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RESEARCH ARTICLE

USING THE CROPWAT 8.0 MODEL TO CALCULATE MAIZE WATER REQUIREMENTS IN JOWHAR-SOMALIA

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ABSTRACT

In this study, the CROPWAT 8.0 model was used to calculate the water needs of maize crops in Jowhar. The United Nations Food Agriculture Organization's decision-support computer software, CROPWAT 8.0, is used to calculate ETo, effective rainfall, crop water need (ETc), and irrigation requirements. Climate, soil, and crop data were obtained using FAO CLIMATWAT 2.0. ETo was calculated as 4.75 mm per day on a yearly basis. Maize irrigation need was predicted to be 242.2 mm during the full growing season, whereas effective rainfall to meet maize crop water requirements was determined to be 203.3 mm. Total maize evapotranspiration was 403.7 mm, with net and gross irrigation calculated to be 248.3 and 354.7 mm, respectively. Field experiments should be carried out throughout the same season and cropping patterns to check the precision of the crop water requirement prediction.

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INTRODUCTION

Water irrigation resources are depleting on a daily basis, and shortages have been reported in many parts of the world. Agriculture is the major consumer of water in Somalia, and significant effort must be put into its optimal usage (Surendran *et al*., 2015). Irrigation is an artificial method of giving water to crops, sometimes complementing rainwater, when rainfall alone is insufficient for promoting crop growth and maximum yield production (Waller and Yitayew 2015). Water is the most significant and critical element in agriculture, and as the climate changes, the demand to use efficient water for irrigation for crops grows. The water need of the plant can be determined using the estimation approach, which equals the potential for evapotranspiration value (ETo) multiplied by the crop coefficient (Kc). Crop water requirements vary according to climatic circumstances, crop area and type, soil type, growing seasons, and crop production frequencies (FAO, 2009; George *et al*., 2000). The Food and Agriculture Organization (FAO) created the CROPWAT software application to help irrigation engineers and agronomists execute standard calculations for water irrigation studies, as well as manage and build irrigation systems (Ewaid *et al*., 2019). The CROPWAT 8.0 model is a type of irrigation software that uses the Penman-Monteith method to calculate reference evapotranspiration. This model can also be used to estimate future irrigation water needs (Sunil *et al*., 2021; Mana *et al*., 2023). The primary functions of CROPWAT include calculating reference evapotranspiration, crop water requirements, and crop irrigation requirements and establish irrigation schedules for various management situations and water supply schemes. Somalia's climate is predominantly arid to semi-arid, with an average yearly daytime temperature of 27 ºC. The annual precipitation average is 282 mm (Omar *et al*., 2022).Somalia has one of the most significant inter-annual rainfall changes of African country, and this variability has the greatest impact on pastoral and agro-pastoral production systems. The distribution of rainfall is bimodal. The wet seasons are Gu (April to June), which receives the highest rainfall, and Deyr (October to November). The dry seasons are Jilal (December–March) and Hagaa (July–September) (Muchiri, 2007). According to SWALIM and FAO's research on Somali climate, there is a greater water imbalance in Somalia: yearly potential evapotranspiration (PET) exceeds annual precipitation, indicating that crops are under water stress throughout the canopy development stage (Ibrahim, 2023). Somalia's agriculture is mostly rain-fed, except that farmers living along two rivers, Shabelle and Jubba, use river water to irrigate their crops, and some farmers living far from rivers irrigate their crops with groundwater accessible through boreholes and wells (Ibrahim *et al*., 2020). Maize (Zea mays L.) is one of the most significant crops in the world, second only to wheat and rice in terms of overall production. Maize is grown all over the world under a variety of climatic circumstances. The United States is the world's largest producer of maize, followed by China, Brazil, Mexico, Argentina, and India (Thimme *et al*., 2013). The southern region of Somalia, particularly the Shabelle and Jubba river valleys, is the principal producer of maize. Maize is farmed in Jowhar using rainfall and a range of irrigation techniques, including floods and modern irrigation. The main objective of this research is using the FAO CROPWAT 8.0 model version to estimate the crop and irrigation water requirements of maize in Jowhar and develop an irrigation schedule.

MATERIALS AND METHODS

Study area: Jowhar is a town in southern Somalia, known as the capital of the Hirshabelle state and the Middle Shabelle region. It is located along the Shebelle River, approximately 90 kilometers (50 miles) north of the Somali capital of Mogadishu. It has fertile soil. The study area is located at 2.76°N and 45.5°E, with an elevation of 108 m. Jowhar has an arid and semi-arid climate, with annual maximum, minimum, and mean temperatures of 33.1°C, 21.8°C, and 27.21°C, respectively, and 492 mm of rainfall (Muchiri, 2007). The rainiest season lasts from April to June, and the shortest season lasts from October to November. The soil is black-clay, with crops such as rice, maize, sesame, sugarcane, citrus and other fruits are grown. Most crops are irrigation and rainfall dependent (Ibrahim *et al*., 2020).

Datacollection: In this research, we used CROPWAT 8.0 to determine agricultural water requirements and effective rainfall. This calculation requires climate data, rain data, crop data, and soil data. The study employed climate, soil,rainfall and crop data from the FAO CLIMWAT database between 1975 and 2006, as meteorology stations in the study area did not provide ready data. CROPWAT uses climate variables such as maximum and minimum temperatures, humidity, wind speed, and sunlight hours to calculate radiation and ETo. Crop data, including the crop coefficient, critical depletion, and yield response factors. Soil data, including maximum infiltration rate, rooting depth, and moisture depletion.

CROPWAT: The FAO (Food and Agriculture Organization) developed CROPWAT, a decision-support tool with the following primary goals: to calculate reference evapotranspiration, crop water requirements, and irrigation needs; to develop irrigation schedules for various management scenarios; and to plan water supply. The Penman-Monteith method is used to determine reference evapotranspiration. This reference estimate of evapotranspiration is used to calculate crop water requirements and irrigation schedules. CROPWAT calculates the amount of irrigation water required at different stages of crop development throughout the growing season, either on a monthly, weekly, or cropping pattern basis in an irrigated area. Meteorological data, crop growth data, and soil data are the primary input parameters for this application. This software saves time and is easy to use. It also provides better outcomes. CROPWATT 8.0's daily prediction of evapotranspiration was calibrated by comparing it to Class A pan evaporation and evapotranspiration measured using gauges in the US. Results show that CROPWAT 8.0's evapotranspiration is reliable. CROPWAT 8.0 was based on two FAO papers on drainage and irrigation: FAO-56 "Crop Evapotranspiration Guidelines for Computing Water Requirement" and FAO-33 "Yield Response to Water" (Allen *et al*., 1998; Doorenbos *et al*., 1980).

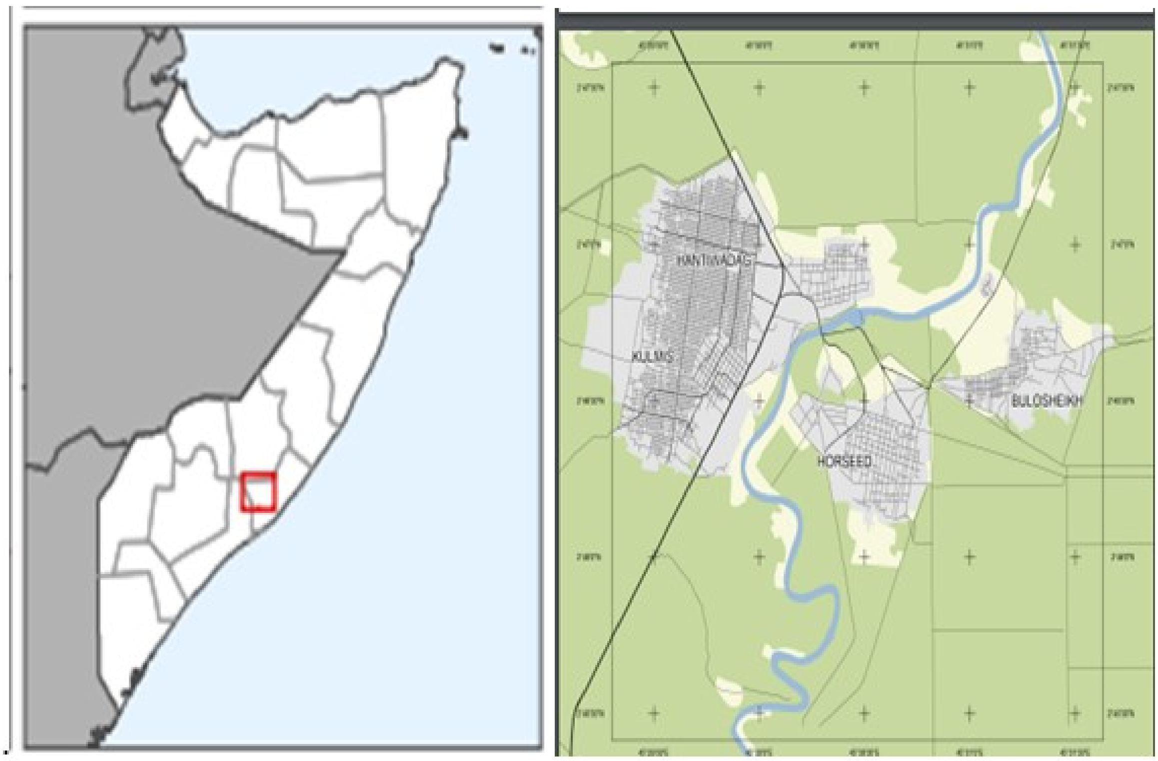

Fig.1. study area

Reference Evapotranspiration (ETo): ETo is initially calculated by the CROPWAT program using the FAO Penman-Monteith method. This method was created by combining the Penman and Monteith methods and can be used in a variety of conditions. The FAO Penman-Monteith approach has become one of the equation methods used by researchers and irrigation engineers to design irrigation schedules as well as estimate future crop and irrigation water demand (Equation 1).

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

Where,

ETo= Reference evapotranspiration, mm day^{-1}
Rn = Net radiation at the crop surface, MJ m2 day^{-1}
G = Soil heat flux density, MJ m2 day^{-1}
T = Mean daily temperature at 2m height, °C
u_2 = Wind speed at 2 m height, ms^{-1}
es = Saturation vapour pressure kPa
ea= Actual vapour pressure, kPa
es – ea = Saturation vapour pressure deficit, kPa
Δ = Slope vapour pressure curve, kPa °C^{-1}
γ = Psychometric constant kPa °C^{-1}

In the experiments, the researchers utilize grass and alfalfa crops as references since they completely cover the ground surface. In the present study, we measured ETo using climate factors such as minimum and maximum temperature, relative humidity, wind speed, daily sunshine duration, and solar radiation.

Effective Rainfall: CROPWAT software is used to compute effective rainfall. Effective rainfall is calculated using four methods: fixed percentage, dependable rainfall, empirical formula, and USDA soil conservation service. The USDA soil conservation service approach was chosen to calculate effective rainfall in the research area since it estimates the lowest possible loss (Amisha and Gohil, 2023). To calculate effective rainfall, use the equation (2, 3).

Peff = P*(125-0.2*P)/ 125 for P < = 250 mm 2

Peff = 125 +0.1 *P for P > = 250 mm 3

Crop coefficient (Kc): The crop coefficient (Kc) represents the difference in evapotranspiration between the reference grass and crop surfaces. The crop coefficient approach calculates crop evapotranspiration under standard conditions by multiplying the reference evapotranspiration (ETo) by the relevant Kc. Crop type has the greatest influence on Kc, while climate and soil evaporation have a lesser influence. Furthermore, the Kc of a crop fluctuates as it grows, affecting ground cover, crop height, and leaf area (Amisha and Gohil, 2023). The Kc of maize was updated from the FAO CROPWAT database.

Crop Evapotranspiration (ETc): Crop evapotranspiration was calculated using the crop coefficient (Kc) from the FAO crop coefficient data and ETo. To compute crop evapotranspiration, kc multiply by ETo (Equation 4) (FAO, 1977).

ETc = Kc × ETo 4

Irrigation scheduling: When rainfall is insufficient to compensate for water loss through evapotranspiration, irrigation is required. The primary purpose of irrigation is to supply the correct amount and timing of water. Irrigation scheduling is carried out under the following circumstances: critical depletion, fixed depletion irrigation, user define interval irrigation, and fixed interval irrigation for every stage. This study used fixed depletion irrigation.

RESULTS AND DISCUSSIONS

Reference Evapotranspiration (ETo): The average daily ETo for the year was calculated using historical meteorological data from Jawhar, Somalia (Table 1). The ETo was derived automatically from the data entered into the CROPWAT software. ETo was calculated at 4.75 mm per day on an annual basis. The highest ETo rates occurred in March, February, and January, with values of 5.85, 5.82, and 5.16 mm. High wind speed during dry seasons adds to increased ETo rates. There is limited literature on evapotranspiration, with only the Global FAO Database providing information.

Rainfall and Effective rainfall: Rainfall is very low in January, February, March, August, and September. Jowhar experiences the highest average rainfall of 99, 75, and 28 mm from October to December, and 100, 97, and 41 mm from April to June. Total rainfall and effective rainfall are 492.0 mm and 431.1 mm, respectively. In Afgoye, Somalia, Ibrahim (2023) reported that the total rainfall is 584 mm, with 511.4 mm of effective rainfall. Their study region has different climate features than this one (Jowhar). Figure 3 shows that rainfall and effective rainfall are roughly equal between the 'Jilaal' (December to March) and 'Xagaa' (June to September) seasons. Because rainfall is bimodal, with higher amounts during rainy months. Both FAO and SWALIM have recorded bimodal rainfall (Muchuri, 2007).

Crop Coefficient, Irrigation and Crop Water Requirement: Table 4 shows the crop and irrigation water requirements, crop coefficients, and effective rainfall values. In the initial stages, the daily average maize water use (ETc) was predicted to be quite low, between 1.46 and 1.41mm/day. However, during the development stage, the maize ETc ranged from 1.85 to 3.81 mm/day, demonstrating that crop evapotranspiration increased rapidly as the crop grew.

"During the middle stage, crop water usage reduces from 4.54 to 4.40 mm/day. In the final stage, the maize ETc decreased rapidly, reaching 1.65 mm. The crop coefficient of maize, which is used to quantify maize crop water use, is also low at the beginning and rapidly increases during the development and middle stages. The lowest and greatest maize Kc values were 0.30 in the initial stage and 1.14 in the middle stage, and Kc increased as the crop grew. Furthermore, the CROPWATT model calculates ETc every ten days. Table 4 shows what happened during the crop's growing phase. The average ETc in mm per decade is likewise consistent with the projected mm per day, demonstrating that it grows as crop stages progress.

Table 1. Annual climate data and reference crop evapotranspiration (ETo) for Jowhar, Somalia

Month	Min Temp ˚C	Max Temp ˚C	Humidity %	Wind km/day	Sun hours	Rad $Mj/m^2/day$	ETo mm/day
January	21.1	34.0	63	173	7.8	20.3	5.16
February	21.5	35.2	60	181	8.7	22.6	5.82
March	22.5	36.2	60	164	8.2	22.3	5.85
April	23.2	35.7	64	112	6.4	19.2	4.86
May	23.0	33.6	70	112	6.2	18.0	4.38
June	21.6	31.5	72	130	5.3	16.1	3.90
July	20.8	30.1	72	138	5.2	16.2	3.82
August	20.8	31.0	70	130	6.3	18.5	4.24
September	21.3	32.3	68	130	7.3	20.5	4.73
October	22.0	32.8	70	173	6.2	18.8	4.69
November	21.8	32.6	72	173	7.1	19.3	4.65
December	21.5	32.5	68	216	7.3	19.3	4.95
Average	21.8	33.1	67	153	6.8	19.3	4.75

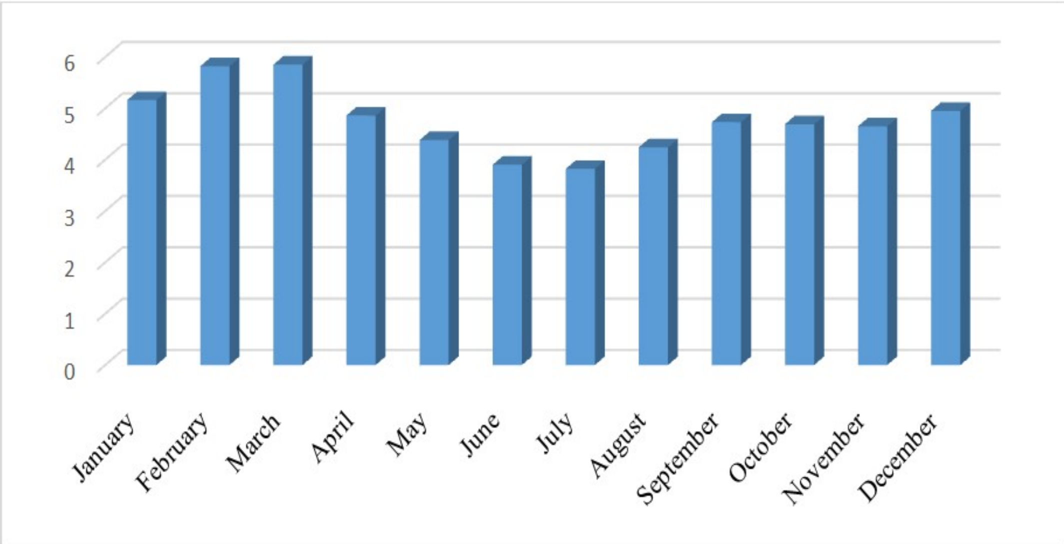

Fig.2. ETo (mm/day)

Table 2. Rainfall and effective rainfall with the USDA S.C. method

Month	Rainfall mm	Effective rainfall mm
January	0.0	0.0
February	1.0	1.0
March	14.0	13.7
April	100.0	84.0
May	97.0	81.9
June	41.0	38.3
July	19.0	18.4
August	12.0	11.8
September	6.0	5.9
October	99.0	83.3
November	75.0	66.0
December	28.0	26.7
Total	492.0	431.1

Table 3. Details of the crop required as per the CROPWAT model

Crop Name	Planting date	Harvesting date	Rooting depth	Crop growth periods				
				Initial	development	mid	late	Total
Maize	12/04	14/08	1 m	20	35	40	30	125

Throughout the growth season, the total maize ETc was estimated to be 403.7 mm, which is higher than the total yearly rainfall. The model estimates the amount of rain and irrigation water needed per millimeter during the growing season.

The lowest irrigation is 0mm in the first 40 days after planting and rapidly grows to 36.6mm in the middle and early final stages. From spring to summer, the maize plant growing in Jowhar requires 242.2 mm of irrigation, which is supplied by

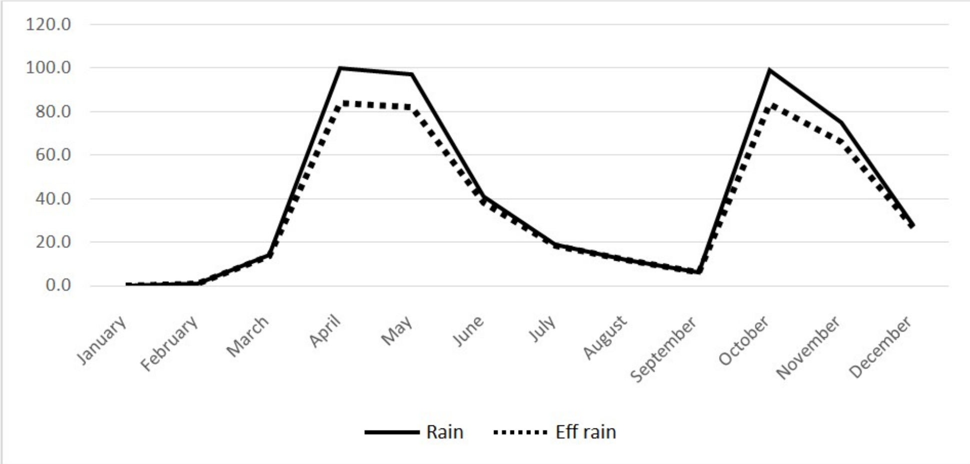

Fig.3. Rainfall and effective rainfall

Table 4. Maize crop water requirement and irrigation requirements

Month	**Decade**	**Stage**	**Kc** Coeff	**Etc** mm/day	**Etc** mm/dec	**Eff rain** mm/dec	**Irr. Req.** mm/dec
Apr	2	Init	0.30	1.46	13.1	28.3	0.0
Apr	3	Init	0.30	1.41	14.1	30.0	0.0
May	1	Deve	0.41	1.85	18.5	28.8	0.0
May	2	Deve	0.65	2.85	28.5	29.3	0.0
May	3	Deve	0.90	3.81	41.9	23.8	18.1
Jun	1	Mid	1.12	4.54	45.4	16.9	28.5
Jun	2	Mid	1.14	4.46	44.6	11.7	32.9
Jun	3	Mid	1.14	4.43	44.3	9.8	34.4
Jul	1	Mid	1.14	4.40	44.0	8.0	36.0
Jul	2	Late	1.10	4.21	42.1	5.5	36.6
Jul	3	Late	0.85	3.37	37.1	5.0	32.1
Aug	1	Late	0.57	2.36	23.6	4.7	18.9
Aug	2	Late	0.39	1.65	6.6	1.6	4.6
Total					**403.7**	**203.3**	**242.2**

Table 5. Irrigation schedule

Date	**Day**	**Stage**	**Rain** Mm	**Ks** fract.	**Eta** %	**Depl** %	**Net Irr** Mm	**Deficit** mm	**Loss** mm	**Gr. Irr** mm	**Flow** l/s/ha
31 May	50	Dev	0.0	1.00	100	22	**41.6**	0.0	0.0	**59.4**	0.14
14 Jun	64	Mid	0.0	1.00	100	21	**42.6**	0.0	0.0	**60.9**	0.50
26 Jun	76	Mid	0.0	1.00	100	21	**42.2**	0.0	0.0	**60.3**	0.58
7 Jul	87	Mid	4.2	1.00	100	20	**40.2**	0.0	0.0	**57.4**	0.60
18 Jul	98	End	0.0	1.00	100	21	**41.3**	0.0	0.0	**58.9**	0.62
31 Jul	111	End	0.0	1.00	100	20	**40.4**	0.0	0.0	**57.8**	0.51
14 Aug	End	End	0.0	1.00	0	11					
							248.3			**354.7**	

203.3 mm of effective rainwater that falls during this period, demonstrating that the irrigation amount is also less than ETc (Table 4). In Ethiopia Tefera and Mitku (2017) reported that the total maize crop evapotranspiration reached 502.1 mm/dec, which higher than the amount found in this study. However, the growing period and the climate characteristics of their study area differ from this study area (Jowhar).

Irrigation schedule: The total mean of gross irrigation has been estimated at 354.7 mm, while the overall mean of net irrigation is approximately 248.3 mm, indicating that irrigation efficiency is 70%. Net irrigation (NIR) refers to the amount of water needed by a crop to achieve its evapotranspiration or attain field capacity. Gross irrigation refers to the total amount of water applied to cropping fields. Climate, soil types, and cropping patterns all have an impact on net irrigation (Ewaid *et al*., 2019).

Traditional irrigation practices are mostly employed in Somalia, particularly Jowhar and other riverine farming, and river water carried by a canal that is far from the river encourages high water loss from evaporation and evapotranspiration. Using modern irrigation methods can improve water efficiency (Lu *et al*., 2019). To improve irrigation water efficiency, it is vital to utilize appropriate irrigation practices.

CONCLUSION

CROPWAT 8.0 is used to calculate ETo, effective rainfall, crop water requirement (ETc), and irrigation needs for water for maize. Climate, soil, and crop data were gathered from the FAO CLIMATWAT 2.0. ETo was calculated at 4.75 mm per day on an annual basis. Maize irrigation demand was estimated to be 242.2 mm over the entire growing season, and effective rainfall to meet the maize crop water requirement was calculated to be 203.3 mm. Total maize evapotranspiration was 403.7 mm, with net and gross irrigation estimated to be 248.3 mm and 354.7 mm, respectively. The results were approximated using computer programs and secondary data rather than gathered from field experiments. Therefore, it is required to conduct an experimental investigation to test or evaluate the reliability of these data, as well as whether the model overestimates crop water requirement.

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