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Original Research Article

Evaluation of reference evapotranspiration estimated from limited climatic parameters using CROPWAT 8.0 model under humid condition of Arsi Zone

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Abstract

The purpose of this study is to evaluate the accuracy of limited climatic parameters and simulated climatic parameters (NewLoclim) through estimation of reference evapotranspiration using CROPWAT 8.0 Model. Full set of climatic parameters is not available to estimate reference evapotranspiration therefore it is important to evaluate the accuracy of limited climatic parameters and simulated climatic parameters against full set of climatic parameters through CROPWAT 8.0 Model, which uses FAO Penman-Monteith method to calculate reference evapotranspiration. SAS 9.0 and Excel were used to analyze correlation coefficient, linear regression and root mean square error (RMSE) for comparison purpose. The result showed that during dry season, reference evapotranspiration estimated using limited climatic parameters with local area mean wind speed (2.5m/s) has a good relationship with reference evapotranspiration calculated using full set of climatic parameters than limited climatic parameters with global mean wind speed (2m/s) and using simulated climatic parameters from NewLoclim model. During rainy season and annually for humid areas of Arsi Zone, reference evapotranspiration estimated using simulated climatic parameters from NewLoclim have good relation with reference evapotranspiration calculated using full set of climatic parameters.

Keywords: CROPWAT, Limited climatic parameters, NewLoclim, Reference evapotranspiration

INTRODUCTION

Irrigation development in Ethiopia considered as the important agricultural operation to increase and stabilize agricultural production and productivity. Irrigation (full or supplementary) of the crops is needed for providing best level of production (Singh, 1997). High crop production could not obtained by increasing the amount of irrigation water applied; instead application of optimum amount of irrigation water could lead to optimum level of crop production. In any case, irrigation water should be applied intelligently in order to make the best use of it. Therefore, a proper irrigation scheduling or best use of irrigation water is needed for efficient use of water and optimum crop production (Nazeer, 1990). Ethiopia has a diverse agro-ecology and high rainfall variations, the demand of irrigation requirement of crops differ with different agro-ecology and climate conditions therefore estimation of crop water requirement for specific site is essential to irrigation planning, irrigation scheduling and improve efficiency of irrigation water resources of the specific site.

Estimation of crop water requirement depends mainly on climatic parameters and crop data, crop water requirement is calculated by multiplying the reference evapotranspiration and crop coefficient. Estimation of reference evapotranspiration (ETo) are widely used in irrigation engineering to define crop water requirements

(Droogers and Allen, 2002). Reference evapotranspiration is the rate of evapotranspiration from an extensive area of 0.08–0.15 m high, uniform, actively growing, green grass that completely shades the soil and is provided with unlimited water and nutrients (Allen et al., 1998). It is not always possible to measure the rate of evapotranspiration practically so theoretical model have been used by professional to estimate the reference evapotranspiration.

CROPWAT 8.0 for Windows is a computer programme for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. According to this paper CROPWAT 8.0 Model has been used to estimate the reference evapotranspiration of the study area and the model uses FAO Penman-Monteith equation, which has been accepted as standard method to calculate reference evapotranspiration (Allen et al., 1998). CROPWAT 8.0 Model requires complete climatic parameters, which are minimum temperature, maximum temperature, relative humidity, wind speed and sunshine hours in order to calculate reference evapotranspiration. The complete set of climatic parameters is limited in most of meteorological stations in the zone of the study area. Even if there are full climatic parameters it's difficult to obtain reliable relative humidity and wind speed data because of old instrument used to collect these data. Previous study under temperate conditions of Kashmir reveled that the ETo estimated from limited data with local mean wind speed have good agreement with that of ETo estimated from full set of climatic data (Raja, 1981).

CROPWAT 8.0 Model has two options two calculate the reference evapotranspiration, one of the method is by using full set of climatic parameters and the other method is using limited climatic parameters (only minimum and maximum temperature with global mean wind speed) but the validity of the reference evapotranspiration is uncertain, so this paper investigate whether the reference evapotranspiration estimated from limited climatic parameters and simulated climatic parameters are accurate with reference evapotranspiration estimated from full set of climatic parameters under Humid condition of Arsi Zone, Ethiopia.

MATERIALS AND METHODS

Meraro area found in Arsi Zone, South West of Ethiopia, located at latitude of 07°25′N and longitude of 39°15'E, at height of 2990m above sea level. Meraro is characterized by high rainfall area with amount of 1196mm annually; Meraro area average maximum and minimum temperature are 18.1°C and 5°C respectively. The meteorological data used for this study collected from National Meteorological Agency and meteorological data records from 1988 to 2009 was used to calculate the reference evapotranspiration. Five climatic parameters are required by CROPWAT 8.0 Model, which are maximum temperature, minimum temperature, relative humidity, wind speed and sunshine hours. Solar radiation always calculated automatically by CROPWAT 8.0 Model.

The reference evapotranspiration (ETo) was calculated by four methods:

1. Using only minimum and maximum temperature data and considering the global mean wind speed 2m/s (ETo (temp)). By default, CROPWAT 8.0 Model uses 2m/s of wind speed as a global mean wind speed while data setting activated on "ETo Penman calculated from temperature data (other data estimated)". The other data will be adjusted automatically while the location data entered.
2. Using only minimum and maximum temperature data and considering the Meraro mean wind speed 2.5m/s (ETo (mean WS)). Annual mean wind speed of Meraro is 2.5m/s, therefore in this method, the local mean wind speed used instead of the default global mean wind speed.
3. Using full set of climatic parameters from NewLoclim model (ETo (NewLoclim)). NewLoclim is a model uses location data to simulate full set of climatic parameters.
4. Using full set of climatic parameters from meteorological station (ETo (FAOPM)). This method uses full set of climatic data from the meteorological station and the data setting was activated on ETo penman calculated from climatic data. CROPWAT 8.0 uses FAO Penman-Monteith equation (Equ 1) as the standard method to calculate the reference evapotranspiration, the equation is as follows:
5.

$$\text{ETo} = \frac{0.408\Delta(\text{Rn}-\text{G})+\left(\frac{\gamma 900}{\text{T}+273}\right)\text{U2}(\text{es}-\text{ea})}{\Delta+\gamma(1+0.34\text{U2})} \quad \text{-------------- (Equ 1)}$$

Where:
ETo is the reference evapotranspiration (mm day-1)
Rn is the net radiation at the crop surface (MJ m-2 day-1)
G is the soil heat flux density (MJ m-2 day-1)
T is the mean daily air temperature at 2 m height (°C)
u2 is the wind speed at 2m height (m s-1)
es is the saturation vapor pressure (kPa)
ea is the actual vapor pressure (kPa)
es-ea is the vapor pressure deficit (kPa)
Δ is the slope of the vapor pressure-temperature curve (kPa °C-1)
γ is a psychometric constant (kPa °C-1)

Correlation coefficient, linear regression and root mean square error analysis (RMSE) were used to evaluate the accuracy of each limited climatic parameters used to calculate the reference evapotranspiration against the FAO Penman-Monteith (CROPWAT 8.0

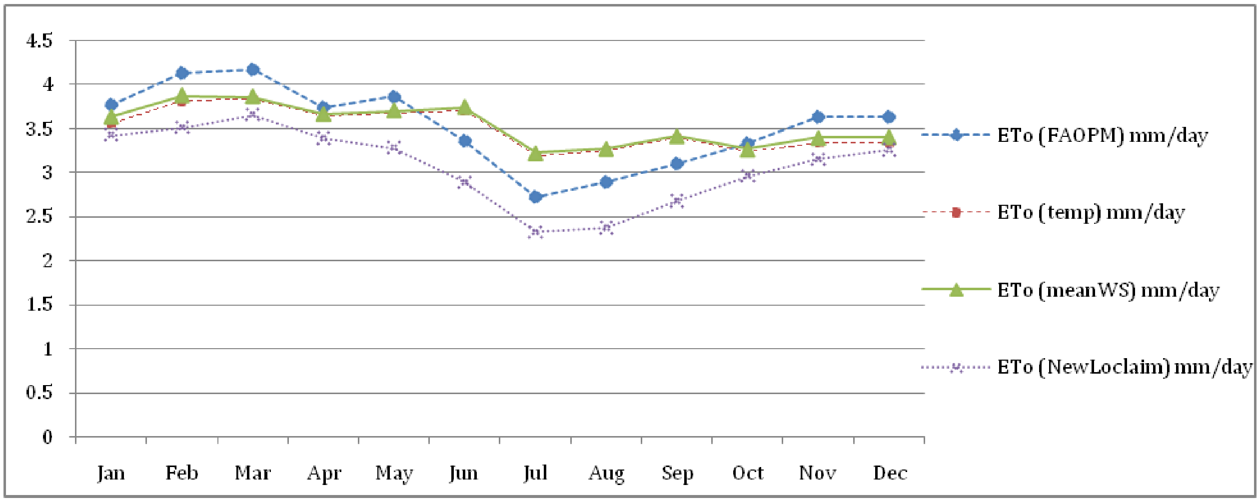

Figure 1. Refrence Evapotranspiration (ETo) at Meraro area

Table 1. Comparison between ETo estimated using FAO PM Equation and ETo estimated using limited temperature with global wind speed, ETo estimated using limited temperature using local wind speed and ETo estimated using climatic parameters from NewLoclim for annually

Methods	Annually				
	Correlation Coefficient	r^2	a	b	RMSE
ETo (FAOPM) Vs ETo (temp)	0.80	0.64	1.59	-2.04	0.29
ETo (FAOPM) Vs ETo (mean WS)	0.83	0.68	1.61	-2.15	0.27
ETo (FAOPM) Vs ETo (NewLoclaim)	0.98	0.96	1.04	0.33	0.09

Model). Correlation coefficient, linear regression and root mean square error were analyzed using SAS 9.0 and Excel.

RESULT AND DISCUSSION

The estimated reference evapotranspiration using four different methods through CROPWAT 8.0 Model is shown in Figure 1. A maximum value of reference evapotranspiration shown in the month of March with a value of 4.17 mm/day, 3.83mm/day, 3.86mm/day and 3.65 for the FAO Penman Monteith, limited temperature, limited temperature with local mean wind speed and NewLoclim methods respectively. The minimum value of reference evapotranspiration shown in the month of July with a value of 2.72mm/day, 3.19mm/day, 3.22mm/day and 2.33mm/day for the FAO Penman Monteith, limited temperature, limited temperature local with mean speed and NewLoclim methods respectively.

The relationship between FAO Penman-Monteith methods and the other three methods where evaluated with correlation, linear regression and root mean square error for annual, dry season and rainy season period. As shown in table1 and figure (2-4), annual reference evapotranspiration estimated using FAO Penman-Monteith and the three methods showed highly significant for the linear regression analysis, relationship between ETo (FAOPM) and ETo (NewLoclim) gives highest correlation, highest r^2 and lowest RMSE with the value of 0.98, 0.96 and 0.09 respectively than ETo (FAOPM) Vs ETo (mean WS) and ETo (FAOPM) Vs ETo (temp).

Reference evapotranspiration calculated by ETo (mean WS) and ETo (temp) over estimate and underestimate the result by 0.19% and 0.92% respectively. While ETo (NewLoclim) underestimate the reference evapotranspiration by 12.83%. Even if the ETo (NewLoclim) underestimate by higher percentage than the other two methods its within acceptable range and further ETo (NewLoclim) has a good relationship with ETo (FAOPM) by all three comparison parameters.

Estimation of reference evapotranspiration during dry season using the three methods showed highly significant for the linear regression analysis, relationship between ETo (FAOPM) and ETo (mean WS) gives highest correlation, highest r^2 and lowest RMSE with the

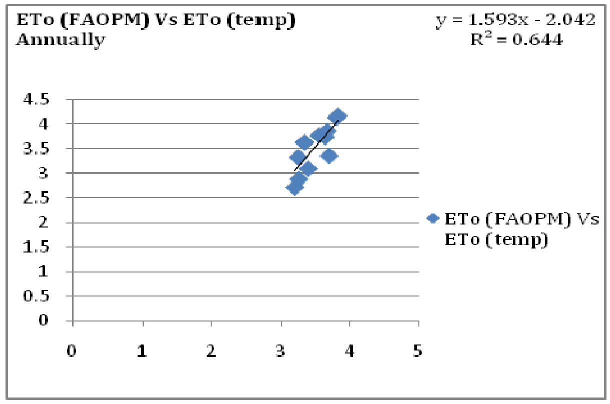

Figure 2. Comparison between ETo estimated using FAO PM Equation and ETo estimated using limited temperature with global wind speed for annually

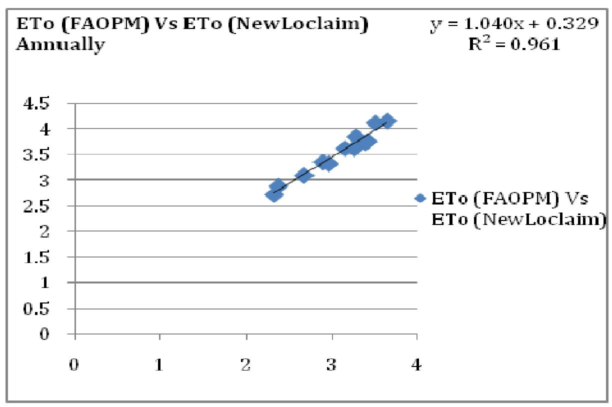

Figure 3. Comparison between ETo estimated using FAO PM Equation and ETo estimated using climatic parameters from NewLoclim for annually

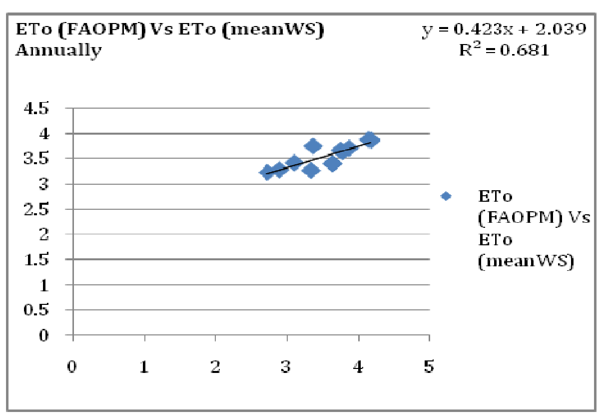

Figure 4. Comparison between ETo estimated using FAO PM Equation and ETo estimated using limited temperature using local wind speed for annually

value of 0.94, 0.88 and 0.085 respectively than ETo (FAOPM) Vs ETo (temp) and ETo (FAOPM) Vs ETo (NewLoclim) (Table 2 and figure (5-7)).

Reference evapotranspiration calculated by ETo (temp) and ETo (NewLoclim) underestimate the result by 6.54% and 12.14% respectively. While ETo (mean

Table 2. Comparison between ETo estimated using FAO PM Equation and ETo estimated using limited temperature with global wind speed, ETo estimated using limited temperature using local wind speed and ETo estimated using climatic parameters from NewLoclim for dry season

	Dry Season				
Methods	**Correlation Coefficient**	r^2	**a**	**b**	**RMSE**
ETo (FAOPM) Vs ETo (temp)	0.92	0.85	1.01	0.21	0.085
ETo (FAOPM) Vs ETo (mean WS)	0.94	0.88	1.07	-0.06	0.085
ETo (FAOPM) Vs ETo (NewLoclaim)	0.87	0.76	1.15	-0.05	0.12

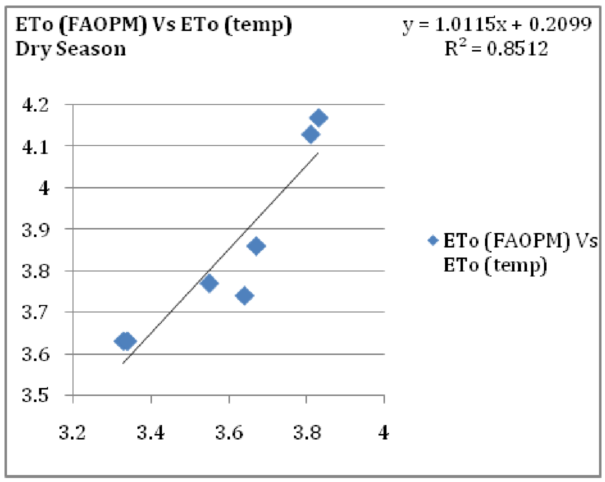

Figure 5. Comparison between ETo estimated using FAO PM Equation and ETo estimated using limited temperature with global wind speed for dry season

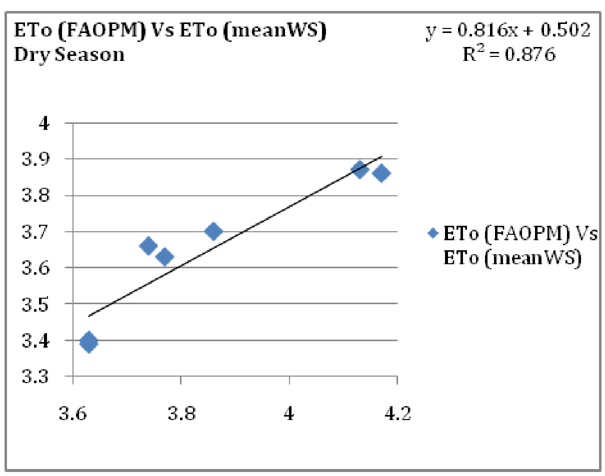

Figure 6. Comparison between ETo estimated using FAO PM Equation and ETo estimated using limited temperature using local wind speed for dry season

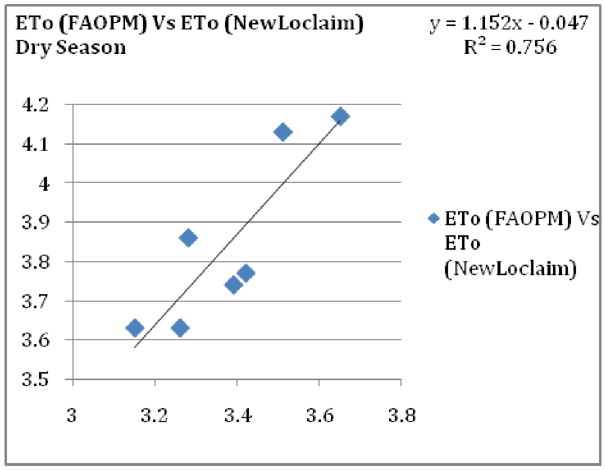

Figure 7. Comparison between ETo estimated using FAO PM Equation and ETo estimated using climatic parameters from NewLoclim for dry season

Table 3. Comparison between ETo estimated using FAO PM Equation and ETo estimated using limited temperature with global wind speed, ETo estimated using limited temperature using local wind speed and ETo estimated using climatic parameters from NewLoclim for rainy season

	Rainy Season				
Methods	**Correlation Coefficient**	**r^2**	**a**	**b**	**RMSE**
ETo (FAOPM) Vs ETo (temp)	0.64	0.41	0.82	0.31	0.25
ETo (FAOPM) Vs ETo (mean WS)	0.63	0.40	0.82	0.31	0.25
ETo (FAOPM) Vs ETo (NewLoclim)	0.98	0.96	0.95	0.58	0.06

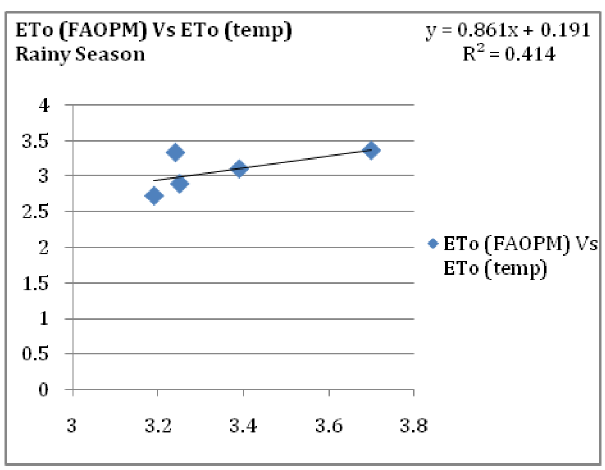

Figure 8. Comparison between ETo estimated using FAO PM Equation and ETo estimated using limited temperature with global wind speed for rainy season

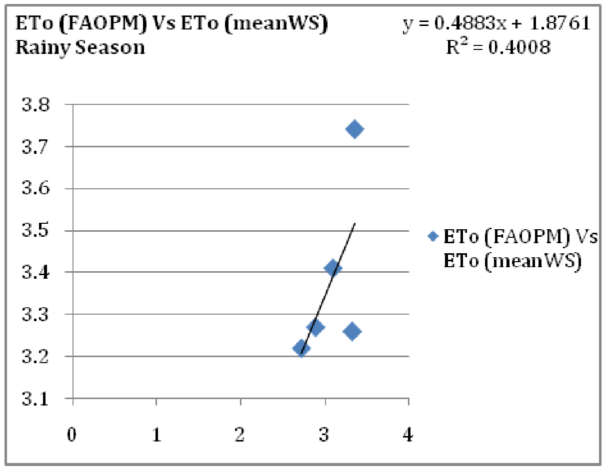

Figure 9. Comparison between ETo estimated using FAO PM Equation and ETo estimated using limited temperature using local wind speed for rainy season

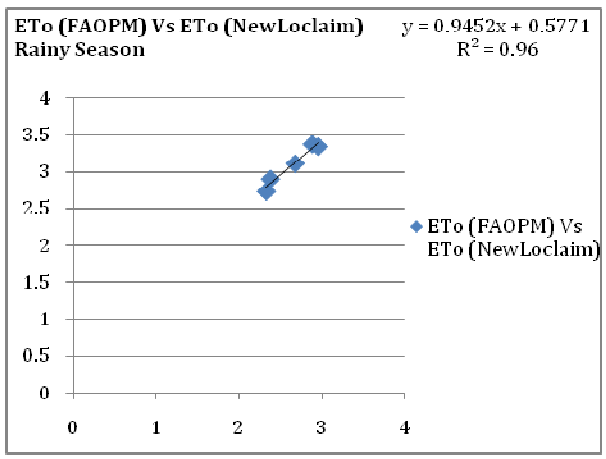

Figure 10. Comparison between ETo estimated using FAO PM Equation and ETo estimated using climatic parameters from NewLoclim for rainy season

WS) underestimate the reference evapotranspiration by 5.27% which is the lowest comparing the other two methods. Because of ETo (mean WS) underestimate by lower percentage than the other methods and ETo (mean WS) has a good relationship with ETo (FAOPM) by all three comparison method, it's possible to conclude that it's better to estimated reference evapotranspiration using limited temperature with local wind speed than limited temperature with global wind speed and simulated full set of climatic parameters using NewLoclim.

Estimation of Reference Evapotranspiration during rainy season using the three methods showed highly significant only for the linear regression analysis of ETo (FAOPM) Vs ETo (NewLoclim). Relationship between ETo (FAOPM) and ETo (NewLoclim) gives highest correlation, highest r^2 and lowest RMSE with the value of 0.98, 0.96 and 0.06 respectively than ETo (FAOPM) Vs ETo (temp) and ETo (FAOPM) Vs ETo (mean WS) (Table 3 and figure 8-10).

Reference evapotranspiration calculated by ETo (temp) and ETo (mean WS) overestimate the result by 8.9% and 9.74% respectively. While ETo (NewLoclim) underestimate the reference evapotranspiration by 14.03% which is the highest comparing the other two methods. Even if ETo (NewLoclim) underestimate by higher percentage than the other methods, its within acceptable range and its good relationship with ETo (FAOPM).

CONCLUSION AND RECOMMENDATION

This study finds out that during dry season, reference evapotranspiration estimated more accurately using limited climatic parameters with local area mean wind speed than limited climatic parameters with global mean wind speed and using climatic parameters from NewLoclim model. During rainy season it's possible to conclude that ETo estimated using climatic parameters from NewLoclim model estimate the reference evapotranspiration of Meraro area accurately than using limited climatic parameters with global mean wind speed and limited climatic parameters with local mean speed. For humid areas of Arsi Zone, this study find out that reference evapotranspiration estimated using climatic parameters from NewLoclim model is more accurate than reference evapotranspiration estimated using limited climatic parameters with global mean wind speed and using limited climatic parameters with local area mean wind speed, moreover it's possible to conclude reference evapotranspiration estimation using limited climatic data with local mean wind speed is the second best alternative to estimate reference evapotranspiration for annually.

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