IRRIGATION STRATEGIES AND WATER RESOURCE MANAGEMENT IN THE SHETRUNJI RIGHT BANK CANAL COMMAND AREA

Ph.D. SYNOPSIS

For the Degree of Doctor of Philosophy
In Civil Engineering

Submitted by

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1 Title of Thesis and Abstract

Title: - IRRIGATION STRATEGIES AND WATER RESOURCE MANAGEMENT IN THE SHETRUNJI RIGHT BANK CANAL COMMAND AREA.

Abstract

The efficient use of available water for agriculture is a critical concern, as water is a limited resource. Irrigated agriculture consumes a significant amount of water, placing a major responsibility on irrigation managers to use it wisely. Irrigation is applied to make up for the moisture deficit in the soil caused by evapotranspiration. To align the irrigation supply with the demand, it is essential to accurately estimate evapotranspiration using appropriate methods.

Evapotranspiration is the loss of water through evaporation from the soil and transpiration from crops. It is estimated using methods that require climatological data, with the FAO-PM method being the standard for reference evapotranspiration. The crop coefficient approach is popular for its simplicity, multiplying crop coefficients with reference evapotranspiration to calculate crop evapotranspiration.

Crop coefficients are classified into single and dual types. The dual crop coefficient provides more accurate estimates of crop water requirements, especially during light or frequent wetting events, and is crucial in moisture-deficit areas affected by climate change in tropical regions. The WEAP model uses this approach to estimate crop water needs more precisely. Changes in soil surface wetness and moisture from rainfall and irrigation can significantly affect crop evapotranspiration. Irrigation, derived from scheduling techniques, is a key input in soil moisture balance models, which can be applied to large areas like the Shetrunji Right Bank Main Canal command Area (SRBMC) to estimate evapotranspiration.

The Shetrunji Right Bank Main Canal Command in Gujarat covers 14,888 hectares, divided into four irrigation sections. The region has a semi-arid climate with erratic and uneven rainfall.

The conventional approach applies a fixed water depth at set intervals, often causing over-irrigation or moisture stress. Optimizing irrigation schedules can maximize yields with available water.

The WEAP-MABIA model was used to calculate actual evapotranspiration and soil moisture balance, utilizing the Penman-Monteith method with the dual crop coefficient approach. Water use efficiency and irrigation water use efficiency were also evaluated to assess the strategies.

The FAO-56 Penman-Monteith model, combined with the dual crop coefficient approach, accurately estimates crop water needs by separately computing soil evaporation and transpiration under normal and stress conditions.

2 A brief description of the state of the art of the research topic

Efficient water management is crucial for sustainable agriculture, especially in regions with erratic rainfall and limited water resources. Conventional irrigation methods, which apply water at fixed depths and intervals, often lead to inefficiencies such as over-irrigation or moisture stress. To optimize water use, advanced irrigation scheduling strategies have been developed, integrating climatic, soil, and crop-specific parameters.

One of the most widely accepted models for estimating crop water requirements is the FAO-56 Penman-Monteith model, which calculates reference evapotranspiration (ET_0). Coupled with the dual crop coefficient approach, this model enhances precision by separately accounting for soil evaporation and plant transpiration under varying water availability. This method ensures better water allocation, particularly in semi-arid regions like Gujarat, where rainfall is inconsistent.

In large irrigation command areas, such as the Shetrunji Right Bank Canal Command in Gujarat (covering 14,888 hectares), optimizing irrigation schedules is essential for improving agricultural productivity. The command is divided into multiple irrigation sections, each with distinct water requirements. Integrating modern irrigation models with WEAP and real-time climate data can further enhance decision-making, ensuring water is distributed efficiently and crop yields are maximized.

2.1 Evapotranspiration

Allen et al. (1998), in the FAO-56 guidelines, described crop evapotranspiration (ET_c) under standard conditions as the water loss from crops that are free from disease, adequately fertilized, and cultivated in expansive fields. These crops are assumed to have optimal soil moisture, superior management practices, and ideal environmental conditions, enabling them to achieve maximum productivity under the prevailing climate. Measuring (ET_c), however, is a complex process that demands advanced and costly equipment, as well as skilled researchers proficient in operating a variety of specialized systems.

Mehta and Pandey (2016) conducted a study to estimate the crop water requirements (ET_c) for various crops in the middle Gujarat region of India. They employed the FAO-56 Penman-Monteith method to calculate reference evapotranspiration (ET_0) and determine the water needs of different crops. The study highlighted significant variations in (ET_c), driven by factors such as crop type, growth stage, and prevailing climatic conditions. The results offer critical insights for farmers and policymakers, aiding in the optimization of irrigation strategies and enhancing water-use efficiency in the region.

Ghiat, and Al-Ansari (2021) et al. review evapotranspiration (ET) measurement models and techniques for agricultural applications. They classify (ET) estimation into direct, indirect, and remote sensing methods. Direct methods, like lysimeters, provide accuracy but are costly. Indirect methods, including empirical models like Penman-Monteith, require extensive data. Remote sensing techniques, using satellite and drone imagery, offer large-scale assessment but face challenges in resolution and data processing.

2.2 Estimation of Crop Evapotranspiration Using Crop Coefficient Approaches

- **Single Crop Coefficient**

The single crop coefficient approach is typically employed for scenarios involving infrequent wetting events and is used to estimate evapotranspiration (ET) over daily, ten-day, or monthly time intervals.

According to Allen et al. (1998), the generalized crop coefficient values used in the single crop coefficient (K_c) method most appropriate for sub-humid climates characterized by average daily minimum relative humidity of around 45% and calm to moderate wind speeds averaging 2 m/s. For other climatic conditions, adjustments to these values are recommended to ensure accurate (ET) calculations. The formula for calculating crop evapotranspiration (ET_c) is given by (eqn. 1)

$$ET_c = K_c \times ET_0 \qquad (1)$$

Where ET_c represents crop evapotranspiration, K_c is the crop coefficient, and ET_0 is the reference evapotranspiration.

- **Dual Crop Coefficient**

The dual crop coefficient approach has gained popularity in recent years, largely due to advancements in computing capabilities that enable calculations at hourly and daily time steps. This method is particularly useful for scenarios involving frequent wetting events, such as those encountered in drip irrigation and automated centre-pivot sprinkler systems. In cases of light rainfall or frequent wetting, evaporation from the top thin soil layer occurs rapidly and significantly, which can greatly influence evapotranspiration (ET) estimates. This effect is especially pronounced during the initial growth stages when vegetation cover is minimal, leading to higher soil evaporation rates. To address these dynamics, researchers have focused on soil and hydrological water balance studies, utilizing the dual crop coefficient method to enhance the accuracy of (ET_c) estimates, as described by Allen et al. (1998). The formula for calculating crop evapotranspiration (ET_c) using this approach is given by (eqn. 2)

$$ET_c = (K_{cb} + K_e) \times ET_0 \tag{2}$$

Where (ET_c) represents crop evapotranspiration, (K_{cb}) is the basal crop coefficient, (K_e) is the evaporation coefficient, and (ET_0) is the reference evapotranspiration. This method provides a more refined estimation of (ET) by separately accounting for plant transpiration and soil evaporation.

Parekh (2007) explores the estimation of crop water requirements using both single and dual crop coefficient approaches. The study compares these methods to identify the more suitable one for determining crop water needs. While the single crop coefficient approach uses a unified coefficient for estimating evapotranspiration, the dual crop coefficient method separates coefficients for crop transpiration and soil evaporation, providing a more detailed analysis. The research concludes that the dual crop coefficient approach, which considers both crop characteristics and soil properties, offers greater accuracy in estimating crop water requirements. This study provides valuable insights into different methodologies for calculating agricultural water needs, contributing to improved irrigation practices and water management strategies.

Sanchez et al. (2012) conducted a study to explore and analyse the relationships between key vegetation indices—such as the Normalized Difference Vegetation Index (NDVI), Leaf Area Index (LAI), Fraction of Vegetation Cover (FVC)—and the basal crop coefficient (K_{cb}). Their goal was to enhance the accuracy of evapotranspiration (ET) and soil moisture estimations as outlined in the FAO-56 guidelines. The researchers specifically investigated the influence of (K_{cb}) on soil moisture estimation, aiming to improve the precision of water balance models and irrigation scheduling. By establishing these relationships, the study provided valuable insights into optimizing ET and soil moisture predictions, contributing to more efficient water management practices in agriculture.

The dual crop coefficient approach offers a more refined method for estimating crop water requirements by separately accounting for transpiration and evaporation. This separation allows for a better understanding of the impacts of irrigation practices, rainfall frequency, and irrigation system types on total crop water use. When soil evaporation contributes significantly to overall water loss, the dual crop coefficient approach provides more accurate estimates of evapotranspiration (ET). While many researchers rely on simpler and widely used models like CROPWAT, which employ the single crop coefficient approach, more advanced models such as WEAP and SIMDualK$_c$ utilize the dual crop coefficient method to achieve greater precision in estimating crop water requirements.

2.3 Soil Moisture Balance

Allen et al. (1998) highlighted the importance of assessing water stress on a daily basis using a soil water balance model for the root zone. In this model, the root zone is conceptualized as a "container" where water content varies over time. The inflow into this container includes rainfall, irrigation, and capillary rise from the groundwater, while the outflow consists of crop transpiration, soil evaporation, and deep percolation losses. The daily water balance is expressed in equation (eqn. 3) terms of depletion at the end of day is:

$$D_{r,i} = D_{r,i-1} - (P - RO)_i - I_i - CR_i + ET_{c,i} + DP_i \tag{3}$$

Here, $D_{r,i}$ represents the root zone depletion at the end of day i (mm), $D_{r,i-1}$ is the water content in the root zone at the end of the previous day $i-1$ (mm), P_i denotes precipitation on day i (mm), RO_i is the runoff from the soil surface on day i (mm), I_i refers to irrigation on day i (mm), CR_i is the capillary rise from the groundwater table on day i (mm), $ET_{c,i}$ represents crop evapotranspiration on day i (mm), and DP_i signifies deep percolation losses on day i (mm).

This equation provides a comprehensive framework for tracking daily changes in soil water content, enabling more accurate irrigation scheduling and water management.

Allen (2011) introduced a new concept to enhance the FAO-56 soil water evaporation model, incorporating the term 'readily evaporable water' (REW) to better account for light wetting events that rapidly wet and evaporate from the soil surface. This modification allowed the model to revert to stage 1 evaporation during such events, improving evaporation estimates, particularly for light and frequent precipitation. For infrequent wetting events, the original FAO-56 model remained effective, accurately calculating evaporation and water balance over time, even with fully mixed water in the evaporation layer. The improved FAO-56 model showed strong agreement with the HYDRUS 1D model and experimental data from weighing lysimeters, demonstrating its enhanced accuracy.

2.4 Irrigation Scheduling

Gontia and Tiwari (2008) developed a baseline equation by correlating canopy-air temperature differences and vapour pressure deficit (VPD) for winter wheat under no water stress conditions. This enabled the quantification of the Crop Water Stress Index (CWSI) for irrigation scheduling. They empirically established lower (non-stressed) and upper (fully stressed) baselines using canopy and ambient air temperature data, measured with infrared thermometry and VPD, under full irrigation and maximum water stress conditions. The derived CWSI values allowed effective monitoring of wheat crop water status and facilitated precise irrigation planning.

Dwivedi et al. (2012) investigated the impact of pre-puddling tillage and puddling intensity on irrigation water productivity in rice cultivation. Their findings indicated that both pre-puddling tillage and puddling intensity were crucial factors in improving irrigation water conservation and increasing rice yield.

Bhatti and Patel (2015) conducted a study on various irrigation scheduling strategies for cotton crops in a semi-arid climate using the Water Evaluation and Planning (WEAP) model. The research aimed to determine effective irrigation scheduling techniques by assessing the crop water requirements and irrigation water demand of cotton. Using the WEAP model, the researchers simulated multiple irrigation scenarios to evaluate their efficiency in meeting crop water needs while minimizing water usage. The study found that deficit irrigation combined with crop development stage-based scheduling significantly reduced water consumption while enhancing cotton yield. These findings highlight the WEAP model's potential as a valuable tool for optimizing irrigation water management and improving agricultural productivity in semi-arid regions.

2.5 Application of WEAP Model in Irrigation Management

Nivesh et al. (2022) examined the future water demand and supply in the Dhasan River Basin, Madhya Pradesh, India, using the WEAP (Water Evaluation and Planning) model. The study highlights the expected increase in water demand due to population growth, urbanization, and industrialization, while supply is projected to decrease because of declining water availability and groundwater depletion. The researchers simulated various scenarios, including climate change impacts and water management strategies, and found that implementing efficient practices like rainwater harvesting and wastewater reuse could significantly reduce demand and improve water availability. This research underscores the importance of sustainable water management in addressing future water challenges in the basin.

Tikariha and Ahmad (2022) explored the use of the WEAP (Water Evaluation and Planning) model to estimate and manage irrigation water in the Tandula Reservoir Command Area, India. The study assessed water resource availability and irrigation water demand, simulating scenarios like climate change impacts. The researchers found that irrigation demand is influenced by climatic conditions and cropping patterns. They emphasized that adopting efficient water management practices, such as drip irrigation and water-saving techniques, could reduce demand and improve water use efficiency. The study highlights the importance of sustainable water management to address growing demand and mitigate climate change impacts.

Carpenter and Choudhary (2022) applied the WEAP (Water Evaluation and Planning) model to assess water demand and supply in the Veda River Basin, Nimar Region, Madhya Pradesh, India. The study aimed to examine water availability, demand, and the impact of climate change on the region’s water resources. The researchers found that increasing water demand, driven by population growth, urbanization, and industrialization, coupled with decreasing water availability and groundwater depletion, poses significant challenges. They recommended sustainable strategies like rainwater harvesting and wastewater reuse to reduce demand and improve water availability. This research highlights the need for sustainable water management to address future water challenges in the basin.

S., Azlinda and A. F., Mohd explored the use of the WEAP (Water Evaluation and Planning) model to assess water supply and demand in Malaysia's Langat Catchment Area. The study aimed to evaluate water availability, demand, and identify potential solutions to address water shortages. The researchers found that water demand is increasing due to population growth, urbanization, and industrialization, while supply is decreasing due to climate change and land-use changes. The authors highlight the role of the WEAP model in optimizing water resources and improving water security in the region.

Agarwal et al. (2018) assessed water supply and demand in the Ur River watershed, Madhya Pradesh, India, using the WEAP (Water Evaluation and Planning) model. The study aimed to evaluate current and future water scenarios and propose management strategies for sustainable water use. The authors highlighted water scarcity in several regions of India, including Madhya Pradesh, and examined the effects of climate change and human activities on water resources. The study found that water supply is decreasing due to factors like population growth, climate change, and land-use changes, while future demand is expected to surpass current supply. The research suggests solutions such as rainwater harvesting, groundwater recharge, and watershed management to improve water availability and reduce demand. The study offers valuable insights for researchers and policymakers focused on sustainable water management in India.

3 Definition of the Problem statement

Water resource management plays a crucial role in ensuring the sustainable use of available water for agriculture, particularly in regions dependent on canal irrigation. The Shetrunji Right Bank Main Canal Command Area and the broader Shetrunji irrigation project face significant challenges in optimizing irrigation strategies due to irregular water supply, inefficient water distribution, inadequate water management, and the increasing demand for agricultural productivity. Additionally, the project is impacted by climate change, highlighting the need for proper maintenance and rehabilitation of infrastructure to ensure sustainable water resource utilization.

Addressing these challenges will require sustained efforts from the government and other stakeholders, including farmers and the local community.

The primary issues include inadequate irrigation scheduling, lack of modern water conservation techniques, and suboptimal water allocation, which lead to water losses, reduced crop yields, and soil degradation. Additionally, climatic variations and socio-economic factors further complicate water management in the region.

This study aims to evaluate the current irrigation strategies and propose effective water resource management solutions to enhance agricultural sustainability. the research seeks to develop a framework that maximizes water use efficiency while ensuring equitable distribution among farmers.

4 Objective of work

- Predict agricultural water demand through the formulation of diverse scenarios employing various irrigation strategies.
- Develop a crop water utilization model employing a dual crop coefficient method.
- Evaluate the performance of irrigation schedules across diverse strategies to gauge their effectiveness in water management.
- Offer valuable insights and recommendations to enhance the efficiencies of irrigation water use management practices based on the evaluation of different strategies.

5 Original contribution by the thesis

This research contributes significantly to the field of irrigation and water resource management by integrating the WEAP MABIA method for a comprehensive assessment of water demand, irrigation efficiency, and resource sustainability in the Shetrunji Right Bank Canal Command Area.

- Integration of Evapotranspiration Analysis for Water Demand Estimation – The research incorporates evapotranspiration (ET) calculations to accurately estimate crop water requirements, improving irrigation planning and ensuring optimal water use efficiency.
- Application of the Dual Crop Coefficient Approach for Precise Water Management – The study utilizes the dual crop coefficient method to separately assess soil evaporation and plant transpiration, leading to more accurate irrigation scheduling and reduced water wastage.
- Soil Moisture Balance Assessment for Efficient Irrigation Scheduling – By analyzing soil moisture balance, the thesis provides insights into soil water retention capacity, optimizing irrigation intervals to prevent over-irrigation or water stress in crops.
- Development of an Adaptive Irrigation Scheduling Framework – The research proposes an irrigation scheduling model that integrates real-time climatic data, soil moisture conditions, and crop water requirements, ensuring timely and precise water application to maximize agricultural productivity.
- Evaluation of Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE) – By assessing WUE and IWUE, the research quantifies how effectively

water is converted into crop yield, providing recommendations for maximizing productivity while minimizing water consumption.

These contributions advance the application of the WEAP-MABIA method in optimizing irrigation strategies and improving water resource management in the Shetrunji Right Bank Main Canal Command Area. The findings provide valuable insights for policymakers, water resource managers, and agricultural practitioners, fostering data-driven decision-making to enhance agricultural productivity and water sustainability in the region.

6 Methodology of Research, Results and validation

6.1 Study Area and Data Collection

The Shetrunji Watershed, located in the Saurashtra region of Gujarat, spans 5514 sq. km across Amreli, Bhavnagar, and Junagadh districts. It lies between 21°00’ to 21°47’ N latitude and 70°50’ to 72°10’ E longitude. The Shetrunji river, a major tributary of the gulf of Khambhat, flows through this semi-arid region, characterized by hot summers (above 40°C), mild winters, and an annual rainfall of 600-700 mm, concentrated in the monsoon season (June–September). Rainfall variability leads to frequent droughts and water scarcity, impacting agriculture and water management.

Bhavnagar district, part of the watershed, is divided into ten talukas, with the Shetrunji sub-watershed shared by Talaja, Palitana, Shihor, and Gariyadhar. Talaja, the lowest part of the watershed, serves as its outlet. The Shetrunji Irrigation Project, a major scheme, supplies water through a network of canals, distributaries, and minor channels. It consists of two main canals: Left Bank Main Canal – 96.60 km, carrying capacity 12.08 m^3/s, and Right Bank Main Canal – 57.96 km, carrying capacity 19.681 m^3/s

In the present study, we have selected the Shetrunji Right Bank Main Canal Command Area (SRBMC), which supplies irrigation water to four sections: Fulsar, Unchadi, Jagdhar, and Datha. The details of the Culturable command area (CCA) for the irrigation sections are provided in the table 1. Below.

Table 1. CCA of SRBMC

Sr. No	SRBMC Section	CCA (Ha)
1	Fulsar	4545.92
2	Unchadi	4668.23
3	Jagdhar	1795.46
4	Datha	3878.11

Land Use and Crop Data

- Crop Types: List of crops grown in the study area (e.g., wheat, maize).
- Crop Area: Total cultivated area for each crop (hectares or acres).

Crop Calendar:

- Planting, growing, and harvesting periods for each crop.

Crop Water Requirements:

- Water needed for each growth stage (mm/day or m^3/ha).
- Can be estimated using FAO's Crop Coefficients (K_c) and PET data.

Irrigation Practices:

- Irrigation methods.
- Efficiency of irrigation systems.
- Percentage of area under irrigation versus rain fed agriculture.

All above data collected from office of Deputy Executive Engineer, Shetrunji Right Bank Main Canal Sub division Talaja, Bhavnagar.

6.2 Climate and Rainfall

Talaja, situated in Bhavnagar district of Gujarat, experiences a semi-arid climate, marked by hot summers, moderate monsoons, and mild winters. During the peak summer months (March to June), temperatures can exceed 40°C, with hot and dry conditions. The monsoon season (June to September) brings the majority of the annual rainfall, averaging between 500 to 800 mm, although rainfall is often erratic, leading to years of drought or heavy rains. July and August are typically the wettest months.

Climate data inputs for WEAP model:

The Water Evaluation and Planning (WEAP) model requires specific climate data to simulate hydrological and water management scenarios. The following climate data inputs are essential and were collected from the Gandhinagar State Water Data Center (GSWDC):

Precipitation:

- Total monthly or daily rainfall (mm).

Temperature:

- Maximum daily or monthly temperature (°C).
- Minimum daily or monthly temperature (°C).

Humidity (optional for more complex analyses):
Relative humidity (%).
Average wind speed (m/s).
Solar Radiation

6.3 Soil Profile

The soil of the district can be divided into the following types as per Fig. 1.

- Medium black soil found in parts of Sihor, Bhavnagar, Talaja, Mahuva, Palitana and Botad talukas and Umrala and Gadhada mahals. This is the most predominant type of soil in the district and covers a major part of its area.
- Coastal sandy alluvial soil in Mahuva taluka.
- Light murram soil in elevated areas of Sihor, Bhavnagar and Palitana talukas.
- Clay lime soil in Gariadhar mahal.
- Clay alluvial soil of Bhal tract.

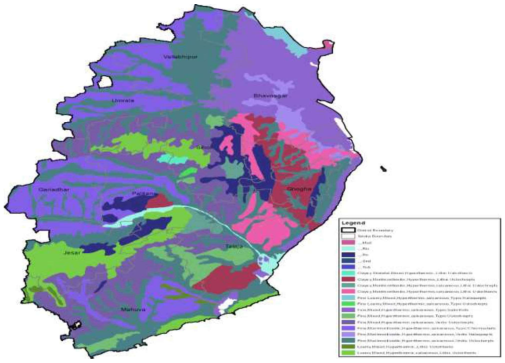


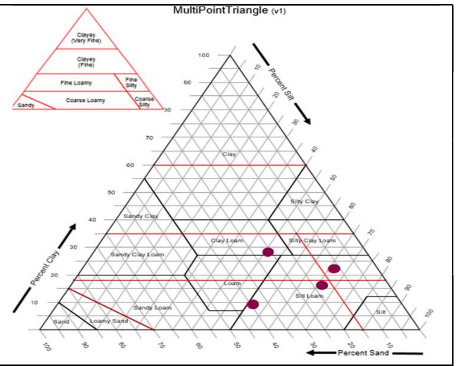
Fig.1 Soil Profile of Bhavnagar District, Source: CDAP, Bhavnagar

The soil sample of the Shetrunji Right Bank Main Canal Command Area and the soil texture analysis are presented in Fig. 2 and Table 2. Below

Fulsar Soil Sample Unchadi Soil Sample Jagdhar Soil Sample Datha Soil Sample

Fig. 2 Soil Sample of SRBMC Command Area

Table 2. Soil Texture Analysis

Point	SRBMC Section	Sand	Clay	Silt	Texture	
1	Fulsar	39.88%	9.03%	51.09%	SILT LOAM	
2	Unchadi	26.15%	27.66%	46.19%	CLAY LOAM	
3	Jagdhar	17.79%	16.24%	65.97%	SILT LOAM	
4	Datha	12.03%	21.87%	66.10%	SILT LOAM	

6.4 Model Description

The Water Evaluation and Planning System (WEAP) represents an advanced generation of water planning software. WEAP's design is driven by several key methodological considerations: a comprehensive, integrated planning framework; scenario analysis to evaluate different development choices; demand-management features; environmental assessment capabilities; and user-friendly functionality. This tool has been widely applied in studies focusing on agricultural systems, municipal water use, single catchments, and complex trans-boundary river systems.

WEAP model has various modules to compute: (1) Irrigation demands only method (FAO Crop Requirements Method), (2) Rainfall Runoff Method (FAO Crop Requirements Method), (3) Rainfall Runoff Method (Soil Moisture Method), and (4) MABIA Method (FAO -56, Dual K_c, Daily). In this study we have used MABIA Method. The MABIA module within WEAP adopts the dual crop coefficient method (FAO-56), offering an improvement over the single crop coefficient approach used by CROPWAT. Schematic view of study area shown in Fig. 3.

- **Reference Evapotranspiration (ET_{ref}) -** ET_{ref} is the estimated evapotranspiration from a reference surface, calculated using the FAO Penman-Monteith equation as described in FAO Paper 56.
- **Soil Water Capacity** - The MABIA method uses field capacity and wilting point data, which can be entered manually or derived from soil texture classes.
- **Basal Crop Coefficient (K_{cb})** - The MABIA method applies a dual (K_c) approach, splitting (K_c) into (K_{cb}) for transpiration under dry soil and (K_e) for soil surface evaporation.
- **Potential and Actual Crop Evapotranspiration (ET_c)** - (ET_c) represents potential evapotranspiration under ideal conditions, while actual ET (ET_a) considers water stress due to insufficient soil moisture.
- **Irrigation** - Irrigation compensates for evapotranspiration losses. Scheduling optimally aligns with root zone depletion thresholds to maintain field capacity without stress.
- **Yield Response to Water Shortage** - Crop yield decreases with water stress, quantified by the yield response factor (K_y). The MABIA method calculates daily yield fractions, aggregated for the season.

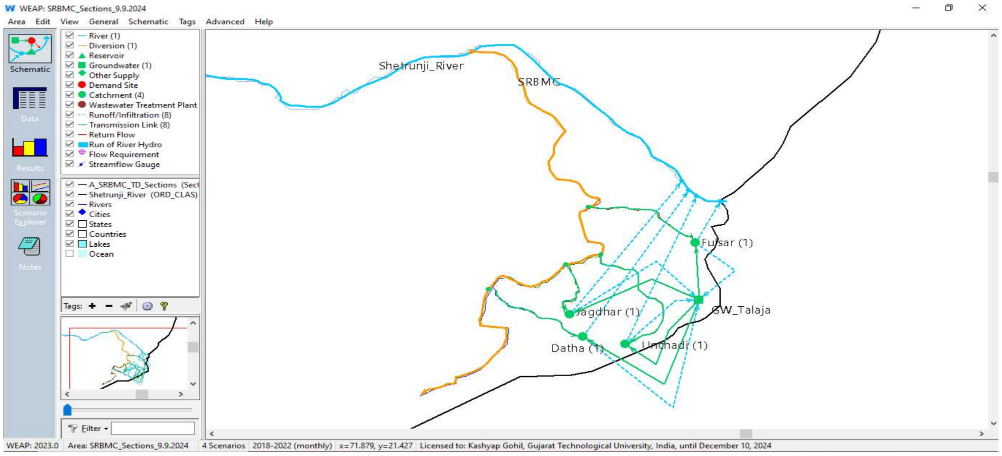


Fig. 3 Schematic view of study area, Source: WEAP

The computation of the model was done by simulating the entire model for the various scenarios for the period (Year: 2019-2022) that were generated using Current Account information for the period (Year: 2018) the following results of the Shetrunji Right Bank Main Canal Command Area were made based on following scenarios:

- ☐ Current Account (Year: 2018)
- ☐ Scenario 1: Deficit irrigation

This scenario was created to assess the possible stress of crop and the impact on crop yield by applying irrigation amount equal to 100% depletion when depletion reaches at 130% of readily available water (RAW). it means crop is already under 30% Stress.

- ☐ Scenario 2: Full irrigation

This scenario, no stress is permitted, Irrigation is trigger when depletion reaches at 100% of RAW and amount of water equal to 100% depletion. Supply as an irrigation amount and possible impact is assessed for crop water requirements and yield of crops.

- ☐ Scenario 3: Irrigation at every 20 days interval

This scenario was created to assess the possible impact on crop water requirements for various crops and yield of crop by applying irrigation at every 20th day throughout crop period. In this irrigation trigger was set at every 20th day from planting date and irrigation amount was set as 100% depletion. Flow chart of WEAP model shown below in Fig. 4

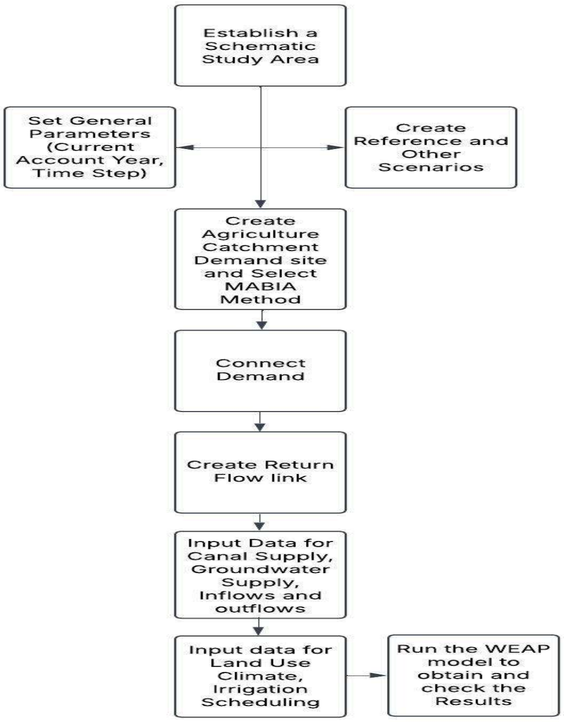


Fig. 4 Flow chart of WEAP model

6.5 The Irrigation schedule options

- **Irrigation Trigger**

The WEAP-MABIA module offers four irrigation trigger methods:

1. ***Fixed Interval:*** Irrigation occurs every N day, where N is the specified trigger value.
2. ***% of RAW:*** Irrigation is triggered when soil moisture depletion reaches or exceeds a set percentage of Readily Available Water (RAW)**.** To prevent water stress, depletion should not exceed RAW.
3. ***% of TAW:*** Irrigation is triggered when soil moisture depletion reaches or exceeds a set percentage of Total Available Water (TAW)**.** To prevent permanent wilting, depletion should not exceed TAW.
4. ***Fixed Depletion:*** Irrigation occurs when soil moisture depletion reaches or surpasses a specified depth (in mm).

The Irrigation Trigger Value corresponds to the Irrigation Trigger Method: days for the fixed interval method, % for the % of RAW or the % of TAW method, and millimetres (mm) for the fixed depletion method.

- **Irrigation Amount**

WEAP-MABIA module includes four irrigation amount methods. The method defines how much water to apply on the days when irrigation occurs.

1. ***% Depletion:*** Apply a specified % of the current soil water depletion.
2. ***Fixed Depth:*** Apply a specified depth of water.
3. ***% of RAW:*** Apply a specified % of the Readily Available Water (RAW) level, regardless of the current soil water depletion.
4. ***% of TAW:*** Apply a specified % of the Total Available Water (TAW) level, regardless of the current soil water depletion.

The Irrigation Amount Value is the value associated with the Irrigation Amount Method: % for the % Depletion, the % of RAW or the % TAW method, and mm for the fixed depth method.

6.5 Water Demand

The chart (Table 3, Fig. 5, X - axis represent different irrigation methods and Y – axis represent water demand in million cubic meters) is a grouped bar chart displaying Water Demand (not including loss, reuse, and DSM) across different irrigation scenarios for four locations: Fulsar, Unchadi, Jagdhar, and Datha. Fulsar consistently exhibits the highest water demand across all irrigation scenarios, with values reaching 51.5 MCM, 57.15 MCM, 67.05 MCM in Deficit, Full and 20 days interval strategies, While Jagdhar exhibits the lowest water demand across all irrigation scenarios with values reaching 14.5 MCM, 17.32 MCM, 20.42 MCM in Deficit, Full and 20 days interval strategies.

Table 3. Water Demand

<table>
<tr><th colspan="5">Water Demand (not including loss, reuse and demand side management) (Million-Cubic Meter)</th></tr>
<tr><th colspan="5">All Months, All Years</th></tr>
<tr><th>Branch</th><th>Deficit Irrigation</th><th>Full Irrigation</th><th>Irrigation at 20 days interval</th><th>Reference</th></tr>
<tr><td>Fulsar</td><td>51.5</td><td>57.15</td><td>67.06</td><td>64.52</td></tr>
<tr><td>Unchadi</td><td>44</td><td>58</td><td>53.88</td><td>61.84</td></tr>
<tr><td>Jagdhar</td><td>14.5</td><td>17.32</td><td>20.42</td><td>20.49</td></tr>
<tr><td>Datha</td><td>33.82</td><td>40.96</td><td>45.41</td><td>45.1</td></tr>
<tr><td>Sum</td><td>143.82</td><td>173.44</td><td>186.77</td><td>191.95</td></tr>
</table>

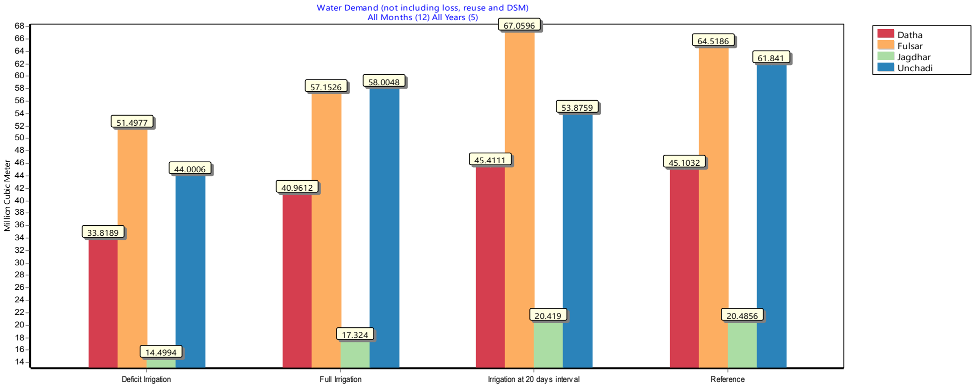
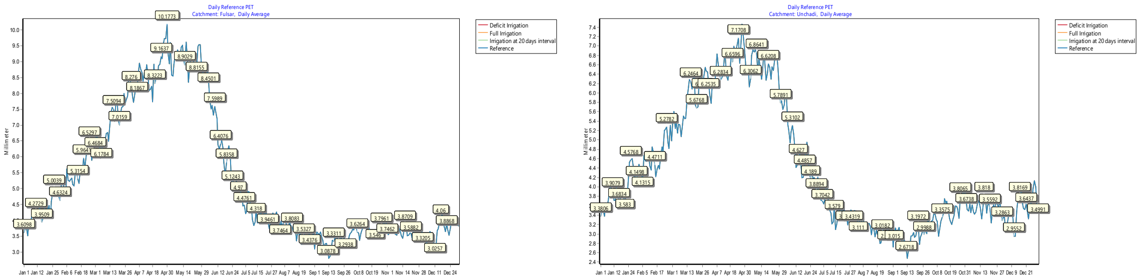


Fig.5: Water demand

6.6 Daily Reference PET

The chart (Fig. 6, X - axis represent different days and Y – axis represent PET in millimeters) is displaying Daily Reference PET across different irrigation sections for four locations: Fulsar, Unchadi, Jagdhar, and Datha. The PET values in (Fig. a.) fluctuate over the recorded period, starting at 3.6098 mm and peaking at 10.1733 mm before gradually decreasing to 3.0257 mm. This indicates variability in atmospheric demand for water from the land surface, which is influenced by factors such as temperature, humidity, and solar radiation in Fulsar section.

a. Daily Reference PET of Fulsar Section **b. Daily Reference PET of Unchadi Section**



c. Daily Reference PET of Jagdhar Section **d. Daily Reference PET of Datha Section**

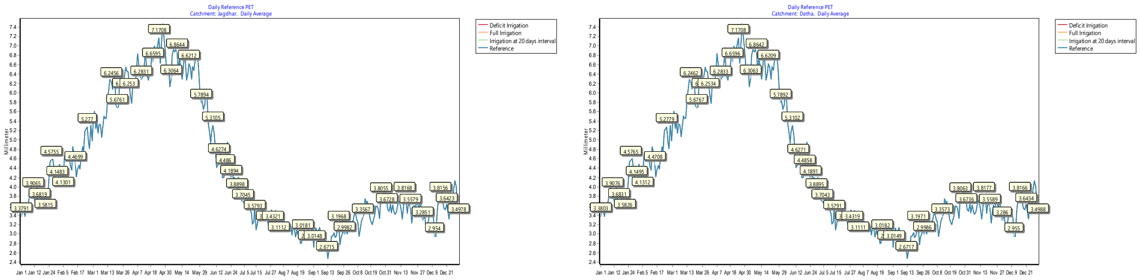


Fig. 6 Daily Reference PET

6.7 ET Actual for Fulsar Section

Evapotranspiration (ET actual, Table 4, Fig. 7a.), including irrigation, across various crops under a Deficit Irrigation scenario for the years 2018 to 2022. The data is presented in millimetres (mm) and showcases the water consumption trends for different crops.

Key Observations

1. Wheat Consumes the Most Water:

- Wheat (blue bars) exhibits the highest ET actual values across all years, ranging from 1,583.79 mm to 1,693.92 mm, indicating a high-water requirement even under deficit irrigation. This suggests that wheat is the most water-intensive crop in the given scenario.

2. Cotton Also Shows High ET Actual Values:

- Cotton (orange bars) consistently records the second-highest water consumption after wheat, with values peaking at 954.30 mm in 2018 and fluctuating between 778.56 mm to 839.79 mm in subsequent years.

3. Moderate Water Demand Crops:

- Groundnut, Greengram, and Sesame fall within a moderate water usage range, with ET actual values between 500 mm to 700 mm across different years. These crops show relatively stable water demand, making them viable under deficit irrigation strategies.

4. Chickpeas Show the Lowest Water Demand:

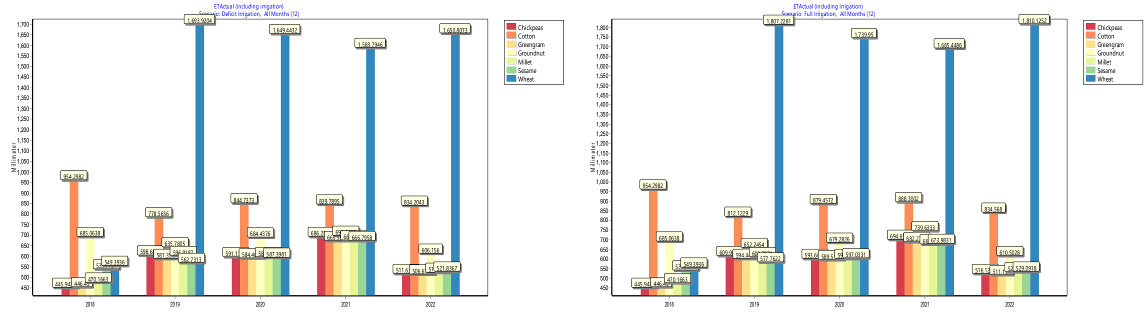
- Chickpeas (red bars) consistently record the lowest ET actual values, ranging between 445.94 mm to 511.60 mm, making them the most water-efficient crop in the given dataset. This suggests that chickpeas could be a sustainable crop choice under water-scarce conditions.

The analysis highlights Wheat as the most water-demanding crop, followed by Cotton, under Deficit Irrigation conditions. Chickpeas and other legumes require significantly less water, making them more sustainable under water-limited scenarios. The trends suggest relative stability in water demand across years, with minor fluctuations that may be attributed to climatic variations or adjustments in deficit irrigation strategies.

Table 4. ET Actual of Fulsar Section

ET Actual (including irrigation) (Millimetre)							
2018-2022, Branch: Demand Sites and Catchments\Fulsar							
Deficit Irrigation							
Year	**Chickpeas**	**Cotton**	**Greengram**	**Groundnut**	**Millet**	**Sesame**	**Wheat**
2018	445.94	954.3	446.43	685.06	470.17	533.71	549.39
2019	598.68	778.57	581.35	635.78	596.92	562.73	1693.92
2020	591.13	844.74	584.46	684.44	589.08	587.4	1649.44
2021	686.28	839.79	665.6	690.26	669.43	666.8	1583.79
2022	511.63	834.2	506.68	606.16	514.84	521.84	1650.81
Average	**566.73**	**850.32**	**556.9**	**660.34**	**568.09**	**574.5**	**1425.47**
Full Irrigation							
2018	445.94	954.3	446.43	685.06	470.17	533.71	549.39
2019	609.91	812.12	594.45	652.25	603.71	577.76	1807.23
2020	593.61	879.46	589.52	679.28	593.49	597.03	1739.95
2021	694.65	888.3	682.28	739.63	669.43	673.98	1685.45
2022	516.13	834.57	511.13	610.5	525.29	529.09	1810.13
Average	**572.05**	**873.75**	**564.76**	**673.35**	**572.42**	**582.32**	**1518.43**

Irrigation at 20 days intervals							
2018	445.94	954.3	446.43	685.06	470.17	533.71	549.39
2019	576.13	783.6	563.7	639.51	582.08	594.37	1801.63
2020	571.04	909.11	569.36	676.55	579.25	608.59	1717.35
2021	679.84	928.49	667.4	683.79	687.28	650.12	1676.35
2022	501.42	884.09	503.68	611.22	536.59	540.79	1741.92
Average	**554.88**	**891.92**	**550.11**	**659.23**	**571.07**	**585.52**	**1497.33**



a. Deficit Irrigation Scenario

b. Full Irrigation Scenario

c. Irrigation at 20 days Interval Scenario

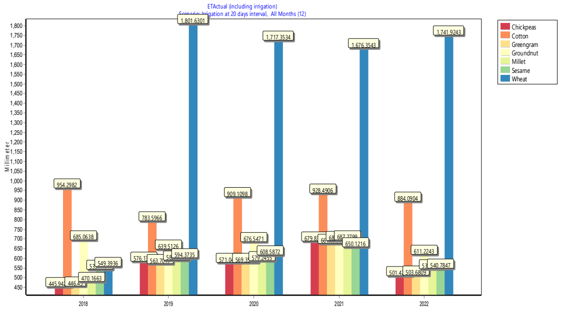


Fig.7 ET actual for Fulsar Section (Deficit, Full and Irrigation at 20 days interval)

6.8 Infiltration and Runoff Flow

The infiltration and runoff flow (Table 5 and Fig. 8, X - axis represent different years and Y – axis represent infiltration/runoff flow in million cubic meters) under Deficit Irrigation, Full Irrigation, 20-day Interval Irrigation, and Reference scenarios over five years (2018-2022), measured in Million Cubic Meters (MCM).

Key Observations:

- The lowest infiltration and runoff values in Deficit Irrigation (59.2 – 84.98 MCM), indicating greater water movement. The highest infiltration and runoff values in 20 days Interval (60.5 – 93.2 MCM), indicating greater water movement.

- Infiltration and runoff are highest under 20 days Interval conditions and lowest under Deficit Irrigation. Managing irrigation methods can optimize water retention and reduce excess runoff, improving efficiency in agricultural water use.

Table 5. Infiltration and Runoff Flow

Infiltration/Runoff Flow (Million Cubic Meter)						
All Scenarios, Annual Total						
Scenario	2018	2019	2020	2021	2022	Sum
Deficit Irrigation	60.5	85	83.1	72.5	59.2	360.2
Full Irrigation	60.5	86.8	89	74.9	64.9	376.1
Irrigation at 20 days interval	60.5	86.1	93.2	80.1	72.6	392.5
Reference	60.5	90	96.1	80.4	68.6	395.6

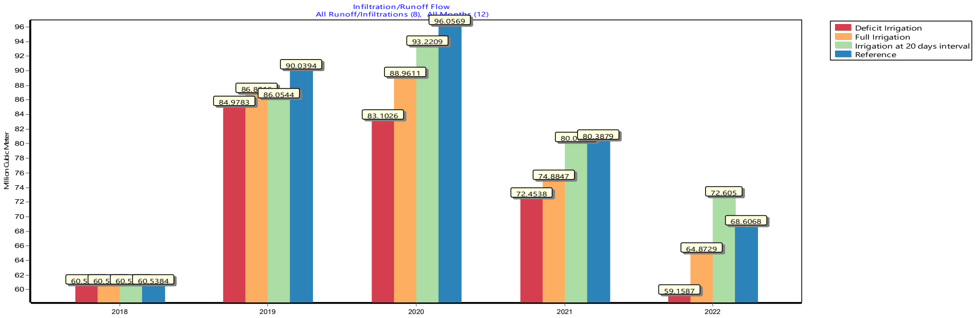


Fig.8 Infiltration and Runoff Flow

6.9 Daily Depletion and Available Water

This analysis (Table 6 and Fig. 9, X - axis represent different days and Y – axis represent daily depletion and available water in millimeter) examines the daily readily available water, soil moisture depletion, and total available water under a Deficit Irrigation scenario over the course of a year. Deficit irrigation leads to significant soil moisture depletion in the early months, impacting water availability. However, natural rainfall or irrigation later in the year helps restore water levels. Effective irrigation scheduling is crucial to prevent early-season moisture stress.

Table 6. Daily Depletion and Available Water

Daily Depletion and Available Water (Millimetre)			
Scenario: Irrigation at 20 days interval, All Variables, Branch: Demand Sites and Catchments\Fulsar\Wheat, Daily Average			
Variable	Daily Readily Available Water	Daily Soil Moisture Depletion	Daily Total Available Water
01-Jan	43.5643	33.4	79.7914
02-Jan	44.5731	35.5609	81.6257
03-Jan	45.582	37.478	83.46
04-Jan	46.5909	39.1157	85.2943

05-Jan	47.5997	40.8093	87.1286
06-Jan	48.6086	4.37128	88.9629
07-Jan	49.6174	8.44841	90.7971
08-Jan	50.6263	12.8159	92.6314
09-Jan	51.6351	17.1001	94.4657
10-Jan	52.644	20.7226	96.3
11-Jan	53.6529	23.86	98.1343
12-Jan	54.6617	26.5049	99.9686
13-Jan	55.6706	28.9159	101.803
14-Jan	56.6794	31.3951	103.637
15-Jan	57.6883	33.4287	105.471
16-Jan	58.6971	35.2632	107.306
17-Jan	59.706	37.0534	109.14
18-Jan	60.7149	38.9477	110.974
19-Jan	61.7237	40.7997	112.809

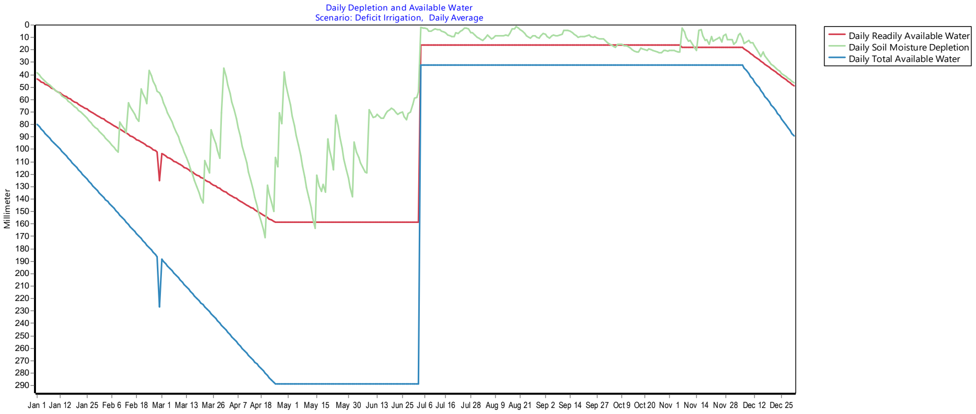


Fig.9 Daily Depletion and Available Water

6.10 Daily Irrigation

This bar chart presents (Table 7 and Fig. 10, X - axis represent different years and Y – axis represent daily Irrigation in millimetre) the total irrigation water applied under different irrigation strategies across multiple years. The four irrigation strategies include Deficit Irrigation, Full Irrigation, Irrigation at 20-day intervals, and Reference values. Deficit Irrigation consistently applies the least water each year, reflecting a water-saving approach. Full Irrigation and Irrigation at 20-day intervals show a moderate increase, suggesting an improved water supply.

Table 7. Daily Irrigation

Daily Irrigation (Millimetre)				
All Scenarios, Branch: Demand Sites and Catchments\Fulsar, Annual Total				
Scenario	**Deficit Irrigation**	**Full Irrigation**	**Irrigation at 20 days interval**	**Reference**
2018	391.183	391.183	391.183	391.183
2019	106.568	196.921	208.991	236.428
2020	204.15	190.42	239.077	211.053
2021	193.391	251.703	288.301	290.412
2022	204.966	194.425	315.032	257.665
Sum	1100.26	1224.65	1442.58	1386.74

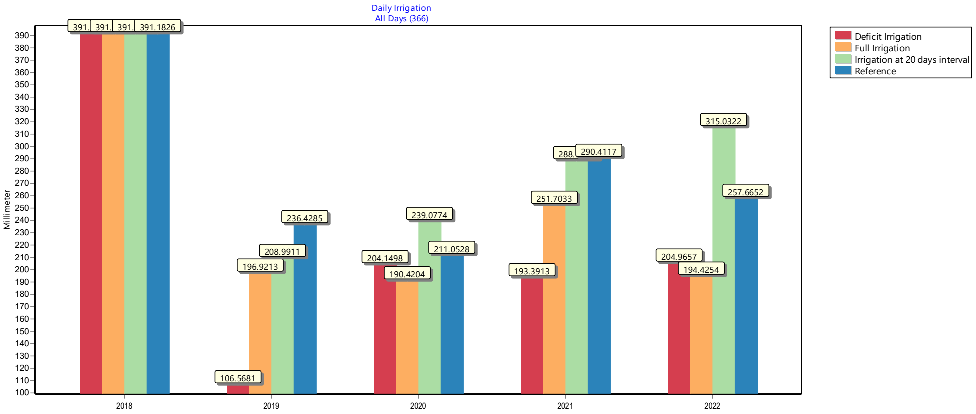


Fig.10 Daily Irrigation

6.11 Land Class Inflow and Outflow

This stacked bar chart (Table 8 and Fig. 11, X - axis represent different years and Y – axis represent land class inflow and outflow in millimeter) represents the water balance components for different years under the Deficit Irrigation scenario. The inflows and outflows include precipitation, irrigation, evapotranspiration, soil moisture changes, surface runoff, and groundwater flow.

Table 8. Land Class Inflow and Out flow

Land Class Inflow and Outflow (in Millimeter)									
Scenario: Deficit Irrigation, Branch: Demand Sites and Catchments\Fulsar\Wheat, All Months									
Variable	**Decrease in Soil Moisture**	**Decrease in Surface Storage**	**Evapotranspiration**	**Flow to Groundwater**	**Increase in Soil Moisture**	**Increase in Surface Storage**	**Irrigation**	**Precipitation**	**Surface Runoff**
2018	85.355	0	-549.394	-356.329	-40.0953	0	213.333	647.13	0
2019	206.409	0	-1693.92	-678.84	-204.777	0	1152.64	1218.49	0
2020	189.393	0	-1649.44	-497.804	-191.621	0	992.985	1156.49	0
2021	300.491	0	-1583.79	-422.681	-300.552	0	943.876	1062.66	0
2022	312.011	0	-1650.81	-231.736	-304.593	0	1000.38	874.75	0
Sum	**1093.66**	**0**	**-7127.36**	**-2187.39**	**-1041.64**	**0**	**4303.21**	**4959.52**	**0**

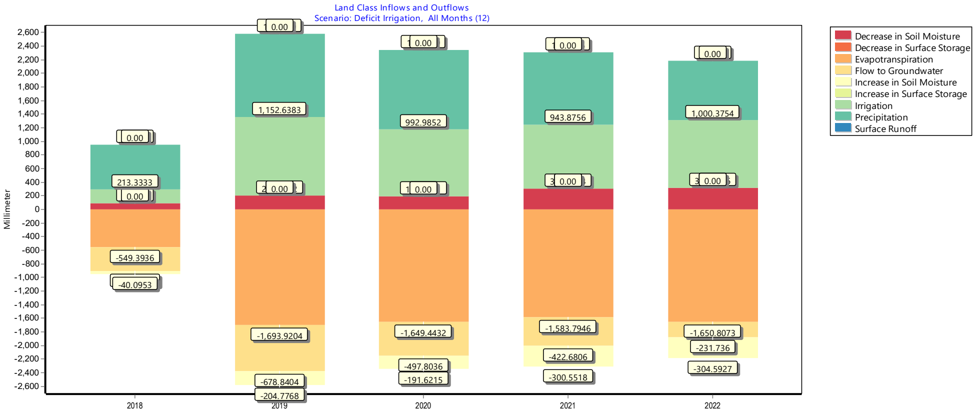


Fig.11 Land Class Inflow and Out flow

6.12 Water Demand for All Branches

This stacked bar chart (Table 9 and Fig. 12, X - axis represent different irrigation methods and Y – axis represent water demand in million cubic meters) represents water demand for different crops under four irrigation scenarios: Deficit Irrigation, Full Irrigation, Irrigation at 20-day Intervals, and Reference.

Table 9. Water Demand for All Sections Crops

Water Demand (not including loss, reuse and DSM) (Cubic Meter)				
All Branches				
Branch	**Deficit Irrigation**	**Full Irrigation**	**Irrigation at 20 days interval**	**Reference**
Datha\Chickpeas	80528.1	94578.2	74020.8	1272400
Datha\Cotton	14184688	16819897	22863978	13462018
Datha\Greengram	514635	556538	478291	413630
Datha\Groundnut	10383852	12798570	10873635	12471942
Datha\Millet	893652	1035155	1301549	1169373
Datha\Sesame	271041	449749	536067	236596
Datha\Wheat	7490469	9206714	9283607	15927455
Fulsar\Chickpeas	87665.1	122221	98820.5	1767369
Fulsar\Cotton	24130876	25514011	35140562	21895673
Fulsar\Greengram	724837	793913	725143	613384
Fulsar\Groundnut	14268628	16561031	15785479	16443009
Fulsar\Millet	751358	855736	1721283	874200
Fulsar\Sesame	403517	522656	841647	413150
Fulsar\Wheat	11130800	12783034	12746634	22369969
Jagdhar\Chickpeas	37283.7	43789.6	34271.5	589128
Jagdhar\Cotton	6566267	7785780	10583292	6231504
Jagdhar\Greengram	238271	257673	221448	191507
Jagdhar\Groundnut	3837903	4629126	4569688	4525640

Jagdhar\Millet	413748	479264	602609	541406
Jagdhar\Sesame	125488	208229	248194	1550918
Jagdhar\Wheat	3280450	3920119	4159476	6786166
Unchadi\Chickpeas	76107.4	84377.2	70651.7	1091604
Unchadi\Cotton	20537571	26416388	29030662	22192522
Unchadi\Greengram	460786	672108	539148	516989
Unchadi\Groundnut	12976170	18585441	12212713	17892671
Unchadi\Millet	512947	644784	1182584	651600
Unchadi\Sesame	504401	607120	611349	346059
Unchadi\Wheat	8932655	10994556	10228780	19049506
Sum	143816593	173442559	186765585	191948403

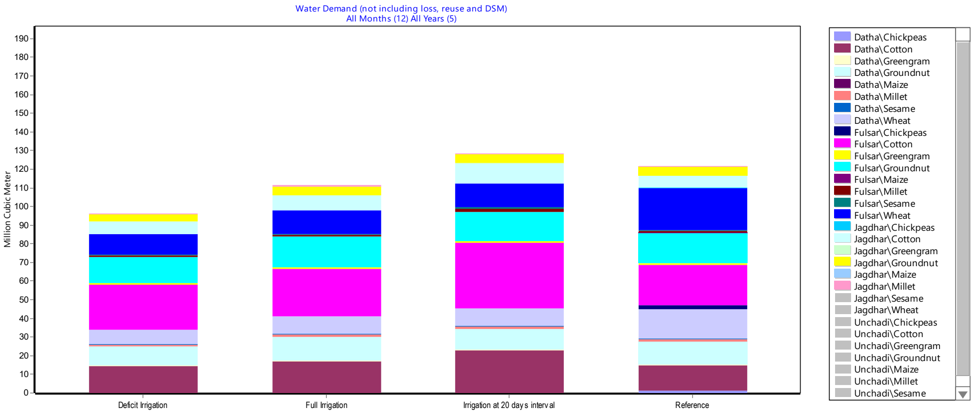


Fig.12 Water Demand for All Sections Crops

6.13 Irrigation

The bar chart (Table 10 and Fig. 13, X - axis represent different irrigation methods and Y – axis represent irrigation in millimeters) represents the irrigation levels for various crops under four different irrigation scenarios: Deficit Irrigation, Full Irrigation, Irrigation at 20-day Intervals, and Reference.

Variation across Scenarios:

- The Reference and Full Irrigation scenarios exhibit the highest water usage across all crops, ensuring optimal water supply.
- Deficit Irrigation shows significantly lower water usage, which may impact crop yield.
- The Irrigation at 20-day Interval scenario maintains moderate irrigation levels, balancing water conservation and crop needs.

Crop-Specific Trends:

- Certain crops, such as Chickpeas, Wheat, and Sesame, show higher water requirements compared to others.
- Variability in irrigation levels suggests different crop water needs and adaptation to irrigation strategies.

Table 10. Irrigation for All Sections Crops

Irrigation (Millimetre)				
All Branches				
Branch	**Deficit Irrigation**	**Full Irrigation**	**Irrigation at 20 days interval**	**Reference**
Datha\Chickpeas	68.5521	85.403	60.7476	93.0575
Datha\Cotton	179.388	215.312	297.708	210.902
Datha\Greengram	50.9745	57.563	45.2602	50.1773
Datha\Groundnut	89.6306	120.026	95.7958	119.346
Datha\Millet	33.522	42.1581	58.4165	49.3452
Datha\Sesame	15.6826	43.1938	56.482	19.426
Datha\Wheat	678.901	834.454	841.423	891.086
Fulsar\Chickpeas	67.6901	103.046	79.1037	110.965
Fulsar\Cotton	280.637	296.723	408.677	316.774
Fulsar\Greengram	77.0537	86.319	77.0947	88.7977
Fulsar\Groundnut	144.251	168.868	160.539	172.562
Fulsar\Millet	18.4025	23.837	68.9023	24.3036
Fulsar\Sesame	43.077	58.7236	100.617	82.9867
Fulsar\Wheat	860.642	988.393	985.579	1067.67
Jagdhar\Chickpeas	68.5578	85.4113	60.7545	93.0642
Jagdhar\Cotton	179.364	215.273	297.647	210.866
Jagdhar\Greengram	50.9798	57.5691	45.2667	50.1844
Jagdhar\Groundnut	73.0795	94.5919	92.9758	94.4952
Jagdhar\Millet	33.5251	42.1619	58.4218	49.3492
Jagdhar\Sesame	15.6858	43.1982	56.4873	50.8356
Jagdhar\Wheat	642.208	767.434	814.293	820.053
Unchadi\Chickpeas	61.9452	70.1848	56.5095	66.7009
Unchadi\Cotton	221.173	287.751	317.358	298.454
Unchadi\Greengram	48.0856	75.6881	58.321	79.25
Unchadi\Groundnut	104.976	163.633	96.9923	161.018
Unchadi\Millet	12.7134	19.3978	46.6651	19.3495
Unchadi\Sesame	36.9523	50.089	50.6298	31.2582
Unchadi\Wheat	672.583	827.834	770.175	885.37
	4830.2326	5924.2366	6158.8426	6207.6472

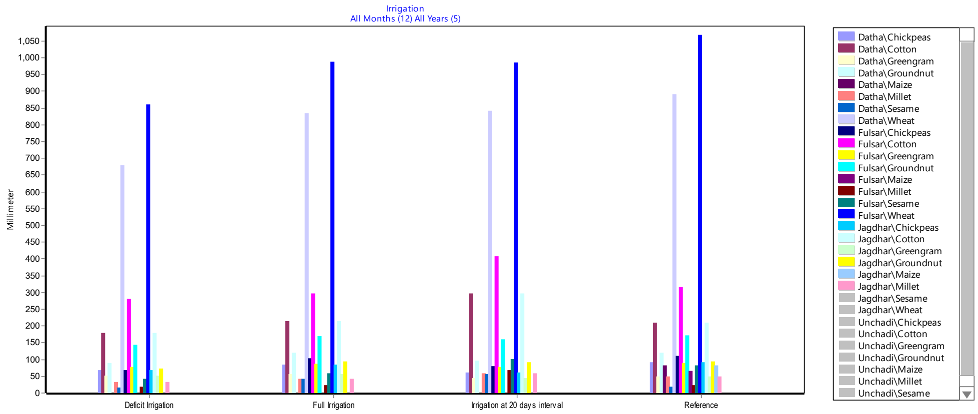


Fig.13 Irrigation for All Sections Crops

6.14 Annual Crop Production

The stacked bar chart (Table 11 and Fig. 14, X - axis represent different irrigation methods and Y – axis represent annual crop production in kilograms) represents annual crop production across different irrigation scenarios: Deficit Irrigation, Full Irrigation, Irrigation at 20-day Intervals, and Reference.

Production Trends across Scenarios:

- The Reference scenario exhibits the highest total crop production, suggesting optimal water availability.
- Full Irrigation closely follows, indicating that continuous water supply supports higher yield.
- Deficit Irrigation leads to lower overall crop production, implying a reduction in yield due to water stress.
- Irrigation at 20-day intervals results in slightly lower production than Full Irrigation but remains a balanced approach.

Crop-Specific Insights:

- Some crops, like Chickpeas, Wheat, and Maize, show a significant dependency on irrigation levels.
- Drought-resistant crops seem less affected by Deficit Irrigation, making them viable options in water-scarce conditions.

Implications:

- Full and Reference Irrigation maximize crop production but require high water input.

- Deficit Irrigation conserves water but significantly reduces yield.
- Irrigation at 20-day intervals provides a balanced approach, ensuring sustainable water use while maintaining production.

Table 11. Annual Crop Production

Annual Crop Production (Kilograms)				
All Branches				
Branch	**Deficit Irrigation**	**Full Irrigation**	**Irrigation at 20 days interval**	**Reference**
Datha\Chickpeas	131859	132825	114930	2629882
Datha\Cotton	4665176	4831416	4830063	3931320
Datha\Greengram	281398	281992	258158	186085
Datha\Groundnut	16290546	16382348	15990210	15889539
Datha\Millet	3556241	3575220	3480919	3725696
Datha\Sesame	351899	36721	346336	156432
Datha\Wheat	2488551	2808361	2464740	4991587
Fulsar\Chickpeas	158874	159913	153999	3086963
Fulsar\Cotton	4231018	4397431	4345320	3342339
Fulsar\Greengram	342525	345194	337438	232772
Fulsar\Groundnut	19517729	19840846	19652126	19263176
Fulsar\Millet	4239156	4247195	4220379	4423582
Fulsar\Sesame	465067	467215	457045	219776
Fulsar\Wheat	2853526	3291961	2868632	5851138
Jagdhar\Chickpeas	61050.6	61498.4	53212.5	1217568
Jagdhar\Cotton	2159967	2236831	2236204	1820111
Jagdhar\Greengram	130289	130564	119528	86161.8
Jagdhar\Groundnut	7625004	7647430	7557043	7419273
Jagdhar\Millet	1646486	1655276	1611610	1724942
Jagdhar\Sesame	162931	170165	160355	1825824
Jagdhar\Wheat	1160637	1300195	1135058	2310970
Unchadi\Chickpeas	161650	163395	157683	3169199
Unchadi\Cotton	5582544	5777615	5745331	4694136
Unchadi\Greengram	349155	351695	342746	236248
Unchadi\Groundnut	19597343	19711143	19127554	19117930
Unchadi\Millet	4350794	4355776	4323903	4536909
Unchadi\Sesame	416240	422547	364908	168451
Unchadi\Wheat	2920846	3380532	1496743	6008565
Sum	**105898501**	**108494104**	**103952172**	**123592164**

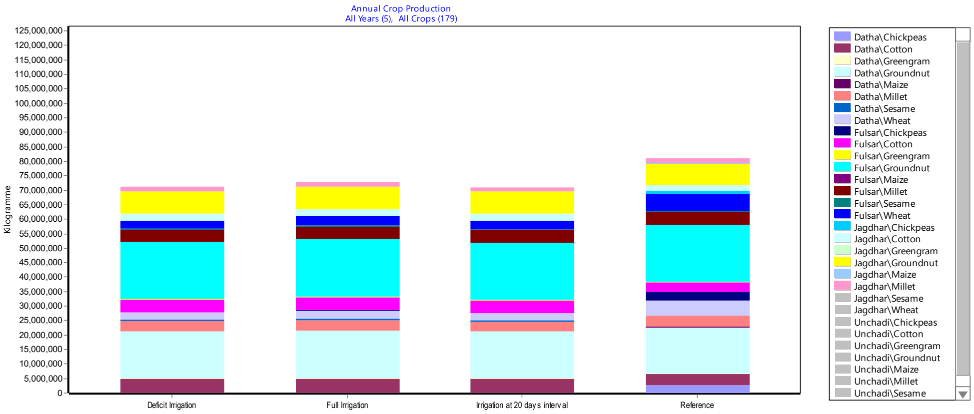


Fig.14 Annual Crop Production

6.15 Evaluation of Irrigation Strategies in Study Area

- Irrigation Strategies for Wheat

Irrigation strategy is optimal for wheat (Table 12, 13 and Fig 15, X - axis represent different irrigation sections and Y – axis represent annual crop production in kilograms, Fig 16, X - axis represent different irrigation sections and Y – axis represent WUE and IWUE), the full irrigation in the Fulsar/Unchadi/Jagdhar/Datha section results in the highest yield (annual crop production), though it is associated with low Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE). However, no significant differences in WUE and IWUE are observed across all irrigation strategies.

As same optimal Irrigation strategy obtained for all crop of four different sections of SRBMC command area.

Table 12. Annual Production of Wheat

Section	Annual Crop Production (Kgs.) Deficit Irrigation	Annual Crop Production (Kgs.) Irrigation at 20 days interval	Annual Crop Production (Kgs.) Full Irrigation
Fulsar	28,53,526	28,68,632	32,91,961
Unchadi	29,20,846	14,96,743	33,80,532
Jagdhar	11,60,637	11,35,058	13,00,195
Datha	24,88,551	24,64,740	28,08,361

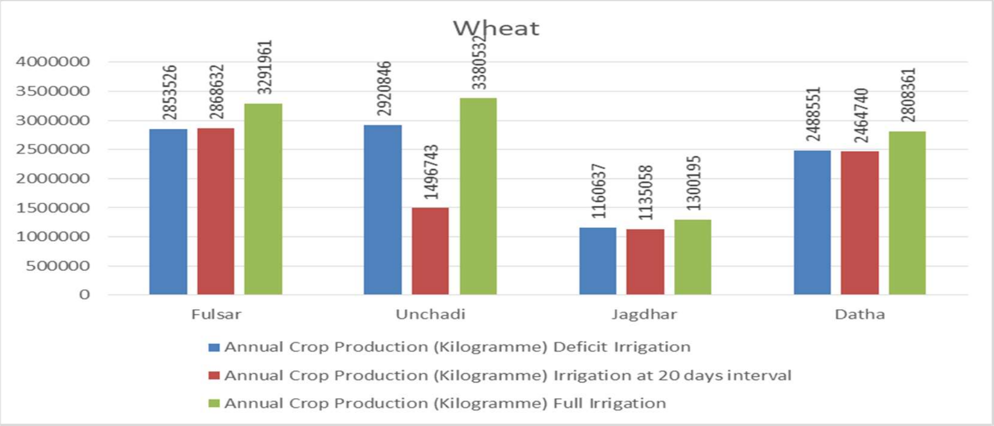


Fig.15 Annual Production of Wheat

Table 13. WUE and IWUE of Wheat

Section	**(WUE)**	**(WUE)**	**(WUE)**	**(IWUE)**	**(IWUE)**	**(IWUE)**
	Deficit Irrigation	**Irrigation at 20 days interval**	**Full Irrigation**	**Deficit Irrigation**	**Irrigation at 20 days interval**	**Full Irrigation**
Fulsar	2.66	2.58	2.56	5.37	5.04	5.03
Unchadi	3.06	3.04	2.91	5.92	5.48	5.27
Jagdhar	3.02	2.9	2.89	6.11	5.34	5.51
Datha	2.9	2.78	2.77	5.47	4.8	4.82

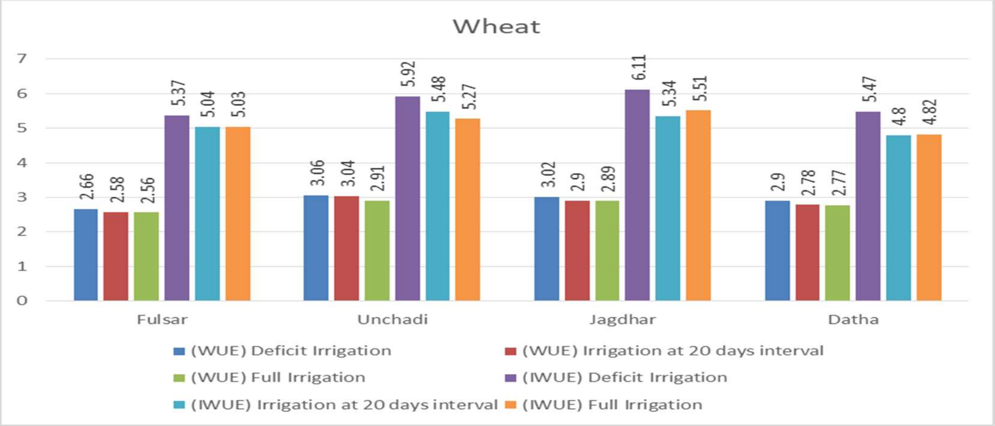


Fig.16 WUE and IWUE of Wheat

7 Achievements with Respect to Objectives.

Table 14. Achievement with respect to objectives

Sr.No	Objectives	Fulfilment	Achievements
1	Predict agricultural water demand through the formulation of diverse scenarios employing various irrigation strategies.	Fulfilled	Agriculture water demand predicted for all crops of four sections of SRBMC
2	Develop a crop water utilization model employing a dual crop coefficient method.	Fulfilled	Developed a crop water utilization model using a dual crop coefficient method for all crops of four sections of SRBMC
3	Evaluate the performance of irrigation schedules across diverse strategies to gauge their effectiveness in water management.	Fulfilled	Performance of irrigation schedules evaluated with three Irrigation strategies.
4	Offer valuable insights and recommendations to enhance the efficiencies of irrigation water use management practices based on the evaluation of different strategies.	Fulfilled	Recommended to enhance the WUE and IWUE of different strategies.

8 Conclusion

- In conclusion, the optimal irrigation strategy for sesame in the Fulsar/Unchadi/Jagdhar/Datha section is deficit irrigation, which achieves the highest Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE). However, no significant differences in yield (annual crop production) are observed across the different irrigation strategies.
- In conclusion, the optimal irrigation strategy for groundnut in the Fulsar/Jagdhar section is deficit irrigation, which achieves the highest Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE). However, no significant differences in yield (annual crop production) are observed across the different irrigation strategies.
- In conclusion, the optimal irrigation strategy for groundnut in the Unchadi/Datha section is full irrigation, which achieves the highest Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE). However, no significant differences in yield (annual crop production) are observed across the different irrigation strategies.
- In conclusion, the optimal irrigation strategy for green gram in the Jagdhar/Datha section is deficit irrigation, which achieves the highest Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE). However, no significant differences in yield (annual crop production) are observed across the different irrigation strategies.

- In conclusion, the optimal irrigation strategy for green gram in the Fulsar/Unchadi section is full irrigation, which achieves the highest Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE). However, no significant differences in yield (annual crop production) are observed across the different irrigation strategies.
- In conclusion, the optimal irrigation strategy for cotton in the Fulsar/Unchadi/Jagdhar/Datha section is deficit irrigation, which achieves the highest Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE). However, no significant differences in yield (annual crop production) are observed across the different irrigation strategies.
- In conclusion, the optimal irrigation strategy for chickpeas in the Fulsar/Unchadi/Jagdhar/Datha section is irrigation at 20 days interval, which achieves the highest Water Use Efficiency (WUE) and Irrigation Water Use Efficiency (IWUE). However, no significant differences in yield (annual crop production) are observed across the different irrigation strategies.
- Overall, the optimal irrigation strategies for all sections (Fulsar, Unchadi, Jagdhar and Datha) and all crops are as follows: 50% deficit irrigation, 37.5% full irrigation, and irrigation at 20-days interval accounting for 12.5%.
- The FAO-56 Penman-Monteith model, coupled with the dual crop coefficient approach (MABIA method, integrated into WEAP), has been effectively used to estimate crop water requirements. This method leverages daily climatological data to accurately calculate daily potential evapotranspiration (PET). By separating soil evaporation and plant transpiration, the dual crop coefficient approach enables precise estimation of crop water needs under both normal and water-stressed conditions. This information is crucial for accurate soil moisture balance modeling in irrigation management. The FAO-56 Penman-Monteith model, therefore, proves to be a valuable tool for optimizing irrigation schedules and water resource management.
- Daily soil moisture balance calculations are essential for optimizing irrigation scheduling, maximizing crop yields, and assessing groundwater recharge. Fluctuations in soil surface wetness and moisture profiles, caused by rainfall and irrigation events, significantly influence crop evapotranspiration. By precisely monitoring and modeling these daily variations, we can make informed decisions to enhance water use efficiency and ensure sustainable agriculture.
- Implementing regulated deficit irrigation techniques during specific crop growth stages can enhance both crop yield and water use efficiency. While moderate water stress during critical periods may result in a minor reduction in yield for some crops, the significant improvement in irrigation water use efficiency compared to conventional practices makes this strategy a viable option.
- By developing and evaluating various irrigation strategies under different assumptions, we can accurately predict irrigation demand and assess the impact of different policies. Comparing these strategies allows us to identify the most effective approach for maximizing crop yields while minimizing water use. This valuable information helps decision-makers select the optimal strategy to achieve both agricultural productivity and water conservation goals.

- Irrigation scheduling based on soil water status can lead to significant yield increases. However, the required irrigation depth can fluctuate considerably between wet and dry years, especially when using irrigation trigger methods based on soil moisture depletion levels. On the other hand, scheduling irrigation based on crop growth stages can result in water stress, particularly during critical early growth periods. To mitigate this, frequent application of smaller irrigation depths, as often practiced in wheat cultivation, can enhance yield, water use efficiency, and irrigation water use efficiency compared to infrequent, deep irrigations.
- An integrated information system, combined with the WEAP model, can empower planners to effectively monitor and make informed decisions regarding crop water requirements. This system will be instrumental in managing irrigation water demand, ensuring optimal water allocation, and promoting sustainable water resource utilization.

9 List of Publications arising from the thesis

i) *Gohil, K. B., & Jain, R. (2023). Extensive review of water resources management using WEAP and its integrated models.* Journal of Indian Water Works Association, April-June 2023*, 119–124.*

ii) *Gohil, K. B., & Jain, R. (2024). Optimizing irrigation strategies for groundnut using WEAP-MABIA: A decision support method for agricultural scenarios in Unchdi section, Shetrunji Irrigation Command Area.* Nanotechnology Perceptions, 20*(S9), 758–766.* *https://doi.org/10.62441/nano-ntp.v20iS9.1684*

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