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# Estimation of Reference Evapotranspiration by Using Different Five Empirical Models for Melkassa Area, Central Rift Valley of Ethiopia

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**Abstract:** Accurate estimate of reference evapotranspiration is essential for water resource and irrigation project planning and operation that include optimal irrigation scheduling. The study was conducted at melkassa the aim of the study was to estimate reference evapotranspiration of Melkassa area using five different empirical models. Evapotranspiration of the crop and reference evapotranspiration are affected by the climatic parameters like temperature, sunshine duration, humidity, wind speed, solar radiation and so on. Hence, all available climatic data gathered and the estimation of reference evapotranspiration of the area calculated based on five models used. ETo computed by The Blaney-Criddle method, Modified penman method, Radiation method, Throntwaite method and Hargreaves equation. From the result Thornthwaite method gave the maximum rate of Reference evapotranspiration (264.7 mm/month) which is over estimated. The Blaney-Criddlemethod provided the smallest reference evapotranspiration rate (83.7 mm/month). Moreover, the Modified Penman method showed relatively high estimation next to Thornthwaite method and it consists of the energy (radiation) terms and the aerodynamic (wind speed and relative humidity) terms which increased the method to be suggested for the area. The Radiation method showed better evapotranspiration next to Modified Penman method it is the best alternative in the presence of measured wind speed and air humidity data.

**Keywords:** Reference Evapotranspiration, Empirical Models, Climatic Parameters, Melkassa

## 1. Introduction

Evapotranspiration is the loss of water to the atmosphere by the combined processes of evaporation from the soil and plant surface and transpiration from plants. Estimation of evapotranspiration is one of the major hydrological components for determining the water budget and is becoming indispensable for the calculation of a reliable recharge and evaporation rate for the groundwater flow analysis. It is therefore, reliable and consistent estimate of evapotranspiration is of great importance for the management of water resources efficiently [2]. The basic approaches to prediction of evaporation have been developed into several usable methods for estimating evapotranspiration.

Evapotranspiration can be determined either by direct method through measurement on field condition or by using models that relates different climatic data and water loss in crop field [14]. This models are empirical formulas which are formulated at different area of the world and can be used anywhere with some limitation since they are formulated with particular climate conditions.

Direct methods consist of measuring using a lysimeter. A lysimeter is a tank which is set up in cultivated area and is designed in such a way that moisture content is kept at a constant level generally field capacity in order to obtain the value of potential evapotranspiration [1, 3, 13]. Adequate devices are used to measure rainfall, effective rainfall and drained water. Periodical measurement of soil moisture is done for any required adjustment of the system. Basic methods are predicting evapotranspiration can be grouped in three categories, namely mass transfer, energy balance and empirical methods [5].

Among the different methods of estimating reference evapotranspiration ($ET_O$), below here in this document five methods are illustrated based on an objective to evaluate available models to estimate reference evapotranspiration of Melkassa based on climatic data of the area.

So, the importance of this study was to estimate reference evapotranspiration of Melkassa area using five different empirical models.

## 2. Materials and Methods

### 2.1. Description of the Area

The area is Located in the Central Rift Valley of Ethiopia. It is geographically located between latitude of 8024' to 8026' N, longitude of 39019' to 39019' E and the mean altitude of the area is 1550 m.a.s.l. Evapotranspiration of the crop and reference evapotranspiration are affected by the climatic parameters like temperature, sunshine duration, humidity, wind speed, solar radiation and so on. Hence, all available climatic data gathered and the estimation of reference evapotranspiration of the area calculated based on five models used for this study.

The mean monthly climatic data for Melkassa area are as presented in the table below [11]

***Table 1.*** *Estimated Mean Monthly Climatic data for Melkassa area (1977-2018).*

| Month | Unit | JAN | FEB | MAR | APR | MAY | JUN | JULY | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T max mean | °C | 26.6 | 28.1 | 29.2 | 30.2 | 30.2 | 28.1 | 20.1 | 25.2 | 26.7 | 27.8 | 26.1 | 25.7 |
| T min mean | °C | 12.0 | 13.1 | 14.5 | 15.0 | 14.5 | 16.2 | 15.3 | 15.6 | 15.1 | 12.3 | 11.3 | 10.5 |
| Rainfall, RF | Mm | 10.0 | 21.0 | 43.0 | 60.0 | 39.0 | 78.0 | 193.0 | 217.0 | 100.0 | 24.0 | 13.0 | 6.0 |
| Av.relative humidity | % | 49.7 | 42.9 | 34.8 | 47.0 | 46.8 | 51.5 | 62.0 | 68.7 | 62.4 | 46.7 | 44.7 | 46.2 |
| wind speed | m/s | 3.2 | 3.3 | 3.0 | 2.8 | 2.8 | 3.2 | 3.3 | 2.5 | 1.7 | 2.3 | 2.9 | 3.2 |
| sunshine, n | Hour | 8.3 | 8.5 | 8.3 | 8.4 | 8.1 | 7.9 | 7.3 | 7.8 | 7.3 | 8.2 | 9.0 | 8.0 |

### 2.2. Methods Used to Determine the Reference Evapotranspiration

There are five methods described here for estimating ETo which are widely applicable in estimation of ETo. ETo was determined in five methods by using long-term (1977-2018) hydro-climatic data, with some missed data, as follows.

i. The Blaney-Criddle method.
ii. Modified penman method.
iii. Radiation method.
iv. Throntwaite method.
v. Hargreaves equation.

#### 2.2.1. BlanneyCriddle Method

Blanney and Criddle developed an empirical method that widely used for determine evapotranspiration from climatological and irrigation data. The procedure is to correlate existing evapotranspiration data for different crops with the monthly temperature, percent of daytime hours, and length of growing season. The coloration coefficients are then applied to determine the evapotranspiration for other areas where only climatological data are available. The monthly evapotranspiration can be computed by the formula.

This method is suggested to use for areas where the climatic data covers temperature data only [7]. It is an empirical equation, which defines the effects of climate parameters of temperature, and day length on crop water requirements since crop water requirements will differ among these climates parameters.

According to FAO 24 areas suitable for this method are

1. In equatorial regions where temperatures remain fairly constant but other weather parameters will change.
2. Small islands and coastal areas where air temperature is affected by the sea temperature having little response to seasonal change in radiation.
3. Area with high altitudes due to fairly low mean daily temperatures (cold nights) even though daytime radiation levels are high.

For Area with wide variability in climatic parameters like sunshine hours during transition months (e.g. monsoon climates, mid altitude climates during spring and autumn)",

The monthly evapo-transpiration can be computed by the formula.

$$ETg=P\ (0.46\ T+8.13) \quad (1)$$

Where: ETg- Monthly evaporation in (mm/day)

T- Mean monthly temperature (°C)

P- Daily hours proportions in (%) $=P = \frac{N}{12*365} * 100$

$$ETo= a+b(ETg) \quad (2)$$

Where: ETo- Reference evapotranspiration (mm/day)

a and b are Constant based on relative humidity, wind speed and n/N ratio.

#### 2.2.2. Modified Penman Equation

The Penman equation or the later Penman-Monteith equation requires numerous meteorological data parameters and is also complicated. The Penman equations were also limited by the lack of availability of net radiation or solar radiation data [12].

The Penman method requires a variety of climatological data, such as maximum and minimum air temperatures, relative humidity, solar radiation, and wind speed. If some of these data are not available, alternative methods must be used for evapotranspiration estimation [6]. The FAO modified Penman method, which has found worldwide application in irrigation development and management projects are somewhat over predicting under non-advective conditions [15].

$$Etg=WRn+ (1-W)*f(u)*(E-e)$$

$$Eto=c*Etg$$

$$Eto = c\ (WRn+ (1-W)*f\ (u)*(E-e)) \quad (3)$$

Where, c= factor coefficient 0.95

W= is factor which depends on temperature and altitude)

W=Δ (Δ+Ɣ), Δ= slope of saturation vapourpressure dependent on temperature, Ɣ=psychrometer constant

Factor W as temperature and altitude dependent parameter

Rn= the net radiation

f (U) is function dependent on wind

E-e=saturation deficit.

The net radiation Rn in mm/day is estimated as a difference between Rs (short wave) and Rl (long wave) radiation.

$$f(e) = 0.34 - 0.044\sqrt{e}$$

$$f(u) = 0.27 * (1 + \frac{u_2}{100})$$

$$Rn = Rns - Rnl_{(mm/day)}$$

$$Rns = (1-\alpha)\,(0.25 + 0.50\, n/N)\, Ra$$

$$Rnl = f(t) * f(e) * f(n/N)$$

Where, Ra=extraterrestrial radiation

α=reflection coefficient (from the majority plant population 25% the radiation from short wave range is reflected, α = 0.25)

e=actual measured vapor Pressure (mbar)

Rn = net radiation at the crop surface (MJ $m^{-2}$ $day^{-1}$)

T = mean daily air temperature at 2 m height (°C)

$u_2$ = wind speed at 2 m height (m $s^{-1}$)

E - e = saturation vapor pressure deficit (mbar)

E = saturation vapor pressure (mbar)

e = actual vapor pressure (kPa)

$$\Delta = \frac{\frac{4098(0.618(17.27Tmean))}{Tmean+2437.3}}{(Tmean+237.3)^2}$$

Where, T mean is obtained from the equation

$$T_{mean} = (T_{max} + T_{min})/2$$

Rs is the global solar exposure ($MJm^{-2}day^{-1}$)

### *2.2.3. FAO Radiation Method*

Determination of reference evapotranspiration using radiation method is reliable than those based on only temperature. That is because of radiation is the cause for temperature and temperature is the effect of radiation.

The radiation method was suggested for areas where available climatic data include measured air temperature and sunshine, cloudiness or radiation, but not measured wind speed and air humidity [8]. The radiation methods show good results in humid climates where the aerodynamic term is relatively small, but performance in arid conditions is erratic and tends to underestimate the evapotranspiration of the area. In fact, in equatorial zones, on small islands, or at high altitudes, the Radiation method may be more reliable even if measured sunshine or cloudiness data are not available [8].

$$ETg = W*(0.25+0.50n/N)*Ra \tag{4}$$

Where: $ET_g$- is fundamental value of water consumption (mm/day)

W- is factor dependent on temperature and altitude

Ra- is Extraterrestrial radiation (mm/day)

n/N- is quotient of actual (n) to maximum possible daily sunshine hours

$$ETo = a+b*ETg \tag{5}$$

Where: ETo is basic water consumption

a=-0.3 and b is estimated from table depending on humidity and wind speed.

### *2.2.4. Thronthwaite Methods*

This is an empirical method used to calculate ETo depending on the temperature. It is more valid method for arid and semi-arid areas. Estimation of ETo can be calculated as follows.

$$ETo=1.6\,(10\,T_m/I)^{\alpha} \tag{6}$$

Where Tm is the mean temperature in °C and I is the annual heat index which is obtained by

$$i = (T_m/5)^{1.514},\ \&\ I = \Sigma i = 101.04$$

The value of α is obtained from: - $\alpha = (67.5x10^{-8})*I^3 - (77.1x10^{-6}) * I^2 + (0.01791)*I+0.4$

$\alpha = (67.5x10^{-8}) * (101.04)^3 - (77.1x10^{-6}) * (101.04)^2 + (0.01791) * (101.04) + 0.4$

α = 2.12

### *2.2.5. Hargreaves Method*

Hargreaves method use the principle of the difference between the maximum and minimum air temperature ($T_{max}$ and $T_{min}$) to indicate the fraction of extraterrestrial radiation that reaches the earth's surface to develop estimates of ETo using only air temperature data [10]. Hargreaves' radiation formula adjusted and validated at several weather stations in a variety of climate conditions when solar radiation data, relative humidity data and/or wind speed data are missing [7].

The Hargreaves method basis was that "for a period of 5 days, the temperature (°F) multiplied by Rs (global radiation at the surface) could predict 94% of the variance in the measurements of ET. Other parameters such as wind speed (U) and relative humidity (RH) only explained 10 and 9%, respectively"[4]. The estimation of ETo with Hargreaves method is calculated by the following equation:

$$ETo = C_i(T_{mean} + 17.78) * (T_{max} - T_{min})0.5 * Ra \tag{7}$$

Where: ETo- is the potential evapotranspiration (mm/day)

$T_{max}$, $T_{min}$ and $T_{mean}$ are the daily maximum, minimum and mean air temperatures (°C), respectively

$C_i$ = 0.0023 is the original empirical constant proposed by [9].

Ra is the water equivalent of the extraterrestrial radiation in mm/day and foundfrom table as expressed in the Radiation and other method.

# 3. Result and Discussion

The analysis of reference evapotranspiration using different models based on the climatic data showed different method estimated different value. The analyzed data revealed that Blaney-Criddle method, Modified penman method, Radiation method, Throntwaite method and Hargreaves equation estimated reference evapotranspiration approximately was tabulated as follows.

### *3.1. Blanney Criddle Method*

Based on the empirical formula of equation 1 and 2 of the Blaney-Criddle method, climate data including mean monthly temperature, percent of daily sunshine hour and constants obtained based on relative humidity and wind speed from tables, reference evapotranspiration (ETo) forMelkassa area was calculated.

***Table 2.*** *Climatic water demand of Melkassa (1977-2018) by Blaney-Criddle Method.*

| Month | Unit | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T max mean | $^{o}$c | 26.6 | 28.1 | 29.2 | 30.2 | 30.2 | 28.1 | 20.1 | 25.2 | 26.7 | 27.8 | 26.1 | 25.7 |
| T min mean | $^{O}$c | 12 | 13.1 | 14.5 | 15 | 14.5 | 16.2 | 15.3 | 15.6 | 15.1 | 12.3 | 11.3 | 10.5 |
| Rainfall, RF | Mm | 10 | 21 | 43 | 60 | 39 | 78 | 193 | 217 | 100 | 24 | 13 | 6 |
| Av.relative humidity | % | 49.7 | 42.9 | 34.8 | 47.0 | 46.8 | 51.5 | 62.0 | 68.7 | 62.4 | 46.7 | 44.7 | 46.2 |
| wind speed | m/s | 3.2 | 3.3 | 3 | 2.8 | 2.8 | 3.2 | 3.3 | 2.5 | 1.7 | 2.3 | 2.9 | 3.2 |
| sunshine, n | Hour | 8.3 | 8.5 | 8.3 | 8.4 | 8.1 | 7.9 | 7.3 | 7.8 | 7.3 | 8.2 | 9.0 | 8.0 |
| Average T | $^{O}$c | 19.3 | 20.6 | 21.85 | 22.6 | 22.35 | 22.15 | 17.7 | 20.4 | 20.9 | 20.05 | 18.7 | 18.1 |
| P | Fraction | 0.264 | 0.27 | 0.27 | 0.28 | 0.28 | 0.286 | 0.286 | 0.28 | 0.28 | 0.27 | 0.264 | 0.264 |
| ETg | mm/day | 4.49 | 4.75 | 4.91 | 5.19 | 5.16 | 5.24 | 4.65 | 4.90 | 4.97 | 4.69 | 4.42 | 4.34 |
| N | Hour | 11.68 | 11.84 | 12 | 12.26 | 12.48 | 12.58 | 12.48 | 12.36 | 12.1 | 11.88 | 11.72 | 11.62 |
| n/N | Fraction | 0.71 | 0.72 | 0.69 | 0.69 | 0.65 | 0.63 | 0.58 | 0.63 | 0.60 | 0.69 | 0.77 | 0.69 |
| A | Fraction | 0.76 | 0.76 | 0.70 | 0.68 | 0.71 | 0.67 | 0.56 | 0.57 | 0.62 | 0.72 | 0.83 | 0.82 |
| B | Fraction | -2.15 | -2.15 | -2.15 | -2.15 | -2.15 | -1.7 | -1.55 | -1.55 | -1.8 | -2.15 | -2.5 | -2.5 |
| ETo | mm/day | 4.05 | 4.41 | 4.62 | 5.01 | 4.96 | 3.85 | 2.55 | 2.77 | 3.02 | 4.32 | 4.61 | 4.49 |
| Month | Days | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| ETo | mm/month | 125.4 | 123.5 | 143.4 | 150.3 | 153.9 | 115.6 | 78.9 | 85.7 | 90.6 | 133.8 | 138.4 | 139.3 |

### *3.2. Modified Penman Equation*

Based on the empirical formula of equation 3 used to determine reference evapotranspiration based on the Modified penman equation, reference evapotranspiration (ETo) for Melkassa area was calculated.

***Table 3.*** *Climatic water balance of Melkassa (1977-2018) by Modified Penman Method.*

| Month | Unit | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T max mean | °C | 26.6 | 28.1 | 29.2 | 30.2 | 30.2 | 28.1 | 20.1 | 25.2 | 26.7 | 27.8 | 26.1 | 25.7 |
| T min mean | °C | 12 | 13.1 | 14.5 | 15 | 14.5 | 16.2 | 15.3 | 15.6 | 15.1 | 12.3 | 11.3 | 10.5 |
| Rainfall | Mm | 10 | 21 | 43 | 60 | 39 | 78 | 193 | 217 | 100 | 24 | 13 | 6 |
| Av.relative humidity | % | 49.7 | 42.9 | 34.8 | 47.0 | 46.8 | 51.5 | 62.0 | 68.7 | 62.4 | 46.7 | 44.7 | 46.2 |
| wind speed | m/s | 3.2 | 3.3 | 3 | 2.8 | 2.8 | 3.2 | 3.3 | 2.5 | 1.7 | 2.3 | 2.9 | 3.2 |
| Sunshine, n | Hour | 8.3 | 8.5 | 8.3 | 8.4 | 8.1 | 7.9 | 7.3 | 7.8 | 7.3 | 8.2 | 9.0 | 8.0 |
| Average T | °C | 19.3 | 20.6 | 21.85 | 22.6 | 22.35 | 22.15 | 17.7 | 20.4 | 20.9 | 20.05 | 18.7 | 18.1 |
| N | Hours | 11.92 | 11.96 | 12 | 12.14 | 12.12 | 12.22 | 12.12 | 12.24 | 12.1 | 12.12 | 12.08 | 11.98 |
| n/N | Fraction | 0.75 | 0.75 | 0.70 | 0.68 | 0.73 | 0.69 | 0.58 | 0.58 | 0.62 | 0.70 | 0.80 | 0.79 |
| Ra | mm/day | 13.60 | 14.50 | 15.30 | 15.60 | 15.30 | 15.00 | 15.10 | 15.40 | 15.30 | 14.80 | 13.90 | 13.30 |
| Rns | | 6.38 | 6.80 | 6.91 | 6.92 | 7.08 | 6.70 | 6.12 | 6.23 | 6.42 | 6.68 | 6.80 | 6.44 |
| E | Mbar | 24.6 | 26.2 | 26.6 | 30.6 | 29.2 | 29.4 | 28.2 | 33.6 | 33.6 | 26.2 | 23.6 | 23.2 |
| E | | 12.23 | 11.24 | 9.26 | 14.38 | 13.67 | 15.14 | 17.48 | 23.08 | 20.97 | 12.24 | 10.55 | 10.72 |
| f(e) | | 0.19 | 0.20 | 0.20 | 0.18 | 0.18 | 0.17 | 0.17 | 0.16 | 0.17 | 0.19 | 0.20 | 0.20 |
| f(n/N) | | 0.47 | 0.47 | 0.45 | 0.44 | 0.46 | 0.45 | 0.38 | 0.38 | 0.41 | 0.45 | 0.49 | 0.49 |
| f(t) | | 14.60 | 14.80 | 15.20 | 15.20 | 15.20 | 15.20 | 14.80 | 14.80 | 14.80 | 14.60 | 14.60 | 14.60 |
| Rnl | | 1.30 | 1.39 | 1.37 | 1.20 | 1.26 | 1.16 | 0.96 | 0.90 | 1.03 | 1.25 | 1.43 | 1.43 |
| Rn | mm/day | 5.08 | 5.41 | 5.54 | 5.72 | 5.82 | 5.54 | 5.16 | 5.33 | 5.39 | 5.43 | 5.37 | 5.01 |
| Wind speed | km/day | 276.48 | 274.19 | 261.41 | 237.26 | 229.69 | 278.63 | 277.13 | 214.07 | 149.09 | 199.96 | 254.03 | 271.56 |
| E-e | Mbar | 12.37 | 14.96 | 17.34 | 16.22 | 15.53 | 14.26 | 10.72 | 10.52 | 12.63 | 13.96 | 13.05 | 12.48 |
| f(u) | | 1.02 | 1.04 | 1.00 | 0.94 | 0.92 | 1.05 | 1.05 | 0.88 | 0.67 | 0.81 | 0.99 | 1.03 |
| W | | 0.72 | 0.73 | 0.75 | 0.75 | 0.75 | 0.75 | 0.73 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 |
| (1-W) | | 0.28 | 0.27 | 0.25 | 0.25 | 0.25 | 0.25 | 0.27 | 0.27 | 0.27 | 0.28 | 0.28 | 0.29 |
| ETg | mm/day | 7.19 | 8.15 | 8.49 | 8.10 | 7.94 | 7.90 | 6.81 | 6.39 | 6.22 | 7.08 | 7.48 | 7.28 |
| C | | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 | 0.95 |
| Eto | mm/day | 6.83 | 7.74 | 8.07 | 7.70 | 7.54 | 7.50 | 6.47 | 6.07 | 5.91 | 6.72 | 7.11 | 6.92 |
| Month | Days | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| Eto | mm/month | 211.8 | 216.8 | 250.0 | 230.9 | 233.7 | 225.1 | 200.4 | 188.2 | 177.3 | 208.4 | 213.3 | 214.5 |

### *3.3. Fao Radiation Method*

Based on the empirical formula of equation 4 and 5 used to determine reference evapotranspiration based on the Radiation method, reference evapotranspiration (ETo) for Melkassa area was calculated.

***Table 4.*** *Climatic water demand of Melkassa (1977-2018) by Radiation Method.*

| Month | Unit | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T max mean | °C | 26.6 | 28.1 | 29.2 | 30.2 | 30.2 | 28.1 | 20.1 | 25.2 | 26.7 | 27.8 | 26.1 | 25.7 |
| T min mean | °C | 12 | 13.1 | 14.5 | 15 | 14.5 | 16.2 | 15.3 | 15.6 | 15.1 | 12.3 | 11.3 | 10.5 |
| Av.relative humidity | % | 49.7 | 42.9 | 34.8 | 47.0 | 46.8 | 51.5 | 62.0 | 68.7 | 62.4 | 46.7 | 44.7 | 46.2 |
| wind speed | m/s | 3.2 | 3.3 | 3 | 2.8 | 2.8 | 3.2 | 3.3 | 2.5 | 1.7 | 2.3 | 2.9 | 3.2 |
| Sunshine | Hour | 8.3 | 8.5 | 8.3 | 8.4 | 8.1 | 7.9 | 7.3 | 7.8 | 7.3 | 8.2 | 9.0 | 8.0 |
| Average T | °C | 19.3 | 20.6 | 21.85 | 22.6 | 22.35 | 22.15 | 17.7 | 20.4 | 20.9 | 20.05 | 18.7 | 18.1 |
| N | Hour | 11.92 | 11.96 | 12 | 12.14 | 12.12 | 12.22 | 12.12 | 12.24 | 12.1 | 12.12 | 12.08 | 11.98 |
| n/N | Fraction | 0.75 | 0.75 | 0.70 | 0.68 | 0.73 | 0.69 | 0.58 | 0.58 | 0.62 | 0.70 | 0.80 | 0.79 |
| Ra | mm/day | 13.60 | 14.50 | 15.30 | 15.60 | 15.30 | 15.00 | 15.10 | 15.40 | 15.30 | 14.80 | 13.90 | 13.30 |
| Rs | mm/day | 8.48 | 9.07 | 9.21 | 9.22 | 9.44 | 8.94 | 8.16 | 8.30 | 8.56 | 8.91 | 9.06 | 8.58 |
| W | | 0.72 | 0.73 | 0.75 | 0.75 | 0.75 | 0.75 | 0.73 | 0.73 | 0.73 | 0.72 | 0.72 | 0.71 |
| Etg | mm/day | 6.10 | 6.62 | 6.91 | 6.92 | 7.08 | 6.70 | 5.96 | 6.06 | 6.25 | 6.41 | 6.53 | 6.09 |
| A | | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 | -0.3 |
| B | | 0.98 | 0.98 | 1.1 | 0.98 | 0.98 | 0.98 | 0.88 | 0.88 | 0.76 | 0.98 | 0.98 | 0.98 |
| Eto | mm/day | 5.68 | 6.19 | 7.30 | 6.48 | 6.64 | 6.27 | 4.94 | 5.03 | 4.45 | 5.99 | 6.10 | 5.67 |
| Month | Days | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| Eto | mm/month | 176.1 | 173.3 | 226.2 | 194.4 | 205.7 | 188.1 | 153.2 | 156.1 | 133.4 | 185.5 | 182.9 | 175.8 |

### *3.4. Thronthwaite Methods*

Based on the empirical formula of equation 6 used to determine reference evapotranspiration based on the Thronthwaite method, reference evapotranspiration (ETo) for Melkassa area was calculated.

***Table 5.*** *Climatic water demand of Melkassa (1977-2018) by Thornthwaite Method.*

| Month | Unit | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T max mean | °C | 26.6 | 28.1 | 29.2 | 30.2 | 30.2 | 28.1 | 20.1 | 25.2 | 26.7 | 27.8 | 26.1 | 25.7 |
| T min mean | °C | 12 | 13.1 | 14.5 | 15 | 14.5 | 16.2 | 15.3 | 15.6 | 15.1 | 12.3 | 11.3 | 10.5 |
| Av.relative humidity | % | 49.7 | 42.9 | 34.8 | 47.0 | 46.8 | 51.5 | 62.0 | 68.7 | 62.4 | 46.7 | 44.7 | 46.2 |
| Sunshine | Hour | 3.2 | 3.3 | 3 | 2.8 | 2.8 | 3.2 | 3.3 | 2.5 | 1.7 | 2.3 | 2.9 | 3.2 |
| wind speed | m/s | 8.3 | 8.5 | 8.3 | 8.4 | 8.1 | 7.9 | 7.3 | 7.8 | 7.3 | 8.2 | 9.0 | 8.0 |
| Average T | °C | 19.3 | 20.6 | 21.85 | 22.6 | 22.35 | 22.15 | 17.7 | 20.4 | 20.9 | 20.05 | 18.7 | 18.1 |
| I | | 7.73 | 8.53 | 9.33 | 9.81 | 9.65 | 9.52 | 6.78 | 8.41 | 8.72 | 8.19 | 7.37 | 7.01 |
| ETo | mm/day | 6.31 | 7.25 | 8.21 | 8.82 | 8.62 | 8.45 | 5.25 | 7.10 | 7.47 | 6.84 | 5.90 | 5.51 |
| Month | Days | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| ETo | mm/month | 195.7 | 203.0 | 254.6 | 264.7 | 267.1 | 253.6 | 162.9 | 220.1 | 224.2 | 212.2 | 177.1 | 170.8 |

### *3.5. Hargreaves Method*

Based on the empirical formula of equation 7 used to estimate reference evapotranspiration by Hargreaves method reference evapotranspiration (ETo) for Melkassa area was calculated.

***Table 6.*** *Climatic water demand of Melkassa (1977-2018) by Hargreaves Method.*

| Month | Unit | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temperature max | °C | 26.6 | 28.1 | 29.2 | 30.2 | 30.2 | 28.1 | 20.1 | 25.2 | 26.7 | 27.8 | 26.1 | 25.7 |
| Temperature min | °C | 12 | 13.1 | 14.5 | 15 | 14.5 | 16.2 | 15.3 | 15.6 | 15.1 | 12.3 | 11.3 | 10.5 |
| Rainfall | Mm | 10 | 21 | 43 | 60 | 39 | 78 | 193 | 217 | 100 | 24 | 13 | 6 |
| Temperature mean | °C | 19.3 | 20.6 | 21.85 | 22.6 | 22.35 | 22.15 | 17.7 | 20.4 | 20.9 | 20.05 | 18.7 | 18.1 |
| Ra | mm/day | 13.60 | 14.50 | 15.30 | 15.60 | 15.30 | 15.00 | 15.10 | 15.40 | 15.30 | 14.80 | 13.90 | 13.30 |
| ETo | mm/day | 4.43 | 4.96 | 5.35 | 5.65 | 5.60 | 4.75 | 2.70 | 4.19 | 4.64 | 5.07 | 4.49 | 4.28 |
| Month | Days | 31 | 28 | 31 | 30 | 31 | 30 | 31 | 31 | 30 | 31 | 30 | 31 |
| Eto | mm/month | 137.4 | 138.8 | 165.8 | 169.5 | 173.5 | 142.6 | 83.7 | 129.9 | 139.1 | 157.2 | 134.6 | 132.7 |

***Table 7.** Summary of ETo Estimation by Different Methods.*

| Monthly and Daily abstraction of ETo inMelkassa area using different methods | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Month** | | | | | | | | | | | | | | |
| **S.no** | **EtoEstmating Methods** | **Unit** | **JAN** | **FEB** | **MAR** | **APR** | **MAY** | **JUN** | **JUL** | **AUG** | **SEP** | **OCT** | **NOV** | **DEC** |
| 1 | Blaney-Criddle | mm/month | 125.4 | 123.5 | 143.4 | 150.3 | 153.9 | 115.6 | 78.9 | 85.7 | 90.6 | 133.8 | 138.4 | 139.3 |
| | | mm/day | 4.05 | 4.41 | 4.62 | 5.01 | 4.96 | 3.85 | 2.55 | 2.77 | 3.02 | 4.32 | 4.61 | 4.49 |
| 2 | Modified Penman | mm/month | 211.8 | 216.8 | 250.0 | 230.9 | 233.7 | 225.1 | 200.4 | 188.2 | 177.3 | 208.4 | 213.3 | 214.5 |
| | | mm/day | 6.83 | 7.74 | 8.07 | 7.7 | 7.54 | 7.5 | 6.47 | 6.07 | 5.91 | 6.72 | 7.11 | 6.92 |
| 3 | Radiation | mm/month | 176.1 | 173.3 | 226.2 | 194.4 | 205.7 | 188.1 | 153.2 | 156.1 | 133.4 | 185.5 | 182.9 | 175.8 |
| | | mm/day | 5.68 | 6.19 | 7.3 | 6.48 | 6.64 | 6.27 | 4.94 | 5.03 | 4.45 | 5.99 | 6.1 | 5.67 |
| 4 | Thornthwait | mm/month | 195.7 | 203.0 | 254.6 | 264.7 | 267.1 | 253.6 | 162.9 | 220.1 | 224.2 | 212.2 | 177.1 | 170.8 |
| | | mm/day | 6.31 | 7.25 | 8.21 | 8.82 | 8.62 | 8.45 | 5.25 | 7.1 | 7.47 | 6.84 | 5.9 | 5.51 |
| 5 | Hargreaves | mm/month | 137.4 | 138.8 | 165.8 | 169.5 | 173.5 | 142.6 | 83.7 | 129.9 | 139.1 | 157.2 | 134.6 | 132.7 |
| | | mm/day | 4.43 | 4.96 | 5.35 | 5.65 | 5.6 | 4.75 | 2.7 | 4.19 | 4.64 | 5.07 | 4.49 | 4.28 |

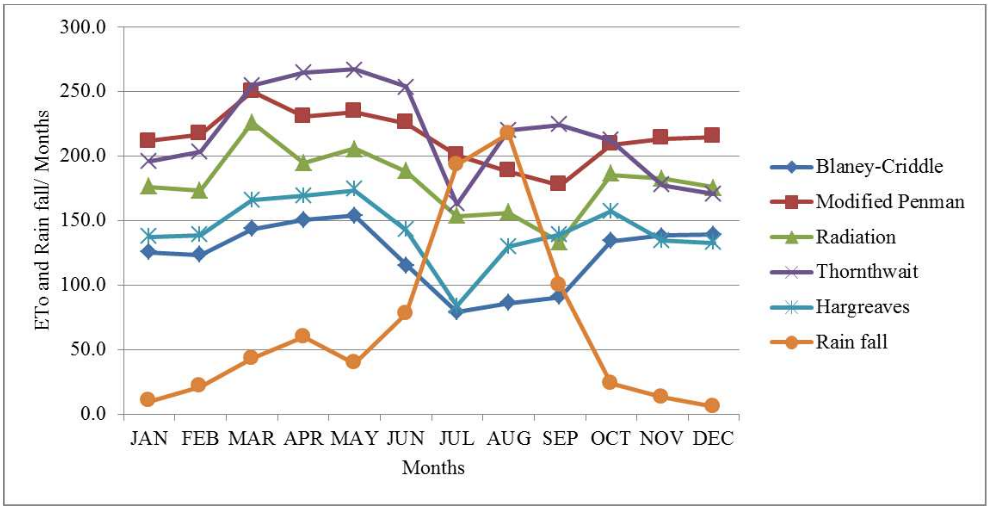


***Figure 1.** Graphical presentation of Eto result of the five methods against months.*

## 4. Conclusions

The analysis of climatic data of the study area, different values of reference evapotranspiration was obtained during estimation using five methods used for the evaluation. As clearly quantified, the values of reference evapotranspiration obtained with different models estimated differently with the highest estimate by the analysis of climatic data of the study area, different values of reference evapotranspiration was obtained during estimation using five methods used for the evaluation. As clearly quantified, the values of reference evapotranspiration obtained with different models estimated differently with the highest estimate by Thornthwaite method and the lowest by Blaney-Criddle.

Results obtained revealed that the wet season, which, the evapotranspiration is lower than the rainfall, is only for three months from mid-June to mid-September based on the average estimate by the two methods of Hargreaves and Blaney-Criddle. However, based on the estimation of modified penman, Radiation and Thornthwaite methods there were few season in which rainfall is above the reference evapotranspiration that states the season no fulfill the crop water requirement by natural rain. Whereas, based on the Blaney-Criddle method, the wet season in which rainfall is above the reference evapotranspiration is exceeded the three months, which highly underestimate as compared to all the methods compared.

## 5. Recommendation

Crop production around Melkassa area should be done with those months of wet season. Nevertheless, the duration is short; cultivation of early maturing crops should be adopted. Moreover, popularization and intensification of supplementary irrigation practice using available water resource like runoff harvesting and underground source should be used to enhance crop production system of the area.

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