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Optimizing Irrigation Strategies for Groundnut Using Weap-Mabia: A Decision Support Method for Agricultural Scenarios in Unchdi Section, Shetrunji Irrigation Command Area

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This study delves into the optimization of groundnut irrigation strategies within the Unchdi Section, employing the Water Evaluation and Planning (WEAP) model. Given groundnut's significance in the local economy, efficient water management is paramount. Utilizing the WEAP-MABIA model, diverse irrigation scenarios are scrutinized, considering soil-water balance and crop-specific needs. The study's findings underscore optimal scheduling strategies to enhance groundnut yield while curbing water wastage. Policymakers and stakeholders can leverage these insights to improve irrigation practices and foster sustainable agriculture in the Unchdi Section.

Keywords: WEAP, Groundwater, Dual Crop Coefficient, Evapotranspiration, Irrigation Strategies, WEAP Model, MABIA Method, Unchdi.

1. Introduction

Irrigation scheduling involves determining the optimal frequency and duration of watering for efficient water management. For irrigation system managers, understanding the precise water requirements of plants is essential to achieve maximum yield. Notably, studies have demonstrated that employing a water balance approach in irrigation scheduling can lead to significant water savings—typically between 15% and 35%—without compromising crop production [1]. Assessing irrigation scheduling manually is a challenging endeavour due to its time-consuming and intricate nature [2].

To address this, computer programs play a crucial role. In our research, we employ the Water Evaluation and Planning (WEAP) model, which offers versatile applications across various sectors, including agriculture. The WEAP model facilitates water demand analysis, conservation efforts, efficient water distribution, and cost-benefit assessments [3].

By leveraging this model, it is aimed to enhance irrigation strategies and optimize water utilization. The primary objectives of study are twofold. First, WEAP-MABIA model to rigorously evaluate irrigation scheduling across three distinct rice growing seasons. By considering soil-water balance and crop-specific requirements, research delves into the intricacies of water management during these critical periods. Second, is to derive optimal irrigation strategies that strike a balance between maximizing groundnut yield and efficiently utilizing water resources throughout the varying seasons. By achieving this delicate equilibrium, it is aimed for sustainable agricultural practices and overall improvement productivity in groundnut cultivation. Numerous studies have explored the application of the WEAP model as a decision support tool for optimizing irrigation strategies, aiming to achieve optimal crop yield while efficiently managing water resources. For instance, Karamouz et al [4].

Bhatti and Patel [5] conducted a case study using the WEAP model to analyse the impact of climate change on crop water usage. They projected future irrigation demands and assessed management scenarios, including agricultural area expansion and climate change effects on water demand. The study demonstrated the effectiveness of deficit irrigation strategies for cotton crops utilizing the WEAP model. Furthermore, Bhatti [6]

Tikariha and Ahmad [7] assessed real-time irrigation demands and proposed water-saving strategies for specific crops using the WEAP model. With escalating water scarcity in India, exacerbated by groundwater over-exploitation and climate change impacts, agricultural sustainability is threatened, particularly in states like Chhattisgarh. Recognizing agriculture's vital role in the Indian economy, understanding, and addressing crop water requirements is crucial to mitigate yield losses from water stress. Husain and Rhyme [8] utilized advanced tools like the water evaluation and planning (WEAP) software, employing the MABIA method to estimate crop water requirement (CWR) and irrigation water requirement (IWR) systematically. Their comprehensive study across seven blocks of Chhattisgarh state revealed a substantial gap between water demand and available resources, leading to significant irrigation deficits. Leveraging optimization techniques such as genetic algorithms, the study proposes tailored crop patterns to maximize economic returns while ensuring sustainable water management practices.

Hamdi, Abdulhameed, et al. [9] investigated the impact of various agricultural irrigation scenarios on MRQ76 rice cultivation in the Wasan padi field in Brunei-Muara District, Brunei Darussalam, utilizing the WEAP model. Specifically, they evaluated irrigation scheduling for three distinct rice growing seasons using the WEAP-MABIA model, which employs a soil-water balance approach. Their findings suggest that the WEAP model is well-suited for determining optimal irrigation scheduling strategies to maximize rice yield and ensure efficient water management.

M. Allani et al. [10] utilized the Water Evaluation and Planning (WEAP) model to enhance the Fallujah irrigation project, covering 63,000 hectares with an annual budget of 1,476 million cubic meters (2020-2021). Results showed that 86% of the irrigation budget, amounting to 1,272 million cubic meters per year, was utilized. Annual production under Fallujah irrigation reached 524.4 million kilograms, generating total economic returns of 393.6 million dollars per year. The study proposed two scenarios for improving the irrigation system. In the first scenario, implementing a sprinkler irrigation system for wheat and barley increased production to 625.7 million kilograms per year and economic returns to 427.2 million dollars annually. The second scenario involved adopting a sprinkler system for wheat and barley and a trickle system for other crops, boosting production to 1164.9 million kilograms per year and economic returns to 559.4 million dollars annually. Ahmed et al. [11] investigate the impact of climate change on the Nebhana dam system's water supply and demand. They utilize future climate scenarios from five general circulation models (GCMs) considering RCP 4.5 and 8.5 emission scenarios for 2021–2040, 2041–2060, and 2061–2080. Statistical methods with LARS-WG are used to downscale the data, and the GR2M hydrological model is calibrated and validated. The model outputs are input into the WEAP model to assess future water availability. Crop growth cycle lengths are estimated using a model based on growing degree days, and crop and irrigation water requirements are projected using the WEAP-MABIA method. Results show an average increase in annual ETo of 6.1%, a decrease in annual rainfall of 11.4%, and a 24% decrease in inflow. Crop growing cycles are expected to decrease, and variations in irrigation requirements are observed, influenced by RCPs and time periods. The study suggests an insufficient supply to meet system demand, highlighting the need for improved water surface utilization planning and sustainable canal water management in the face of escalating water demand and climate fluctuations. Najm [12] conducted a study within the Chaj Doab, part of the Indus Basin Irrigation System (IBIS) in Pakistan, utilizing the WEAP (Water Evaluation and Planning) model. Six scenarios revealed surface water availability falling short of crop water requirements, with the Lower Jhelum Canal (LJC) command area showing greater sensitivity to water scarcity than the Upper Jhelum Canal (UJC). Future climate change scenarios until 2070 under RCP 4.5 and 8.5 indicated decreased catchment reliability. Implementing scenario 3, focusing on improving irrigation efficiency and transitioning to low delta crops, effectively reduced canal water deficit, optimizing canal water allocation. This underscores the importance of enhancing the irrigation system and optimizing cropping areas for efficient canal water management.

The study by Jahangirpour and Zibaei [13] employed the Water Evaluation and Planning (WEAP) model to enhance the Ramadi irrigation project, covering 28,342 hectares with an annual budget of 326 million cubic meters for 2018-2019. Results showed total water utilization of 111.5 million cubic meters per year, representing 34.2% of the irrigation budget. Annual production reached 39.3 million kilograms, generating total economic returns of 16.04 million dollars per year. Two scenarios aimed at improving cultivated areas were introduced, resulting in increased productivity and economic returns. However, the second scenario led to escalated conveyance loss, constituting 15% of the water budget. Additionally, another study assessed historical gross margin of key crops in the Bakhtegan Basin under different irrigation systems, utilizing stochastic dominance and efficiency approaches. Results highlighted the significance of considering risk premiums when allocating subsidies to incentivize farmers towards adopting more efficient irrigation systems.

2. Study Area and Data Collection

The study area for this research is Unchadi Village, situated in the Talaja region of Bhavnagar, Gujarat. The selection of this location is justified by its proximity to the Shatrunjay Dam, a significant reservoir serving the Saurashtra region of Gujarat. This dam plays a crucial role in irrigation activities, making Unchadi Village an ideal site for studying groundnut cultivation and irrigation practices. The coordinates of the study area are approximately 21.245°N latitude and 72.038°E longitude. Data for the study is sourced from reputable sources, including the State Irrigation Department, Deputy Executive Engineer S.R.B.M.C. Sub-division Talaja, and the Statistics Branch District Panchayat Office Bhavnagar. Soil analysis conducted at Shantilal Shah Engineering College, Bhavnagar, has identified the soil type as Clay Loam, providing valuable insights into groundnut cultivation conditions. Meteorological data, including average humidity, temperature, wind speed, and precipitation, is obtained from NASA Power, a reliable platform for predicting worldwide energy resources. By integrating data from these sources, this research aims to comprehensively analyse groundnut cultivation dynamics in the study area, with a focus on optimizing irrigation practices for enhanced crop yield and sustainability.

3. Results and Discussion

In this study, irrigation scheduling analysis was conducted for groundnut cultivation using three different scenarios: full irrigation, deficit irrigation, and irrigation at 20-day intervals. The analysis spanned four years, starting from 2018 as the base year and continuing through 2019, 2020, 2021, and 2022. Each irrigation scheduling case was evaluated based on specific parameters to assess its impact on groundnut yield and water use efficiency. For the full irrigation scenario, readily available water (RAW) considered to be 100%, indicating that irrigation was triggered when the available water reached full capacity. Irrigation was applied until there was complete depletion of water resources. In the deficit irrigation scenario, the irrigation trigger was set at 130% of the RAW, indicating that irrigation was initiated when the available water exceeded the specified threshold. Despite this, the irrigation amount remained consistent, resulting in 100% depletion of water resources. In the case of irrigation at 20-day intervals, 80mm fixed irrigation trigger was set at intervals of 20 days throughout the growing season. Like the deficit irrigation scenario, irrigation was applied until there was complete depletion of water resources. To determine the most effective irrigation strategy, built-in daily soil moisture balance feature in WEAP was used.

This analysis focused on groundnut cultivation, considering parameters such as actual evapotranspiration (ETc), rainfall, irrigation, surface runoff, and flow to groundwater, yield, water use efficiency (WUE), and Irrigation Water Use Efficiency (IWUE). The study spanned a period of five years, from 2018 to 2022, with 2018 serving as the base year. We evaluated three different irrigation strategies to assess their impact on soil moisture balance in the root zone. The results of this analysis are presented in Table 2, providing valuable insights into the effectiveness of each irrigation strategy in optimizing groundnut cultivation and water management practices. The equation below shows the calculation for soil moisture depletion. The value of capillary rise is considered as zero in the calculation.

$$D_{r,i} - D_{r,i-1} = -R_i + SR_i - I_i - CR_i + ET_{c,i} + DP_i$$

Where;

$D_{r,i} - D_{r,i-1}$: Change in soil moisture depletion in the root zone

R_i : Rainfall depth

SR_i : Surface Runoff

I_i : Irrigation depth

CR_i : Capillary rise

$ET_{c,i}$: Crop Evapotranspiration

For instance, substituting values in above equation for calculating soil moisture depletion for base year where capillary rise is considered as zero in calculation.

$29.29 = -718.52 + 0 - 209.86 - 0 + 513.59 + 443.65$

Water Use Efficiency (WUE) is computed by dividing the crop yield per hectare (kg/ha) by the evapotranspiration (ETc) in millimetres. Irrigation Water Use Efficiency (IWUE) is determined by dividing the crop yield by the amount of irrigation water applied. As irrigation water application increases, both average WUE and IWUE increase due to the effective utilization of soil water storage. Under the Full irrigation scenario, the average values are as follows: ETc (596 mm), WUE (3.13 kg/ha/mm), and IWUE (12.47 kg/ha/mm), yielding the highest average yield of 1857.58 kg/ha. In the Deficit Irrigation scenario, the average values are: ETc (583 mm), WUE (3.19 kg/ha/mm), and IWUE (26.06 kg/ha/mm), also resulting in the highest average yield of 1857.58 kg/ha. Lastly, in the Irrigation at 20-day intervals with 80mm fixed depth scenario, the average values are: ETc (562 mm), WUE (3.30 kg/ha/mm), and IWUE (4.45 kg/ha/mm), with the highest average yield of 1857.58 kg/ha. This indicates that reducing water consumption is adequate for sustaining crop growth without encountering a decrease in yield.

Table 1: Irrigation strategies for Groundnut in Unchdi Section

FULL IRRIGATION			
Year	Irrigation Scheduling (Days After sowing)	Irrigation Amount	Remarks
2018 (Base Year)	1,4,6,8,10,12,14,16,18,20,22,68,106,120,135	Varying	Full irrigation that is decided by model; soil moisture is allowed to deplete when 100% RAW for a trigger with irrigation depth applied at 100% depletion.
2019	1,4,7,9,20,23,43,49		
2020	1,3,23,27,134		

2021	1,3,6,9,12,14,31,33,36,74		
2022	1,3,5,7,9,14,26,98,127		
DEFICIT IRRIGATION			
Year	Irrigation Scheduling (After sowing)	Irrigation Amount	Remarks
2018 (Base Year)	1,4,6,8,10,12,14,16,18,20,22,68,106,120,135	Varying	Deficit irrigation that is decided by model; 130% readily available water (RAW), depth applied at 100% depletion and stress is allowed.
2019	5,9,21,26		
2020	1,25		
2021	1,5,8,11,14,32,35,38		
2022	1,3,5,7,10,28		
IRRIGATION at 20 DAYS Interval, 80 mm Fixed Depth			
Year	Irrigation Scheduling (After sowing)	Irrigation Amount	Remarks
2018 (Base Year)	1,4,6,8,10,12,14,16,18,20,22,68,106,120,135	80 mm fixed depth	For 20 days irrigation that is decided by model; fix interval of every 20 days and 80 mm fixed depth of irrigation water is applied.
2019	1,21,41,81		
2020	1,21,61,101,121,		
2021	1,41,61,81		
2022	1,21,61,81,101,121		

Table 2: Water balance, yields and efficiencies for Groundnut cultivation

Year	Etc (mm)	Irrigation (mm)	Rainfall (mm)	Decrease in soil moisture (mm)	Run-off (mm)	Flow to GW (mm)	Yield (kg/ha)	WUE (Ec)	IWUE
Full Irrigation									
2018 (Base Year)	513.59	209.86	718.52	29.29	0	443.65	1912.57	3.724	9.114
2019	610.87	116.15	1107.7	28.88	0	619.84	1751.05	2.866	15.076
2020	593.91	110.31	1160.8	38.33	0	659.85	2149.72	3.62	19.488
2021	683.55	170.69	1079.7	31.32	0	587.11	1977.93	2.894	11.588
2022	582.73	211.16	941.38	51.59	0	560.17	1496.63	2.568	7.088
Deficit Irrigation									
Year	Etc (mm)	Irrigation (mm)	Rainfall (mm)	Decrease in soil moisture (mm)	Run-off (mm)	Flow to GW (mm)	Yield (kg/ha)	WUE (Ec)	IWUE
2018 (Base Year)	513.59	209.86	718.52	29.29	0	443.65	1912.57	3.724	9.114
2019	574.57	60.05	1107.7	28.88	0	600.03	1751.05	3.048	29.16
2020	583.27	35.64	1160.8	35.91	0	640.96	2149.72	3.686	60.318
2021	671.17	125.46	1079.7	76.46	0	509.12	1977.93	2.947	15.765
2022	577.38	93.87	941.38	38.73	0	470.69	1496.63	2.592	15.944
20 Days Irrigation, 80 mm Fixed Depth									
Year	Etc (mm)	Irrigation (mm)	Rainfall (mm)	Decrease in soil moisture (mm)	Run-off (mm)	Flow to GW (mm)	Yield (kg/ha)	WUE (Ec)	IWUE
2018 (Base Year)	513.59	209.86	718.52	29.29	0	443.65	1912.57	3.724	9.114
2019	579.56	560	1107.7	28.88	0	1094.99	1751.05	3.021	3.127
2020	587.24	560	1160.8	36.03	0	1150.27	2149.72	3.661	3.839
2021	600.92	560	1079.7	70.7	0	1025.01	1977.93	3.292	3.532
2022	532.31	560	941.38	71.8	0	959.44	1496.63	2.812	2.673

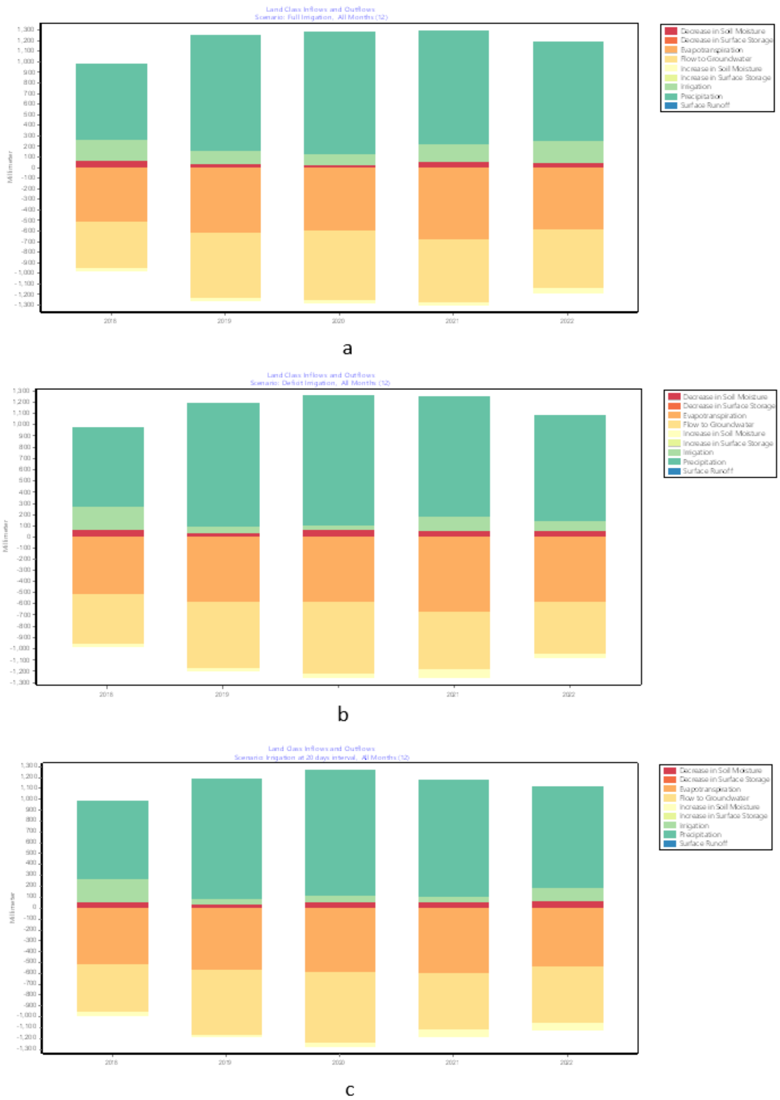

Figure 1: Land class inflow and outflow three different irrigation strategies (a) Full Irrigation, (b) Deficit Irrigation, (c) Irrigation at fixed interval of 20 days with 80mm fixed depth

4. Conclusion

The determination of actual evapotranspiration employs the Penman- Monteith Method and a dual crop coefficient approach, integrated within the MABIA module in the WEAP model. By utilizing this model, water stress conditions are mitigated, resulting in improved crop yields. The FAO-56 Penman-Monteith model proves highly effective in accurately estimating daily potential evapotranspiration based on daily climatological data. The dual crop coefficient approach facilitates the separate computation of soil evaporation and transpiration under both normal and water stress conditions, enhancing precision in water resource management for agricultural purposes. This research delved into optimizing irrigation strategies for groundnut cultivation in Unchadi Village, Talaja, Bhavnagar, Gujarat. Through the utilization of the WEAP-MABIA model and comprehensive data analysis, we explored three distinct irrigation scenarios: full irrigation, deficit irrigation, and irrigation at 20-day intervals. The study spanned a period of five years, from 2018 to 2022, with a focus on assessing soil moisture balance, crop yield, water use efficiency (WUE), and Irrigation Water Use Efficiency (IWUE). Given that deficit irrigation yielded the highest crop yield while maintaining high water use efficiency (WUE) and irrigation water use efficiency (IWUE), as indicated in Table 2, it stands out as the optimal strategy among the three options.

Our findings indicate that effective irrigation scheduling plays a pivotal role in maximizing groundnut yield while conserving water resources. We observed that both WUE and IWUE tend to improve with increased irrigation water application, highlighting the significance of optimizing irrigation practices for sustainable agriculture. By providing valuable insights into the efficacy of different irrigation strategies, this research contributes to the advancement of water-efficient farming techniques and promotes sustainable agricultural practices in the region. The WEAP model proves to be not only a fitting tool for determining the optimal irrigation strategy but also serves as a decision support system for forecasting crop yields and offering valuable insights into irrigation water usage without compromising crop productivity.

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