Spatial and Temporal Characteristics of Reference Evapotranspiration in Amhara Region, Ethiopia

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Abstract
The FAO Penman-Monteith equation is the standard method which is commonly used for estimating reference evapotranspiration (ET_o). This method requires use of full weather data measured at the principal stations. Here, we used 25 principal stations in Amhara region to calculate ETo. In addition to this, we tested Hargreave, Thorntwait and Blaney-Criddle techniques to calculate ETo so as to choose best estimating model for the region at 19 temperature stations using Penman-Monteith as a reference. The statistical analysis of the results of these models showed that Hargreave model is the best among the tested techniques. As a result, this model is then calibrated and empirical coefficients at each station were determined for estimating ETo. Finally, Iso-ETo map for Amhara region is developed using thin-plate smoothing splines interpolation method in Geo-statistical analysis based on a total of 44 stations. This work can be used as an input for agricultural research and development in water resource planning, irrigation scheduling, design of irrigation schemes and hydrological studies in Amhara region.

Keywords: Penman-Monteith, Temperature stations, Hargree, Iso-ETo map, Amhara region

Introduction

Design of an irrigation system, estimation of crop water requirement, planning irrigation scheduling, drainage and hydrological studies all critically demand information on reference evapotranspiration (ET_0). The need for development of several approaches for quantification of ETo for a given area may arise from the relative importance of the parameter in both agricultural and hydrological fields. These techniques vary from sophisticated empirical models that employ climatic data as an input to the direct measurement techniques received from instrumentations.

Equation developed by the United Nations Food & Agriculture Organization (FAO) is normally considered to be a standard method for estimating reference evapotranspiration (Allen et al., 1998). This technique requires relatively larger number of data such as relative humidity, sunshine hour, wind speed and air temperature. This technique will be challenged when there are limited measured meteorological parameters which is a common phenomenon in the Amhara region. This calls for development of alternative ETo estimation techniques for wide range of use. In this study three alternative ETo estimating models which require maximum and minimum air temperature data were compared and calibrated against the ETo estimated by Penman-Monteith. Finally, best ETo estimating model was selected that employes temperature data alone in order to develop Iso-ETo map of the Amhara region. This work was designed to meet three objectives: 1) to select appropriate ETo estimation methods for areas of inadequate meteorological information in the region; 2) to generate regional information on spatio-temporal trends and distribution of reference evapotranspiration for water resource planning, irrigation scheduling and hydrological studies; and 3) to develop Iso-ETo maps for the Amhara region.

Material and Methods

Data acquisition

Monthly weather data with five parameters such as sunshine duration, wind speed, relative humidity, minimum and maximum temperatures were collected from 25 principal stations in Amhara Region for the period of 2000 - 2008. In addition to these, temperature data measured over 19 temperature stations in the study area were also collected. The spatial distributions of these meteorological stations are shown in Figure 1.

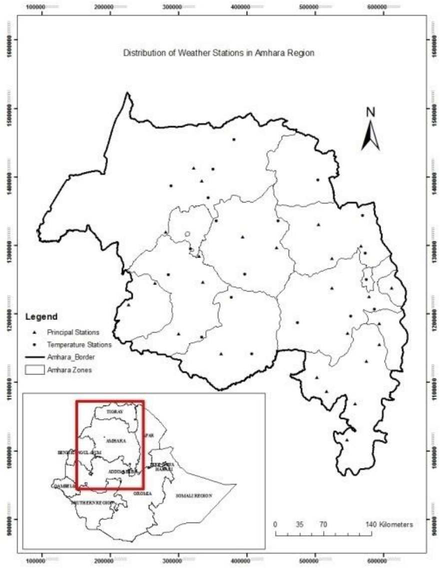


Figure 9. Spatial distribution of the Meteorological stations in Amhara Region

Data Analysis using ETo Models

The Penman-Monteith equation (FAO-PM) of the Food and Agriculture Organization of the United Nations is employed herein to calculate monthly reference evapotranspiration (ETo) over the 25 principal stations for each of the 12 months. This was done using the mean values of the meteorological parameters of each station over the study periods. We introduced the three energy and mass balance models namely Hargreave (E_H), Thorntwait (ET_{Th}) and Blaney-Criddle (ET_B) methods for ETo estimations. These models are the most commonly used and simple to estimate ETo by using only the temperature data. The temperature data at the principal stations was used to evaluate the performance of the three models. To select best method of estimating ETo among the three alternative techniques, the FAO-PM ETo and estimated ETo values were calculated and compared graphically as well as statistically at the 25 principal stations. Finally, the best fit model with the FAO-PM ETo was chosen and calibrated. This model was used to estimate ETo at the temperature stations in the region.

FAO-Penman-Monteith equation

The FAO has proposed FAO-PM ETo method as the standard method for estimating reference evapotranspiration [Allen, 1998] given by,

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

Where, ETo is the calculated reference evapotranspiration (mm/day), Rn is the net radiation at the crop surface (MJ/m^2 day), G is soil heat flux density (MJ/m^2 day), T is air temperature at 2 m height (^oC), u_2 is wind speed at 2 m height (m/s), e_s is saturation vapour pressure (Kpa), e_a is actual vapour pressure (Kpa), e_s-e_a is saturation vapour pressure curve (Kpa/^oC), γ is psychrometric constant (Kpa/ ^oC).

Hargreaves Model

In areas where climatic data such as solar radiation, wind speed and relative humidity data are missing, the Hargreaves model can be employed as an alternative to estimate ETo of a given area [Allen et. at., 1998]. Mathematically Hargreaves Model is given by:

$$ET_H = 0.0023 \times Ra \times (T_m + 17.8)(\mathrm{T_{max}} = T_{min})^{0.5} ,$$

Where, ET_H is estimated reference evapotranspiration (mm/day), Ra is extraterrestrial for daily period (mm/day), T_{max} and T_{min} are the maximum and minimum temperatures, and T_m is daily mean temperature. The monthly estimated ETo can be obtained by multiplying the number of days in a given month. The mathematical method of estimating Ra for a given latitudinal position and month is described by [Allen, 1998],

$$Ra = 0.408\frac{24(60)}{\pi G_{sc}}d_r[\omega_s \sin(\varphi)\sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_{s\omega}],$$

Where, G_{sc} is solar constant equals (0.0820 MJ/m^2/min), d_r is inverse relative distance Earth-Sun, ω_s is sunset hour angle in radian, φ φ is latitude in radian, and δ δ solar declination in radian.

Thornthwaite Model

Thornthwaite model is one of an empirical method used for estimating the evapotranspiration from mean temperature data. This method was developed principally from rainfall and runoff data of drainage basins. It has been used extensively by agriculturists, foresters, and agricultural meteorologists. The relative simplicity of the methodology is its few data requirement (i.e. only mean temperature and latitude data) contributed for wide usage and acceptance of this technique. Many users proved existence of high correlation between measured evapotranspiration and the Thornthwaite estimate even though the Thornthwaite method is empirical. The equation developed by Thornthwaite which relates the mean temperature to evapotranspiration is given by,

$$EP = 16\left(\frac{10T_m}{J}\right)^a,$$

Where, EP is potential evaporation in mm/month in a standard month of 30 days, J is yearly heat index written as,

$$J = \sum_1^{12}\left(\frac{T_m}{5}\right)^{1.514},$$

Where, T_m is the monthly mean temperature in month m, and a is an empirical exponent given by

$$a=0.000000675\,J^3 - 0.0000771\,J^2 + 0.01792J + 0.49239.$$

According to Thornthwaite for a month with D_m number of days and a mean day light hour N_m, estimated evapotranspiration ET_{Th} can be obtained from,

$$ET_{TH} = EP\frac{D_m N_m}{360}.$$

Blaney-Criddle method

Estimation of reference evapotranspiration (ETo) can also be done by empirical model which is developed by The Blaney-Criddle. Mathematically, it is defined as,

$$ET_B = P(0.46T_m + 8),$$

Where, ET_B in mm/month, P is the mean daily percentage of annual day time hours. The value of ET_B in mm/day can be obtained by dividing the number of days in a given month.

Statistical Analysis

The procedures and calculations of estimation of ETo for the three models were carried out by preparing a MATLAB script, while the FAO-PM ETo is obtained using Instat statistical software. Here, the estimated ETo results of the three models were subjected to statistical analysis by least square technique. This was done by considering the FAO-PM ETo as the dependent variable and ET_{TH}, ET_B, and ET_H as independent variables. Accordingly, a simple linear regression was developed using the following relation,

$$ETo_{est} = a \times [\text{an independent variable}] + \text{b},$$

Where, ETo_{est} is estimated ETo, a is slope and b is intercept of the regression line. Consequently, the values of the regression parameters were determined for each station by using least square. Then the performances of the models were evaluated using statistical parameters (i.e. Root Mean Square Error (RMSE) and Coefficient of Determination (R^2)). According to Gavilan et al. (2005) and Paulo et al (2009), the mathematical equation used for computing these standard parameters are,

$$\text{RMSE} = \sqrt{\frac{\sum_{i=0}^{12}(\text{ETo}-\text{ETo}_{est})^2}{12}}, \quad (\text{mm/day}),$$

Where, the summation is done over 12 months, ETo_{est} is the estimated ETo using an alternative models for each month.

On the other hand, the coefficient of determination (R^2) is given as ,

$$R^2 = \frac{\textit{explained variation}}{\textit{total variation}} = \frac{\sum_{i=1}^{12}(\text{ETo}_{est}-\overline{\text{ETo}})^2}{\sum_{i=1}^{12}(\text{ETo}-\overline{\text{ETo}})^2},$$

Where, $\overline{\text{ETo}}$ is mean of FAO-PM ETo over the twelve months.

Results and Discussion

Estimation of Reference Evapotranspiration (ETo)

Mean monthly ETo values obtained from the FAO-PM and estimated (ETo_{est}) results of the three alternative models were compared for the study period over 25 principal weather stations with a full data sets. The overall aim of analyzing these techniques is to choose best ETo estimating model for the Amhara Region. The mean monthly FAO-PM ETo in mm/day for the study period is shown in Table 1. Relatively higher values FAO-PM ETo is observed in March, April and May in the western Amhara while in the eastern part this is observed in April, May and June. Graphical analysis was also done to inspect patterns and trends of ET_{TH}, ET_B and ET_H with respect to the FAO-PM ETo in all stations.

It was generally observed that Blaney-Criddle method over estimates ETo values as compared to Hargreaves. On the contrary, Thornthwaite model under estimates ETo values in all stations with the exception of Matema station. Thornwaite model at Matema station showed significantly different pattern for the months of March, April and May. This might be attributed to the limitations of the model. That is, mean monthly temperatures of these months exceed 31^oC and the model was recommended only for areas where mean temperature ranges are less or equal to 26 ^oC [Paulo C. S. et al., 2009, Yagob D., 2006].

The values of the statistical parameters a, b, RMSE, and R^2 corresponding to the three alternative ETo estimation models were analyzed. The parameter RMSE is used to quantify the differences between the FAO-PM ETo and the EToest for the three models. The value of RMSE varied from 0.03 - 0.12, 0.04- 0.15, 0.07- 0.17 mm/day for the Hargreaves, Thornthwaite and Blaneye Criddle, respectively. Higher value of R^2 and lower value of RMSE are observed in 22 stations out of 25 for the Hargreaves model. The results of these parameters for each station and the value of the slope (a) and the intercept (b) for Hargreaves model (ET_H) are presented in Table 2.

FAO Penman–Monteith versus Hargrave method

Many research outputs have been reported for the calibration of the Hargreaves, the Thornthwaite and the Blaneye Criddle models using FAO-PM ETo as a reference [Gavilan et. al, 2005, Jabloun, 2008, Fooladmand et al., 2008]. In this paper, the statistical analysis presented in Table 2 shows that, Hargreaves model is the best model to choose among the alternatives tested for the region. Hence, in the Amhara

Region at the temperature stations the reference evapotranspiration can be calibrated from Hargraeves model using,

$$ETo_{est} = a \times ET_H + b.$$

Table 2. Mean Reference Evapotranspiration ETo (mm/day) using FAO-PM over Amhara Region (2000 - 2008)

Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Adet	3.13	3.28	4.19	4.27	4.15	3.42	2.99	2.99	3.44	3.49	3.16	2.59
BahirDar	3.33	3.90	4.41	4.68	4.48	3.78	3.07	3.02	3.43	3.78	3.46	3.07
Chagni	3.62	4.15	4.55	4.81	4.38	3.27	2.86	2.80	3.05	3.23	3.43	3.26
Dangla	3.19	3.73	4.12	4.28	4.12	3.26	2.88	2.84	3.22	3.10	3.04	2.95
Dmarkos	3.54	4.36	4.43	4.42	4.05	3.06	2.58	2.64	3.15	3.70	3.55	3.25
Dtabor	3.28	3.82	4.27	3.91	3.66	3.23	2.79	3.00	3.19	3.26	3.14	3.05
Gondar	3.91	4.59	5.02	4.97	4.75	3.49	3.01	3.21	3.72	3.82	3.75	3.54
Laybir	3.74	4.23	4.80	4.70	4.55	3.52	2.88	2.81	3.03	3.58	3.17	3.44
Metema	4.16	4.82	5.63	6.18	5.96	4.65	3.69	3.65	3.79	4.11	4.17	4.03
Nmewicha	3.18	3.82	3.43	3.49	3.76	3.03	2.46	2.46	2.90	2.97	2.75	2.64
Shahura	4.27	4.94	5.34	5.45	4.97	3.54	2.96	2.93	3.30	3.64	3.77	3.93
A/ketema	4.04	4.63	4.69	4.69	5.02	4.05	2.99	2.85	3.45	4.20	4.06	3.70
D/berihan	3.44	3.97	3.97	3.88	4.08	3.63	2.81	2.84	3.07	3.33	3.26	3.27
Enewari	3.98	4.51	4.49	4.24	4.63	3.62	2.53	2.52	3.26	3.94	3.80	3.60
Majete	3.13	3.94	4.25	4.30	4.92	4.67	4.19	4.02	3.82	3.97	3.57	3.31
M/Meda	3.33	3.86	3.87	3.68	4.28	3.84	3.03	3.01	3.54	3.67	3.28	3.15
Sh/Gebeta	3.27	4.02	4.21	4.10	4.28	3.55	2.81	2.70	3.09	3.62	3.40	3.09
Am/Mariam	3.30	4.05	4.00	4.01	4.37	3.75	2.93	2.95	3.32	3.59	3.31	3.16
Bati	2.91	3.62	4.09	4.31	4.80	4.77	4.18	4.05	3.85	3.72	3.38	2.97
Chefa	3.38	4.49	5.09	4.88	5.35	5.82	4.24	4.39	3.89	4.01	3.80	3.29
Kombolcha	3.14	3.80	4.09	4.31	4.55	4.39	3.94	3.96	3.69	3.49	3.27	3.01
Lalibela	3.96	4.43	4.55	4.65	4.78	3.83	2.74	2.84	3.42	3.95	3.69	3.58
Sirinka	2.87	3.76	4.24	4.47	4.90	4.93	3.87	3.80	3.69	3.71	3.37	2.87
Woreilu	4.02	4.44	4.44	4.50	5.10	4.35	3.09	3.04	3.58	4.21	3.84	3.59
W/Tena	3.26	3.76	4.01	3.89	4.69	3.67	2.79	3.01	3.33	3.45	3.30	3.21

Spatial Distribution of Mean Monthly ETo

To develop Iso - ETo map of the Amhara region, the values obtained at 44 stations (25 principal and 19 temperature stations) need to be interpolated spatially over the region. Use of thin-plate smoothing splines in Geo-statistical analysis is recommended for interpolating climate variables taking into account valued error prediction, data assumptions, and computational simplicity (Hartkamp et al., 1999.). Given one particular interval (x_k, x_{k+1}), linear interpolation in that interval can be given by the formula,

$$f = Af_k + Bf_{k+f}$$

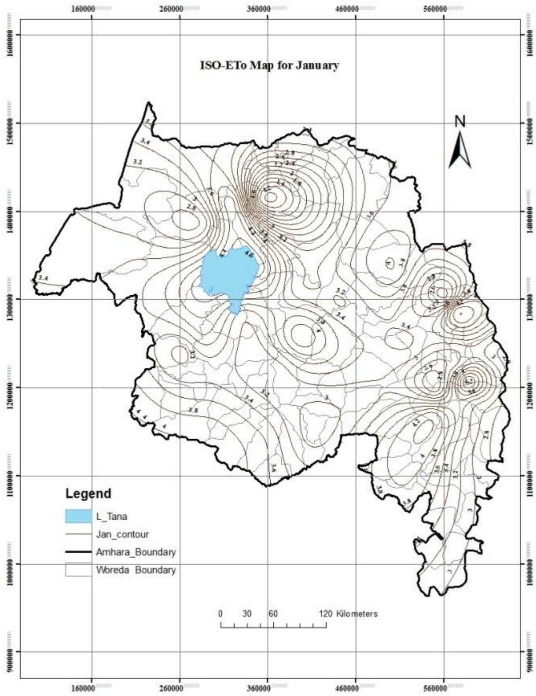
Where, $A = \frac{X_{k+1} - X}{X_{k+1} - X_k}$, $B = 1 - A = \frac{X - X_k}{X_{k+1\_} - X_k}$

The interpolated values were subject to cross-validation by sequentially omit a point and estimate its value using the rest of the data points, and compare the regression values with the interpolated values. The parameters obtained for a and b as shown in Table 3 are reasonable for spatial interpolation at the temperature stations. Finally, the spatial distribution of monthly ETo for each of the twelve months were developed for Amhara Region.

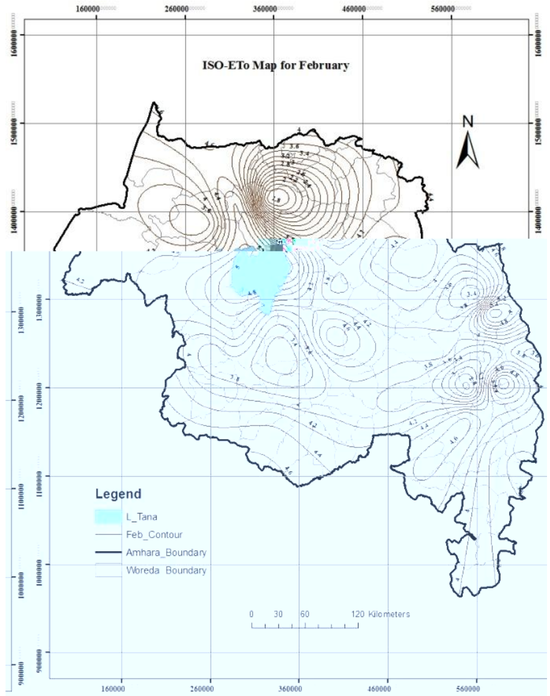
Iso-ETo map showing spatial distribution and trends of mean monthly reference evapotranspiration (mm/day) in the Amhara Region for the months January to December is indicated in the figures 2 ((a) to (l)) below.

Table 3. Values of statistical parameters for each principal station in the Amhara Region

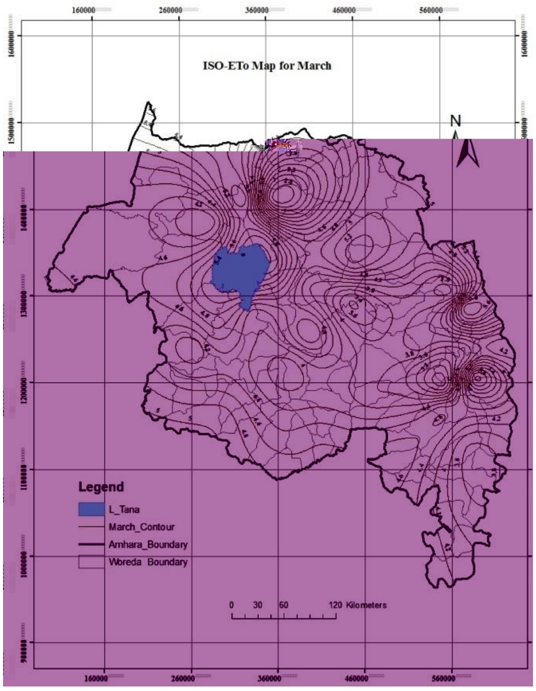
Station name	R^2			RMSE (mm/day)			$ETo_{est}=a*ET_H+b$	
	E_{TH}	ET_B	ET_H	ET_{TH}	ET_B	ET_H	a	b
Adet	0.7591	0.542	0.9245	0.07	0.1	0.04	0.7953	-0.2826
Bahir Dar	0.665	0.4472	0.8736	0.09	0.12	0.06	0.8982	-0.5181
Chagni	0.6434	0.3466	0.9466	0.11	0.15	0.04	0.8290	-0.4668
Dangla	0.5402	0.3628	0.9067	0.1	0.12	0.04	0.8081	-0.3115
Debre Markos	0.6708	0.3644	0.9396	0.1	0.14	0.04	1.1821	-1.1625
Debre Tabor	0.6595	0.373	0.8711	0.07	0.1	0.04	0.8525	-0.0039
Gondar	0.8509	0.4455	0.9683	0.07	0.14	0.03	1.2885	-1.8920
Laybir	0.9627	0.602	0.9678	0.04	0.12	0.04	0.9759	-1.4155
Metema	0.9625	0.689	0.9717	0.05	0.14	0.04	0.8882	-0.7677
Nefas Mewucha	0.7576	0.6456	0.6532	0.06	0.08	0.08	0.5402	1.7166
Shahura	0.9158	0.5153	0.7705	0.07	0.17	0.12	1.6240	-2.3872
Alem Ketema	0.8161	0.489	0.842	0.08	0.14	0.08	1.2106	-1.0719
Debre Birhan	0.1118	0.125	0.7476	0.12	0.11	0.06	1.0699	-0.5780
Enewari	0.4313	0.2035	0.8675	0.15	0.17	0.07	1.3045	-1.1666
Majete	0.76	0.7467	0.9483	0.07	0.07	0.03	0.8390	-0.1116
Mehal Meda	0.292	0.2643	0.5693	0.09	0.09	0.07	1.1062	-0.1836
Shola Gebeya	0.3221	0.2464	0.8165	0.12	0.13	0.06	1.5916	-2.0429
Amba Mariam	0.5169	0.4062	0.765	0.09	0.1	0.06	1.1228	-0.4649
Bati	0.8319	0.8367	0.9694	0.07	0.07	0.03	0.9473	-0.6687
Chefa	0.6706	0.6908	0.8439	0.12	0.12	0.09	1.1003	-1.5550
Kombolcha	0.7838	0.8092	0.9314	0.06	0.06	0.04	0.7921	0.0054
Lalibela	0.92	0.5421	0.884	0.05	0.12	0.06	1.3068	-1.4844
Sirinka	0.7332	0.7557	0.8818	0.1	0.09	0.06	0.9478	-0.4001
Woreilu	0.3121	0.206	0.5387	0.14	0.15	0.12	1.1211	-0.2746
Wegel Tena	0.3877	0.2759	0.713	0.11	0.12	0.08	1.0849	-0.4549


ISO-ETo Map for January
N
Legend
L_Tana
Jan_contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

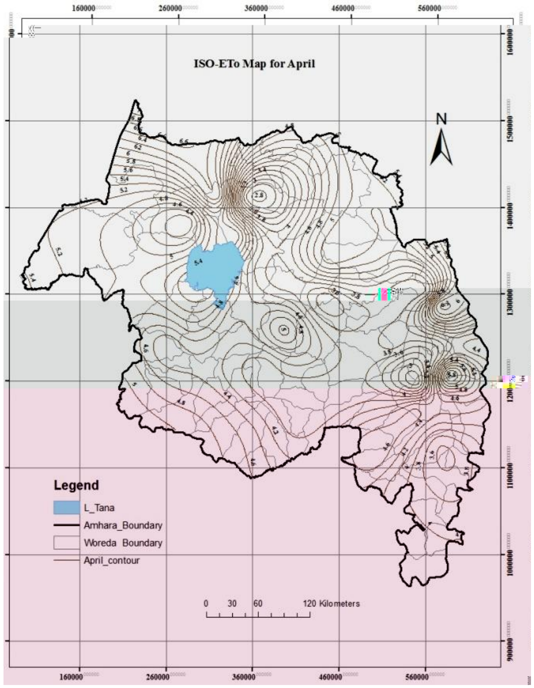
(a)


ISO-ETo Map for February
N
Legend
L_Tana
Feb_Contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

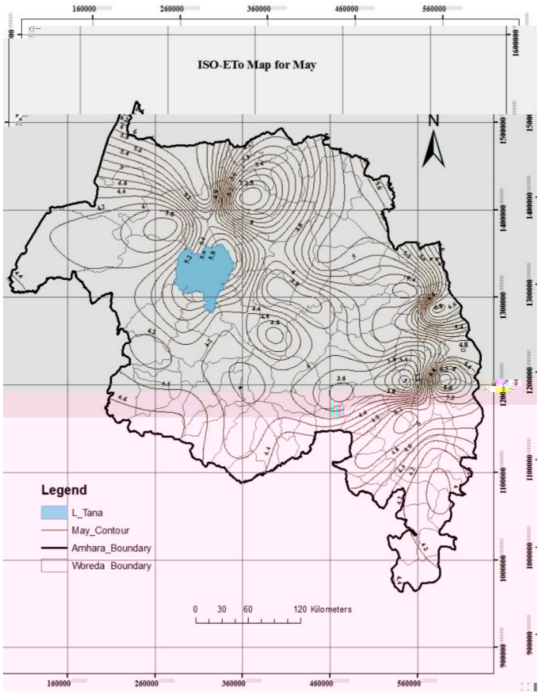
(b)


ISO-ETo Map for March
N
Legend
L_Tana
March_Contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

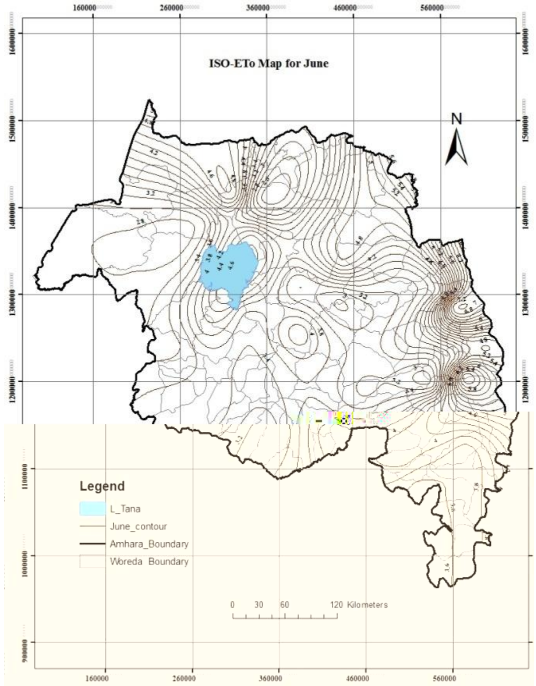
(c)


ISO-ETo Map for April
N
Legend
L_Tana
Amhara_Boundary
Woreda Boundary
April_contour
0 30 60 120 Kilometers

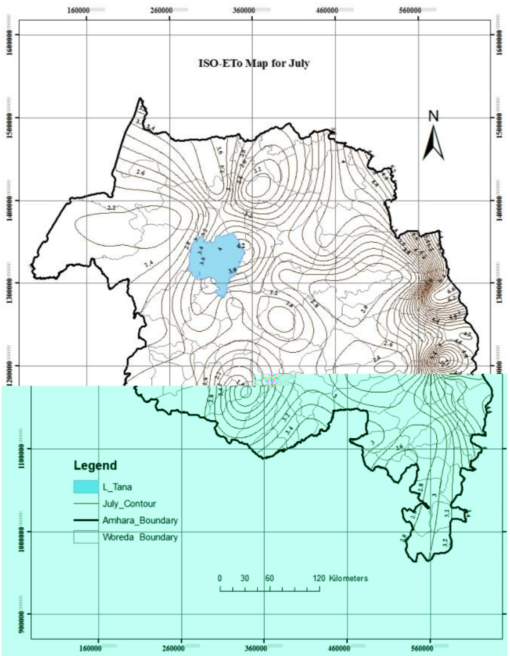
(d)


ISO-ETo Map for May
Legend
L_Tana
May_Contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

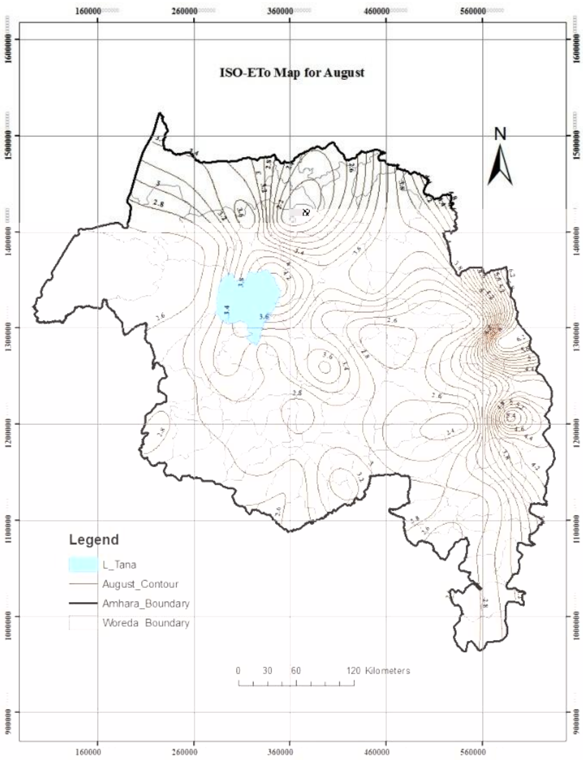
(e)


ISO-ETo Map for June
Legend
L_Tana
June_contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

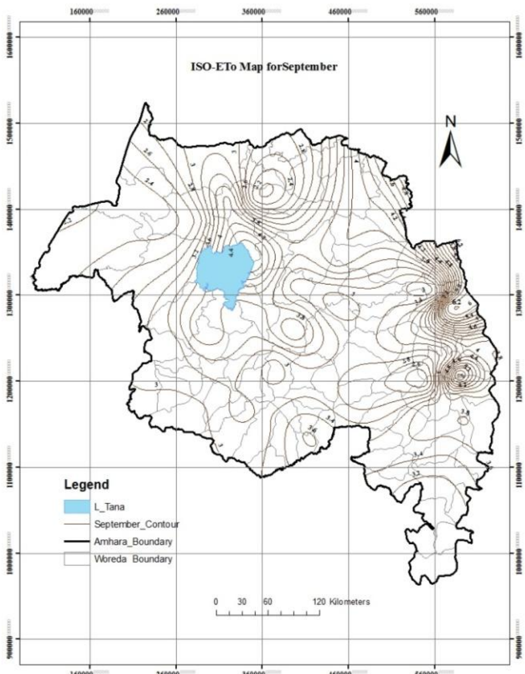
(f)


ISO-ETo Map for July
Legend
L_Tana
July_Contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

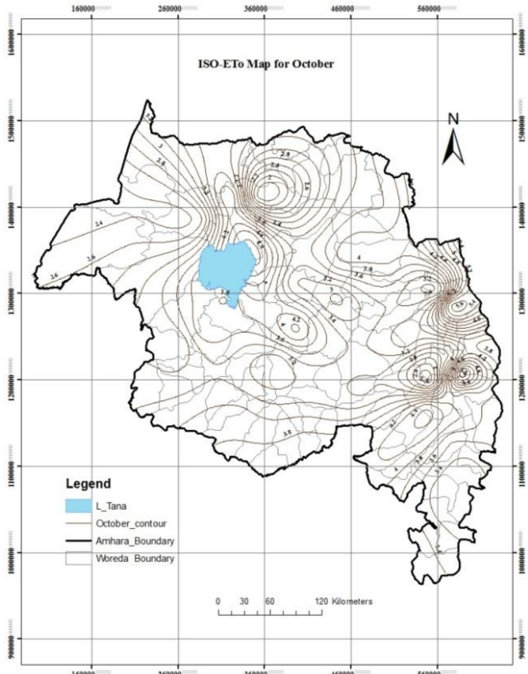
(g)


ISO-ETo Map for August
Legend
L_Tana
August_Contour
Amhara_Boundary
Woreda Boundary
0 30 60 120 Kilometers

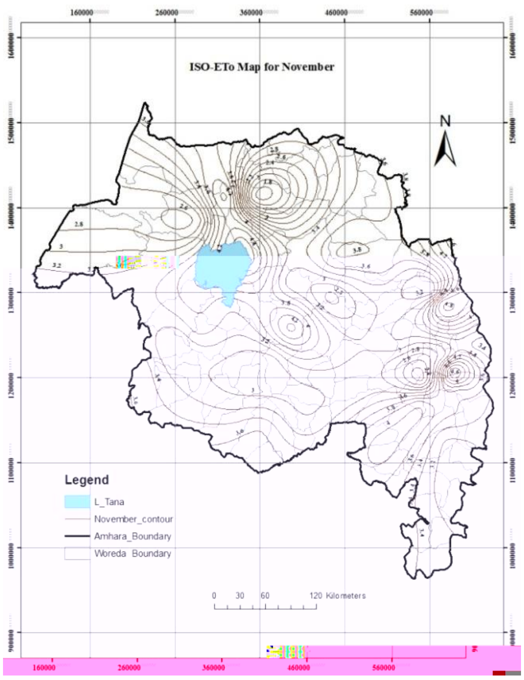
(h)



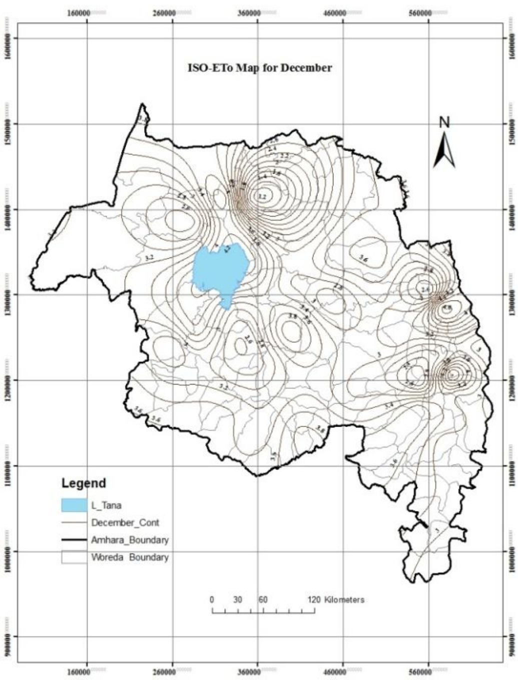
(i)



(j)



(k)



(l)

Figure 2 Spatial distribution of mean monthly reference evapotranspiration (mm/day) for the months January to December (i.e a to l) of Amhara Region

Table 4. The estimated ETo and the value of regression parameters, a and b, at the temperature stations

Sations	a	b	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Aykel	1.242	-1.579	2.94	3.85	4.26	4.42	3.94	3.07	2.45	2.87	2.79	2.66	2.77	2.68
AmbaGiorigis	1.250	-1.709	1.48	1.97	2.97	3.15	3.09	2.72	2.25	2.24	2.39	2.08	2.00	1.45
Debark	1.152	-1.155	2.61	3.18	3.68	4.05	3.63	2.77	2.46	2.20	2.53	2.77	2.62	2.14
Adis zemen	0.957	-0.436	4.43	5.15	5.90	4.43	5.54	4.48	4.16	4.21	4.49	4.59	4.36	4.05
Estie	0.812	0.209	4.16	4.71	5.00	5.06	4.92	4.11	3.60	3.65	3.96	4.23	4.24	3.95
Mota	0.864	-0.339	3.17	3.65	3.98	3.99	4.06	3.58	2.86	2.80	3.00	3.13	3.00	2.97
Dembecha	1.023	-1.082	3.58	4.28	4.48	4.48	4.25	3.25	1.76	2.98	3.26	3.62	3.15	3.36
Wotetabay	0.897	-0.581	3.76	4.25	4.71	4.79	4.54	3.80	3.33	3.23	3.72	3.69	3.47	3.70
Zegie	0.934	-0.609	3.86	4.50	5.05	5.26	5.14	4.51	3.72	3.46	3.67	3.61	3.60	3.65
Maksegnit	1.186	-1.410	4.12	4.76	5.67	5.40	5.43	4.34	3.57	3.94	4.27	4.43	4.25	3.81
Yetmen	1.143	-1.059	2.95	4.16	4.52	3.96	4.43	3.82	3.33	3.26	3.59	3.78	3.11	3.82
Sekota	1.069	-0.555	3.68	4.24	4.82	4.99	5.31	4.96	4.04	3.80	4.21	3.84	3.53	3.42
Kobo	1.042	-0.621	3.47	4.37	5.07	5.34	5.99	5.93	5.37	5.14	5.22	4.87	4.21	3.64
AynaBugna	1.185	-0.992	3.51	4.27	5.15	5.00	5.11	4.70	3.70	3.62	3.85	3.96	3.72	3.46
Kabie	0.908	-0.455	2.54	2.85	3.03	2.99	3.05	3.16	2.76	2.60	2.61	2.41	2.41	2.32
Harbu	1.034	-0.401	4.40	5.09	5.77	5.97	6.34	6.42	5.74	5.46	5.41	5.26	4.74	4.40
MekanSelam	0.960	-0.418	3.12	3.70	3.82	3.84	3.53	3.17	2.47	2.45	2.82	3.16	3.06	2.95
Mersa	1.156	-0.598	4.18	5.24	5.70	5.97	6.56	6.80	6.10	5.89	5.74	5.34	4.59	4.37
Haik	0.923	-0.367	3.21	3.88	4.20	4.34	4.54	4.87	4.31	3.90	3.97	3.93	3.69	3.33

Conclusion

Careful analysis of measured weather data with four widely used energy and mass balance models is done to generate regional information on spatial and temporal trends and distributions of mean monthly reference evapotranspiration in Amhara region. Based on results of the linear regression and the statistical parameters of RMSE and R^2, it can be concluded that Hargreaves model can be selected as the most appropriate model for calibration in the process of estimating ETo in the region. The reference evapotranspiration at 44 meteorological stations in the region is produced. Accordingly, spatial distribution of mean monthly ETo map (ISO-ETo Map) is produced for all months using suitable interpolation technique. This work can be used as an input for agricultural research and development in water resource planning, irrigation scheduling, design of irrigation schemes and hydrological studies in Amhara region.

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References

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., (1998). Crop evapotranspiration: Guidelines for computing crop water requirements. FAO Irrigation and Drainage Paper no. 56, Rome.

Fooladmand H.R. , H. Zandilak and M. H. Ravanan, (2005), Comparison of different types of Hargreaves equation for estimating monthly evapotranspiration in the south of Iran, *Archives of Agronomy and Soil Science, Vol. 54, No. 3, P 321–330.*

Gavilan. P, I.J. Lorite, S. Tornero, J. Berengena, (2005), Regional calibration of Hargreaves equation for estimating reference ET in a semiarid environment, *Journal of Agri. water managment*, 81 (2006) 257 281.

Hartkamp, A.D., K. De Beurs, A. Stein, and J.W. White. 1999. Interpolation Techniques for Climate Variables. NRG-GIS Series 99-01. Mexico, D.F.: CIMMYT.

Jabloun. M , A. Sahli, (2008), Evaluation of FAO-56 methodology for estimating reference evapotranspiration using limited climatic data Application to Tunisia, *Journal of agri. and water management 95(2008)707-715.*

Paulo C. Sentelhas , Terry J. Gillespie , Eduardo A. Santos , (2009), Evaluation of FAO Penman Monteith and alternative methods for estimating reference evapotranspiration with missing data in Southern Ontario, Canada, *Journal of Agri. water managment, 97 (2010) 635–644.*

Yagob Dinpashoh, (2006), Study of reference crop evapotranspiration in I.R. of Iran, *Journal of agri. and water management, 84(2006)123-129.*