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Estimation of Crop Water Needs and Irrigation Scheduling using CROPWAT in Unchadi, Bhavnagar, Gujarat

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Abstract: The Earth's total potable water supply is finite and remains constant due to the continuous processes of evaporation and precipitation in the hydrological cycle. Only a mere 0.01% of this finite resource is available as surface water in lakes and rivers. Given that agriculture heavily relies on surface water, prudent water management practices can contribute to preserving this precious resource. This study is aimed at enhancing agricultural productivity in the Unchadi village of Talaja, Bhavnagar, by calculating crop water requirements and irrigation scheduling for groundnuts, wheat, sorghum, and millet. To achieve this objective, the FAO-developed Cropwat-Penman-Monteith approach is applied. The irrigation scheduling process involves optimizing soil replenishment in the field's capacity along with strategic timing for irrigation during critical depletion stages. This choice of irrigation scheduling minimizes yield losses. In 2019, the reference evapotranspiration (ET_0) reaches a high of 3.79 mm/dec. This study analyzes four crops, with wheat having a minimum crop water requirement (CWR) of 189.3 mm/dec and a maximum of 436.9 mm/dec. For sorghum, the CWR ranges from 382.4 to 462.7 mm/dec. The results of this research are expected to significantly improve crop yields and contribute to water conservation in the Unchadi village.

***Index Term* - Plant water requirements, FAO-Cropwat, evapotranspiration, irrigation schedule, groundnut, wheat, sorghum, and millet.**

I. INTRODUCTION

Water is an essential resource for the survival, growth, and production of an adequate food supply from plants to meet human needs. A complex interplay of biological, physical, and chemical processes occurs within the context of crops, climate, soil, and water. A crop's maximum potential yield is largely determined by its genetic makeup and the prevailing climatic conditions. To achieve optimal yields, irrigation systems must be carefully planned and operated to provide the right amount and timing of water.

A fundamental requirement for both farm crop planning and irrigation project planning is the assessment of crop water requirements (WR). Water demand, in this context, refers to the quantity of water needed for healthy crop development over a specific time and location, regardless of the crop's origin. This includes losses due to evapotranspiration or consumptive usage, unavoidable losses during water application, and water needed for specific tasks such as pre-sowing irrigation, transplanting, and site preparation. Evapotranspiration and unavoidable water loss processes, such as deep percolation, fall under the category of water requirements. Additionally, it encompasses the leaching of salts when necessary and pre-sowing irrigation. Crop-specific parameters, including leaf area, root length, root density, growth stage, crop type, and species, influence the crop water requirement. Meteorological factors such as temperature, radiation, humidity, and wind speed also impact the crop's water needs.

Irrigation scheduling involves the decision-making process of when and how much water to apply during irrigation. Three critical factors must be considered when devising an irrigation schedule: the depth of the effective root zone, the available soil moisture capacity, and the daily water requirements of the crop. Proper timing and precise water application are crucial for achieving the highest crop productivity. In India, the monsoon season, spanning from June to September, witnesses significant rainfall. However, the remaining eight months experience insufficient precipitation to meet crop water needs, necessitating irrigation.
Weather, water availability, and soil type are the three fundamental factors influencing agriculture. As of 2021, 51% of agricultural land in India is irrigated, with the remaining portion relying on rainfall. Efforts are being made to improve the surface water canal lining system to facilitate the efficient and profitable use of water in agriculture. Currently, agriculture consumes 80% of the available water resources in India.

II. STUDY AREA AND DATA COLLECTION

2.1 Study Area Location

Unchadi village, situated within Talaja Taluka, Bhavnagar District, Gujarat State, serves as the focal point for this research. Positioned 67 kilometres to the south of Bhavnagar's district centre, the village boasts an elevation of 65 meters above sea level. Unchadi's predominant crops encompass wheat, onions, bananas, cotton, sorghum, millet, and brinjal.

Figure 2.1 Google imaginary map showing the study area

2.2 Climate Data

This study utilizes meteorological data collected over a span of four years, covering the period from 2016 to 2019. The results of this data analysis can be found in Table 2.1. The data is sourced on a daily basis from the State Water Data Centre (SWDC) through the satellite-based NASA website, with data retrieval based on geographical coordinates.

Table 2.1 Meteorological data

Month	Min Temp	Max Temp	Humidity	Wind	Sun
	°C	°C	%	km/day	hours
January	19.5	35.6	30	7	8.9
February	18.5	33.4	45	5	9.7
March	23.5	36.8	60	9	6.7
April	23.9	40.6	70	8	10.6
May	25.6	40.7	87	7	11.7
June	22	35.6	44	6	7.8
July	21	33.4	56	4	9.8
August	21.8	34.7	79	9	6.9
September	20.8	20.9	89	7	8.7
October	19.6	27.7	73	6	7.9
November	18.5	33.7	54	8	4.6
December	18	34	76	9	5.7
Average	21.1	33.9	64	7	8.3

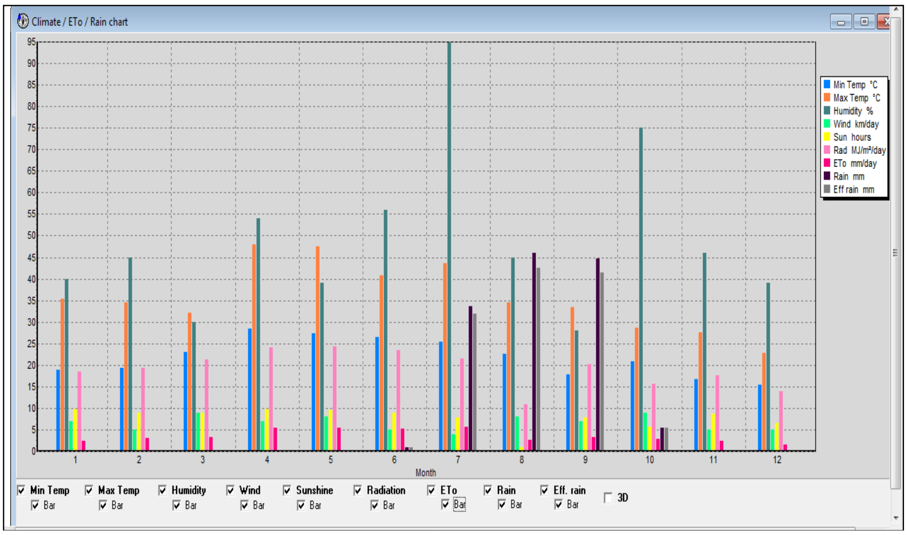

Figure 2.2 climate data graphical representation

2.3 Soil Data

Physical processes, including water infiltration rate, transportation, retention, and accessibility to plant roots, play a vital role in soil. Hence, a thorough comprehension of the physical properties of soil concerning water is essential for effective irrigated agriculture management. The soil parameters essential for irrigation scheduling using the FAO CROPWAT program are detailed in Table 2.2. In the research area, there are varying soil types, including sandy, loam, and black clay soils.

Table 2.2 Soil Parameters

Soil parameters	Value
Total available soil moisture (mm/meter)	190
Maximum infiltration rate (mm/dec)	70
Maximum rooting depth (cm)	150
Initial soil moisture depletion (%)	0
Initial available soil moisture (mm/meter)	190

2.4 Crop Data

Within the research area, various crops, including groundnut, wheat, millet, and sorghum, are cultivated. Essential crop data was collected, encompassing details such as planting dates, actual harvesting dates, durations of different growth stages, K_C and K_Y values at various growth stages, allowable soil moisture depletion levels, and crop rooting depths.

This crop data encompasses specific information, including the name of the crops, planting and harvesting dates, KC values, initial days, developmental stages, mid-season stages, late-season stages, rooting depths, permissible soil moisture depletion levels, yield response factors, and crop heights.

III. METHODOLOGY

The manual calculation of reference evapotranspiration is a laborious and time-consuming task that can be susceptible to mathematical errors. When estimating crop water requirements for multiple irrigation projects manually, it can lead to a significant amount of time and effort for irrigation engineers and professionals. To streamline the process, minimize redundancy, and enhance computational efficiency, computerization is essential. An illustrative instance of such computerized tools is the FAO CROPWAT software, designed for the prediction of ET0 and crop water requirements.

3.1 Reference Evapotranspiration

The estimation of reference evapotranspiration relies on the FAO Penman-Monteith method. Within CROPWAT 8.0, irrigation schedules are generated through daily soil-water balance, incorporating a variety of user-defined parameters for irrigation management and water supply. The Penman-Monteith equation is expressed as follows:

$$\mathbf{ETo = (Rn - G) / \Delta + \gamma * [(es - ea) / T * (1 + 0.34 * u2)]}$$

Where:
ETo = Reference evapotranspiration, in millimeters per day (mm/dec)
Rn = Net radiation at the crop surface, in megajoules per square meter per day (MJ m^2 day^{-1})
G = Soil heat flux density, in megajoules per square meter per day (MJ m^2 day^{-1})
T = Mean daily temperature at a 2-meter height, in degrees Celsius (°C)
u2 = Wind speed at a 2-meter height, in meters per second (m/s)
es = Saturation vapor pressure, in kilopascals (kPa)
ea = Actual vapor pressure, in kilopascals (kPa)
es - ea = Saturation vapor pressure deficit, in kilopascals (kPa)
Δ = Slope of the vapor pressure curve, in kilopascals per degree Celsius (kPa $°C^{-1}$)
γ = Psychrometric constant, in kilopascals per degree Celsius (kPa $°C^{-1}$)

3.2 Effective Rainfall

The algorithm we intend to employ in the software's selection module for calculating effective rainfall is depicted in Figure 3. Given that the fourth approach presented in the diagram provides more precise results compared to other methods, it is chosen for further estimation.

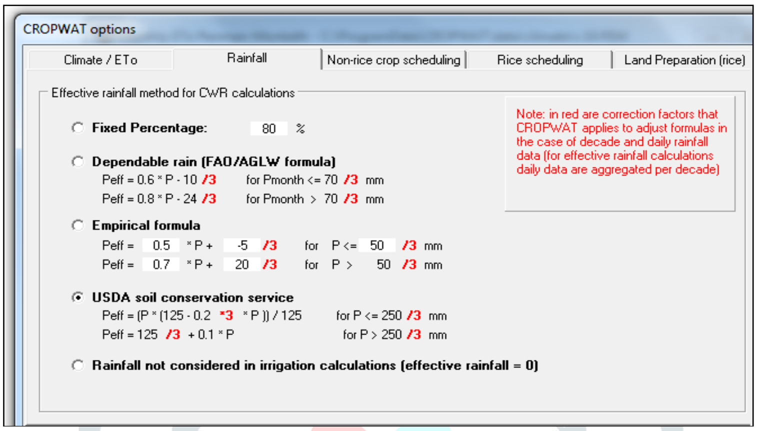

Figure 3.1 effective rainfall methods

3.3 Irrigation Planning

The program includes options for scheduling irrigation, involving the timing and application choices. The timing option determines when irrigation is to be applied, with choices such as watering at user-defined intervals, relying solely on rainfall (no irrigation required), irrigation at a fixed depletion level, critical depletion level, fixed intervals per point, or when there is a specified yield loss. Among the timing options mentioned, the choice of irrigating at critical depletion, where a complete depletion occurs, was considered. The Applications option addresses the quantity of water required for each irrigation.

3.4 Crop Water Requirement

Upon inputting crop data, CROPWAT utilizes the provided information along with previously calculated ET_0 and effective rainfall values to ascertain the water and irrigation requirements for the specific crop. This involves the determination of Crop Evapotranspiration (ETc), Crop Coefficient, and the Crop Coefficient Curve.

IV. RESULT AND DISSCUSSION

4.1 Reference Evapotranspiration (ET0)

The outcomes indicating daily reference ET in millimeters for Uchadi Village are presented in Table 4.1. Reference evapotranspiration at the research site ranges from 3.10 mm/dec to 6.57 mm/dec. The average ET0 value was calculated at 3.79 mm/dec. The highest ET_0 value was observed in May, while the lowest occurred in December.

Table 4.1 ETo result

Month	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Avr
Eto	2.32	3.09	3.57	5.49	6.57	4.26	4.61	4.32	3.75	3.05	2.15	2.3	3.79

4.2 Effective Rainfall Outcome

The results of employing all strategies simultaneously to estimate effective rainfall are provided here. By utilizing the USDA SCS method, we achieved a more accurate effective rainfall measurement of 122.3 mm. This outcome will be considered for subsequent calculations.

4.3 Crop Water Requirement

Using the reference evapotranspiration, we calculated the water requirements for various crops, including millet, sorghum, wheat, and groundnut. In 2019, the highest crop water requirement was 462.7 mm/dec for sorghum, while the lowest was 189.3 mm/dec for wheat in 2016. Millet required 363.4 mm/dec, and groundnut required 380.7 mm/dec of water in the month of May. The highest CWR for sorghum is presented here.

Table 4.2 CWR for all crops

Crops Name	High Crop Water Requirement (mm/dec)	low CWR mm/dec
Groundnut	380.7	299.4
Wheat	436.9	189.3
Sorghum	462.7	382.4
Millet	384.4	249.8

Table 4.3 High Crop water requirement for sorghum

Month	Decade	Stage	Kc	ETc	Effective ETc	Effective rain	Irrigation Requirement
			coefficient	mm/dec	mm/dec	mm/dec	mm/dec
Oct	3	Initial	0.7	1.92	11.5	0	11.5
Nov	1	Initial	0.7	1.67	16.7	0.1	16.5
Nov	2	Initial	0.7	1.43	14.3	0	14.3
Nov	3	Initial	0.7	1.49	14.9	0	14.9
Dec	1	Development	0.71	1.61	16.1	0	16.1
Dec	2	Development	0.78	1.8	18	0	18
Dec	3	Development	0.85	1.97	21.6	0	21.6
Jan	1	Development	0.92	2.14	21.4	0	21.4
Jan	2	Mid	0.99	2.3	23	0	23
Jan	3	Mid	1.01	2.6	28.6	0	28.6
Feb	1	Mid	1.01	2.86	28.6	0	28.6
Feb	2	Mid	1.01	3.12	31.2	0	31.2
Feb	3	Mid	1.01	3.29	26.3	0	26.3
Mar	1	Late	1.01	3.38	33.8	0	33.8
Mar	2	Late	0.98	3.41	34.1	0	34.1
Mar	3	Late	0.93	3.87	42.6	0	42.6
Apr	1	Late	0.89	4.3	43	0	43
Apr	2	Late	0.85	4.65	37.2	0	37.2
					462.8	0.1	462.7

Figure 4.1 Graphical representation of irrigation scheduling for sorghum

V. CONCLUSION

By accomplishing the objectives of this study, the research's aim to enhance crop production in Unchadi Village within the Bhavnagar district has been achieved. The process of calculating crop water requirements and irrigation demands has facilitated the development of an irrigation schedule for each crop considered in this study. The outcomes indicated that the crop water requirements, measured in millimetres per month, were as follows: 380.7 for groundnuts, 462.7 for sorghum, 436.9 for wheat, and 394.4 for millet. Minor disparities between the crop harvesting date in the output data and the actual scenario suggest the reliability of Cropwat's findings for predicting crop production in Unchadi Village.

A significant finding of this study is the consistent trend where the computed net irrigation requirements (NIR) for all crops remained lower than the gross irrigation requirements (GIR). This indicates that factors such as runoff, deep percolation, and other losses contribute to the reduction of irrigation water availability. Understanding the distinction between NIR and GIR is vital for efficient water management and the prevention of excessive water usage.

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