International Journal of Natural Resource Ecology and Management
2021; 6(3): 108-115
http://www.sciencepublishinggroup.com/j/ijnrem
doi: 10.11648/j.ijnrem.20210603.12
ISSN: 2575-3088 (Print); ISSN: 2575-3061 (Online)

Spatial and Temporal Variability Analysis and Mapping of Reference Evapotranspiration for Jimma Zone, Southwestern Ethiopia

Minda Tadesse

Jimma Agricultural Research Centre, Ethiopian Institute of Agricultural Research, Jimma, Ethiopia

Email address:
mindat9@gmail.com

To cite this article:
Minda Tadesse. Spatial and Temporal Variability Analysis and Mapping of Reference Evapotranspiration for Jimma Zone, Southwestern Ethiopia. *International Journal of Natural Resource Ecology and Management*. Vol. 6, No. 3, 2021, pp. 108-115.
doi: 10.11648/j.ijnrem.20210603.12

Received: May 15, 2021; **Accepted**: July 13, 2021; **Published**: July 22, 2021

Abstract: ETo is important parameter in determination of crop water requirement and in irrigation scheduling. The absence of rainfall during four to six months of the year affects crop production. Study was undertaken in Jimma zone, Southwestern Ethiopia, with the objective of evaluating and characterizing the reference evapotranspiration and mapping for planning and management options for Jimma Zone. The study was undertaken at 22 sites of which 14 being from Jimma zone and the remaining eight sites were from around the vicinity of study area. The ETo was estimated using Penman–Monteith method in CROPWAT 8.0 software with monthly datasets of 22 stations for the period of 31 years. The results of ETo were further analyzed by means of geo-statistical tools in R software using gstat package. Maps were created using ordinary kriging combined with regression method. The results have shown that the ETo, have shown moderate to greater variability. The high annual and monthly ETo values were observed around the extreme eastern tip, extreme southern tip and north western tip. In contrary low ETo values were observed in southeastern and western regions. March (4.61 mm/day) and July (2.97mm/day), respectively, presented the highest and the smallest ETo. The ETo for Jimma zone is a good indicator and benefits to farmers to help in planning the water resources of the area for best irrigation water management practices.

Keywords: Reference Evapotranspiration, Spatial and Temporal Variability, Mapping of ETo, Spatial Distribution

1. Introduction

Water is one of the most important inputs essential for the crop production because plants require water for growth and tissue expansion. Plants need water continuously during their life and in huge quantities [1]. However, over 90% of the water required by plants is lost through transpiration [2]. Thus, the evapotranspiration is an important hydrological process [3]. Hence improved water management in agriculture depends on reliable estimates of water use by plants [4].

The first step in estimation of crop water requirement is determination of evaporative demand of atmosphere, which is expressed as the reference evapotranspiration [5]. Its accurate estimates were important in irrigation management. However, direct measurement is both inconvenient and expensive. For this reason, many methods have been developed for estimating ETo from climate data [6, 7]. However, despite difference in their climate data requirement, most of the methods lack required accuracy in estimating the value of ETo for any particular area. But, Penman Monteith method provides more accurate estimation of ETo [7]. The major environmental factors affecting ETc are climate and water which limiting plant growth [8]. Crop water requirement can be either directly measured or in-directly estimated. Direct measurement is remains challenging, because it is expensive and time consuming [9] particularly for developing country like Ethiopia. Among in-direct methods, ETc estimated by combining ETo and Kc, is the widely used method. But it is impractical for large areas, to resolve this problem, ETc estimates from ETo is among best alternatives at stations [10].

In recent year, drought severity happed frequently in Jimma zone. For example, in 2016/17 during dry years, hundreds hectares of crops and animal forage were devastated due to the lack of supplemental irrigation [11]. This is happed because of farmer practiced poor irrigation management; they just traditionally wait for rain. One of the main problems of the irrigator is not know the amount of water that has to be applied to the field to meet the water needs of the crops. In addition, most farmers in study area have not an appropriate plan for irrigation [12].

As Jimma is a large zone also in practice estimating of ETo at every spatial location is difficult from sparsely distributed data. Geo-statistical interpolation methods such as ordinary kriging are a promising tool to overcome this problem. It generates both spatial autocorrelation and prediction map depending up on semi-variogram and distance [13]. However, ordinary kriging method is not capable of using secondary information as predictor. Thus, combined method of ordinary kriging with linear regression helps to solve this problem [14]. For areas like Jimma, which is characterized by diverse topography and limited number of stations, using auxiliary information such as elevation plays significant role in improving interpolation quality.

The temporal and spatial distribution of rainfall throughout the year is un-evenly distributed in Jimma zone. Over 71.1% of rainfall is received during the rainy summer season (June to September) while the rest 28.9% received during eight months (October to May). This means atmospheric water demand is greater than rainfall during dry spells. To achieve effective planning on irrigation water management, accurate information is needed for potential evapotranspiration. The availability of spatial and temporal ETo information is limited in study area and yet not estimated. In addition, the shortfalls of data at a regional scale and for irrigation project design engineers. The objective of this study was to analyze and characterize the ETo and mapping for planning and management options for Jimma zone.

2. Materials and Methodology

2.1. Description of Study Area

The study was conducted in one of coffee growing areas of Jimma zone, Oromia region state, south west of Ethiopia. It is geographically located approximately between 7° 5' 38"N - 8° 54' 19" N latitude and 34° 49' 34" E - 38° 39' 17" E longitude with maximum and minimum altitude of 3231 and 859 m above sea level, respectively. Due to altitudinal differences, the zone has great physiographic diversity. The zone has a total area of about 19,293.5 km^2. It has 19 districts and one administrative town with a total of 545 kebeles (lowest administrative units) of which 515 of them are rural and 30 are urban.

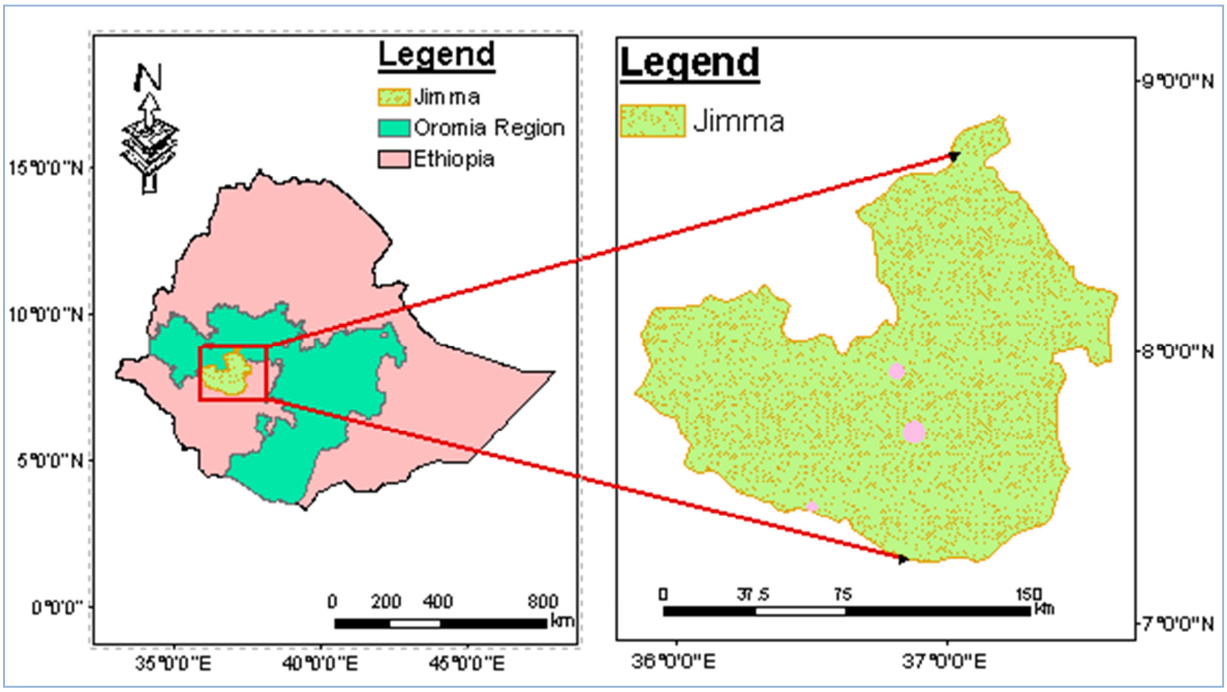

Figure 1. *The location Map of the study area.*

2.2. Procedures

2.2.1. Selection of Meteorological Station

The Thiessen polygon method [15] was used to select spatially representative stations and clipped to study area's boundary in ArcGIS 10.1. Accordingly, 20 stations were clipped to study area as of polygon. It includes Chida, Gojeb, Shebe, Dedo, Jimma, Yebu, Gore, Bedelle, Arjo, Ejajji, Atinago, Limmu-genet, Natri, Sokoru, Yaya, Wolkite, Botorbacho, Gatira, Chira, Agaro and Asendabo. Additionally 2 stations were added to increase the extent of data to cover the entire area of zone; it includes Gore and Bonga. Hence a total 22 stations were used for this study, fourteen being in Jimma zone and remaining eight from around the vicinity of study area (Figure 2).

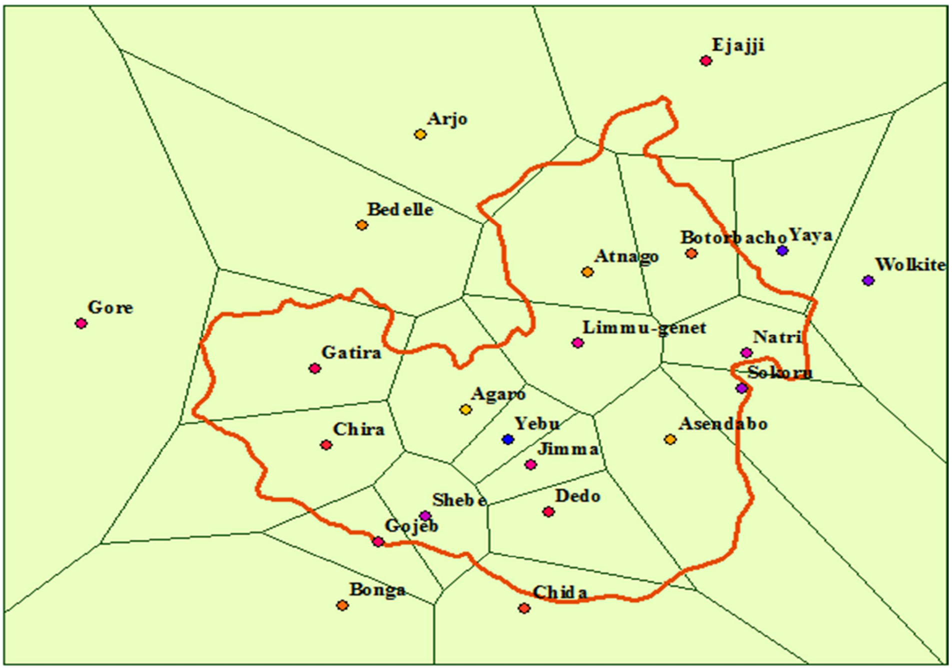

Figure 2. *Meteorological stations and selected stations by Thiessen polygons.*

2.2.2. Meteorological Data and Data Management

The daily climatic data for the period 1985 through 2016 (31 years) were collected from ENMA. These collected climate data series includes maximum temperature, minimum temperature, and wind speed at 2 m height, relative humidity, sunshine hours and rainfall.

Climate Data Processing: The climate time series at stations is require careful analysis for their missing value, validity and homogeneity test before use. The monthly climate data were tabulated in “Table” for each month starting from 1985 to 2016.

Filling missed climate time series: These were entered in R-software with MICE package [16]. The monthly missed climatic variables including rain fall were entered from the same months in the given time interval (1985-2016) using multivariate imputation and chained equations method.

Homogeneity test of time series: Standard normal homogeneity test (SNHT) method proposed according to [17] was used for detecting inhomogeneity of annual mean or total climate time series of Tmin, Tmax, RH, WS, sunshine hours and rainfall data from 1985-2016 at gauging stations. SNHT performed using XLSTAT 2017 software [18]. Change in average or a presence of trend was detected.

The breaks in a certain year were corrected by double mass slopes with help of Hydrognomon software [19].

Importing monthly Wind speed, relative humidity and sunshine hours: Agglomerative hierarchical clustering classification method [20] was used to classify meteorological stations into similar climate regime with an input of parameter latitude, longitude, altitude, Tmin, Tmax, and precipitation. The similarity between meteorological stations was calculated using Ward's method [21]. The Euclidian distance was used to determine the distance between stations as dendrogram height.

2.2.3. Estimation of Reference Evapotranspiration

The CROPWAT 8.0 models based on Penman -Monteith equation was used for estimation of ETo for each meteorological stations: The ETo was calculated using equation 3.3:

$$\mathrm{ET_O} = \frac{0.408\,\Delta(\mathrm{R_n}-\mathrm{G1})+\gamma\frac{900}{\mathrm{T}+273}\mathrm{u_2}(\mathrm{e_s}-\mathrm{e_a})}{\Delta+\gamma(1+0.34\mathrm{u_2})} \quad (1)$$

where, $\mathrm{ET_O}$: Reference evapo transpiration [$\mathrm{mm\ day^{-1}}$], $\mathrm{R_n}$: Net radiation at crop surface [$\mathrm{JM\ m^{-2}\ day^{-1}}$], G: soil heat flux [$\mathrm{JM\ m^{-2}\ day^{-1}}$], T: mean daily temperature [°C], u_2: Wind speed at 2m height [$\mathrm{m\ s^{-1}}$], $(e_s - e_a)$: Saturation vapor pressure [kPa], Δ: Slope vapor pressure curve [kpa $℃^{-1}$], γ: Psychrometric constant [kpa $℃^{-1}$]

The monthly values of climate parameters T max (°C), T min (°C), RH (%), wind speed (km $\mathrm{day^{-1}}$) at 2 m height and sunshine hours of each year was fed into a computer-based CROPWAT 8.0 for windows. The monthly ETo values for each year from the long-term meteorological data were obtained from CROPWAT 8.0 [22].

The accuracy of ETo estimation through CROPWAT 8.0 from limited climatic data was evaluated with that of full set of climatic data. The accuracy of exported data from neighboring stations was also accessed with that of ETo estimated from full set of climatic data.

The monthly long-term from 1985 to 2016 (31 years) ETo data obtained were entered and fitted to different standard frequency distribution models using a computer-based routine, Rainbow software [23]. The distribution that best fitted the data was used to work out ETo occurrence at 80 percent probability of non-exceedance level. Kolmogorov-Smirnov (KS) test was used to test monthly ETo (185-2016) normality for individual station separately in rainbow software. Homogeneity test of monthly ETo was performed based on the cumulative deviations from the mean [24] in rainbow software. Once the normality and homogeneity of ETo data was checked for individual station, the ETo at 80 percent probability of non-exceedance was taken out for all stations. Then the extracted regional monthly ETo values was again subjected to normality test using Shapiro-Wilk test.

2.3. Statistical Analysis of ETo

ETo estimated at each station were further analyzed with non-parametric comparison (Kruskal-Wallis), to detect monthly variation, where station considered as replication and month as treatments, the monthly means were compared using LSD test in R-softwatre at $p<0.05$.

2.4. Mapping of ETo

To improve the accuracy of estimation, a linear regression equation was developed between observed data and station's elevation. Using the above regression equation the residuals of ETo were estimated as the difference between observed and predicted values at gage locations. Then the residuals of ETo value were interpolated using ordinary Kriging over the entire region. Using DEM and regression equation, station based data was further extended to 5km spatial grids. The experimental semi-variogram was calculated and variogram models were fitted for extended dataset of ETo. Next ETo for each month starting from January to December were interpolated to 1km×1km spatial resolution by ordinary kriging using gstat package [25] in R software [26].

The final estimation of ETo and ETc at any location were obtained by:

Final prediction = residual interpolated map + regression kriged map

The performances of the each fitted model prediction at un-sampled location were checked by RMSE. The measured data at 22 stations were used to cross-validation by living one out method; the model with smallest values of RMSE was selected for final interpolation [27]:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(O_i - p_i)^2}{n}} \quad (2)$$

where: RMSE is root mean square error, O_i is obseverd value, P_i is predicted value, n is number of samples.

3. Results and Discussion

3.1. Validation of CROPWAT 8 Model

The results revealed that the ETo estimated from exported data from similar climate regime have good agreement with that of ETo estimated from full set of climatic data at Jimma stations. The root mean square error (RMSE) value was 0.14 mm/day. It was also exhibited by strong correlation coefficient of R^2 value of 0.88. While, the ETo estimated from limited data have lower accuracy to estimate ETo, because when compared to ETo estimate with full set of climatic data have RMSE value of 1.24 mm/day and R^2 value of 0.6. The result show that the relation between ETo estimated from exported data and full data were better for estimation of monthly ETo (Table 1).

Table 1. *ETo estimated from full, exported and CROPWAT estimated data at Jimma station for 2015.*

Month	CROPWAT (full data)	exported data	CROPWAT estimated
January	3.52	3.66	5.37
February	4.15	4.25	5.88
March	4.47	4.65	6.02
April	4.35	4.52	5.44
May	4.29	4.05	5.08
June	3.46	3.45	4.65
July	2.71	3.07	4.06
August	3.18	3.27	4.48
September	3.78	3.62	4.78
October	3.88	3.81	4.73
November	3.75	3.75	4.44
December	3.74	3.78	4.93
Annual	3.77	3.82	4.99
RMSE		0.14	1.26
Adjusted R^2		0.88	0.60

3.2. Cross-validations of Models

Among the fitted models, the exponential model has superior performance in producing lower RMSE in seven situations including March, April, May, June, Jul, August, November, and annual. The spherical model produced smaller RSME during the month of February, October and December, whereas, the Gaussian model produced lower RMSE during the months of January, June and September (Table 2).

Table 2. *RMSE value between modeled monthly ETo and observed ETo values.*

Month	Ordinary kriging		
	Spherical	Exponential	Gaussian
January	0.16	0.16	0.15*
February	0.18*	0.19	0.22
March	0.22	0.19*	0.20
April	0.23	0.20*	0.28
May	0.20	0.19*	0.23
June	0.26	0.21*	0.22
July	0.22	0.17	0.16*
August	0.24	0.22*	0.23
September	0.25	0.25	0.24*
October	0.24*	0.24	0.24
November	0.23	0.22*	0.24
December	0.21*	0.21	0.22
Annual	0.19	0.18*	0.20

RMSE=Root mean square error, "*" = is selected model for interpolation.

3.3. Annual and Monthly Spatial Distribution of Reference Evapotranspiration

Annual ETo varied from 3.53 to 4.20 mm day^{-1} and averaged 3.84 mm day^{-1} when all 22 weather stations were combined (Table 3). Figure 3 M clearly indicates that the maximum annual ETo value were located in southern tip (Shebe-Sombo, Dedo and Omonada), northeastern (Botor-Tollay) and eastern (Sokoru) regions. Of the locations, highest annual ETo value (4.5 mm day $^{-1}$) was found in extreme eastern tip. The minimum annual ETo value in Jimma zone were located in the western highlands (Gera, Setama, Sigmo and Gatira), southern (Dedo and Seka-Chekorsa) and northeastern regions. From these areas, lowest ETo value (3.2 mm day^{-1}) was located in southeast part at mount Maigudo, corresponding to highest places in the zone. The lowest ETo had a reduction of 25.1% as compared highest ETo predicted in extreme southern tip.

In general, ETo was smaller in highland areas because it is associated with colder climate and higher precipitation. However, ETo was higher in low altitude areas, hence it is associated with warmer climates. Thus, the spatial variability of predicted ETo value caused by varied elevation. The decrease of ETo with altitude is in accordance with the decrease of air temperature with altitude. Because an altitudes have significant strong negative correlation with annual ETo in Jimma zone (Table 4). The lower ETo in the highland areas may contributed from altitudinal difference, the highland areas characterized by high altitudes as compared to lowland areas. This means the greater altitude of an area is the smaller temperatures, as altitudes increase the temperature decreases because the temperature is the major climatic factor, which affects ETo [7]. With increasing elevation, the air temperature decreases and RH increase; thus, the ETo generally decreases [28]. ETo will vary with altitude, every 1000 m rise in altitude will result in 10% ETo reductions [6].

The monthly ETo spatial distribution presented in Figure 3 has shown some variations through the year. The spatial distribution was more or less similar for monthly and annual ETo values. The monthly ETo increases from the southern highland areas towards the extreme southern tip lowlands and again increase from eastern highland to extreme eastern tip lowland areas along Gibe river basin, whereas ETo had decreasing trend from central region to western highland region of Jimma zone.

There were significant ($p<0.01$) temporal variations in monthly ETo values from January to December across Jimma zone (Figure 3). The maps show a decrease from March to July and increase from December to March. The high ETo values were predicted from January to May and the values ranged from 3.94 to 4.97 mm day^{-1}, corresponding to dry season. Of all months, the highest ETo value was predicted in March and the value varied from 4.12 to 4.97 mm day^{-1} (Figure 3). The highest ETo value in March might due to warmer air and lower humidity. During dry season, high amount of energy was available when temperatures are higher.

ETo values during summer season (July to September) was sufficiently low and the values ranged from 2.24 to 3.99 mm day^{-1} with the mean of 3.18 mm day^{-1}. Summer season is a main rainy season in Jimma zone. Of these months, the smallest ETo value was predicted during the rainy month of July and the values varied from 2.34 to 3.43 mm day-1 (Figure 3 G, H and I). ETo during July had a reduction of 35.9% as compared to march. This low ETo value during rainy season may associated to lower air temperature and higher humidity, which suppressed by progressed rain fall. According Singo et al. [28] who reported that the evapotranspiration rates tended to drop to low levels when the air around the plants was too humid during rainy season. Moreover, the temporal variation of ETo was observed due to changes in solar radiations as a result of a change in the season. The monthly ETo values varies with same pattern with maximum air temperature and sunshine hours, but varies in opposite direction with rainfall. Sunshine hour duration had strong positive significant correlations with monthly ETo of November, December, January, April, and May with the correlation values ranged from 0.79 to 0.89 (Table 4). Usually the rises of temperature are happen, due to clear sky during dry season, and consequently increasing ETo.

Maximum air temperatures had positively strong significant correlation (0.57* to 0.80***) with 12 months and annual ETo values. Implying seasonal ETo values was mainly affected by maximum air temperature (Table 4), as air temperature increases ETo will increase. This phenomenon was confirmed by Rasul and Farooqi [29] who stated that an increase in temperature will directly influence the evapotranspiration rate of atmosphere. The rainfall was negatively correlated with ETo especially during the rainy month of July (-0.50), i.e. as rainfall increases ETo become decreased (Table 4). Summer rainfall plays a vital role in reducing the evaporative demand to some extent [30]. In equatorial countries like Ethiopia, the difference in ETo is due to cloud cover, temperature and relative humidity [32].

This result was in agreements with Savva and Frenken [32] who reported that ETo value of 4.2 mm day^{-1} for April at Jimma zone. Similar finding was reported by [33] who reported that ETo values varied from 3 to 5 mm day^{-1} for February at Jimma Zone areas. Also similar results of ETo values were reported by [34] with the values varied from 4.01 to 5.24 mm day $^{-1}$, with mean of 4.62 mm day^{-1} at Akaki areas. They found out that lower and higher ETo values during rainy and dry season respectively.

Table 3. *Statistical analysis of monthly and annual ETo for Jimma zone.*

Station ETo							**Model predicted**		
Period	**Mean (mm)**	**Max (mm)**	**Min (mm)**	**SD**	**CV (%)**	**Shapiro-Wilk P-value**	**min (mm)**	**mean (mm)**	**max (mm)**
January	3.91^{de}	4.23	3.70	0.15	3.84	0.51	3.49	3.90	4.22
February	4.43^{b}	4.79	4.10	0.18	4.18	0.95	3.94	4.42	4.79
March	4.61^{a}	4.99	4.20	0.20	4.44	0.77	4.12	4.60	4.97
April	4.47^{b}	4.89	4.11	0.20	4.50	0.92	4.17	4.46	4.67
May	4.12^{c}	4.47	3.66	0.19	4.62	0.91	3.63	4.10	4.48

Station ETo							Model predicted		
Period	Mean (mm)	Max (mm)	Min (mm)	SD	CV (%)	Shapiro-Wilk P-value	min (mm)	mean (mm)	max (mm)
June	3.59^{g}	3.94	2.98	0.26	7.22	0.33	2.90	3.57	4.10
July	2.97^{j}	3.25	2.57	0.19	6.53	0.21	2.34	2.95	3.43
August	3.04^{i}	3.34	2.46	0.23	7.64	0.12	2.24	3.02	3.63
September	3.42^{h}	3.70	2.88	0.23	6.82	0.11	2.64	3.40	3.99
October	3.95^{d}	4.40	3.39	0.23	5.80	0.75	3.37	3.93	4.37
November	3.85^{e}	4.30	3.43	0.23	5.89	0.92	3.16	3.84	4.36
December	3.78^{f}	4.14	3.46	0.20	5.29	0.54	3.13	3.76	4.26
Annual mean	3.84	4.20	3.53	0.19	5.05	0.85	3.17	3.77	4.23
LSD (0.05)	0.06								

Means followed by the same letters in a column are not significantly different from each other at a 5% probability level, CV= coefficient of variation, SD=standard deviation

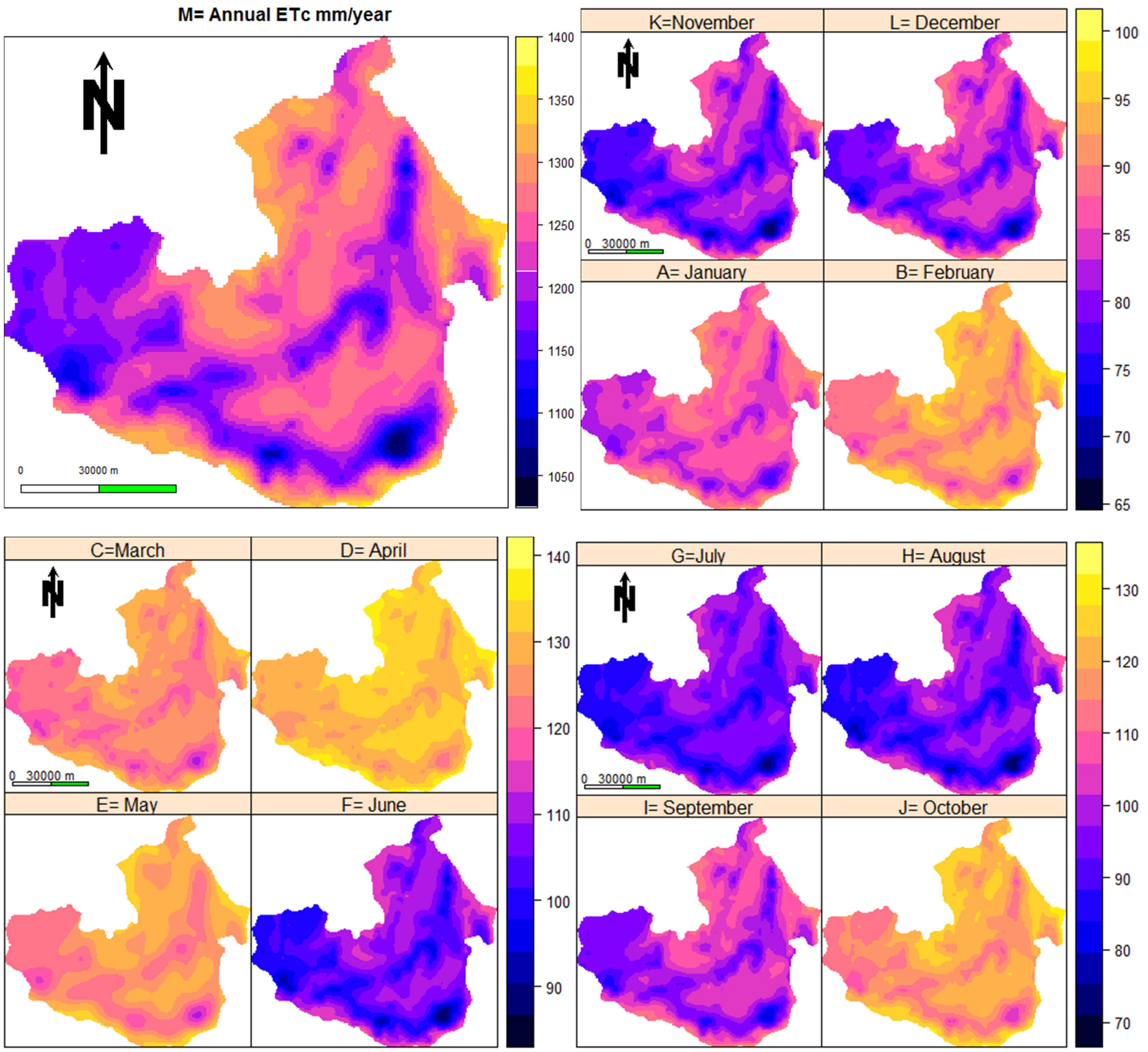

__Figure 3.__ ETo kriging maps of annual and monthly ETo for Jimma zone.

Table 4. *Pearson Correlations of monthly ETo with metrological parameters.*

Period	**Monthly Metrological parameters**				
	Altitude	**Tmin**	**Tmax**	**Sunshine**	**Rainfall**
January	-0.69**	0.43*	0.69**	0.88*	-0.11
February	-0.64**	0.47*	0.65**	0.83*	-0.07
March	-0.58**	0.38	0.61*	0.86*	-0.21
April	-0.34	0.26	0.41	0.89*	-0.43
May	-0.62**	0.39	0.57*	0.83*	-0.32
June	-0.65**	0.29	0.66**	0.52	-0.42
July	-0.78***	0.24	0.77***	0.54	-0.41
August	-0.84***	0.33	0.8***	0.39	-0.50*
September	-0.81***	0.39	0.76***	0.44	-0.34
October	-0.61**	0.34	0.59**	0.68	-0.22
November	-0.75**	0.37	0.76***	0.79*	-0.33
December	-0.79***	0.43*	0.77***	0.83*	-0.12
Mean	-0.78**	0.42*	0.75***	0.79*	-0.44*

*, ** and *** = significant at 0.05, 0.01 and < 0.0001 level, respectively, WS= wind speed, RH=relative humidity

4. Conclusions

From the results maximum ETo was observed around the extreme southern tip and extreme eastern tip region. Whereas smaller values were founds around western and southern part. The temporal variation of ETo was significant, the highest ETo value was recorded during dry season in March (4.61mm day^{-1}) and the smallest in July during major rainy season. Lastly, Results of this study may literally help for designing purposes for engineers and irrigation practitioners in the absence of data. In view of the explicit distinction made by the geo-spatiality of the ETo in Jimma zone, a correct understanding of the ETo value for each locality will be most useful to farmers, where irrigation management is concerned. However, for more accurate ETo estimation, it should be supplemented with replicated field experiment and satellite image.

References

[1] Nidhi, J. S. and H. M. Petel. 2012. Estimation of water requirement in mahi right bank canal command area. India

[2] Morison, J. I, N. R. Baker, P. M. Mullineaux and W. J. Davies. 2008. *Improving water use in crop production. Philosophical Transactions of the Royal Society B: Biological Sciences* 363 (1491): 639-658.

[3] Lu, J. B., G. Sun, S. G. McNulty and D. M. Amataya. 2005: A comparison of six potential evapotranspiration methods for regional use in the southeastern United States. *J American Water Reso. Asso.* 41: 621-633.

[4] Pereira, H. C., 1957. Field measurements of water use for irrigation control in Kenya coffee. *J Agri. Sci. 49* (4*)*: 459-466.

[5] ASCE (American Society of Civil Engineers). 2005. The ASCE Standardized Reference Evapotranspiration Equation. American Society of Civil Engineers, Reston, VA, USA

[6] Doorenbos, J, and W. O. Pruitt, 1977. Crop water requirements. FAO Irrigation and Drainage Paper 24, FAO. Rome. Italy.

[7] Allen, R. G., L. S. Pereira, D. Raes and M. Smith. 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrig. Drain. Paper No. 56. FAO. Rome, Italy.

[8] Sijali, I. V., 2001. Drip irrigation: Options for smallholder farmers in Eastern and Southern Africa (No. 24). Regional land management unit. Nairobi, Kenya, 70 pp.

[9] Amatya, D. M., S. Irmak, P. Gowda, G. Sun, J. E. Nettles, K. R. Douglas-Mankin. 2016. Ecosystem evapotranspiration: challenges in measurements, estimates, and modeling. *Trans. ASABE* 59: 555–560.

[10] Lemos Filho, L. C. D. A., C. R. D. Mello, M. A. D. Fariaand and L. G. D. Carvalho. 2010. Spatial-temporal analysis of water requirements of coffee crop in Minas Gerais State, Brazil. *Brazilian J Agri. and Enviro. l Engg 14* (2): 165-172.

[11] ECFF (Environment and Coffee Forest Forum). 2017. Coffee farming and climate change in Ethiopia. Impacts, forecasts, resilience and opportunities summary report*. Enviro. Manag.* 24 (1): 39-54.

[12] JZIA (Jimma Zone Irrigation Authority). 2017. Annual report of Jimma Zone irrigation development, Jimma Zone. Unpublished report

[13] Li, J. and A. D. Heap. 2008. A Review of Spatial Interpolation Methods for Environmental Scientists. Geoscience Australia, Australia, 137 pp.

[14] Knotters, M., D. J. Brus and J. H. Voshaar. 1995. A comparison of kriging, cokriging and kriging combined with regression for spatial interpolation of horizon depth with censored observations. Geoderma 67: 227-246.

[15] Fiedler, F. R. 2003. Simple, practical method for determining station weights using Thiessen polygons and isohyetal maps. *Journal of Hydro. l Engg* 8 (4): 219-221.

[16] Van Buuren, S. and K. Groothuis-Oudshoorn. 2011. MICE: Multivariate Imputation by Chained Equations in R. *J Stat Software* 45 (3): 1-67.

[17] Alexandersson, H. 1986. A homogeneity test applied to precipitation data. *J Clim* 6: 661-675.

[18] Addinsoft, S. A. R. L. 2017. XLSTAT Premium version 19.5: A complete statistical add-in for Microsoft Excel. Addinsoft SRL, Paris, France.

[19] Kozanis, S., A. Christofides, N. Mamassis, A. Efstratiadis and D. Koutsoyiannis. 2010. Hydrognomon open source software for the analysis of hydrological data. In: European Geosciences Union General Assembly, 2-5 May, 2010, Geophysical research abstracts (Vol. 12), Vienna, Austria, 10p

[20] Everitt, B. S., S. Landau and M. Leese. 2001. Cluster analysis (4th edition). Arnold, A member of the Hodder Headline Group, London. United Kingdom.

[21] Ward J. H. 1963. Hierarchical groupings to optimize an objective function. *J American Stati. Asso.* 58: 238-244.

[22] FAO (Food and Agricultural Organization). 2009. CROPWAT 8.0 for windows user guide. FAO. Rome. Italy.

[23] Raes, D., A. Timmerman, M. Hermy, and J. Mentens. 2006. Green roof water balance model. K. U. Leuven University, Faculty of Bioscience Engineering, Division of Soil and Water Management, Leuven, Belgium.

[24] Buishand, T. A. 1982. Some methods for testing the homogeneity of rainfall records. *J hydro.* 58 (1-2): 11-27.

[25] Graler, B., E. Pebesma and G. Heuvelink, 2016. Spatio-Temporal interpolation using gstat. The *RFID J* (1): 204-218.

[26] Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

[27] Pebesma, E. and R. S. Bivand. 2005. Classes and Methods for Spatial Data: the sp Package. *R news* 5 (2): 9-13.

[28] Singo, L. R., P. M. Kundu and F. I. Mathivha. 2016. Spatial variation of reference evapotranspiration and its influence on the hydrology of Luvuvhu River Catchment. *J. Agri. and Envi. Manage.* 5 (6) 187-196.

[29] Rasul, G. and A. B. Farooqi. 1993: Water Requirement of Cotton Crop in Pakistan. *J Engg and Applied sci.* 4 (2): 154-165.

[30] Naheed, G. and G. Rasul. 2010. Projections of crop water requirement in Pakistan under global warming. *Pakistan J Meteo.* 7 (13): 45-51.

[31] Adem Anwar, Aynalem Dessalew, Tilahun Seifu and T. S. Steenhuis. 2017. Predicting reference evaporation for the Ethiopian highlands. *J Water Reso and Protection* 9: 1244-126.

[32] Savva, A. P. and K. Frenken. 2002. Crop water requirements and irrigation scheduling. FAO Sub-Regional Office for East and Southern Africa, Harare. Zimbabwe. 132p.

[33] De Bruin, H. A. R.., I. F. Trigo, M. A. Jitan, Temesgen Enku, C. Tol and A. S. M. Gieske. 2010. Reference crop evapotranspiration derived from geo-stationary satellite imagery: a case study for the Fogera flood plain, NW-Ethiopia and the Jordan Valley, Jordan. *Hydro. and earth system sci.* 14 (11): 2219-2228.

[34] Fitsume Yemenu, Kidist Abera, Michael Eshetu, Richard Koech and Molla Mekonnen Alemu. 2017. Irrigation water planning for crops in the central highlands of Ethiopia, aided by FAO CROPWAT Model. *African J Agri. Research* 12 (28): 2329-2335.