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# Crop Water Requirement Estimation by Using Cropwat Model: A Case Study of Abrajit Earthen Dam Command Area, East Gojjam, Ethiopia

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**Abstract:** Currently, the Ethiopian government has launched an extensive irrigation system in the country and is constructing various small earthen dams in each woreda. But there is a gap between the water potential that we have and the water needs for the command area that has not been adequately studied. To solve this problem, these researchers are trying to compare the potential of the existing dams and the water needs of the exiting command areas using a CROPWAT model. The main crops cultivated are tefe, wheat, corn, paper, cabbage, corn, etc. However, for this work, the researcher only admitted that the whole area was suitable for wheat because of suitability, need, ease of irrigation and agricultural practice as well of the dominant irrigation type of the community should be used. The gross area of the project area covers a total of 6,456 hectares. Of this, only 4,566 hectares of the command area has been used for agricultural purposes by the villagers of the study area, while 286 hectares of the command area is currently irrigated by Abrajit dams. From the CROPWAT software model analysis consequence we have agreed that the total artificial application of water request for the existing command area in the region at seventeen percent (70%) effectiveness is 179.5 millimeter and a net irrigation requirement of 123.1 millimeter of water. Currently, the irrigation system taking place in the study area is 77.4% of the dam's capacity. There is additional irrigation capacity in the study area that will allow 22.6% of the earth dams to be irrigated in the future without having to build an additional dam.

**Keywords:** Irrigation Demand, CROPWAT Model, Reference and Evapotranspiration of Crops, Effective Rainfall, Irrigation Planning

## 1. Introduction

Due to its rising demand in the agricultural and industrial sectors, water is becoming increasingly valuable and scarce. The population is mostly supported by agriculture, and harnessing the water resources available to support agriculture requires scientific management. Identifying the water requirements of crops is an essential component of agricultural planning. The total amount of water a crop required to grow varies dramatically from crop to crop and from growing season to growing season. The reference crop evapotranspiration (ETo), which is multiplied by the cultural factor Kc to determine the value of the water needed by the crop [2, 11, 10], is the primary parameter to be determined for predicting the water demands of the crops.

## 2. Materials and Methods

*Study Area*

The Abrajit Earthen Dam was constructed by the Amhara Water Works and Design and Supervision Enterprise. The dam was found in East Gojjam, Enagre Enawuga Wored in Abrajit Kebele. The dam was built over the seasonal Abrajit River, which is a tributary of the Abay River. The dam is located at 1039 north latitude and 3810 east longitude and is about 488 meters above mean sea level. The topography of the Abrajit Command is almost flat, with some parts being terrain and well-watered by canals The dam has a total capacity of 1,388,873 m3, with the gross operational area of the project being 8,456 ha and the current buildable operational area being 4,566 ha. The existing irrigated command area in Abrajit command is 286 ha and consists of different cropping patterns, namely wheat, cabbage and paper crops. The main crops grown in this district include wheat, cabbage, paper, tea leaves, corn, soybeans and potatoes. However, for this work, the researcher only admitted that the entire area should be used for wheat due to suitability, need, ease of irrigation and farming practices, and the predominant irrigation style of the community. The climate in the districts varies between 8°C and 25°C. The land of the Abrajit Command is simple and favorable for productivity. There is one type of soil profile in the command area, namely the "Eutric Fluvisols" soil type, which consists predominantly of clay with varying infiltration capacity and soil depth. The soils are ideal for growing wheat, rice, soybeans, vegetables, etc.

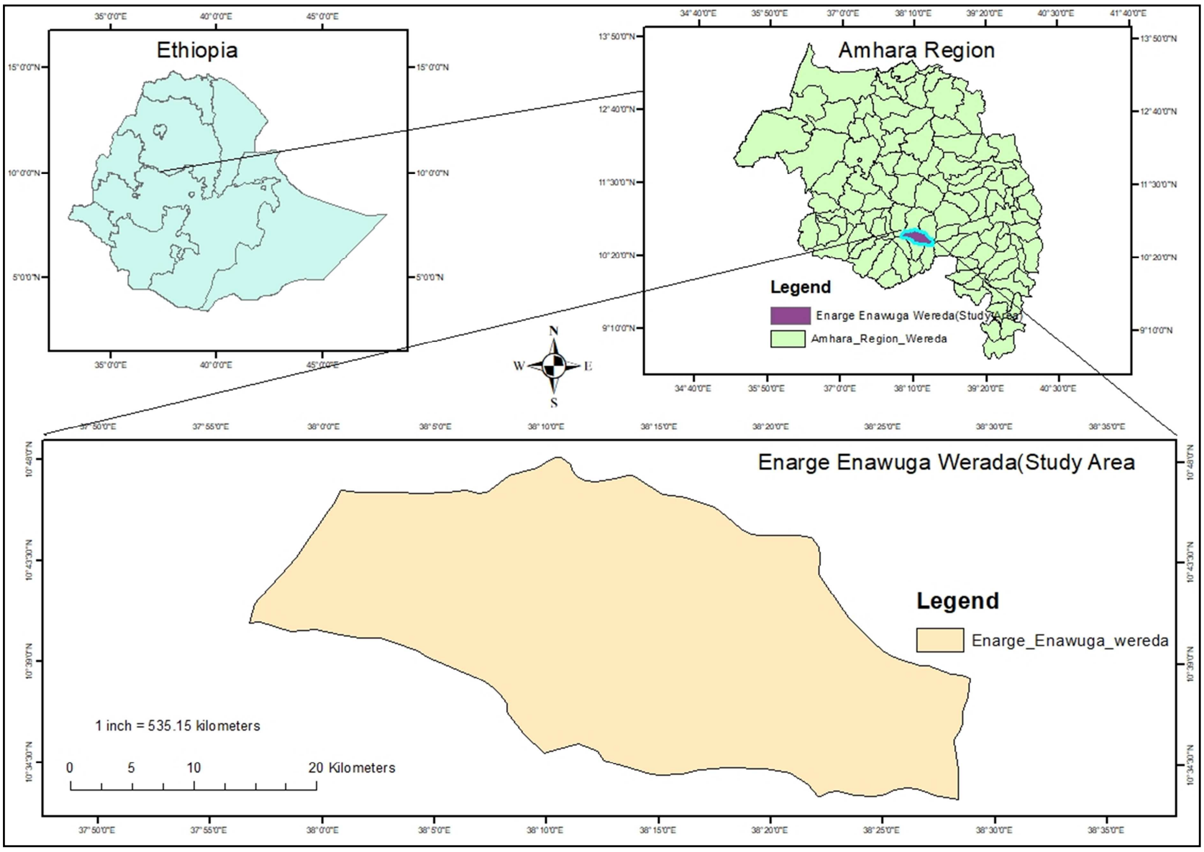



***Figure 1.*** *Location Map of Abrajit Command Area.*

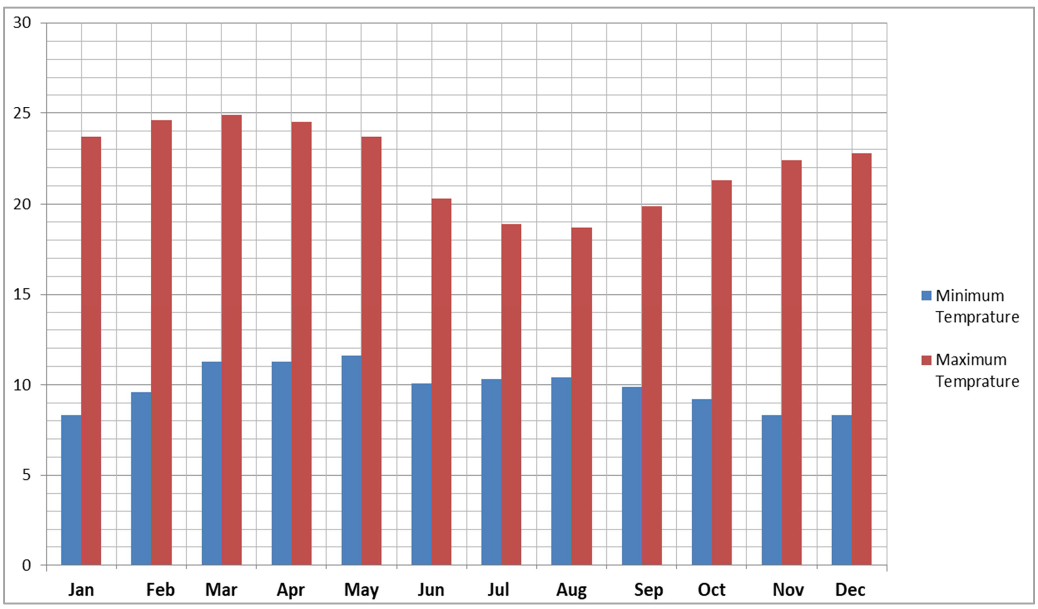



***Figure 2.*** *Min and Max Temperatures of the Study Area.*

## 3. Data Requirements

Precipitation data, climate data, harvest data, and soil data were the key resources and tools the researcher used to run the CROPWAT 8.0 model software for this study [15]. The site's coordinates and elevation are included with seven long-term monthly climate parameters in the CLIMWAT 2.0 software. The monthly high and low temperatures (C), the wind speed (km/h), the mean relative humidity (%), the sunshine hours (h), the precipitation data (mm), and the effective precipitation amount (mm) [7] are the variables. The CROPWAT program incorporates harvest information for wheat, such as yelling depth, crop factor, critical reduction, yield response factor, and length of plant growth phases [7]. Details are provided by the soil parameters acquired from the FAO CROPWAT 8.0 model. A. The entirety of the accessible moisture content, the initial moisture degradation, the extreme rain penetration rate, and the maximum depth of precipitation.

B. The total accessible moisture content, the starting point of moisture degradation, and the maximum depth of precipitation. 2.3 Model selection The Organization's Department of Land and Water Development of the Food and Agriculture Organization of the United Nations established the decision support program that is called the CROPWAT model [1, 3, 6, 10]. It is an empirical process culture model that is used to figure out the irrigation and water requirements for crops, enabling for the development of irrigation schedules under various management scenarios and the computation of water supply systems for various crop patterns, climatic circumstances, and crop input data. Next to; Based on daily calculations of the soil water balance, the program can also be used to forecast crop performance under both rainy and irrigated situations. In order to construct water supply plans to accommodate different cropping patterns within a multi-cultivar irrigation system and to assess farmers' irrigation practices on both a small-scale and a large-scale [10, 13, 18]. The program's decreased data needs as well as its simplicity and convenience of use are advantages of CROPWAT. The model is a strong simulation tool that supports irrigation management and planning by analyzing intricate interactions between agricultural characteristics (crop, climate, and soil). This model is widely used in the field of water management throughout the world because it is essential for calculating crop evapotranspiration, irrigation planning, and agricultural water demand with various cropping patterns [19, 21].

## 4. Framework Conceptual and Model Development Data

The Penman-Monteith method was used to calculate the ETo for each year using the climate information from the computer program CROPWAT8 [1]. If other individuals want to use Window's data for computations, the software also needs to include additional ways of calculating the operational precipitation. [14, 11, 7].

## 5. Effective Rainfall

One of the four methods listed in CROPWAT 8.0 (Fixed Percentage, Reliable Rainfall, Empirical Formula, USDA Soil Protection Service) can be used to account for losses due to runoff or infiltration.

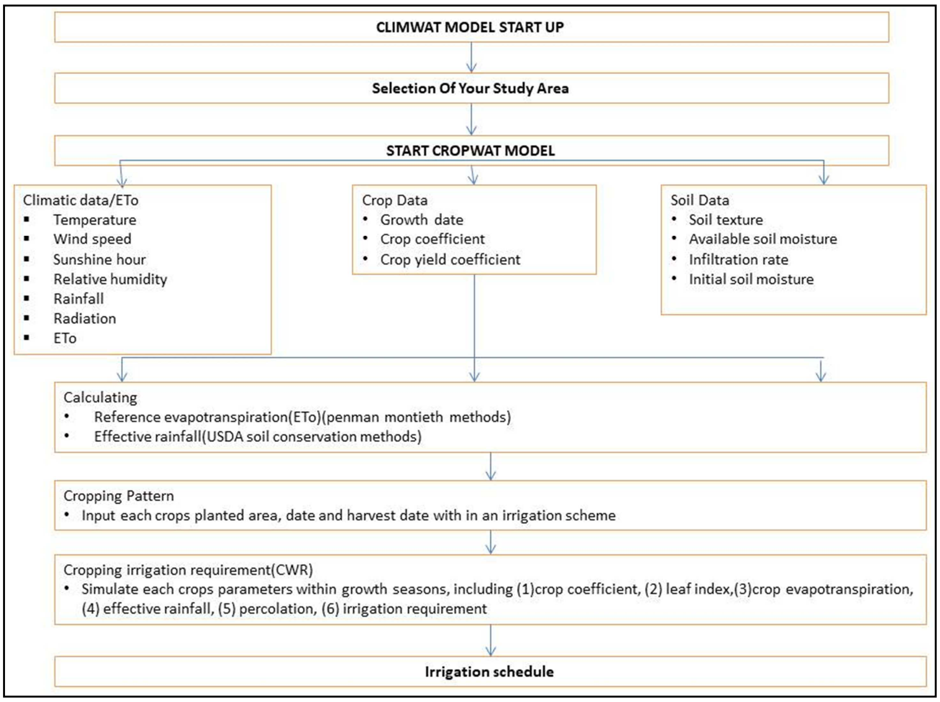



***Figure 3.*** *Working principles of CROPWAT-8 MODEL.*

Calculation of the reference evapotranspiration (ETo) The reference evapotranspiration ETo was calculated according to the FAO Penman-Monteith method using the FAO-developed decision support software CROPWAT 8.0 based on the FAO Irrigation and Drainage Paper 56 called FAO56. FAO56 has adopted the Penman Montieth method as the global standard for estimating ETo from meteorological data. The Penman-Monteith equation incorporated in the CROPWAT program is expressed by the following equation. [10, 12, 20].

$$\frac{0.408\Delta(R_n-G)+\gamma\frac{900}{T+273}U_2(e_s-e_a)}{\Delta+\gamma(1+0.34U_2)} \quad (1)$$

Where: ET0 is the reference evapotranspiration (mm day1), T, G and Rn are the daily mean temperature oC at 2 m altitude, the soil heat flux density (MJ m-2 day-1) and the net radiation value at the plant surface (MJ m-2 days -1) and u2, (esea), D and c respectively represent the wind speed at 2 m height (m s-1), the saturated vapor pressure at the given temperature (kPa), the actual vapor pressure (kPa) and the saturated vapor pressure deficit (kPa)., slope of the saturation vapor pressure curve (Pa/oC) or psychometric constant (kPa/oC) [1]. [As the ET0 is a crucial component of the water cycle, it will have significant effects on ecosystem models, water use by agriculture, wet/dry conditions, and runoff due to precipitation estimation, according to Yin et al. (2008). The calculation of ET0 requires a number of equations. The FAO's Penman-Monteith approach, one of the most precise formulae, was used to determine the ET0, and the Cropwat8 model is based on it. [10, 12, 20].

*Calculation of Total Available Soil Moisture (TAW):*

To calculate the total available soil moisture for the Cropwat8 model, the formula for total available soil water (TAW) calculated from the soil permanent wilting point (PWP) and field capacity (FC) as follows must be used: [10, 4, 15].

$$\frac{(Fc-Pwp)}{100} * BD * Dz \quad (2)$$

Where: TAW is total available soil water (mm/m), FC and PWP in % on weight basis, BD is the bulk density of the soil in gm cm-3, and Dz is the maximum effective root zone depth in mm.

*Crop Water Requirement (CWR)*

Plant water requirement is the amount of water equivalent to the loss of a planted field through ET and is expressed by the ET rate in mm/day. The estimate of the CWR is derived from the evapotranspiration (ETc) of the crops, which can be calculated using the following equation:

$$ETc = Kc\ ET0 \quad (3)$$

Where Kc is the crop coefficient. It is the ratio of the crop ETc to the ET0 and represents an integration of the effects of four key traits that distinguish the crop from the reference grass and includes albedo (reflection) of the crop soil surface, plant height, canopy resistance, and evaporation from the soil. Due to the ET differences during the growth stages, the Kc value of the crop fluctuates during the development phase, which can be divided into four different phases: early stage, crop development, mid-season and late season. [10, 9, 6].

*Crop water Requirements (CU)*

The model can calculate the daily root zone water balance up to root zone depletion at the end of the day using the following equation:

$$Dr,i = Dr,i1\ (P\ ROi)\ Ii\ CRi + ETci + Dpi \quad (4)$$

where Dr,i is the water content in the root zone at the end of day i (mm), Dr,i1 is the root zone depletion at the end of day i (mm), Pi is the amount of precipitation on day (mm)., Ii is the net irrigation depth that penetrated the soil on day i (mm), and ROi is the soil's surface runoff on that day (mm). DPi is the water loss of the root zone on day i (mm), ETci is the crop's evapotranspiration on day i (mm), and Cri is the capillary rise from the water table on day i (mm). [10, 13, 21]. Watering Schedule: The watering schedule decides when and how much water should be used for irrigation. Wheat irrigation schedules are developed using the CROPWAT model, which computes ET0, CWR, and IRs**.**

# 6. Result and Discussion

### *6.1. Evapotranspiration of the Area*

The mean annual reference evapotranspiration (ETo) of the Abrajit Dam is estimated at 1241 mm. The months of February to May show relatively high values, more than 3.7mm per day, and the months of June to September show the lowest ETo. These periods coincide with the dry and rainy seasons. This gives the observed differences in meteorological parameters within one year. In the dry season, the resulting low relative humidity combined with high temperatures led to increased evapotranspiration during this period of a year. Conversely, the low ETo values in the rainy season can be attributed to the high frequency of precipitation in combination with high relative humidity and relatively low temperatures. In Abrajit, Enarge Enawuga wereda found a low ETo due to the high humidity in the study area. Since the trend of ETo is influenced by climatic factors such as temperatures, solar radiation and precipitation, and wind, relative humidity is consequently a climate parameter. With the variations in these parameters, ETo will vary greatly within and between seasons. The results agree with Adeniran et al. [17] agree, showing that ETo was lowest during the wet season peak and highest during the dry season peak.

***Table 1.*** *Evapotranspiration of the study area in mm/day for each month.*

| Month | Min Temp °C | Max Temp °C | Humidity % | Wind km/day | Sun Hours | Rad MJ/m²/day | ETo mm/day |
|---|---|---|---|---|---|---|---|
| January | 8.3 | 23.7 | 36 | 78 | 7.8 | 18.9 | 3.51 |
| February | 9.6 | 24.6 | 36 | 86 | 7.8 | 20.1 | 3.93 |
| March | 11.3 | 24.9 | 42 | 86 | 6.1 | 18.6 | 3.93 |
| April | 11.3 | 24.5 | 44 | 95 | 8.1 | 22 | 4.44 |
| May | 11.6 | 23.7 | 51 | 61 | 6 | 18.5 | 3.71 |
| June | 10.1 | 20.3 | 72 | 43 | 4.6 | 16 | 3.01 |
| July | 10.3 | 18.9 | 81 | 52 | 2.6 | 13.1 | 2.49 |
| August | 10.4 | 18.7 | 82 | 43 | 2.3 | 12.9 | 2.44 |
| September | 9.9 | 19.9 | 71 | 52 | 5 | 17 | 3.06 |
| October | 9.2 | 21.3 | 58 | 86 | 7.2 | 19.4 | 3.55 |
| November | 8.3 | 22.4 | 48 | 78 | 7.6 | 18.7 | 3.41 |
| December | 8.3 | 22.8 | 48 | 78 | 7.7 | 18.2 | 3.29 |
| Average | 9.9 | 22.1 | 56 | 70 | 6.1 | 17.8 | 3.4 |

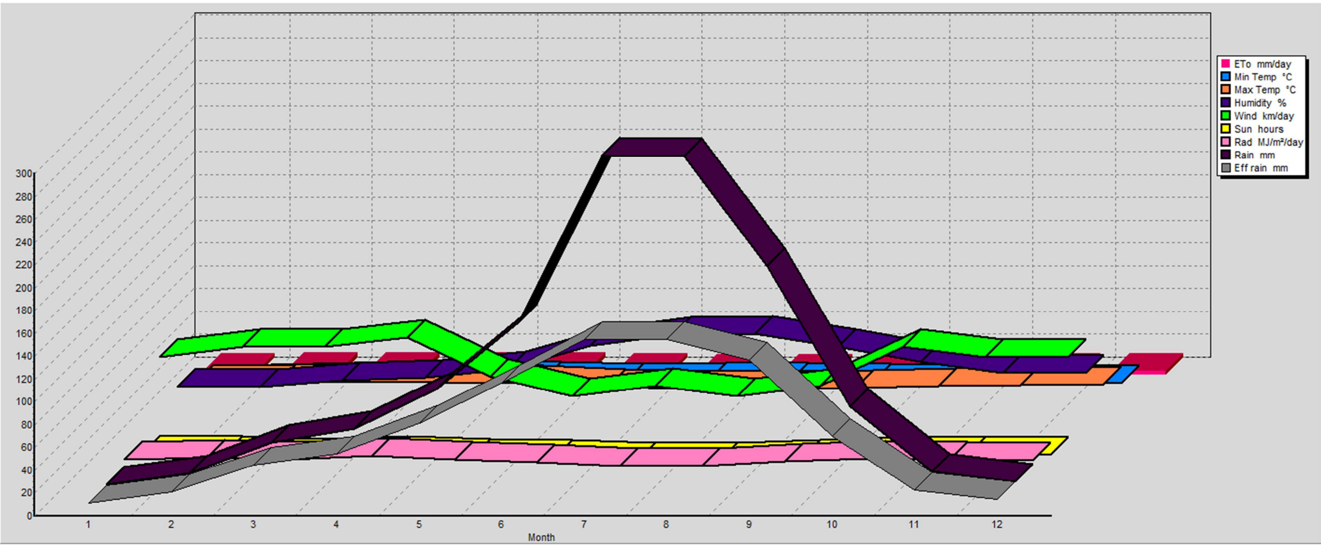



***Figure 4.*** *Climate/ ETo/ Rain chart.*

## *6.2. Crop Water Requirements of the Study Area*

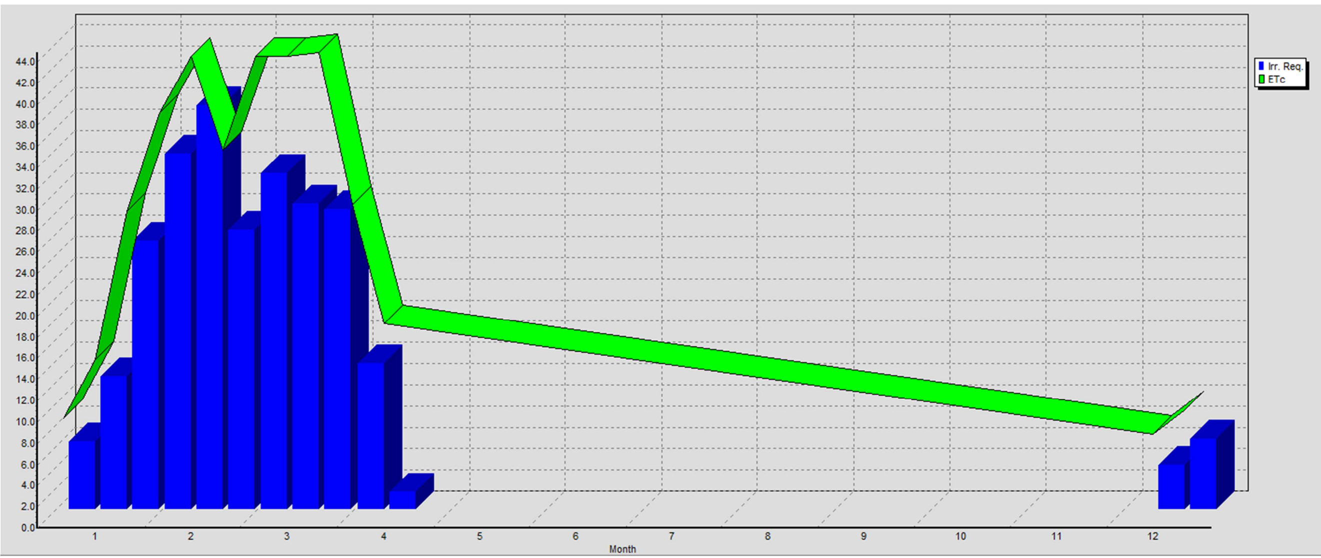



***Figure 5.*** *Crop Water Requirement Graph.*

***Table 2.*** *Crop water requirements of Abrajit command area.*

| Month | Decade | Stage | Kc coeff | ETc mm/day | ETc mm/dec | Eff rain mm/dec | Irr. Req. mm/dec |
|---|---|---|---|---|---|---|---|
| Dec | 2 | Init | 0.3 | 0.99 | 8.9 | 4.2 | 4.2 |
| Dec | 3 | Init | 0.3 | 1.01 | 11.1 | 4.4 | 6.7 |
| Jan | 1 | Init | 0.3 | 1.03 | 10.3 | 3.9 | 6.4 |
| Jan | 2 | Deve | 0.45 | 1.59 | 15.9 | 3.4 | 12.5 |
| Jan | 3 | Deve | 0.74 | 2.72 | 29.9 | 4.6 | 25.3 |
| Feb | 1 | Mid | 1.03 | 3.92 | 39.2 | 5.6 | 33.6 |
| Feb | 2 | Mid | 1.13 | 4.46 | 44.6 | 6.4 | 38.1 |
| Feb | 3 | Mid | 1.13 | 4.46 | 35.6 | 9.3 | 26.3 |
| Mar | 1 | Mid | 1.13 | 4.46 | 44.6 | 12.8 | 31.7 |
| Mar | 2 | Mid | 1.13 | 4.46 | 44.6 | 15.7 | 28.9 |
| Mar | 3 | Late | 0.99 | 4.08 | 44.9 | 16.6 | 28.3 |
| Apr | 1 | Late | 0.7 | 3.05 | 30.5 | 16.8 | 13.7 |
| Apr | 2 | Late | 0.43 | 1.93 | 19.3 | 17.6 | 1.7 |
| Total | | | | | 379.2 | 121.2 | 257.5 |

According to the result, a total of 257.5 mm per season was needed for wheat production in the December to April season. Therefore, if we see that this amount of precipitation is not available from natural precipitation, the area should effectively introduce the artificial water treatment for its command area of Abrajit earth dams.

### *6.3. Irrigation Scheduling*

Information about crop watering needs and watering schedules improves watering management in the command area. Irrigation water management is all about monitoring the amount, timing and rate of irrigation in a well-organized and predetermined manner. Figure 6 and Figure 7 show the crop irrigation schedules for the wheat crops. In the numbers above, (TAM) is the total available moisture or the total amount of water available to the plant. The (RAM) is the readily available water or fraction of (TAM) that the plant can obtain from the root zone without experiencing water stress. The irrigation water should be applied to the crops when the amount of water consumed is greater than the RAW in the field. This type of research helps farmers select crop types based on water availability for cultivation.

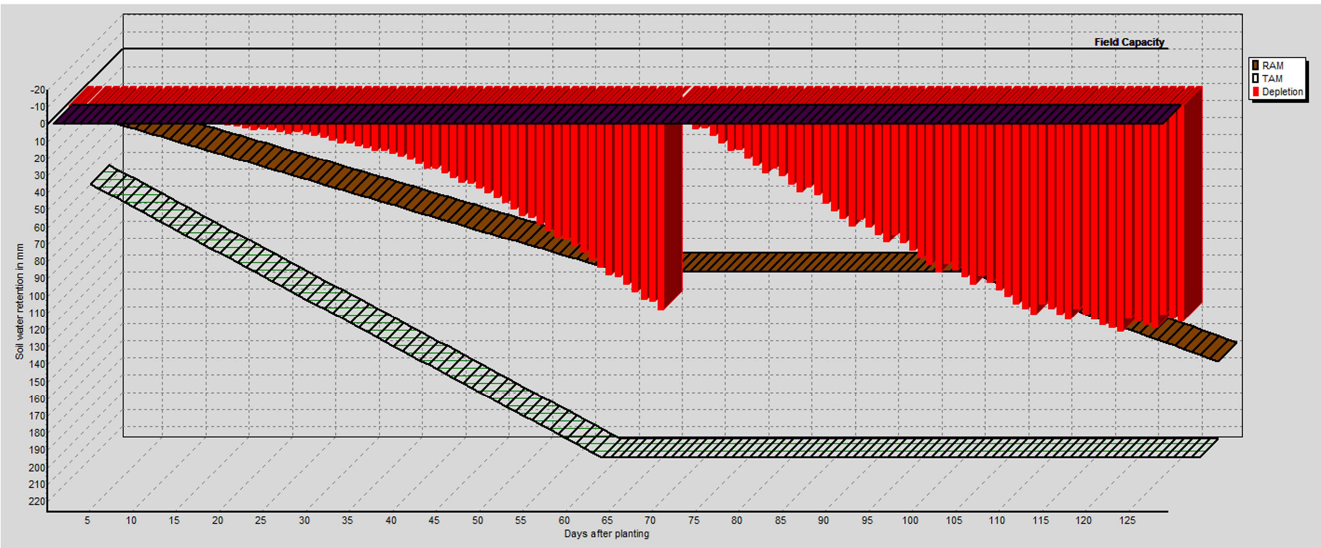
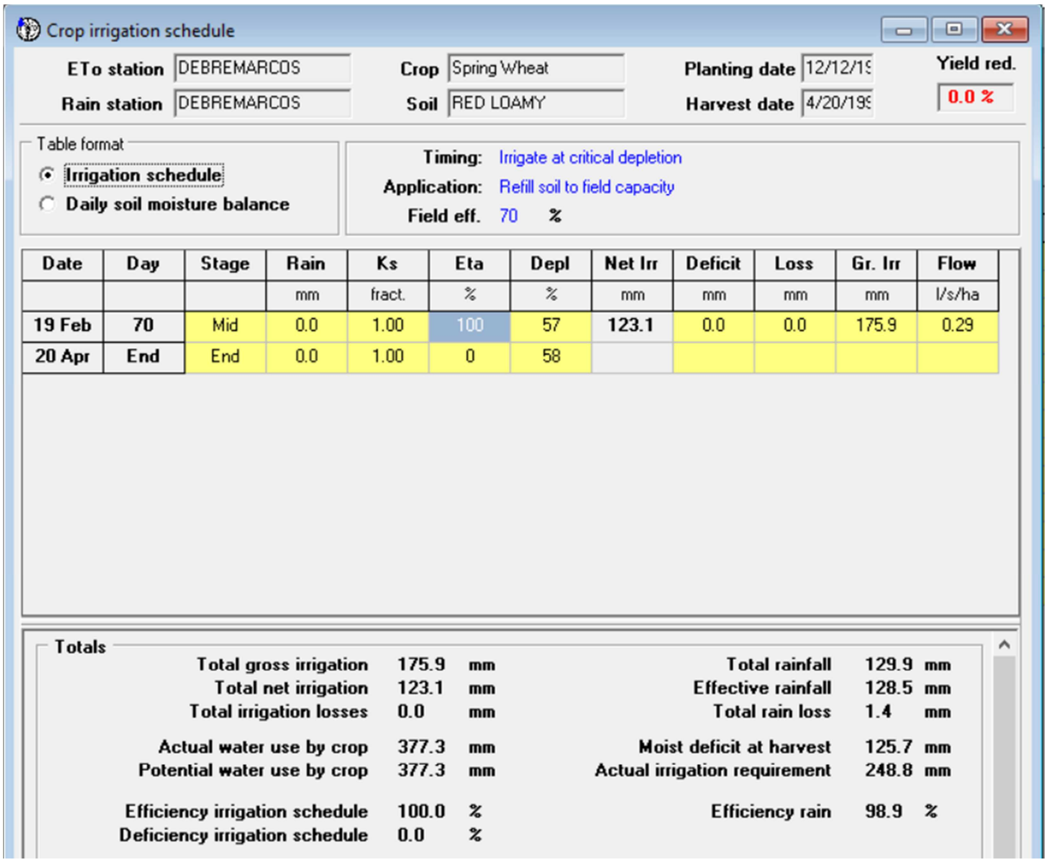



***Figure 6.*** *Irrigation Scheduling Graph of the Study Area.*

***Table 3.*** *Comparison of existing performance of the dam capacity and used water.*

| Duty (l/s/ha) | Existing Irrigated Command area (ha) | Discharge (l/s) | Discharge ($m^3$/day) | Capacity per Season ($m^3$) | Earthen Dams Capacity ($m^3$) | Currently used Water for irrigation | Unusable water from the dam |
|---|---|---|---|---|---|---|---|
| 0.29 | 286 | 82.94 | 7166.016 | 1074902.4 | 1388870 | 77.4 % | 22.6 % |
| 0.29 | 4566 | 1324.14 | 114405.696 | 17160854.4 | | | |


Crop irrigation schedule

ETo station DEBREMARCOS | Crop Spring Wheat | Planting date 12/12/1 | Yield red. 0.0 %

Rain station DEBREMARCOS | Soil RED LOAMY | Harvest date 4/20/19

Table format: Irrigation schedule / Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

| Date | Day | Stage | Rain | Ks | Eta | Depl | Net Irr | Deficit | Loss | Gr. Irr | Flow |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | mm | fract. | % | % | mm | mm | mm | mm | l/s/ha |
| 19 Feb | 70 | Mid | 0.0 | 1.00 | 100 | 57 | 123.1 | 0.0 | 0.0 | 175.9 | 0.29 |
| 20 Apr | End | End | 0.0 | 1.00 | 0 | 58 | | | | | |

Totals

| | | | | | |
|---|---|---|---|---|---|
| Total gross irrigation | 175.9 | mm | Total rainfall | 129.9 | mm |
| Total net irrigation | 123.1 | mm | Effective rainfall | 128.5 | mm |
| Total irrigation losses | 0.0 | mm | Total rain loss | 1.4 | mm |
| Actual water use by crop | 377.3 | mm | Moist deficit at harvest | 125.7 | mm |
| Potential water use by crop | 377.3 | mm | Actual irrigation requirement | 248.8 | mm |
| Efficiency irrigation schedule | 100.0 | % | Efficiency rain | 98.9 | % |
| Deficiency irrigation schedule | 0.0 | % | | | |

***Figure 7.*** *Overall irrigation scheduling of the project.*

### *6.4. Trend Analysis*

When we observe the trend analysis of the rainfall distribution of the area there is somehow similar trends of rainfall distribution.

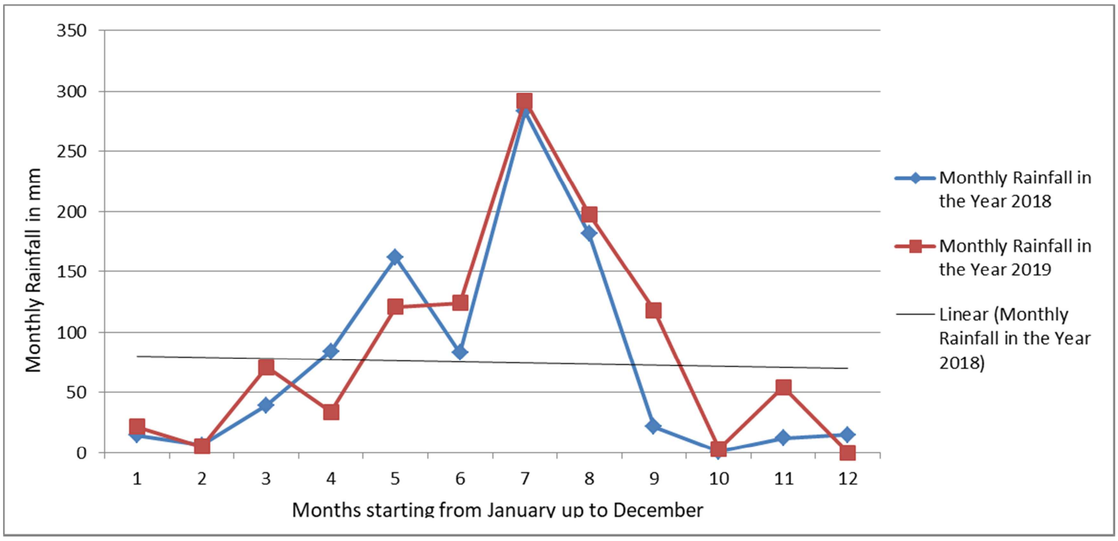



***Figure 8.*** *Rainfall distribution of the study area for 2 consecutive years.*

## 7. Conclusion

The results generated from the FAO CROPWAT 8.0 model yielded an interesting and interactive result with an effective result representation. Crop water requirements and schedules were detailed to take the farm activity and study the water required by the plant according to the regular and environmental features of the command areas.

The Crop WAT 8.0 model shows that it can predicted and calculated all the data required for successful irrigation implementation like that of crop water requirements and irrigation scheduling.

The study conducted in Abrajit Command area for Wheat crops showed in detailed which increases our understanding of the water requirements, which will accordingly help increase the management of water resources and the yield through policies based on these findings. The result shows that Total water requirements of 179.5 millimeter and a net irrigation requirement of 123.1 millimeter of water. There for the existing irrigation project works in a good manner but it needs serious managements of the dam to protect it from sedimentation problems.

# 8. Recommendation

It needs an optimization use of water for the future to increase the number of command areas and increase food production too.

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