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Spatiotemporal Variation in Reference Evapotranspiration Over Horro Guduru Wollega Zone Using Kriging Method

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Abstract: Reference Evapotranspiration, ETo, is an important agro-meteorological parameter for irrigation and water resources planning and management. This study was aimed at analyzing spatial and temporal variability in ETo across Horro Guduru Wollega Zone, in western Ethiopia. Temporal ETo was estimated with FAO-Penman Monteith method using climatic data collected from nine stations. Geostatistical interpolation technique called Ordinary Kriging was used for the spatial interpolation of ETo. The results showed that the average annual ETo was 4.1 mm/day across Horro Guduru Wollega zone and it ranges from 3.66 mm/day (at Alibo) to 4.29 mm/day (at both Bereha and Hareto). The highest and lowest mean monthly ETo was 4.76 (in April) and 3.58 mm/day (in August) respectively. The ETo of MAM season was the highest. The share of MAM, ONDJF and JJAS seasons ETo were 37.53%, 32.31% and 30.16% of the annual ETo. ETo values shows positive correlation with observed mean temperature. The obtained ETo values were relatively higher in South-East part of the zone.

Key words: Reference Evapotranspiration · Ordinary Kriging · Horro Guduru Wollega Zone

INTRODUCTION

Reference evapotranspiration, ETo, is recognized as being the most important agro-meteorological variable in hydrological ecological processes and agricultural water management or irrigation [1, 2]. The reference evapotranspiration provides a standard to which evapotranspiration at different periods of the year or in other regions can be compared; evapotranspiration of other crops can be related [3]. Therefore, accurate estimation of ETo is very vital for the estimation of crop water requirement and irrigation water requirement [4] and to enhance irrigation water application efficiency, water reuse and scheduling of irrigation [1].

A considerable amount of literature has been published on reference Evapotranspiration throughout the world. These studies revealed variety of methods available for estimation of reference Evapotranspiration. FAO Penman-Monteith method is now recommended as the sole standard method for the definition and calculation of the reference crop evapotranspiration because (1) it has been found to be a method with a strong likelihood of correctly predicting ETo in a wide range of locations and climates (2) the method provides values that are more accurate and consistent with actual crop water use worldwide and (3) the method has provisions for calculating ETo in cases where some of the climatic data are missing [3]. Due these, FAO Penman-Monteith method is widely used to estimate ETo and to calibrate and validate other methods for specific area or zone or country. For instance, Castañeda and Rao [5] investigated the accuracy of four existing evapotranspiration methods (Thornthwaite, Blaney-Criddle, Turc and Makkink) for southern California and compared with those of the FAO Penman-Monteith method. Heydari *et al.* [6] also compared fourteen evapotranspiration models for estimating ETo with FAO Penman-Monteith method in the center of Iran using fourteen years observed weather data. Similarly, Tabari and his collogues [7] compared thirty one methods and evaluated against the FAO Penman-Monteith model.

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Regionalization of measured quantities at a given spatial locations is a common practice in the field of applied and engineering hydrology. Kriging is a popular geostatistical method of regionalization. This method requires the complete specification of the spatial dependence that characterizes the spatial process. These models take the form of a covariance or semivariance function [8]. Kriging can be used to produce the maps of kriging predicted values; maps of kriging standard errors associated with predicted values; maps of probability, indicating whether or not a predefined critical level was exceeded and maps of quantiles for a predetermined probability level [9].

Kriging techniques have the advantages of avoiding data clustering, gives estimate of estimation error (including error map) and provides the basis for stochastic simulation for the possible realization of estimate variables [8]. It is not always possible to sample every location. Therefore, unknown values must be estimated from data taken at specific locations that can be sampled. Interpolation methods are crucial in bridging such gaps through spatial mapping of regionalized variables such as evapotranspiration. However, researchers have not treated the hydrological behavior of Horro Guduru Wollega zone in much detail. Even, no previous study has investigated spatiotemporal variations of ETo across the zone in general, using kriging method particularly.

Bearing in mind the previous points, it is imperative to analyse both spatial and temporal variations in reference Evapotranspiration for a given area or region using geostatistical techniques such as kriging method in areas where meteorological data are scarce. On the other hand, it is necessary to emphasise that spatial and temporal variation of ETo for better planning and managing of agricultural water. Therefore, the main objective of this study is to predict spatial and temporal variability of Reference Evapotranspiration across Horro Guduru Wollega zone of Oromia regional state, Western Ethiopia.

MATERIALS AND METHODS

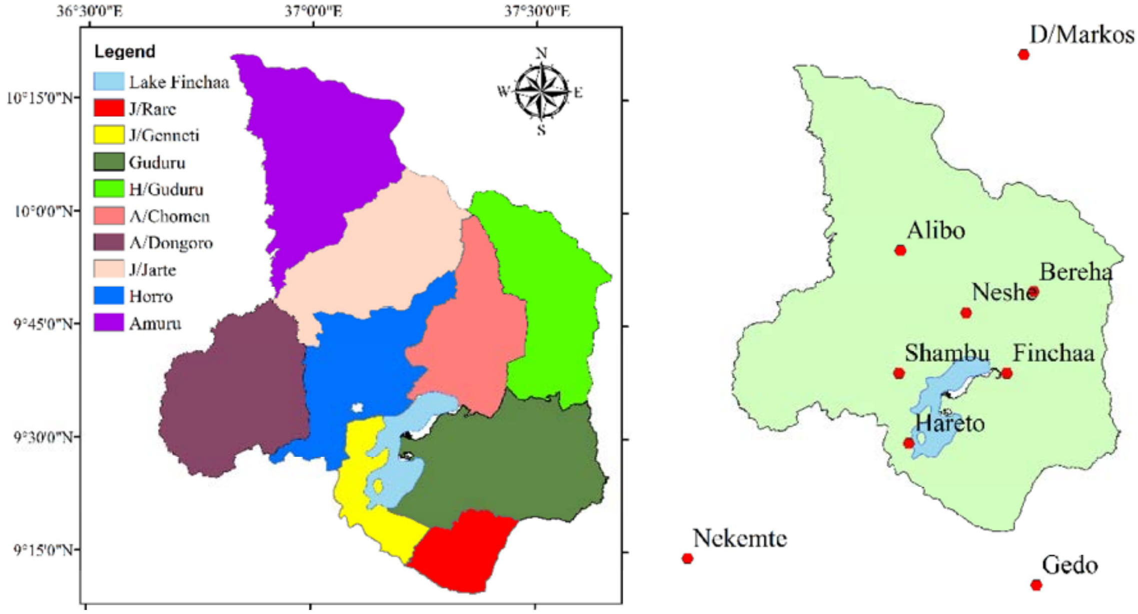
Study Area: The study was carriedout in Horro Guduru Wollega Zone of Oromia Regional State, Western part of Ethiopia. Geographically it is located between 9°10’ and 10°22’ North and 36°37’ and 37°42’ East. The zone comprises ten (10) districts (Fig. 1a) including the capital city of the zone so called Shambu town. It covers a total area of 8, 288 square kilometer. The zone shares boundaries with East Gojjam zone in the North, East Wollega zone in the Nort-West and South-West and with West Shewa zone in South-West, South-East and East directions.

Input data Data and Its Source: To estimate reference evapotranspiration over Horro Guduru Wollega zone using FAO-PM method daily temperature (maximum and minimum), wind speed, sunshine hour and relative humidity data recorded at nine (9) meteorological stations (Table 1) located in and arournd the zone controlled by the Ethiopian National Meteorological Agency (ENMA) were used for the period of 1991 to 2015 (25 years). Debre Markos, Gedo and Nekemte stations are located in neighbour zones (Fig. 1b). Shambu, Nekemte, Debre Markos (D/Markos) stations are synoptic type of station, whereas the remaining stations are indicative (principal) and ordinary type of station. For ordinary stations ETo were estimated from temperature data only.

Method of Reference Evapotranspiration Estimation: Reference Evapotranspiration (ETo) under current climatic conditions was estimated using the FAO Penman-Monteith (FAO-PM) method. Because, this method is recommended as the sole standard method for the definition and calculation of the reference crop evapotranspiration due to its capability of correct prediction of ETo in a wide range of locations and climates. It provides values that are more accurate and consistent with actual crop water use worldwide and it has provisions for calculating ETo in cases where some of the climatic data are missing [3]. This study used ETo calculator for Windows version 3.2 software to estimate ETo according to FAO-PM model as given in equation below.

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

where: ETo is Reference evapotranspiration [mm day^{-1}]; Rn is Net radiation at the crop surface [MJ m^{-2} day^{-1}]; G is Soil heat flux density [MJ m^{-2} day^{-1}]; T is Mean daily air temperature at 2 m height [°C]; u_2 is Wind speed at 2 m height [m s^{-1}], e_s is Saturation vapor pressure [kPa]; e_a is Actual vapor pressure [kPa]; e_s–e_a is Saturation vapor pressure deficit [kPa]; Δ is Slope vapor pressure curve [kPa °C^{-1}] and γ is Psychometric constant [kPa °C^{-1}].



(a) (b)

Fig. 1: Map of the study area (a) Horro Guduru Wollega Zone and its District and (b) Location of meteorological stations

Table 1: Geographical location and elevation of the meteorological stations

No	Station	Longitude (°)	Latitude (°)	Altitude (m)	Zone
1	Alibo	9.89	37.07	2513	Horro Guduru Wollega
2	Debre Markos	10.32	37.74	2446	East Gojjam
3	Finchaa	9.57	37.37	2248	Horro Guduru Wollega
4	Gedo	9.02	37.46	2520	West Shewa
5	Hareto	9.35	37.12	2260	Horro Guduru Wollega
6	Nekemte	9.08	36.46	2080	East Wollega
7	Neshe	9.72	37.29	2060	Horro Guduru Wollega
8	Shambu	9.57	37.12	2460	Horro Guduru Wollega
9	Bereha	9.75	37.38	1410	Horro Guduru Wollega

Method of Reference Evapotranspiration Mapping: In the current study geostatistical interpolation technique was employed to map the spatio-temporal variability of reference evapotranspiration over Horro Guduru Wollega zone. Geostatistics methods assume that at least some of the spatial variation of natural phenomena can be modeled by random processes with spatial autocorrelation. Geostatistical technique was used to describe and model spatial patterns (variography) and predict values at unmeasured locations (kriging). It was also used to assess the uncertainty associated with a predicted value at the unmeasured locations.

Modeling the Semivariogram: To describe and model spatial patterns of mean monthly and seasonal reference evapotranspiration Spherical model was used. The spherical model is the most widely used semivariogram model and is characterized by a linear behavior at the origin. The form of spherical model is;

$$\gamma(h) = \begin{cases} \left(\frac{3}{2}\frac{h}{a} - \frac{1}{2}\frac{h^3}{a^3} \right) & \text{where } h \le a \\ C & \text{where } h \ge a \end{cases}$$

where $\gamma(h)$ is semivariogram; a is the range of influence of a sample; C is the sill of the semivariogram and h is distance between points. The semivariogram created for Horro Guduru Wollega zone fitting with spherical model using mean monthly reference evapotranspiration (mm/day) was illustrated in Fig. 2.

Ordinary Kriging Method: In this study, spatial prediction and mapping of ETo across the study area was performed ordinary kriging method using the Geostatistical Analyst extension available in ESRI© ArcMap™ v10.4.1 for windows (ESRI, Inc., 2010). Ordinary kriging is the most common and simplest type of kriging in practice. It uses dimensionless points to

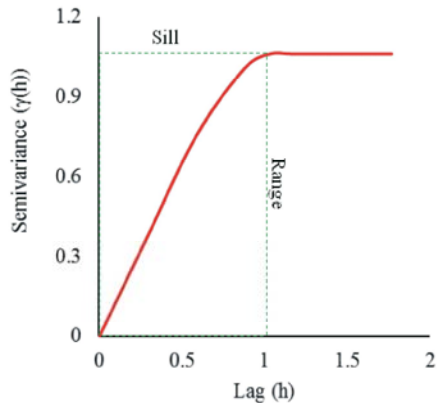


Fig. 2: Semivariogram of mean reference evapotranspiration over Horro Guduru Wollega zone

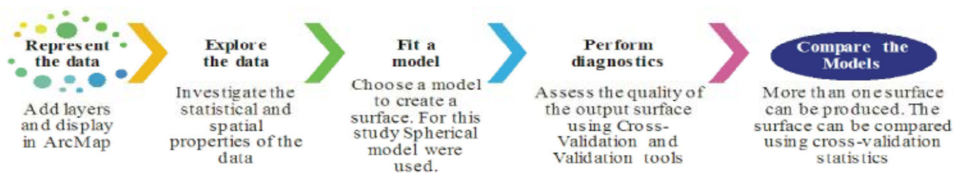


Fig. 3: Spatial data processing procedures (adopted from Johnston *et al*. [9])

estimate other dimensionless points and the regionalized variable is assumed to be stationary. In this case Z, at point p, Ze (p) to be calculated using a weighted average of the known values or control points. This estimated value will most likely differ from the actual value at point p, Za(p) and this difference is called the estimation error.

$$Z_e(p) = \sum w_i \times Z(p_i)$$
$$\varepsilon_p = Z_e(p) - Z_a(p)$$

If no drift exists and the weights used in the estimation sum to one, then the estimated value is said to be unbiased. The scatter of the estimates about the true value is termed the error or estimation variance,

$$\sigma_z^2 = \frac{\sum_{i=1}^{n}[Z_e(p_i) - Z_a(p_i)]_i^2}{n}$$

Kriging tries to choose the optimal weights that produce the minimum estimation error. Optimal weights, those that produce unbiased estimates and have a minimum estimation variance, are obtained by solving a set of simultaneous equations.

$$w_1\gamma(h_{11}) + w_2\gamma(h_{12}) + w_3\gamma(h_{13}) = \gamma(h_{1p})$$
$$w_1\gamma(h_{21}) + w_2\gamma(h_{22}) + w_3\gamma(h_{23}) = \gamma(h_{2p})$$
$$w_1\gamma(h_{31}) + w_2\gamma(h_{32}) + w_3\gamma(h_{33}) = \gamma(h_{3p})$$
$$w_1 + w_2 + w_3 = 1$$

A fourth variable is introduced called the Lagrange multiplier.

$$w_1\gamma(h_{11}) + w_2\gamma(h_{12}) + w_3\gamma(h_{13}) + \lambda = \gamma(h_{1p})$$
$$w_1\gamma(h_{21}) + w_2\gamma(h_{22}) + w_3\gamma(h_{23}) + \lambda = \gamma(h_{2p})$$
$$w_1\gamma(h_{31}) + w_2\gamma(h_{32}) + w_3\gamma(h_{33}) + \lambda = \gamma(h_{3p})$$
$$w_1 + w_2 + w_3 = 1$$

$$\begin{bmatrix} \gamma(h_{11}) & \gamma(h_{12}) & \gamma(h_{13}) & 1 \\ \gamma(h_{21}) & \gamma(h_{21}) & \gamma(h_{23}) & 1 \\ \gamma(h_{31}) & \gamma(h_{32}) & \gamma(h_{33}) & 1 \\ 1 & 1 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \lambda \end{bmatrix} = \begin{bmatrix} \gamma(h_{1p}) \\ \gamma(h_{2p}) \\ \gamma(h_{3p}) \\ 1 \end{bmatrix}$$

Once the individual weights are known, an estimation can be made by:

$$z_e(p) = w_1 z_1 + w_2 z_2 + w_3 z_3$$

And an estimation variance can be calculated by:

$$\sigma_z^2 = w_1\gamma(h_{1p}) + w_2\gamma(h_{21p}) + w_{13}\gamma(h_{3p}) + \lambda$$

Processing Data: The following procedures (Fig. 3) were adopted to process/map spatial variation of the estimated Reference Evapotranspiration at different temporal scales as it recommended in the Geostatistical Analyst module of ArcGIS, version 9.0 [9].

Table 2: The summary Mean Climatology of all stations used in the study (1991-2015)

Station	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind (km/day)	Sunshine (hour)	Radiation (MJ/m²/day)	ETo (mm/day)
Alibo	11.9	23	75	172	7.5	20	3.82
Debre Markos	10.4	22.7	73	173	8.2	20.9	3.92
Finchaa	10.3	25.4	70	173	9.8	23.3	4.51
Gedo	9.6	22.4	72	175	8.6	21.6	4
Hareto	10.7	24.5	71	173	9.1	22.4	4.29
Nekemte	12.9	24.4	75	173	7.7	20.3	3.96
Neshe	10.7	24.6	71	174	9.2	22.4	4.28
Shambu	11.2	22.7	74	173	7.8	20.3	3.83
Bereha	14.7	30.9	62	178	7.9	20.6	4.29

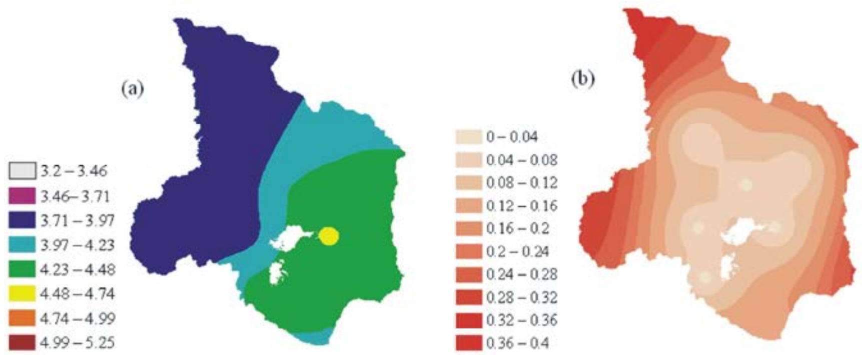


Fig. 4: Spatial distribution of Predicted ETo and Standard Error Maps across the study area (a) Annual Average Reference Evapotranspiration (mm/day) (b) Standard Error (mm/day)

RESULTS

The current study uses FAO-Penman Monteith model and Ordinary Kriging interpolation technique to estimate the temporal and map spatial variability of reference evapotranspiration -ETo- respectively across the administrative boundary of Horro Guduru Wollega Zone from meteorological data for the period of 1991 to 2015 (Table 2). The obtained results of analysis were organized in annual, seasonal and monthly time scales. The obtained results were presented in the subsequent paragraphs.

Annual Reference Evapotranspiration: The investigation result indicated that mean annual reference evapotranspiration over Horro Guduru Wollega zone was 4.1 mm/day (1497.5 mm). Maximum values was obtained as 4.29 mm/day for both Bereha (Finchaa Valley) and Hareto (Jimma Genneti) stations followed by Neshe station (4.28 mm/day). In contrast the minimum value of reference evapotranspiration rate was estimated for Alibo (Jarte district) and Shambu as 3.82 and 3.83 mm/day respectively. As it is illustrated in Fig. 4a, the spatial distribution map of average reference evapotranspiration across the zone, the average reference evapotranspiration decreases as it go from South-East to North-West part of the zone. In other words, higher reference evapotranspiration was obtained at Abbay Chommen (Finchaa), Guduru, Jimma Rare and Hababo Guduru districts of Horro Guduru Wollega zone.

The results of the standard error analysis are presented in Fig. 4b. The predicted Standard error of spatial interpolation of reference evapotranspiration was less than 0.4 mm/day (less than 10% of average ETo). This is highly in the acceptable range, which further indicates the ability of spatial interpolation techniques selected for the analysis purposes.

Seasonal Reference Evapotranspiration Variation: The current study found that the highest (lowest) reference evapotranspiration during MAM (JJAS) season for all stations over Horro Guduru Wollega zone with the average value of 4.68 (3.76) mm/day (Fig. 5). From the average annual reference evapotranspiration, 37.53%, 32.31% and 30.16% was the account of MAM, ONDJF and JJAS season reference evapotranspiration.

Further analysis showed that the seasonal reference evapotranspiration also relatively higher for in the South-East than North-West portion of the zone for all seasons. Reference evapotranspiration decreases from JJAS to MAM season and at the same time as we move from South-East toward North-West areas of Horro Guduru Wollega zone (Fig. 6).

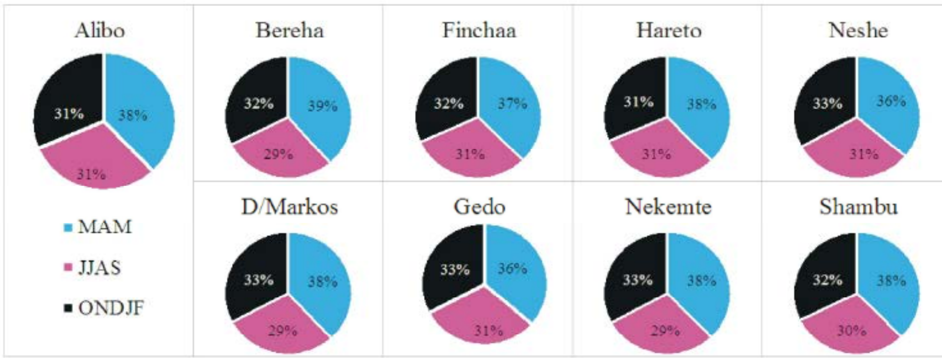


Fig. 5: Seasonal reference evapotranspiration at each meteorological stations

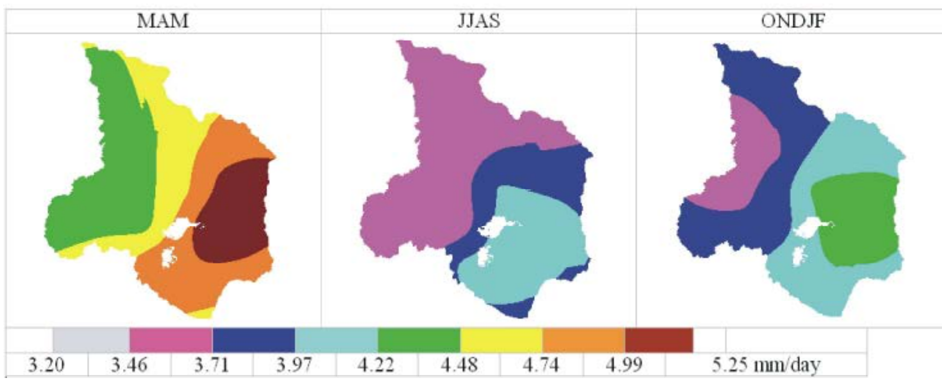


Fig. 6: Seasonal reference evapotranspiration spatial distribution over Horro Guduru Wollega Zone

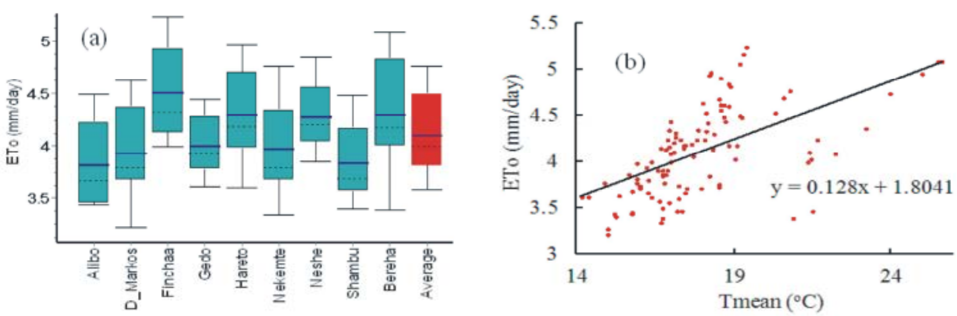


Fig. 7: Monthly reference evapotranspiration and its correlation with mean temperature (a) Box Plot of Monthly Reference Evapotranspiration (mm/day) for each station (b) Monthly reference evapotranspiration correlation with Monthly Mean temperature

Monthly Reference Evapotranspiration Variation: The result of analysis indicated that the highest mean monthly reference evapotranspiration was 5.23 mm/day at Finchaa station for the month of April. Maximum mean monthly reference evapotranspiration were observed in March, April and May for all stations across the zone. Except at Nekemte and Debre Markos stations, the maximum monthly average reference evapotranspiration was obtained in the April. Fig. 7a demonstrate box plot of mean monthly reference evapotranspiration of nine stations with the average value. Mean monthly reference evapotranspiration Finchaa, Hareto Neshe and Bereha (Finchaa Valley) were higher than the average of the whole zone (red box plot in Fig. 7a). As it was provided in Fig. 7b there is strong and positive correlation between observed mean monthly temperatures at each stations and estimated average monthly reference evapotranspiration for respective stations.

The obtained result indicates the lower mean monthly reference evapotranspiration were estimated for July, August and September months. As illustrated in Fig. 8, mean monthly reference evapotranspiration of Horro Guduru Wollega zone increases from January to April and August to October where as it decreases as it goes

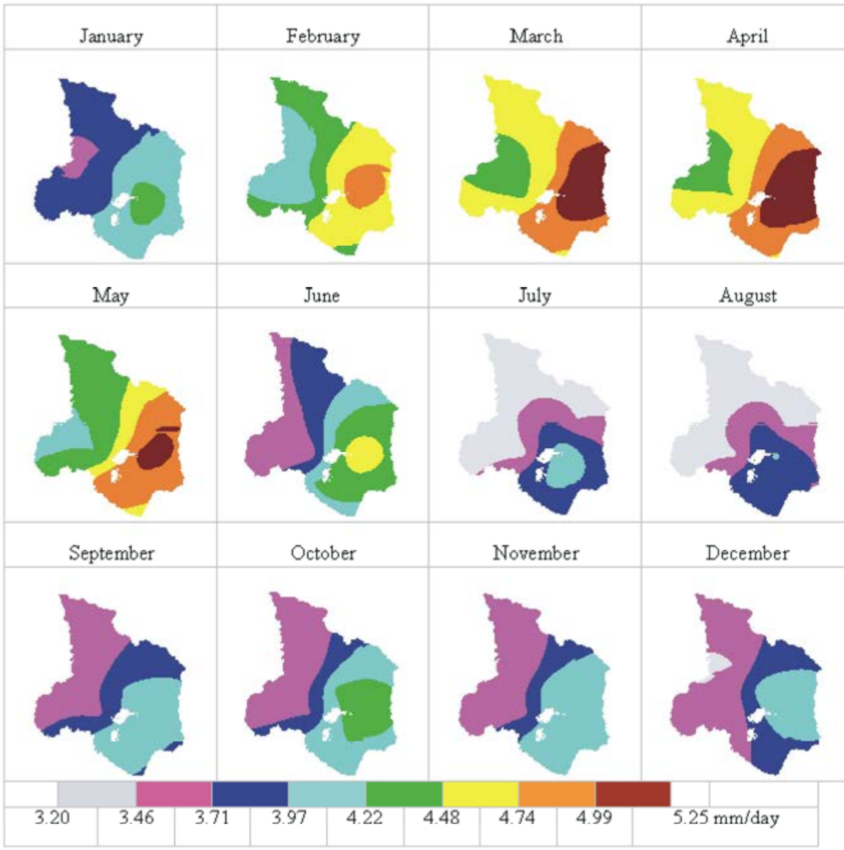


Fig. 8: Spatial Distribution of Monthly Reference Evapotranspiration over Horro Guduru Wollega Zone

from April to August and October to January. Interestingly, for all months' higher values of reference evapotranspiration were obtained at the South-East portion of the zone in Guduru, Hababo Guduru and Abbay Chommen districts.

DISCUSSION

The results of this study indicate that there was temporal and spatial variations in Reference Evapotranspiration rates over Horro Guduru Wollega zone. Reference Evapotranspiration increases by 7.2% and 24.5% as it moves from JJAS season to ONDJF and MAM seasons respectively. This is probably due to climatic variations across the zone. Reference Evapotranspiration was higher during dry periods and lower during rainy season. The finding is fully in agreement with the work of Chala [10], Djaman *et al.* [11] and Wodaje *et al.* [12]. The higher Reference Evapotranspiration at a time of water shortage in the zone may aggravate the drought prone conditions in the area.

Furthermore, the overlap of lower Reference Evapotranspiration with rainy season may also leads to the loss of scarce and fresh water resources in the study area. In other words the coincide of higher Reference Evapotranspiration rates with dry periods possibly causes the deficit of net rainfall in the area that may further limit the availability of water for irrigation to either supplement rainfall or fully satisfy the different amount of water demand for different crops at different level of growth stages. In addition to this, the rise in Reference Evapotranspiration directly increase the amount of water required for irrigating different crops [13].

Another important finding was that there were variations in the average monthly rate of Reference Evapotranspiration across the zone. It increases by 18.7% and 10.9% from January to April and August to October. In contrast, it decline from April to August and October to January by 24.8% and 1% respectively. These results match those observed in earlier study. For instance, Chala [10] obtained 4.29 mm/day average monthly Reference Evapotranspiration in Finchaa valley.

It is interesting to note that at annual, seasonal and monthly time scales comparatively, Reference Evapotranspiration of North-West areas of the zone was smaller than South-East portions. To put it in another way, the obtained Reference Evapotranspiration rates at Abe Dongoro, Amuru, Jardaga Jarte and Horro districts were smaller than that of Jimma Genneti, Guduru, Ababo Guduru, Jimma Rare and Abbay Chommen districts. The possible factor for the spatial variations of Reference Evapotranspiration for the same time is the difference in altitude [14, 15]. In the South-East part of the zone there is a large valley (called Finchaa Valley) which may increase relatively the Reference Evapotranspiration of the area. It is clear from the above that growing crops with larger water requirement at the North-West part of the zone is more advantageous than growing it at the South-East sections in terms of reducing irrigation water requirement and using effective portion of rainfall.

Variations of Reference Evapotranspiration both in time and space over the zone may become more severe in the future if it will increases in the coming periods due to climate change as it is obtained by the work of Chala and Leta [16]. They found that there is a possibility of rise in temperature up to 2.3°C for both RCP4.5 and RCP8.5 climate change scenarios at the end of 2055 in the South-East part in general and particularly in Finchaa Valley of the zone due to climate change. Mekonnen and Rao [17] also found that in Finchaa sub-basin potential evapotranspiration will rise annually on average 4 to 19% at the end 2070 for both A2a and B2a emissions scenarios due to increase in temperature. Temperature is the main influencing factor for the change of Reference Evapotranspiration rates and magnitude [15, 18-21]. Therefore, analyzing the past trends in Reference Evapotranspiration over the area may be another gap for the researchers.

Equally important, the South-East part of the zone is where three artificial lakes namely, Finchaa, Amerti and Neshe reservoirs, are located. Particularly, the largest lake (Finchaa) is surrounded by those districts with higher evaporation rates i.e it is found in the boundary of Jimma Genneti, Jimma Rare, Guduru and Abbay Chommen districts. This indicates that high amount of water is lost from these open water sources due to evaporation. Therefore, it is very vital to implement different structural and non-structural measures to reduce evaporation from these reservoir. This is an assignment for the local and national water managers and other stakeholders to devise the mechanisms for the reduction of water losses due to evaporation from the lakes.

CONCLUSION

The current study uses the most commonly used and recommended methods called FAO-Penman Monteith model and Ordinary Kriging interpolation technique to estimate the temporal and map spatial variability of reference evapotranspiration across Horro Guduru Wollega Zone from meteorological data for the period of 1991 to 2015. The obtained results of analysis show that the highest average reference evapotranspiration in Horro Guduru Wollega zone was found in South-East portions, specifically in and around Finchaa valley. The highest seasonal and monthly reference evapotranspiration was in MAM season and April month, respectively. Uneven distribution of reference evapotranspiration rates both in time and space over the zone possibly leads to either loss of water or limit availability and enhance the demand of irrigation water for the crops can be grown in the zone.

Conflicts of Interest: The authors declare no conflict of interest.

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