuddalore district. The main crops include rice, groundnut and sugarcane. The crop water requirement was determined using 15-year climatic data using CROPWAT 8.0. In the method reference crop evapotranspiration (ET_o) was determined using the FAO Penman - Monteith method and the effective rainfall was calculated using USDA S.C method. The study shows that the dam can conveniently supply the water requirement for irrigation in the area used at present and also in the entire land area. The results obtained from the study can be used as a guide by farmers for selecting the amount and frequently of irrigation water for the main crop.

Kulkarni *et al.* (2015) carried out comparative study of evaluation of evapotranspiration methods and calculation of crop water requirements at chaskaman command area in pune region. In experiment seven different methods were used; which are radiation based, temperature based and combine parameters based (FAO-56 modified Penman Monteith, FAO-24 Penman Monteith, FAO-56 Hargreaves, Turc, Thornthwaite, Blaney-Criddle and Priestley Taylor. Chaskaman dam and its left bank canal were selected for this project. The objective of the project work was to calculate daily, monthly and yearly reference ET_o using modified PM equations for left bank canal of Chaskaman dam and its command area. Further ET_c (crop evapotranspiration/crop water requirement) was calculated for that command area.

Ganesh Babu *et al.* (2015) estimated of crop water requirement, effective rainfall and irrigation water requirement for vegetable crops using CROPWAT for the Bapatla region in Andhra Pradesh state, India. Daily meteorological data including rainfall, maximum and minimum temperatures, relative humidity, wind speed and sunshine hours were collected for the period of 2009 to 2013 and used as input data for CROPWAT. Average peak monthly ET_o was observed to be 8.09 mm/day for the month of June and followed by the 7.55 mm/ day for the month of May. Whereas average minimum ET_o were observed were 3.85 and 3.92 mm/day in the months of December and January, respectively. The average effective rainfall was estimated for the study area as 769.3 mm out of 1060.3 mm annual rainfall. The crop water requirement (ET_c) and

irrigation water requirement were estimated for vegetable crops during Rabi season in the study area (Bapatla) as 516.3 mm and 470.4 mm, respectively.

Lhomme *et al.* (2015) estimated crop water requirement by extending the one-step approach to dual crop coefficients. This method was challenged to the benefit of a one-step approach, where crop evapotranspiration is directly calculated from a Penman–Monteith equation, its surface resistance replacing the crop coefficient. The case of dual crop coefficients (K_{cb} for the crop and K_e for the soil) using a full two-layer model as a reference, it is shown that the FAO-56 dual crop coefficient approach can be translated into a one-step approach based upon a modified combination equation. This equation has the basic form of the Penman–Monteith equation but its surface resistance is calculated as the parallel sum of a foliage resistance (replacing K_{cb}) and a soil surface resistance (replacing K_e). They also showed that the foliage resistance, which depends on leaf stomatal resistance and leaf area, was inferred from the basal crop coefficient (K_{cb}) in a way similar to the Matt–Shuttleworth method.

Khandelwal *et al.* (2015) estimated irrigation water requirements of different crops in Limbasi branch canal command area of Gujarat. The Hargreaves – Samani approach for reference crop evapotranspiration (ET_o) estimation was used for thirteen years of available data and the mean monthly ET_o values were computed which were analysed statistically. The potential crop evapotranspiration (ET_c) and net irrigation requirement (NIR) of different crops in kharif, rabi and summer season were estimated. Results show that the NIR values (mm) for kharif crop paddy was 166.8; rabi crops jowar, tobacco & wheat were 404.3, 504.2 & 564.7 and summer crops paddy & bajri were 851.1 & 619mm, respectively.

Banavath Ranga Naik (2016) carried out optimal crop water requirement for Araniar reservoir basin by using the FAO CROPWAT model. The CWR was determined in this study for the cropping pattern of the year 2013-14. The results obtained as the CWR requires for the Kharif season was 23.49 MCM (Million Cubic Meter) to irrigate 2226.7 ha and for Rabi Season which was about 8.07 MCM to irrigate 1416 ha in the study area as per 2013 and 2014 cropping pattern system.

Nithya *et al.* (2016) studied water requirement of selected crops using CROPWAT 8.0 is carried out to determine the crop water requirement of few selected crops for the command area Tarikere. The crops include arecanut, coconut, cotton, and banana for two seasons, sweet pepper, onion, potato, rice, pulses, mango, cotton, sugarcane and millet (ragi). Crop water requirement for each crop was determined by using 30-year climatic data in CROPWAT. Reference crop evapotranspiration (ET_0) was determined using the FAO Penman-Monteith method. For all the crops considered, three decades: decades I, II, and III and seven crop growth stages: nursery,

nursery/land preparation, initial stage, development stage, mid-season and late season stage were considered. The study shows that reference evapotranspiration (ET₀) varies from 2.5 to 3.36 mm/day for the area under study. The gross water requirement was 342.42 mm/year with an application efficiency of 70% and hence the entire crop area of 4466 ha requires 16 MCM. Thus, the dam can conveniently supply the water required for irrigation in the area.

Shreedhar *et al.* (2016) Studied on water requirement of selected crops under Markandeya command area. The selected crops include jowar, Groundnut, Hybrid Maize, Pulses, Mexican Wheat, Bengal Gram, Green Gram and Sunflower. Crop water requirement for each of the crops was determined by using 30-year climatic data. Reference crop evapo-transpiration (ET₀) was determined using the FAO Penman Monteith method. For all the crops, crop growth stages such as nursery, land preparation, initial stage, development stage, mid-season and late season stage were considered. The net irrigation requirement was 218.1mm/year. The gross water requirement was 311.57 mm/year with an application efficiency of 70%. Therefore, the entire land area of 21290 ha requires 66.33 million cubic meters. Thus, the results of the study estimated that dam can conveniently supply the water required for irrigation in the command area.

Shah *et al.* (2017) carried out determination of crop water requirement and irrigation scheduling for banana in Dhandhoda station of Vadodara district in Gujarat, India. The climatological data of ten years (2005 to 2014) and CROPWAT were used for study. Crop water requirement for Banana varies from 936.6 mm to 745.6 mm over a period of ten years. Crop water requirement of Banana crop for the year 2014 is 853.8 mm and as per irrigation scheduling carried out by Critical depletion scenario, the total depth of irrigation is 878.8 mm with 0.1 percent yield reduction. It is recommended to irrigate the field as per critical depletion scenario as it applies water before the crop goes under water stress and hence it gives maximum yield.

Mehanuddin *et al.* (2018) studied on water requirement of selected crops and irrigation scheduling using CROPWAT 8.0 in the Shimoga Taluk in Karnataka state, India. The crops include cotton, maize for two seasons and sugarcane. By using the 10-year climatic data, Crop evapotranspiration (ET_c) and Reference crop evapotranspiration (ET₀) for each crop were determined using CROPWAT 8.0. The study shows that for both cotton and maize crops in Rabi season effective rainfall is not sufficient to fulfil the crop water requirement. Hence irrigation requirement is needed to satisfy Crop water requirement. But for the same crops in Kharif season effective rainfall is enough to compensate crop water requirement. The crop sugarcane is a perennial crop for its crop period effective rainfall is sufficient to compensate the crop water requirement.

Janhavi *et al.* (2019) determined water requirement and irrigation schedule for right bank canal command of Shahid Veer Narayan Singh dam using CROPWAT 8.0. In this study after analysing water requirements during the entire growth period of Paddy crop (Main Kharif crop of the study area), data on seasonal water discharge, soil data, meteorological data was collected and irrigation scheduling of Paddy crop was carried out through the application of CROPWAT 8.0 Software with the aim to maximize crop cultivation area and optimum utilization of water resources. The designed discharge capacity of water in the study area of Right bank canal at head is 6.65 cumecs and after analysis it was found that in practice 19.92 Mm³ of water is supplied in the study area. During the Kharif season, crop water requirement (CWR) scheme supply requires only 8.95 Mm³ after optimization through CROPWAT 8.0 software, which was 44.92 % of actual supplied water.

Gautam *et al.* (2019) estimated crop water requirement (CWR) of major vegetable crops of selected Agro-climatic zones of Madhya Pradesh, India, on the basis of Reference Evapotranspiration. The study was performed for major vegetable crops namely tomato, onion, pea, brinjal, potato and okra. The mean annual sum of CWR of vegetable crops in all districts was found highest for Brinjal, in winter season it is maximum in Barwani (32.87 litre) during peak period and minimum in Alirajpur (5.59 litre) during lean period whereas in monsoon season maximum in Neemuch (23.68 litre) during peak period and minimum in Jhabua (5.43 litre) during lean period and lowest for pea, in winter season it is maximum in Ratlam (6.22 litre) during peak period.

Baker *et al.* (2020) determined water requirements of crops under various Kc coefficient approaches by using water evaluation and planning for various soil textures. The results compared with the outputs of Single-Kc approach for summer and winter crops in addition to trees. The results showed when applying Dual-Kc approach, the water requirements was more compared with the Single-Kc approach, except the tomato, eggplant, and broad bean crop, which decreased by 5%, 4%, and 17% ,respectively. Also, there was a different in values of coefficient when compare two approaches, it was increased in Dual-Kc approach for wheat by 62% with 20% during initial and end-stage while ranged between 26-58% for trees during all season with more different for other winter and summer crops. The water requirement of crops was different according to soil texture. The net water requirement of wheat was 429 mm and 433 mm for sandy loam and clay loam, respectively with different in irrigation intervals 11 and 12, respectively, while the silt loam was recording water requirement 417 mm with 8 irrigation intervals.

Roja *et al.* (2020) estimated of crop water requirement of maize crop using FAO CROPWAT 8.0 model in north coastal districts of Andhra Pradesh. The simulation study was conducted with the

objectives of determining irrigation water requirement and irrigation scheduling for some major crops like maize and sugarcane. The Penman - Monteith method was used for evapotranspiration calculation in the model. 80% of critical soil moisture depletion was considered for irrigation. The model predicted the daily, decadal as well as monthly crop water requirement at different growing stages of maize crop. The crop water requirement and irrigation requirement for maize crop 238.6 mm and 212.6 mm.

Sahithya *et al.* (2021) determined the crop water requirement of selected crops for the command area of Bapatla channel. The major crops include paddy and maize for two seasons (kharif and rabi). CROPWAT 8.0 was used to estimate the reference evapotranspiration, crop water requirement and irrigation water requirement. Average peak monthly reference evapotranspiration (ET_o) was observed to be 6.65 mm day⁻¹ for the month of May. Whereas average minimum ET_o was observed as 3.28 mm day⁻¹ in the month of December. The results obtained as the TWD (Total Water Demand) of Bapatla channel command for two seasons (kharif and rabi) of crops paddy and maize was found to be 6500.04 ha-m in the year 2012-13. Similarly, for 2013-14, 2014-15, 2015-16- and 2016-17-years TWD was found to be 6325.18, 6521.42, 3102.40 and 5376.19 ha-m, respectively. It was observed that total water demand (TWD) was least in the year 2015-16 (3102.40 ha-m) and maximum in the year 2014-15 (6521.42 ha-m).

Madhusudhan *et al.* (2021) estimated crop water and net irrigation requirement of major crops grown in Mandya city using CROPWAT 8.0. The main crops grown in the city include Rice, Millet, Sugarcane and Pulses. The four crop growth stages (initial, development, mid and late) were considered for all crops and crop co-efficient (K_c) of various growth stages of the crops were obtained from Irrigation manual for each crop. Reference crop evapotranspiration (ET_o) was determined by using FAO Penman Monteith method and effective rainfall was calculated using USDA S.C method. The study shows that reference crop evapotranspiration, ET_o varied from 2.95 mm/day to 6.97 mm/day. The crop evapotranspiration (ET_c) and Net irrigation for Rice varied from 0.64mm/day to 8.61mm/day and 1145.8 mm, for Millet 1.76 mm/day to 7.23 mm/day and 366.0 mm, for Sugarcane 2.43 mm/day to 7.57 mm/day and 1164.3 mm and for Pulses 2.29 mm/day to 8.23 mm/day and 361.8 mm, respectively.

Chakravarti *et al.* (2022) estimated crop water requirement for Bargi left bank canal command area by multiplying reference crop evapotranspiration with crop coefficient values. Various methods of estimation of evapotranspiration were used. It was found that the wheat has the highest water requirement whereas maize has the minimum water requirement throughout the periods and the February month requires the maximum supply of water. The Gross water

requirement is found out to be 16,082,177.24 m³ per year and 5,064,098.5 m³ per year by Blaney Criddle Method and modified Penman method, respectively.

Feilong Jie *et al.* (2022) estimated effects on net irrigation water requirement of joint distribution of precipitation and reference evapotranspiration in the Jingdian District in Northwest China. A Copula function–Monte Carlo method (CFMC) was used to calculate the probability of irrigation water requirement. The results revealed the optimal distribution functions of precipitation and reference evapotranspiration to be gamma distribution and lognormal distribution. The probability density map of the joint distribution of precipitation and reference evapotranspiration has a “saddle” shape; that is, irrigation water requirement and reference evapotranspiration are usually inversely related. As the probability of the irrigation water requirement increases, the net irrigation water requirement in the irrigation area also increases.

2.3 Design of Pipe Distribution Network

Smout (1999) reported that low-pressure pipelines on surface irrigation distribution systems serve about 4.5% of the world irrigation area. The main benefits compared with open channels are reduced leakage rates and land take requirements, and flexibility in irrigation timing which is important for diversified cropping systems. His research has shown that low-pressure buried-pipeline distribution systems can make a major contribution for improving water management in surface irrigation, both by reducing leakage from the distribution system and by providing users with a more flexible irrigation supply. These contributions, however, depend on the standard of survey, design and construction, and the limited knowledge of buried-pipe distribution systems among irrigation engineers is an important constraint. The resulting benefits also depend on the management of the system, and on agricultural, economic and social factors.

Mniruzzaman *et al.* (2002) assessed the performance of PVC and plastic pipe water distribution system for command area development and irrigation time saving by minimizing water losses. In the system, total discharge from deep tube well (DTW) was diverted to two or three directions by using PVC and plastic pipe of different length and diameters. Technical and economic feasibility of the system were also evaluated. The conveyance loss was 2.8 to 9.5% in PVC and plastic pipe whereas in earthen channel it varied from 30 to 33% in silty-clay loam soil, which indicate that on an average 83% water can be saved by improved pipe distribution system. By improving the pipe system about 37 to 41% command area was increased in both locations. The BCR of the pipe irrigation system varied from 2.74 to 1.43 on the basis of the 15 to 45 % discount rates.

Shah *et al.* (2010) carried out study on Sardar Sarovar Project (SSP) and reported that against an ultimate potential of 1.8 million hectares (Mha), Gujarat’s famous Sardar Sarovar Project (SSP) is irrigating less than 100,000 hectares (ha) by gravity flow 5 years after the dam, and the main

and branch canals were completed. The key problem is that farmers who are to benefit from irrigation refuse to part with the land needed to construct a surface distribution system below the outlet. They argue that the government should consider a buried piped distribution system as an alternative to sub-minors and field channels. The idea, however, is strongly criticized by irrigation engineers, based on the poor track record of piped distribution under government management.

Kolhe (2012) carried out study on optimal utilization of irrigation water by use of pipe distribution network (PDN) instead of canal distribution network (CDN) in command area. The objective of the study is to emphasis on the use of pipe distribution network (PDN) instead of canal distribution network (CDN) in command area of irrigation project to improve efficiency of water use. By virtue of PDN the water use efficiency can be improved to 70 to 80% from existing efficiency of 25 to 40 %. Thus, there is about two to three times increase in the water use efficiency for irrigation, which means that there will be 55 to 65 % improvement in overall water use efficiency. This study based on the design of PDN of Nagthana-2 Minor Irrigation (MI) project, located at Amravati district of Maharashtra state, which was initially designed to irrigate culturable command area (CCA) of 600 ha by conventional CDN, and now planned for gravity PDN and result implies that same volume of water could irrigate CCA of 1200 ha. In his study, focus was placed on the use of PDN instead of CDN in command area of irrigation project to improve efficiency of water use. By virtue of PDN the water use efficiency can be improved to 70 to 80 % from existing efficiency of 25 to 40 %.

Jadhav *et al.* (2014) conducted study on water loss from tank as well as canal network through seepage was determined and evaporation loss was estimated for Panchnadi Minor Irrigation Project in Konkan region. The conveyance efficiency of the lined, unlined section of the main canal and field channel was observed as 75.3, 52.1 and 34.8%, respectively. They developed scenario for increasing conveyance efficiency by canal lining or adaption of closed conduit and concluded that, if whole canal network is converted in closed conduit, then and additional area of 92.6 ha can be brought under irrigation i.e., about 2.6 times more than the existing area.

Mtolera *et al.* (2014) studied optimization of tree pipe networks layout and size, using particle swarm optimization, a commonly used design method for irrigation pipe network (IPN). Layout and size often involve trial and error approach. This makes it difficult to minimize capital investment and energy cost. Study was done to optimize simultaneously size and layout of the irrigation pipe networks using particle swarm optimization (PSO) technique. This technique was linked to the MATLAB software to reduce the pipeline investment cost in irrigation projects. The performance of PSO technique was tested and results were compared with non-optimized (Step-by-step) and genetic algorithm optimization methods. The proposed PSO technique with

an increase in the search space showed a quick response in the size of the swarm and the initial swarm compared to the non-optimized (Step-by-step) design method and genetic algorithm.

Patel *et al.* (2014) carried out study in replacement of sub minors with pressurized irrigation systems in canal command area. They said that there is no possibility to irrigate the entire command area of SSP through conventional flow irrigation. There is strong need for efficient and cost-effective use of limited delta to cover the entire command area where optimization of water use is the prime consideration. It has been recognized that use of modern irrigation methods like drip and sprinkler irrigation is the only alternative using Pressurized Irrigation Network System (PINS). Pressurized Irrigation Network System (PINS) is substitute arrangement for sub-minors and field channels in an open canal network.

Radhakrishna and Ravikumar (2014) in order to minimize the losses in conveyance of water from the source to the target site, the buried pipe distributaries systems have been designed and developed, which is the first of its kind for tank command irrigation with the adoption of solar pump to lift water from the jack well in order to reduce the dependence on the erratic electric supply at village level. The effect of on-demand water supply on different crops yields during Kharif and Rabi 2003 to 2008 indicated that there was a significant change in the yield of crops and cropping pattern in command area due to intervention of on demand water supply. During 2003 kharif, the WUE was 18.5 kg/ha cm and 13.0 kg/ha cm in paddy and mulberry, respectively. However, during 2007 the WUE was 88.12 and 39 kg/ha cm in paddy and mulberry, respectively.

Gadekar *et al.* (2015) carried out study on Nashik Left Bank Canal, Nashik. The reach of this canal is 64 km which is running open to atmosphere through the alluvial type of soil. The objective of study was to use closed circular conduits for the entire 64 km reach of canal in place of open canal irrigation [OCI] network to minimize the conveyance losses. They were estimated that 15.55 Mm³ of the water within the stretch of 64 km can be saved by using CCI for NLBC. The benefit-cost ratio as calculated for CCI system over OCI was 3.18 which is greater than 1, therefore CCI system can be thought for the implementation so as to optimally utilize the irrigation water.

2.4 Economics of Pipe Distribution Network

Briti Sundar Sil *et al.* (2013) computed least cost of pipe network. Hardy Cross Method was used for estimating the required discharge in each outlet of the pipe network, and optimization of the system was done to reduce the cost with the help of Microsoft-excel. The proposed optimization setup was very close to the original value, thereby validating its use for optimization.

Minakshi Shrivastava *et al.* (2014) carried out study on optimization technique for water supply network. The large amount of money is involved in laying of pipe network and its maintenance. Nearly 80-85% of the cost of total water supply system is invested in water transmission and distribution network. Hence efficient and cost-effective design of pipe network is of utmost importance and challenging task for engineers. Various optimization techniques have been used in last three decades by different investigators to analyse and optimize pipe network problem.

Nitish Kumar Gautam and Shibayan Sarkar (2018) estimated crop water requirements and assessed irrigation water distribution cost for rice production using a pipe network. The study carried out at humid subtropical region with sandy clay loam soil and farmers use border strip irrigation. The Man Kendall test was performed on six years monthly rainfall data to check for the presence of a trend. Thereafter, the crop water requirement for rice production was calculated based on FAO guidelines and average monthly rainfall. The crop water requirement in the study area amounted to 7.22 lakh m³, of which Phase I is 6.12 lakh m³ and Phase II is 1.2 lakh m³. In order to fulfil this requirement, irrigation was conducted through a pipe network. Actual irrigation value was calculated based on four years of irrigation water distribution data. Finally, the average depth of water logging, time of pumping and cost for surplus irrigated water were calculated. The cost of annual surplus irrigated water for rice was 4.32 lakhs for an irrigation area of 1.284 km² (phase I), and the same is INR 0.84 lakh for 0.252 km² (phase II).

Bhoir *et al.* (2018) carried out study on analysis and design of pipeline system instead of the canal system in Khadka Irrigation Project, located on Mule River basin in Ahmednagar district, Maharashtra. Pipes were selected to construct a network of the pipeline due to the availability of Plastic Irrigation Pipes and Reinforced Concrete Pipes. This study was undertaken to analyse canal system and to design a pipeline system to replace it. The overall efficiency of pipeline system was found out to be much better than Open Canal System also the distribution efficiency by use of lift irrigation was found out to be boundless.

Critique on review of literature

For effective irrigation water management and to reduce the salinity and waterlogging in command area, one of the techniques viz. pipe distribution network instead of canal network is carried out. So far considerable studies have been conducted to design the pipe distribution network irrigation system in command area for improving the water use efficiency, land and water productivity and preventing land degradation.

Satellite remote sensing technology has found its acceptance worldwide for rapid resource assessment and monitoring, particularly in the developing world. Satellite remote sensed images have been utilized for land use land cover mapping and also for change detection in land use land cover. As most of the researchers used Landsat and LISS satellite images for land use land cover mapping but for better accuracy Sentinel-2 images are used in the present study, because of the higher resolution than Landsat and LISS images. The above review found useful to understand the methodology for classification on satellite data and preparation of classification maps.

Determination of crop water requirement is required for irrigation scheduling, proper design of irrigation systems and water resource planning. Calculations of water requirement of crops are calculated based on the crop coefficient and reference evapotranspiration. Also major factors affecting water requirement of crops are humidity and wind speed. So far number of formulae available for calculation of crop evapotranspiration out of which many researchers followed Modified Penman Monteith equation. Hence Modified Penman Monteith was used in present study for calculation of crop evapotranspiration. Also many researchers followed CROPWAT model for determination of water requirement.

For better management of irrigation water pipe distribution network plays important role in improving water use efficiency. A prior knowledge of available flows, available storage, cropping pattern of command area required for designing of pipe distribution network. Most of the studied are carried out for drinking water distribution analysis as compared to PDN of irrigation system. No any research study was available on IrriCAD software for designing of PDN and analysis of PDN so in the present study IrriCAD was used for design and analysis of PDN.

3. MATERIALS AND METHODS

The study entitled, “Design of pipe distribution network irrigation system in command area for improving water use efficiency (WUE), land and water productivity and preventing land degradation”, was conducted with the objectives to prepare the land use land cover map of the left bank command area of Mula River irrigation network, managed by Water Users’ Association (WUA), to work out the water requirement of crops in the selected command, to design the pipe distribution network irrigation system for the selected command and to evaluate economics of pipe distribution network. The details of the methodology adopted in this study are described below;

3.1 Study Area

A portion of left bank command area, managed by Water Users’ Association WUA (namely, Renuka Mata Pani Vapar Sanstha, Manori, Tal-Rahuri), of Mula River irrigation network in Ahmednagar district of Maharashtra was selected as study area. The area lies between $74^{\circ}42'0''\text{E}$ to $74^{\circ}44'0''\text{E}$ longitude and $19^{\circ}26'30''\text{N}$ to $19^{\circ}27'30''\text{N}$ latitude with 657m elevation. This WUA controls 611 ha of cultural command and gets canal water supply from Left Bank Canal of Mula Dam. The sugarcane is important cash crop of Maharashtra. Also, sugarcane crop is main crop of this irrigation command. Farmers sell their sugarcane to Rahuri Cooperative Sugar Factory, Shri Shivaji Nagar, Rahuri. The crop productivity within command varies from 35 to 45 t/ha. It is lesser than potential productivity. It is mainly due to waterlogging, soil salinity and improper water and nutrient management. The subsurface drainage (SSD) is efficient technology for controlling waterlogging and soil salinity. However, water table has to be within 1.5 m for installation of SSD. However, there are some areas in irrigation command where water table remains well below 2.0 m but less than 3 m from soil surface (i.e., within capillary zone). Thus, SSD is not justified but crops suffer from soil salinity. Such areas remain under cultivation but with low crop productivity. By improving irrigation water management, it appears that problems of such areas can be solved. Maharashtra government supports national vision of “more crop per drop of water” and desires to bring all sugarcane area under drip. If drip system is to be installed in exiting canal network, secondary reservoir is required to store canal supply initially. The secondary reservoir known as Musulwadi lake of 33 Mcft capacity already exists in the command and it can effectively use for storing canal water which can be used later on for drip system. Therefore, whole irrigated area of WUA can be brought under micro irrigation by providing pumping stations at Musulwadi Lake and necessary pipe network for distribution of irrigation water. The location of the study area is shown in Fig. 3.1. The details of the Mula major project are presented in Table 3.1 and details of Musulwadi Dam are presented in Table 3.2 and Table 3.3.

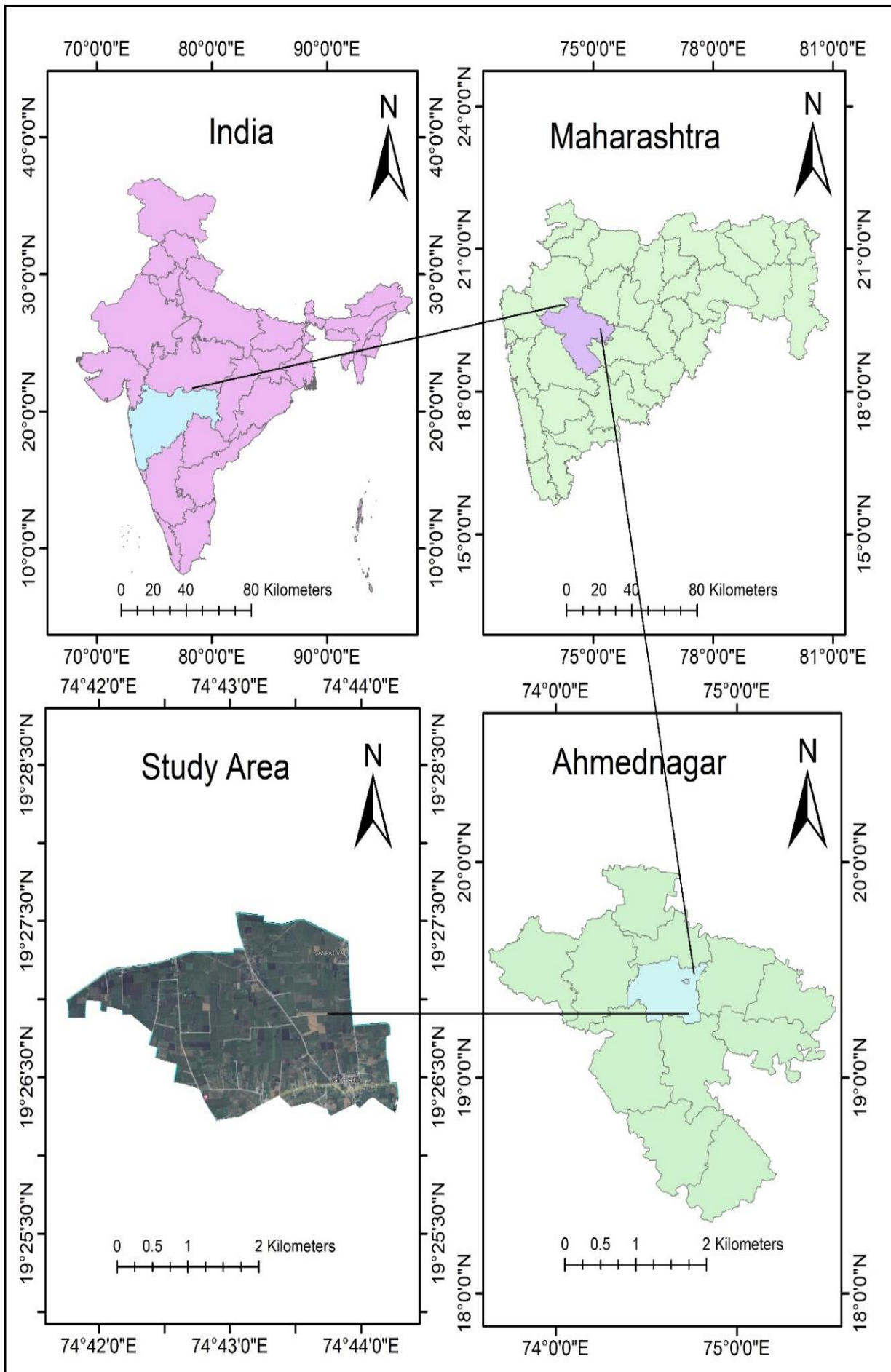


Fig. 3.1 Location map of study area

Table 3.1 Salient features of Mula Major Project

Sr. No.	Item	Details	
1.	Name of the project	Mula Major Project	
2.	Village	Baragaon Nandur	
3.	Taluka	Rahuri	
4.	District	Ahmednagar	
5.	River	Mula River	
6.	Basin	Godavari River	
7.	Catchment Area (sq. km)	2274	
8.	Classification of reservoir (Major/Medium/Minor)	Major project	
9.	Year of construction	1974	
10.	Dead storage Mm ³	128.38	
11.	Live storage Mm ³	608.80	
12.	Gross storage Mm ³	736.24	
13.	Submergence area Ha.	5344	
14.	T.B.L.(m)	549.80	
15.	M.W.L. (m)	553.21	
16.	F.R.L. (m)	552.30	
17.	M.D.D.L. (m)	534.010	
18.	R.B.L. (m)	568.43	
19.	Type of dam	Earthen Dam with Gated Spillway	
20.	Length of dam including spillway (m)	2856	
21.	Max. height of dam (m)	46.63	
22.	Capacity of outlet (Irrigation m ³ /sec)	RBC	LBC
		46.72	8.50
23.	Total Length of Canal (Km)	52	25
24.	Gross Command Area (ha)	110381	17004
25.	Cultivable Command Area (ha)	103370	15182
26.	Irrigable Command Area (ha)	70689	10121
27.	Irrigation Potential (ha)	71396	10222
28.	No. of Villages Under Command (Nos)	161	18

Table 3.2 Details of the Musalwadi Minor Irrigation Project

Particulars	Value
Length (m)	2300
Maximum Height of Tank (m)	14.80
Top Bank Level (m)	512.50
Full Reservoir Level (m)	510.50
High Flood Level (m)	511.50

Top Width of Tank (m)	3.00
D/s Slope of Embankment	2:1
U/s Slope of Embankment	2.5:1
Length of Waste Weir (m)	20
Diameter of Irrigation Outlet Valve (m)	0.75
Gross Storage Capacity (MCM)	5.36
Water Reserved for N.I. P. (MCM)	1.25
Probable Evaporation Losses (MCM)	1.44

Table 3.3 Details of canal network of Minor Irrigation Project

Sr. No.	Distributary no.	Length, m	Flow, Cusecs	Flow, Cubic m/hr	Area covered, ha
1	3-A	1400	4	407.76	105.56
2	3-B	2100	4	407.76	67.3
3	4	6500	15	1529.1	258.39
4	5-A	700	3	305.82	20
5	5-B	1200	4	407.76	39.84
Total					491.09

3.2 Data collection

The data used in this study was satellite data and other collateral data, and were collected from different sources.

3.2.1 Climatological data

Daily maximum and minimum temperature, maximum and minimum relative humidity, actual sunshine hours, wind velocity, rainfall data for year 2021-2022 for Rahuri station required for estimation of reference evapotranspiration (ET_r) were obtained from the India Meteorological Department observatory located at AICRP on Irrigation Water Management, Mahatma Phule Krishi Vidyapeeth, Rahuri. The ET_r data is shown in [Table A1](#) of Appendix- A. were calculated using FAO Penman Monteith method in Phule Jal application which uses latitude, day of year, wind speed, sunshine hours, maximum and minimum temperature and relative humidity as input parameters. The ET_r calculated in mm/day. This daily reference evapotranspiration data was used to calculate crop water requirement of all the crops in the command area according to crop period.

3.2.2 Crop data

The data on area under different crops were calculated from results obtained from seasonal cropping pattern maps of command area. Seasonal cropping pattern maps were derived from satellite data of year 2021-2022 using GIS software.

The other data such as crop coefficients used in ETc calculation were collected from recommendations from Mahatma Phule Krishi Vidyapeeth, Rahuri and some from literature.

Table 3.4 Details of major crops in the command area

Season	Crop	Crop Period (days)	Sowing Time	Harvesting Time
Summer	Cotton	180	01/04/2021	27/09/2021
	Maize	100	01/03/2021	08/06/2021
	Groundnut	120	07/02/2021	06/06/2021
Kharif	Soybean	100	01/07/2021	08/10/2021
	Onion	100	01/07/2021	08/10/2021
	Maize	100	01/07/2021	08/10/2021
	Groundnut	120	15/06/2021	12/10/2021
	Cotton	180	01/04/2021	27/09/2021
Rabi	Chickpea	100	15/10/2021	22/01/2022
	Onion	100	15/10/2021	22/01/2022
	Maize	100	15/10/2021	22/01/2022
	Wheat	110	01/11/2021	18/02/2022
Annual	Sugarcane	370	11/02/2021	15/02/2022

3.2.3 Remote sensing data

The Sentinel 2 satellite data was used as primary input in this study. Sentinel-2 serve a wide range of applications related to Earth's land and coastal water. The mission provides information for agricultural and forestry practices and for helping manage food security. (Source: <https://en.wikipedia.org/wiki/Sentinel-2>). Satellite images are used to determine land use land cover of the study area and to prepare thematic maps of cropping pattern. This is particularly important for to find out the area covered by each major crop in the study area.

Spatial, spectral and temporal resolution of satellite images are very important for the studies dealing with crop water requirements. Many studies on irrigation water management have indicated that Sentinel-2 has high resolution which applicable for hydrological purposes.

These sensors are suitable for agricultural areas with medium to big fields due to their high spatial resolution. Sentinel-2 covering the part of study area has been used in the present work.

The sensor details of Sentinel-2 are given in Table 3.5.

The high-resolution sentinel-2 satellite images (10 m) were used in this study to identify the fieldsizes, shapes and the crop types and preparation of different thematic maps.

The Sentinel-2 mission has the following characteristics:

- Multi-spectral data with 13 bands in the visible, near infrared and short-wave infrared part of the spectrum.
- Systematic global coverage of land surfaces from 56°S to 84°N, coastal waters, and all of the Mediterranean Sea.
- Revisiting every 5 days under the same viewing angles. At high latitudes, Sentinel swath overlap and some regions will be observed twice or more every 5 days, but with different viewing angles.
- Spatial resolution of 10m, 20m and 60m.
- 290 km field of view.
- Free and open data policy.

Sentinel-2 satellite image has been downloaded from the website: <https://earthexplorer.usgs.gov> acquired for the peak season months of the year 2021.

Table 3.5 Band characteristics of Sentinel-2

Sentinel-2 Bands	Central wavelength (µm)	Resolution (m)
Band 1- Coastal aerosol	0.443	60
Band 2 – Blue	0.490	10
Band 3 – Green	0.560	10
Band 4 – Red	0.665	10
Band 5 – Vegetation Red Edge	0.705	20
Band 6 – Vegetation Red Edge	0.740	20
Band 7 - Vegetation Red Edge	0.783	20
Band 8 – NIR	0.842	10
Band 8A – Vegetation Red Edge	0.865	20
Band 9 – Water vapor	0.945	60
Band 10 – SWIR – Cirrus	1.375	60
Band 11 – SWIR	1.610	20
Band 12 – SWIR	2.190	20

The downloaded satellite data for the command area is shown in Fig. 3.2, Fig.3.3 and Fig.3.4 for the season's *Summer*, *Kharif* and *Rabi*, respectively for year 2021.



Fig. 3.2 Satellite image for *summer* season of 2021

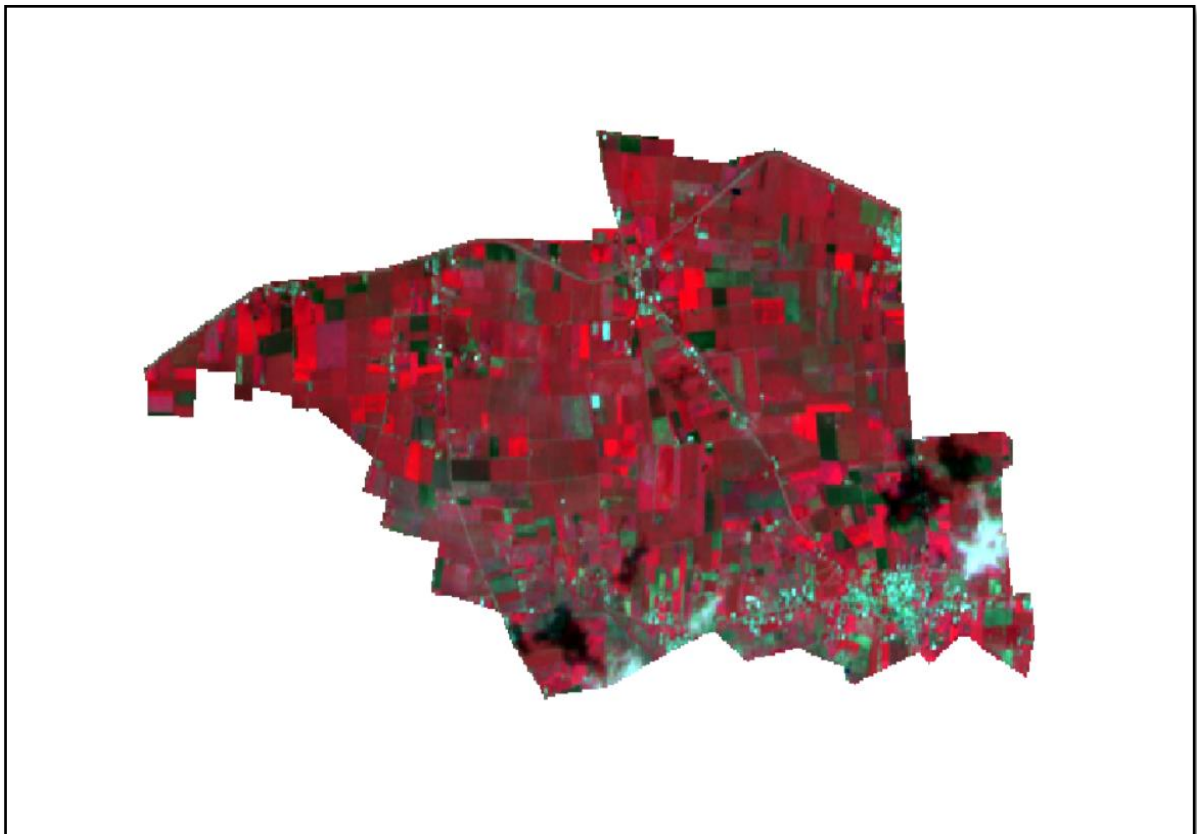


Fig.3.3 Satellite image for *kharif* season of 2021



Fig. 3.4 Satellite image for *rabi* season of 2021

3.2.4 Ground truth data

The ground truth data collected using Hand GPS during *Summer*, *Kharif* and *Rabi* seasons of 2021-2022 were used in identification of crops and aiding in selection of training sets for images classification.

3.3 Resources used in this study

A description of the resources used in the research study is described below:

3.3.1 Software used

The following software's were used in this research study, for image processing, deriving of thematic maps, ETr and ETc calculation and designing pipe distribution network. This software's are described as below;

3.3.1.1 ArcGIS v10.7

ArcGIS is geospatial software to view, edit, manage and analyse geographic data. ArcGIS 10.7 software was used to generate the GIS database and generation of the different cropping pattern maps in the different seasons of year 2021. Also, to calculate area covered by different crops in the images for year 2021. Fig. 3.5 shows interface for the ArcMap.

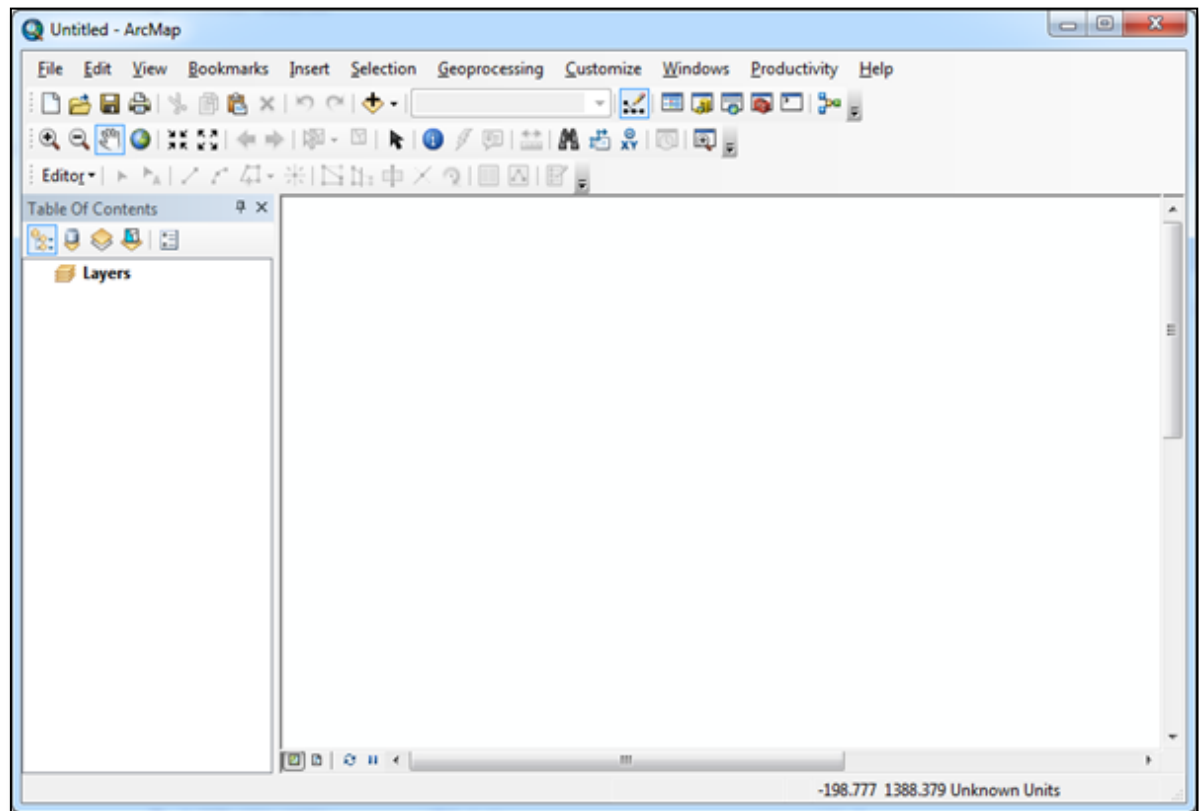


Fig.3.5 Interface of ArcMap

3.3.1.2 IrriCAD

IrrCAD was used for designing of pipe distribution network in command area. IrrCAD is the global leader in irrigation design software, developed by irrigation engineers at Lincoln Agritech. IrrCAD is used for designing all types of pressurised irrigation systems from concept through to completion; it is the essential design package. The program allows for rapid analysis of complex hydraulic systems, which facilitates faster design changes. The IRRICAD program comes with fully customisable databases from major irrigation suppliers. Fig. 3.6 shows interface for the IrrCAD software. (Source: <https://www.irricad.com>)

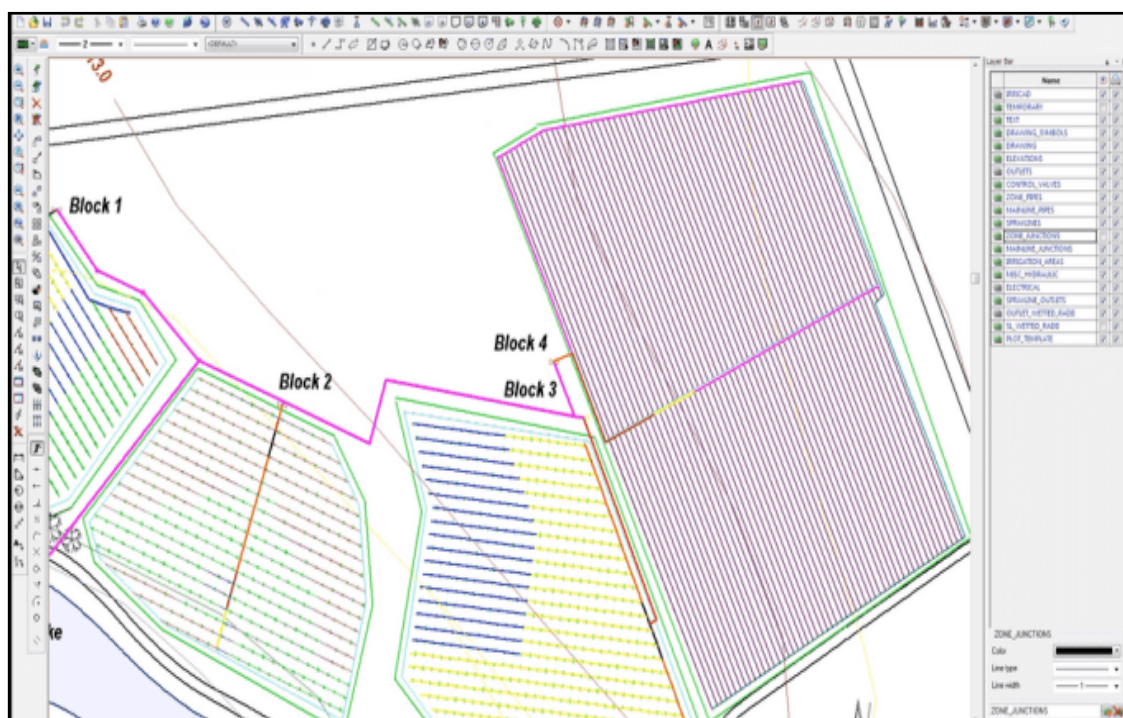


Fig. 3.6 Interface of IrriCAD

3.3.2 Application used

3.3.2.1 Phule Irrigation Scheduler

“Phule Irrigation Scheduler” mobile and web-based applications estimate the reference evapotranspiration (E_{Tr}) by the different standardized methods for the specific form by fetching the required input weather data (maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, wind speed, sunshine hours, etc.) from the “Open weather”, weather service provider for the current and 3 days ahead. The crop coefficient values are estimated daily from the crop and crop growth stage specific information on crop coefficient generated in this project based on literature and experimentation. The crop coefficient (K_c) is multiplied by the reference evapotranspiration (E_{Tr}) rate to determine the crop water use for the specific day. Further by integrating other information on crop and soil, location of farm, irrigation system, the precise irrigation requirement and time of application are estimated. Fig. 3.7 depicts the Reference evapotranspiration calculation by Phule Irrigation Scheduler. (Source: www.rkviwras.ac.in)

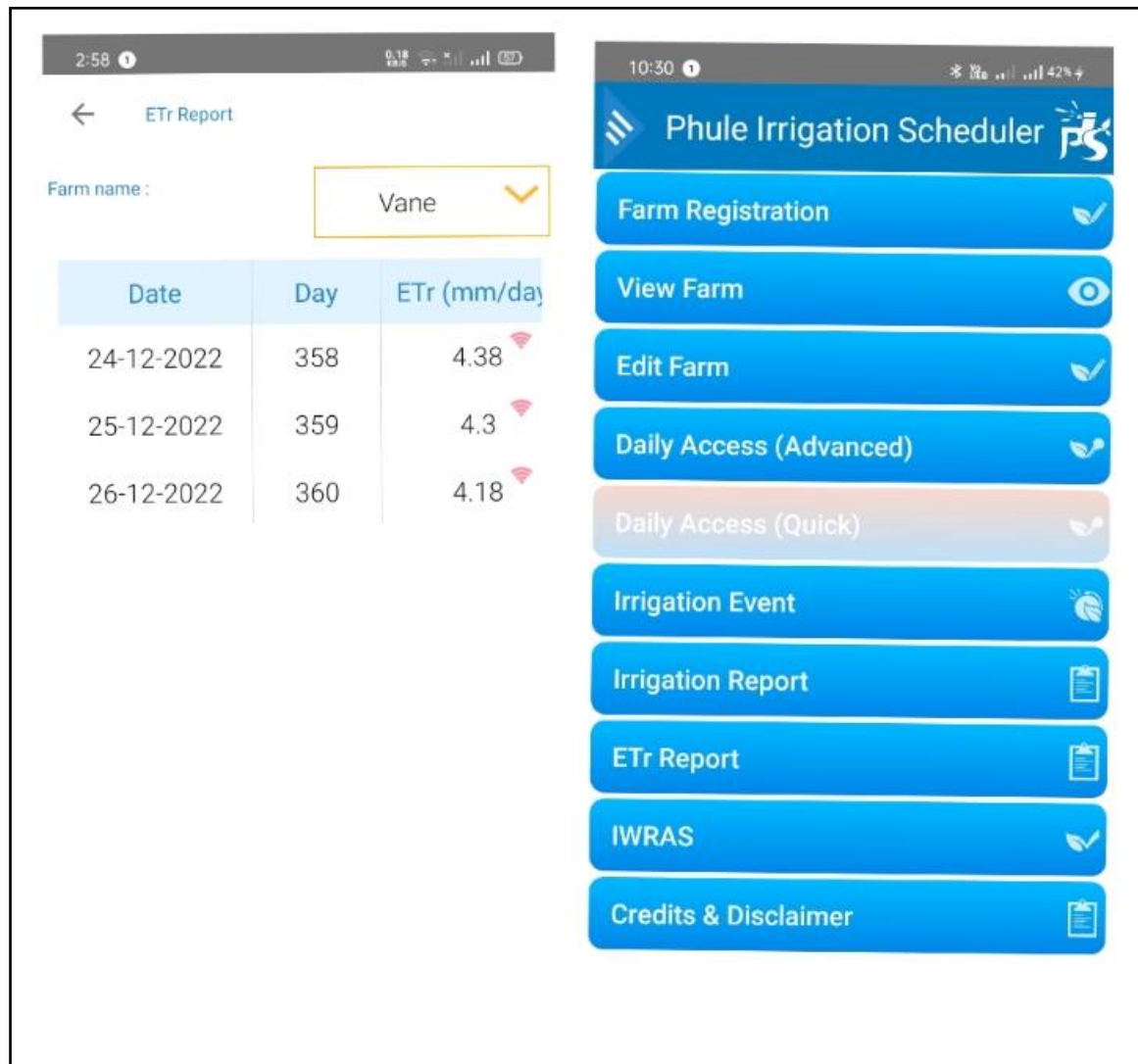


Fig.3.7 Reference evapotranspiration calculation by Phule Irrigation Scheduler

3.4 Methodology

This section describes in detail the procedures and the techniques used; to develop Land Use Land Cover mapping and to calculate area covered by major crops using remote sensing and GIS techniques for generation of resource database for study area, to estimate crop evapotranspiration and water requirement of crops in command area, to design the pipe distribution network in command area, and lastly, to evaluate economics of designed network in command area.

3.4.1 Crop pattern mapping

3.4.1.1 Geographic registration

The main objective of the geographic registration is to prepare the geographically consistent and correct base image across the study area. The images from SENTINEL-2 were registered to UTM WGS 84 as Datum for Zone 43N projection system. Image registration is the process of transforming different sets data into one coordinate system.

3.4.1.2 Image enhancement

Enhancement is modification of images to alter its impact on the viewer. Enhancement is also known as processing step in application where human viewing of an image is required for further processing. Overall, image enhancement is used to make images look better. Normally, image enhancement contains many ways and methods applied for increasing the visual distinguishing among structures in a scene. The intention is to form or create new imageries from an original image to increase the visual by increasing the apparent distinction between the features.

There are various methods available for image enhancements which help to find the category information from the images. Filtering, histogram modification and band compositions are some of the methods. For the present research band composition method has been implemented. Each band composition algorithm enhances the different category information from the images. False color composition has been used which is a combination of bands 2, 3, 4 and 8, in which vegetation seems as red tones, urban areas appear blue towards to grey water appears blue. Using this composite was helped to distinguish between the agricultural lands easily and shades of different crops were different and identifying different crops in the image was one of the objectives of the research. False composite colors created and used in the generation of cropping pattern maps, are shown in Fig. 3.2, Fig. 3.3, and Fig 3.4 for *Summer*, *Kharif* and *Rabi* seasons, respectively.

3.4.1.3 Image Classification

Image classification is the task of extracting information classes from multiband raster image. The resulting raster image can be used to create raster. Based on the idea that different features on the earth's surface have a different spectral reflectance and remittance properties, their recognition is carried out through the classification processes. In other words, image classification is the process of categorizing all pixels in an image or raw remotely sensed satellite data to obtain a given set of labels or land cover themes (Lillesand, Keifer 1994). The image classification categorises the pixels having similar as well as closer DN values together. Image classification techniques are broadly categorising of two types i.e., supervised and unsupervised classification. For crop pattern mapping, supervised classification method was applied in Arc GIS software.

Supervised classification can be defined informally as the process of using samples of known identity to classify pixel of unknown identity. Samples of known identity are those pixels located within training areas or training fields. The analyst, usually, defines training areas by identifying regions on the image that can be clearly matched to areas of known identity on the image. In the present study ground truth data of different crops was used for identifying different crops in the command area.

The maximum likelihood classifier used to carry out supervised classification. The tool considers both the variances and covariances of the class signatures when assigning each cell to one of the classes represented in the signature file. With the assumption that the distribution of a class sample is normal, a class can be characterized by the mean vector and the covariance matrix. Given these two characteristics for each cell value, the statistical probability is computed for each class to determine the membership of the cells to the class. When the default EQUAL option for a priori probability weighting is specified, each cell is assigned to the class to which it has the highest probability of being a member.

In this study, supervised classification technique was applied. Sample pixels in an image were selected as a representative of other pixels in ArcMap v10.7 software by taking trainingsets using GPS control points. The training set selections were taken according to major crops production in the study area during for *Summer*, *Kharif* and *Rabi* seasons. (Fig.3.2, Fig. 3.3 and Fig 3.4)

Major crops like cotton, sugarcane, chickpea, maize, onion, wheat, groundnut, soybean and other features such as built-up land and other etc. in the study area were taken into considerations. Finally, the crop types were identified under supervised classification and cropping pattern map was successfully created. Later area covered by each major crop was calculated. The Fig. 3.8 shows the selection of training areas with the help of ground truth.

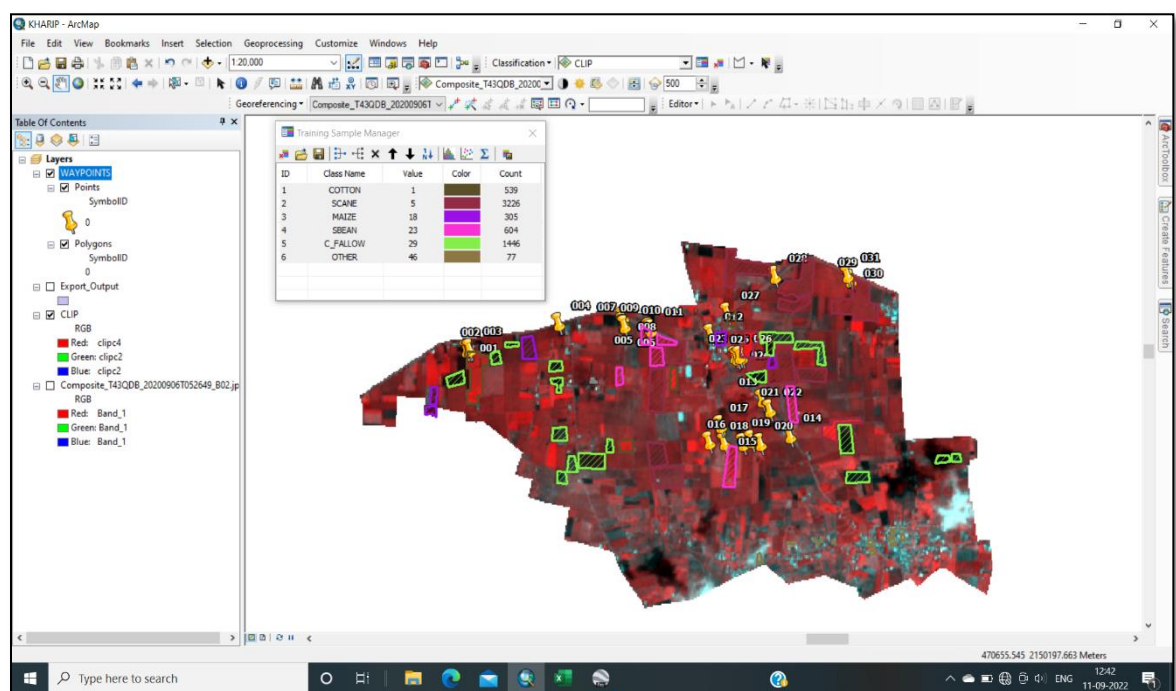


Fig. 3.8 Selection of the training samples on satellite data with the help of ground truth points

Finally, the crop types were identified under supervised classification and cropping pattern maps were successfully created for the peak period months of the season's *Summer*, *Kharif* and *Rabi* for year 2021. The Fig. 3.9 depicts the procedure for preparing cropping pattern maps.

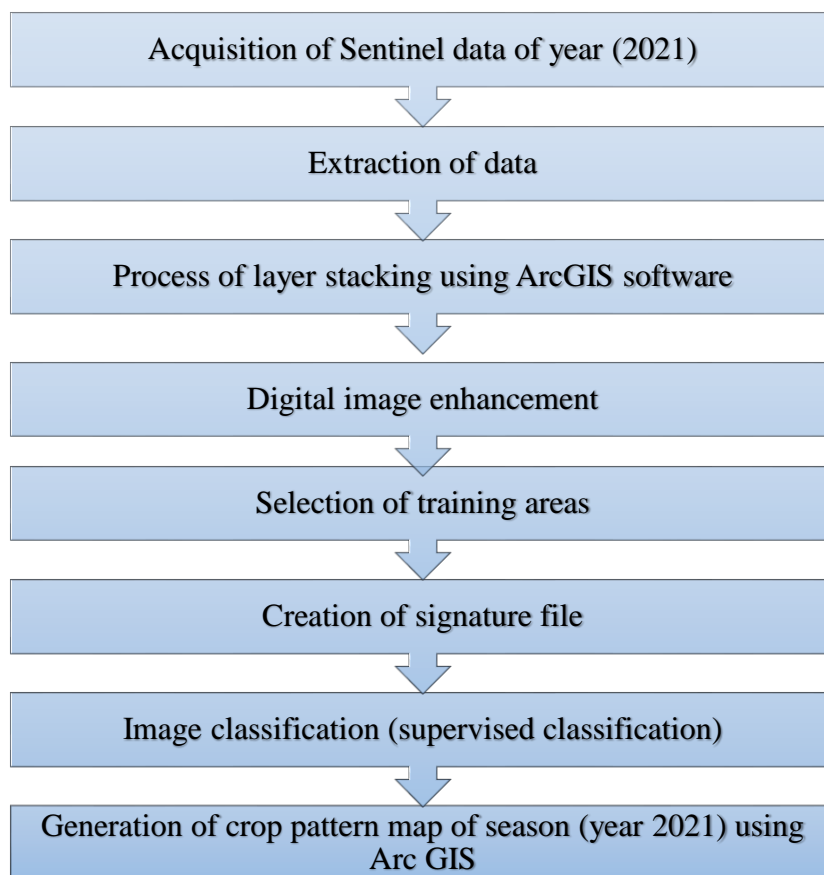


Fig. 3.9 Procedure for crop pattern mapping

3.4.2 Determination of irrigation water requirement

Irrigation water requirement is the quantity of water required by a crop in a given period of time for normal growth under field conditions. It includes evaporation and other unavoidable wastes. And generally, water requirement for crop is expressed in water depth per unit area. The irrigation requirement does not include water from natural sources (such as precipitation) that crops can effectively use.

Total irrigation water requirement of crops was determined by calculating crop evapotranspiration values of all the major crops in the command area grown in the *Summer*, *Kharif* and *Rabi* seasons of year 2021.

3.4.2.1 Crop evapotranspiration

Evapotranspiration (ET) is the sum of water loss from the soil surface through evaporation (E) and water lost through plants by transpiration (T). Evapotranspiration forms the total amount of water lost by the crop canopy to the atmosphere. Evaporation from the soil surface is included because it is, in most cases, an unavoidable loss of water from the root zone, which has to be replaced by either rainfall or irrigation.

Crop evapotranspiration is a physical process in which water passes from the liquid to the gaseous state while moving from the soil to the atmosphere. It refers to evaporation from soil and

vegetative surfaces and transpiration from plants. Crop evapotranspiration is a function of both weather (ET_r) and the growth stage of the plant. The ratio between reference ET and crop ET is the crop coefficient, which changes during the season with crop physiological changes. At the time of planting, most ET is evaporation from the bare soil surface, but as the canopy matures ET is predominantly transpiration from the crop (Peter Waller and Muluneh Yitayew, 2016).

The proportion of E and T depends on the amount of bare soil surface in the canopy. At sowing 100% of ET comes from evaporation (E), while at full crop cover more than 90% of ET comes from transpiration (T). Consequently the factors affecting crop evapotranspiration may be grouped under five categories as follows: meteorological factor (i.e. solar radiation, temperature, relative humidity, wind and altitude), soil factors (such as available water, soil temperature and solute), irrigation practices and cultural practices. Crop evapotranspiration can be calculated under standard conditions or under non-standard conditions. Standard conditions refer to crops grown in large fields under excellent agronomic and soil water conditions. In the crop coefficient approach and for this research study, crop evapotranspiration (ET_c) is estimated by using FAO-56 methodology as a product of the ET_r and K_c .

The crop evapotranspiration was estimated using equation,

$$ET_c = ET_r \times K_c$$

Where,

ET_c = Crop evapotranspiration (mm/day)

ET_r = Reference evapotranspiration (mm/day)

K_c = Crop coefficient

3.4.2.2 Reference evapotranspiration

The potential evapotranspiration is considered as an important element of the hydrological cycle, which plays an important role in agricultural studies, management plans of irrigation and drainage networks, and water structures. (Gundekar *et al.* 2008; López-Urrea *et al.* 2006; Shayannejad *et al.* 2022; Ostad-Ali-Askari 2022; Vanani *et al.* 2017; Snyder *et al.* 2005). According to FAO standard, reference evapotranspiration is the amount of water consumed by a farm with reference crop cover (such as grass) during a determined period in order to prevent plants to suffer from water shortages during the growth period (Allen *et al.* 1998).

For determination of reference evapotranspiration different methods were used. But in the present study FAO Penman-Monteith was used and for the calculation Phule Irrigation Scheduling application was used.

Following equation represents the FAO Penman-Monteith equation used to estimate reference evapotranspiration;

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

Where,

ET_r = Reference evapotranspiration [mm day^{-1}]

Rn = Net radiation at the crop surface [$\text{MJ m}^{-2} \text{day}^{-1}$]

G = Soil heat flux density [$\text{MJ m}^{-2} \text{day}^{-1}$]

T = Mean daily air temperature at 2 m height [$^{\circ}\text{C}$]

u_2 = Wind speed at 2 m height [m s^{-1}]

e_s and e_a = Saturation and actual vapour pressure [kPa], respectively.

$(e_s - e_a)$ = Saturation vapour pressure deficit [kPa]

Δ = Slope vapour pressure curve [$\text{kPa } ^{\circ}\text{C}^{-1}$]

γ = Psychometric constant [$\text{kPa } ^{\circ}\text{C}^{-1}$]

3.4.2.3 Crop coefficient (Kc)

Crop coefficient is a ratio between the actual crop evapotranspiration (ET_c) under standard condition and the reference crop evapotranspiration (ET_r). The Kc values integrates crop characteristics such as crop type, climate and growing stages and integrated or averaged effects of evaporation from the soil surface (Allen *et al.* 1998).

The crop coefficient, Kc value represents the crop type and the growing stages of the crop. There may be various Kc values for a single crop depending on the development stage of crop. At the time of germination and establishment major evaporation from soil occurs. After development of crop canopy evaporation decreases and transpiration increases. Therefore, Kc value is highest at mid-season of crop and hence water requirement also maximum at mid-season stage of crop and Kc is usually determined by field experiment. Each agronomic crop has a series of specific crop coefficients and used to predict water requirement at different growth stages. An example of a Kc curve as a function of days or weeks after planting is shown in Fig. 3.10.

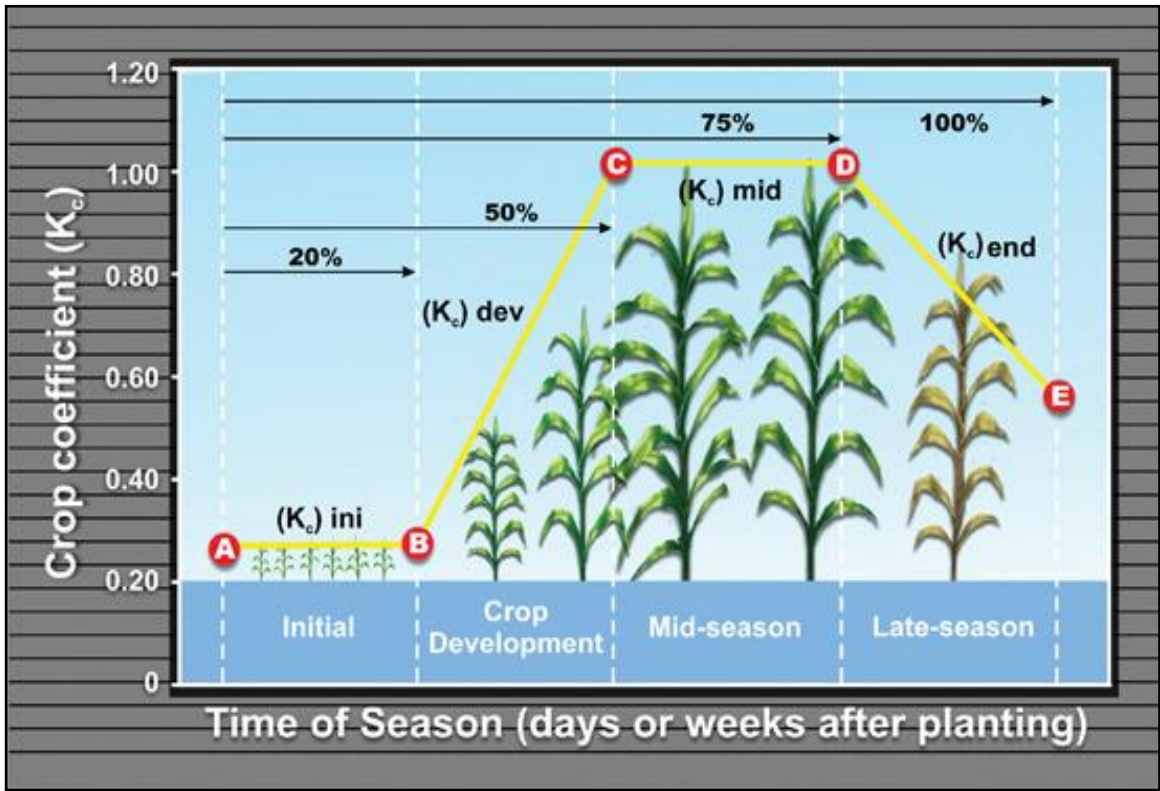


Fig. 3.10 Crop coefficient value vary according to plant growth stage

(Source: <https://extensionpublications.unl.edu>)

Values of crop coefficient depend on crop growth stage. It can be daily or crop stage wise or can be calculated from equation. The equation form of crop coefficient values is represented by polynomial equation. The daily values of crop factor are obtained by the equation (Research Review Committee Report, 2010-2011) given below.

$$Kc = m_0 + m_1 \left(\frac{t}{T}\right) + m_2 \left(\frac{t}{T}\right)^2 + \dots \dots \dots m_n \left(\frac{t}{T}\right)^n$$

Where,

- Kc = Crop factor at time
- t_n = Order of equation.
- $m_0, m_1, m_2, \dots m_n$ = Coefficient of equation
- t = Day
- T = Total crop growth period, days

The empirical functions used to estimate the daily crop coefficient (Kc) are presented in Table 3.6.

Table 3.6 Empirical functions used to estimate the daily crop coefficient (Kc)

Season	Crop	Crop Period (Days)	Kc equation
Summer	Cotton	180	$-3.943(t/T)^5 + 30.76(t/T)^4 - 54.8(t/T)^3 + 32.94(t/T)^2 - 5.163(t/T) + 0.572$
	Maize	100	$-8.523 (t/T)^5 + 31.21 (t/T)^4 - 38.39 (t/T)^3 + 17.82 (t/T)^2 - 2.174 (t/T) + 0.659$
	Groundnut	120	$-5.842 (t/T)^5 + 17.31(t/T)^4 - 21.64(t/T)^3 + 10.69(t/T)^2 - 0.272 (t/T) + 0.346$
Kharif	Soybean	100	$2.647(t/T)^5 + 0.140(t/T)^4 - 8.761(t/T)^3 + 5.862(t/T)^2 + 0.260(t/T) + 0.494$
	Onion	100	$1.732(t/T)^4 - 4.616(t/T)^3 + 2.313(t/T)^2 + 0.562(t/T) + 0.676$
	Maize	100	$-5.2633(t/T)^3 + 4.4781(t/T)^2 + 0.8085(t/T) + 0.2832$
	Groundnut	120	$-10.018(t/T)^5 + 13.509(t/T)^4 - 2.9891(t/T)^3 + 2.6683(t/T)^2 - 2.0873(t/T) + 0.4958$
	Cotton	180	$-3.943(t/T)^5 + 30.76(t/T)^4 - 54.8(t/T)^3 + 32.94(t/T)^2 - 5.163(t/T) + 0.572$
Rabi	Chickpea	100	$2.3266(t/T)^5 + 8.5503(t/T)^4 - 24.573(t/T)^3 + 14.708(t/T)^2 - 1.8175(t/T) + 0.8965$
	Onion	100	$8.062(t/T)^5 - 24.31(t/T)^4 + 20.15(t/T)^3 - 5.761(t/T)^2 + 1.498(t/T) + 0.561$
	Maize	100	$77.475(t/T)^5 - 193.14(t/T)^4 + 165.98(t/T)^3 - 60.13(t/T)^2 + 10.175(t/T) - 0.0431$
	Wheat	110	$10.092(t/T)^5 - 20.039(t/T)^4 + 12.871(t/T)^3 - 7.0936(t/T)^2 + 3.7412(t/T) + 0.5942$
Annual	Sugarcane	370	$0.484(t/T)^4 - 4.948(t/T)^3 + 3.988(t/T)^2 + 0.636(t/T) + 0.372$

3.4.2.4 Irrigation water requirement

The irrigation requirement of a crop is the total amount of water that must be supplied by irrigation to a disease-free crop, growing in a large field with adequate soil water and fertility, and achieving full production potential under the given growing environment (Doorenbos and Pruitt, 1977). The irrigation requirement includes water used for crop consumptive use, maintaining a favourable salt balance within the root zone, and overcoming non-uniformity and inefficiencies of irrigation. The irrigation requirement does not include water from natural sources (such as precipitation) that crops can effectively use.

The total irrigation water demand of each crop in the study area was estimated by multiplying total ETC of particular crop during the entire growth period with the total area under the crop.

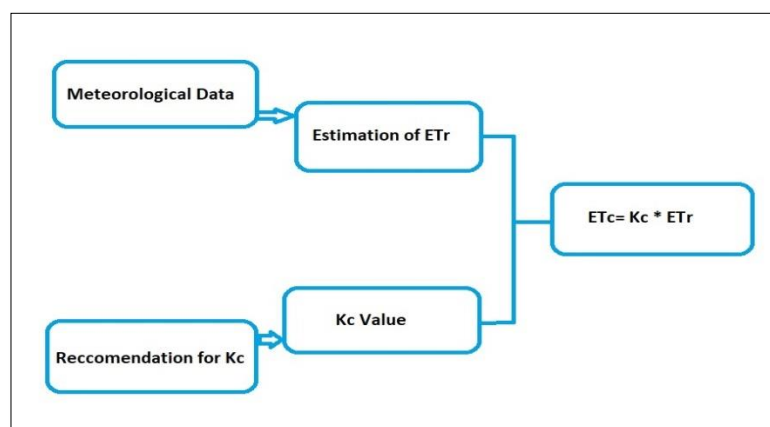


Fig. 3.11 Flow chart showing step wise procedure to obtain ETC

3.4.3 Design of Pipe Distribution Network

3.4.3.1 Basic details required for designing PDN

➤ Basic Details

- Current status of the command area
 - Current irrigation status
 - Irrigation issues
 - Irrigation rotational cycle
- Salient features of command area
- Number of farmers
- List of farmers

➤ Water source details

- Availability of water (Duration: daily hrs, seasonal duration)
- Flow through each distributary (CUSECS)
- Flow as per crop water requirement at each distributary, (Need to check)
- Finalization of design flow at each distributary

➤ Technical Details

Index map

Preparation of map

- Digitization of map
- Detailing of CCA
- Contour map
- Irrigation time, (Daily design hrs)

➤ Design and planning

- Marking of chaks
- Working of chak wise flow
- Irrigation scheduling
- Marking of pipe alignment
- Design of pipe network with IrriCAD
- Preparation of pipe cutoff statement
- Working on pipe L section and hydraulic gradient

➤ Deciding on irrigation equipment

- Trash rack
- Distributary gate/ Control valve
- Drain valves
- Air valves
- HDPE pipe

➤ Preparation of BOQ (Bill of quantities)

3.4.3.2 Process list for preparation of basic map using QGIS and AutoCAD software

- Import **KMZ** of study in QGIS.
- Double click on **Google Satellite Map** in Browser panel.
- Set the coordinate system and units to the layer.
- Click on SRTM Downloader at the top. Set canvas extend and download DEM.
- Extract the contours, (Contour interval, 5m).
- Contour Layer will generate without elevation value.
- Double click on **v.to.3d** in Processing Toolbox.
- **DXF** file will export with elevation value (3D).
- Export map into image.
- Insert image in AutoCAD.
- Extend all the layers as all layers in a group format hence use explode command for ungroup and then joint the one-by-one layer.

- Marking of canal or road with reference image, (use the Polyline command).
- Insert raster image
- Add texts

Figure 3.12 depicts the basic map of the command area for designing pipe distribution network.

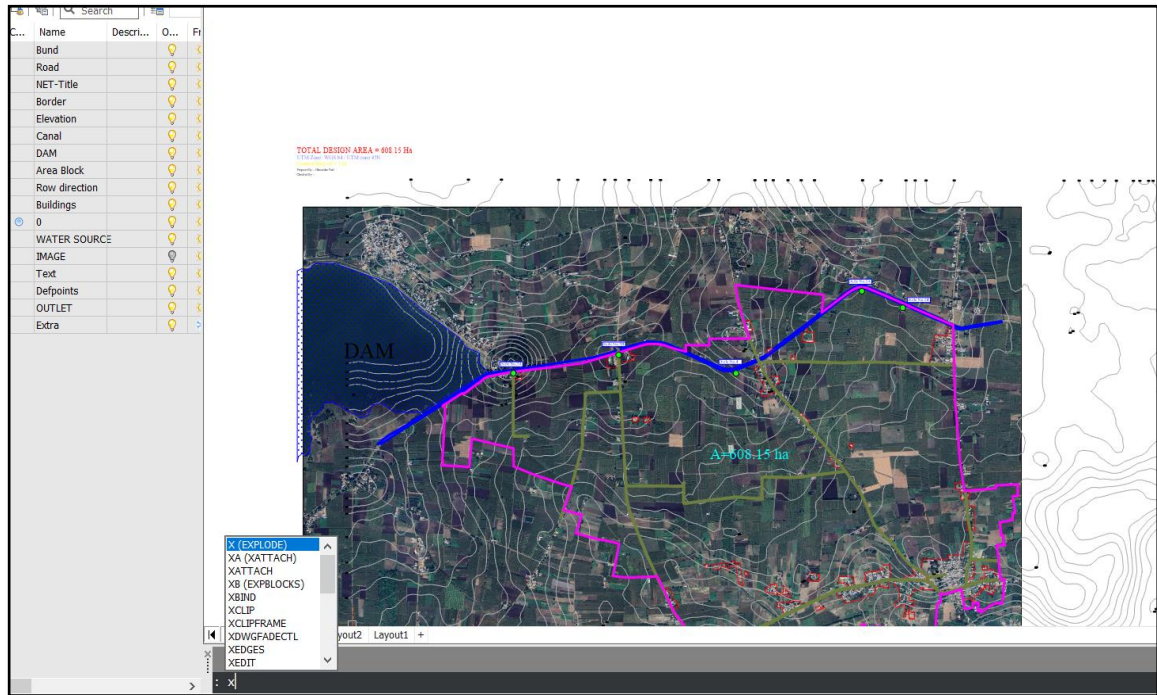


Fig. 3.12 Basic map of PDN in AutoCAD software

3.4.3.3 Process list for preparation of PDN map using IrrCAD software

After preparation of basic map, chak design will be carried out in IrrCAD software. To begin using IrrCAD it is helpful to know the steps that are necessary to produce a design. Although there is no rigidly prescribed way of producing designs (this is a major strength of the program), the following procedure is recommended as a starting point. A basic outline of the design procedure is:

- Enter design details.
- Enter background information - place property boundaries, buildings and elevation data on the design.
- Layout the Irrigation System - position water supplies, outlets, valves and connect with pipes.
- Management and Design - enter system management information (zone and system flow operating times), and hydraulically design and / or analyze the system.
- Costing - select fittings and generate a Bill of Materials and Costs for clients.

- Printing - print or plot plans and reports.

1. Database settings:

- Select correct Database as per country standard and keep the database folder in final folder.
- Open the database file and select Pipes, Driplines, Valves and all other items as per design requirements

2. IrriCAD settings:

- Open the IrriCAD file set the database prepared for that project.
- Save IrriCAD design file.
- In IrriCAD Go to Setting and Fill all the basic information.
- Client: client name, address (Location), home phone (system type), fax (area size), work phone (crop name).

3. Import drawing and contours:

- Import the drawing from Basic map folder, then import only contours in (DXF file 2000 Version format).
- Grid/Origin: Set X, Y co-ordinates and UTM zone from received KMZ file.
- Check block borders should be match with Google earth.

4. Check 3D DEM view:

- After importing the contour highlight elevation.
- After completing the above step go for the 3D DEM view.

5. Export as KMZ or view in Google Earth:

- Export IrriCAD as KMZ file to get an idea about actual blocks and roads.

6. Create laterals:

- Drip System: Create the lateral, submain and valve by Tape Irrigation Block for inline drip system.
- Sprinkler System: Spray irrigation block for Sprinkler and online drip system.

7. Primary design idea:

- Divide the parent block as per design requirement in multiple of shift number and keep 2m roads for mainline if required.

8. Design layout and mainline route:

- Decide the mainline pipe route- it should be shortest as much as possible.
- Make group of valves 1, 2, 4 with respect to mainline pipe route.

9. Shift arrangement:

- Assign the no. of shifts asked in questionnaire and it should be serially

- Open zone design configuration table and fill all the details.

10. Design parameters for standard design:

- Fill out the velocity for zone and mainline pipes.
- Zone: 2.2 m/s (Maximum up to 3 m/s)
- Mainline: 1st design with 1.9 m/s, then 1.8 m/s (Maximum upto 2m/s) and check which one is suitable for that project.

11. Zone design:

- Design within given zone pipe size and zone pressure range. Also check for minimum pressure of Dripline / Drippers / Sprinklers.
- Complete the zone design for entire area.
- In case of non-pressure compensated system, run detailed analysis after velocity design and check the flow variation of each block and confirm that it is not more than limit as 10% (Report: Zone CV table).
- Check valve size which should correct as per actual design flow.
- If design with flushing manifold, then need to check block pressure to achieve minimum flush velocity
- For draft design stage: check with virtual run method.
- For final design stage: check with actual run method

12. Mainline design:

- Run mainline design.

13. Critical valve:

- Find critical valve (Report: Pump Duty Breakdown) in design and check if we can reduce pump pressure.
- Set the pressure required at water source, check available pressure at each valve upstream and see if we can to reduce submain pipe size.
- Decide system pressure.

14. Check the reports:

- Report: mainline pipe over pressure report, mainline pipe velocity report and confirm that it is within limit.
- Set the pressure at water source and check the valve ratio (Report: Mainline Sum-Valve HL-ratio C) which should not exceed more than 1:3.

15. Air valve & Mainline flush valves:

- Place air valve as per proper location according to elevation and pipe length.
- Maximum pipe length between 2 air valves should not more than 500m in case of gradual slope OR put air valve at highest elevation point.
- Mainline size 250mm and below use 2" air valve

- Mainline size 280mm and more use 2 x 2” air valve
- Mainline pressure upto 100 m use PN 10 air valve and upto 160 m use PN 16 air valve
- Place the flush valve at end of each branch of mainline according to flow in mainline.

16. Plot layout & labels:

- Place the plot layout as per suitable scale and paper size.

17. IrriCAD for draft:

- Once final draft is ready then changes the status in service. Now as draft design review.
- Export file from IrriCAD to AutoCAD (dwg) for first draft

18. Final :

- After draft approval, export for final.
- Export KMZ file in final folder then prepare excel summary and BOM.
- Prepare PDF of pump duty breakdown and mainline valve ratio report from IrriCAD.
- Export BOM from excel summary.

3.4.4 Evaluation of cost economics

The bill of material obtained for the design, also costs of cultivation for different crops were obtained from another related research work. At last benefit cost ratio was calculated by considering the life of drip and sprinkler system for seven years.

4. RESULTS AND DISCUSSION

The chapter explains the results obtained in the research as per the methodology explained in chapter 3. The objective of this study forms the basis of all the analysis carried out in this chapter. This research study was carried in order develop efficient methodology for designing of pipe distribution network using remote sensed based techniques. The area under each major crop in command area during *Summer*, *Kharif* and *Rabi* seasons of year 2021-2022 were estimated from sentinel-2 satellite data. The recommended crop coefficient (Kc) values which then combined with reference evapotranspiration (ET_o) to compute crop evapotranspiration (ET_c). And at last pipe distribution network designed by considering peak water requirement of season. The results of the study are presented and discussed in this chapter, to estimate total water requirement of each crop and total irrigation water demand of command area in different seasons of year 2021-2022 using RS and GIS techniques.

4.1 Land use land cover (Cropping pattern map of the command area)

The cropping pattern maps of command area on the left bank canal of Mula Irrigation Project for *Summer*, *Kharif* and *Rabi* seasons of year 2021-2022 were prepared using Remote Sensing data and ArcGIS v10.7. These maps were prepared based on the Ground truth information collected in peak period months of crops in different seasons of year 2021-2022 in command area using hand GPS. False Colour Composite (FCC) images of Sentinel 2 were used as a base for identification. Supervised classification was carried out to produce classified maps from Sentinel 2 satellite data by taking Region of Interest (ROI) of individual entity. The names of identified major crops in command area during year 2021-2022 are given in Table 4.1.

Table 4.1 Major crops identified during different seasons of year 2021-22

Season	Summer	Kharif	Rabi
Major crops identified	Cotton Maize Groundnut Sugarcane	Soybean Onion Maize Groundnut Cotton Sugarcane	Chickpea Onion Maize Wheat Sugarcane

4.1.1 Land Use Land Cover for *Summer* season

The land use land cover map of command area was prepared using Sentinel image. The image used for the classification is from the month of May 2021. The supervised image classification approach was adopted to prepare the map. The major crops identified during summer season are Cotton, Maize, Groundnut and Sugarcane. The LULC map of *Summer* season is shown in Fig. 4.1.

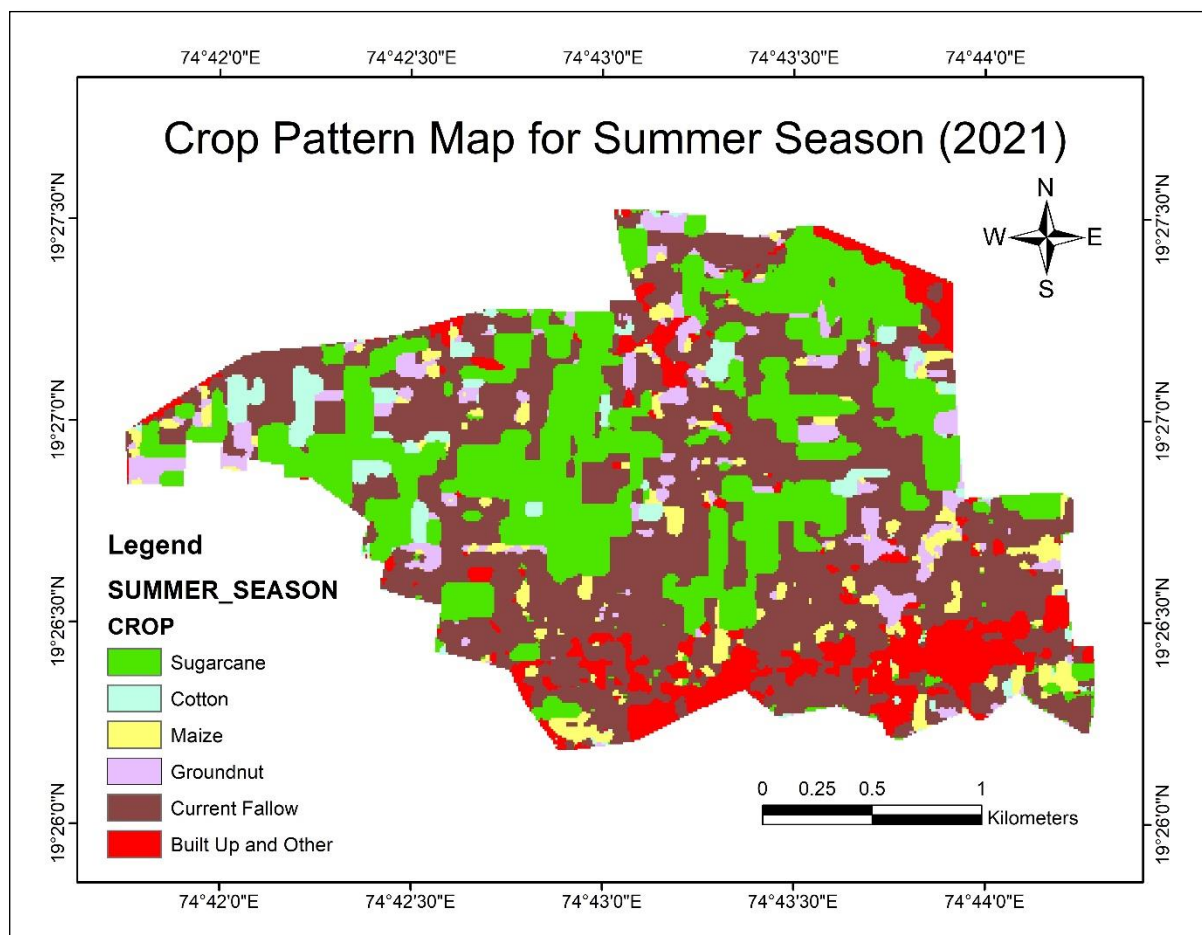


Fig. 4.1 LULC map of *Summer* season (2021)

The statistical analysis of the LULC map of *Summer* season (2021) shown in Table 4.2. It is seen from the Table 4.2 that, the total extent of area under study is 611.06 ha out of which 274.6 ha (44.93%) is under cultivation. Among the cultivated land, major area lies under Sugarcane crop which is about 178.42 ha (29.20 %) followed by Groundnut, 36.31 ha (5.94%), Cotton, 30.63 ha (5.01%) and Maize, 29.24 ha (4.78%). The area lies under the current fallow is 270.52 ha (44.27%) and under built up is 65.94 ha (10.79%).

Table 4.2 LULC for *Summer* Season (2021)

Sr. No.	LULC class	Area (ha)	% Area
1	Sugarcane	178.42	29.20
2	Cotton	30.63	5.01
3	Maize	29.24	4.78
4	Groundnut	36.31	5.94
5	Current Fallow	270.52	44.27
6	Built Up and Other	65.94	10.79
Total		611.06	100

The Fig 4.2 shows the representation of LULC statistics of the percentage of the area covered by each crop for the *Summer* season in the form of pie chart for year 2021.

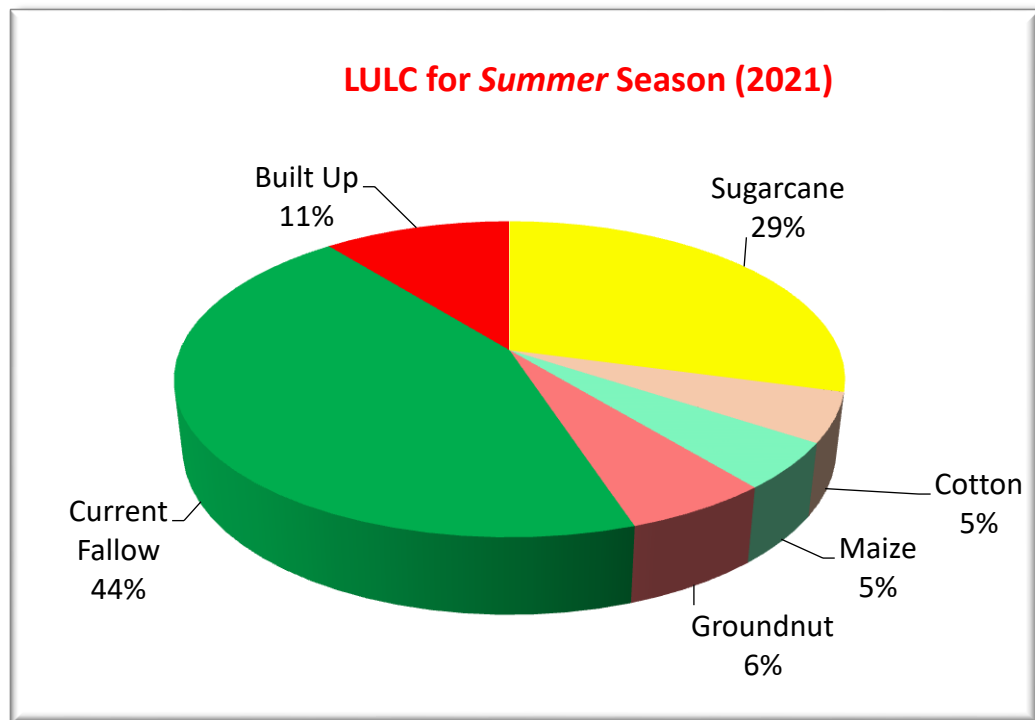


Fig. 4.2 Area in percentage covered by the crops and other features in *Summer* season

4.1.2 Accuracy assessment of Land Use Land Cover for *Summer* season

The validation of land use land cover classification map is crucial for this study. Detailed observations were made during accuracy assessment to classify numerous sample points into different land use land cover classes and results were compared with LULC map. User's and producer's accuracy were determined. The overall accuracy is a measure of how well the classified pixels match the ground truth data. Table C1 of Appendix- C shows the results of error matrix for LULC classification of command area. Results shows that good overall accuracy of 90.47%.

4.1.3 Land Use Land Cover for *Kharif* season

The land use land cover map of command area was prepared using Sentinel image. The image used for the classification is from the month of September 2021. The supervised image classification approach was adopted to prepare the map. The major crops identified during *Kharif* season are Cotton, Maize, Groundnut, Onion, Soybean and Sugarcane. The LULC map of *Kharif* season is shown in Fig. 4.3.

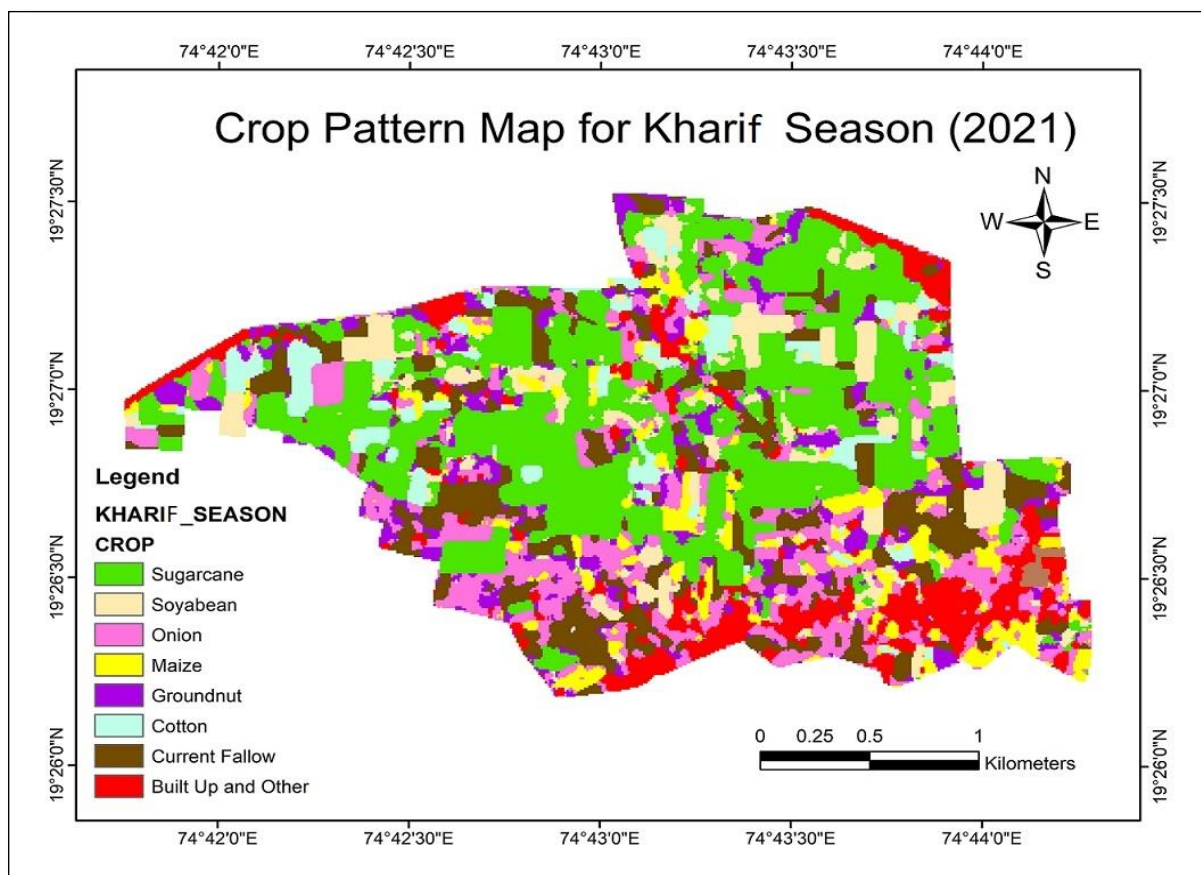


Fig. 4.3 LULC map of *Kharif* season (2021)

The statistical analysis of the LULC map of *Kharif* season (2021) shown in Table 4.4. It is seen from the Table 4.4 that, the total extent of area under study is 611.06 ha out of which 460 ha (75.27%) is under cultivation. Among the cultivated land, major area lies under Sugarcane crop which is about 179.06 ha (29.30 %) followed by Onion, 80.09 ha (13.10%), Soyabean, 71.38, (11.68%), Groundnut, 64.92 ha (10.62%), Maize, 35.54 ha (5.81%) and Cotton, 29.08 ha (4.75%). The area lies under the current fallow is 85.32 ha (13.96%) and under built up is 65.67 ha (10.74%).

Table 4.3 LULC for *Kharif* season (2021)

Sr. No.	LULC class	Area (ha)	% Area
1	Sugarcane	179.06	29.30
2	Soyabean	71.38	11.68
3	Onion	80.09	13.10
4	Maize	35.54	5.81
5	Groundnut	64.92	10.62
6	Cotton	29.08	4.75
7	Current Fallow	85.32	13.96
8	Built Up	65.67	10.74
Total		611.06	100

The Fig 4.4 shows the representation of LULC statistics of the percentage of the area covered by each crop for the *Kharif* season in the form of pie chart for year 2021.

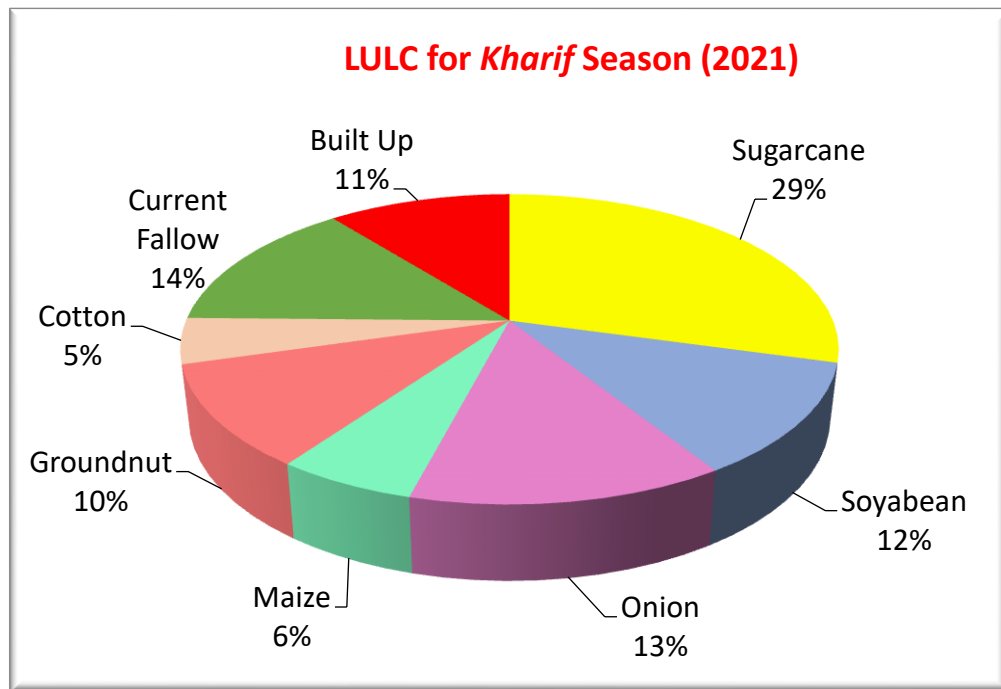


Fig. 4.4 Area in percentage covered by the crops and other features in *Kharif* season

4.1.4 Accuracy assessment of Land Use Land Cover for *Kharif* season

The overall accuracy is a measure of how well the classified pixels match the ground truth data. Table C2 of Appendix- C shows the results of error matrix for LULC classification of command area for *Kharif* season. Results shows that good overall accuracy of 90.30%.

4.1.5 Land Use Land Cover for *Rabi* season

The land use land cover map of command area was prepared using Sentinel image. The image used for the classification is from the month of December 2021. The supervised image classification approach was adopted to prepare the map. The major crops identified during *Rabi* season are Gram, Maize, Groundnut, Onion, Wheat and Sugarcane. The LULC map of *Rabi* season is shown in Fig. 4.5.

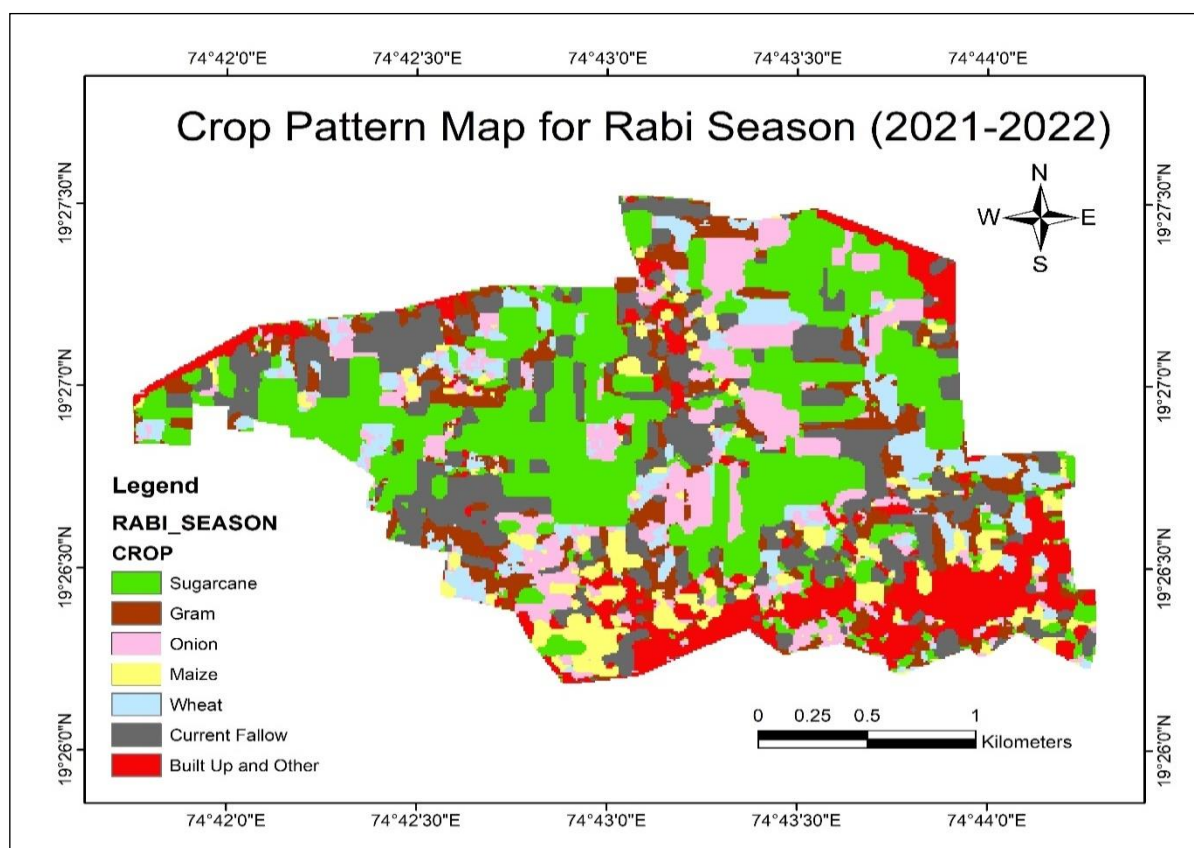


Fig. 4.5 LULC map of *Rabi* season (2021-2022)

The statistical analysis of the LULC map of *Rabi* season (2021-2022) is shown in Table 4.4. It is seen from the Table 4.4 that, the total extent of area under study is 611.06 ha out of which 430 ha (70.37%) is under cultivation. Among the cultivated land, major area lies under Sugarcane crop which is about 179.73 ha (29.41 %) followed by Onion, 82.71 ha (13.53%), Gram, 70.78, (11.58%), Wheat, 59.38 ha (9.71%) and Maize, 37.41 ha (6.12%). The area lies under the current fallow is 115.69 ha (18.93%) and under built up is 65.36 ha (10.69%).

Table 4.4 LULC for *Rabi* Season (2021-2022)

Sr. No.	LULC class	Area (ha)	% Area
1	Sugarcane	179.73	29.41
2	Gram	70.78	11.58
3	Onion	82.71	13.53
4	Maize	37.41	6.12
5	Wheat	59.38	9.71
6	Current Fallow	115.69	18.93
7	Built Up	65.36	10.69
Total		611.06	100

The Fig 4.6 shows the representation of LULC statistics of the percentage of the area covered by each crop for the *Rabi* season in the form of pie chart for year 2021-2022.

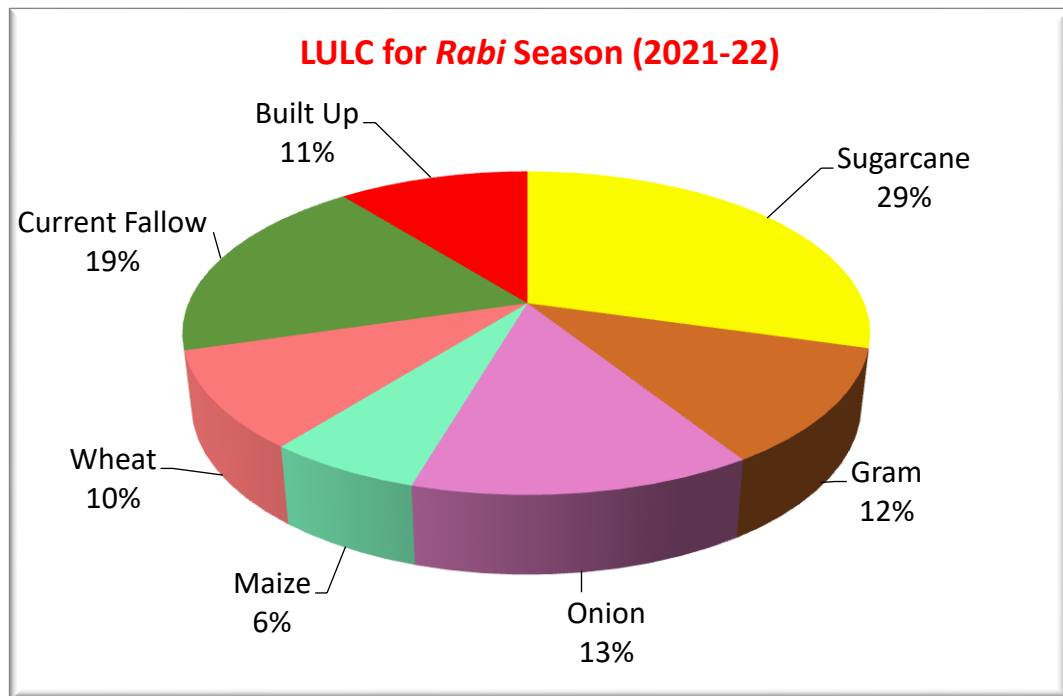


Fig. 4.6 Area in percentage covered by the crops and other features in *Rabi* season

4.1.6 Accuracy assessment of Land Use Land Cover for *Rabi* season

The overall accuracy is a measure of how well the classified pixels match the ground truth data. Table C3 of Appendix- C the results of error matrix for LULC classification of command area for *Rabi* season of year 2021-2022. Results shows that good overall accuracy of 91.17%.

4.2 Irrigation water requirement of major crops in the command area

The irrigation requirement of a crop is the total amount of water that must be supplied by irrigation to a disease-free crop, growing in a large field with adequate soil water and fertility, and achieving full production potential under the given growing environment (Doorenbos and Pruitt, 1977). Total irrigation water requirement of crops was determined by calculating crop evapotranspiration values of all the major crops in the command area grown in the *Summer*, *Kharif* and *Rabi* seasons of year 2021.

4.2.1 Reference evapotranspiration

Reference evapotranspiration is the amount of water consumed by a farm with reference crop cover (such as grass) during a determined period in order to prevent plants to suffer from water shortages during the growth period. In the present study FAO Penman-Monteith was used for calculating reference evapotranspiration. Fig. 4.7 shows the monthly average reference evapotranspiration for all the months in the year 2021.

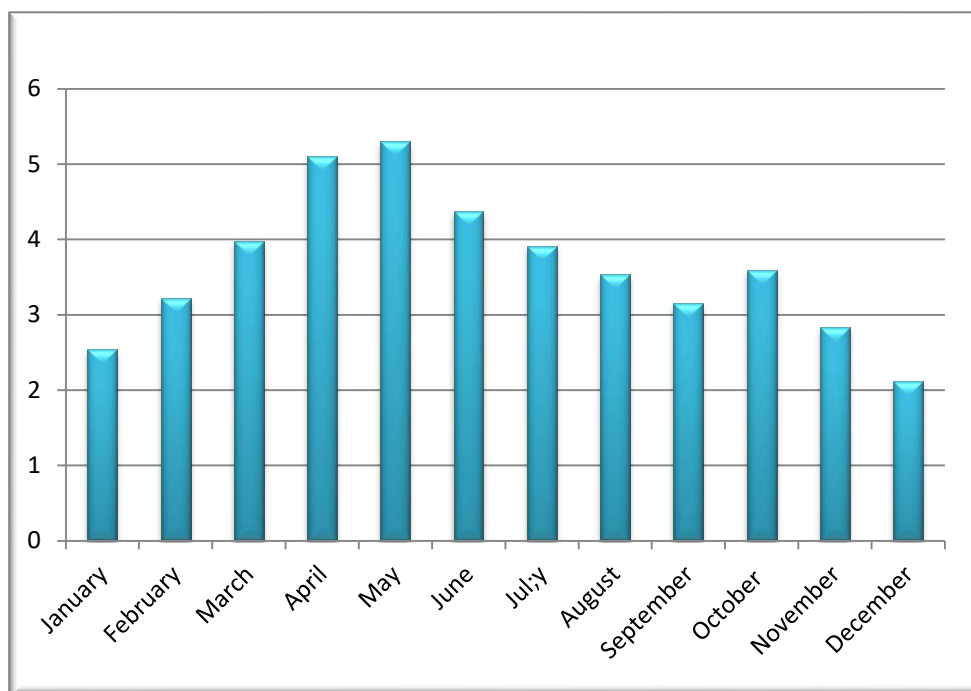


Fig. 4.7 Average monthly reference evapotranspiration for year 2021

It was observed that the average monthly reference evapotranspiration was maximum in the month of April (5.10 mm/day) and May (5.30 mm/day) and minimum in the month of December (2.11 mm/day) and January (2.54 mm/day).

4.2.2 Crop coefficient (Kc)

Crop coefficient is a ratio between the actual crop evapotranspiration (ET_c) under standard condition and the reference crop evapotranspiration (ET_o). The crop coefficient, K_c value represents the crop type and the growing stages of the crop. K_c is usually determined by field experiment. In the present study recommended K_c equation was taken from literature. Derived average crop coefficient value for each crop is represented in Table 4.5.

Table 4.5 Crop coefficient values of crops

Season	Crop	Crop Period (Days)	Average Kc Value
Summer	Cotton	180	0.76
	Maize	100	0.73
	Groundnut	120	0.85
Kharif	Soybean	100	0.85
	Onion	100	0.92
	Maize	100	0.86
	Groundnut	120	0.93
	Cotton	180	0.76

Rabi	Chickpea	100	0.83
	Onion	100	0.90
	Maize	100	0.78
	Wheat	110	0.99
Annual	Sugarcane	370	0.87

4.2.3 Crop water requirement (ETc)

Crop water requirements (CWR) are defined as the depth of water [mm] needed to meet the water consumed through evapotranspiration (ETc) by a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility, and achieving full production potential under the given growing environment. Crop water requirement of various crops were calculated by using reference evapotranspiration and crop coefficient values. The sample calculations for sugarcane, maize and groundnut are shown in Table B1 to B3 of Appendix- B. And the similar procedure was carried out for other remaining crops. Calculated crop water requirement of major crops in command area is given in the Table 4.6.

Table 4.6 Crop water requirement of crops

Season	Crop	Crop Period (Days)	ETc (Kc* ET ₀) (mm)
Summer	Cotton	180	577.66
	Maize	100	349.47
	Groundnut	120	479.47
Kharif	Soybean	100	301.01
	Onion	100	324.72
	Maize	100	298.84
	Groundnut	120	399.45
	Cotton	180	577.66
Rabi	Chickpea	100	222.42
	Onion	100	229.78
	Maize	100	194.18
	Wheat	110	270.64
Annual	Sugarcane	370	1147.47

The graphical representation of crop water requirement of each crop is depicted in Fig. 4.8. A result shows that Crop water requirement is highest in sugarcane, cotton and summer groundnut. And crop water requirement is lowest in chickpea and rabi maize.

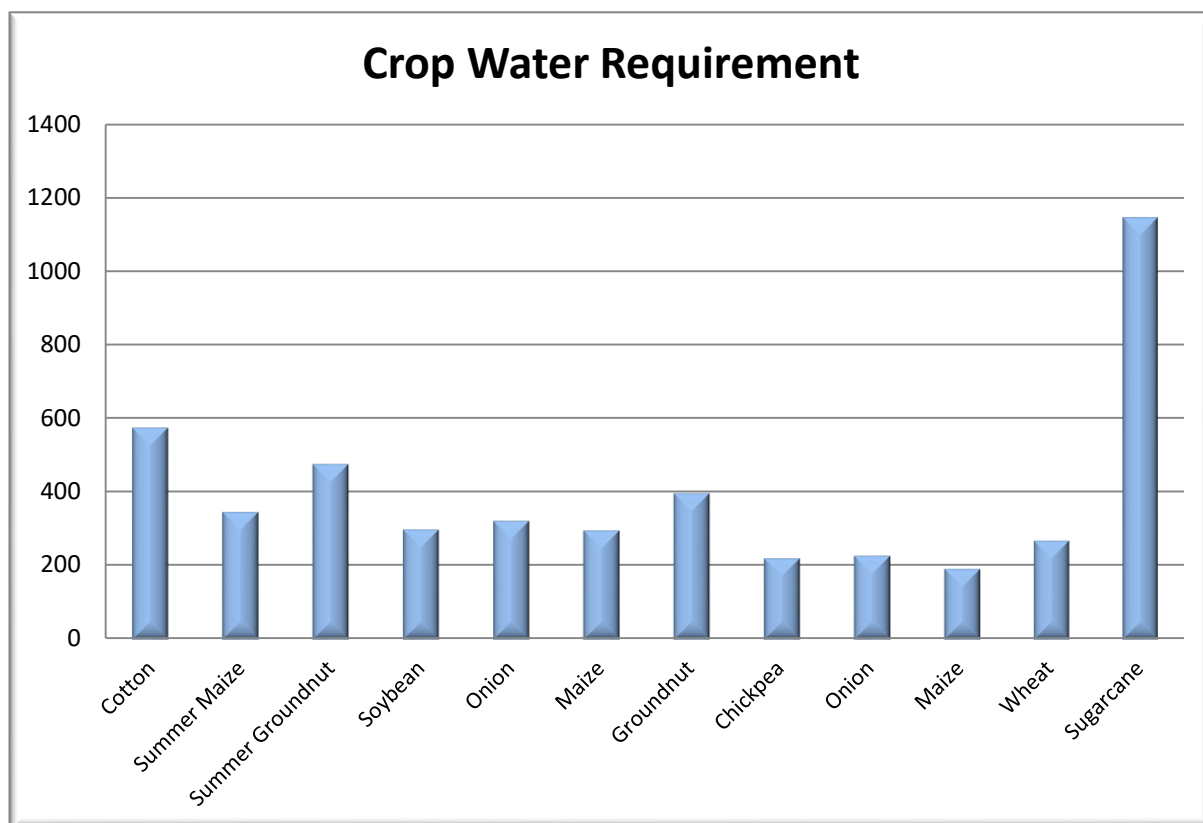


Fig. 4.8 Crop water requirement for different crops

4.2.4 Irrigation water requirement

Irrigation water requirement was calculated by multiplying crop area with crop water requirement. The areas under each crop were calculated by using satellite data with the help of ground truth points. And by considering 60 % efficiency for surface irrigation, 90% efficiency for drip irrigation and 85% efficiency for sprinkler irrigation, irrigation water requirement were calculated. Calculated irrigation water requirement of major crops in command area is given in the Table 4.7. The yearly irrigation water requirement by surface irrigation and micro irrigation is 6.5 MCM and 4.4 MCM, respectively. Among the micro irrigation techniques drip is mainly used for sugarcane, maize and cotton, while micro sprinkler is used for groundnut, soyabean, chickpea, onion and wheat.

Table 4.7 Irrigation water requirement of major crops

Season	Crop	Crop Period (Days)	ETc (Kc* ET ₀) (mm)	Crop Area (ha)	CWR (Etc* Crop Area) (ha-mm)	IWR by Surface Irrigation (ha-mm) (Efficiency 60%)	IWR by Micro Irrigation (Efficiency: Drip 90%, Sprinkler 80%)	
							Drip	Micro Sprinkler
Summer	Maize	100	349.47	29.24	10218.50	17030.838	11353.892	
	Groundnut	120	479.47	36.3	17404.76	29008.056		20476.104
Kharif	Soyabean	100	301.1	71.3	21462.01	35770.497		25249.469
	Onion	100	324.72	80	25977.60	43296		30561.6
	Maize	100	298.84	35.5	10608.82	17681.485	11787.42	
	Groundnut	120	399.45	64.9	25924.30	43207.824		30499.755
	Cotton	180	577.66	30	17329.80	28883.1	19255.2	
Rabi	Chickpea	100	222.42	70.7	15725.09	26208.49		18500.069
	Onion	100	229.78	82.7	19002.80	31671.619		22356.291
	Maize	100	194.18	37.4	7262.33	12104.136	8069.424	
	Wheat	110	270.64	59.3	16048.95	26748.451		18881.12
Annual	Sugarcane	370	1147.47	179	205397.13	342328.55	228219.63	
Total					392362.11 ha-mm	653939.04 ha-mm	445209.97 ha-mm	
Total					3923621.15 m³	6539390.46 m³	4452099.74 m³	

4.3 Design of pipe distribution network

The methodology developed in section 3.4.3 was used to obtain all the required parameters as the preliminary design input data for optimal design of micro irrigation pipe network.

4.3.1 Calculation of irrigation parameters

The basic preliminary design parameters such as crop water requirement (ET_C), depth of irrigation (d), irrigation interval (F), emitter discharge (q) and field division into subunits i.e., chak size were computed using data of Table D1 of Appendix- D. The computed data that were used as input data for designing PDN are presented in Table 4.8.

Table 4.8 Computed preliminary irrigation data

Particular	Project
Total Culturable area, ha	575.00
No. of chaks	30
Average chak area, ha	19.2
Application rate, mm/hr	4.16
Design CWR, mm/day	6.80
Irrigation frequency, days	1.00
Water application / irrigation, mm	6.80
Shift duration / irrigation, hrs	1.63
No of shifts / irrigation cycle	11
No of shifts / day	11
Total operating hours/day	17.95
Average chak shift area, ha	1.74
Average chak shift flow, m ³ /hr	72.60
Total Shift area, Ha	52.3
Total shift flow rate, m ³ /hr	2158.0
Duty, lps/ha	1.05

Before designing of PDN computation on irrigation data was carried out. Design CWR was calculated by considering the daily maximum crop water requirement per day. It was obtained as 6.14 mm per day and by considering 90% efficiency design CWR obtained as 6.80 mm/day. There was division of all the culturable area into 30 numbers of chaks. Chak have average area about 19.2 Ha. Application rate was 4.16 which was calculated by formula emitter flow rate divided by emitter spacing and pipe spacing. Irrigation frequency is of one day i.e. on each day irrigation will be given. By considering 18 operating hours/day there will 11 no. of per day and each shift having duration 1.63 hrs. Average chak shift area will be 1.74 ha having flow 72.60 m³/hr which was calculated by multiplying shift area with application rate. For 30 chaks total

shift area will be 52.3 ha and required flow will be 2158 m³/hr. And final design was carried out to carry 2158 m³/hr flow.

4.3.2 Preparation of basic map of command area

The main purpose of maps is to represent all the features of the command area at a specific scale. Moreover, different symbols and colors used to represent the selected features of an area. The basic map was prepared in the AutoCAD software and digitization was done in the QGIS with the help Google Earth. The contours were extracted with the help of SRTM DEM with 1 m interval. The outlet points were given at each junction of canal and distributaries. The basic maps of command area with satellite image and without satellite image are depicted in figure 4.9 and 4.10, respectively.

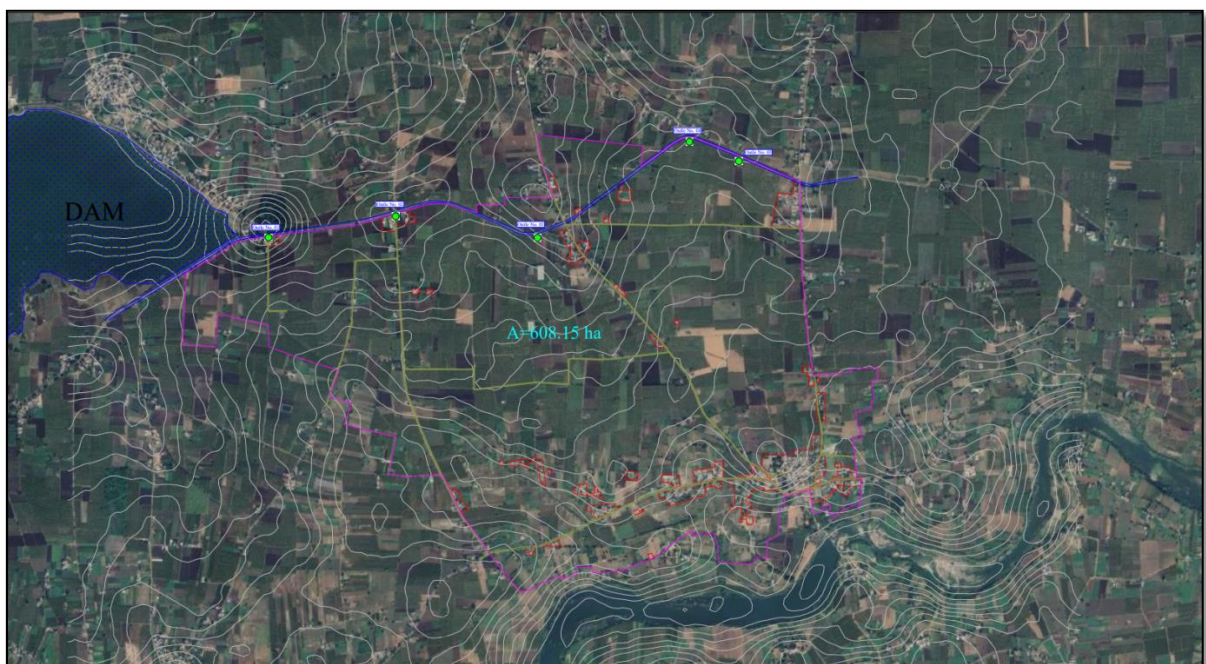


Fig.4.9 Basic map for command area with image

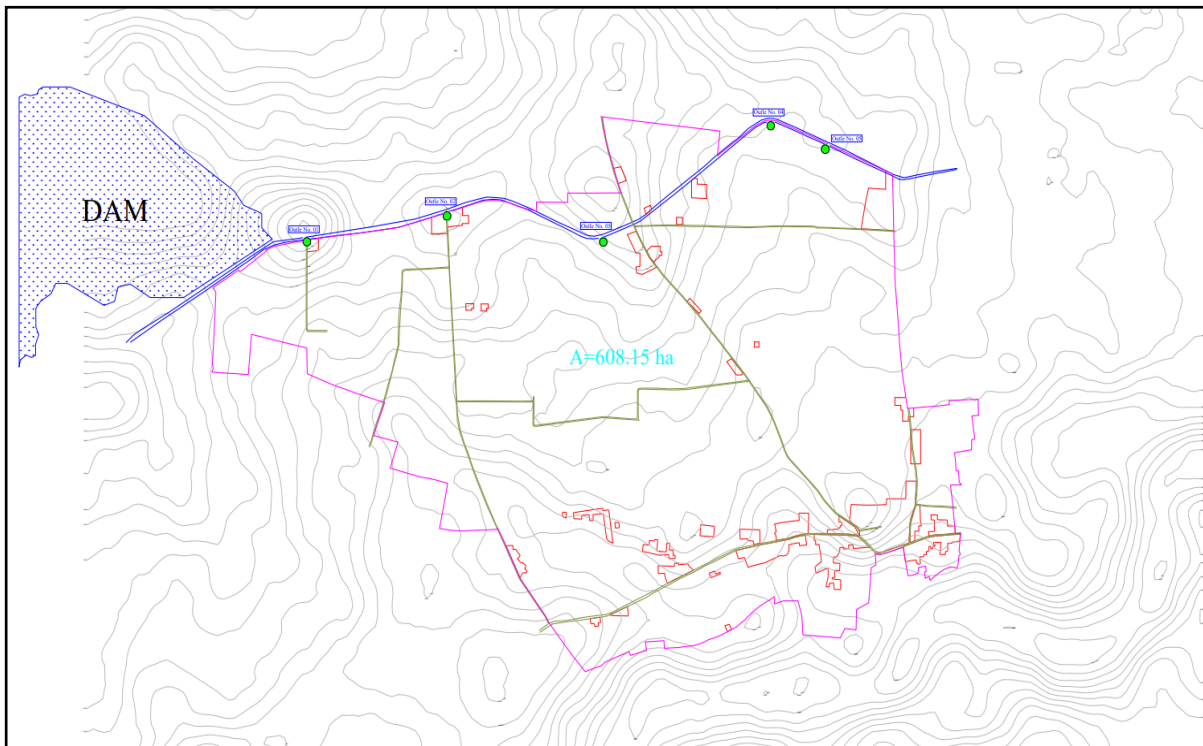


Fig. 4.10 Basic map for command area without image

4.3.3 Pipe distribution network design

Pipe distribution network design was carried out in IrriCAD software. The design map of PDN depicted in fig. 4.11 This design was carried out up to chak level. The design parameters are explained below.

- Existing dam in the command area was considered as the water source for irrigating command area and inflow of canal will be diverted to dam and dam will be the storage reservoir.
- Outlets of each chak were given at highest elevation point on the chak corners of each chak area. To reduce the head losses in pipes, points given at highest position. For 30 chaks 30 outlets were given.
- Required pressure at each outlet was estimated by analyzing minimum pressure requirement at all the components in pipe network. The minimum pressure requirement at different components is given in the Table E 1 of Appendix- E. According to calculations, 32 m will be required pressure at each outlet.
- The 50 m pump inlet pressure was given. At each outlet the available pressure is greater than required pressure. So, 50 m inlet pressure is sufficient to provide required head at each outlet. The details of each chak are given in the Table 4.9.

- The design was carried out for total flow of 2158 m³/hr. This flow is divided into 5 mainlines. For each mainline 5-7 numbers of chaks were connected. The details of area under each mainline is given in the Table 4.10.

Table 4.9 Details of chak outlets

Valve Name	U/S Pressure (m)	Valve Pressure (m)	Chak Area(ha)	Flow (m ³ /hr)	Elevation (m)
A01	32	39	18.59	70.4	514.7
A02	32	41.2	19.37	73.4	510.0
A03	32	41.0	18.38	69.6	510.3
A04	32	39.1	17.63	66.8	509.8
A05	32	35.6	19.99	75.7	511.3
A06	32	35.7	18.83	71.3	511.3
A07	32	42.9	19.65	74.4	506.1
A08	32	41.2	20.14	76.3	506.8
A09	32	42.0	19.49	73.8	503.5
A10	32	41.6	19.49	73.8	502.0
A11	32	39.4	19.53	74.0	501.0
A12	32	41.0	19.18	72.7	502.3
A13	32	40.4	20.60	78.0	504.6
A14	32	35.7	19.11	72.4	508.8
A15	32	40.1	19.21	72.8	509.4
A16	32	39.6	18.79	71.2	509.0
A17	32	35.3	19.67	74.5	509.1
A18	32	41.1	18.89	71.6	504.9
A19	32	38.0	19.77	74.9	503.0
A20	32	39.5	19.60	73.3	499.9
A21	32	38.4	16.20	61.4	503.0
A22	32	40.3	19.06	72.2	503.8
A23	32	33.3	17.60	66.7	504.9
A24	32	40.4	19.60	74.4	503.8
A25	32	32.4	18.19	68.9	504.9
A26	32	32.8	19.09	72.3	513.1
A27	32	35.9	19.01	72.0	506.5
A28	32	35.9	18.60	72.5	506.8
A29	32	33.9	18.71	70.9	511.6
A30	32	32.5	17.18	65.1	513.5
Total			575 ha	2158 m³/hr	

- Head control valve given at the outlet of water source to regulate the head required at output. Mainline flush valves, air release valves and pressure regulating valves given at required points on the mainline.

4.3.3.1 Valve pressure

The 50 m pump inlet pressure was given at input side. And at output side on each chak outlet pressure varies. Fig. 4.12 depicts the variation of available pressure at each outlet. The maximum pressure 42.9 m will be available at outlet no. 7 and minimum pressure 32.4 m will be available at outlet no. 25 i.e. maximum of 17.6 m head loss at outlet no. 25.

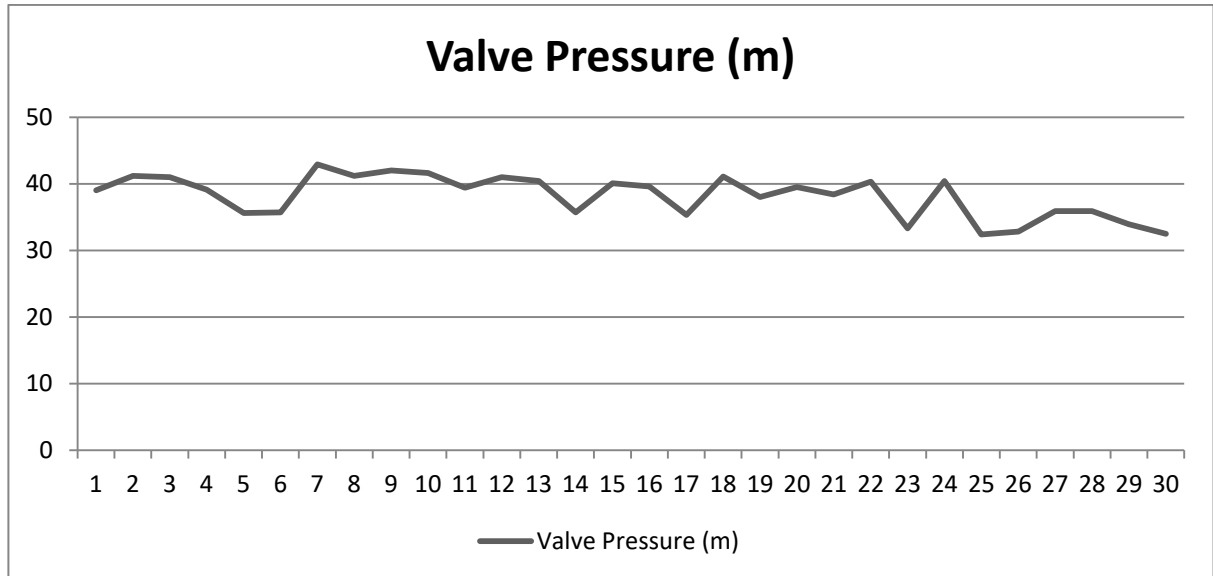


Fig. 4.12 Valve pressure distribution at chak outlet

4.3.3.2 Velocity distribution

The velocity distribution at different points on different mainlines is given in the Fig. 4.13. The velocity varies from 0.58 to 1.49 which clearly indicated that velocity is maintained in between 0.5 m/s and 1.50 m/s which the recommended range of velocity in the pipe system (CWC Guidelines, 2017). The detail data about velocities at the different points in the pipe network is given in the Table F 1 of Appendix- F.

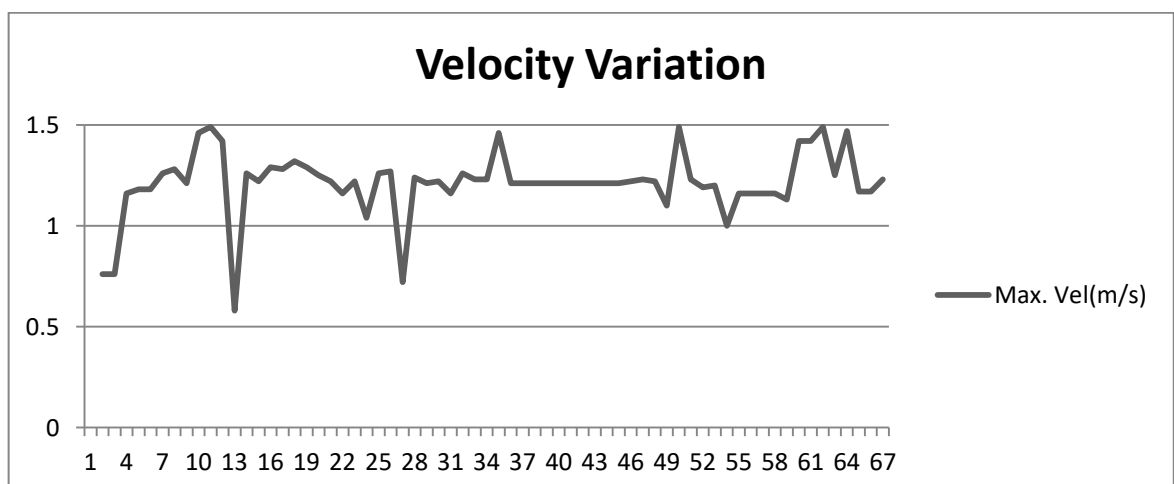


Fig. 4.13 Velocity variation in pipe network

4.3.4 Design for drip irrigation

A drip irrigation system consists of a main line, submains, laterals, and emitters. The main line delivers water to the submains, and the submains deliver water into laterals. The emitters, which are attached to the laterals, distribute water for irrigation.

4.3.4.1 Calculation of irrigation parameters

The computed data for drip irrigation is given in the Table 4.10. For sample designing one chak from study area was selected having area 18.3 ha. For designing 2 lph dripper was selected. In the study area drip irrigation were generally used for sugarcane crop. Aries 16008 type of dripper was used in design. Emitter spacing and lateral spacing were kept as 0.4 m and 1.2 m, respectively. Application rate was 4.16 which was calculated by formula emitter flow rate divided by emitter spacing and pipe spacing. Maximum daily consumption considered as 6.20 mm/day. Irrigation frequency is of one day i.e. on each day irrigation will be given. Time required for each operation will be 1.49 hrs, therefore for completing 11 shifts per day 16.4 hrs per day will be required. Average chak shift area will be 1.67 ha having flow 69.4 m³/hr which was calculated by multiplying shift area with application rate. Required pressure at each outlet was estimated by analyzing minimum pressure requirement at all the components in pipe network. So, required pressure at outlet will be 32m. The design map of drip irrigation is depicted in figure 4.13.

The computed preliminary irrigation data for drip irrigation design is given in Table 4.10.

Table 4.10 Computed preliminary irrigation data for drip design

PDN - Irrigation Data (2 LPH)		
Description	Units	
Crop Type		Mix crop
Irrigation Area According Season (Net)	ha.	18.3
Rows\Beds Spacing	m	1.20
Plants Spacing	m	-
Irrigation System	m	Drip
Irrigation System		Aries 16008
Emitter - Min. Allowed Pressure	m	7.0
Emitter Discharge	L/H	2.0
Emitter Spacing	m	0.40
Laterals Average Spacing	m	1.20
No. of Laterals per Row\Bed	No.	1.0
Application Rate	mm/h	4.17
Max. Daily Consumption	mm/day	6.20
Irrigation Cycle (days)	Days	1.0
Number of Irrigation days per week	Days	7.0
Duration of one Operation	hrs.	1.49
Number of Operations	No.	11.0
Max. Daily Operation Duration	Hrs.	16.4
Available Daily Duration	Hrs.	24.0
Maximum Shift Area	ha.	1.67
Maximum Ave. Discharge Required	m ³ /h	69.4
Maximum highest Discharge Required	Cumec	76.38
Maximum Discharge Required	m ³ /h	73.0
Required Pressure at Outlet	m	32.0

The Table 4.10 and 4.11 shows the scheme of operation of drip design and flow variation in the system. The total 18.3 ha area divided into 11 units. The maximum pressure required at shift will be 31.2m so the pressure required at the outlet will be considered as 32m. The Maximum and minimum flow variation in system will be 17.7 % and 6.3%, respectively. The average flow variation in system will be 12.9 percent.

Table 4.11 Scheme of operation for drip design

SCHEME OF OPERATION: PND Drip Model Design.						
Operation	Net area (ha.)	Appl. rate (mm/hr)	Irr. time (hr)	Total Q (m ³ /hr)	Required pressure at each shift above ground (m)	Pressure at outlet above ground (m)
1	1.55	4.17	1.5	63.5	28.4	32.0
2	1.57	4.17	1.5	64.1	30.5	
3	1.58	4.17	1.5	65.1	30.0	
4	1.67	4.17	1.5	68.6	29.3	
5	1.78	4.17	1.5	72.0	30.4	
6	1.77	4.17	1.5	72.8	30.5	
7	1.64	4.17	1.5	69.1	30.1	
8	1.75	4.17	1.5	71.5	30.4	
9	1.66	4.17	1.5	68.2	31.0	
10	1.66	4.17	1.5	70.2	31.2	
11	1.70	4.17	1.5	68.0	30.8	
Total	18.33		16.4			

Table 4.12 Flow variation in drip design

Zone name	Area (ha)	Valve	Flow (m ³ /h)	Req. pressure (m)	Min. pressure (m)	Max Pressure (m)	Mean Flow (lph)	Flow Variation (%)
CV-06-01	1.55	4" DO	63.5	18.0	9.0	11.2	2.1	9.5
CV-06-02	1.57	4" DO	64.1	20.0	8.4	12.3	2.2	16.1
CV-06-03	1.58	4" DO	65.1	20.0	8.4	12.8	2.2	17.7
CV-06-04	1.67	4" DO	68.6	19.0	9.6	11.0	2.1	6.3
CV-06-05	1.78	4" DO	72.0	20.0	8.5	12.7	2.2	16.7
CV-06-06	1.77	4" DO	72.8	20.0	8.1	12.2	2.2	16.9
CV-06-07	1.64	4" DO	69.1	20.0	9.4	12.5	2.2	12.0
CV-06-08	1.75	4" DO	71.5	20.0	8.5	12.0	2.2	14.7
CV-06-09	1.64	4" DO	68.2	20.0	9.2	11.2	2.1	8.3
CV-06-10	1.66	4" DO	70.2	20.0	9.7	12.6	2.2	11.2
CV-06-11	1.70	4" DO	68.0	20.0	8.5	11.3	2.1	12.4
							Avg.	12.9
							Min.	6.3
							Max.	17.7

4.3.5 Design for Sprinkler irrigation

A sprinkler irrigation system consists of a main line, submains, laterals, and sprinklers. The main line delivers water to the submains, and the submains deliver water into laterals. The sprinklers, which are attached to the risers, distribute water for irrigation.

4.3.5.1 Calculation of irrigation parameters

The computed data for drip irrigation is given in the Table 4.13. For sample designing one chak from study area was selected having area 18.3 ha. For designing 410 lph sprinkler was used. In the study area sprinkler irrigation were generally used for onion, gram, soybean, etc. D Net 8550 type of sprinkler was used in design. Sprinkler spacing and lateral spacing both were kept as 10 m. Application rate was 4.10 mm/hr, which was calculated by formula emitter flow rate divided by emitter spacing and pipe spacing. Maximum daily consumption considered as 6.20 mm/day. Irrigation frequency is of one day i.e. on each day irrigation will be given. Time required for each operation will be 1.51 hrs, therefore for completing 11 shifts per day 16.6 hrs per day will be required. Average chak shift area will be 1.67 ha having flow $68.3\text{m}^3/\text{hr}$ which was calculated by multiplying shift area with application rate. Required pressure at each outlet was estimated by analyzing minimum pressure requirement at all the components in pipe network. So, required pressure at outlet will be 32m. The design map of sprinkler irrigation is depicted in figure 4.14.

The computed preliminary irrigation data for sprinkler irrigation design is given in Table 4.13. The Table 4.14 and 4.15 shows the scheme of operation of sprinkler design and flow variation in the system. The total 18.3 ha area divided into 11 units. The maximum pressure required at shift will be 31.8 m so the pressure required at the outlet will be considered as 32m. The Maximum and minimum flow variation in system will be 15.1 % and 5.60 %, respectively. The average flow variation in system will be 10.17 %.

Table No. 4.13 Computed preliminary irrigation data for sprinkler design

PDN - Irrigation Data (410 LPH)		
Description	Units	
Crop Type		Mix crop
Irrigation Area According Season (Net)	ha.	18.3
Rows\Beds Spacing	m	10.00
Plants Spacing	m	-
Irrigation System		Sprinkler
Irrigation System		D Net 8550
Emitter - Min. Allowed Pressure	m	13.0
Emitter Discharge	lph	410.0
Emitter Spacing	m	10.00
Laterals Average Spacing	m	10.00
No. of Laterals per Row\Bed	No.	1.0
Application Rate	mm/h	4.10
Max. Daily Consumption	mm/day	6.20
Irrigation Cycle (days)	Days	1.0
Number of Irrigation days per week	Days	7.0
Duration of one Operation	hrs.	1.51
Number of Operations	No.	11.0
Max. Daily Operation Duration	hrs.	16.6
Available Daily Duration	hrs.	24.0
Maximum Shift Area	ha.	1.67
Maximum Ave. Discharge Required	m ³ /h	68.3
Maximum heighest Discharge Required	Cumec	68.32
Maximum Discharge Required	m ³ /h	73.0
Required Pressure at Outlet	m	32.0

Table No. 4.14 Scheme of operation for sprinkler design

SCHEME OF OPERATION : PDN Model Design Sprinkler						
Operation	Net Area (ha.)	Appl. Rate (mm/hr)	Irr. Time (hr)	Total Q (m³/hr)	Required pressure at each shift above ground (m)	Pressure at outlet above ground (m)
1	1.55	4.10	1.5	68.3	29.9	32.0
2	1.57	4.10	1.5	66.5	30.9	
3	1.58	4.10	1.5	64.2	31.8	
4	1.66	4.10	1.5	72.4	29.6	
5	1.78	4.10	1.5	70.3	31.3	
6	1.77	4.10	1.5	72.4	31.5	
7	1.64	4.10	1.5	62.0	29.2	
8	1.76	4.10	1.5	72.6	31.6	
9	1.66	4.10	1.5	68.3	30.8	
10	1.66	4.10	1.5	62.3	30.9	
11	1.70	4.10	1.5	67.9	31.7	
Total	18.33		16.6			

Table No. 4.15 Flow variation in sprinkler design

Zone Name	Area (ha)	Valve	Flow (m³/h)	Req. pressure (m)	Min. pressure (m)	Max. pressure (m)	Mean flow (lph)	Flow variation (%)
CV-06- 01	1.55	4" DO	68.3	19.0	15.8	18.8	409.1	8.2
CV-06- 02	1.57	4" DO	66.5	20.0	15.9	19.4	412.8	9.6
CV-06- 03	1.58	4" DO	64.2	21.0	15.3	20.4	414.9	13.3
CV-06- 04	1.66	4" DO	72.4	18.0	14.8	17.1	392.9	6.8
CV-06- 05	1.78	4" DO	70.3	20.0	14.7	19.7	407.8	13.5
CV-06- 06	1.77	4" DO	72.4	20.0	15.1	18.8	404.8	10.2
CV-06- 07	1.64	4" DO	62.0	19.0	14.5	18.4	398.7	11.1
CV-06- 08	1.76	4" DO	72.6	20.0	13.4	18.7	393.2	15.1
CV-06- 09	1.66	4" DO	68.3	19.0	15.0	16.9	393.0	5.6
CV-06- 10	1.66	4" DO	62.3	20.0	15.9	19.0	410.9	8.6
CV-06- 11	1.70	4" DO	67.9	20.0	14.7	18.1	398.5	9.9
							Avg	10.17
							Min	5.60
							Max	15.10

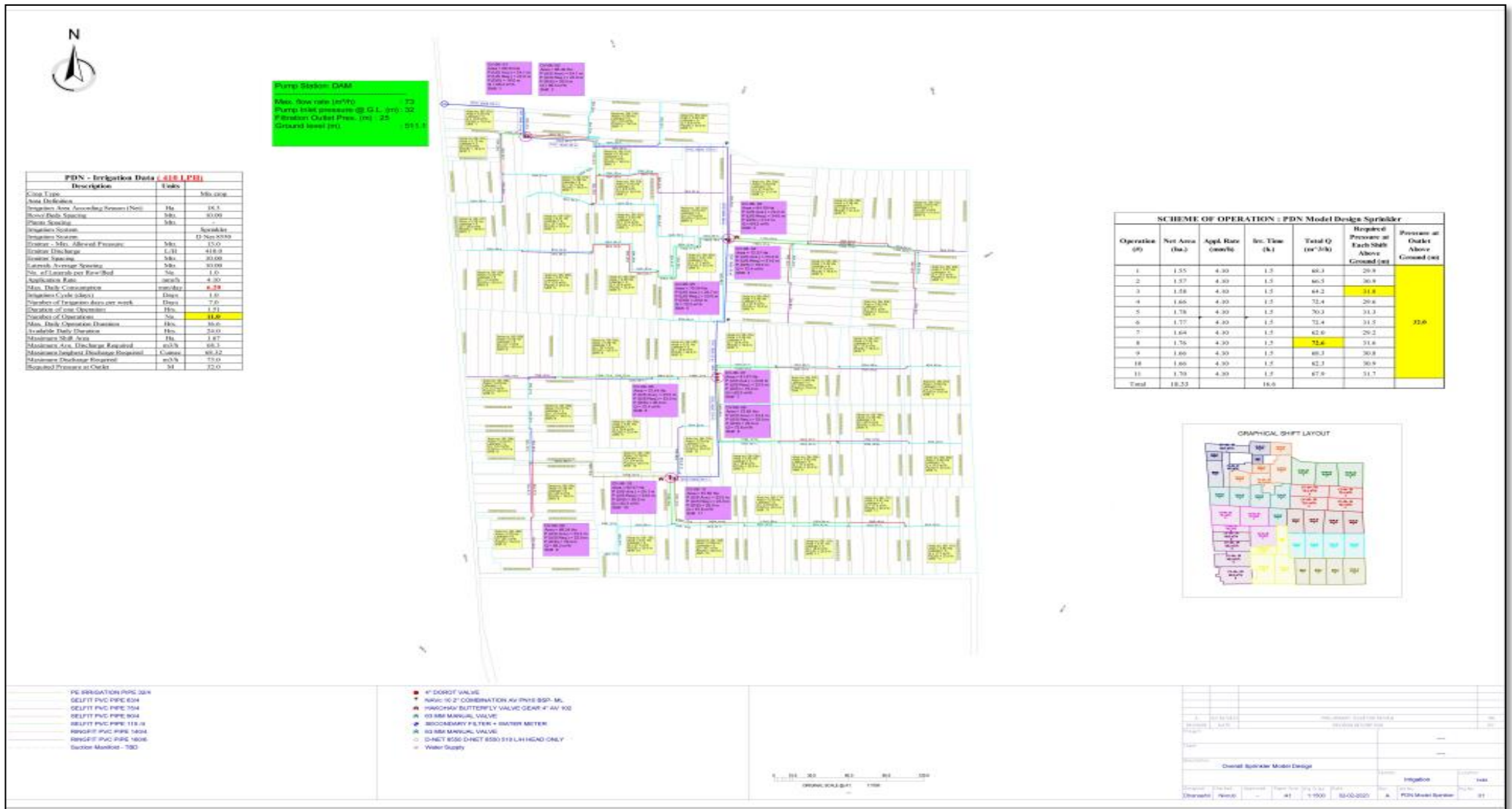


Fig. 4.15 Sprinkler irrigation design

4.3.6 Comparison of area irrigated

The total area of command is 611 ha out of which area irrigated by existing canal network is 491 ha. By adopting pipe network in command area cultural command area will be 575 ha. Therefore about 17 % of area will increase over area under existing canal network. Fig. 4.14 depicts comparison between area irrigated by canal distribution network and pipe distribution network.

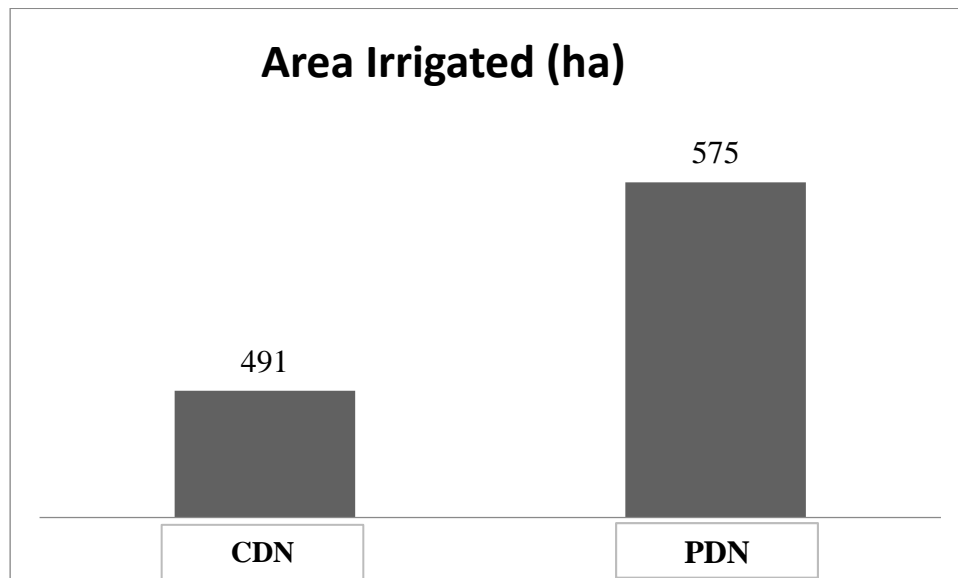


Fig. 4.16 Comparison of area irrigated

4.3.7 Economics of pipe network

The cost economics of pipe network were worked out by considering the total cost of irrigation system, inputs required for crop produce and output obtained from per hectare irrigated crop. The details are presented in Table G4 to G 12 of Appendix- G. While working out the cost economics, cost of production, gross monetary returns, were considered to work out the benefit cost ratio and are presented in Table 4.16. As the cost reports for pipe network were obtained directly from software, and reports obtained for 18.3 ha area. So, all the calculations were done for 18.3 ha. Different cropping patterns were suggested for different micro irrigation methods. The benefit cost ratio for intercropping with sugarcane crop under drip irrigation will be highest than the other cropping patterns.

Table No. 4.16 Economics of pipe network

Season	Crop	Period (Days)	Micro irrigation	Cost of cultivation, (Rs)	Cost of microirrigation, (Rs)	Total cost, (Rs)	Gross monetary returns, (Rs)	Net income, (Rs)	B/C ratio
Annual	Sugarcane	370	Drip	250191	8289	258480	343644	85164	1.33
Summer	Maize	100	Drip	94090	2763	96853	131988	35135	1.36
	Groundnut	120	Sprinkler	77752	2481	80233	110901	30668	1.38
	Cotton	180	Drip	92046	4144	96190	173377	77187	1.80
Kharif	Soyabean	100	Sprinkler	79855	2481	82336	123894	41558	1.50
	Onion	100	Sprinkler	186136	2481	188617	273902	85285	1.45
	Maize	100	Drip	92208	2763	94971	130106	35135	1.37
	Groundnut	120	Sprinkler	75838	2481	78319	128987	50668	1.65
Rabi	Gram	100	Sprinkler	59373	2481	61854	72193	10339	1.17
	Onion	100	Sprinkler	254422	2481	256903	314188	57285	1.22
	Maize	100	Drip	94090	2763	96853	131988	35135	1.36
	Wheat	110	Sprinkler	67721	2481	70202	105193	34991	1.50

5. SUMMARY AND CONCLUSIONS

The utilization of remote sensing and GIS tool were helpful in land use land cover classification of left bank command area of Mula basin. The study conducted in one of the economically fast-growing regions of Ahmednagar district (Maharashtra) advocates that multi temporal satellite imagery plays a vital role in quantifying spatial and temporal phenomenon which is otherwise not possible to attempt through conventional mapping.

One of the most vital inputs necessary for the growth of crops is water, which plants require in significant amounts continuously throughout their lives. Along with other processes, it has a significant impact on cell division, respiration, absorption, translocation, and utilization of mineral nutrients. A plant's growth and development are directly impacted by both an excess and a lack of irrigation water, which has an impact on both yield and quantity. Estimation of crop evapotranspiration (ET_c) is necessary for irrigation water management in any region.

Water is life for the existence of all living beings on the earth. Water ensures food security, feed livestock, maintain organic life and fulfill domestic and industrial needs (Kolhe 2012). The population of mankind is increasing at distressing rate and human is tapping natural resources to cater his need. The available resources including water and food are falling shorter to cope up with the need of mankind. To overcome this problem it is very essential to conserve the water in many ways and utilize it so that food production should be sufficient to serve for mankind need at reasonably low cost. To increase food production from agriculture land, irrigation is one of the tools to conserve the water and utilize it for agriculture production. Irrigation sector is the biggest consumer of water as more than 80% of available water resources in India are being presently utilized for irrigation purposes.

Despite of the popularity of micro irrigation system for increasing in productivity and considerable saving in water, the development of appropriate design criterion with minimum cost continues to be an important issue for researchers. Proper design and optimization techniques are essential to achieve the minimum cost solution for a micro irrigation pipe network consisting of laterals, manifolds, sub mains and mainline.

Pipe line system is being increasingly used for conveying irrigation water on the farm. Main advantage of these system are saving of land, elimination of seepage losses, and relatively little maintenance need. Under most of the conditions a properly installed pipeline system will function well for several years, however they need high initial cost as compared to open channel

The present study has been planned to evaluate water requirement of command area by different irrigation methods and use of pipe distribution network to reduce the losses. The study area, lies at Manori village in Ahmednagar district of Maharashtra. Study area is comes under canal command of left bank canal of Mula irrigation network.

5.1 Conclusions

The present study is aimed towards developing a methodology for designing pipe distribution network in the command area of irrigation projects, wherein the canal irrigation method is in existence. The developed methodology with the help of different software's led to the following conclusions.

1. Remote Sensing and Geographic Information System has proved to be powerful and cost effective method for land use land cover classification in the portion of left bank command area of Mula irrigation network.
2. Supervised image classification is effective technique for land use land cover classification.
3. The LULC map prepared for portion of left bank command area of Mula irrigation network shows that major area covered by sugarcane in year 2021-2022 is nearly about 129 ha (29 %), which is followed by groundnut (36 ha, 6%) in *summer* season, onion (80 ha, 13%) in *kharif* season and onion (82 ha, 13%) and gram (72 ha, 12%) in *rabi* season of year 2021-2022.
4. The yearly crop water requirement of command area is 3.92 MCM. Then by surface irrigation technique, the yearly irrigation water requirement of study area is 6.5 MCM while yearly irrigation water requirement by micro irrigation techniques (Drip/Sprinkler) is 4.4 MCM. Nearly 2 MCM water is saved annually by micro irrigation techniques and water saved which can be effectively used for increasing the area under command.
5. About 575 ha is culturable command area in which total 30 number of chaks were demarcated. Average chak area obtained was 19.2 ha.
6. In drip design maximum pressure required at shift will be 31.2m so the pressure required at the outlet will be considered as 32m. The Maximum and minimum flow variation in system will be 17.7 % and 6.3%, respectively. The average flow variation in system will be 12.9 percent.
7. In sprinkler design maximum pressure required at shift will be 31.8 m so the pressure required at the outlet will be considered as 32m. The Maximum and minimum flow variation in system will be 15.1 % and 5.60 %, respectively. The average flow variation in system will be 10.17 %.

8. The total area of command is 611 ha out of which area irrigated by existing canal network is 491 ha. By adopting pipe network in command area cultural command area will be 575 ha. Therefore about 17 % of area will increase over area under existing canal network.
9. In the *summer* season, cotton crop under drip irrigation gives highest B/C ratio. Similarly, in *kharif* season groundnut under micro sprinkler and in *rabi* season wheat under micro sprinkler gives highest benefit cost ratio.

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7. APPENDICES

Appendix A-1

The daily reference evapotranspiration data surrounding the rahuri weather station

Table A.1 Daily reference evapotranspiration data for year 2021-2022

Date	No of Day in year	Tmax (°C)	Tmin (°C)	Rhmax (%)	Rhmin (%)	Wind Speed (km/hr)	BSSH (Hrs)	Epan (mm/day)	Rainfall (mm)	ETr
1/1/2021	1	26	14.7	94	43	0.8	5.6	3.4	0	2.13
1/2/2021	2	27.6	19.4	72	48	0.4	5.7	3	0	2.2
1/3/2021	3	27.8	15.4	88	37	0.9	3.7	2.6	0	1.99
1/4/2021	4	30.2	16.9	81	49	0.9	7.6	3.2	0	2.63
1/5/2021	5	27.4	18.1	89	45	0.9	4.2	2.4	0	2.11
1/6/2021	6	26.2	18.9	89	51	0.8	0.9	2.5	0	1.63
1/7/2021	7	28.6	20.3	87	38	0.9	5.7	3	0	2.39
1/8/2021	8	28.2	20.7	95	54	1.6	3.6	2.6	18.6	2.22
1/9/2021	9	25	20.5	93	39	0.9	0	2.4	2	1.55
1/10/2021	10	28.2	19.9	95	43	0.3	6	2.8	0	2.35
1/11/2021	11	28.8	18.3	94	48	0.4	7	3	0	2.51
1/12/2021	12	28.6	16.3	88	45	1.2	9.2	3.4	0	2.88
1/13/2021	13	29.4	16.9	88	43	0.2	7.7	2.8	0	2.52
1/14/2021	14	29	15.4	92	38	0.3	9.2	3.2	0	2.66
1/15/2021	15	30	15.3	90	32	0.4	8.8	3	0	2.62
1/16/2021	16	31.8	16.5	92	42	0.8	8.8	3.4	0	2.93

1/17/2021	17	29.4	17.4	87	35	0.4	8	3	0	2.6
1/18/2021	18	29	19.9	84	39	0.6	6.1	3.2	0	2.47
1/19/2021	19	28	19.5	75	35	0.9	7.3	3.4	0	2.64
1/20/2021	20	31.6	16.1	88	40	1.8	7.9	3.6	0	3.05
1/21/2021	21	31	14.5	85	34	0.9	8.8	3.4	0	2.85
1/22/2021	22	30	12.9	83	36	0.7	9.1	3	0	2.77
1/23/2021	23	29.8	14.7	92	38	0.7	9.2	3	0	2.89
1/24/2021	24	30.6	15.4	86	28	0.7	9	3.2	0	2.83
1/25/2021	25	33.2	13.9	87	34	0.7	8.6	3.5	0	2.9
1/26/2021	26	30.6	13.3	89	40	0.9	9	3	0	2.95
1/27/2021	27	28.4	13.5	83	37	0.2	8.3	2.8	0	2.57
1/28/2021	28	28.6	15.4	84	22	0.5	8.6	2.6	0	2.66
1/29/2021	29	31.8	13.4	83	43	0.7	8.9	3	0	2.99
1/30/2021	30	27.4	12.5	82	43	0.7	7.9	2.4	0	2.66
1/31/2021	31	26.8	12.7	87	39	0.9	7.4	2.6	0	2.62
2/1/2021	32	28	13.4	83	39	0.7	7.4	2.5	0	2.65
2/2/2021	33	27.6	11.7	86	23	0.7	7.2	2.8	0	2.51
2/3/2021	34	28	12.5	84	23	0.4	9.5	3.2	0	2.74
2/4/2021	35	29.8	12.1	65	27	1.2	9.6	3	0	3.06
2/5/2021	36	30	13.3	83	35	1	9.6	3.4	0	3.15
2/6/2021	37	28.2	13.1	78	39	1	8.8	2.8	0	2.99
2/7/2021	38	26.4	10.9	75	32	1.2	9.5	2.6	0	2.97
2/8/2021	39	26.8	9.4	80	21	1.5	10.2	3	0	3.1
2/9/2021	40	28	9.5	85	20	1.3	9	2.5	0	2.97
2/10/2021	41	29.2	9.1	82	19	1.3	10.1	2.8	0	3.15
2/11/2021	42	29.8	12.4	74	21	1.2	10	3.2	0	3.23

2/12/2021	43	30	12.7	78	26	0.7	9.5	3	0	3.08
2/13/2021	44	30.6	14.3	77	19	0.8	9.1	3.4	0	3.08
2/14/2021	45	32.6	15.9	78	30	1.2	9.2	3.5	0	3.47
2/15/2021	46	30	16.5	77	32	0.7	8.7	3	0	3.18
2/16/2021	47	30.8	15.9	78	34	0.6	7.7	3.2	0	3.04
2/17/2021	48	30	16.5	77	40	0.6	8	3	0	3.13
2/18/2021	49	29	15.6	88	34	1.1	8.2	2.8	0	3.23
2/19/2021	50	30	16.1	82	46	0.9	8.3	2.5	7.2	3.33
2/20/2021	51	25.4	12.9	91	37	2	7.1	3	0	3.05
2/21/2021	52	26.8	14.9	83	39	3.4	9.3	3.6	0	3.8
2/22/2021	53	29.2	15.5	86	31	2.1	9	3.2	0	3.67
2/23/2021	54	30	15.3	86	25	1.1	9.4	3.8	0	3.5
2/24/2021	55	31.6	14.7	83	34	0.4	9.5	3.5	0	3.44
2/25/2021	56	31.4	15.6	84	28	0.8	9.8	3.8	0	3.6
2/26/2021	57	32.6	17.5	84	25	0.3	9.4	4.2	0	3.48
2/27/2021	58	31.6	14.1	77	30	1.1	9.8	4.2	0	3.68
2/28/2021	59	30	15.9	82	15	1.7	10.7	4.5	0	3.93
3/1/2021	60	34.6	19.4	67	21	1	10.4	4.2	0	3.97
3/2/2021	61	34.8	16.3	77	24	0.3	8.5	4.8	0	3.38
3/3/2021	62	33.6	15.5	82	18	1.2	10	4.2	0	3.88
3/4/2021	63	34.6	15.9	63	16	1.2	9.8	4.6	0	3.83
3/5/2021	64	35	15.5	63	16	1.5	9.4	5	0	3.93
3/6/2021	65	34.4	14.9	72	19	0.6	9.8	4.8	0	3.65
3/7/2021	66	35.2	14.4	77	20	1.4	9.5	5.4	0	4
3/8/2021	67	34.2	14.3	69	21	1.2	9.4	5	0	3.86
3/9/2021	68	34.6	15.5	70	22	0.9	9.1	5.6	0	3.77

3/10/2021	69	35.2	16.4	73	22	1	8.6	5.8	0	3.8
3/11/2021	70	36.2	17.9	71	18	0.6	8.7	6.2	0	3.7
3/12/2021	71	37	16.5	75	16	1.1	8.1	6.6	0	3.81
3/13/2021	72	36	17.4	70	27	0.9	9.2	6.2	0	4.03
3/14/2021	73	33.8	16.5	75	19	1.6	9	5.6	0	4.09
3/15/2021	74	36.6	17.4	68	21	1.3	9.1	6	0	4.16
3/16/2021	75	37.2	17.7	69	20	0.9	8.5	6.8	0	3.93
3/17/2021	76	35.2	17.5	67	20	1	8.8	6.2	0	3.94
3/18/2021	77	35.6	17.9	66	22	0.5	8.5	6.6	0	3.74
3/19/2021	78	35.4	22.9	46	29	1.7	7.5	5.8	0	4.17
3/20/2021	79	34.4	18.5	71	30	1.3	7.3	5.6	0	3.89
3/21/2021	80	34.4	17.4	90	34	3.4	7.5	4.8	14.6	4.53
3/22/2021	81	33.4	18.9	89	33	1	8.3	4.6	5.4	4.06
3/23/2021	82	33	19.5	78	37	0.6	6	4.2	3.4	3.47
3/24/2021	83	31.6	18.9	87	31	0.5	6.9	4	0	3.56
3/25/2021	84	34.4	19.5	78	23	0.6	8	4.8	0	3.86
3/26/2021	85	35	17.9	76	23	0.8	8.9	5.2	0	4.09
3/27/2021	86	35.8	18.9	80	17	1.5	9.2	5.6	0	4.46
3/28/2021	87	36.6	16.5	79	16	1.4	9.4	6.2	0	4.42
3/29/2021	88	37.8	18.7	73	12	1	9.5	6.6	0	4.32
3/30/2021	89	38.8	18.4	71	11	1.3	9.6	7.4	0	4.5
3/31/2021	90	39.4	20.4	46	12	1.1	9.7	7.5	0	4.39
4/1/2021	91	38.4	18.4	65	10	1.4	9.9	7	0	4.57
4/2/2021	92	37.6	19.5	75	17	2.7	9.8	7.2	0	5.24
4/3/2021	93	36.2	20.4	81	13	2.7	9.7	6.8	0	5.16
4/4/2021	94	38.2	21.5	83	15	3.6	9.5	7	0	5.65

4/5/2021	95	37.4	21.9	66	14	3.2	9.4	7.6	0	5.43
4/6/2021	96	39	21.4	56	17	2.4	9.8	8.2	0	5.25
4/7/2021	97	38	21.6	52	16	2.6	9.2	7.2	0	5.16
4/8/2021	98	38.2	22.4	62	15	1.6	9	7	0	4.74
4/9/2021	99	37.2	23.5	60	17	1.1	6	5.8	0	3.91
4/10/2021	100	36.6	22.5	63	18	2.2	7.8	6.4	0	4.72
4/11/2021	101	38.6	24.6	57	20	2.4	7.5	6.8	0	4.91
4/12/2021	102	36.8	21.4	59	20	1.8	8.5	6.5	0	4.7
4/13/2021	103	36.8	23.4	53	22	2.2	9.6	7.2	0	5.15
4/14/2021	104	36.2	23.7	66	19	2.8	5.8	6	0	4.58
4/15/2021	105	36.8	21.4	64	20	1.9	9.3	6.8	0	4.94
4/16/2021	106	36.4	21.9	69	16	1.6	10.5	7.2	0	5.06
4/17/2021	107	36.6	23.4	31	15	2	10.5	7.8	0	5.07
4/18/2021	108	38.6	25.9	48	18	1.7	10	8.2	0	5.17
4/19/2021	109	38.4	27.3	44	16	1.7	9.6	8	0	5.08
4/20/2021	110	38.2	27.4	65	17	2.7	10.7	8.6	0	5.88
4/21/2021	111	38.8	21.9	64	19	2.9	9	8.4	0	5.46
4/22/2021	112	37	21.4	61	14	3	8.3	7.2	0	5.22
4/23/2021	113	38.2	23.9	43	17	2.6	9.2	7.8	0	5.34
4/24/2021	114	37	21.9	50	12	0.9	9.6	7.6	0	4.47
4/25/2021	115	38.4	26.4	55	17	0.8	10.5	8.5	0	4.96
4/26/2021	116	39	27.3	45	15	1.8	10.3	9	0	5.33
4/27/2021	117	39.4	24.4	59	17	2.8	7.4	9.4	0	5.2
4/28/2021	118	38.4	26.9	43	20	3.5	9.3	9.6	0	5.9
4/29/2021	119	38.6	23.9	57	18	2.4	8.9	9.2	0	5.29
4/30/2021	120	38.2	24.9	56	21	2.2	10	9.8	0	5.47

5/1/2021	121	38	25.4	55	29	3.8	6.7	10.2	0	5.36
5/2/2021	122	34.6	25.9	52	34	1	1.7	6.4	0	3.03
5/3/2021	123	34	23.4	77	27	1.6	1.5	5.5	2	3.12
5/4/2021	124	36.4	26.4	57	22	1.7	9.7	6.8	0	5.19
5/5/2021	125	37.8	25.4	62	21	1.5	9.4	8.8	0	5.09
5/6/2021	126	38.4	26.5	63	23	1.3	10.1	9.6	0	5.28
5/7/2021	127	38.6	27.3	57	27	1.7	8.8	10.2	0	5.18
5/8/2021	128	37	26.9	63	25	1.1	7.7	8.4	0	4.61
5/9/2021	129	38.6	27.9	62	27	1.4	9.5	9.8	0	5.29
5/10/2021	130	38.4	26.3	69	24	0.9	5.6	7.6	0	4.07
5/11/2021	131	39.4	25.9	55	23	1.6	9.6	10.8	0	5.28
5/12/2021	132	38.4	23.9	70	21	2.6	10.9	11.2	0	5.88
5/13/2021	133	38.8	25.3	64	23	2.4	10.7	11	0	5.84
5/14/2021	134	37.2	26.4	61	24	3.3	9.8	10.4	0	5.89
5/15/2021	135	38.8	26.9	72	30	1.9	8.8	9.6	1.2	5.33
5/16/2021	136	38.2	25.9	77	38	5.6	5.8	8.4	1.4	5.52
5/17/2021	137	35.6	26.3	64	47	8.4	4.1	5.8	0	5.5
5/18/2021	138	32.4	25.9	70	43	10.5	1.6	4.2	0	5.08
5/19/2021	139	35	27.4	63	54	9.8	1.5	6	0	4.95
5/20/2021	140	31	24.5	71	31	6.7	5.1	5.5	0	5.18
5/21/2021	141	35.4	25.5	71	25	5.9	10.4	7.8	0	6.63
5/22/2021	142	38.4	24.7	74	29	2.5	9.1	8.2	0	5.5
5/23/2021	143	36.6	24.9	71	29	3.6	8	7.6	0	5.47
5/24/2021	144	36.4	25.1	71	28	3.5	6.1	6.8	0	4.99
5/25/2021	145	37.8	25.9	66	30	4.5	9	7.6	0	6.11
5/26/2021	146	36.6	25.4	70	26	5.6	2.3	6.8	0	4.85

5/27/2021	147	38.2	26.5	65	30	10.1	10.7	8	0	8.16
5/28/2021	148	37.2	25.9	70	31	5.8	10.3	8.6	0	6.71
5/29/2021	149	37.8	27.1	67	33	4.5	8.7	9.2	0	6.05
5/30/2021	150	38	24.1	82	37	3.5	7.5	8.4	1.8	5.33
5/31/2021	151	27.2	26.4	68	47	1.7	5.3	7.8	0	3.86
6/1/2021	152	35	25.5	78	34	2.5	2.5	6.6	0	3.69
6/2/2021	153	37	24.7	86	47	1.6	6	7	4.2	4.4
6/3/2021	154	34.8	24.5	79	36	1.6	5.3	7.4	2.2	4.1
6/4/2021	155	35.2	25.7	64	45	1.5	8.3	8.8	0	4.88
6/5/2021	156	32	23.9	87	45	0.5	3.6	6.2	0.8	3.3
6/6/2021	157	33.2	23.4	90	56	1.2	3.4	5	20.4	3.41
6/7/2021	158	31.2	24.9	80	67	0.4	4.8	4.8	0	3.66
6/8/2021	159	29.6	25.4	75	53	0.7	2.3	3.4	0	2.98
6/9/2021	160	33.4	25.1	78	52	3	9	6.8	0	5.24
6/10/2021	161	32.2	25.9	72	49	5.6	4.3	6.5	0	4.57
6/11/2021	162	31.2	25.4	70	58	8.1	6.6	7.6	0	5.25
6/12/2021	163	30.4	24.9	80	42	8.7	3.1	7	1.8	4.71
6/13/2021	164	35.2	25.4	78	39	6.1	9.6	8.2	0	6.23
6/14/2021	165	36.4	25.3	78	42	5.1	9.3	8.8	0	6.02
6/15/2021	166	35.6	25.7	77	41	4.4	7.3	9.4	0	5.34
6/16/2021	167	35.4	25.9	72	47	5.7	3.7	9	0	4.69
6/17/2021	168	32.8	25.3	78	48	4.7	2.5	7.6	4.6	3.94
6/18/2021	169	33.2	24.9	72	50	6	3.7	6.8	0	4.52
6/19/2021	170	32.6	23.9	79	44	7.7	5.7	6.2	1	5.24
6/20/2021	171	32.2	25.1	75	41	6.7	5.4	5.8	2.2	5.1
6/21/2021	172	33.6	24.4	76	38	7.2	7.4	7.2	1.4	5.8

6/22/2021	173	34	25.5	72	34	6.8	9.8	7.6	0	6.43
6/23/2021	174	34.8	25.4	73	59	5.8	7.9	8	0	5.47
6/24/2021	175	31.2	23.9	87	55	1.7	2.2	6.2	4.4	3.12
6/25/2021	176	29.4	24.4	79	70	4.6	0	5	0	2.8
6/26/2021	177	28.2	23.9	81	75	4.8	1.1	4.4	0	2.93
6/27/2021	178	27.8	23.1	93	69	2.3	0.7	2.8	39.8	2.58
6/28/2021	179	29.1	22.5	97	65	3.5	0.3	1	31.8	2.62
6/29/2021	180	30.8	23.9	89	54	1.7	2.5	4.6	6.4	3.18
6/30/2021	181	33	25.1	83	55	0.3	8.8	6.4	8.2	4.75
7/1/2021	182	33.4	24.4	79	44	3.5	10.4	7.2	0	5.66
7/2/2021	183	33.2	23.9	82	49	4.3	5.5	6.8	0	4.53
7/3/2021	184	33	24.4	78	43	5.8	9.4	7.8	0	5.82
7/4/2021	185	33.8	24.5	78	37	3.6	9.2	7.4	0	5.45
7/5/2021	186	35	25.4	75	41	3.1	9.3	7.8	0	5.48
7/6/2021	187	34.8	25.5	73	41	1.7	10	7.2	0	5.32
7/7/2021	188	35	26.4	70	51	2.4	8	8	0	5.03
7/8/2021	189	34.2	25.9	74	55	2.5	7.2	7.6	0	4.76
7/9/2021	190	33	24.1	93	71	1.2	3.1	5.2	11.6	3.3
7/10/2021	191	29.2	24.4	87	66	1.6	0	4.8	23.4	2.43
7/11/2021	192	30	24.3	92	67	3.2	2	5.2	2	3.09
7/12/2021	193	30.2	22.7	98	77	0.5	2.3	3.2	71.6	2.91
7/13/2021	194	29.8	23.9	89	61	0.5	4.8	4.8	1.2	3.57
7/14/2021	195	31.8	23.4	92	72	2.7	3.4	4.2	8.4	3.43
7/15/2021	196	28.2	23.5	88	63	2.9	0.3	4	0.4	2.62
7/16/2021	197	30	24.4	84	63	1.7	2.7	3.6	5.2	3.18
7/17/2021	198	31.4	23.9	85	60	2.2	5.5	4.6	9.8	4.01

7/18/2021	199	31.6	23.7	90	61	0.7	5.9	4.2	21.8	3.94
7/19/2021	200	30.2	23.5	82	61	3.5	4.1	3.8	4.4	3.75
7/20/2021	201	30.6	23.9	84	75	0.7	2.4	4.8	1.4	2.98
7/21/2021	202	28.2	23.7	82	67	1.7	0.6	4.2	1	2.56
7/22/2021	203	28.4	23.9	90	72	5.3	0	4	0	2.63
7/23/2021	204	28.6	24.3	93	60	8.1	0	4.6	0	3.08
7/24/2021	205	29.2	25.1	81	60	6.4	0.5	4.4	0.4	3.26
7/25/2021	206	30.6	25.5	78	59	4.9	5.2	5	2.4	4.33
7/26/2021	207	30.2	24.9	83	53	6.4	0.6	3.8	0	3.45
7/27/2021	208	31.2	24.4	84	52	6.6	8.9	5.4	0	5.45
7/28/2021	209	31.2	24.5	72	63	9.2	6.8	5.6	0	5.2
7/29/2021	210	29.6	23.4	85	66	6.9	3.2	4.8	0	3.73
7/30/2021	211	28.2	23.1	85	86	9.4	0	4.4	0	2.56
7/31/2021	212	35.2	23.4	84	63	7.5	0	4.2	2.6	3.45
8/1/2021	213	28.4	23.9	74	67	7.3	3.7	4.6	0	3.97
8/2/2021	214	28	22.3	90	78	3.1	2.8	3.4	0.6	3.05
8/3/2021	215	26	23.4	85	59	8.6	0	4	1.6	3.14
8/4/2021	216	29.6	23.9	82	60	5.6	4.1	4.8	0	3.97
8/5/2021	217	30.4	25.1	75	54	5.3	4.3	5.6	0	4.23
8/6/2021	218	31.2	24.7	77	51	8.6	8.9	6	0	5.8
8/7/2021	219	31.6	23.5	87	46	4.9	1.5	4.4	0	3.54
8/8/2021	220	33	25.5	74	50	3.3	8.2	5.8	0	5.05
8/9/2021	221	32.4	24.9	80	65	3.1	7.9	6.4	0	4.79
8/10/2021	222	30.4	23.6	84	73	0.7	4.8	5.4	0	3.58
8/11/2021	223	31.2	24.1	76	59	0.5	4.3	4.2	1.2	3.42
8/12/2021	224	29.2	22.9	83	59	1.3	3.2	4	0	3.16

8/13/2021	225	30.2	22.7	85	47	2.7	2.5	4.2	0.6	3.29
8/14/2021	226	32.8	22.9	82	54	2.4	7.9	6.2	0	4.66
8/15/2021	227	30.2	23.3	82	69	3.5	4.9	5.8	0	3.82
8/16/2021	228	29	23.1	87	57	4.5	1.3	5.6	3.2	3.1
8/17/2021	229	30.8	22.9	92	83	0.9	3.8	4.2	4.2	3.3
8/18/2021	230	26.4	22.1	95	72	0.7	0	2.4	15.8	2.15
8/19/2021	231	28	21.9	93	92	0.8	0	3.2	10.4	2.14
8/20/2021	232	23.8	22.1	95	87	1	0	0.6	8.4	2.07
8/21/2021	233	25.4	22.9	97	91	1.1	0	1.4	12.6	2.09
8/22/2021	234	23.6	21.7	93	65	1.2	0	1	27.8	2.13
8/23/2021	235	28.8	22.4	96	58	0.7	4.3	3.8	0	3.29
8/24/2021	236	30.8	22.7	95	56	0.5	9.3	5.2	0	4.63
8/25/2021	237	31.8	21.5	90	59	0.9	8.9	5.4	0	4.56
8/26/2021	238	30.4	22.4	91	60	0.6	7	6.2	0	4.01
8/27/2021	239	29.8	22.3	90	60	0.4	5.9	5.8	1.2	3.67
8/28/2021	240	29.8	22.5	91	52	1	7.1	6	0	4.02
8/29/2021	241	32	23.9	81	57	2.2	3.4	6.4	0	3.41
8/30/2021	242	30.8	23.4	82	71	0.4	4.3	6	0	3.33
8/31/2021	243	28.6	21.9	98	97	0.9	0	2	69.4	2.08
9/1/2021	244	25.2	23.7	87	66	0.9	0.9	2	10.4	2.35
9/2/2021	245	29.2	22.4	88	58	2.2	5.1	2	0.2	3.61
9/3/2021	246	30	22.9	88	53	4	4.8	3.2	0	3.85
9/4/2021	247	31.2	24.3	85	55	3.7	8.9	5.2	0	4.9
9/5/2021	248	32	22.4	98	64	2.6	7.2	4.6	18.2	4.25
9/6/2021	249	29	22.7	95	74	2	2.2	3.2	5.2	2.77
9/7/2021	250	28.6	21.9	98	89	0.9	1.3	1.4	74.6	2.41

9/8/2021	251	26.6	23.4	92	70	1.4	0	1.8	18.8	2.14
9/9/2021	252	29.9	23.7	85	65	3.7	6	4	0	3.98
9/10/2021	253	29.9	23.4	85	58	5	8.3	4.6	0	4.68
9/11/2021	254	31	24.4	81	65	4	6	5.2	0	4.1
9/12/2021	255	30.8	23.9	87	76	6.2	5.5	4.4	3.6	3.9
9/13/2021	256	29.2	14.1	89	64	4.8	2.6	4	2.2	3.02
9/14/2021	257	29.8	23.7	85	67	5.1	3.9	4.4	1.8	3.54
9/15/2021	258	28.4	24.3	81	59	5.1	2.8	3.8	0	3.39
9/16/2021	259	29.2	23.4	80	57	3.8	0.9	3.2	0	2.84
9/17/2021	260	29.2	21.9	86	53	3.6	1.8	3.6	0	2.98
9/18/2021	261	31	22.4	83	73	3	5.1	4.6	0	3.58
9/19/2021	262	27.6	24.1	82	52	2.4	3.9	3.8	0	3.25
9/20/2021	263	32.4	24.9	80	89	0.6	6.4	5.6	0	3.91
9/21/2021	264	25.8	22.9	93	70	0.5	4.1	2.6	11.2	2.94
9/22/2021	265	29.6	22.4	93	77	1.3	1.1	2.8	6.8	2.34
9/23/2021	266	26.6	22.9	93	68	1.4	3.1	3.2	33.6	2.77
9/24/2021	267	30.2	22.5	95	64	0.6	0.9	3.5	15.6	2.25
9/25/2021	268	29.8	22.7	90	65	0.9	2.2	3.4	0	2.59
9/26/2021	269	29.4	22.1	95	82	0.9	1.8	3	13.4	2.44
9/27/2021	270	26.8	21.9	97	69	0.7	0	2.6	20.2	1.94
9/28/2021	271	29	22.3	95	86	0.6	2.1	3.2	2.8	2.48
9/29/2021	272	25.6	22.9	85	66	0.8	0	2.6	6.8	1.95
9/30/2021	273	29.6	22.7	88	54	1.6	4.8	3.8	0	3.23
10/1/2021	274	31.8	22.4	95	57	2.7	9.5	5.2	0	4.51
10/2/2021	275	32.8	21.9	95	67	1	8.7	5.8	20.8	4.21
10/3/2021	276	29.8	22.4	93	89	1.1	5.3	5	0	3.26

10/4/2021	277	27	23.5	95	57	0.4	4.2	3	10.2	2.84
10/5/2021	278	32.6	21.9	98	62	0.6	9.2	5.4	24.8	4.21
10/6/2021	279	31.6	23.1	90	61	0.5	8.5	5.2	1.8	3.98
10/7/2021	280	32.6	23.4	93	63	0.5	8.3	5.8	5.6	4.01
10/8/2021	281	32.8	24.1	90	89	0.8	7.4	5.6	0	3.95
10/9/2021	282	27	22.4	98	80	0.9	3.3	3	21.8	2.6
10/10/2021	283	26.4	22.7	95	56	0.7	2.4	2.6	3.6	2.38
10/11/2021	284	31.6	21.9	97	58	0.9	5.6	5.2	0	3.24
10/12/2021	285	31.4	22.9	93	49	0.5	7.6	5.6	0	3.59
10/13/2021	286	33	24.1	84	44	0.6	8	6	0	3.72
10/14/2021	287	33.2	21.1	89	40	0.5	8.6	6.4	0	3.68
10/15/2021	288	33.4	21.9	81	37	0.6	8	6.6	0	3.54
10/16/2021	289	32.2	19.9	91	38	1.1	8.9	5.4	0	3.74
10/17/2021	290	32.4	22.7	90	53	0.5	7.2	5.6	0	3.46
10/18/2021	291	31	22.4	78	56	0.6	5.7	5	0	3.06
10/19/2021	292	33	19.9	81	34	1	9.5	5.5	0	3.74
10/20/2021	293	32	18.9	87	29	0.7	9	5.2	0	3.45
10/21/2021	294	32	19.4	85	29	1.6	9.9	5	0	3.85
10/22/2021	295	32.2	17.5	88	29	2.6	9.8	5.6	0	4.05
10/23/2021	296	32.4	19.4	77	27	1.8	10.6	5.8	0	3.97
10/24/2021	297	33.2	18.9	82	37	0.9	10.3	6.4	0	3.76
10/25/2021	298	32	18.4	85	32	0.9	9.3	6	0	3.46
10/26/2021	299	31.8	18.5	87	32	0.7	9.6	5.6	0	3.44
10/27/2021	300	31.6	18.3	83	30	1.2	9.8	5.8	0	3.55
10/28/2021	301	31.4	18.5	83	37	0.8	9.3	5.4	0	3.39
10/29/2021	302	31.8	17.9	77	30	1.9	8.8	5.2	0	3.55

10/30/2021	303	30.4	16.5	73	32	1.9	9.7	4.8	0	3.55
10/31/2021	304	31.6	17.9	76	35	1.5	9.8	5.4	0	3.56
11/1/2021	305	31.6	17.3	84	38	0.8	9.4	5.6	0	3.31
11/2/2021	306	33	17.9	85	37	0.6	8.1	5.8	0	3.1
11/3/2021	307	30.6	19.3	80	40	1	7.7	4.8	0	3.08
11/4/2021	308	31.2	20.5	79	41	0.9	6.45	5.2	0	2.9
11/5/2021	309	32.8	21.9	83	50	1.3	6.5	5.4	0	3.13
11/6/2021	310	30.2	21.1	86	44	1.2	6.5	4.6	0	2.95
11/7/2021	311	31.4	21.4	78	40	1.7	7.1	5.2	0	3.19
11/8/2021	312	30.2	18.3	83	29	1.2	6	4.4	0	2.73
11/9/2021	313	30.6	13.4	89	25	1.9	9.4	4	0	3.26
11/10/2021	314	30.6	12.5	84	22	2.2	9.4	4.8	0	3.32
11/11/2021	315	29.4	13.1	85	21	1.7	9.1	4.6	0	3.05
11/12/2021	316	30	12.5	78	32	2.1	9	5.2	0	3.18
11/13/2021	317	29.8	17.9	79	51	2.3	9.4	5	0	3.4
11/14/2021	318	30	21.4	79	49	3.2	6.5	4.8	0	3.23
11/15/2021	319	31.8	20.9	89	51	2.1	5.7	4.6	0	2.94
11/16/2021	320	31.4	20.4	87	63	0.8	6.6	5	0	2.85
11/17/2021	321	29.8	21.9	88	57	1.4	0	4.2	0	1.76
11/18/2021	322	30.2	22.4	88	49	0.5	2.5	4	0	2.04
11/19/2021	323	31.8	21.4	95	57	1.2	8.6	4.8	1.4	3.28
11/20/2021	324	29.6	22.3	82	60	1.8	4.4	4	0	2.55
11/21/2021	325	29.6	21.9	90	55	1.5	4.2	4.2	0	2.45
11/22/2021	326	31.4	22.1	95	55	0.9	3.1	4.6	3.6	2.22
11/23/2021	327	31	22.4	95	56	1.4	3.9	4	45.4	2.42
11/24/2021	328	31	21.5	91	56	0.7	7	4.4	0	2.82

11/25/2021	329	31.2	20.3	87	49	1.7	6.9	5	0	2.91
11/26/2021	330	31	18.4	91	46	0.4	7.7	4.6	0	2.69
11/27/2021	331	30.2	17.5	88	37	1.3	8.1	4.8	0	2.82
11/28/2021	332	29.8	14.5	87	26	0.9	8.3	4.4	0	2.57
11/29/2021	333	28	14.4	75	40	1.5	9	4.6	0	2.78
11/30/2021	334	24.6	19.1	72	46	0.6	3.8	3.4	0	1.95
12/1/2021	335	26	18.7	87	73	1.3	0.7	3	0	1.59
12/2/2021	336	20	14.4	98	89	2	0	1	23.2	1.26
12/3/2021	337	18.8	17.6	96	67	1.7	0	1.4	1.2	1.38
12/4/2021	338	26.6	18.5	92	68	2.3	3.5	2.8	46.2	2.13
12/5/2021	339	26.4	17.9	91	55	0.6	4.1	3.2	0	2.01
12/6/2021	340	28	16.7	94	48	0.3	8	3.8	0	2.49
12/7/2021	341	28.2	17.3	92	47	0.4	6.6	3.4	0	2.33
12/8/2021	342	28	16.5	92	48	0.7	5.8	3.2	0	2.25
12/9/2021	343	27.4	17.1	92	48	0.5	5	3	0	2.1
12/10/2021	344	28	17.4	88	47	0.7	5.3	3.6	0	2.19
12/11/2021	345	28.8	16.5	88	48	1.1	6.1	4	0	2.38
12/12/2021	346	27.4	14.9	88	44	0.7	6.5	3.4	0	2.24
12/13/2021	347	27.2	14.1	87	50	0.7	7.4	3.8	0	2.35
12/14/2021	348	27.6	15.9	80	41	0.2	5.7	4.2	0	2.03
12/15/2021	349	29.8	16.5	92	50	0.6	6.5	4	0	2.37
12/16/2021	350	28.4	15.9	88	44	0.5	2.2	3.8	0	1.71
12/17/2021	351	28	15.3	88	41	0.4	3.8	4.2	0	1.86
12/18/2021	352	29.4	13.4	89	41	0.9	7.7	4.8	0	2.44
12/19/2021	353	27.4	13.1	87	43	0.3	8	4.2	0	2.27
12/20/2021	354	27	11.4	95	42	0.5	7.7	3.8	0	2.23

12/21/2021	355	26.4	10.3	93	37	0.2	8.1	3.6	0	2.12
12/22/2021	356	27.4	11.5	91	32	0.4	7.9	4.2	0	2.18
12/23/2021	357	29.2	13.1	91	37	0.4	8.2	4.6	0	2.34
12/24/2021	358	30	14.9	88	28	0.3	8	4.8	0	2.28
12/25/2021	359	31.6	12.9	91	77	0.4	7.7	5.2	0	2.64
12/26/2021	360	26	12.7	95	40	0.5	8.4	3.6	0	2.31
12/27/2021	361	29.2	13.7	91	43	0.5	7.7	4.2	0	2.38
12/28/2021	362	27.8	15.5	88	34	0.4	7.3	3.8	0	2.25
12/29/2021	363	29.6	12.9	91	46	0.2	3.5	3.2	0	1.79
12/30/2021	364	25.8	13.5	93	75	0.5	7.6	3	0	2.4
12/31/2021	365	20.6	14.7	94	58	0.6	0	1.8	0	1.3

Appendix B

Computation of crop water requirement

Appendix B-1 Computation of crop water requirement for sugarcane crop

Table B 1 Crop water requirement for sugarcane crop

Sr. No.	Date	t	T	t/T	Kc	Eto	Etc
1	2/11/2021	1	377	0.0027	0.3737	2.67	3.21
2	2/12/2021	2	377	0.0053	0.3755	2.54	3.03
3	2/13/2021	3	377	0.0080	0.3773	2.12	3.14
4	2/14/2021	4	377	0.0106	0.3792	2.97	3.39
5	2/15/2021	5	377	0.0133	0.3811	3.32	3.17
6	2/16/2021	6	377	0.0159	0.3831	3.32	3.03
7	2/17/2021	7	377	0.0186	0.3852	3.42	3.09
8	2/18/2021	8	377	0.0212	0.3872	3.5	3.26
9	2/19/2021	9	377	0.0239	0.3894	3.65	3.08
10	2/20/2021	10	377	0.0265	0.3916	3.6	2.88
11	2/21/2021	11	377	0.0292	0.3938	3.65	3.63
12	2/22/2021	12	377	0.0318	0.3961	3.22	3.5
13	2/23/2021	13	377	0.0345	0.3985	3.47	3.34
14	2/24/2021	14	377	0.0371	0.4009	3.98	3.34
15	2/25/2021	15	377	0.0398	0.4033	3.5	2.79
16	2/26/2021	16	377	0.0424	0.4058	3.61	3.51
17	2/27/2021	17	377	0.0451	0.4083	3.92	3.65
18	2/28/2021	18	377	0.0477	0.4109	3.84	4.01
19	3/1/2021	19	377	0.0504	0.4136	4.12	3.89
20	3/2/2021	20	377	0.0531	0.4162	3.74	3.88
21	3/3/2021	21	377	0.0557	0.4190	3.62	4.5
22	3/4/2021	22	377	0.0584	0.4217	3.82	4.41
23	3/5/2021	23	377	0.0610	0.4245	4.9	4.47
24	3/6/2021	24	377	0.0637	0.4274	4.18	4.12
25	3/7/2021	25	377	0.0663	0.4303	4.37	4.48
26	3/8/2021	26	377	0.0690	0.4332	4.27	4.31
27	3/9/2021	27	377	0.0716	0.4362	3.7	4.2
28	3/10/2021	28	377	0.0743	0.4392	4.03	4.22
29	3/11/2021	29	377	0.0769	0.4423	3.99	4.16
30	3/12/2021	30	377	0.0796	0.4454	3.74	4.22
31	3/13/2021	31	377	0.0822	0.4485	4.34	4.29
32	3/14/2021	32	377	0.0849	0.4517	4.33	4.49
33	3/15/2021	33	377	0.0875	0.4549	3.63	4.5

34	3/16/2021	34	377	0.0902	0.4582	3.73	4.26
35	3/17/2021	35	377	0.0928	0.4615	3.84	4.25
36	3/18/2021	36	377	0.0955	0.4648	3.99	3.99
37	3/19/2021	37	377	0.0981	0.4682	3.86	4.41
38	3/20/2021	38	377	0.1008	0.4716	4.44	4.12
39	3/21/2021	39	377	0.1034	0.4750	3.98	4.8
40	3/22/2021	40	377	0.1061	0.4785	4.34	4.27
41	3/23/2021	41	377	0.1088	0.4820	4.39	3.6
42	3/24/2021	42	377	0.1114	0.4856	4.87	3.74
43	3/25/2021	43	377	0.1141	0.4892	4.69	4.08
44	3/26/2021	44	377	0.1167	0.4928	3.78	4.23
45	3/27/2021	45	377	0.1194	0.4964	3.94	4.65
46	3/28/2021	46	377	0.1220	0.5001	4.2	4.56
47	3/29/2021	47	377	0.1247	0.5038	3.7	4.49
48	3/30/2021	48	377	0.1273	0.5075	3.88	4.62
49	3/31/2021	49	377	0.1300	0.5113	4.5	4.45
50	4/1/2021	50	377	0.1326	0.5151	4.25	4.67
51	4/2/2021	51	377	0.1353	0.5189	4.13	5.28
52	4/3/2021	52	377	0.1379	0.5228	4.37	5.22
53	4/4/2021	53	377	0.1406	0.5267	4.33	5.72
54	4/5/2021	54	377	0.1432	0.5306	4.44	5.47
55	4/6/2021	55	377	0.1459	0.5345	4.41	5.23
56	4/7/2021	56	377	0.1485	0.5385	4.68	5.16
57	4/8/2021	57	377	0.1512	0.5425	4.76	4.7
58	4/9/2021	58	377	0.1538	0.5465	4.76	3.83
59	4/10/2021	59	377	0.1565	0.5505	4.53	4.65
60	4/11/2021	60	377	0.1592	0.5546	4.44	4.84
61	4/12/2021	61	377	0.1618	0.5587	4.55	4.58
62	4/13/2021	62	377	0.1645	0.5628	4.56	5.01
63	4/14/2021	63	377	0.1671	0.5669	4.88	4.48
64	4/15/2021	64	377	0.1698	0.5711	5.09	4.77
65	4/16/2021	65	377	0.1724	0.5753	4.93	4.89
66	4/17/2021	66	377	0.1751	0.5795	5.32	4.87
67	4/18/2021	67	377	0.1777	0.5837	5.8	4.9
68	4/19/2021	68	377	0.1804	0.5879	4.43	4.86
69	4/20/2021	69	377	0.1830	0.5922	5.94	5.63
70	4/21/2021	70	377	0.1857	0.5965	5.44	5.23
71	4/22/2021	71	377	0.1883	0.6008	5.32	4.99
72	4/23/2021	72	377	0.1910	0.6051	5.54	5.04
73	4/24/2021	73	377	0.1936	0.6094	5.63	4.2
74	4/25/2021	74	377	0.1963	0.6138	5.77	4.48

75	4/26/2021	75	377	0.1989	0.6182	6.2	4.99
76	4/27/2021	76	377	0.2016	0.6225	6.19	4.91
77	4/28/2021	77	377	0.2042	0.6269	5.8	5.56
78	4/29/2021	78	377	0.2069	0.6314	5.96	4.94
79	4/30/2021	79	377	0.2095	0.6358	6.06	5.04
80	5/1/2021	80	377	0.2122	0.6402	5.44	5.12
81	5/2/2021	81	377	0.2149	0.6447	5.88	2.77
82	5/3/2021	82	377	0.2175	0.6492	5.74	2.84
83	5/4/2021	83	377	0.2202	0.6537	6.66	4.77
84	5/5/2021	84	377	0.2228	0.6582	7	4.62
85	5/6/2021	85	377	0.2255	0.6627	5.79	4.74
86	5/7/2021	86	377	0.2281	0.6672	6.57	4.66
87	5/8/2021	87	377	0.2308	0.6717	6.74	4.14
88	5/9/2021	88	377	0.2334	0.6763	6.49	4.73
89	5/10/2021	89	377	0.2361	0.6808	6.76	3.65
90	5/11/2021	90	377	0.2387	0.6854	6.14	4.73
91	5/12/2021	91	377	0.2414	0.6899	6.46	5.32
92	5/13/2021	92	377	0.2440	0.6945	5.46	5.23
93	5/14/2021	93	377	0.2467	0.6991	5.73	5.35
94	5/15/2021	94	377	0.2493	0.7037	6.31	4.73
95	5/16/2021	95	377	0.2520	0.7083	5.66	5.28
96	5/17/2021	96	377	0.2546	0.7129	3.79	5.48
97	5/18/2021	97	377	0.2573	0.7175	5.42	4.74
98	5/19/2021	98	377	0.2599	0.7221	5.58	5.14
99	5/20/2021	99	377	0.2626	0.7267	6.79	4.35
100	5/21/2021	100	377	0.2653	0.7313	7.3	6
101	5/22/2021	101	377	0.2679	0.7360	7.14	4.87
102	5/23/2021	102	377	0.2706	0.7406	7.94	4.91
103	5/24/2021	103	377	0.2732	0.7452	6.63	4.49
104	5/25/2021	104	377	0.2759	0.7499	8.68	5.55
105	5/26/2021	105	377	0.2785	0.7545	7.3	4.46
106	5/27/2021	106	377	0.2812	0.7591	7.39	7.76
107	5/28/2021	107	377	0.2838	0.7638	6.67	6.11
108	5/29/2021	108	377	0.2865	0.7684	7.62	5.47
109	5/30/2021	109	377	0.2891	0.7730	7.21	4.77
110	5/31/2021	110	377	0.2918	0.7777	7.31	3.32
111	6/1/2021	111	377	0.2944	0.7823	6.84	3.18
112	6/2/2021	112	377	0.2971	0.7870	6.54	3.79
113	6/3/2021	113	377	0.2997	0.7916	2.68	3.53
114	6/4/2021	114	377	0.3024	0.7962	2.77	4.14
115	6/5/2021	115	377	0.3050	0.8008	2.9	2.77

116	6/6/2021	116	377	0.3077	0.8055	3.52	2.91
117	6/7/2021	117	377	0.3103	0.8101	4.44	3.04
118	6/8/2021	118	377	0.3130	0.8147	5.54	2.5
119	6/9/2021	119	377	0.3156	0.8193	5.14	4.54
120	6/10/2021	120	377	0.3183	0.8239	5.53	4.05
121	6/11/2021	121	377	0.3210	0.8285	6.25	4.95
122	6/12/2021	122	377	0.3236	0.8331	5.98	3.9
123	6/13/2021	123	377	0.3263	0.8377	5.26	5.53
124	6/14/2021	124	377	0.3289	0.8422	2.82	5.38
125	6/15/2021	125	377	0.3316	0.8468	4.19	5.33
126	6/16/2021	126	377	0.3342	0.8513	3.05	4.8
127	6/17/2021	127	377	0.3369	0.8559	4.32	3.95
128	6/18/2021	128	377	0.3395	0.8604	4.55	4.56
129	6/19/2021	129	377	0.3422	0.8650	4.07	5.1
130	6/20/2021	130	377	0.3448	0.8695	2.97	5.05
131	6/21/2021	131	377	0.3475	0.8740	4.57	5.74
132	6/22/2021	132	377	0.3501	0.8785	5.04	6.36
133	6/23/2021	133	377	0.3528	0.8830	5.64	5.84
134	6/24/2021	134	377	0.3554	0.8874	4.32	3.23
135	6/25/2021	135	377	0.3581	0.8919	5.17	5.03
136	6/26/2021	136	377	0.3607	0.8963	5.3	3
137	6/27/2021	137	377	0.3634	0.9008	5.37	2.43
138	6/28/2021	138	377	0.3660	0.9052	3.99	2.57
139	6/29/2021	139	377	0.3687	0.9096	4.18	3.13
140	6/30/2021	140	377	0.3714	0.9140	3.38	4.74
141	7/1/2021	141	377	0.3740	0.9183	3.69	5.62
142	7/2/2021	142	377	0.3767	0.9227	4.58	4.59
143	7/3/2021	143	377	0.3793	0.9270	4.77	5.73
144	7/4/2021	144	377	0.3820	0.9313	4.49	5.43
145	7/5/2021	145	377	0.3846	0.9356	4.19	5.49
146	7/6/2021	146	377	0.3873	0.9399	4.7	5.32
147	7/7/2021	147	377	0.3899	0.9442	2.95	4.37
148	7/8/2021	148	377	0.3926	0.9484	3.36	4.15
149	7/9/2021	149	377	0.3952	0.9526	4.72	2.84
150	7/10/2021	150	377	0.3979	0.9568	5.22	2.4
151	7/11/2021	151	377	0.4005	0.9610	5.04	3.1
152	7/12/2021	152	377	0.4032	0.9652	4.55	2.9
153	7/13/2021	153	377	0.4058	0.9693	4.52	3.07
154	7/14/2021	154	377	0.4085	0.9735	4.39	3.24
155	7/15/2021	155	377	0.4111	0.9776	3.52	2.2
156	7/16/2021	156	377	0.4138	0.9816	4.12	2.75

157	7/17/2021	157	377	0.4164	0.9857	2.3	3.49
158	7/18/2021	158	377	0.4191	0.9897	3.13	3.39
159	7/19/2021	159	377	0.4218	0.9937	3.57	3.32
160	7/20/2021	160	377	0.4244	0.9977	3.92	2.56
161	7/21/2021	161	377	0.4271	1.0016	3.74	2.18
162	7/22/2021	162	377	0.4297	1.0056	3.88	2.44
163	7/23/2021	163	377	0.4324	1.0095	3.35	2.52
164	7/24/2021	164	377	0.4350	1.0134	4.19	3.01
165	7/25/2021	165	377	0.4377	1.0172	3.19	3.9
166	7/26/2021	166	377	0.4403	1.0210	2.23	3.07
167	7/27/2021	167	377	0.4430	1.0248	3.44	4.96
168	7/28/2021	168	377	0.4456	1.0286	4.54	5.13
169	7/29/2021	169	377	0.4483	1.0323	4.49	3.49
170	7/30/2021	170	377	0.4509	1.0360	3.88	2.95
171	7/31/2021	171	377	0.4536	1.0397	3.81	2.5
172	8/1/2021	172	377	0.4562	1.0433	4.32	3.76
173	8/2/2021	173	377	0.4589	1.0470	4.07	2.83
174	8/3/2021	174	377	0.4615	1.0505	3.94	2.46
175	8/4/2021	175	377	0.4642	1.0541	4.63	3.68
176	8/5/2021	176	377	0.4668	1.0576	2.99	3.84
177	8/6/2021	177	377	0.4695	1.0611	3.29	5.74
178	8/7/2021	178	377	0.4721	1.0646	4.26	3.24
179	8/8/2021	179	377	0.4748	1.0680	3.53	4.68
180	8/9/2021	180	377	0.4775	1.0714	4.48	4.49
181	8/10/2021	181	377	0.4801	1.0747	4.38	3.23
182	8/11/2021	182	377	0.4828	1.0781	3.48	3.14
183	8/12/2021	183	377	0.4854	1.0813	2.74	2.1
184	8/13/2021	184	377	0.4881	1.0846	2.41	2.24
185	8/14/2021	185	377	0.4907	1.0878	2.19	2.84
186	8/15/2021	186	377	0.4934	1.0910	2.09	2.6
187	8/16/2021	187	377	0.4960	1.0941	2.08	2.11
188	8/17/2021	188	377	0.4987	1.0972	2.97	1.96
189	8/18/2021	189	377	0.5013	1.1003	2.44	1.95
190	8/19/2021	190	377	0.5040	1.1033	2.22	2.01
191	8/20/2021	191	377	0.5066	1.1063	2.36	1.89
192	8/21/2021	192	377	0.5093	1.1092	2.65	2.1
193	8/22/2021	193	377	0.5119	1.1121	2.4	2.04
194	8/23/2021	194	377	0.5146	1.1150	2.92	3.3
195	8/24/2021	195	377	0.5172	1.1178	2.43	4.64
196	8/25/2021	196	377	0.5199	1.1206	4.42	4.54
197	8/26/2021	197	377	0.5225	1.1234	5.52	3.82

198	8/27/2021	198	377	0.5252	1.1261	5.19	3.5
199	8/28/2021	199	377	0.5279	1.1287	5.46	3.88
200	8/29/2021	200	377	0.5305	1.1313	2.91	4.78
201	8/30/2021	201	377	0.5332	1.1339	2.76	3.17
202	8/31/2021	202	377	0.5358	1.1365	2.7	2.07
203	9/1/2021	203	377	0.5385	1.1389	3.76	2.22
204	9/2/2021	204	377	0.5411	1.1414	4.92	1.37
205	9/3/2021	205	377	0.5438	1.1438	3.77	1.76
206	9/4/2021	206	377	0.5464	1.1461	3.75	4.91
207	9/5/2021	207	377	0.5491	1.1484	4.48	4.29
208	9/6/2021	208	377	0.5517	1.1507	3.54	2.82
209	9/7/2021	209	377	0.5544	1.1529	4.13	2.41
210	9/8/2021	210	377	0.5570	1.1551	4.1	0.85
211	9/9/2021	211	377	0.5597	1.1572	4.03	3.93
212	9/10/2021	212	377	0.5623	1.1593	3.88	4.6
213	9/11/2021	213	377	0.5650	1.1613	3.41	4.17
214	9/12/2021	214	377	0.5676	1.1633	3.9	4.1
215	9/13/2021	215	377	0.5703	1.1652	3.73	2.81
216	9/14/2021	216	377	0.5729	1.1671	4.21	3.59
217	9/15/2021	217	377	0.5756	1.1689	2.68	3.28
218	9/16/2021	218	377	0.5782	1.1707	2.78	2.82
219	9/17/2021	219	377	0.5809	1.1724	2.08	2.93
220	9/18/2021	220	377	0.5836	1.1741	2.3	3.72
221	9/19/2021	221	377	0.5862	1.1757	2.97	3.15
222	9/20/2021	222	377	0.5889	1.1772	2.03	3.74
223	9/21/2021	223	377	0.5915	1.1788	2.51	3.1
224	9/22/2021	224	377	0.5942	1.1802	3.99	2.36
225	9/23/2021	225	377	0.5968	1.1816	2.66	2.76
226	9/24/2021	226	377	0.5995	1.1830	2.24	2.38
227	9/25/2021	227	377	0.6021	1.1843	4.08	2.41
228	9/26/2021	228	377	0.6048	1.1855	3.07	2.9
229	9/27/2021	229	377	0.6074	1.1867	2.82	1.78
230	9/28/2021	230	377	0.6101	1.1878	2.43	2.98
231	9/29/2021	231	377	0.6127	1.1889	4.11	1.91
232	9/30/2021	232	377	0.6154	1.1899	4.12	3.49
233	10/1/2021	233	377	0.6180	1.1909	4.01	4.27
234	10/2/2021	234	377	0.6207	1.1918	4.09	4.16
235	10/3/2021	235	377	0.6233	1.1927	3.95	3.25
236	10/4/2021	236	377	0.6260	1.1934	4.28	2.91
237	10/5/2021	237	377	0.6286	1.1942	3.94	4.18
238	10/6/2021	238	377	0.6313	1.1949	3.55	4.45

239	10/7/2021	239	377	0.6340	1.1955	4.23	4.42
240	10/8/2021	240	377	0.6366	1.1960	3.96	4.3
241	10/9/2021	241	377	0.6393	1.1965	4.02	2.6
242	10/10/2021	242	377	0.6419	1.1969	3.3	2.37
243	10/11/2021	243	377	0.6446	1.1973	3.25	3.23
244	10/12/2021	244	377	0.6472	1.1976	3.3	3.64
245	10/13/2021	245	377	0.6499	1.1979	1.85	4.33
246	10/14/2021	246	377	0.6525	1.1981	3.06	3.71
247	10/15/2021	247	377	0.6552	1.1982	2.76	4.02
248	10/16/2021	248	377	0.6578	1.1982	2.12	3.73
249	10/17/2021	249	377	0.6605	1.1982	1.95	3.36
250	10/18/2021	250	377	0.6631	1.1982	3.32	3.05
251	10/19/2021	251	377	0.6658	1.1980	3.87	3.91
252	10/20/2021	252	377	0.6684	1.1978	3.42	3.5
253	10/21/2021	253	377	0.6711	1.1976	3.18	3.85
254	10/22/2021	254	377	0.6737	1.1972	3.26	4.05
255	10/23/2021	255	377	0.6764	1.1969	3.28	3.98
256	10/24/2021	256	377	0.6790	1.1964	3.13	3.66
257	10/25/2021	257	377	0.6817	1.1959	3.58	3.5
258	10/26/2021	258	377	0.6844	1.1953	3.18	3.44
259	10/27/2021	259	377	0.6870	1.1946	2.6	3.56
260	10/28/2021	260	377	0.6897	1.1939	2.46	3.33
261	10/29/2021	261	377	0.6923	1.1931	3.54	3.57
262	10/30/2021	262	377	0.6950	1.1922	3.41	3.54
263	10/31/2021	263	377	0.6976	1.1913	3.3	3.54
264	11/1/2021	264	377	0.7003	1.1903	3.21	3.29
265	11/2/2021	265	377	0.7029	1.1892	3.32	3.11
266	11/3/2021	266	377	0.7056	1.1880	3.16	3.06
267	11/4/2021	267	377	0.7082	1.1868	2.95	2.88
268	11/5/2021	268	377	0.7109	1.1855	2.96	3.1
269	11/6/2021	269	377	0.7135	1.1842	2.93	2.96
270	11/7/2021	270	377	0.7162	1.1827	2.86	3.19
271	11/8/2021	271	377	0.7188	1.1812	2.98	2.75
272	11/9/2021	272	377	0.7215	1.1796	3.09	3.27
273	11/10/2021	273	377	0.7241	1.1780	2.94	3.32
274	11/11/2021	274	377	0.7268	1.1763	3.06	3.06
275	11/12/2021	275	377	0.7294	1.1745	2.89	3.17
276	11/13/2021	276	377	0.7321	1.1726	2.94	3.33
277	11/14/2021	277	377	0.7347	1.1706	3.01	3.17
278	11/15/2021	278	377	0.7374	1.1686	3.26	2.9
279	11/16/2021	279	377	0.7401	1.1665	3.05	2.76

280	11/17/2021	280	377	0.7427	1.1643	3.02	1.7
281	11/18/2021	281	377	0.7454	1.1621	3.07	2.02
282	11/19/2021	282	377	0.7480	1.1598	3.37	3.19
283	11/20/2021	283	377	0.7507	1.1573	3.17	2.52
284	11/21/2021	284	377	0.7533	1.1549	3.21	2.41
285	11/22/2021	285	377	0.7560	1.1523	2.96	2.19
286	11/23/2021	286	377	0.7586	1.1497	3.07	3.16
287	11/24/2021	287	377	0.7613	1.1469	2.84	3.77
288	11/25/2021	288	377	0.7639	1.1441	2.53	3.85
289	11/26/2021	289	377	0.7666	1.1413	2.22	3.69
290	11/27/2021	290	377	0.7692	1.1383	2.85	3.86
291	11/28/2021	291	377	0.7719	1.1353	2.78	3.66
292	11/29/2021	292	377	0.7745	1.1321	2.76	3.79
293	11/30/2021	293	377	0.7772	1.1289	2.94	2.59
294	12/1/2021	294	377	0.7798	1.1256	2.9	1.71
295	12/2/2021	295	377	0.7825	1.1223	2.77	1.35
296	12/3/2021	296	377	0.7851	1.1188	2.69	1.28
297	12/4/2021	297	377	0.7878	1.1153	2.76	2.12
298	12/5/2021	298	377	0.7905	1.1117	2.56	2.02
299	12/6/2021	299	377	0.7931	1.1080	2.78	2.52
300	12/7/2021	300	377	0.7958	1.1042	2.47	2.32
301	12/8/2021	301	377	0.7984	1.1003	2.95	2.23
302	12/9/2021	302	377	0.8011	1.0964	2.61	2.08
303	12/10/2021	303	377	0.8037	1.0924	2.61	2.17
304	12/11/2021	304	377	0.8064	1.0882	2.35	2.36
305	12/12/2021	305	377	0.8090	1.0840	2.51	2.24
306	12/13/2021	306	377	0.8117	1.0797	1.72	2.3
307	12/14/2021	307	377	0.8143	1.0754	2.13	3.33
308	12/15/2021	308	377	0.8170	1.0709	1.7	3.7
309	12/16/2021	309	377	0.8196	1.0664	1.33	1.69
310	12/17/2021	310	377	0.8223	1.0617	2.36	1.85
311	12/18/2021	311	377	0.8249	1.0570	2.47	2.43
312	12/19/2021	312	377	0.8276	1.0522	2.22	2.24
313	12/20/2021	313	377	0.8302	1.0473	2.32	2.22
314	12/21/2021	314	377	0.8329	1.0423	2.36	2.14
315	12/22/2021	315	377	0.8355	1.0372	2.9	2.19
316	12/23/2021	316	377	0.8382	1.0320	2.46	2.29
317	12/24/2021	317	377	0.8408	1.0267	2.17	2.34
318	12/25/2021	318	377	0.8435	1.0214	2.39	2.27
319	12/26/2021	319	377	0.8462	1.0159	2.45	2.47
320	12/27/2021	320	377	0.8488	1.0104	2.48	2.34

321	12/28/2021	321	377	0.8515	1.0048	2.48	2.29
322	12/29/2021	322	377	0.8541	0.9991	2.33	1.74
323	12/30/2021	323	377	0.8568	0.9932	2.7	2.26
324	12/31/2021	324	377	0.8594	0.9873	2.36	1.27
325	1/1/2022	325	377	0.8621	0.9813	2.44	2.42
326	1/2/2022	326	377	0.8647	0.9753	2.41	1.94
327	1/3/2022	327	377	0.8674	0.9691	3.01	2.17
328	1/4/2022	328	377	0.8700	0.9628	2.63	2.07
329	1/5/2022	329	377	0.8727	0.9564	2.23	2.34
330	1/6/2022	330	377	0.8753	0.9499	2.15	2.34
331	1/7/2022	331	377	0.8780	0.9434	2.2	2.35
332	1/8/2022	332	377	0.8806	0.9367	2.2	2.51
333	1/9/2022	333	377	0.8833	0.9300	2.19	2.56
334	1/10/2022	334	377	0.8859	0.9231	2.68	2.4
335	1/11/2022	335	377	0.8886	0.9161	2.37	2.8
336	1/12/2022	336	377	0.8912	0.9091	1.86	3.04
337	1/13/2022	337	377	0.8939	0.9019	2.26	1.81
338	1/14/2022	338	377	0.8966	0.8947	2.43	1.76
339	1/15/2022	339	377	0.8992	0.8874	2.55	2
340	1/16/2022	340	377	0.9019	0.8799	2.31	2.18
341	1/17/2022	341	377	0.9045	0.8724	2.59	1.95
342	1/18/2022	342	377	0.9072	0.8647	2.31	2.26
343	1/19/2022	343	377	0.9098	0.8570	2.41	2.62
344	1/20/2022	344	377	0.9125	0.8492	2.54	2.66
345	1/21/2022	345	377	0.9151	0.8412	2.44	2.87
346	1/22/2022	346	377	0.9178	0.8332	2.57	3.78
347	1/23/2022	347	377	0.9204	0.8250	2.7	3.39
348	1/24/2022	348	377	0.9231	0.8168	2.83	2.57
349	1/25/2022	349	377	0.9257	0.8085	2.81	2.16
350	1/26/2022	350	377	0.9284	0.8000	2.69	2.78
351	1/27/2022	351	377	0.9310	0.7915	2.67	2.48
352	1/28/2022	352	377	0.9337	0.7828	2.88	2.72
353	1/29/2022	353	377	0.9363	0.7740	3.12	2.91
354	1/30/2022	354	377	0.9390	0.7652	2.73	2.73
355	1/31/2022	355	377	0.9416	0.7562	2.64	2.67
356	2/1/2022	356	377	0.9443	0.7472	2.69	2.78
357	2/2/2022	357	377	0.9469	0.7380	3.01	2.78
358	2/3/2022	358	377	0.9496	0.7287	2.78	3.77
359	2/4/2022	359	377	0.9523	0.7193	3.21	4.31
360	2/5/2022	360	377	0.9549	0.7098	3.14	3.99
361	2/6/2022	361	377	0.9576	0.7002	3.17	4

Appendix B-3 Computation of crop water requirement for summer groundnut crop

Table B 3 Crop water requirement for summer groundnut crop

Sr. No.	Date	t	T	t/T	Kc	Eto	Etc
1	2/7/2021	1	120	0.01	0.34	2.97	1.02
2	2/8/2021	2	120	0.02	0.34	3.1	1.07
3	2/9/2021	3	120	0.03	0.35	2.97	1.03
4	2/10/2021	4	120	0.03	0.35	3.15	1.10
5	2/11/2021	5	120	0.04	0.35	3.23	1.14
6	2/12/2021	6	120	0.05	0.36	3.08	1.10
7	2/13/2021	7	120	0.06	0.36	3.08	1.12
8	2/14/2021	8	120	0.07	0.37	3.47	1.28
9	2/15/2021	9	120	0.08	0.38	3.18	1.20
10	2/16/2021	10	120	0.08	0.39	3.04	1.17
11	2/17/2021	11	120	0.09	0.40	3.13	1.24
12	2/18/2021	12	120	0.10	0.41	3.23	1.31
13	2/19/2021	13	120	0.11	0.42	3.33	1.39
14	2/20/2021	14	120	0.12	0.43	3.05	1.31
15	2/21/2021	15	120	0.13	0.44	3.8	1.68
16	2/22/2021	16	120	0.13	0.45	3.67	1.67
17	2/23/2021	17	120	0.14	0.47	3.5	1.63
18	2/24/2021	18	120	0.15	0.48	3.44	1.65
19	2/25/2021	19	120	0.16	0.50	3.6	1.78
20	2/26/2021	20	120	0.17	0.51	3.48	1.77
22	2/28/2021	22	120	0.18	0.54	3.93	2.12
23	3/1/2021	23	120	0.19	0.56	3.97	2.21
24	3/2/2021	24	120	0.20	0.57	3.38	1.93
25	3/3/2021	25	120	0.21	0.59	3.88	2.28
26	3/4/2021	26	120	0.22	0.60	3.83	2.31
27	3/5/2021	27	120	0.23	0.62	3.93	2.44
28	3/6/2021	28	120	0.23	0.64	3.65	2.32
29	3/7/2021	29	120	0.24	0.65	4	2.61
30	3/8/2021	30	120	0.25	0.67	3.86	2.59
31	3/9/2021	31	120	0.26	0.69	3.77	2.59
32	3/10/2021	32	120	0.27	0.70	3.8	2.67
33	3/11/2021	33	120	0.28	0.72	3.7	2.66
34	3/12/2021	34	120	0.28	0.74	3.81	2.80
35	3/13/2021	35	120	0.29	0.75	4.03	3.03
36	3/14/2021	36	120	0.30	0.77	4.09	3.14
37	3/15/2021	37	120	0.31	0.78	4.16	3.26
38	3/16/2021	38	120	0.32	0.80	3.93	3.14

39	3/17/2021	39	120	0.33	0.82	3.94	3.21
40	3/18/2021	40	120	0.33	0.83	3.74	3.11
41	3/19/2021	41	120	0.34	0.85	4.17	3.53
42	3/20/2021	42	120	0.35	0.86	3.89	3.35
43	3/21/2021	43	120	0.36	0.88	4.53	3.97
44	3/22/2021	44	120	0.37	0.89	4.06	3.62
45	3/23/2021	45	120	0.38	0.91	3.47	3.14
46	3/24/2021	46	120	0.38	0.92	3.56	3.27
47	3/25/2021	47	120	0.39	0.93	3.86	3.60
48	3/26/2021	48	120	0.40	0.95	4.09	3.87
49	3/27/2021	49	120	0.41	0.96	4.46	4.28
50	3/28/2021	50	120	0.42	0.97	4.42	4.29
51	3/29/2021	51	120	0.43	0.98	4.32	4.25
52	3/30/2021	52	120	0.43	1.00	4.5	4.48
53	3/31/2021	53	120	0.44	1.01	4.39	4.42
54	4/1/2021	54	120	0.45	1.02	4.57	4.65
55	4/2/2021	55	120	0.46	1.03	5.24	5.39
56	4/3/2021	56	120	0.47	1.04	5.16	5.36
57	4/4/2021	57	120	0.48	1.05	5.65	5.93
58	4/5/2021	58	120	0.48	1.06	5.43	5.75
59	4/6/2021	59	120	0.49	1.07	5.25	5.61
60	4/7/2021	60	120	0.50	1.08	5.16	5.56
61	4/8/2021	61	120	0.51	1.09	4.74	5.14
62	4/9/2021	62	120	0.52	1.09	3.91	4.27
63	4/10/2021	63	120	0.53	1.10	4.72	5.19
64	4/11/2021	64	120	0.53	1.11	4.91	5.44
65	4/12/2021	65	120	0.54	1.11	4.7	5.23
66	4/13/2021	66	120	0.55	1.12	5.15	5.77
67	4/14/2021	67	120	0.56	1.13	4.58	5.15
68	4/15/2021	68	120	0.57	1.13	4.94	5.58
69	4/16/2021	69	120	0.58	1.14	5.06	5.74
70	4/17/2021	70	120	0.58	1.14	5.07	5.78
71	4/18/2021	71	120	0.59	1.14	5.17	5.91
72	4/19/2021	72	120	0.60	1.15	5.08	5.82
73	4/20/2021	73	120	0.61	1.15	5.88	6.75
74	4/21/2021	74	120	0.62	1.15	5.46	6.28
75	4/22/2021	75	120	0.63	1.15	5.22	6.02
76	4/23/2021	76	120	0.63	1.15	5.34	6.16
77	4/24/2021	77	120	0.64	1.15	4.47	5.16
78	4/25/2021	78	120	0.65	1.15	4.96	5.73
79	4/26/2021	79	120	0.66	1.15	5.33	6.15

Appendix C

Accuracy assessment of image classification

Appendix C-1 Accuracy assessment of image classification in summer season

Table C1 Accuracy assessment of image classification in summer season

	Sugarcane	Cotton	Maize	Groundnut	Current fallow	Built up	Total (user)
Sugarcane	9	0	0	0	0	1	10
Cotton	0	7	0	0	1	0	8
Maize	0	0	6	0	0	0	6
Groundnut	0	0	1	7	0	0	8
Current fallow	0	0	0	0	5	0	5
Built up	0	0	0	0	1	4	5
Total (Producer)	9	7	7	7	7	5	42

$$\text{Overall accuracy} = (9+7+6+7+5+4)/42*100$$

$$= 0.9047*100$$

$$=90.47\%$$

Appendix C-2 Accuracy assessment of image classification in kharif season

Table C2 Accuracy assessment of image classification in kharif season

	Sugarcane	Cotton	Maize	Onion	Groundnut	Soyabean	Current fallow	Built up	Total(user)
Sugarcane	8	0	0	0	0	1	0	0	9
Cotton	0	5	0	0	0	0	1	0	6
Maize	0	0	4	0	0	0	0	0	4
Onion	0	0	0	4	0	0	0	0	4
Groundnut	0	0	0	1	3	0	0	0	4
Soyabean	0	0	0	0	0	5	0	0	5
Current fallow	0	0	0	0	0	0	4	0	4
Built up	0	0	0	0	0	0	1	9	10
Total(producer)	8	5	4	5	3	6	6	9	46

$$\text{Overall accuracy} = (8+5+4+4+3+5+4+9)/46*100$$

$$= 0.9130*100$$

$$=91.30\%$$

Appendix C-3 Accuracy assessment of image classification in rabi season

Table C3 Accuracy assessment of image classification in rabi season

	Sugarcane	Gram	Onion	Maize	Wheat	Current fallow	Built up	Total(user)
Sugarcane	6	0	0	1	0	0	0	7
Gram	0	3	1	0	0	0	0	4
Onion	0	0	4	0	0	0	0	4
Maize	0	0	0	3	0	1	0	4
Wheat	0	0	0	0	4	0	0	4
Current fallow	0	0	0	0	0	5	0	5
Built up	0	0	0	0	0	0	6	6
Total(producer)	6	3	5	4	4	6	6	34

$$\text{Overall accuracy} = (7+4+4+4+5+4+6)/34*100$$

$$= 0.9117*100$$

$$= 91.17\%$$

Appendix D

Irrigation data computation formulae

Table D1 Irrigation data computation formulae

1	Application Rate (mm/hr)	:	$\frac{\text{Dripper Discharge (lit/h)}}{\text{Lateral Spacing (m)} \times \text{Dripper Spacing (m)}}$
2	Shift Duration (hr/day)	:	$\frac{\text{PWR(mm/day)}}{\text{AR(mm/hr)}}$
3	No. of Shifts per Day	:	$\frac{\text{Power Available per day (hr)}}{\text{Shift Duration(hr)}}$
4	Total Lateral Length (m)	:	$\frac{\text{Total area(sq.m)}}{\text{Lateral Spacing(m)}}$
5	Dripper/sprinkler Spacing (m)	:	$\frac{\text{Plant Spacing(m)}}{\text{No.of drippers per plant}}$
6	Total No. of Drippers/sprinklers	:	$\frac{\text{Total Lateral Length(m)}}{\text{Dripper Spacing(m)}}$
7	Total Drippers Flow Rate(lph)	:	Total no. of Drippers/sprinklers \times Drippers/sprinkler Discharge(lph)
8	Valve area	:	$\frac{\text{Valve flow rate (m}^3\text{/hr)}}{\text{AR (mm/hr)}}$
9	Discharge needed to irrigate given area (m ³ /hr)	:	$\frac{\text{Area (sq. m.)} \times \text{PWR(mm/day)}}{\text{Operating hours per day}}$
10	Average chak area(ha)	:	Total area/ No. of chaks

Appendix E

Table E1 Minimum pressure requirement considered at chak level

Minimum pressure requirement considered at chak level	
Parameter	Pressure, m
Emitter operating pressure, m	10
Emitting pipe HL, m	1 – 2
Drip manifold HL, m	1 – 2
Manual valve + fertigation, m	4 – 5
Submain HL, m	1 – 2
SV cluster HL, m	2 – 3
Mainline HL, m	3 - 4
Secondary filter HL, m	4 – 5
Total, m	≈ 32

Appendix F

Table F 1 Velocity distribution at different points on mainline

From		To		Size	Max. Vel(m/s)	Length (m)
X	Y	X	Y			
468573.5	2150966.2	468645.7	2150978.8	1000	0.76	73.3
468645.7	2150978.8	468660.5	2150959.3	1000	0.76	24.4
468651.5	2150950	468653.8	2150912.8	400	1.16	37.3
468821.7	2150639.3	468804.9	2150638	160	1.18	16.9
468841.4	2150640.8	469330	2150689.6	280	1.18	491.1
469330	2150689.6	469586	2150692.3	225	1.26	256
469586	2150692.3	469585.5	2150707.5	160	1.28	15.2
469586	2150692.3	469586.9	2150673.7	160	1.21	18.7
468653.8	2150912.8	468821.7	2150639.3	315	1.46	320.9
468821.7	2150639.3	468841.4	2150640.8	280	1.49	19.8
468657.3	2150956.1	468666.9	2150920.7	400	1.42	36.7
468657.3	2150956.1	468651.5	2150950	1000	0.58	8.5
469427.3	2150265.8	469418.8	2150256.2	160	1.26	12.8
469427.3	2150265.8	469611.3	2150101.5	400	1.22	246.6
469611.3	2150101.5	469623.8	2150116.9	160	1.29	19.8
469611.3	2150101.5	469987.9	2149761.6	355	1.28	507.3
469987.9	2149761.6	470059.9	2149836.9	160	1.32	104.2
469987.9	2149761.6	470046.7	2149711.9	315	1.29	77.1
470046.7	2149711.9	470063.7	2149736.2	160	1.25	29.7
470046.7	2149711.9	470378.9	2149518.5	280	1.22	384.3
468662.8	2150961.7	468720.7	2150932.6	400	1.16	64.8
471561.2	2150181.6	471555.2	2150159.7	160	1.22	22.7
471561.2	2150181.6	471959.5	2150073.4	160	1.04	412.7

471561.2	2150181.6	471565.6	2150197.4	160	1.26	16.4
471548.6	2150185	471464.5	2149748	225	1.27	445
471548.6	2150185	471561.2	2150181.6	355	0.72	13
471464.5	2149748	471430.3	2149554.9	160	1.24	196.2
471099.4	2150294.5	471098.9	2150278.2	160	1.21	16.3
471099.4	2150294.5	471548.6	2150185	355	1.22	462.4
468664.7	2150963.8	468721.8	2150934.6	400	1.16	64.1
470517.1	2150476.5	470533.8	2150498.3	160	1.26	27.4
470517.1	2150476.5	470499.8	2150454.6	160	1.23	27.9
469878.2	2150672.7	469870.5	2150635.2	160	1.23	38.3
469878.2	2150672.7	470517.1	2150476.5	280	1.46	668.3
469878.2	2150672.7	469935.5	2150800.1	160	1.21	139.6
468660.5	2150959.3	468720.2	2150930.4	355	1.21	66.3
468720.2	2150930.4	469294	2151008.8	355	1.21	579.2
469294	2151008.8	469732.5	2151126.1	355	1.21	454
469732.5	2151126.1	469786.7	2151130	355	1.21	54.3
469786.7	2151130	469825.9	2151127.6	355	1.21	39.3
469825.9	2151127.6	470262.7	2150950.1	355	1.21	471.5
470262.7	2150950.1	470343.3	2150950.1	355	1.21	80.6
470343.3	2150950.1	470518.9	2151017.9	355	1.21	188.3
470518.9	2151017.9	470525	2151017.9	355	1.21	6.1
471354.9	2151017.9	471354.9	2151000.2	160	1.22	17.6
471322.3	2151017.9	471322.3	2151037.4	160	1.23	19.5
471322.3	2151017.9	471354.9	2151017.9	160	1.22	32.6
470525	2151017.9	470512.3	2151055.7	160	1.1	39.9
470525	2151017.9	470545.5	2151017.9	280	1.49	20.5
470545.5	2151017.9	470545.5	2151004.2	160	1.23	13.7
470545.5	2151017.9	470618.7	2151017.9	280	1.19	73.3
470618.7	2151017.9	470618.7	2151040	160	1.2	22.1
470618.7	2151017.9	471322.3	2151017.9	250	1	703.6
468884.5	2150960	469878.2	2150672.7	400	1.16	1034.5

468721.8	2150934.6	468884.5	2150960	400	1.16	164.7
468720.7	2150932.6	468884.4	2150956.7	400	1.16	165.4
468884.4	2150956.7	471099.4	2150294.5	400	1.16	2312
471106	2150295.2	471119.1	2150302.9	160	1.13	15.1
468666.9	2150920.7	468834.3	2150655.4	400	1.42	313.7
468834.3	2150655.4	469427.3	2150265.8	400	1.42	709.6
470378.9	2149518.5	470386	2149530.8	200	1.49	14.3
470378.9	2149518.5	470658.8	2149303.7	160	1.25	352.8
470517.1	2150476.5	471106	2150295.2	200	1.47	616.2
471106	2150295.2	471042.3	2150372.6	160	1.17	100.3
471042.3	2150372.6	471055.2	2150383.8	160	1.17	17.1
470386	2149530.8	470414.4	2149541.8	160	1.23	30.4

Appendix G


Appendix G1 Cost details of pipe network up to chak level

Irricad Version 20.2	Zone Summary/Mainline Bill of Materials	24-01-2023
Company :	Designer :	Dhanashri
Client :	Design Date :	24-01-2023
Site :	Report Date :	24-01-2023 14:40:25
Notes :		
Prices reported are RETAIL discounted by 0.0 % Pipe lengths include extra allowances but are not rounded.		

Mainline		
Length/Number	Description	Warehouse Code
1775.9	HDPE(100)-160/6	
630.4	HDPE(100)-200/6	
701.0	HDPE(100)-225/6	
703.6	HDPE(100)-250/6	
1657.3	HDPE(100)-280/6	
398.0	HDPE(100)-315/6	
2922.2	HDPE(100)-355/6	
5149.3	HDPE(100)-400/6	
116.9	TBD	
1.0	Head control	
30.0	HYDRANT POINT	
Total		35,338,305.83


Unconnected		
Length/Number	Description	Warehouse Code
20.0	NAVc 10 2" COMBINATION AV PN10 -FL	
13.0	6" Mainline Flush Valve	
Total		\$1,316.48

Appendix G2 Cost details of sprinkler irrigation network for 18.3 ha

 Irricad Version 20.2	Zone Summary/Mainline B.O.M wth eXtra Allowance	02-02-2023
Company :	Designer :	Dhanashri
Client :	Design Date :	02-02-2023
Site :	Report Date :	02-02-2023 17:21:14
Notes :		
Prices reported are RETAIL discounted by 0.0 % Pipe lengths include extra allowances (see inside the groups) but are not rounded		

Zone Items			
Length/Number	Description	Warehouse Code	Xtra[%]
18603.4	PE IRRIGATION PIPE 32/4	40500-006410	0.0
1845.6	SELFIT PVC PIPE 63/4	00435-001225	0.0
974.9	SELFIT PVC PIPE 75/4	00435-001285	0.0
661.7	SELFIT PVC PIPE 90/4	00435-001345	0.0
615.0	SELFIT PVC PIPE 110 /4	00435-001425	0.0
495.7	RINGFIT PVC PIPE 140/4	00435-001485	0.0
11.0	4" DOROT VALVE	71000-011340	0.0
11.0	KINETIC AIR VALVE 2" AV-010 BSP	70540-001500	0.0
11.0	NAVc 10 2" COMBINATION AV PN10 BSP- ML	32600-004000	0.0
11.0	SAGIV BALL VALVE 2 M*F LONG SAL 200	76000-003900	0.0
47.0	63 MM MANUAL VALVE		0.0
11.0	PVC ADAPTOR-GLUE 75/63*2"M	77400-028300	0.0
11.0	BUSHING ADAP THR-CEM PVC 75(90)2.	77400-028900	0.0
22.0	PVC FLANGE ADAPTOR 110MM GLUE	77400-002800	0.0
22.0	PVC LOOSE FLANGE 110	77400-002000	0.0
22.0	PVC SHORT REDUCING BUSHING 110M-75F GLU	77400-023200	0.0
22.0	PVC 90 DEG TEE GLUE 110	77400-013000	0.0
1870.0	D-NET 8550		0.0
1870.0	D-NET 8550 510 L/H HEAD ONLY	60100-000990	0.0
Total			542,845.79


Mainline			
Length/Number	Description	Warehouse Code	Xtra [%]

 Irricad Version 20.2		Zone Summary/Mainline B.O.M with eXtra Allowance		02-02-2023
672.5	RINGFIT PVC PIPE 160/6	00435-001580	0.0	
2.0	Suction Manifold - TBD	SUCT-MANIF	0.0	
1.0	SECONDARY FILTER + WATER METER	FILT	0.0	
Total			409,963.09	

Unconnected				
Length/Number	Description	Warehouse Code		
2.0	NAVc 10 2" COMBINATION AV PN10 BSP- ML	32600-004000	0.0	
2.0	HAKOHAV BUTTERFLY VALVE GEAR 4" AV 102	72200-001400	0.0	
Total			\$461.45	


Total Cost	953,270.33
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Appendix G3 Cost details of drip irrigation network for 18.3 ha

	Irricad Version 20.2	Zone Summary/Mainline B.O.M with eXtra Allowance	02-02-2023
Company :		Designer :	Dhanashri
Client :		Design Date :	02-02-2023
Site :		Report Date :	02-02-2023 16:29:57
Notes :			
Prices reported are RETAIL discounted by 0.0 %			
Pipe lengths include extra allowances (see inside the groups) but are not rounded			

Zone Items			
Length/Number	Description	Warehouse Code	Xtra[%]
150712.2	ARIES 16008 2.00L/H 0.40M 500M IND	12780-003650	0.0
356.0	PVC PIPE 50MM -06KG/CM2-IND	00435-001170	0.0
1726.5	PVC PIPE 63MM -04KG/CM2-IND	00435-001220	0.0
904.0	PVC PIPE 75MM -04KG/CM2-IND	00435-001280	0.0
439.7	PVC PIPE 90MM -04KG/CM2-IND	00435-001340	0.0
765.0	PVC PIPE 110MM -04KG/CM2-IND	00435-001420	0.0
608.4	PVC PIPE 140MM -04KG/CM2-IND	00435-001480	0.0
11.0	4" DOROT VALVE	71000-011340	0.0
11.0	KINETIC AIR VALVE 2" AV-010 BSP	70540-001500	0.0
11.0	NAVc 10 2" COMBINATION AV PN10 BSP- ML	32600-004000	0.0
11.0	SAGIV BALL VALVE 2 M°F LONG SAL 200	76000-003900	0.0
47.0	63 MM MANUAL VALVE + FERTIGATION		0.0
11.0	PVC ADAPTOR-GLUE 75/63*2"M	77400-028300	0.0
11.0	BUSHING ADAP THR-CEM PVC 75(90)2.	77400-028900	0.0
22.0	PVC FLANGE ADAPTOR 110MM GLUE	77400-002800	0.0
22.0	PVC LOOSE FLANGE 110	77400-002000	0.0
22.0	PVC SHORT REDUCING BUSHING 110M-75F GLU	77400-023200	0.0
22.0	PVC 90 DEG TEE GLUE 110	77400-013000	0.0
Total			602,942.81

Mainline			
Length/Number	Description	Warehouse Code	Xtra [%]
416.7	PVC PIPE 160MM -06KG/CM2-IND	00435-001580	0.0
Page			1

 Irricad Version 20.2		Zone Summary/Mainline B.O.M wth eXtra Allowance		02-02-2023
266.3	PVC PIPE 180MM -06 KG/CM2-IND	00435-001540	0.0	
1.8	Suction Manifold - TBD	SUCT-MANIF	0.0	
1.0	SECONDARY FILTER + WATER METER	FILT	0.0	
Total			458,408.28	

Unconnected				
Length/Number	Description	Warehouse Code		
2.0	NAVc 10 2" COMBINATION AVPN10 BSP- ML	32600-004000	0.0	
2.0	HAKOHAV BUTTERFLY VALVE GEAR 4" AV 102	72200-001400	0.0	
Total			\$461.45	

Total Cost	1,061,812.54
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Appendix G4 Per hectare cost of cultivation for sugarcane crop



SCHEME FOR COST OF CULTIVATION STUDIES, (GOVT. OF MAHARASHTRA)

ITEMWISE PER HECTARE COST OF CULTIVATION

Year: 2021-22	Crop Type: Independent	Sizegroup: --All--
University: MPKV	Crop: Sugarcane-Suru	No. Of Cultivators: 85
District: --All--	Variety: --All--	Source Of Irrigation: --All--
Taluka: --All--	Practice: --All--	Area(ha.): 62.77
Village: --All--	Zone: --All--	Strain: --All--

Sr. No.	COST ITEMS	QUANTITY	RATE (₹)	VALUE (₹)
1	Hired Human Labour (Days)			
	a. Male	96.21	358.63	34,504.95
	b. Female	100.58	265.80	26,733.18
2	Bullock Power (Days)	1.36	1,698.12	2,301.21
3	Machine Power (Hrs.)	51.89	436.40	22,646.47
4	Seed (Kg.) / Seedlings (No.s)	5,511.57	3.31	18,244.11
5	Manures (Qtl.)	72.86	230.73	16,810.34
6	Fertilizer (Kg.)			
	a. Nitrogen (N)	270.63	25.43	6,882.93
	b. Phosphorous (P)	198.82	51.23	10,184.66
	c. Potash (K)	206.81	28.40	5,874.09
7	Bio-Fertilizers (₹)			419.61
8	Micronutrients (₹)			2,948.52
9	Irrigation Charges (₹)			13,921.53
10	Plant Protection Charges (₹)			319.20
11	Incidental Charges (₹)			1,449.29
12	Repairs On Farm Implements (₹)			713.21
13	Insurance Premium (₹)			0.00
14	Growth Regulators (₹)			301.62
15	Weedicides (₹)			2,842.35
16	Rab Material (₹)			0.00
17	Working Capital ₹ (1 to 16)			165,295.19
18	Interest On Working Capital (₹)			9,917.71
19	Depreciation On Farm Implements (₹)			3,022.08
20	Land Revenue & Other Taxes (₹)			303.62
21	COST - 'A' ₹ (17 to 20)			178,538.61
22	Rental Value Of Land (₹)			60,962.63
23	Interest On Fixed Capital (₹)			6,815.90
24	Amortization Cost (₹)			0.00
25	COST - 'B' ₹ (21 to 24)			246,317.14
26	Family Labour (Days)			
	a. Male	47.52	331.58	15,755.44
	b. Female	11.31	180.32	2,039.62
27	COST - 'C' ₹ (25 + 26)			264,112.20
28	Output (Qtl.)			
	a. Main Produce	1,184.98	290.00	343,644.18
	b. By Produce	129.44	185.05	23,953.32
29	COST - 'C' Net Of By Produce ₹ (27-28b)			240,158.88
30	Per Quintal Cost ₹ (29 / 28a)			202.67

Appendix G5 Per hectare cost of cultivation for cotton crop


SCHEME FOR COST OF CULTIVATION STUDIES, (GOVT. OF MAHARASHTRA)
ITEMWISE PER HECTARE COST OF CULTIVATION

Year: 2021-22 **Crop Type:** Kharif Crop **Sizegroup:** --All--
University: MPKV **Crop:** Cotton L.S. **No. Of Cultivators:** 52
District: --All-- **Variety:** --All-- **Source Of Irrigation:** --All--
Taluka: --All-- **Practice:** Irrigated **Area(ha.):** 81.93
Village: --All-- **Zone:** --All-- **Strain:** --All--

Sr. No.	COST ITEMS	QUANTITY	RATE (₹)	VALUE (₹)
1	Hired Human Labour (Days)			
	a. Male	8.18	292.89	2,395.20
	b. Female	79.70	193.29	15,405.27
2	Bullock Power (Days)	8.02	1,540.83	12,363.02
3	Machine Power (Hrs.)	41.50	139.32	5,782.29
4	Seed (Kg.) / Seedlings (No.s)	2.12	1,628.58	3,452.96
5	Manures (Qtl.)	14.32	238.85	3,419.69
6	Fertilizer (Kg.)			
	a. Nitrogen (N)	102.16	23.55	2,406.38
	b. Phosphorous (P)	49.50	56.17	2,780.58
	c. Potash (K)	52.29	27.14	1,419.00
7	Bio-Fertilizers (₹)			41.57
8	Micronutrients (₹)			173.28
9	Irrigation Charges (₹)			5,593.90
10	Plant Protection Charges (₹)			2,902.90
11	Incidental Charges (₹)			1,021.72
12	Repairs On Farm Implements (₹)			519.07
13	Insurance Premium (₹)			232.39
14	Growth Regulators (₹)			141.19
15	Weedicides (₹)			0.00
16	Rab Material (₹)			0.00
17	Working Capital ₹ (1 to 16)			59,984.60
18	Interest On Working Capital (₹)			3,599.08
19	Depreciation On Farm Implements (₹)			1,668.26
20	Land Revenue & Other Taxes (₹)			126.16
21	COST - 'A' ₹ (17 to 20)			65,378.10
22	Rental Value Of Land (₹)			18,183.38
23	Interest On Fixed Capital (₹)			4,803.88
24	Amortization Cost (₹)			0.00
25	COST - 'B' ₹ (21 to 24)			88,365.35
26	Family Labour (Days)			
	a. Male	21.63	285.31	6,172.59
	b. Female	16.00	193.84	3,101.14
27	COST - 'C' ₹ (25 + 26)			97,639.07
28	Output (Qtl.)			
	a. Main Produce	13.50	8,135.48	109,857.23
	b. By Produce	0.00	0.00	0.00
29	COST - 'C' Net Of By Produce ₹ (27-28b)			97,639.07
30	Per Quintal Cost ₹ (29 / 28a)			7,230.66

Appendix G6 Per hectare cost of cultivation for wheat crop


SCHEME FOR COST OF CULTIVATION STUDIES, (GOVT. OF MAHARASHTRA)
ITEMWISE PER HECTARE COST OF CULTIVATION

Year: 2021-22 **Crop Type:** Rabi Crop **Sizegroup:** --All--
University: MPKV **Crop:** Wheat **No. Of Cultivators:** 35
District: --All-- **Variety:** --All-- **Source Of Irrigation:** --All--
Taluka: --All-- **Practice:** Irrigated **Area(ha.):** 13.60
Village: --All-- **Zone:** --All-- **Strain:** --All--

Sr. No.	COST ITEMS	QUANTITY	RATE (₹)	VALUE (₹)
	Hired Human Labour (Days)			
1	a. Male	1.40	452.63	632.35
	b. Female	22.54	235.32	5,303.31
2	Bullock Power (Days)	1.30	1,582.79	2,051.23
3	Machine Power (Hrs.)	25.09	510.34	12,805.29
4	Seed (Kg.) / Seedlings (No.s)	92.94	46.03	4,278.31
5	Manures (Qtl.)	2.28	261.29	595.59
	Fertilizer (Kg.)			
6	a. Nitrogen (N)	89.76	23.46	2,105.56
	b. Phosphorous (P)	47.45	51.09	2,424.32
	c. Potash (K)	18.85	25.22	475.49
7	Bio-Fertilizers (₹)			0.00
8	Micronutrients (₹)			0.00
9	Irrigation Charges (₹)			7,063.05
10	Plant Protection Charges (₹)			155.51
11	Incidental Charges (₹)			1,923.76
12	Repairs On Farm Implements (₹)			1,386.47
13	Insurance Premium (₹)			0.00
14	Growth Regulators (₹)			66.18
15	Weedicides (₹)			283.09
16	Rab Material (₹)			0.00
17	Working Capital ₹ (1 to 16)			41,549.51
18	Interest On Working Capital (₹)			2,492.97
19	Depreciation On Farm Implements (₹)			3,092.74
20	Land Revenue & Other Taxes (₹)			33.74
21	COST - 'A' ₹ (17 to 20)			47,168.96
22	Rental Value Of Land (₹)			10,939.42
23	Interest On Fixed Capital (₹)			6,925.23
24	Amortization Cost (₹)			0.00
25	COST - 'B' ₹ (21 to 24)			65,033.61
	Family Labour (Days)			
26	a. Male	23.46	364.62	8,552.43
	b. Female	5.01	239.29	1,198.66
27	COST - 'C' ₹ (25 + 26)			74,784.69
	Output (Qtl.)			
28	a. Main Produce	27.62	2,376.66	65,655.15
	b. By Produce	2.46	74.63	183.82
29	COST - 'C' Net Of By Produce ₹ (27-28b)			74,600.87
30	Per Quintal Cost ₹ (29 / 28a)			2,700.48

Appendix G7 Per hectare cost of cultivation for Soyabean crop


SCHEME FOR COST OF CULTIVATION STUDIES, (GOVT. OF MAHARASHTRA)
ITEMWISE PER HECTARE COST OF CULTIVATION

Year: 2021-22 **Crop Type:** Kharif Crop **Sizegroup:** --All--
University: MPKV **Crop:** Soyabean **No. Of Cultivators:** 25
District: --All-- **Variety:** --All-- **Source Of Irrigation:** --All--
Taluka: --All-- **Practice:** Irrigated **Area(ha.):** 23.12
Village: --All-- **Zone:** --All-- **Strain:** --All--

Sr. No.	COST ITEMS	QUANTITY	RATE (₹)	VALUE (₹)
	Hired Human Labour (Days)			
1	a. Male	11.34	328.06	3,721.24
	b. Female	26.56	267.06	7,092.34
2	Bullock Power (Days)	0.29	1,519.88	443.74
3	Machine Power (Hrs.)	37.93	459.66	17,435.99
4	Seed (Kg.) / Seedlings (No.s)	68.56	104.90	7,191.26
5	Manures (Qtl.)	10.42	271.58	2,830.88
	Fertilizer (Kg.)			
6	a. Nitrogen (N)	14.27	42.53	607.04
	b. Phosphorous (P)	31.39	46.96	1,474.09
	c. Potash (K)	8.45	24.91	210.40
7	Bio-Fertilizers (₹)			0.00
8	Micronutrients (₹)			100.86
9	Irrigation Charges (₹)			1,386.81
10	Plant Protection Charges (₹)			1,394.46
11	Incidental Charges (₹)			1,134.05
12	Repairs On Farm Implements (₹)			113.60
13	Insurance Premium (₹)			0.00
14	Growth Regulators (₹)			153.98
15	Weedicides (₹)			1,537.85
16	Rab Material (₹)			0.00
17	Working Capital ₹ (1 to 16)			46,770.98
18	Interest On Working Capital (₹)			2,806.26
19	Depreciation On Farm Implements (₹)			1,383.49
20	Land Revenue & Other Taxes (₹)			37.71
21	COST - 'A' ₹ (17 to 20)			50,998.43
22	Rental Value Of Land (₹)			21,366.67
23	Interest On Fixed Capital (₹)			4,117.36
24	Amortization Cost (₹)			0.00
25	COST - 'B' ₹ (21 to 24)			76,482.45
	Family Labour (Days)			
26	a. Male	10.03	347.51	3,487.15
	b. Female	5.40	241.32	1,302.12
27	COST - 'C' ₹ (25 + 26)			81,271.73
	Output (Qtl.)			
28	a. Main Produce	21.05	5,955.46	125,355.75
	b. By Produce	17.74	173.10	3,070.50
29	COST - 'C' Net Of By Produce ₹ (27-28b)			78,201.23
30	Per Quintal Cost ₹ (29 / 28a)			3,715.22

Appendix G8 Per hectare cost of cultivation for rabi onion crop


SCHEME FOR COST OF CULTIVATION STUDIES, (GOVT. OF MAHARASHTRA)
ITEMWISE PER HECTARE COST OF CULTIVATION

Year: 2021-22 **Crop Type:** Independent **Sizegroup:** --All--
University: MPKV **Crop:** Onion Rabi **No. Of Cultivators:** 30
District: --All-- **Variety:** --All-- **Source Of Irrigation:** --All--
Taluka: --All-- **Practice:** --All-- **Area(ha.):** 33.60
Village: --All-- **Zone:** --All-- **Strain:** --All--

Sr. No.	COST ITEMS	QUANTITY	RATE (₹)	VALUE (₹)
1	Hired Human Labour (Days)			
	a. Male	23.02	406.06	9,349.38
	b. Female	143.54	327.00	46,938.39
2	Bullock Power (Days)	0.49	1,653.59	812.03
3	Machine Power (Hrs.)	45.18	290.78	13,136.90
4	Seed (Kg.) / Seedlings (No.s)	7.86	2,593.56	20,377.98
5	Manures (Qtl.)	62.51	299.86	18,745.54
6	Fertilizer (Kg.)			
	a. Nitrogen (N)	93.46	48.04	4,489.32
	b. Phosphorous (P)	174.58	59.45	10,378.12
	c. Potash (K)	131.38	26.95	3,540.38
7	Bio-Fertilizers (₹)			822.79
8	Micronutrients (₹)			1,473.54
9	Irrigation Charges (₹)			7,356.93
10	Plant Protection Charges (₹)			5,054.82
11	Incidental Charges (₹)			1,186.99
12	Repairs On Farm Implements (₹)			282.35
13	Insurance Premium (₹)			0.00
14	Growth Regulators (₹)			47.62
15	Weedicides (₹)			2,045.39
16	Rab Material (₹)			0.00
17	Working Capital ₹ (1 to 16)			144,936.05
18	Interest On Working Capital (₹)			8,696.16
19	Depreciation On Farm Implements (₹)			4,747.88
20	Land Revenue & Other Taxes (₹)			35.83
21	COST - 'A' ₹ (17 to 20)			158,415.93
22	Rental Value Of Land (₹)			65,276.04
23	Interest On Fixed Capital (₹)			16,361.37
24	Amortization Cost (₹)			0.00
25	COST - 'B' ₹ (21 to 24)			240,053.33
26	Family Labour (Days)			
	a. Male	44.29	378.65	16,770.02
	b. Female	17.17	288.53	4,954.78
27	COST - 'C' ₹ (25 + 26)			261,778.14
28	Output (Qtl.)			
	a. Main Produce	254.48	1,539.91	391,871.22
	b. By Produce	0.00	0.00	0.00
29	COST - 'C' Net Of By Produce ₹ (27-28b)			261,778.14
30	Per Quintal Cost ₹ (29 / 28a)			1,028.69

Appendix G9 Per hectare cost of cultivation for kharif onion crop


SCHEME FOR COST OF CULTIVATION STUDIES, (GOVT. OF MAHARASHTRA)
ITEMWISE PER HECTARE COST OF CULTIVATION

Year: 2021-22 **Crop Type:** Independent **Sizegroup:** --All--
University: MPKV **Crop:** Onion Kh **No. Of Cultivators:** 29
District: --All-- **Variety:** --All-- **Source Of Irrigation:** --All--
Taluka: --All-- **Practice:** Irrigated **Area(ha.):** 26.02
Village: --All-- **Zone:** --All-- **Strain:** --All--

Sr. No.	COST ITEMS	QUANTITY	RATE (₹)	VALUE (₹)
	Hired Human Labour (Days)			
1	a. Male	8.07	330.20	2,663.37
	b. Female	160.28	272.71	43,709.65
2	Bullock Power (Days)	2.36	1,517.82	3,575.81
3	Machine Power (Hrs.)	65.29	224.55	14,660.22
4	Seed (Kg.) / Seedlings (No.s)	9.52	2,944.90	28,039.97
5	Manures (Qtl.)	44.17	273.30	12,070.71
	Fertilizer (Kg.)			
6	a. Nitrogen (N)	89.55	38.83	3,477.38
	b. Phosphorous (P)	122.11	51.51	6,289.48
	c. Potash (K)	66.63	24.99	1,664.97
7	Bio-Fertilizers (₹)			565.91
8	Micronutrients (₹)			1,002.43
9	Irrigation Charges (₹)			5,166.47
10	Plant Protection Charges (₹)			5,728.13
11	Incidental Charges (₹)			1,607.48
12	Repairs On Farm Implements (₹)			260.26
13	Insurance Premium (₹)			0.00
14	Growth Regulators (₹)			1,471.79
15	Weedicides (₹)			1,465.30
16	Rab Material (₹)			0.00
17	Working Capital ₹ (1 to 16)			132,500.88
18	Interest On Working Capital (₹)			7,950.05
19	Depreciation On Farm Implements (₹)			2,024.24
20	Land Revenue & Other Taxes (₹)			28.33
21	COST - 'A' ₹ (17 to 20)			142,503.50
22	Rental Value Of Land (₹)			43,358.99
23	Interest On Fixed Capital (₹)			5,439.84
24	Amortization Cost (₹)			0.00
25	COST - 'B' ₹ (21 to 24)			191,302.33
	Family Labour (Days)			
26	a. Male	49.51	312.49	15,470.98
	b. Female	38.64	249.44	9,637.93
27	COST - 'C' ₹ (25 + 26)			216,411.25
	Output (Qtl.)			
28	a. Main Produce	131.82	1,974.72	260,308.57
	b. By Produce	0.15	100.00	15.37
29	COST - 'C' Net Of By Produce ₹ (27-28b)			216,395.88
30	Per Quintal Cost ₹ (29 / 28a)			1,641.59

Appendix G10 Per hectare cost of cultivation for kharif maize crop


SCHEME FOR COST OF CULTIVATION STUDIES, (GOVT. OF MAHARASHTRA)
ITEMWISE PER HECTARE COST OF CULTIVATION

Year: 2021-22 **Crop Type:** Kharif Crop **Sizegroup:** --All--
University: MPKV **Crop:** Maize Kh **No. Of Cultivators:** 33
District: --All-- **Variety:** --All-- **Source Of Irrigation:** --All--
Taluka: --All-- **Practice:** Irrigated **Area(ha.):** 29.44
Village: --All-- **Zone:** --All-- **Strain:** --All--

Sr. No.	COST ITEMS	QUANTITY	RATE (₹)	VALUE (₹)
	Hired Human Labour (Days)			
1	a. Male	21.74	312.41	6,792.80
	b. Female	31.67	264.29	8,368.89
2	Bullock Power (Days)	5.23	1,363.85	7,134.27
3	Machine Power (Hrs.)	34.27	421.92	14,460.60
4	Seed (Kg.) / Seedlings (No.s)	18.31	328.46	6,013.62
5	Manures (Qtl.)	33.39	297.66	9,938.86
	Fertilizer (Kg.)			
6	a. Nitrogen (N)	98.75	24.04	2,373.77
	b. Phosphorous (P)	50.42	52.63	2,653.71
	c. Potash (K)	35.38	23.53	832.44
7	Bio-Fertilizers (₹)			191.17
8	Micronutrients (₹)			452.80
9	Irrigation Charges (₹)			1,882.73
10	Plant Protection Charges (₹)			1,416.78
11	Incidental Charges (₹)			1,246.43
12	Repairs On Farm Implements (₹)			347.22
13	Insurance Premium (₹)			0.00
14	Growth Regulators (₹)			0.00
15	Weedicides (₹)			770.55
16	Rab Material (₹)			0.00
17	Working Capital ₹ (1 to 16)			64,599.85
18	Interest On Working Capital (₹)			3,875.99
19	Depreciation On Farm Implements (₹)			2,290.81
20	Land Revenue & Other Taxes (₹)			44.90
21	COST - 'A' ₹ (17 to 20)			70,811.55
22	Rental Value Of Land (₹)			16,526.26
23	Interest On Fixed Capital (₹)			6,752.79
24	Amortization Cost (₹)			0.00
25	COST - 'B' ₹ (21 to 24)			94,090.59
	Family Labour (Days)			
26	a. Male	18.82	309.39	5,823.30
	b. Female	9.49	238.49	2,262.16
27	COST - 'C' ₹ (25 + 26)			102,176.06
	Output (Qtl.)			
28	a. Main Produce	52.55	1,631.87	85,747.93
	b. By Produce	66.81	204.73	13,679.01
29	COST - 'C' Net Of By Produce ₹ (27-28b)			88,497.05
30	Per Quintal Cost ₹ (29 / 28a)			1,684.19

Appendix G11 Per hectare cost of cultivation for kharif groundnut crop


SCHEME FOR COST OF CULTIVATION STUDIES, (GOVT. OF MAHARASHTRA)
ITEMWISE PER HECTARE COST OF CULTIVATION

Year: 2021-22 **Crop Type:** Kharif Crop **Sizegroup:** --All--
University: MPKV **Crop:** Groundnut Kh **No. Of Cultivators:** 24
District: --All-- **Variety:** --All-- **Source Of Irrigation:** --All--
Taluka: --All-- **Practice:** Irrigated **Area(ha.):** 5.72
Village: --All-- **Zone:** --All-- **Strain:** --All--

Sr. No.	COST ITEMS	QUANTITY	RATE (₹)	VALUE (₹)
1	Hired Human Labour (Days)			
	a. Male	1.91	338.29	646.85
	b. Female	43.71	210.80	9,213.29
2	Bullock Power (Days)	2.93	1,557.61	4,561.20
3	Machine Power (Hrs.)	11.61	635.39	7,375.87
4	Seed (Kg.) / Seedlings (No.s)	86.01	139.74	12,019.23
5	Manures (Qtl.)	14.77	276.92	4,090.91
6	Fertilizer (Kg.)			
	a. Nitrogen (N)	40.80	38.47	1,569.21
	b. Phosphorous (P)	49.45	54.27	2,683.85
	c. Potash (K)	32.79	25.59	838.90
7	Bio-Fertilizers (₹)			0.00
8	Micronutrients (₹)			0.00
9	Irrigation Charges (₹)			1,914.72
10	Plant Protection Charges (₹)			0.00
11	Incidental Charges (₹)			1,006.84
12	Repairs On Farm Implements (₹)			199.13
13	Insurance Premium (₹)			0.00
14	Growth Regulators (₹)			0.00
15	Weedicides (₹)			56.82
16	Rab Material (₹)			0.00
17	Working Capital ₹ (1 to 16)			46,176.82
18	Interest On Working Capital (₹)			2,770.61
19	Depreciation On Farm Implements (₹)			1,411.02
20	Land Revenue & Other Taxes (₹)			31.65
21	COST - 'A' ₹ (17 to 20)			50,390.10
22	Rental Value Of Land (₹)			8,413.28
23	Interest On Fixed Capital (₹)			4,687.29
24	Amortization Cost (₹)			0.00
25	COST - 'B' ₹ (21 to 24)			63,490.68
26	Family Labour (Days)			
	a. Male	28.46	330.90	9,418.71
	b. Female	21.94	220.72	4,842.66
27	COST - 'C' ₹ (25 + 26)			77,752.04
28	Output (Qtl.)			
	a. Main Produce	11.03	4,338.67	47,861.89
	b. By Produce	15.05	186.53	2,807.69
29	COST - 'C' Net Of By Produce ₹ (27-28b)			74,944.35
30	Per Quintal Cost ₹ (29 / 28a)			6,793.69

Appendix G12 Per hectare cost of cultivation for gram crop



ITEMWISE PER HECTARE COST OF CULTIVATION

Year: 2021-22 **Crop Type:** Rabi Crop **Sizegroup:** --All--
University: MPKV **Crop:** Gram **No. Of Cultivators:** 35
District: --All-- **Variety:** --All-- **Source Of Irrigation:** --All--
Taluka: --All-- **Practice:** Irrigated **Area(ha.):** 15.07
Village: --All-- **Zone:** --All-- **Strain:** --All--

Sr. No.	COST ITEMS	QUANTITY	RATE (₹)	VALUE (₹)
	Hired Human Labour (Days)			
1	a. Male	3.04	310.93	943.93
	b. Female	22.38	240.21	5,375.71
2	Bullock Power (Days)	1.00	1,575.13	1,580.88
3	Machine Power (Hrs.)	23.32	460.60	10,743.20
4	Seed (Kg.) / Seedlings (No.s)	69.41	79.39	5,510.62
5	Manures (Qtl.)	0.00	0.00	0.00
	Fertilizer (Kg.)			
6	a. Nitrogen (N)	21.63	43.49	940.49
	b. Phosphorous (P)	45.14	46.52	2,099.72
	c. Potash (K)	9.61	25.57	245.72
7	Bio-Fertilizers (₹)			31.85
8	Micronutrients (₹)			0.00
9	Irrigation Charges (₹)			2,935.14
10	Plant Protection Charges (₹)			999.00
11	Incidental Charges (₹)			1,491.36
12	Repairs On Farm Implements (₹)			538.29
13	Insurance Premium (₹)			0.00
14	Growth Regulators (₹)			0.00
15	Weedicides (₹)			53.09
16	Rab Material (₹)			0.00
17	Working Capital ₹ (1 to 16)			33,465.11
18	Interest On Working Capital (₹)			2,007.91
19	Depreciation On Farm Implements (₹)			1,917.55
20	Land Revenue & Other Taxes (₹)			32.47
21	COST - 'A' ₹ (17 to 20)			37,423.04
22	Rental Value Of Land (₹)			11,999.84
23	Interest On Fixed Capital (₹)			4,863.90
24	Amortization Cost (₹)			0.00
25	COST - 'B' ₹ (21 to 24)			54,286.78
	Family Labour (Days)			
26	a. Male	13.83	363.46	5,027.07
	b. Female	13.64	219.48	2,994.77
27	COST - 'C' ₹ (25 + 26)			62,308.63
	Output (Qtl.)			
28	a. Main Produce	14.94	4,657.86	69,589.71
	b. By Produce	8.25	315.73	2,604.18
29	COST - 'C' Net Of By Produce ₹ (27-28b)			59,704.45
30	Per Quintal Cost ₹ (29 / 28a)			3,996.21

VITAE

MS. DHANASHRI DIPAK PATIL
MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)
IN
IRRIGATION AND DRAINAGE ENGINEERING
2023

Title of thesis		:	Design of pipe distribution network irrigation system in command area for improving water use efficiency (WUE), land and water productivity and preventing land degradation
Major field		:	Irrigation and Drainage Engineering
Biographical information:			
Personal	Date of Birth	:	23 th March, 1999
	Place of Birth	:	Kolhapur
	Father's Name	:	Mr. Dipak Yashwant Patil
	Mother's Name	:	Mrs. Sunita Dipak Patil
Educational	Bachelor's Degree Obtained	:	B. Tech (Agricultural Engineering)
	Class	:	First Class with Distinction
	Name of University	:	Mahatma Phule Krishi Vidyapeeth
Contact	Address	:	At/Post Gotkhindi, Tal. Walwa, Dist. Sangli, 416301.
	E-mail ID	:	dhanashripatil23399@gmail.com
	Mobile Number	:	+91 9075570678