

Full Length Research Paper

Sensitivity analysis of climatic parameters on Reference Evapotranspiration (ET_o) calculated by FAO Penman - Monteith Equation (CROPWAT MODEL 8.0) for Sub-humid to humid areas of Arsi Zone, Ethiopia

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The sensitivity of reference evapotranspiration calculated by CROPWAT 8.0 model to climate variables in Kulumsa and Meraro, Arsi Zone Ethiopia has been investigated. Sensitivity analysis of ET_o to minimum temperature, maximum temperature, relative humidity, wind speed and sunshine hours were conducted using SAS 9.0 and Excel based on correlation coefficient, linear regression and root mean square error (RMSE). The sensitivity coefficients were derived for each variable on a monthly basis. The results of correlation, linear regression and RMSE between the reference evapotranspiration and climatic variables showed that during annual and dry season period, relative humidity and maximum temperature showed high negative and positive correlation coefficient respectively for both Kulumsa and Meraro study sites but during rainy season, sunshine hours and relative humidity showed high positive and negative correlation for Kulumsa and Meraro study sites. For Kulumsa study site, relative humidity, maximum temperature and wind speed showed high regression coefficient and low root mean square error for annual, dry season and rainy season respectively, while relative humidity showed high regression coefficient and low root mean square error for both annual and rainy season for Meraro study site. However during the dry season at Meraro study site, maximum temperature showed high regression coefficient and low root mean square error.

Key words: FAO 56-PM equation, reference evapotranspiration, climatic variables, correlation, linear regression, root mean square error.

INTRODUCTION

The evaporative demand of the atmosphere was studied using reference independently of crop type, crop development and management practices (Zotarelli et al., 2009). Climatic parameters can be computed from weather data and it is the only factor that can affect calculation of reference evapotranspiration, represented by vegetated surface and shows the effect of climatic parameters in crop water requirement (Allen et al., 1998). Even if there are several methods to define and calculate reference evapotranspiration, FAO-PM Model was recommended as a standard method for defining and computing reference evapotranspiration by international experts in May 1990 (Jensen et al., 1997). FAO Penman-

Monteith equation requires air temperature, humidity, radiation, wind speed and sunshine duration data for daily, weekly, ten-day or monthly calculations as input data for climatic parameters and also altitude above sea level (m) and latitude (degrees north or south) of the location should be specified (Allen et al., 1998).

The FAO56-PM model has proved to be a relatively accurate method in both humid and arid climate because of incorporating thermodynamic and aerodynamic

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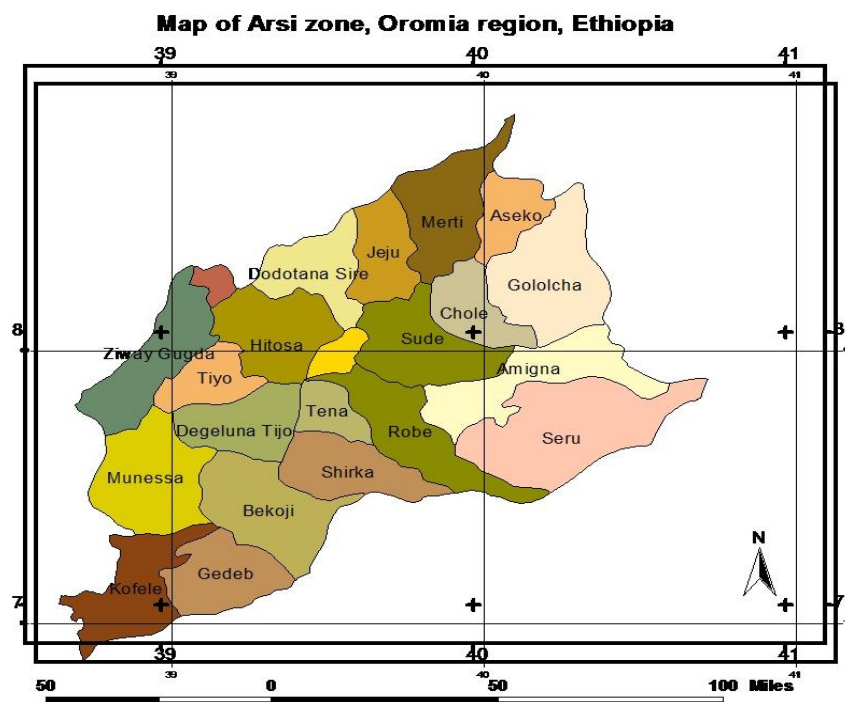


Figure 1. Map of Arsi zone, Oromia region, Ethiopia.

aspects (Yunhe et al., 2008). Calculations of the reference crop evapotranspiration E_{To} are often computerized using software packages like CROPWAT 8.0. CROPWAT 8.0 requires climatic data on minimum temperature, maximum temperature, relative humidity, wind speed and sunshine hours. On the base of climatic data available, CROPWAT 8.0 estimates the solar radiation reaching soil surface.

Knowledge of the relative effects of the climate variables in the evapotranspiration process is of fundamental importance in the context of irrigation (Araujo et al., 2011). Reference evapotranspiration required for planning, designing and management of irrigation practices but lack of information on reference evapotranspiration is one of the factors that affect the development of irrigation practices in Ethiopia. Computation of limited climatic parameters from lower level weather station and lack of knowledge on how to choose and use the appropriate method for the given climatic parameters makes it even difficult to calculate reference evapotranspiration. Therefore, there is a need for understanding the relative effect of the most important climatic parameters in the estimation of reference evapotranspiration, so that it is possible to compute the relevant climatic parameters under lower class weather station and also to choose the appropriate reference evapotranspiration calculation model under limited climatic parameter.

Calculation of the sensitivity analysis of climatic parameters to reference evapotranspiration is required to understand the physical meaning of their relation (Ambas

et al., 2012). In the past, several papers have been published based on sensitivity analysis of Penman-Monteith to climatic variables in arid, semi-arid, sub-humid and humid areas. Under the environment of a semi humid sub tropic region of Bangladesh, sensitivity coefficient of reference evapotranspiration calculated using FAO-PM shows that reference evapotranspiration is most sensitive to maximum temperature, relative humidity, sunshine hours, wind speed and minimum temperature orderly (Ali et al., 2009). In less arid warm areas, sensitivity coefficient shows solar radiation is the most sensitive variable than relative humidity, wind speed and air temperature than in arid and semiarid cool areas (Bakhtiari et al., 1982).

If the change of the dependent variable of an equation is studied with respect to change in each of the several independent variables, the sensitivity coefficient will show the relative importance of each of the variables to the model solution (Bakhtiari et al., 1982). Therefore, the present investigation was undertaken to access the sensitivity of climatic parameter in terms of relationship, influence and performance on E_{To} calculated by CROWAT 8.0 Model under conditions of Kulumsa and Meraro.

MATERIALS AND METHODS

Study sites and weather data sources

The study sites selected for this activity are Kulumsa and Meraro which are found in Tiyo, and Lemu and Bilbilo

Woreda respectively, Arsi Zone, Ethiopia (Figure 1). The reason for selecting these study sites is because of the availability of long term weather data. Kulumsa weather station found in Kulumsa Agricultural Research Center is located at 08.0194°N, 39.153°E and 2200 m altitude, whereas Meraro weather station found in Meraro sub-research center under Ethiopian Institute of Agricultural Research is located at 07.4075°N, 39.249°E and 2900 m altitude. The annual average rainfall reaches 820 mm and 1196 mm for Kulumsa and Meraro weather stations respectively.

Reference evapotranspiration (ET_o) values were computed with monthly weather data and 20 years of weather data were collected from both locations for this study. The data are composed of minimum temperature, maximum temperature, relative humidity, wind speed and sunshine hours. These values were used to compute ET_o using FAO Penman-Monteith method (CROPWAT MODEL 8.0).

Cropwat Model 8.0

CROPWAT 8.0 Model was used to calculate the reference evapotranspiration (ET_o) based on FAO Penman-Monteith equation. The input data required by the model include monthly temperature (maximum and minimum), relative humidity, sunshine hours and wind speed. The model was used to calculate monthly values of ET_o using weather data of two study sites.

Statistical analysis

Sensitivity analysis was used to estimate the relative contribution of climate variables to the calculated ET_o. Sensitivity analysis studies the impact of change of one parameter to another (McCuen, 1973). In this study, sensitivity analysis studies the impact of measured meteorological variables to the estimated reference evapotranspiration with FAO Penman-Monteith (CROPWAT 8.0 Model). This study used SAS 9.0 and Excel for correlation, linear regression and RMSE. Correlation coefficient analysis used to determine the degree of association between ET_o and climatic parameter. The linear regression applied to test the effect of change in the value of climate parameter has on ET_o. The equation used for linear regression is $y=a+bx$, where y represents ET_o calculated by FAO Penman-Monteith equation (CROPWAT MODEL 8.0), x is climatic parameter, a and b are constant representing the intercept and slope of the regression equation respectively.

The root mean square error (RMSE) used to test which climatic parameter performed best.

RESULTS AND DISCUSSION

ET_o values trend for Kulumsa and Meraro

The ET_o was calculated using FAO Penman-Monteith for

Kulumsa and Meraro have similar trend through the month. According to Figures 2 and 3, the highest ET_o found in Kulumsa and Meraro is during dry season in March with a value of 4.73 mm/day and 4.1 mm/day respectively and the lowest ET_o found in Kulumsa and Meraro is during rainy season in August with a value of 3.19 mm/day and 2.79 mm/day respectively. The difference between ET_o values for Kulumsa and Meraro is different because of the difference between altitude and agroecological zone.

Annual and seasonal based correlation of climate variables to ET_o

Results from correlation of annual climate variables to ET_o for Kulumsa site shows that relative humidity has high negative correlation coefficient in both study sites according to Tables 1 and 2. From both study sites, minimum temperature has the lowest negative correlation coefficients. It is clearly seen that maximum temperature, wind speed, sunshine hours and radiation has positive correlation with ET_o and minimum temperature and relative humidity has a negative correlation with ET_o for both study sites. As shown in Figures 2 and 3, during dry season (November to May), the climatic parameters and ET_o trend showed different trends from the visual feature of figure 2 and 3; it may be because of the change of the sensitivity of climatic variables with the change of the season so it is necessary to make correlation analysis of the climatic variables and ET_o based on dry and rainy seasons.

During the dry season in Kulumsa and Meraro study sites, maximum temperature has high positive correlation on both sites with a value of 0.78875 and 0.80677, on the other hand relative humidity and minimum temperature has low negative and low positive correlation with ET_o in Kulumsa and Meraro study sites respectively.

On both study sites, the relative humidity and sunshine hours has negative correlation including wind speed only in Kulumsa site. During rainy season in Kulumsa and Meraro study sites, sunshine hours and relative humidity has high positive and high negative correlation with ET_o respectively. Relative humidity with a value of negative 0.79650 correlation coefficient and sunshine hour with a value of positive 0.94740 correlation coefficient has second highest correlation coefficient with ET_o for Kulumsa and Meraro study sites respectively. On the other hand, minimum temperature and maximum temperature has low negative and positive correlation with ET_o for Kulumsa and Meraro study sites respectively.

Annual and seasonal based performance of climate variables on ET_o

All studies (McCuen, 1973; Coleman et al., 1976; Beven, 1979; Yunhe et al., 2008; Chong-yu et al., 2006) showed that potential evaporation or evapotranspiration was

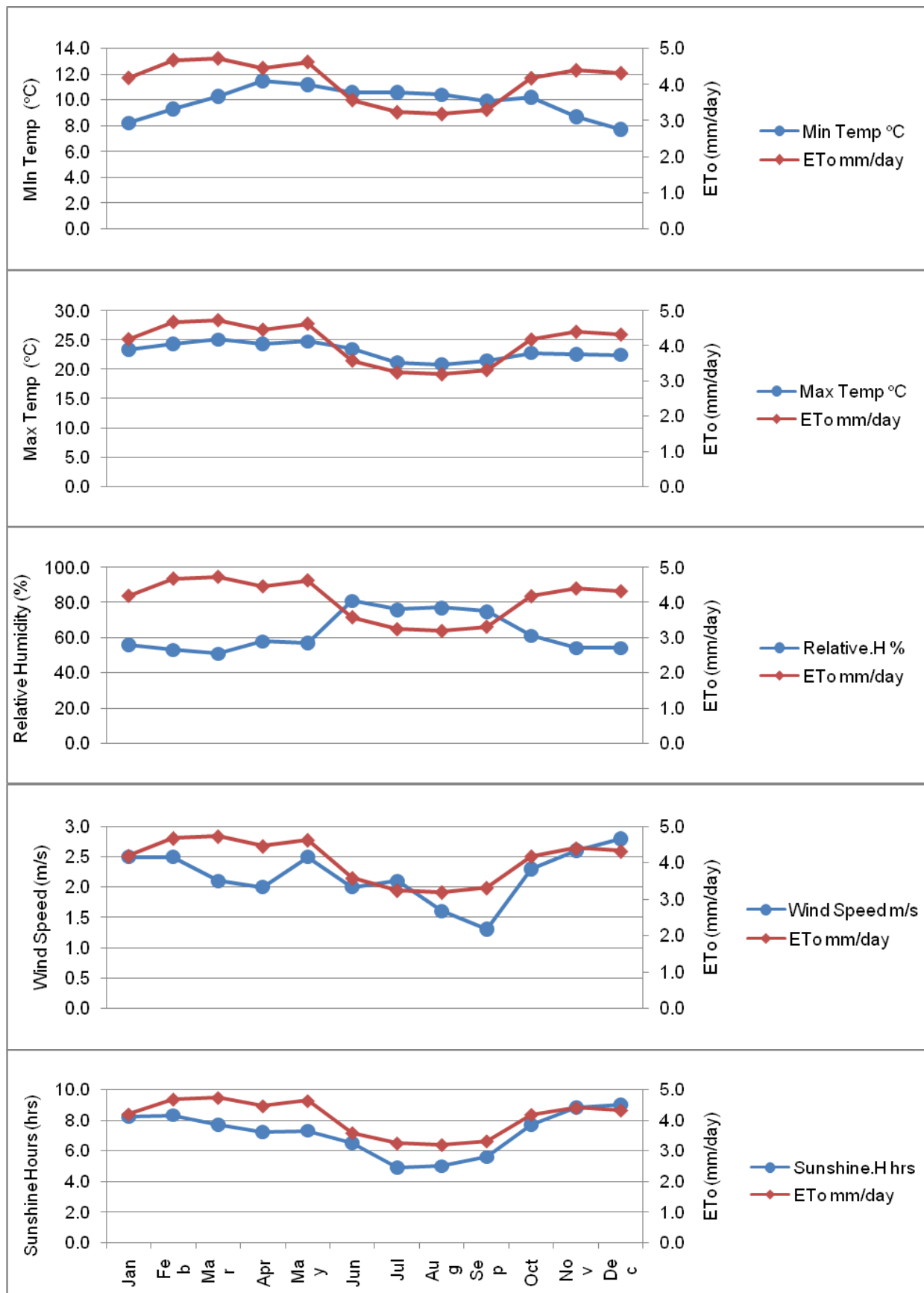


Figure 2. Relationships between climatic variables and ET₀ calculated for Kulumsa.

Table 1. Correlation coefficient for climatic variable with ETo in Kulumsa.

ETo vs Climatic Variable	Kulumsa Site		
	Annual	Dry Season	Rainy Season
ETo vs Minimum Temperature	-0.16255	0.61914	-0.15872
ETo vs Maximum Temperature	0.85340	0.78875	0.71624
ETo vs Relative Humidity	-0.93562	-0.40908	-0.79650
ETo vs Wind Speed	0.69253	-0.42115	0.65884
ETo vs Sunshine Hours	0.84403	-0.46156	0.97483

Table 2. Correlation coefficient for climatic variable with ETo in Meraro.

ETo vs Climatic Variable	Meraro Site		
	Annual	Dry Season	Rainy Season
ETo vs Minimum Temperature	-0.30863	0.23733	-0.92631
ETo vs Maximum Temperature	0.87559	0.80677	0.60540
ETo vs Relative Humidity	-0.93599	-0.57129	-0.97660
ETo vs Wind Speed	0.89401	0.48002	0.79149
ETo vs Sunshine Hours	0.79006	-0.33581	0.94740

Table 3. Relationships between climatic variable and ETo estimated from the variable in Kulumsa.

ETo vs Climatic Variable	Kulumsa Site								
	Annual			Dry Season			Rainy Season		
	a	b	r ²	a	b	r ²	a	b	r ²
ETo vs Minimum Temperature	-0.081	4.873	0.026	0.084	3.685	0.383	-0.219	5.762	0.025
ETo vs Maximum Temperature	0.351	-4.020	0.728	0.150	0.899	0.622	0.262	-2.264	0.513
ETo vs Relative Humidity	-0.049	7.168	0.875	-0.034	6.334	0.167	-0.043	6.664	0.634
ETo vs Sunshine Hours	0.350	1.555	0.712	-0.300	5.216	0.177	0.667	2.259	0.434
ETo vs Wind Speed	0.932	2.032	0.479	-0.132	5.551	0.213	0.340	1.480	0.950

Table 4. Relationships between climatic variable and ETo estimated from the variable in Meraro.

ETo vs Climatic Variable	Meraro Site								
	Annual			Dry Season			Rainy Season		
	a	b	r ²	A	B	r ²	a	b	r ²
ETo vs Minimum Temperature	-0.132	4.247	0.095	0.040	3.559	0.056	-0.663	7.266	0.858
ETo vs Maximum Temperature	0.368	-3.115	0.767	0.282	-1.445	0.651	0.177	-0.004	0.367
ETo vs Relative Humidity	-0.049	6.794	0.876	-0.027	5.434	0.326	-0.054	7.201	0.954
ETo vs Sunshine Hours	0.268	1.555	0.624	0.469	2.456	0.230	0.469	2.088	0.626
ETo vs Wind Speed	0.741	1.634	0.799	-0.096	4.554	0.113	0.274	1.395	0.898

much more sensitive to radiation and humidity. The linear regression between ETo versus the climate variable are described in Tables 3 and 4 for Kulumsa and Meraro respectively. During the annual period, ETo has better fitting with relative humidity with a value of r^2 0.875 and r^2

0.876 for Kulumsa and Meraro study sites respectively (Figures 4 and 7). ETo estimated using CROPWAT 8.0 model are most sensitive to maximum temperature and second best sensitive to relative humidity under semi-humid sub-tropics region of Bangladesh

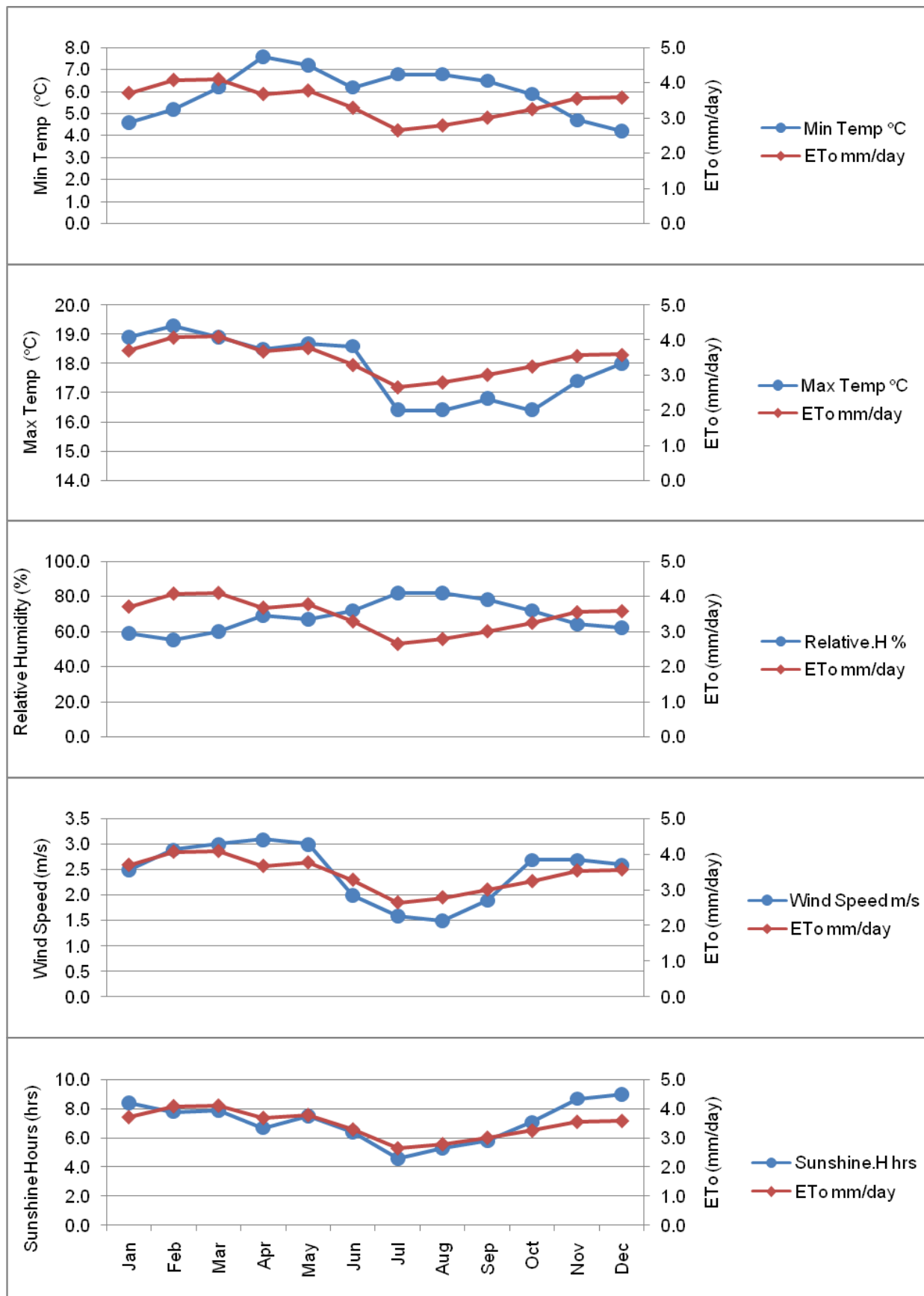


Figure 3. Relationships between climatic variables and ET₀ calculated for Meraro.

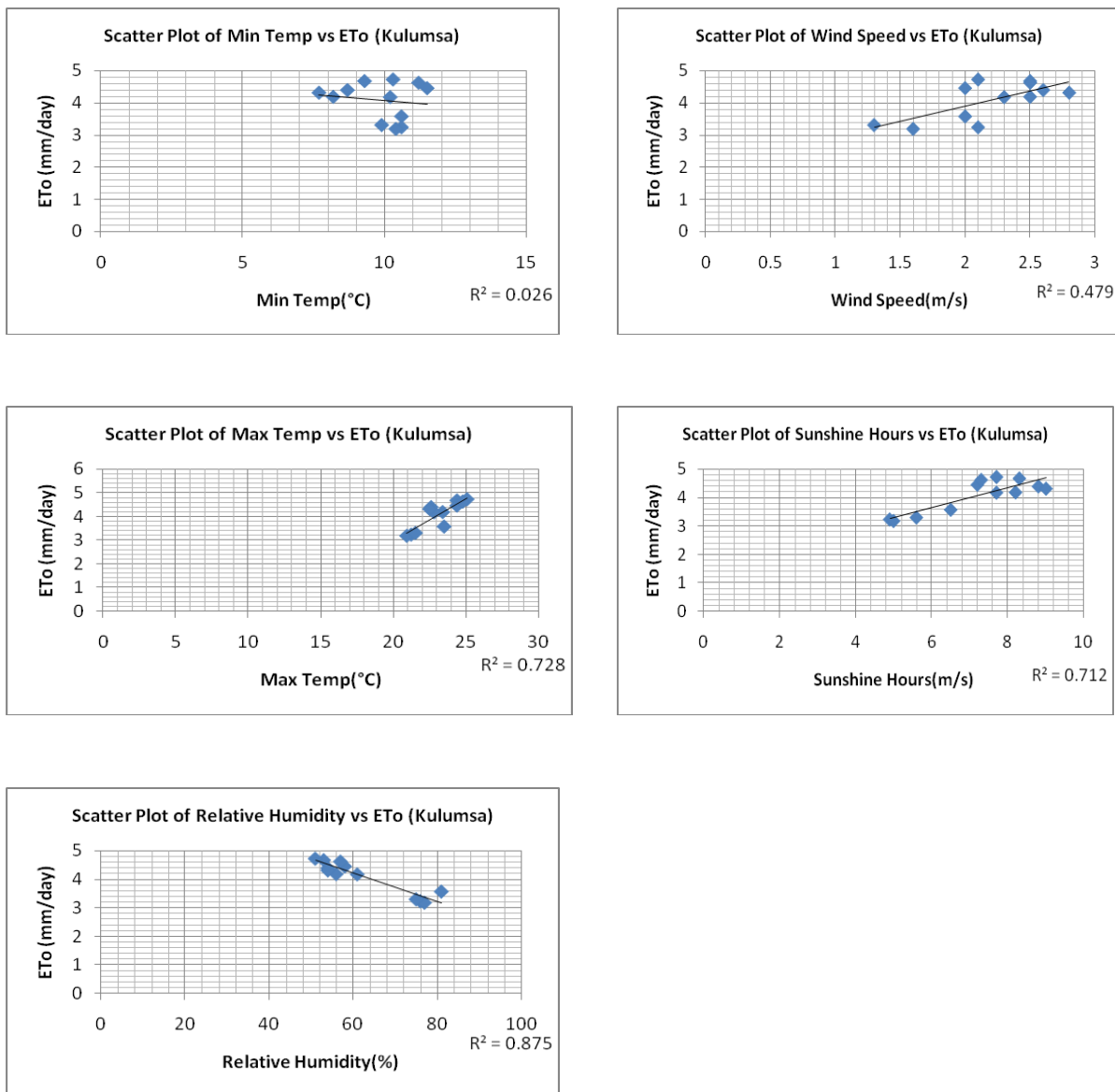


Figure 4. Scatter plot of climatic parameters versus ETo for Kulumsa area annually.

(Bakhtiari et al., 1982). During the dry season, maximum temperature has the highest regression coefficient with a value of r^2 0.622 and r^2 0.651 for Kulumsa and Meraro study sites respectively (Figures 5 and 8).

During the rainy season for Kulumsa site, the relation between ETo and wind speed has a maximum regression coefficient of r^2 0.950 and relative humidity has the second best relation with ETo with a value of r^2 0.634 (Figure 6). In the case of Meraro site, relative humidity has the highest regression coefficient of r^2 0.954 and wind speed has the second highest regression coefficient of r^2 0.898 (Figure 9). Thus, this shows that ETo has high sensitivity to relative humidity and maximum temperature for both Kulumsa and Meraro during annual and dry season respectively. ETo is sensitive to wind speed and relative humidity during rainy season for Kulumsa and

Meraro sites respectively. Reference evapotranspiration is most sensitive to the net total radiation, followed by relative humidity, air temperature and wind speed (Chong-yu et al., 2006).

According to Tables 5 and 6, Kulumsa study site RMSE values range from 0.216 to 0.604, 0.135 to 0.200 and 0.105 to 0.466 for annual, dry season and rainy season respectively, whereas for Meraro study site, the RMSE values range from 0.173 to 0.467, 0.145 to 0.238 and 0.069 to 0.257 for annual, dry season and rainy season respectively. The smaller the RMSE value, the better the climate variable influence on ETo calculation. For Kulumsa study site, relative humidity, maximum temperature and wind speed has RMSE value of 0.216, 0.135 and 0.105 for annual, dry season and rainy season respectively (Table 5). On the other hand, for Meraro

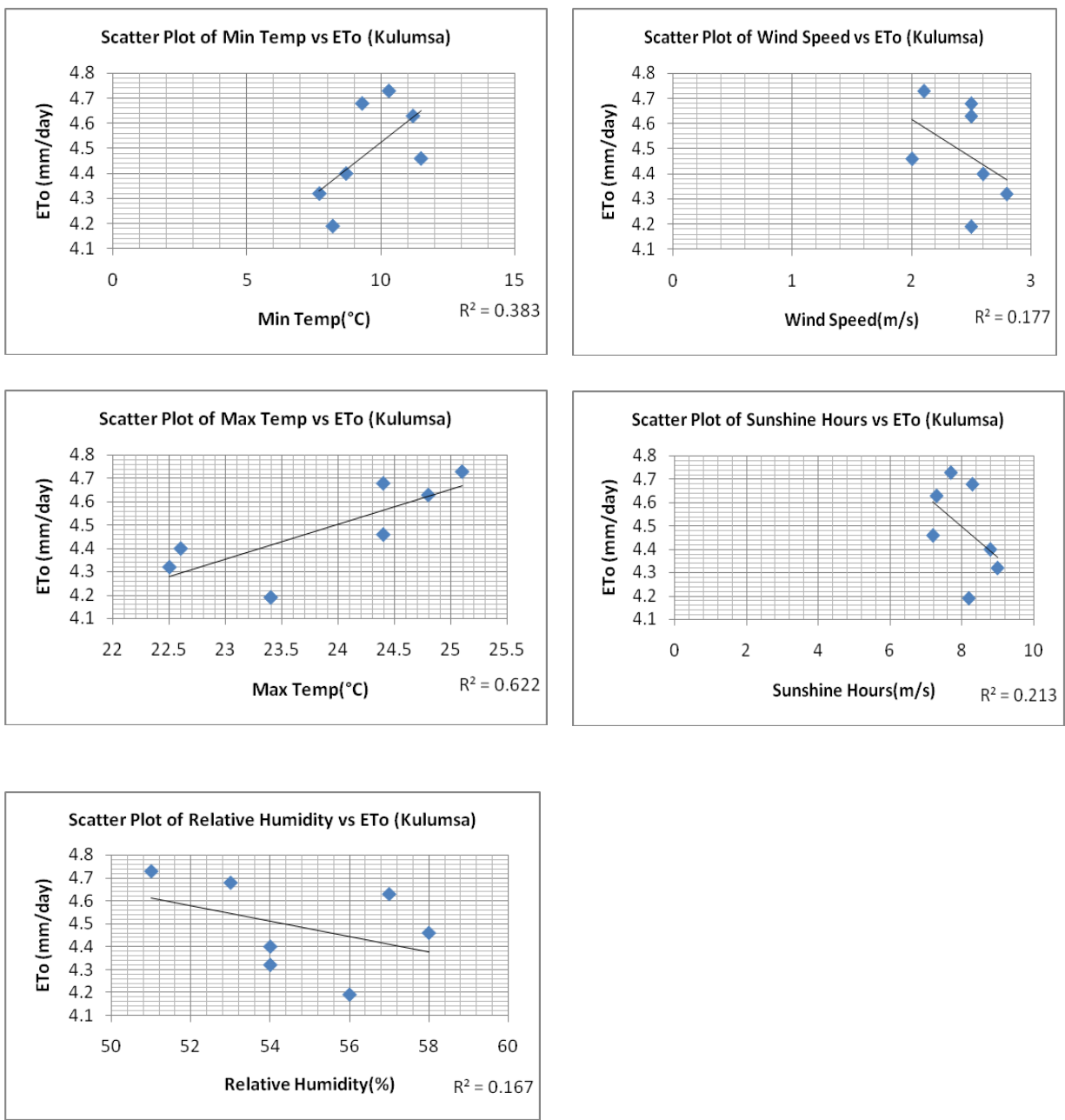


Figure 5. Scatter plot of climatic parameters versus ETo for Kulumsa area during dry season.

study sites, RMSE value of 0.173, 0.145 and 0.069 is the smallest value of relative humidity, maximum temperature and humidity for annual, dry season and rainy season respectively (Table 6).

CONCLUSION

The performance of climatic parameters has been evaluated based on FAO Penman Monteith method (CROPWAT 8.0 Model) for the two study sites: Kulumsa and Meraro. It is discovered from this study that for Kulumsa study site which has sub-humid dry agro

ecological zone, relative humidity has an effect annually, but for the dry and rainy seasons, maximum temperature and wind speed has effect on calculated ETo using FAO Penman-Monteith method respectively. For Meraro study site which has sub-humid to humid agro ecology zone, relative humidity, maximum temperature and relative humidity has an effect on calculated ETo using FAO Penman-Monteith method for annual, dry season and rainy season respectively. Therefore, from the result of this study, it is concluded that wind speed during rainy season in sub-humid dry areas of Arsi Zone has influence on ETo, and at the same time ETo is sensitive to relative

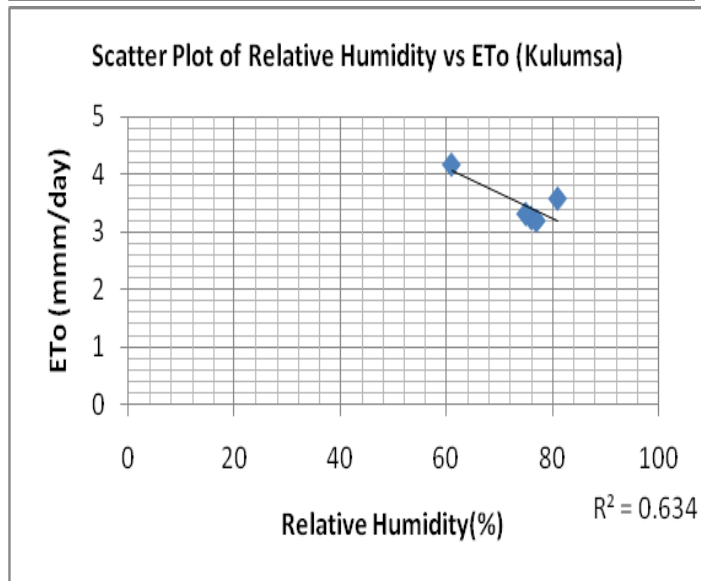
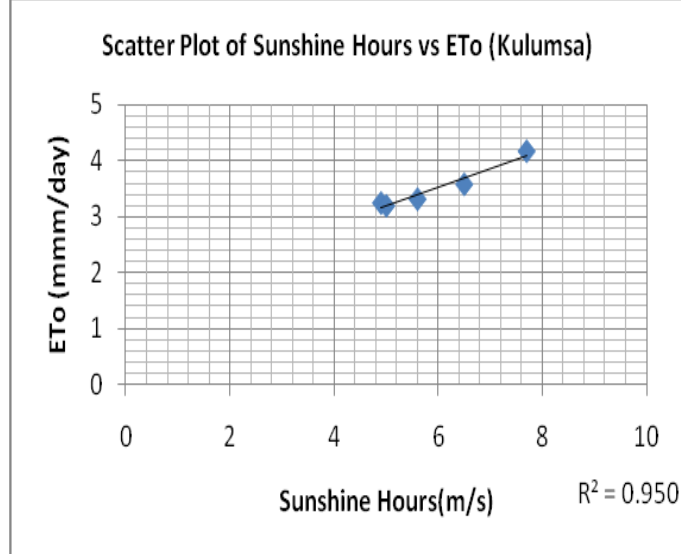
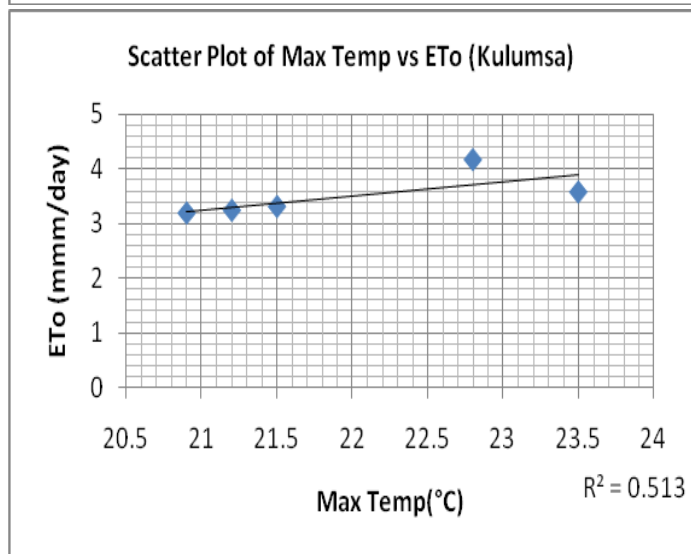
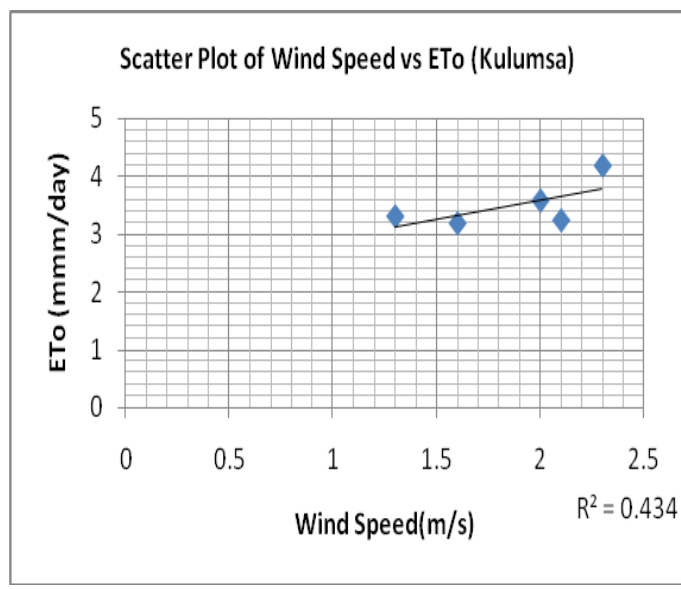
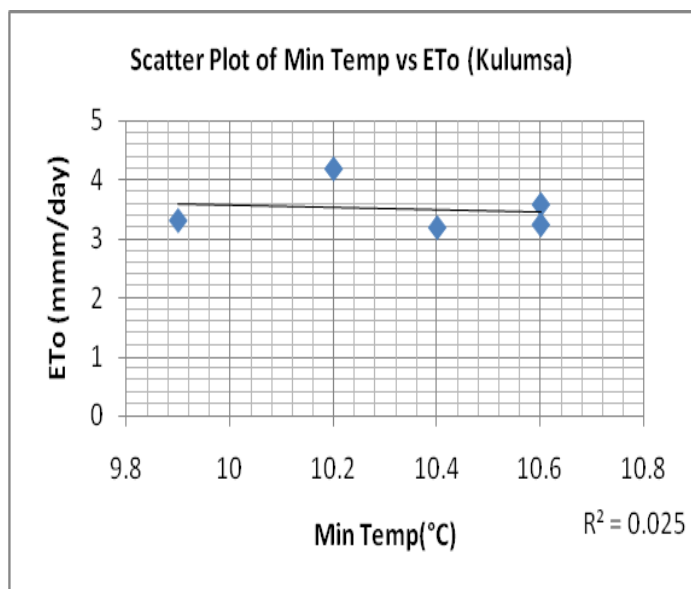


Figure 6. Scatter plot of climatic parameters versus ETo for Kulumsa area during rainy season.

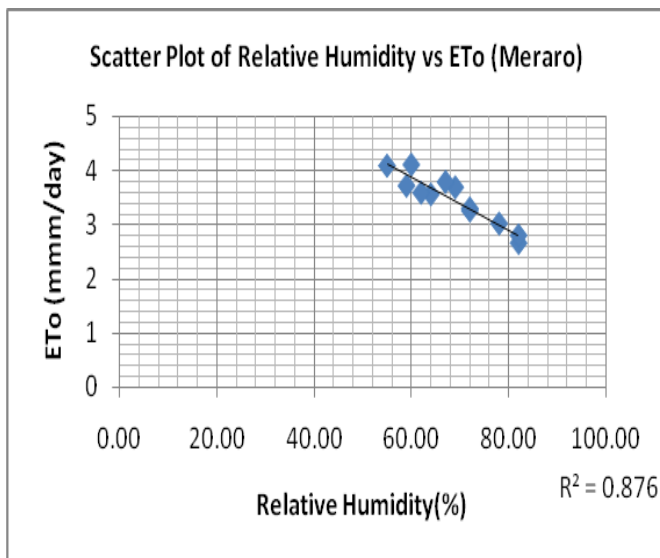
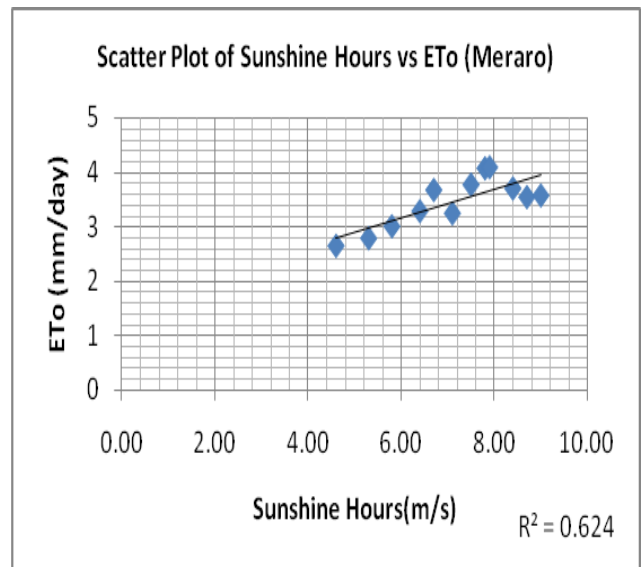
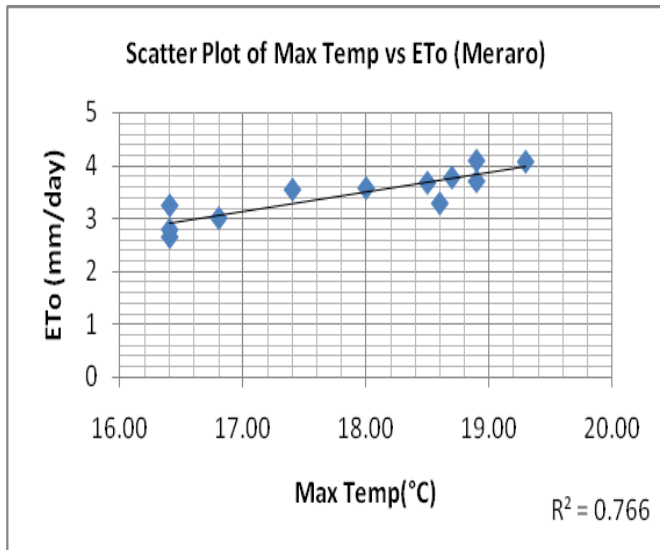
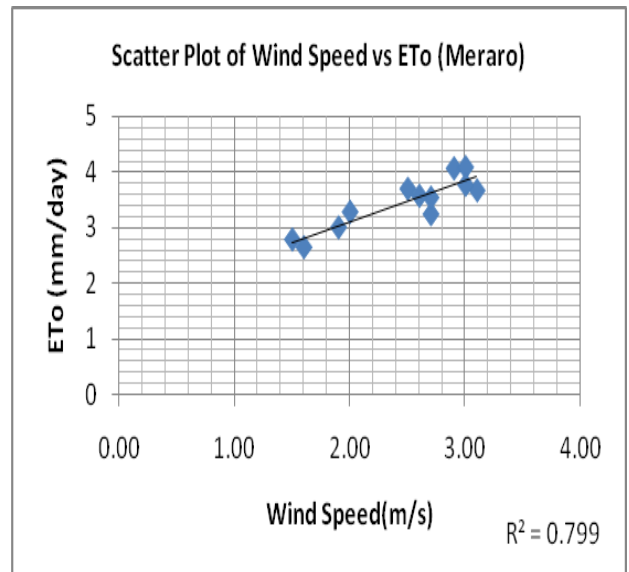
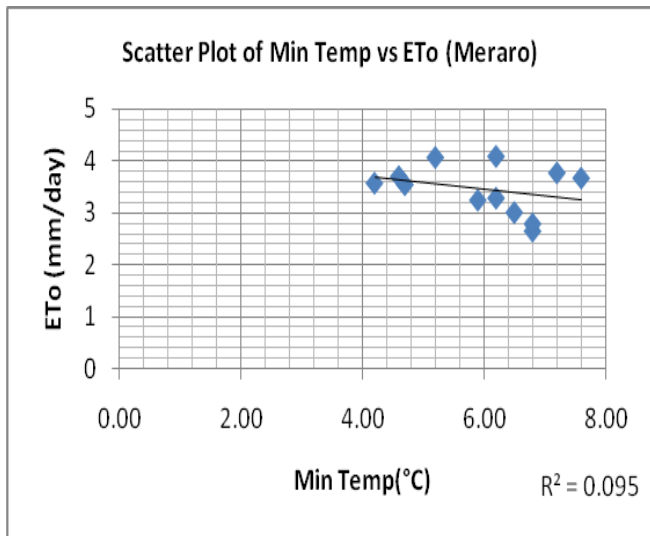


Figure 7. Scatter plot of climatic parameters versus ETo for Meraro area annually.

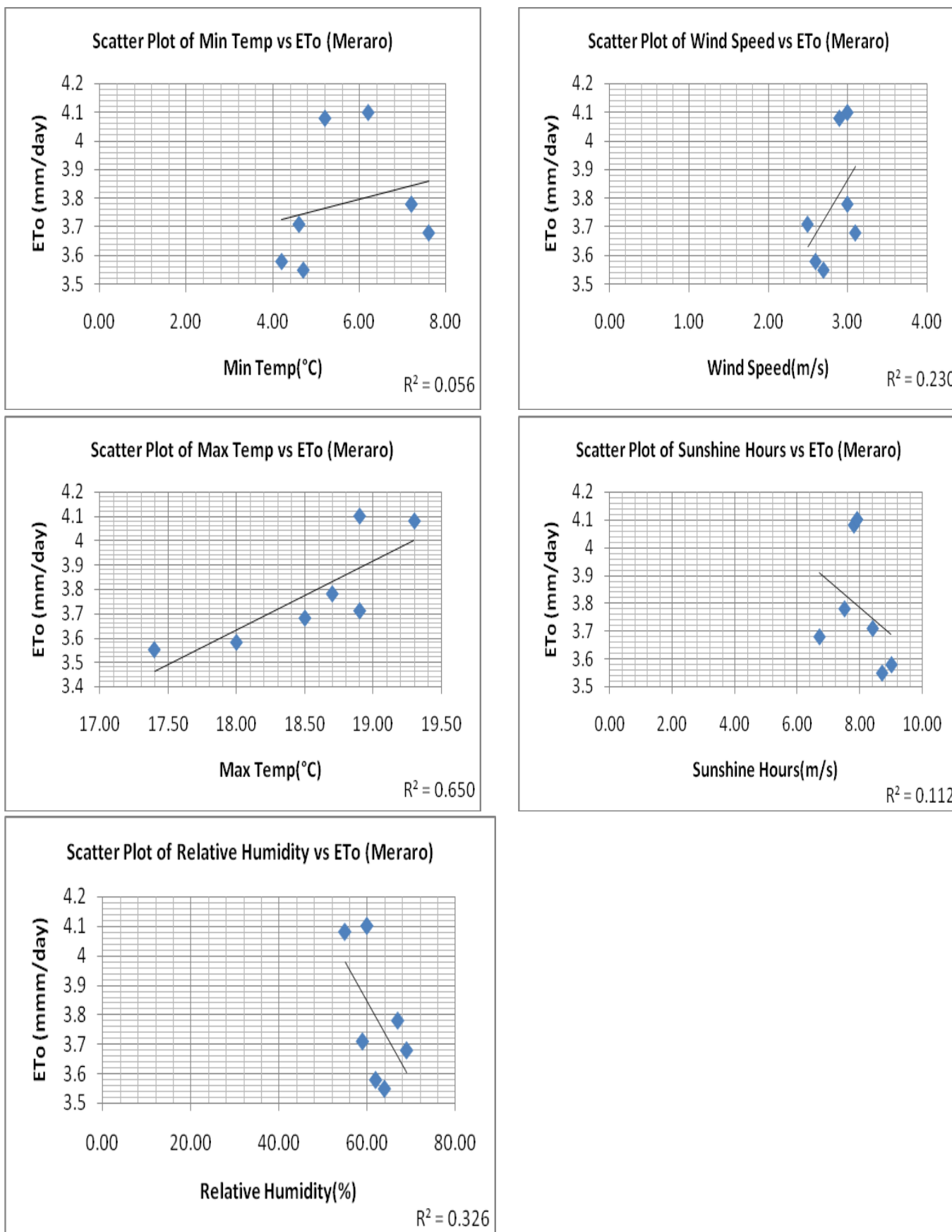


Figure 8. Scatter plot of climatic parameters versus ETo for Meraro area during dry season.

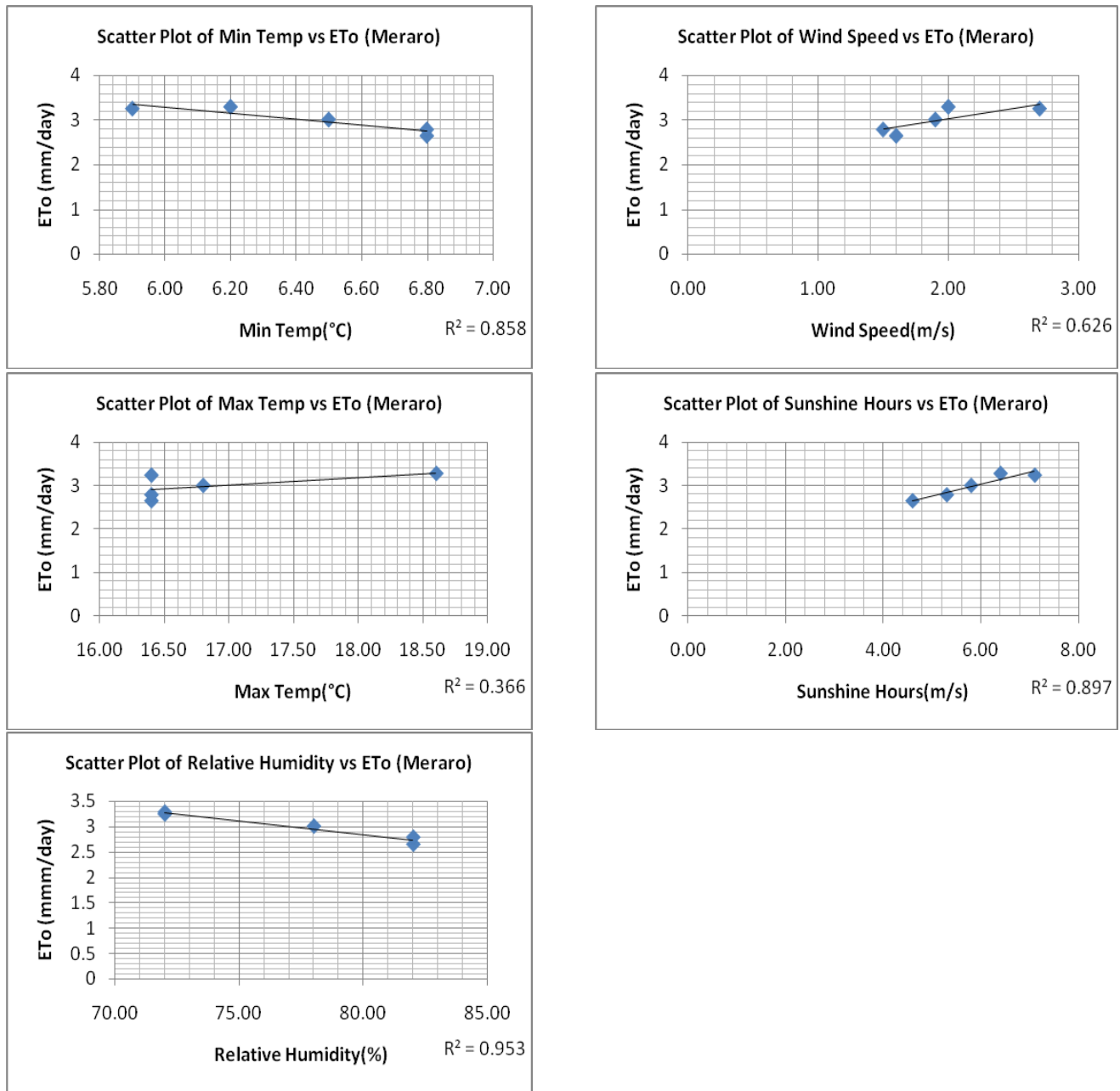


Figure 9. Scatter plot of climatic parameters versus ETo for Meraro area during rainy season.

Table 5. Error analyses performed on climatic variable and estimated ETo values from the variable in Kulumsa.

ETo vs Climatic Variable	Kulumsa Site		
	Annual	Dry Season	Rainy Season
Root Mean Square Error (RMSE)			
ETo vs Minimum Temperature	0.604	0.172	0.466
ETo vs Maximum Temperature	0.319	0.135	0.329
ETo vs Relative Humidity	0.216	0.200	0.285
ETo vs Sunshine Hours	0.328	0.199	0.355
ETo vs Wind Speed	0.442	0.195	0.105

Table 6. Error analyses performed on climatic variable and estimated ETo values from the variable in Meraro.

ETo vs Climatic Variable	Meraro Site		
	Annual	Dry Season	Rainy Season
Root Mean Square Error (RMSE)			
ETo vs Minimum Temperature	0.467	0.238	0.122
ETo vs Maximum Temperature	0.237	0.145	0.257
ETo vs Relative Humidity	0.173	0.201	0.069
ETo vs Sunshine Hours	0.301	0.215	0.198
ETo vs Wind Speed	0.220	0.231	0.103

humidity during rainy season for sub-humid to humid areas of Arsi Zone.

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