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COMPARISON OF TEMESGEN-MELESSE AND ABTEW METHODS ET ESTIMATION WITH FAO-56 PENMAN-MONTEITH METHOD USING DATA OF NINE CLASS I METEOROLOGICAL STATIONS IN ETHIOPIA

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Abstract: Evapotranspiration is one of the essential hydrological parameter that has to be accurately estimated for appropriate water use. In this study one temperature-based method of estimating ET known as Temesgen-Melesse (TM) method and one surface radiation-based method known as Abtew method were compared with the standard FAO 56 PM method using data of nine Class-I meteorological stations, in Ethiopia. Performances of the methods were tested using parameters such as Coefficient of Efficiency (CE), Coefficient of Residual Mean (CRM), combination of coefficient of determination (R^2) and slope of the linear regression, Mean Percent Error (MPE) and coefficient of variation (CV) calculated from standard deviation and mean of the data statistics. Besides, 1:1 line, 95% prediction bounds and residual plots were used to supplement the test parameters. Based on the tests, TM performed well on three of the nine sites for which there is no need for calibration. Abtew method did not do so well on all of the sites either because of over or under estimation or due to crossing of the regression line with the 1:1 line. TM method requires site-based calibration for six and Abtew method, for all the sites. When using performance test parameters, it is important to include 1:1 line and prediction bounds to get information that is not clearly obtained from the other parameters.

Keywords: ET estimation; Radiation-based ET method; Temperature-based ET method; Performance test parameters.

1. Introduction

Evapotranspiration (ET) is an agro-ecological phenomenon which manifests two combined & separate processes in an agricultural environment. ET is the term that refers to the simultaneous dual process in which water is lost from the soil surface on one hand through evaporation and from the crop plants through transpiration on the other. Since both evaporation and transpiration processes are occurring at the same time, it is very difficult to distinguish the two separate spatio-temporal phenomena in the field.

Quantification of ET is used for many purposes such as irrigation, water resources planning and management, for drainage requirements and environmental assessment (Xu and Sing, 2001; Wang *et al.,* 2009). It is also required for mass and energy balance (Xiong *et al.,* 2008).

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Irrigation agriculture accounts for 70% of global fresh water use (Alblewi, 2012; Ilesanmi *et al.,* 2014). ET on the other hand, accounts for more than 60 – 70% of the water balance (Semu Ayalew, 2010). Accurate estimation of ET is important especially in semi-arid areas where 70-80% of precipitation is lost by ET unlike cold climates where it consumes only 30% of precipitation (Tegos *et al.,* 2013).

There are two approaches of finding ET. These are direct measurement and estimation using empirical methods (Wang *et al.,* 2009). Direct measurement is labor intensive, time consuming and expensive (Temesgen and Melesse, 2013). In order to tackle the difficulty, several empirical methods were developed over decades. While some models tried to predict ET using temperature only (e.g. Thornthwaite; Lincare) others tried to use solar radiation (e.g. Hamon used daylight length with saturated vapor density) (Xu and Singh, 2001). Still others like Hargreaves and Samani (1985) and Blaney-Criddle used both temperature and solar radiation in their methods to estimate ET (Xu and Singh, 2001). All of the methods are considered energy based since both temperature and solar radiation are energy based. The most widely used and the one recommended by FAO is the Penman-Monteith (PM) method (Kariyama, 2014). What separates this method from the rest is in its use of aerodynamic term in addition to the energy term. Because of its use of the two terms, it is considered as a combination method. While all energy term based methods lack wide applicability outside the location and climatic conditions for which they were developed, the PM gives accurate results over wide climate regimes (Alblewi, 2012; Kariyama, 2014).

The current trend is to continue using the simpler energy based methods and to make calibrations as needed. In Ethiopia due to recurrent drought there is a need for irrigation to bring self-sufficiency in food. In an attempt to have good water use planning and management, two simple ET estimation methods were tested using ten Class -1 meteorological stations (Temesgen and Melesse, 2013). The first method is known as Abtew method and is based only on solar radiation. The ET obtained by this method is hereafter identified as ET_A and is estimated as (Abtew, 1996),

$$ET_A = k\frac{R_s}{\lambda} \tag{1}$$

The evapotranspiration is in mm d^{-1}, *k* is the conversion constant initially estimated to be 0.53 but may need to be calibrated for different locations. R_s is incoming solar radiation in $MJm^{-2}d^{-1}$, which is divided by λ (= 2.26 MJ m^2 mm^{-1}) according to Medeiros *et al.* (2011) and 2 .45 MJ kg^{-1} according to Allen *et al.* (2006), to get R_s in mm d^{-1}. According to Wang *et al.*

(2009), solar radiation is the second most influential parameter (next to maximum temperature) to estimate ET and hence the use of this parameter as ET predictor is justified.

The second method is temperature based and was developed from Eq. (1) by Temesgen and Melesse (2013) by replacing both k and λ by a single constant k*. They used power form of maximum temperature (T_{mx}) to estimate ET and the method is hereafter denoted as ET_{TM}.

$$ET_{TM} = \frac{(T_{mx})^n}{k^*} \tag{2}$$

The authors assumed *n* value of 2.5 and they used maximum temperature dependent k^* of $48T_{mx}$- *330* for combined dry and wet conditions or seasons. The maximum temperature when daily ET_{TM} is estimated is the daily maximum temperature, in °C.

For the sake of comparison, the two methods were compared with the Penman-Monteith ET (noted as ET_{PM} hereafter) which is given as (Temesgen and Melesse, 2013),

$$ET_{PM} = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T-273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{3}$$

The conditions under which the equation was developed and the units are as given in Allen *et al.* (2006) i.e., where ET_{PM} is reference evapotranspiration (mm d^{-1}); R_n is the net radiation at the crop surface ($MJm^{-2}d^{-1}$); *G* is soil heat flux density ($MJm^{-2}d^{-1}$), assumed zero on daily basis; *T* (°C) is mean daily air temperature at 2-m height; 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 of vapor pressure curve (kPa $^oC^{-1}$); and γ is psychrometric constant (kPa $^oC^{-1}$).

In this study, nine locations of different agro-climatic conditions were selected in Ethiopia and the performances of the two methods were tested against the PM method.

2. Materials and Methods

2.1. Description of the study areas

For this study, data of nine class I meteorological stations that represent different climatic and agro-ecological settings over Ethiopia were selected. From among the nine, four stations (Bahar Dar, Dangla, Addis Ababa, and Addet) have previously been used for comparison with PM method by Temesgen and Melesse (2013). The remaining five class I meteorological stations (Methara, Ziway, Debre Brhan and Dessie) are included to test if the calibrations the authors suggested for the former areas perform well or not. The locations of the study sites in the country are shown in Fig. 1.

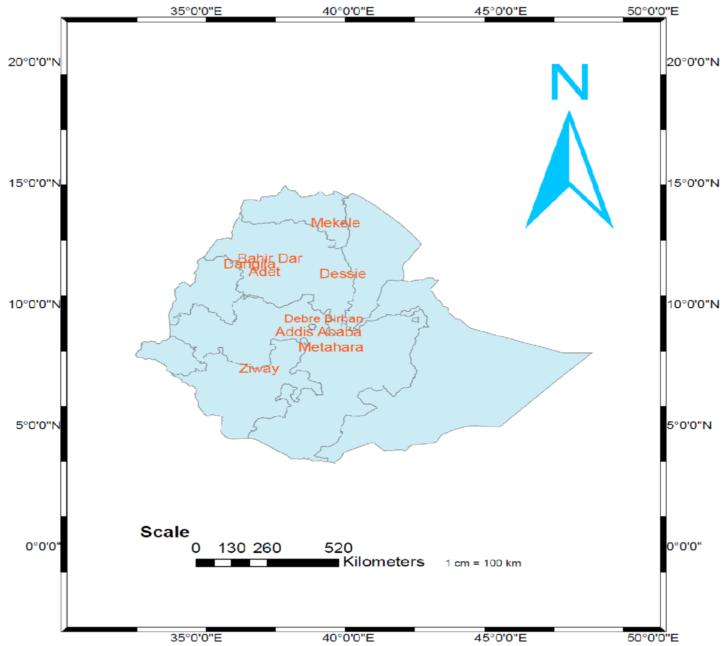


Fig.1. Location map of the study areas

2.2. Data source

The meteorological data used in this study could be divided into two parts. The first four Class I daily meteorological data were obtained from the branch office of the Amhara Meteorological Agency Bureau during a training workshop on climate change and water resources for Water Resources Professionals in ANRS in 2012. The data collected for the first group include daily minimum and maximum temperatures, wind speed at 2 m, relative humidity and sunshine hours. Data of the remaining five Class I stations were obtained from the National Meteorological Agency of Ethiopia. The data for the second group (Mekele, Dessie, Debre Brhan, Methara and Ziway study sites) were monthly meteorological data and because monthly meteorological data were not convenient for the conventional ET estimation methods data conversion from monthly meteorological to daily values was done using the Weatherman module of the DSSAT software. For these stations daily minimum and maximum temperatures, wind speed at 2 m, sunshine hours and relative humidity data were the converted values by DSSAT software. Background geographic and meteorological information for the stations are summarized in Table 1.

Table I. Background information of the stations.

Station	Location		Altitude (m)	Temperature (°C)			RH	SS	WS	Data period (months)
	Latitude	Longitude		T_{avg}	T_{mx}	T_{mn}				
Addis Ababa	8.59°	38.48°	2386	17.1	23.8	10.3	59.0	6.7	0.6	127
Addet	11.27°	37.49°	2179	17.6	25.6	9.7	80.5	7.8	0.7	116
Bahr Dar	11.36°	37.24°	1800	18.2	25.6	10.8	72.1	7.8	0.1	101
Dangla	11.25°	36.83°	2116	17.7	25.7	9.7	85.4	7.0	0.7	38
Debre Brhan	9.38°	39.3°	2750	13.6	19.8	7.3	54.0	4.8	1.6	130
Dessie	11.07°	39.38°	2553	15.6	22.8	8.3	58.0	7.7	0.9	101
Mekele	13.31°	39.28°	2000	20.1	26.8	13.3	64.0	7.2	1.8	130
Methara	8.51°	39.55°	944	22.6	27.8	17.3	74.0	8.7	1.2	131
Ziway	7.56°	38. 42°	1640	20.1	26.8	13.3	66.0	9.1	1.2	131

T_{avg} = mean temperature; T_{mx} = maximum temperature; T_{mn} = minimum temperature; RH = relative humidity; SS= sunshine hours; WS= wind speed; Latitudes are in N and longitudes in E directions.

2.3. Data analysis

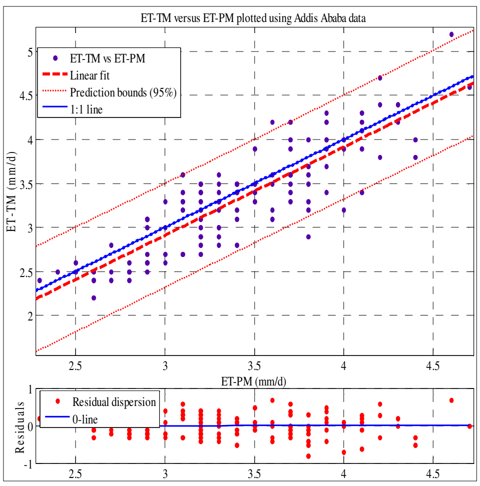
In this study a temperature based ET estimation method developed by Temesgen and Melesse (abbreviated as ET_{TM} or as ET-TM in figures) and a surface radiation based ET estimation method by Abtew (abbreviated as ET_A or as ET-A in figures) were compared with standard FAO-56 Penman-Monteith (ET_{PM} or ET-PM in figures). In order to measure the performances of the former two methods against ET-PM, different techniques were used. Method tendencies (overestimation/underestimation) were checked using the slope of the regression line (Alblewi, 2012), by Coefficient of Residual Mean (CRM) as recommended by Alblewi (2012) and by comparing with the 1:1 line. Thereafter performances of the two methods were checked using Coefficient of Efficiency (CE) as recommended by Tegos *et al.* (2013), Alblewi (2012) and Maule *et al.* (2006); by simultaneously considering the slope and correlation coefficient (R^2) of the regression line and the cross correlation between ET-TM or ET-A and ET-PM as suggested by Allen *et al.* (1998), Alblewi (2012), Xu and Singh (2001) and Wang *et al.* (2009); by coefficient of variation (CV) from residuals plots and 95% prediction bounds. Besides, root mean square errors (RMSE) were used to check precision in time series analysis and mean percentage errors MPE as suggested by Alblewi (2012); Medeiros *et al.* (2011); Ilesanmi *et al.* (2014), and Xu and Singh (2001), respectively, were determined. Performance parameters were calculated using Microsoft office Excel while plots were drawn and statistical parameters and data statistics were obtained using Matlab software.

3. Results and Discussion

In this section, graphical representations, linear regression parameters and performance test results are given. Discussions of why the methods fail or perform poorly are also given for those sites for which the methods do not do well.

3.1. Comparison of TM and Abtew methods against PM method

Plots of ET by TM and Abtew methods against PM method are shown in Fig. 2 and the summary table showing statistical parameters and method performance parameters is shown in Table 2. The tendency of the methods either to overestimate or underestimate were checked in three ways, i.e., from the slopes, the *CRM* (Alblewi, 2012). Tendency is also visually observed from the residual plots (Xu and Singh, 2001) shown below every linear regression plot) and the 1:1 lines. Similarly performance tests were made in four ways, i.e., using *CE* (Alblewi, 2012; Tegos *et al.,* 2013), combination of R^2 and slope (Allen *et al.,* 1998), using prediction bounds and using *MPE* (Xu and Singh, 2001).



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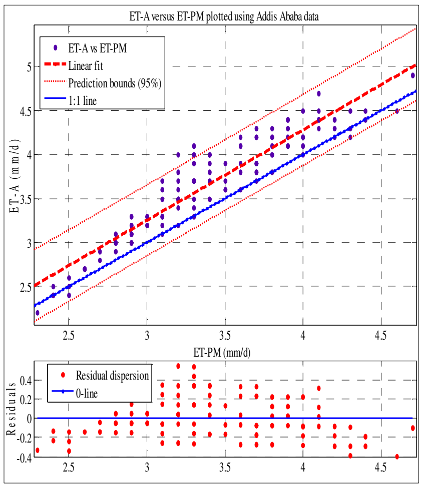

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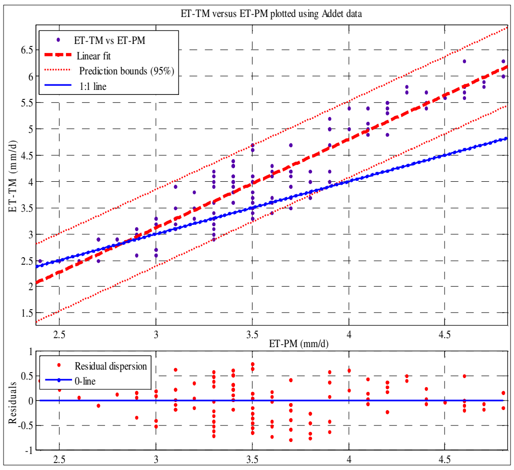

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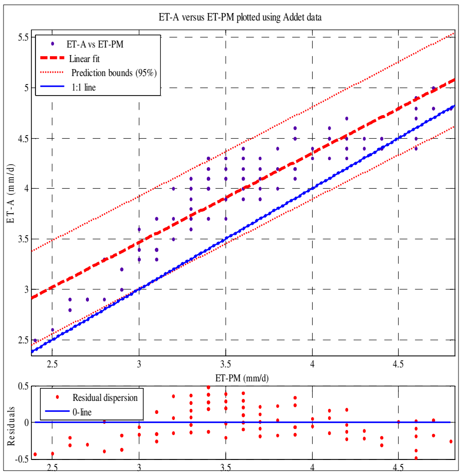

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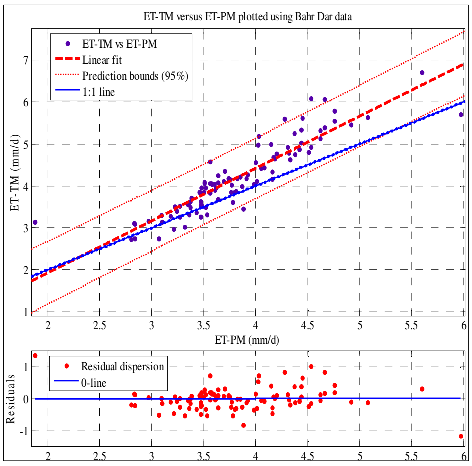

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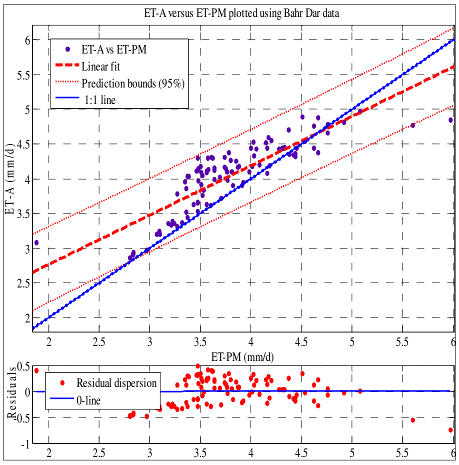

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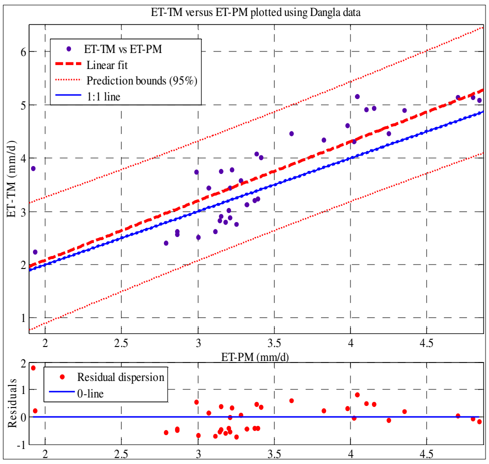

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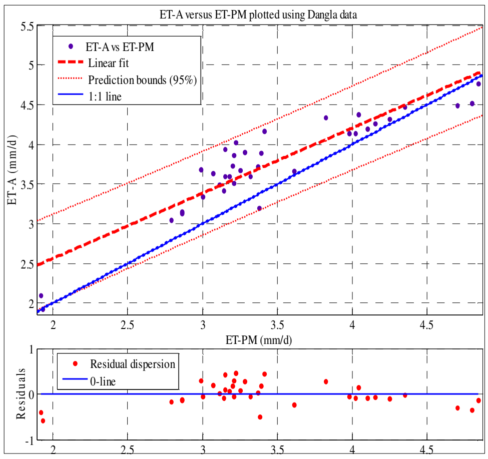

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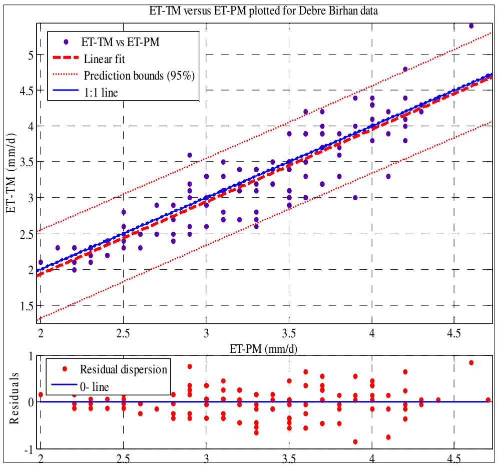

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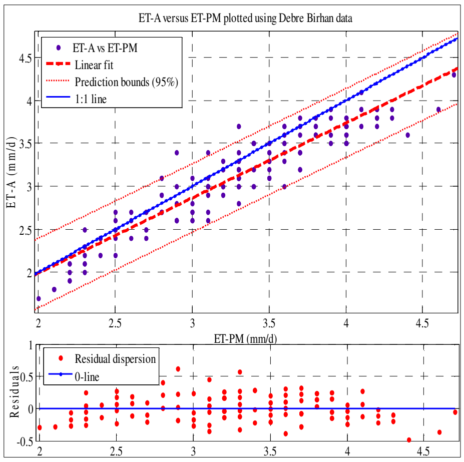

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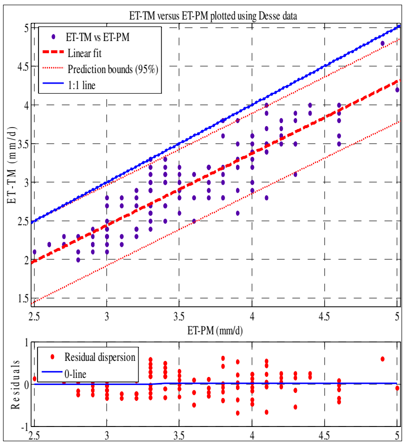

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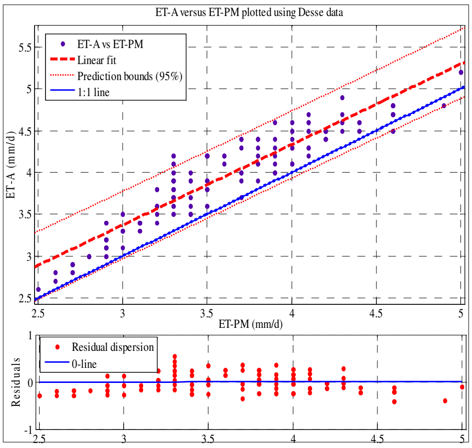

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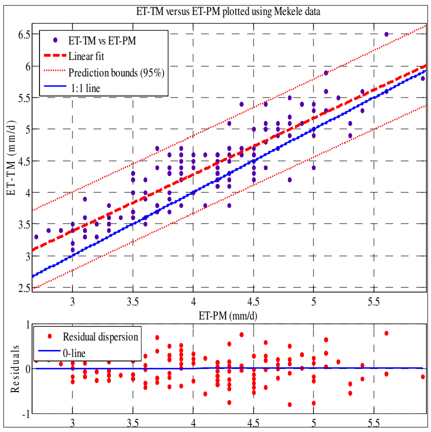

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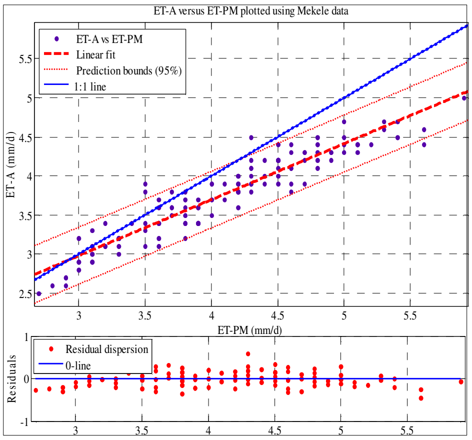

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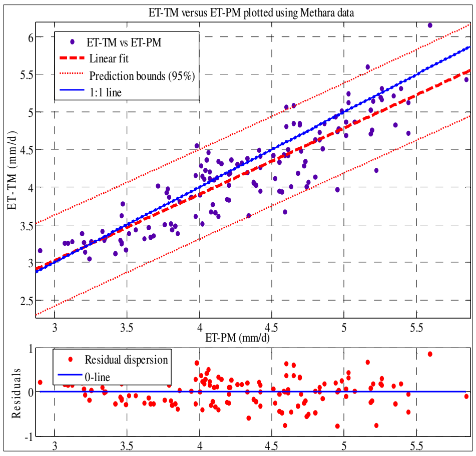

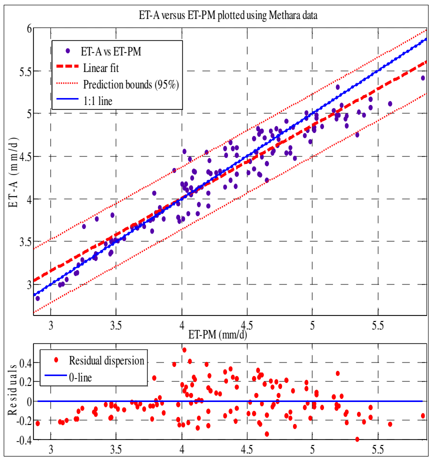

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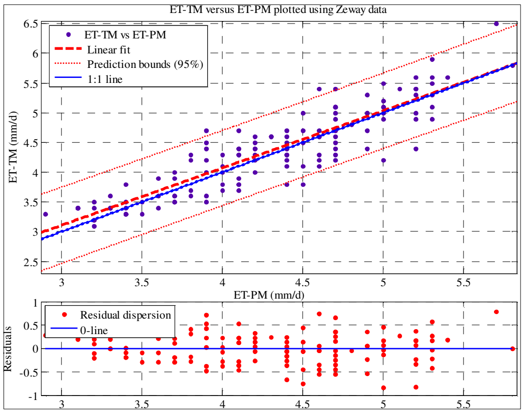

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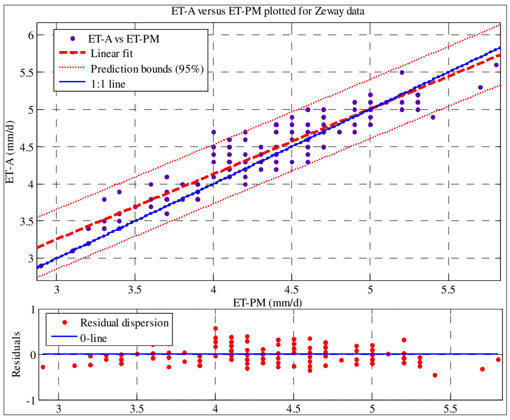

(b9)

Figure 2. ET obtained by Temesgen and Melesse (*ET-TM*) method plotted against ET obtained from Penman-Monteith (*ET-PM*) shown on the left side (a1-a9) and ET obtained by Abtew (*ET-A*) plotted against *ET-PM* shown on the right side (b1-b9).

Table 2. Summary showing statistical parameters, method tendencies and performances

Site	Method	Statistical parameters						Model tendency			Model performance			
		R^2	Slope (b)	Int. (a)	RMSE	CE	CRM	By CRM	By slope	By 1:1 line	By CE	By R^2 and b	PB	MPE
Addis Ababa	ET_{TM}	0.760	1.005	-0.107	0.2564	0.67	0.025	Slight UE	OE (0.5%)	UE	Satisfactory	Good	Good	3.36
	ET_A	0.876	1.028	0.167	0.2022	0.59	0.078	Slight UE	OE (2.8%)	OE	Satisfactory	Good	Good	6.78
Addet	ET_{TM}	0.868	1.683	-1.932	0.3648	-0.77	-0.143	OE	OE (68%)	<2.75, UE; >2.75, OE	Poor	Poor	Satisfactory	10.3
	ET_A	0.822	0.886	0.806	0.2297	0.29	-0.112	OE	UE (11.4%)	OE	Poor	Good	Satisfactory	10.1
Bahr Dar	ET_{TM}	0.819	1.245	-0.560	0.3609	0.23	-0.097	OE	OE (24.5%)	<2.25, UE; >2.25, OE	Poor	Poor	>5, out	7.88
	ET_A	0.736	0.711	1.343	0.2626	0.57	-0.064	OE	UE (28.9)	<2.9, UE; >2.9, OE	Satisfactory	Good	<2.9, out	6.16
Dangla	ET_{TM}	0.665	1.112	-0.139	0.5409	0.22	-0.229	OE	OE (11.2%)	OE	Poor	Poor	Satisfactory	4.45
	ET_A	0.830	0.821	0.921	0.2546	0.62	0.258	UE	UE (17.9%)	OE	Satisfactory	Good	Satisfactory	8.22
Debre-Brhan	ET_{TM}	0.806	1.009	-0.084	0.3056	0.75	0.020	Slight UE	OE (0.9%)	Slight UE	Good	Good	Good	-2.61
	ET_A	0.879	0.874	0.243	0.2007	0.80	0.050	Slight UE	UE (12.6%)	UE	Good	Good	Good	-5.85
Dessie	ET_{TM}	0.783	0.929	-0.344	0.2608	-0.51	0.168	UE	UE (7.1%)	UE	Poor	Good	Poor	-21.34
	ET_A	0.866	0.963	0.483	0.2022	0.43	-0.097	Slight OE	UE (3.8%)	OE	Satisfactory	Good	Satisfactory	8.78
Mekele	ET_{TM}	0.805	0.894	0.706	0.3091	0.65	-0.067	Slight OE	UE (10.6%)	OE	Satisfactory	Good	Good	6.20
	ET_A	0.885	0.718	0.824	0.1824	0.63	0.080	Slight UE	UE (19%)	<3.0, OE; >3.0, UE	Satisfactory	Good	Satisfactory	8.38
Methara	ET_{TM}	0.785	0.881	0.380	0.3000	0.73	0.030	Slight UE	UE (11.9%)	<3.25, OE; >3.25, UE	Satisfactory	Good	Good	-3.39
	ET_A	0.901	0.852	0.599	0.1838	0.90	0.009	Slight UE	UE (14.8)	< 4, OE; > 4, UE	Good	Good	Satisfactory	-0.83
Zeway	ET_{TM}	0.792	0.963	0.219	0.3182	0.75	-0.010	Slight OE	UE (3.7%)	<5, Slight OE	Good	Good	Good	0.87
	ET_A	0.889	0.874	0.634	0.1992	0.88	-0.020	Slight OE	UE (12.6%)	<5, OE; >5, UE	Good	Good	Good	2.11

Int. = intercept; ET_{TM} = Temesgen and Melesse method; ET_A= Abtew method; OE = overestimation; UE = underestimation; Numbers in brackets represent percent OE/UE; Numbers following '<' or ' >' are ET values where the fitted and 1:1 line cross each other; MPE = mean percentage error.

3.1.1. Comparison of TM method with PM method

As shown both in the figures and in the table, ET-TM showed three distinct behaviors over the nine sites. The method showed close agreement with ET-PM for Addis Ababa, Debre Brhan and Zeway sites shown in Fig. 2a1, 2a5 and 2a9, respectively.

All in all, the performance of the TM method on all the nine sites could be summarized in Table 3. The differences of the sites that need calibration from the others that do not could be either due to problems with the data or due to the inability of the method to work for these sites without calibration.

Table 3. Summary of evaluation of the performance of TM method

Site	MPE	Agreement between 1:1 & fitted lines	Enclosure of prediction bound	Combined performance	Rank	Recommendation
Zeway	0.87	Almost overlap	Bounds fitted & 1:1 line	Good	1	no calibration required
Debre Brhan	-2.61	Almost overlap	Bounds fitted & 1:1 line	Good	2	no calibration required
Addis Ababa	3.36	Almost overlap	Bounds fitted & 1:1 line	Good	3	no calibration required
Methara	3.39	Separation at high ET	Bounds fitted & 1:1 line	Satisfactory	4	Calibration required
Dangla	4.45	Separation at high ET	Bounds fitted & 1:1 line	Poor	8	Calibration required
Mekele	6.20	Separation at low ET	Bounds fitted & 1:1 line	Satisfactory	5	Calibration required
Bahr Dar	6.78	Separation at high ET	1:1 line partially out	Poor	6	Calibration required
Addet	10.30	The two cross each other	1:1 line partially out	Poor	7	Calibration required
Dessie	21.39	Big separation	1:1 line outside PB	Poor	9	Calibration required

MPE = mean percentage error; used with 1:1 line for ranking instead of using R^2

3.1.2. Comparison of Abtew method with the PM method

For Abtew method the nine sites are categorized into three groups. Zeway, Methara and Bahr Dar are in the first group and they showed mixed behavior because the 1:1 line and the regression line crossed each other for all the three. The crossing indicates part overestimation and part underestimation. Only the first two sites from this group performed relatively well with this method as shown in Table 4. Perhaps the similarity among the three is due to their similarities in their maximum temperatures (25.6 – 27.8^{o}C) and the presence of lakes at the three locations.

All in all, Abtew method was not in good agreement with the 1:1 line even when percent error was low as in the case of Methara and Zeway. Except in the case of Dessie with MPE of 8.78 at all other MPE greater than six, the 1:1 line is partially out of the prediction bound. Poor performance of the method may be due to quality of data (Semu Ayalew, 2010) or due to the inherent problem with the method itself. In order to check the latter, calibration is required for all the sites. The fact that the pattern is the same for most sites shows that the method may work better after calibration. The combined performance and approximate rank for this method are shown in Table 4. According to Allen *et al.* (2006), radiation-based methods show good results in humid climates where aerodynamic term is small but may show bias under arid conditions.

Table 4. Summary of evaluation of the performance of Abtew method

Site	MPE	Agreement of 1:1 & fitted lines	Enclosure of prediction bound	Combined performance	Rank	Recommendation
Methara	0.83	Cross each other	Bounds fitted & 1:1 line	Satisfactory	2	Calibration required
Zeway	2.11	Cross each other	Bounds fitted & 1:1 line	Good	1	Calibration required
Debre Brhan	5.85	Separation at high ET	Bounds fitted & 1:1 line	Good	4	Calibration required
Addis Ababa	6.78	Uniform separation	Bounds fitted & 1:1 line	Good	3	Calibration required
Bahr Dar	6.76	Cross each other	1:1 Line partially out	Satisfactory	7	Calibration required
Dessie	8.78	Uniform separation	Bounds fitted & 1:1 line	Satisfactory	5	Calibration required
Mekele	8.38	Separation at high ET	1:1 Line partially out	Satisfactory	6	Calibration required
Dangla	8.22	Separation at low ET	1:1 Line partially out	Satisfactory	9	Calibration required
Addet	10.06	Non-uniform separation	1:1 Line partially out	Satisfactory	8	Calibration required

MPE = mean percentage error; used with 1:1 line for ranking instead of using R^2

3.1.3. Comparison of TM method with Abtew method

TM method showed poor performance by *CE* in four out of the nine sites while Abtew method showed only on one site. By the combined R^2 and slope parameters, TM showed poor performance in three out of the nine sites but Abtew scored well for all the nine sites. The MPE of TM (excluding Dessie site which is a kind of outlier) are between 0.87 and 10.3 and for Abtew, between 0.91 and 10.06. Sites with greater than five percent error were five for

TM and seven for Abtew. From all of these, one can conclude that Abtew method performed well in terms of MPE but not so with the 1:1 line.

According to Allen *et al.* (1998) when conditions of R^2 and slope indicate poor performance, there is suspicion of missing data points. In an attempt to check if there were differences between the two methods their data statistics were compared with that of PM method and the results are shown in Table 5.

Table 5. TM and Abtew methods data statistics compared with that of PM

Site	Method	Data statistics								CV_E-CV_{PM}
		Minimum	Maximum	Mean	Median	Mode	Std	Range	CV (%)	CV_{PM}
Addis Ababa	PM	2.30	4.70	3.413	3.40	3.20	0.5213	2.40	15.3	
	TM	2.20	5.20	3.324	3.30	3.30	0.6016	3.00	18.1	0.18
	A	2.20	4.90	3.676	3.70	4.20	0.5726	2.70	15.6	0.02
Addet	PM	2.40	4.80	3.578	3.50	3.30	0.5539	2.40	15.5	
	TM	2.50	6.30	4.089	4.00	4.10	1.0010	3.80	24.5	0.58
	A	2.50	5.00	3.977	4.10	4.10	0.5416	2.50	13.6	-0.12
Bahr Dar	PM	1.88	5.97	3.801	3.70	3.47	0.6133	4.09	16.1	
	TM	2.73	6.71	4.171	4.06	3.86	0.8437	3.98	20.2	0.25
	A	2.86	4.97	4.046	4.13	4.18	0.5083	2.11	12.6	-0.22
Dangla	PM	1.92	4.84	3.446	3.27	2.86	0.6747	2.92	19.6	
	TM	2.24	5.16	3.694	3.67	3.44	0.9206	2.92	24.9	0.27
	A	1.93	4.77	3.751	3.73	3.60	0.6084	2.84	16.2	-0.17
Debre Birhan	PM	2.00	4.70	3.264	3.30	3.50	0.6154	2.70	18.9	
	TM	2.00	5.40	3.208	3.20	2.30	0.6913	3.40	21.5	0.14
	A	1.70	4.30	3.095	3.20	3.50	0.5736	2.60	18.5	-0.02
Dessie	PM	2.50	5.00	3.578	3.50	3.30	0.5327	2.50	14.9	
	TM	2.00	4.80	2.979	3.00	3.20	0.5587	2.80	18.8	0.26
	A	2.60	5.20	3.928	4.00	4.20	0.5508	2.60	14.0	-0.06
Mekele	PM	2.70	5.90	4.086	4.10	3.80	0.7011	3.20	17.2	
	TM	3.10	6.50	4.358	4.35	4.30	0.6983	3.40	16.0	-0.07
	A	2.50	5.00	3.758	3.80	3.90	0.5532	2.50	14.7	-0.14
Methara	PM	2.90	5.84	4.297	4.29	3.46	0.6470	2.94	15.1	
	TM	3.05	6.16	4.167	4.15	3.39	0.6439	3.11	15.5	0.03
	A	2.84	5.42	4.260	4.32	3.77	0.5809	2.58	13.6	-0.09
Zeway	PM	2.90	5.80	4.296	4.30	4.70	0.6426	2.90	15.0	
	TM	3.10	6.50	4.355	4.35	4.30	0.6952	3.40	16.0	0.07
	A	2.90	5.60	4.390	4.50	5.00	0.5958	2.70	13.6	-0.09

Std= standard deviation; CV_E = coefficient of variation for the estimated (TM or Abtew) method; CV_{PM} = coefficient of variation of PM method.

Data statistics give some information about overestimation and underestimation, especially when the mean and median values are compared. In this work negative values imply overestimation while the positive ones imply underestimation. When looked at with Table 2, the crossing lines may fall under overestimation or underestimation. For the absolute values of the ratio less than 0.20, the method performance is considered good, from 0.20 to 0.25 satisfactory and greater than 0.25 implies poor performance. Best performance is when the value approaches zero since it implies very good agreement with PM method. In other words, the CV of an estimated method must be within 20% of PM CV to be considered a good method.

3.2. **Evaluation of the different performance testing parameters**

Out of several parameters used for method tendency and performance tests, the 1:1 line is found to be superior because it shows several things which other parameters fail to address. The scenario where the regression line is above the 1:1 line implies method overestimation even when the slope and CE indicate underestimation (e.g. ET estimated by Abtew method for Dangla site shown in Table 2). In most cases performance tests by *CE* and 1:1 line agreed with each other. The other benefit of the 1:1 line is its capability to show where the regression line crosses it when it does. Crossing indicates overestimation and underestimation by the same method but at different ranges of ET. When there is crossing the method needs another correction factor which has a tendency to slightly rotate the regression line so that it could overlap with the 1:1 line. In this work, the slope method did not perform as well as the others since it gave different results from the 1:1 line in four out of nine cases (44% of the time). The problem with the slope is that it does not show where the regression line is with respect to the 1:1 line. Besides, estimation of over or underestimation from the slope is sometimes exaggerated as in the case TM method applied to Dangla site where the slope indicated 68% overestimation while the PB does not indicate such overestimation.

The other good method performance indicator found in this study is the prediction bounds. Once in a while, the regression line may have a slope close to one (which means identical to the 1:1 line) but its location within the prediction bound matters. For instance, the two lines could be parallel but the 1:1 line could be outside the prediction bound.

The root mean square error (RMSE) was used as a measure of relative error. In this study the sites with good performance showed RMSE less than 0.32 for TM method and less than 0.2 for Abtew method.

The superiority of 1:1 line is its capability to show the mixed trends (when one part of the regression line is above while the other part is below the 1:1 line). Regression line that somehow crosses the 1:1 line has the potential to give a clue about the nature of the terms that are going to be included in the method during calibration.

4. Conclusion

In this study, one temperature based method of estimating ET (ET-TM) and one radiation based method (ET-A) were compared with the standard FAO 56 PM method using data of nine Class I meteorological sites. Using combined performance criteria, TM method showed good performance for three of the nine sites for which the method could be used without the need for calibration. The method performed poorly for four sites in terms of CE and yielded MPE greater than 7. Even though the method performed satisfactorily for the remaining two sites, it still needs to be calibrated since it either over-predicted or underpredicted. Abtew method did not do well for most sites except on Methara and Zeway with MPE less than 3. In spite of that, the method has to be calibrated for all sites since the regression lines either crossed the 1:1 line or showed deviation in a big way. As far as performance tests are concerned, it is good to include 1:1 line and prediction bounds along with other test parameters to get a clearer picture of what is happening.

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