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Estimation of Crop Water Requirement using CROPWAT 8.0 for different irrigated crops in Addis Zemen District, Amhara Region, Ethiopia

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Abstract
Water is the main governing element for agricultural productivity. Many water resources have been tapped in for the purpose of irrigation. In order to increase crop productivity and fulfil future food demand while ensuring food security, irrigation systems are crucial. Reduced precipitation patterns due to the country's scarce water supply in the north and south east sides would have a substantial impact on livestock productivity and might threaten food security. High land areas have recently been at risk from drought, and patterns indicate that Ethiopia has seen an increase in this risk. The country's annual rainfall has varied greatly, indicating that huge seasonal anomalies in rainfall are a crucial factor in the intensity of the food supply. To manage irrigation effectively, it is necessary to estimate the crop water requirements for various crops at various management levels in order to achieve optimal water resource usage. Using the FAO CROPWAT 8.0 computer simulation model, the amount of water needed by various crops in the Addis Zemen District was determined. The goal of the simulation study was to calculate how much water would be needed to irrigate 13 different crops. Using CROPWAT 8.0, crop evapotranspiration (ET_C) and reference crop evapotranspiration (ET_O) were calculated for each crop. This study demonstrated the use of the CROPWAT model for estimating crop irrigation requirements for efficient management of water resources.

Key words: CROPWAT 8.0, Addis zemen district, Irrigation, Crop water requirement, Reference evapotranspiration (ET_o)

1. INTRODUCTION

To support the growth of irrigation agriculture, water is one of the primary inputs in agriculture. Effective management of an irrigation system is crucial because irrigated agriculture contributes significantly to food security, the elimination of poverty, and economic growth [1]. To improve water management and solve related issues, comprehensive irrigation water management techniques are required[11]. Ethiopia's economy depends heavily on agriculture, yet the majority of the country's cropland is farmed using a rain-fed technique [2].

Ethiopia has a lot of water resources from precipitation, surface runoff, and underground sources, but for the past 40 years, it has experienced severe drought and significant geographical and temporal water resource fluctuations [3]. Crop production failures occur in Ethiopia because of the great geographical and temporal variability of rainfall. The population is expanding quickly and is predicted to do so indefinitely, which inexorably raises the need for food [4]. Ethiopian farmers must contend with issues like intense competition for water, erratic rainfall, a lack of resources, and climate change. As a result of realizing these difficulties, the Ethiopian government started making significant investments in the construction of irrigation infrastructure over the past 20 years.

Crop water requirement is influenced by weather, crop type, soil type, growing seasons, and frequency of crop output [5]. Crop Coefficient (Kc) and potential evapotranspiration value are two factors influencing the value of the crop water need. (ETo). Evapotranspiration is the combination of two distinct processes whereby water is lost through evaporation from the soil surface and on the other hand, by transpiration from a plant.

When determining a crop's water requirements, a model must be tested before being used in a new environment. With various cropping patterns, CROPWAT 8.0 and CLIMWAT 2 facilitates the estimate of crop evapotranspiration, irrigation schedules, and agricultural water requirements for irrigation planning and management. According to reports, the Penman-Monteith approach [6] often produces more accurate reference evapotranspiration (ETo) estimations under a variety of climatic conditions [7]. Under the same meteorological conditions, various crops require different amounts of water. One of the key elements used in irrigation planning, design, and operation is the estimation of crop water requirement (ETc). [8] provide thorough analyses of the techniques often employed to calculate evapotranspiration and estimate agricultural water requirements. Using the FAO-compiled software Cropwat 8.0 is one method of calculating the crop water requirement [9].

2. METHODOLOGY

The decision-support tool CROPWAT 8.0 with CLIMWAT 2 is used for this study. CROPWAT 8.0 is a software which is created by the FAO to calculate crop water requirements (CWR) by using climate data, rainfall, crop andsoil data. Irrigation water requirement (IR), Reference evapotranspiration (ETo) and irrigation scheduling can also be calculated using the software. This program incorporates generic data for diverse crop characteristics, the local climate, and soil characteristics to enhance irrigation schedules and computation of scheme water supply for varied crop patterns under irrigated and rain-fed situations. The data needed for the CROPWAT software are data on rainfall, climate, soil, and crops.

The CROPWAT tool uses the CLIMWAT 2.0 meteorological database, which enables the computation of IRs for various crops for a variety of climatological stations across the world. CLIMWAT includes seven long-term monthly maximum and minimum temperatures (in degrees Celsius), wind speed (in kilometres per hour), mean relative humidity (in percentage), sunshine hours (in hours), rainfall data (in millimetres), and effective rainfall (mm). Root depth, crop coefficient, critical depletion, yield responses factor, and duration of plant growth stages are some of the crop data that is incorporated to the CROPWAT program from the FAO Manual 56. Dates for planting is determined using the Ethiopian Metrological Agency's manual, which divides the year into wet and dry seasons. The FAO CROPWAT 8.0 model's soil parameters provide specific information on the soil close to the climate station, such as the maximum rate of rainwater infiltration and rooting depth. This study employes the soil conservation (S. C.) method developed by the United States Department of Agriculture (USID).

2.1 Location of Study Area

The Shine River, the upper basin of Lake Tana, and the Rib watershed are both in the South Gondar Zone of Ethiopia's Amhara region. The study area (36 km2) was conducted on these two rivers. It is located 67 kilometers to the northwest of Debre Tabor and 747 kilometers north of Addis Abeba, the country's capital. The location of the area, which is on average 1975 meters above sea level, is 13° 38'24.84"N and 36° 63'41.44"E, respectively. The mean daily maximum and minimum rainfall in this area, according to the Ethiopian Meteorology Agency, are approximately 150 and 5mm, respectively.The research area's average maximum and lowest temperatures are 26° C and 14° C, respectively, while the overall average temperature is 20° C. One of the obstacles to this region's economic growth and agricultural output is the lack of water. The research region's natural land use and cover is a plain, unpolluted environment that is appropriate for irrigation activities in agriculture. In this aspect, water management has become a crucial step that must be taken.

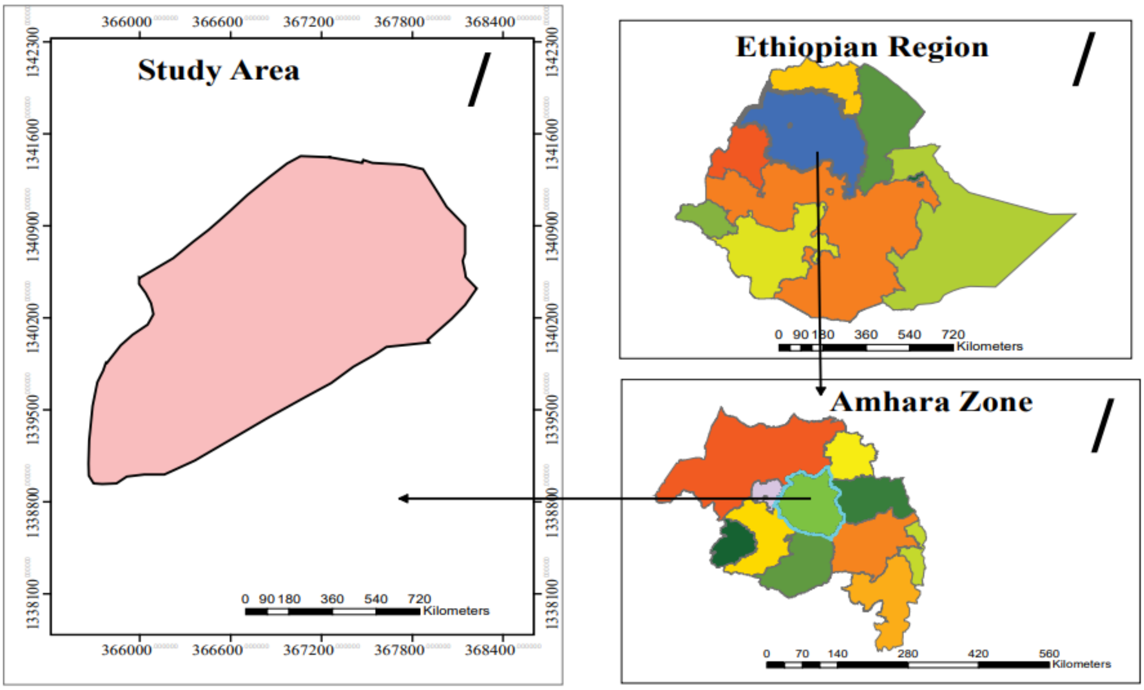

Fig.1 Location of the study area

2.2 Crop water requirement

The amount of water needed for crops is determined by the rate of Evapotranspiration in mm/day and is equal to the amount of water lost from a cropped field by evapotranspiration. Crop evapotranspiration (ETc), which may be computed using the following equation, is used to estimate CWR.

$ET_c = K_c \times ET_o$

Kc stands for crop coefficient. The albedo (reflectance) of the crop-soil surface, crop height, canopy resistance, and evaporation from the soil are the four key characteristics that set the crop apart from reference grass. This ratio measures the crop's ETc to ETo and integrates their impacts. The crop's Kc will change over the growing period, which can be classified into four distinct stages: initial stages, crop development, mid-season, and late season, as a result of ET variations over the growth stages.
Based on FAO Irrigation and Drainage Paper 56 [6], the reference evapotranspiration ETo is estimated by the FAO Penman- Monteith method using the decision support tool CROPWAT 8.0. The FAO CROPWAT program [6] includes methods for calculating crop water requirements and reference crop evapotranspiration. It also enables modelling of crop consumption of water under various climatic, crop, and soil conditions (www.fao.org).

2.3. Soil data

Red loamy soil makes up the soil type in this area. The software requires a few general soil data points, including total soil moisture that is currently available, the maximum rate of rain infiltration, the maximum depth of roots, initial soil moisture depletion, and initial soil moisture that is currently accessible. This data was taken from FAO Manual 56.

3. RESULTS AND DISCUSSION

3.1 Reference evapotranspiration (ETo)

The Reference Evapotranspiration (ETo) for each month of the year is shown in the following table (I). Due to differences in temperature, humidity, sunshine hours and wind speed, the month of March has the highest reference evapotranspiration (5.23 mm/day), and the months of August and July have the lowest reference evapotranspiration 2.72 mm/day and 2.73 mm/day respectively. In the dry season, low relative humidity combined with high temperatures resulted in increased evapotranspiration over this period of a year. Inversely, the high frequency of rainfall paired with high relative humidity and relatively low temperatures may be the cause of the low ETo values during the rainy season. Because of the climatic factors including temperatures, rainfall, wind, solar radiation and relative humidity of the air have an impact on the trend of ETo, ETo is a climatic parameter. When these factors are changed, it is discovered that ETo varies significantly throughout and between seasons. The findings are in line with those of Adeniran et al. (Adeniran et al., 2010), who found that ETo ranged from being lowest at the height of the rainy season to being highest at the height of the dry season.

Table I: Long term monthly average climatic data of the study district

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	km/day hours	MJ/m²/day	mm/day
January	9.9	27.8	52.2	164.2	8.2	19.0	4.28
February	10.9	29.5	49.0	164.2	9.2	21.8	4.96
March	11.9	29.8	46.9	146.9	9.1	23.0	5.23
April	12.1	29.3	47.1	129.6	8.3	22.4	5.06
May	12.1	29.5	56.2	164.2	6.8	19.8	4.86
June	12.0	26.9	70.2	164.2	5.6	17.7	4.03
July	12.2	23.8	80.0	103.7	2.1	12.5	2.73
August	12.0	24.0	80.0	86.4	2.3	12.9	2.72
September	11.6	25.2	75.1	103.7	6.7	19.4	3.74
October	10.8	27.2	65.1	138.2	8.4	20.9	4.26
November	10.4	27.3	60.0	138.2	9.1	20.4	4.14
December	10.3	27.6	56.0	121.0	8.7	19.1	3.88
Average	11.3	27.3	61	135	7.0	19.1	4.16

3.2 Rainfall Data

Based on data in Table II, the amount of rainfall in a year at the study area was 1032.0 mm, this is the sum of the rainfall value of each month. The peak rainy season was 355.0 mm which occurred in July while the lowest rainfall was 0.0 mm occurred in march.

The value of effective rain is considered to be 0, as the method used in the study does not use rainfall for the calculation of irrigation water requirement.

Table II: Rainfall and Effective Rainfall

Month	Rain (mm)	Eff Rain (mm)
January	6.0	0.0
February	2.0	0.0
March	0.0	0.0
April	11.0	0.0
May	32.0	0.0
June	110.0	0.0
July	355.0	0.0
August	319.0	0.0
September	129.0	0.0
October	51.0	0.0
November	13.0	0.0
December	4.0	0.0
Total	1032.0	0.0

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Based on the classification of the climatic type the study area experienced wet months for four months in a row from June –September (rainfall greater than 100mm) while there was an experience of five consecutive dry months from January up toMay (rainfall less than 100mm).

C. Crop Coefficient (K_c)

Crop coefficients (Kc) data were required in order to calculate the crop water requirement. Each type of crop has a different Kc value. The Kc values utilized in this investigation were derived from Table 12 of FAO Irrigation and Drainage Paper No. 56. The initial phase, development phase, mid-season phase, and late phase are the four phases that make up the growth stage in general. While only three phases which are initial phase, middle phase, and the late phaseare known to be the value of Kc in the FAO book. In Table III, the Kc values for each crop are listed.

Table III: Values of K_c for Different Crop

Crop type	Total stage date (Days)	K_c Values		
		Initial	Mid	Late
Tomato	145	0.6	1.15	0.8
Soybean	85	0.4	1.15	0.5
Potato	130	0.5	1.15	0.75
Maize	125	0.3	1.2	0.35
Sunflower	130	0.35	1.15	0.35
Cotton	195	0.35	1.20	0.60
Barley	120	0.30	1.15	0.25
Pulses	110	0.40	1.15	0.35
Sweet Peppers	125	0.60	1.05	0.90
Cabbage	165	0.70	1.05	0.95
Tobacco	110	0.50	1.15	0.80
Green beans	90	0.50	1.05	0.90
Dry beans	110	0.40	1.15	0.35

The Kc value in the development phase is believed to be the same as the Kc value in the mid-season phase because this phase's Kc value falls between the starting phase and the mid-season phase, with midseason having the greatest Kc value. Kc values are essentially consistent at 1.15 for all crops during the mid-season period. It shows that the amount of crop water required in the late-season phase is decreasing till the final stage of the growing season as the value of Kc drops from the end of the mid-season phase until the end of the planting period. When harvesting, the Kc value was 0.25 at its lowest.

TableIV: Yield response factor

Crop Type	Crop height (m)	Yield response factor				
		Initial	Development	Mid	Late	total
Tomato	0.6	0.5	0.6	1.1	0.8	1.05
Soybean	0.6	0.4	0.8	1.0	0.4	0.85
Potato	0.6	0.45	0.8	0.8	0.3	1.1
Maize	2.00	0.4	0.40	1.30	0.50	1.25
Sunflower	2.00	0.4	0.6	0.80	0.80	0.95
Cotton	1.3	0.20	0.50	0.50	0.25	0.85
Barley	1.00	0.20	0.60	0.50	0.40	1.00
Pulses	0.40	0.4	0.60	0.80	0.60	0.80
Sweet Peppers	0.70	1.40	0.60	1.20	0.60	1.10
Cabbage	0.4	0.20	0.40	0.45	0.60	0.95
Tobacco	1.2	0.40	1.00	1.00	0.50	0.90

Green beans	0.4	0.20	1.10	0.75	0.40	1.15
Dry beans	0.40	0.20	0.60	1.00	0.20	1.15

Table V: Rooting depth at different stages ***Table VI: Critical depletion fraction***

Crop Name	Rooting depth for different crops		
	Initial	Mid	Late
Tomato	0.25	1.00	1.00
Soybean	0.30	1.00	1.00
Potato	0.30	0.60	0.60
Maize	0.30	1.00	1.00
Sunflower	0.3	1.30	1.30
Cotton	0.30	1.40	1.40
Barley	0.30	1.10	1.10
Pulses	0.30	1.00	1.00
Sweet Peppers	0.25	0.80	0.80
Cabbage	0.25	0.50	0.50
Tobacco	0.25	0.80	0.80
Green beans	0.30	0.70	0.70
Dry beans	0.30	0.90	0.90

3.3. Crop Water Requirement

The amount of water lost by crops through evapotranspiration (ETc) equals the crop's required amount of water. In other word, The amount of plant evapotranspiration is valued as the same as the crop's water requirement. Table VII shows the value of the decadal crop water requirements for each crop. It is crucial to note that the decadal crop water requirement refers to the amount of water needed for ten days of irrigation.

Crop Name	Critical depletion fraction value		
	Initial	Mid	Late
Tomato	0.30	0.40	0.50
Soybean	0.50	0.60	0.90
Potato	0.25	0.30	0.50
Maize	0.55	0.55	0.80
Sunflower	0.45	0.50	0.80
Cotton	0.65	0.65	0.90
Barley	0.55	0.55	0.90
Pulses	0.60	0.60	0.80
Sweet Peppers	0.20	0.30	0.50
Cabbage	0.45	0.45	0.45
Tobacco	0.40	0.50	0.65
Green beans	0.45	0.45	0.60
Dry beans	0.45	0.45	0.60

Table VII: Crop water requirement of each crop

Crop Name	Planting date	Harvest date	ETc mm/dec	Irrigation Req. mm/dec
Tomato	13/04	03/09	471.5	471.5
Soybean	13/04	06/07	337.4	337.4
Potato	13/04	20/08	426.5	426.5
Maize	13/04	15/08	380.7	380.7
Sunflower	13/04	20/08	376.1	376.1
Cotton	13/04	24/10	587.1	587.1
Barley	13/04	10/08	392.1	392.1
Pulses	13/04	31/07	361.2	361.2
Sweet Peppers	13/04	15/07	397.5	397.5
Cabbage	13/04	24/09	527.5	527.5
Tobacco	13/04	31/07	387.2	387.2
Green beans	13/04	11/07	316.3	316.3
Dry beans	13/04	31/07	361.2	361.2

Of the above crops, cotton has the highest crop water requirement. The growing season's water demand for Cotton crop is 587.1 mm/dec. Cotton's crop water requirements rise from the early to the late stages of development; they begin to decline from the mid to the late stages; they rise again during the first three decades of the late season in September; and they reach their lowest point at harvest in the final two decades of the late stages in October. For cotton crop at the development phase, which begins in the third decade of June, is when crops require the most water, with a requirement of 38.7 mm/dec, while the late phase, when water demand was lowest, had a requirement of 10.3 mm/dec.

For the majority of crops, the midseason phase, which is the third decade of June, is when the greatest crop water requirement occurs. While the late-season phase has the lowest water demand value because the plants are mature and require less water, the highest water demand value occurs during this phase. The phase of the growing season leading up to the late season is when the plants demand the most water since fruit development requires the most energy. The value of water demand is reduced because of the process of fruit ripening. The growth of the crop has been maximized already and there will not be further development as the crops approach the harvesting phase.

4. CONCLUSION

The study's findings improve our knowledge of the various crops' water requirements in the study district, which will help us better manage our water resources and increase production by shaping our policies. For the most accurate estimation of crop water requirements, scientific technologies like CROPWAT and CLIMWAT are used. The findings of this study can be utilized as a guide for farmers to allocate irrigation water for the various crops studied here as well as by water resource planners for future planning, helping to save water in fulfilling the crop water demand. These findings can be applied to the study district to maximize crop production and use water as efficiently as possible.

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