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# Analysis of Temporal Variability and Trend of Reference Evapotranspiration in Sinana District, South Eastern Ethiopia.

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***Abstract**: This study was undertaken in sinana district to analyze the temporal variability and trends of reference evapotranspiration (ETo) based on meteorological data for the period of 1986-2015. FAO-56 Penman-Monteith method was employed to calculate the monthly, seasonal (Feb-May, June-September and October-December) and annual ETo time series with the help of CROPWAT 8.0 software. In order to detect the existing trend in ETo the non-parametric Mann-Kendall and Sen's estimator method was employed, and multiple linear regression model was developed to quantify the cause and effect relationship of meteorological variables and reference evapotranspiration during the study period. The non-parametric Mann-Kendall statistical trend test shows a significant decreasing trend of annual and seasonal (June-September and October-December) reference evapotranspiration time series at 5% level of significance. Reference evapotranspiration attained its lowest and peak value at 3.22 and 4.38 mm/day in month of October and February, respectively. The regression result showed that the highest variation in reference evapotranspiration on seasonal and annual time scale was experienced by wind followed by radiation in the study area. This result suggests the need for providing great care in modeling meteorological variables on ETo for agricultural water planning, irrigation system design and management under changing climate.*

***Keywords**: Mann-Kendall; Penman-Monteith; Reference evapotranspiration (ETo); Sinana district; Trend*

## INTRODUCTION

The world is facing extraordinary water resource challenges in the 21$^{st}$century. Increasing population growth, energy consumption, agricultural expansion, ground water extraction, and global climate change are putting massive pressure on our limitedwater resources potentially resulting in many of the world wide water crises today (ASABE, 2014). Studies have shown that increase in $co_2$ and associated increase in temperature and rainfall may stimulate vegetation growth and increase evapotranspiration (ET), which act as a cooling mechanism, and on global scale, may slow the climate-warming trend. Across all continent evapotranspiration is 70% of precipitation, and roughly three fifths of the available annual solar radiation received at the earth surface globally are consumed in the process of evapotranspiration (McMahon et al., 2012; Wang and Dickinson, 2012; Wild et al., 2013). Water resources needs to be substantially managed to meet increasing societal needs for consumption, and land cleaning for urban expansion and tourism development may reduce evapotranspiration (ET) and increase runoff (Elhag*et* *a*l., 2011). Quantification of evapotranspiration plays an important role for prediction and estimation of global climate change experienced on hydrological and agricultural sectors, specifically for crop production, allocation of water resource, natural resource management, irrigation system design and management( Tilahun, 2006; Irmak,2009; Suleiman and Hoogenboom, 2009; ILRI, 2009). Thus, the change in evapotranspiration due to factors related to weather parameters, crop characteristics, management and environmental aspects are of great influence on agricultural water planning, irrigation system design and management and hydrological system and other activities (FAO, 1998, Abu-Zeid and Hamdy, 2002;Elhag et al., 2011; Wane and Nagdeve, 2014). Thus, analysis of variability and trend of reference evapotranspiration will help us to better understand climate change and its effect on hydrological and agricultural sectors, mainly to determine crop water stress (Elhag et al., 2011).

Scientific studies, which quantify reference evapotranspiration(ETo) variability and trend was not undertaken in the study district. Thus, in view of these facts, this paper, aims to analyze variability and trends of reference evapotranspiration on annual, seasonal and intra-seasonal basis.

## MATERIALS AND METHODS

### Description of the Study area

The study area covers Sinana District, which is small portions of Southern Highlands of Bale zone in Ethiopia located between$6^0$ 50' N-$7^0$17' N and $40^0$ 06' E-$40^0$24' E (Figure 1). It extends from 1700 to 3100 meters above mean sea level (.a.m.s.l). This District is under Indian Ocean influences as southerly fluxes generating rainfall when strong southerly moisture flow and easterly perturbation engulf. This can be also affected by heavy rainfall events coming from northward advancement and southward retreat of ITCZ (Korecha and Barnston, 2007). As a result it experiences an annual average temperature of $9^0$C to $25^0$C and annual rainfall totals of between 452.7 mm and 1129.5 mm, respectively (Fitsum, 2015).Most parts of Sinana District is found in SH2 (humid sub humid to cool mild highland) agro-ecology (MoA, 2000). Rainfall climatologically patterns of the area also follow a bimodal distribution (NMSA, 1996; Bekele, 1997).In the Sinana District of Bale Region the area is characterized by bimodal rainfall pattern,*Kiremt*(main rainy season) and *Belg*(small rainy season). The mean onset and cessation date of *Kiremt* season is July one and October twenty eight for Robe and surrounding areas respectively (Segele and lamb, 2005). Agriculture is the main economic practices in the district, from which the majority of dwellers earn their livelihood income mainly from crop cultivation. Major crops grow in the district include wheat, barley, oat, maize, bean and peas (Bogale*et al., 2009).* Topographical delineation of Sinana district includes moderate, steep slope and plateaus. Out of total land area of the district serving for crop cultivation, which is 163,554 hectares, 99,992 hectares are currently used for farm. However, there are a number of climate related hazards that are recurrent in this part of Ethiopia. As a result, of this, crop productivity is always at risk under changing climate (Bessie, 2010; SDAO, 2006).

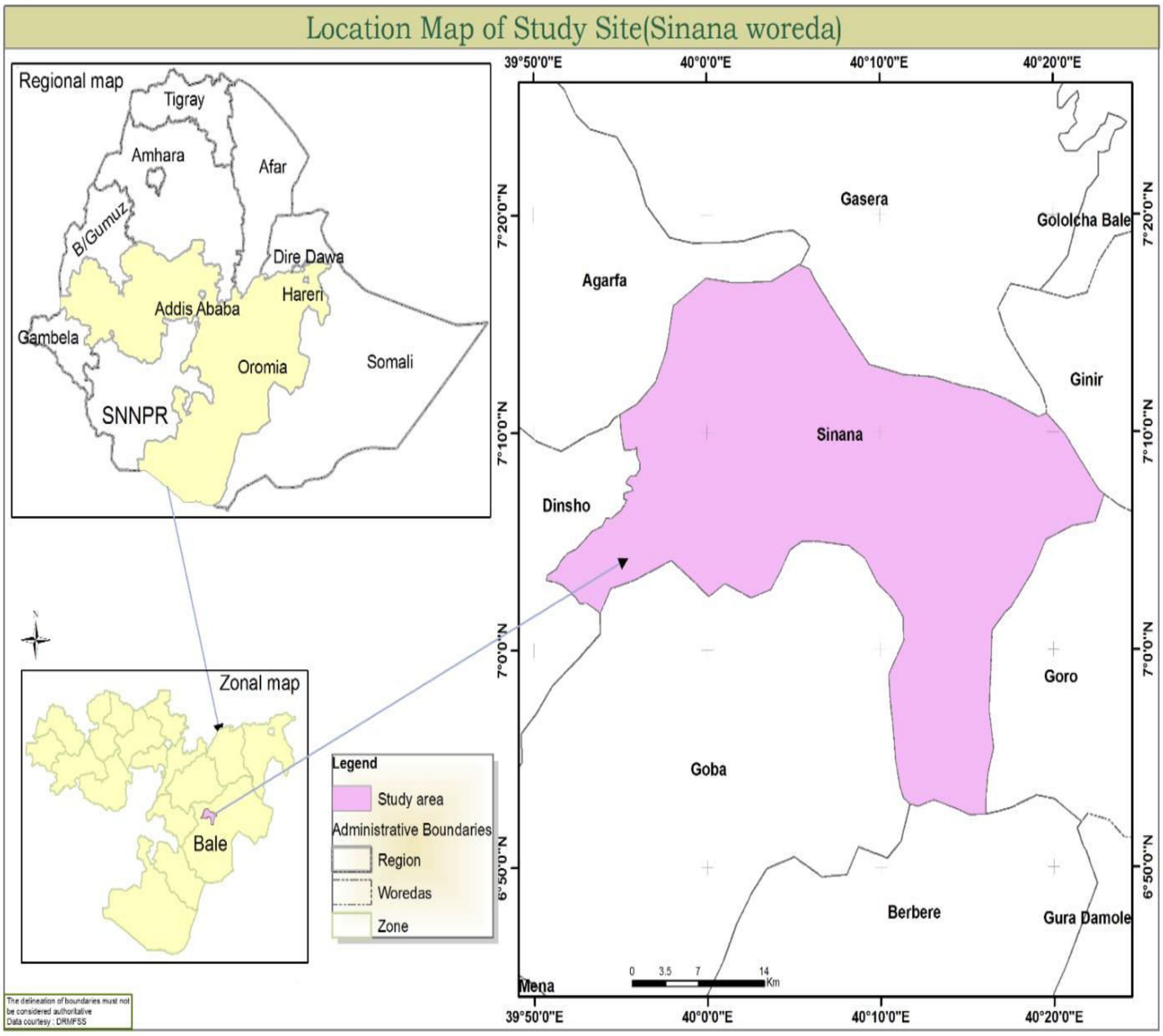


Fig. 1: Map of the study district

**Data sources**

**Observed data**

Observed daily Meteorological data including maximum temperature, minimum temperature, relative humidity, wind speed and sunshine hours were obtained from National Meteorological Agency (NMA) of Ethiopia. Due to shortage of available meteorological data one station that has 30 years data series was selected for this study. The geographical location, type, and database length for the selected station are depicted in table 1.

Table 1**:** Geographical location, type, and database length for Robe station used in the study.

| Stations | Altitude (m) | Latitude (°N) | Longitude (°E) | Database periods | Data type: Maximum and minimum temperature(°c), Relative Humidity (%),Wind Speed (m/s) and Sunshine hours (hr) |
|---|---|---|---|---|---|
| Robe | 2480 | 7.13 | 40.05 | 1986-2015 | Available |

**Normality test of ETo time series**

The standardized coefficients of Skeweness ($Z_1$) and Kurtosis ($Z_2$)statistics as defined by Brazel and Balling (1986) were used to test for the normality in decadal, monthly, seasonal and annual evapotranspiration series for the study area.The standardized coefficients of Skeweness ($Z_1$) can be calculated as follows:

$$Z_1 = \left[\left(\sum_{i=1}^{N}(x_i-\bar{x})^3/N\right) \Big/ \left(\sum_{i=1}^{N}(x_i-\bar{x})^2/N\right)^{3/2}\right] \Big/ (6/N)^{1/2}$$

and the standardized coefficients of kurtosis ($Z_2$) can be calculated as:

$$Z_2 = \left[\left(\sum_{i=1}^{N}(x_i-\bar{x})^4/N\right) \Big/ \left(\sum_{i=1}^{N}(x_i-\bar{x})^2/N\right)^{2} - 3\right] \Big/ (24/N)^{1/2}$$

Where, $\bar{X}$ is the long term mean of xi values and N is the number of years in the sample. In this study the two statistics were used to test the null hypothesis that the individual temporal samples came from a population with a normal distribution. Thus, if the computed absolute value of Z1 or Z2 is greater than 1.96, a significant deviation from the normal curve is indicated at the 95% confidence level. If the data series are not found to be normally distributed, various transformation models could be used to normalize the series such as Log transformation and Lambda transformations of Box and Cox (1964) and Square and Cube Root transformations (Stidd, 1970) amongst others.SYSTAT version 8.0 was used to determine Skeweness ($Z_1$) and Kurtosis ($Z_2$) statistics.

**Calculating Reference Evapotranspiration (ETo)**

Currently, several methods are available for estimating ETo which had been proposed by many authors, and such as FAO-Penman, Penman, 1982-Kinberly-Penman, FAO-Corrected–Penman, Penman-Monteith, Blanney-Criddle, Priestley-Taylor, FAO-Radiation, Hargreaves, and FAO-BlanneyCriddle (Allen *et al*., 1998; Dockter, 1999; Wang *et al*., 2003; DehghaniSaniji *et al*., 2004; Pereira and Pruitt, 2004; Dodds *et al*., 2005). Many of the above models except FAO Penman-Monteith are subject to local calibration thereby making them to have limited global acceptance, in most cases the FAO Penman-Monteith Method used for verification of other empirical methods (Chen *et al*., 2005)**.** Due to the higher performance andstrong likelihood of correctly predicting ETo in a wide range of locations and climates FAO-56 Penman-Monteith (FAO-56 PM) model has been considered as a universal standard to determine ETo in different parts of the world when compared with other models (Allen, *et al*., 1989, 1994, 1998; Hess, 1998; Zhao *et al*., 2005; Garcial *et al*., 2006; Gavila, *et al*, 2006). In order to calculate referenceevapotranspiration(Eto) values using the FAO Penman-Montieth equation,dekade/monthly climatic data: minimum and maximum air temperature, relative humidity, sunshine duration and wind speed are required.

According to FAO 56-Penman-Monteith (Allen,*et al*.,1998) method reference evapotranspiration (ETo) can be calculated using the following equation:

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

Where:

$ET_o$ = reference evapotranspiration, mm $day^{-1}$;
$R_n$ = net radiation at the crop surface, MJ $m^{-2}$ $d^{-1}$;
G = soil heat flux density, MJ $m^{-2}$ $d^{-1}$;
T = mean daily air temperature at 2 m height, °C;
$u_2$ = wind speed at 2 m height, m $s^{-1}$;
$e_s$ = saturation vapor pressure, kPa;
$e_a$ = actual vapor pressure, kPa;
Es-ea = saturation vapor pressure deficit, kPa;

Δ = slope of the vapor pressure curve, kPa ºC$^{-1}$;
γ= psychrometric constant, kPa °C$^{-1}$.

The PM model uses a hypothetical green grass reference surface that is actively growing and is adequately watered with an assumed height of 0.12m, with a surface resistance of 70s m-1and an albedo of 0.23 (Allen et al., 1998) which closely resemble evapotranspiration from an extensive surface of green grass cover of uniform height, completely shading the ground and with no water shortage.
In order to calculate reference evapotranspiration(ETo) values many software packages use the FAO Penman-Monteith equation such as FAO EToCalculatorand CROPWAT.CROPWAT is a DOS or Windows based decision support system designed as a tool to helpagro-meteorologists, agronomists, and irrigation engineers carry out standard calculations for evapotranspiration and crop water use studies, particularly the design and management of irrigation schemes (FAO, 1992). For this study, CROPWAT 8.0for Windows which is a decision support tool developed by the Land and Water Development Division of FAO in 2006 was adopted.

**Effect of Meteorological variables**

In order to establish the causality of meteorological variables on reference evapotranspiration multiple linear regression methods was employed, and Coefficients of multiple determinations ($R^2$) were used to determine the percentage of variation explained jointly by the climate variables. Student t-test in a multiple regression was employed to assess whether the independent variable adds unique and predictive value as a predictor for statistical significance (Armi Collins, *et al.,* 1994; Agrawal*et al.*, 1986;Odekunle *et al.*, 2007), and analyzed with the help of statistical software like SPSS (V20).

**Statistical analysis of reference evapotranspiration(ETo) variability and trend**

**Variability analysis**

Mean and coefficient of variation were used in analyzing the variation in annual, seasonal and monthly reference evapotranspiration (ETo) time series.

**Temporal trend analysis**

In order to detect increasing or decreasing trends in a time series the non-parametric Mann-Kendall's test is widely used by different authors(Partal and Kahya, 2006 and Hadgu et al., 2013). The Mann-Kendall's statistical test is preferable among others, because it is simple, is expected to be less affected by the outliers because its statistic is based on the sign of differences, not directly on the values of the random variable, no need to change the existed data type to any statistical distribution (Partal and Kahya, 2006 and Yenigun et al., 2008).
The non-parametric Mann-Kendall's test statistic is given as:

$$S = \sum_{i-1}^{N-1} \sum_{j-i+1}^{N} sgn(X_j - X_i)$$

Where S is the Mann-Kendal's test statistics; *x*i and *x*j are the sequential data values of the time series in the years *i* and *j* (j>*i)* and *N* is the length of the time series. A positive *S* value indicates an increasing trend and a negative value indicates a decreasing trend in the data series. The sign function is given as:

$$Sgn(x_i - x_i) = \begin{cases} +1\ if(x_j - x_i) > 0 \\ 0\ if(x_j - x_i) = 0 \\ -1\ if(x_j - x_i) < 0 \end{cases}$$

The variance of *S*, for the situation where there may be ties (that is, equal values) in the *x* values is given by: $Var(S) = \frac{1}{18}[N(N-1)(2N+5) - \sum_{i-1}^{m} t_i\,(t_i - 1)(2t_i + 5)]$

Where *m* is the number of tied groups in the data set and $t_i$ is the number of data points in the ithtied group. For n larger than 10, $Z_{MK}$ approximates the standard normal distribution (Partal and Kahya, 2006; Yenigun *et al.*, 2008) and computed as follows:

$$Z_{MK=} \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} ifS > 0 \\ ifs = 0 \\ \dfrac{S-1}{\sqrt{Var(S)}} ifS < 0 \end{cases}$$

The presence of a statistically significant trend is evaluated using the ZMK value. In a two-sided test for trend, the null hypothesis Ho should be accepted if $|Z_{MK}| < Z_{1-\alpha/2}$ at a given level of significance. $Z_{1-\alpha/2}$ is the critical value of $Z_{MK}$ from the standard normal table For 5% significance level, the value of $Z_{1-\alpha/2}$ is 1.96. In MAKESENSE the tested significance levels $\alpha$ are 0.001, 0.01, 0.05 and 0.1.MAKESENS1.0 which is primarily developed for detecting and estimating trend in time series was adopted in this study.

**The Sen's estimator of slope**: to estimate the true slope of an existing trend (as change per year) of ETo time series on annual, seasonal and monthly basis,the Sen's non parametric method is used. The value of slope estimator (Q) can be positive, negative and zero, which indicates an increasing values with time (upward trend), decreasing value with time (downward trend) and data fluctuation around the mean, respectively. The Sen's method is not greatly affected by single data errors or outliers and also it can be computed when data are missing (Sen's, 1968; Partal and Kahya, 2006 and Karpouzos et al., 2010).

## Results and Discussion

### Statistical analysis of temporal reference evapotranspiration (ETo)

Table1 shows basic statistics of annual, seasonal reference evapotranspiration and its contribution to annual reference evapotranspiration totals. As can be seen, the results of the standardized coefficient of Skewness ($Z_1$) and Kurtosis ($Z_2$) revealed that monthly (Table 2), seasonal and annual ETo time series were accepted as an indicative of normality, which, did not need any transformation at the 95% significant level. Belg season (FMAM) contributes the highest amount (36%) to the annual reference evapotranspiration totals, while, the dry season (ONDJ) contributes the lowest amount (31%) to the annual reference evapotranspiration totals. The lowest (81 mm/month) and highest (162.13 mm/month) monthly reference evapotranspiration was recorded in the month of November and March, respectively (table 2). The coefficient of variation in the study district showed that reference evapotranspiration had less monthly, seasonal and annual variability (Table 1 and 2). The study indicated that, the lowest annual variability (CV of 4%) and highest monthly (CV of 10%) was observed in the study area. Overall, the lowest variability which was found on monthly, seasonal and annual basis is an indication that the pattern of ETo can be easily understood, predictable and vary over a short period of time. This finding is in line with a study conducted by Hare (1983), NMSA (1996) and Australia Bureau of Meteorology (2010), who reported CV<20% is classified under less variable categories.

Table 1: Basic statistics ofannual, seasonal reference evapotranspiration (ETo) and its contribution to annual evapotranspiration totals in Sinana district for the period 1986-2015.

| Basic statistics | Annual | JJAS | ONDJ | FMAM |
|---|---|---|---|---|
| Mean | 1372.5 | 450 (33%) | 426 (31%) | 493.16 (36%) |
| C.V | 0.04 | 0.06 | 0.08 | 0.06 |
| Skewness($Z_1$) | $-0.251^{ns}$ | $0.545^{ns}$ | $-0.3^{ns}$ | $-0.43^{ns}$ |
| Kurtosis($Z_2$) | $0.387^{ns}$ | $1.519^{ns}$ | $-0.18^{ns}$ | $-0.41^{ns}$ |

ns is non-significant at 0.05 significance level.
Kiremt (June-September), Bega (October-January) and Belg (February-May).
Percentage contribution to annual reference evapotranspiration is given in parentheses.

Table 2: Basic statistics of Monthly (Jan-Dec) temporal reference evapotranspiration totals in Sinana district for the period 1986-2015.

| Basic statistics | January | February | March | April | May | June |
|---|---|---|---|---|---|---|
| Minimum | 91.45 | 105.84 | 110.67 | 98.4 | 99.2 | 97.5 |
| Maximum | 136.4 | 142.97 | 162.13 | 138.6 | 144.77 | 133.2 |
| Mean | 118.55 | 123.66 | 134.71 | 114.58 | 120.22 | 117.27 |
| C.V | 0.09 | 0.08 | 0.1 | 0.09 | 0.08 | 0.08 |
| Skewness($Z_1$) | $-0.6^{ns}$ | $0.05^{ns}$ | $0.16^{ns}$ | $0.57^{ns}$ | $-0.06^{ns}$ | $-0.13^{ns}$ |
| Kurtosis($Z_2$) | $0.12^{ns}$ | $0.43^{ns}$ | $-0.67^{ns}$ | $0.07^{ns}$ | $0.51^{ns}$ | $-0.76^{ns}$ |

| Basic statistics | July | August | September | October | November | December |
|---|---|---|---|---|---|---|
| Minimum | 94.86 | 97.96 | 89.1 | 86.49 | 81 | 88.04 |
| Maximum | 131.13 | 132.06 | 124.8 | 120.59 | 124.31 | 127.72 |
| Mean | 115 | 112.5 | 105.3 | 99.68 | 100.3 | 110.85 |
| C.V | 0.07 | 0.07 | 0.08 | 0.09 | 0.11 | 0.1 |
| Skewness($Z_1$) | $-0.09^{ns}$ | $0.61^{ns}$ | $0.45^{ns}$ | $0.73^{ns}$ | $0.0^{ns}$ | $-0.08^{ns}$ |
| Kurtosis ($Z_2$) | $0.09^{ns}$ | $0.38^{ns}$ | $0.16^{ns}$ | $0.05^{ns}$ | $-0.49^{ns}$ | $-0.75^{ns}$ |

**Reference evapotranspiration *(ETo)***

As it was presented in table 3 reference evapotranspiration attained peak value of4.38 mm/day in the month of February, and in all seasons and years of this months, the peak value may be due to the high temperature recorded in the respective month in the study area. Reference evapotranspiration reaches its lowest point 3.22 mm/day in October, and this lowest record is mainly because, the country predominantly falls under the influence of dry and cool northeasterly winds (Pedgley, 1966; NMSA, 1996).

Table 3: Calculated average reference evapotranspiration for Robe meteorological station for the period 1986-2015.

| Month | Min Temp (°c) | Max Temp (°c) | Humidity (%) | Wind (m/s) | Sun (hours) | Rad ($MJ/m^2$/day) | ETo (mm/day) |
|---|---|---|---|---|---|---|---|
| January | 6.31 | 22.54 | 54.73 | 1.49 | 8.29 | 20.17 | 3.82 |
| February | 6.97 | 23.62 | 51.57 | 1.71 | 8.81 | 22.14 | 4.38 |
| March | 8.17 | 23.55 | 57.77 | 1.8 | 7.86 | 21.52 | 4.35 |
| April | 9.38 | 21.94 | 68.4 | 1.54 | 6.85 | 20.02 | 3.82 |
| May | 9.65 | 22.28 | 67.63 | 1.51 | 7.56 | 20.48 | 3.88 |
| June | 9.35 | 22.68 | 65.43 | 1.69 | 7.59 | 20.06 | 3.91 |
| July | 9.08 | 22.19 | 70 | 1.68 | 7.09 | 19.45 | 3.71 |
| August | 9.05 | 21.46 | 72.43 | 1.67 | 6.68 | 19.38 | 3.63 |
| September | 8.88 | 20.99 | 71.4 | 1.55 | 6.15 | 18.75 | 3.51 |
| October | 8.55 | 19.97 | 72.13 | 1.25 | 5.88 | 17.81 | 3.22 |
| November | 7.06 | 20.54 | 65.47 | 1.26 | 7.22 | 18.78 | 3.33 |
| December | 6.09 | 21.6 | 58.33 | 1.36 | 8.38 | 19.87 | 3.58 |

ETo is the Reference Evapotranspiration calculated by the FAO Penman-Montheith Method

**Trend analysis of annual and seasonal reference evapotranspiration**

In order to test the significance of the existing seasonal and annual reference evapotranspiration trend the non-parametric Mann-Kendall test is done. The result of trend analysis of the reference evapotranspiration is shown in table 4. The non-parametric Mann-Kendall statistical trend test shows a decreasing trend of annual and seasonal (June-September and October-December) reference evapotranspiration at Robestation that were statistically significant at 5% level of significance. However, the positive trend at Robe meteorological station was not statistically significant. The trend magnitude (slope) presented in table 4 revealed the amount of reference evapotranspiration decreasing/increasing per year, and the negative trend magnitude was found for annual and seasonal (June-September and October-January) with Theil-Sen's slope equal to 2.52, 1.02 and 1.59 mm/year, while the positive magnitude was found for small rainy season with Theil-Sen's slope equal to 0.06 mm/year. In the last 30 years (three decades) at the station of Robe, reference evapotranspiration had decreased by 75.6 mm.

Table 4. Trends of annual and seasonal temporal reference evapotranspiration totals in Sinana district for the period 1986-2015.

| Station | Annual | | Kiremt season | | Bega season | | Belg season | |
|---|---|---|---|---|---|---|---|---|
| | $Z_{MK}$ | Slope | $Z_{MK}$ | Slope | $Z_{MK}$ | Slope | $Z_{MK}$ | Slope |
| Robe | -1.99* | -2.52 | -2.14* | -1.02 | -2.28* | -1.59 | $0.04^{ns}$ | 0.06 |

$Z_{MK}$ isMann-Kendal trend test, Slope (Sen's slope) the change (mm) per annual; ns is non-significant trend at 0.01, 0.05, and * indicates significant trend at 5% level of significance. Kiremt (June-September), Bega (October-January) and Belg (February-May).

**Monthly reference evapotranspiration trends**

The Mann-Kendall non parametric trend test was used for Robe meteorological station to establish the monthly reference evapotranspiration trend. The trends of monthly (February-May, June-September and October-January) were tested at 1% and 5% level of significance. September, October and November had a statistically significant decreasing trend at 1% and 5% significance level. However, most of the months in the season showed non-statistically increasing and decreasing trend. The result of trend magnitude revealed that most of the months show negative trend magnitude relative to negative magnitude with low to medium change of reference evapotranspiration per year (Table 5, 6 and 7).

Table 5. Trends of seasonal (February-May) temporal reference evapotranspiration totals in Sinana district for the period 1986-2015.

| | February | March | April | May |
|---|---|---|---|---|
| Station | $Z_{MK}$Slope | $Z_{MK}$Slope | $Z_{MK}$Slope | $Z_{MK}$Slope |
| Robe | $0.05^{ns}$0.03 | $0.54^{ns}$0.24 | $-0.02^{ns}$-0.02 | $-1.45^{ns}$-0.31 |

$Z_{MK}$ isMann-Kendal trend test, Slope (Sen's slope) the change (mm) per annual; ns is non-Significant trend at 0.01, 0.05, and * indicates significant trend at 5% level of significance.

Table 6. Trends of seasonal (June-September) temporal reference evapotranspiration totals in Sinana district for the period 1986-2015.

| | June | July | August | September |
|---|---|---|---|---|
| Station | $Z_{MK}$Slope | $Z_{MK}$Slope | $Z_{MK}$Slope | $Z_{MK}$Slope |
| Robe | $-1.53^{ns}$-0.45 | $-0.82^{ns}$-0.15 | $-1.64^{ns}$-0.29 | -2.82**-0.48 |

$Z_{MK}$ isMann-Kendall trend test, Slope (Sen's slope) the change (mm) per annual; ns is non-Significant trend at 0.01, 0.05, and * indicates significant trend at 5% level of significance.

Table 7. Trends of seasonal (October- January) temporal reference evapotranspiration totals in Sinana district for the period 1986-2015.

| | October | November | December | January |
|---|---|---|---|---|
| Station | $Z_{MK}$Slope | $Z_{MK}$Slope | $Z_{MK}$Slope | $Z_{MK}$Slope |
| Robe | -2.53*-0.5 | -2.75**-0.65 | $-1.34^{ns}$-0.31 | $-1.48^{ns}$-0.31 |

$Z_{MK}$ isMann-Kendal trend test, Slope (Sen's slope) the change (mm) per annual; ns is non-Significant trend at 0.01 and 0.05, and * and ** indicates significant trend at 1% and 5 level of significance.

**Effect of Meteorological Variables**

In order to quantify physical relationship that exists between reference evapotranspiration and climate variables. maximum temperature (Tmax), minimum temperature (Tmin), relative humidity (RH), sunshine and radiation were identified as explanatory variables. Reference evapotranspiration was regressed on these variables by employing stepwise regression procedure in order to see the variation in ETo and the result is shown in table 6. The regression result presented in table 6 showed that given a unit change in any of the climate variables included in the study while holding others constant the highest variation in reference evapotranspiration of all seasons and annual time series in the area will be experienced by wind (103.2 mm/year, 40 mm/season, 31 mm/season and 26.1 mm/season), followed by radiation (41.6 mm/year, 22.6 mm/season, 13.5 mm/season and 12.3 mm/season) and the least change in ETo will be from relative humidity ( -5.8 mm/year, -2.3 mm/season, -1.9 mm/season and -1.7 mm/season). This study suggested that among the climate variables included in the study, wind is the most important variable that has significant impact on ETo in the study area indicating that ETo is higher when wind on seasonal and annual time series is getting higher. In contrast relative humidity has a negative impact in seasonal and annual time series, meaning that there was higher ETo under years with lower RH. Furthermore, statistical t-test analysis indicated that almost all climate variables on seasonal time series are statistically significant in influencing ETo at 5% confidence level (Table 6). The computed value for coefficient of multiple determinations ($R^2$)on monthly, seasonal and annual time series is presented in table 6 (.9, .951, .981, .655 and .977). Among the listed $R^2$ for instance, 97.7% of the variation on ETo value per year is explained jointly by wind, RH, Rad and Tmin. The remaining 2.3% of the variation in ETo, however, could be explained by other climatic and non-climatic factors.

Table 6. Multiple linear regression analysis for effect of meteorological variables on ETo.

| Station | Periods | Climate variables | Slope | T | Sig. | $R^2$ |
|---|---|---|---|---|---|---|
| | | wind | 103.2 | 16.8 | .000 | |
| | | RH | -5.8 | -15.7 | .000 | |
| | Annual | Rad | 41.6 | 12.7 | .000 | .997 |
| | | Tmin | 10.5 | 2.3 | .026 | |
| | | wind | 26.1 | 8.9 | .000 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Robe | | RH | -1.9 | -10.9 | .000 | |
| | JJAS | Rad | 12.3 | 10.4 | .000 | |
| | | Tmax | 6.6 | 3 | .005 | .951 |
| | | wind | 40 | 14.2 | .000 | |
| | | RH | -2.3 | -11.3 | .000 | |
| | | Rad | 22.6 | 13.5 | .000 | |
| | FMAM | Tmin | 5.3 | 2.88 | .003 | .981 |
| | | Tmax | 3.6 | 3.2 | .008 | |
| | | wind | 31.9 | 3.4 | .002 | |
| | ONDJ | RH | -1.7 | -3.1 | .004 | |
| | | Rad | 13.5 | 3.8 | .001 | .655 |
| | Monthly | Tmax | 8.43 | 9.4 | .000 | .9 |

RH = Relative Humidity, Rad = Radiation; Tmin and Tmax is minimum and maximum temperature

## Conclusion and Recommendation

This study aims to analyze the temporal variability and trends of reference evapotranspiration based on meteorological variables for the period of 1986-2015. The results of the standardized coefficients of Skewness and Kurtosis revealed that monthly, seasonal and annual time series were accepted as an indicative of normality at 5% level of significance. The coefficient of variation in the study district showed that reference evapotranspiration had less monthly, seasonal and annual variability, which is an indication that the pattern of ETo can be easily understood, predictable and vary over a short period of time. The Mann-Kendall and Sen's estimator shows more pronounced significant decreasing trend than non-significant trend on seasonal and annual time scale. The lowest and highest value of reference evapotranspiration was observed in the month of October and February, mainly due to temperature increment. Among the climatic variables included in the study for causality relationship with ETo, wind is the most important variables that has significant impact on ETo, followed by radiation. To highlight some of the variation explained by the combined effects of climatic variables, 97% of the variation on ETo values per year is explained jointly by wind, radiation and minimum temperature. It is recommended that, when calculating ETo for crop water need, irrigation scheduling and other activities climatic variables should be strictly analyzed.

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