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Comparison of five different methods in estimating reference evapotranspiration in Cape Coast, Ghana

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A number of methods have been developed to estimate reference crop evapotranspiration (ETo), but most of the reliable methods are complex and parameter rich models and therefore difficult to apply in data scarce regions. This study was conducted to determine suitable simple ETo methods in Cape Coast by comparing estimated ETo values of three indirect-measurement methods: Hamon, Hargreaves, Blaney Criddle; and two direct-measurement methods: Class A pan and Piche evaporimeter with the Food and Agriculture Organization (FAO) Penman-Monteith equation (FAO56-PM) estimated ETo values. All the methods underestimated ETo values obtained by the FAO56-PM method. However, the estimated ETo values by the Hamon, Hargreaves, and Blaney-Criddle are strongly correlated (R = 0.89, 0.87 and 0.81 respectively), while the Class A pan and Piche evaporimeter methods are weakly correlated (R= 0.37 and 0.31, respectively) with the FAO56-PM method. All but the Piche evaporimeter methods appeared suitable for estimating ETo in the study area. The Class A pan, though weakly correlated with the FAO56-PM method, was also suitable because it had the least mean absolute error (MAE; 0.26 mm day^{-1}) and mean absolute percentage error (MAPE; 6.5%) among the other methods and its ETo curve was closer to the FAO56-PM's.

Key words: Reference crop evapotranspiration, Cape Coast, Food and Agriculture Organization (FAO) Penman-Monteith equation, direct-measurement method.

INTRODUCTION

Efficient consumption of water as agricultural irrigation, drinking water and industrial use is an important issue in the coastal savanna region of Ghana especially during the dry season months. With the growing scarcity of fresh water globally due to climate change, it is increasingly important to maximize efficiency of water usage. This implies proper management of available water to effectively apply water according to the crop water needs.

Evapotranspiration (ETo) is the loss of water to the atmosphere by the combined processes of evaporation from the soil and plant surfaces and transpiration from plants (Allen et al., 1998). Evapotranspiration is one of the major hydrological components of water budget and an indispensable component in water use in crop

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production. Accurate quantification of ET is crucial in water allocation, irrigation management, and development of best management practices to protect surface and ground water quantity and quality (Irmak and Irmak, 2008). Therefore, a reliable and consistent estimate of evapotranspiration is of great importance for the efficient management of water resources.

In a given agricultural field, the ET process is impacted by many different soil, plant and management factors. However, ET is primarily driven by climatic conditions, such as air temperature, solar radiation, relative humidity of air, and wind speed. Familiar practices for estimating ET are to first estimate reference ETo and then relate it to a corresponding crop coefficient. According to Allen et al. (1998), reference ETo is defined as the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sm^{-1} and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground. Quantification of ETo expresses the evaporative power of the atmosphere at a specific location and time of the year, and therefore ETo is necessary in crop production, management of water resources, scheduling of irrigation, evaluation of the effects of changing land use on water yields and environmental assessment.

In Cape Coast and the surrounding communities, almost all crop farming activities come to a halt in December, January and February. This is because apart from being within the driest months, it is during these months that the coastal savanna experiences harmattan dry northeasterly trade winds from the Sahara Desert. The harmattan is characterized by cold, dry, dusty-laden winds and also wide fluctuations in the temperatures of day and night. During the harmattan season, temperature can be low all day but sometimes in the afternoon the temperature can soar to as high as 30°C, while the relative humidity drops to a low level (Emiko and Javier, 2012). Therefore, insufficient water availability to meet crop water requirement especially during these months coupled with a strong competition from other water users are limiting for all year-round crop production to meet the demand of the high population growth in Cape Coast and the surrounding towns which are fast expanding. It is anticipated that this water demand causes the reduction in irrigation water availability for vegetable production which abound in the area. It is in this regard that reliable and consistent estimates of reference evapotranspiration have to be determined for water managers responsible for planning and distribution of water in the metropolis to understand the spatial and temporal fluctuations of the processes of evapotranspiration for all-year-round crop production realization.

A number of methods have been developed to estimate reference ETo but unfortunately most of the reliable ETo methods are parameter rich models and therefore difficult to apply in data scarce regions. Again most these methods are developed from different climatic variables and adaptation are often subject to rigorous local calibration and prove to have limited validity for different locations. Testing the accuracy of the methods under different conditions normally is laborious, time-consuming and costly.

Although many approaches have been developed and adopted for various applications based on available input data, there is still a remarkable range of uncertainty related to which method is to be adopted in the estimation of ETo in Cape Coast of Ghana. The FAO Penman-Monteith equation (FAO56-PM) which is recommended as the sole standard for estimating ETo is relatively high data demanding and sensitive to data that are difficult to measure (Allen et al., 1998; Chen et al., 2005). The lack of instruments, remote access, computer control and automation, and measurement tools in many meteorological stations in and around Cape Coast presents a serious problem to data collection and data use in evapotranspiration research and practices. In this study, the FAO56-PM estimates of ETo were used as a standard to evaluate the performance of other methods in estimating the ETo.

The objective of this study was to determine reference evapotranspiration methods that closely approximate ETo in the study area during the dry season of the year based on the available climatic data by comparing five different methods of estimating ETo with FAO56-PM approach. This can help establish a common method for the estimation of ETo in Cape Coast, and in turn help the local farmers in the area to adopt a simple method for practical use in determining crop water requirement during the dry season. This also can help the University of Cape Coast in particular to adopt less costly and easy applicable method for ETo research and practice.

MATERIALS AND METHODS

Study area

The study was conducted in 2013 and repeated in 2014 and 2015 at the agro-meteorological station at University of Cape Coast. According to Asamoah (1973), the study area falls within the coastal savanna ecological zone and has two rainfall regimes separated by a dry period. The major rainy season starts from March to July with the peak in June, while the minor season is from September to November with the peak in October. The dry period is from December to February, characterized by hot days, cool nights and low relative humidity coupled with relatively high ETo during which farming activities come to a halt. The annual rainfall ranges from 800 to 900 mm. Temperature is relatively uniform throughout the year with the mean annual minimum temperature of 25°C and maximum of 32°C (Asamoah, 1973).

Agro-meteorological station and data collection

An agro-meteorological station number 0501/044/23 was used for the study. The station was situated on latitude 5.1°N and longitude 1.4°W at altitude of 31.1 m above sea level. It was fenced up to 1.2 m in height with a dimension of 10 m × 10 m and within a field of 50 m × 50 m. This station provided meteorological information on rainfall, relative humidity, temperature, wind speed, sunshine duration, radiation and evaporation relevant to agricultural production within the university and the entire Cape Coast metropolis. The data collected covered December, January, and February because apart from being the driest months in the year, it was during these months that the study area experienced the harmattan dry winds, resulting to a halt of crop farming especially vegetables farming activities. Most of the readings were recorded twice each day (0900 and 1500 h GMT) over the three months for three consecutive years (2013, 2014 and 2015) and the mean daily values of 8-day periods of the parameters were used for the study.

ETo methods used

Five simple methods, namely, Class A evaporation pan, Piche evaporimeter or atmometer, Blaney-Criddle, Hargreaves and Hamon were selected to estimate the ETo of the study area. These methods were grouped into two categories, viz, direct-measurement method (Class A evaporation pan and Piche evaporimeter) and indirect-measurement method (Blaney-Criddle, Hargreaves and Hamon methods). The performances of these methods were measured by comparing their ETo estimates with the FAO56-PM method's ETo estimates (ETo-PM).

Class A evaporation pan

Class A evaporation pans are the most widely used type of devices to perform measurements of evaporation and subsequently reference evapotranspiration (McVicar et al., 2012). The standard Class A pan, developed by the US Weather Bureau was used for the study. The pan was a spherical tank of galvanized iron, with a diameter around 120 cm and was 25 cm deep, and mounted on a wooden platform (Sanchez-Lorenzo et al., 2014). The pan was filled with water to about 5 cm below the rim and the daily fall of the water level was manually measured every morning at 0900 h, refilling the water level if needed or reducing the content of water if rain had caused the tank to overflow (WMO, 2008). The pan evaporation was then related to the reference evapotranspiration by a pan coefficient as (Allen et al., 1998):

$$ET_0 - AP = K_p E_{pan} \quad (1)$$

where ET_o-AP is the reference evapotranspiration (mmd^{-1}), K_p is the pan coefficient = 0.7 (based on the prevailing climatic and environmental conditions at the study area), E_{pan} is the pan evaporation (mm day^{-1}).

Piche evaporimeter (atmometer)

The Piche evaporimeter used for the study consisted of a 3 cm diameter disc of filter paper held by a metal clip to the bottom of an inverted graduated cylindrical tube of 1.5 cm in diameter, which supplied deionized water to the disc as outlined by Sanchez-Lorenzo et al. (2014). The water thus evaporated from the surface of the filter paper. The volume of water remaining in the graduated tube was measured daily and the amount of water lost by evaporation in millimeters was determined by the difference between water levels on consecutive days (Diop et al., 2015). The Piche evaporimeter was placed inside a meteorological (Stevenson) screen together with other meteorological instruments (WMO, 2008). The ETo was calculated using the recorded evaporation readings, Epi, multiplied by two coefficients as Casanova et al. (2008):

$$\mathrm{ET}_o - \mathrm{P_i} = \propto \mathrm{E}_{pi} \rho(\sigma) \quad (2)$$

where ETo-P*i* is the Piche evaporimeter estimated reference evapotranspiration (mm day^{-1}); $\propto$ is a factor that considers the semi-protection of the Piche evaporimeter from the solar radiation = 0.27; E_{pi} is the evaporation reading by the Piche evaporimeter (mm day^{-1}); $\rho(\sigma)$ is a prevailing temperature dependent factor = 2.41 (Casanova et al., 2008).

Penman-Monteith equation

The United Nations Food and Agriculture Organization (FAO) in paper 56 recommended the use of Penman-Monteith (PM) equation (FAO56-PM) as the standard method for estimating reference ETo, and for appraisal of other methods (Allen et al., 1998). The FAO56-PM method is ranked as the best method for estimating daily and monthly ETo in all climates (Galvilan et al., 2006; Trajkovic and Kolakovi, 2009). In the FAO56-PM method, ETo is computed as (Allen et al., 1998):

$$ET_o - PM = \frac{0.408\Delta(\mathrm{R_n} - \mathrm{G}) + \gamma\left(\frac{900}{\mathrm{T}+273}\right)\mathrm{U_2}(\mathrm{e_s} - \mathrm{e_a})}{\Delta + \gamma(1 + 0.34U_2)} \quad (3)$$

where ET_o-PM is the FAO56-PM estimated reference evapotranspiration (mmd^{-1}); Δ is the slope vapour pressure curve (kPa °C^{-1}); Rn is the net radiation (MJm^{-2}d^{-1}); G is the soil heat flux density (MJm^{-2}d^{-1}); γ is the psychometric constant (kPa°C^{-1}); T is the mean daily air temperature (°C); U_2 is the wind speed at 2 m height (ms^{-1}); and (e_s–e_a) is the vapour pressure deficit (kPa).
The FAO56-PM is a physically based approach and required the following input (Subburayan et al., 2011): air temperature (°C), relative humidity (%), wind speed (ms^{-1}), solar radiation (MJm^{-2}day^{-1}), and number of daylight hours (h).

A software, CROPWAT 8.0 (FAO, 2015), was used to compute the reference evapotranspiration values using the FAO Penman Monteith equation.

Blaney-Criddle method

The Blaney-Criddle equation is simple and a temperature-based method (Shahidian et al., 2012) that is used to estimate reference evapotranspiration. The Blanney-Criddle reference evapotranspiration, ET_o-BC, (mm day^{-1}) is thus determined as (FAO, 1986):

$$ET_o - BC = p(0.46T_{mean} + 8) \quad (4)$$

where T_{mean} is the mean daily temperature (°C); p is mean daily percentage of annual daytime hours.
The Blanney-Criddle method used the following measurements: mean daily temperatures, T_m (°C) and mean daily percentage of day light hours.

Hargreaves method

The Hargreaves method is also a temperature-based method that is

Table 1. Mean daily climatic condition of the study area.

Period	Mean values of meteorological data for 5-day period intervals						
	Maximum Temperature (ºC)	Minimum Temperature (ºC)	Mean Temperature (ºC)	Solar radiation (MJm^{-2} day^{-1})	Relative Humidity (%)	Wind speed (km day^{-1})	Sunshine (h day^{-1})
1	31.7	24.8	28.2	19.1	81.8	27.3	6.74
2	30.9	23.8	27.3	17.5	84.4	25.4	5.25
3	32.1	24.1	28.1	22.3	82.2	24.5	8.50
4	31.6	24.3	27.9	18.9	84.8	23.9	6.70
5	32.0	24.0	28.0	20.5	84.4	24.7	7.05
6	31.4	24.9	28.1	21.5	84.0	25.6	7.77
7	30.9	24.0	27.4	18.5	89.0	17.7	6.60
8	31.8	25.3	28.5	18.2	84.2	19.4	6.70
9	31.6	24.3	27.9	19.6	84.0	20.3	7.06
10	32.0	24.5	28.2	18.0	85.0	25.3	6.92
11	31.5	20.5	26.0	17.8	80.2	28.1	6.50

usually used to determine reference evapotranspiration especially for areas that lack many meteorological data (Shahidian et al., 2012; Subburayan et al., 2011). The Hargreaves reference evapotranspiration (ETo-Hr), is thus determined as (Hargreaves, 1994):

$$ET_o - Hr = 0.0023 R_a (T_{max} - T_{min})^{0.5} \left(\frac{T_{max}+T_{min}}{2} + 17.8\right) \quad (5)$$

where R_a is the extraterrestrial radiation (mmday^{-1}); T_{max} is the mean daily maximum temperature (°C) and T_{min} is the mean daily minimum temperature (°C).

The Hargreaves method therefore required measurements of the following: Mean daily maximum air temperature, T_{max} (°C); Mean daily minimum air temperature, T_{min} (°C); and Ra is the extraterrestrial radiation (mm day^{-1}).

Hamon method

One of the simplest estimates of reference evapotranspiration is that of the Hamon equation. The Hamon reference evapotranspiration, ETo-Ha, is given as (Haith and Shoemaker, 1987):

$$ET_o - Ha = \frac{2.1 {H_t}^2 e_s}{(T_t + 273.2)} \quad (6)$$

where Ht is the average number of daylight hours per day during the period in which day t falls; e_s is the saturated vapour pressure at temperature, T, (kPa); and T_t is the daily average temperature at day t (°C) and

$$e_s = 0.6108 exp \frac{17.2 T_t}{T_t + 237.3} \quad (7)$$

Therefore, the Hamon method used the following measurements: (1) Average number of day light hours per day and (2) Daily mean air temperature (°C).

Data analysis

The data obtained from the climatic variables were analyzed by finding their means over 8-day periods. The means of the 8-day periods were used to compute ETo values for the tested methods. The ETo values were aggregated into eleven periods with each period representing 8-day interval. The performance of the methods were analyzed by computing the mean absolute error (MAE), the mean absolute percentage error (MAPE) and the correlation co-efficient of the 8-day period estimate of ETo with those of FAO56-PM (ETo-PM) as the dependent variable using Microsoft excel.

RESULTS AND DISCUSSION

Prevailing climatic condition at the study area during the periods

The mean daily values of climatic parameters obtained for 8-day periods in the driest months (December, January and February) of the year at the study area are presented in Table 1. Period 3 recorded the highest maximum temperature (32.1°C), while periods 2 and 7 recorded the lowest maximum temperatures (30.9°C). The highest minimum temperature (24.9°C) and lowest (20.5°C) were recorded in periods 6 and 11, respectively. Period 8 had the highest mean temperature (28.5°C), whereas period 11 had the lowest mean temperature (26.0°C). Relative humidity was the highest (89%) in the period 7 and lowest (80%) in the period 11. Wind speed was lower (17.7 km day^{-1}) in the period 7 and higher (28.1 km day^{-1}) in the period 11. Period 6 had long hours of sunshine (7.77 h), while period 2 had short hours of sunshine (5.25 h). The solar radiation followed similar trend as the number of sunshine hours. The highest solar radiation (22.3 MJm^{-2} day^{-1}) was in Period 3 and the least (17.5 MJm^{-2} day^{-1}) was recorded in Period 2 with the corresponding least number of sunshine hours.

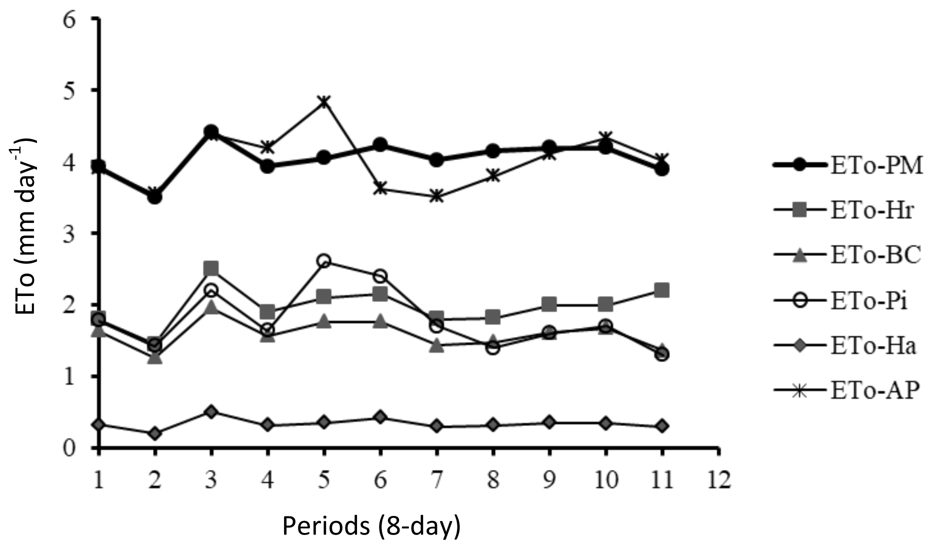

Figure 1. Comparison of mean daily ETo obtained by Penman-Monteith (ETo-PM) with Blaney-Criddle (ETo-BC), Piche Evaporimeter (ETo-Pi), Hargreaves (ETo-Hr), Class A pan (ETo-AP), and Hamon (ETo-Ha) for the periods under study.

Comparison of ETo estimates of the Penman-Monteith method and the other methods

Figure 1 shows the comparison of daily ETo estimated by Hargreaves, Blaney-Criddle, Hamon, Piche evaporimeter and Class A pan methods with FAO56-PM method for Cape Coast, a hot and humid tropical coastal savanna town of Ghana. The ETo values estimated by the FAO56-PM method ranged between 3.5 and 4.42 mm day^{-1}. The range of values were within the range obtained in a similar hot and humid coastal location in India by Subburayan et al. (2011) which had a wider range. The narrow range obtained could be attributed to relatively lower mean wind speed in the study area (<2 ms^{-1}) as compared to Subburayan et al. (2011) mean wind speed of 7.7ms^{-1}.

The ETo values estimated by the indirect measurement methods (Blaney-Criddle, Hargreaves and the Hamon methods) followed similar trend as the Penman-Method except that the Hargreaves slightly deviated at Period 11. This suggested that the estimation of ETo by these methods were greatly influenced by their corresponding input climatic data since all had their ETo values peaked at Period 3 where both the maximum temperature, sunshine hours and solar radiation were the highest with relatively low humidity (Table 1). The ETo values estimated by the two direct measurement methods (Class A pan and the Piche evaporimeter) followed similar trend as ETo-PM from Periods 1 to 3, but deviated from the other Periods. However, the distribution trend of estimated ETo values by Class A pan and Piche evapoerimeter were relatively similar, only that Class A pan had higher magnitude whilst Piche evaporimeter had low magnitude of values and both methods had their highest estimated ETo value at Period 5. This suggested that same climatic variables affected these two direct measurement methods. Nevertheless, the estimated ETo values by the Class A pan were higher at all the periods than that of the Piche evaporimeter. The difference could be due to the fact that the Piche Evaporimeter was shielded from solar radiation by the screensaver and its measurement could not be directly affected by the radiative parameters controlling the ETo (Sanchez-Lorenzo et al., 2014).

All the methods except Class A pan (which was subject to the drudgeries of all the climatic parameters) mostly underestimated ETo values obtained by the FAO56-PM method. The Class A pan, however, overestimated the ETo-PM values in Periods 4, 5, 10 and 11, underestimated ETo-PM in Periods 6, 7, 8 and 9, and estimated equally in Periods 1, 2 and 3 (Figure 1). The maximum overestimation and the maximum underestimation were 19 and 14%, respectively. The overestimation in Periods 4, 5 and 10 could be attributed to relatively high maximum temperature during those periods, while the Period 11 could be attributed to relatively high wind speed and low relative humidity. Relatively low maximum temperature coupled with low wind speed and high relative humidity could also be the cause of the underestimation. In comparison with the other methods, the ETo-AP curve was closer to the ETo-PM curve (Figure 1). This suggested that the Class A pan was better than the other methods in estimating the ETo. The Class A pan was therefore worth considering in estimating ETo in the study area when weather data are not sufficient.

The Piche evaporimeter method underestimated ETo-PM values at all periods. The underestimation partly could be due to lack of sufficient wind in the Stevenson's screen that was shielding the evaporimeter Sanchez-Lorenzo et al. (2014). These underestimations of the ETo results were similar to those of Diop et al. (2015), but different from those of Knox et al. (2011) who observed overestimation of ETo relative to FAO56-PM. The underestimation was in the range of 35 to 60%. The ETo-Pi increased in Periods 5 when the temperature and the number of sunshine hours were high (Table 1). The higher ETo-Pi in Period 5 could be as a result of the peak of the harmattan season in the study area. The ETo-Pi gradually reduced from Period 6 to 8 and slightly increased again at Period 9 and then started decreasing up to Period 11. Apart from Periods 9 to 11 where the decrease ETo-Pi followed the trend of decreasing the number of sunshine hours and invariably decreasing solar radiation, the ETo-Pi did not follow the trend of any specific determined climatic factor. This suggested that the use of Piche evaporimeter method in estimating ETo was not greatly influenced by a specific climatic factor but a combination of climatic factors.

The distribution pattern of the Hargreaves estimated ETo curve was deviated at Period 11 relative to the ETo-PM curve. Across the periods, the ETo-Hr increased with increase in its input parameters (temperature and solar radiation). The Hargreaves method underestimated ETo values as compared to the FAO56-PM method estimates and the underestimation ranged between 40 and 50%. This is comparable to similar underestimation for humid location reported by Subburayan et al. (2011), but was contrary to overestimation for humid location by Temesgen et al. (2005) and Trajkovic (2007). The Hargreaves method was nearly accurate as FAO56-PM in ETo estimation (Hargreaves, 1994) as depicted by the closeness of the curve to the ETo-PM as compared to the other indirect measurement methods and the Piche evaporimeter. The higher values of the estimate ETo by the Hargreaves method could be based on the solar radiation as input variable as compared to the Blaney-Criddle and the Hamon methods which used sunshine hours as input variable. This suggested that the Hargreaves method could be used in the study area when the weather data were scanty.

From Figure 1, lower values of ETo-BC were observed at Periods 2, 7 and 11. This could be attributed to relatively low number of sunshine hours and the corresponding low temperature. This was not surprising because these parameters were the inputs for the Blaney-Criddle method and therefore, any variations to them were likely to affect the estimated ETo (Papadopoulou et al., 2013). The Blaney-Criddle method also underestimated ETo-PM with the maximum underestimation of over 50%. The Blaney-Criddle method had higher estimate ETo values and closer with the FAO56-PM method than the Hamon method which had the lowest estimate ETo values.

The Hamon method underestimation of ETo-PM was over 70%. Nonetheless, the Hamon method gave the least underestimation of ETo values relative to the FAO56-PM across the periods (Figure 1), when day light hours were more and the temperature was relatively high as depicted at Period 3. However, as depicted at other periods, when the day hours were short and the temperatures were relatively low, the Hamon gave the higher underestimation of ETo relative to the FAO56-PM. It can be seen across the periods that the Hamon ETo estimates increased with increasing number of sunshine hours and a corresponding increase in temperature. This was not surprising because the Hamon method directly depended on daylight hours and temperature.

Degree of agreement between ETo-PM and ETo estimated by the other methods

The ETo estimates by each method were compared with the estimation of the Penman-Monteith method (ETo-PM) to measure the accuracy and reliability of the ETo methods under study. The performance of the ETo methods were measured using the following parameters: (1) MAE which measured how close the estimates were to the ETo-PM; (2) MAPE which expressed accuracy as a percentage of the error; and (3) Correlation coefficient (R) which gave a measure of the strength of the correlation between the ETo estimates.

The correlations between FAO56-PM method and the other five methods and expressed in a linear regression form (y = Ax + B) are shown in Figure 2. The results showed higher correlation coefficient ($R > 0.8$) for the indirect measurement methods (Hargreaves, Blaney-Criddle and Hamon) compared with the direct measurement methods (Class A pan and Piché evaporimeter) ($R < 0.4$) (Table 2). This indicated that the indirect measurement methods had a strong correlation with the Penman-Monteith method and therefore can efficiently approximate the actual ETo pattern in Cape Coast. However, the direct measurement methods showed their capability to estimate ETo with relatively least MAE and MAPE (Table 2). This suggested that both the direct and indirect measurements have their own pros and cons in estimating ETo in the study area.

The strength of association between FAO56-PM and Hamon was the highest ($R = 0.89$) among the indirect measurement methods even though it had the highest MAE and MAPE (3.7 mm day^{-1} and 75%, respectively). The stronger correlation between Hamon and FAO56-PM could be attributed to the high temperature and long hours of sunshine prevailing in the study area. This corroborated with the observation by Irmak et al. (2003) that those methods which used average number of day light hours and temperature were as important as FAO56-PM in estimation of ETo in coastal areas. This

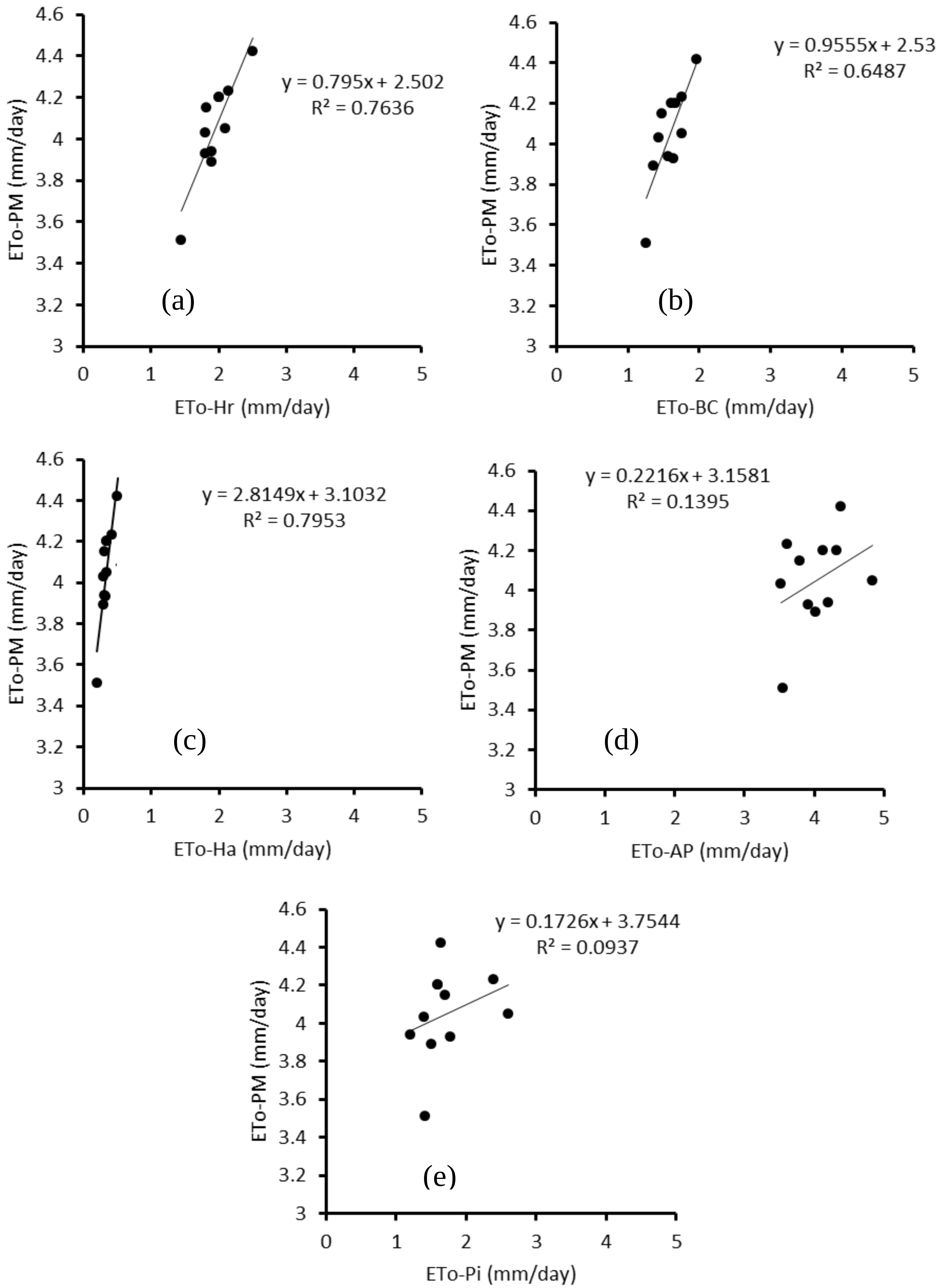

Figure 2. Regression analysis for the ETo estimates of FAO-56PM with (a) Hargreaves (b) Blaney-Criddle, (c) Hamon, (d) Class A pan, and (e) Piche evaporimeter.

Table 2. Errors and correlation between Penman-Monteith method and other ETo methods under study.

Reference evapotranspiration, ETo, method	Error		Correlation coefficient (R)
	MAE (mm day^{-1})	MAPE (%)	
Penman-Monteith	-	-	-
Class A Pan	0.26	6.50	0.37
Piche Evaporimeter	2.39	49.10	0.31
Hargreaves	2.10	42.10	0.87
Blaney-Criddle	2.45	50.00	0.81
Hamon	3.71	75.00	0.89

suggested that Hamon method can be considered as one of the simplest applicable methods to estimate ETo values in the study area, since it required only average number of day light hours per day and mean temperature (Haith and Shoemaker, 1987).

The Hargreaves and the Blaney-Criddle methods also showed higher correlation coefficients as compared to the direct measurement methods (Table 2). Even though the capabilities of the three indirect measurement methods were similar and they all needed a few number of parameters to estimate ETo, the estimation of ETo curve by the Hargreaves was closer to the estimation by the FAO56-PM as compared to the other two methods. Notwithstanding the comparatively closeness of the ET-Hr curve to the ETo-PM, there was also a strong correlation (R= 0.87) and relatively small MAE and MAPE (2.1 mm day^{-1} and 42%, respectively) established between the Hargreaves and the FAO56-PM. Hargreaves (1994) noted that Hargreaves method was as accurate as the FAO56-PM in ETo estimation. This suggested that Hargreaves method could be used in the study area when sufficient climatic data was lacking.

A high correlation coefficient (R = 0.81) established between Blaney-Criddle and FAO56-PM was an indication of a strong correlation between the two methods. This could be attributed to the prevalence of constantly high temperature (a major input) in the study area. Papadopoulou et al. (2003) observed that ETo values estimated by Blaney-Criddle method decreased as temperature dropped and even tended to cease when temperature dropped below 0°C. The Blaney-Criddle method could be used to estimate ETo as it was simple, required very few climatic data and the temperature which was a major input was always high in the study area.

Both the Class A pan and the Piche evaporimeter produced very low correlation coefficients (R). This showed that direct measurement methods had a weak relationship with the FAO56-PM. However, the Class A pan had the least MAE and MAPE (0.26 mm day^{-1} and 6.5% respectively) relative to the Piche evaporimeter and even among all the methods. The difference in their correlation coefficients and the errors could be due to the fact that the Piche evaporimeter was shielded from solar radiation and its measurement could not be directly affected by the radiative parameters controlling ETo which was not the case for the Class A pan which was in the open as intimated by Sanchez-Lorenzo et al. (2014).

The Class A pan gave R = 0.37 with FAO56-PM method and this was a weak correlation. This could be attributed to the absence of a ring at the circumference of the Class A pan at the Agro-meteorological station where the study took place which probably caused the pan to tilt when containing water. The characteristic behavior of the pan that could have enormous effect such as underestimation or overestimation of ETo as explained by Allen et al. (1998). On some occasions, frogs and birds were seen around the pan suggesting probable drinking of water by these animals. This was likely to cause a reduction in the water level and therefore changed the ETo estimation values of the pan. The fact that the Class A pan had the minimum errors though with weak correlation with the Penman-Monteith method showed that Class A pan was a good estimator of reference evapotranspiration when used in the study area.

Conclusion

ETo is one of the most important variables in the hydrological cycle. It plays an important role in the water and energy balance on earth's surface and it is of particular interest to agricultural and irrigation practices. Climate change could affect hydrological processes mainly through ET and assessing it in the context of climatic variability was therefore very important in crop production. Performance of five ETo methods were tested relative to standard Penman-Monteith with the aim to guide water practitioners, researchers and farmers in selecting appropriate method for estimating ET during the harmattan season in Cape Coast, Ghana.

Though the indirect measurement methods (Hamon, Hargreaves and Blaney-Criddle) had higher errors, the correlation between them and the Penman-Moteith method were very high and therefore can be concluded that the indirect measurement methods can efficiently approximate the actual ETo pattern in the study area. This suggested that the input parameters of these methods were significant for obtaining the proximate values in the ETo estimations. The high correlation of

Table 3. Correlation between the ETo estimates by the various ETo methods under study.

Method	ETo-PM	ETo-AP	ETo-Pi	ETo-Hr	ETo-BC	ETo-Ha
ETo-PM	-					
ETo-AP	0.37	-				
ETo-Pi	0.31	0.11	-			
ETo-Hr	0.87	0.33	0.16	-		
ETo-BC	0.81	0.35	0.27	0.82	-	
ETo-Ha	0.89	0.17	0.16	0.94	0.84	-

ETo by Hamon, followed by Hargreaves and Blaney-Criddle methods with FAO56-PM method reflected the importance of temperature, day light hours and solar radiation. This suggested the significance of sunshine duration and temperature in the study area when estimating ETo. The very strong correlation (R ranging from 0.82 to 0.94) (Table 3) among the indirect methods suggested that either of these methods could be used to estimate the reference evapotranspiration in the study area. However, the direct measurement methods (Class A pan and Piche evaporimeter) estimation of ETo were found to be weakly correlated with the FAO56-PM estimation. In spite of this, the Class A pan had the least MAE and MAPE value, and the ETo-AP curve was closer to the ETo-PM curve (Figure 1) compared with all the other methods suggesting that the Class A pan can be used in the study area. The very weak correlation (R = 0.11) between the Class A pan and the Piche evaporimeter indicated that it may not be advisable to substitute one method for the other in the study area in estimating the reference evapotranspiration. The Piche evaporimeter method was not useful in obtaining proximate values of ETo estimation in the study area owing to its very weak correlation coupled with relatively high errors with the Penman-Monteith method.

In conclusion, in data sparse region like the study area where only limited meteorological data is available and the FAO56-PM equation recommended as the standard for estimating ETo is not applicable due to the complexity of its input parameters, the use of Hamon, Hargreaves, Blaney-Criddle and Class A pan are considered as suitable methods for estimating ETo. The Class A pan was suggested as practical method for estimating ETo due to the closeness of its estimated ETo curve to that of the FAO56-PM estimated ETo curve and its low values of MAE and MAPE even though it correlated weakly with FAO56-PM. It is also recommended that the Hamon, Hargreaves, Blaney-Criddle and Class A pan should be considered for other places where the climatic conditions are similar to that of the study area.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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REFERENCES

Allen GR, Pereira LS, Raes D, Smith M (1998). Crop evapotranspiration- Guidelines for computing crop water requirement. FAO Irrigation and Drainage Paper 56, FAO, Rome.

Asamoah GK (1973). Soils of the proposed farm site of the University of Cape Coast. Soil Research Institute (CSIR) Technical Report No. 88.

Casanova MP, Messing I, Joel A, Cañete AM (2008). Methods to estimate lettuce evapotranspiration in greenhouse conditions in the central zone of Chile. Chilean J. Agric. Res. 69(1):60-70.

Chen D, Gao G, Xu C-Y, Guo J, Ren G (2005). Comparison of the Thornthwaite method and pan data with the standard Penman-Monteith estimates of reference evapotranspiration in China. Clim. Res. 28:123-132.

Diop L, Bodian A, Diallo D (2015). Use of atmometers to estimate reference evapotranspiration in Arkansas. Afri. J. Agric. Res. 10(48):4376-4383.

Emiko T, Javier B (2012). Sahara wind stirs cocoa market. Financial Times. Availabe: https://www.ft.com/content/b681e5f0-42b7-11e1-b756-00144feab49a

Food and Agriculture Organization (FAO) (2015). Water Development and Management Unit. [Online] Available: http://www.fao.org/infores_database_cropwat.html. Last accessed: 18.05.2016.

Food and Agriculture Organization (FAO) (1986). Irrigation water management: Irrigation water needs. Training Manual No. 3. FAO, Rome, Italy.

Galvilan P, Lorite IJ, Tomero S, Berengena J (2006). Regional calibration of Hargreaves equation for estimating reference ET in a semiarid environment. Agric. Water Manage. 81(3):257-281.

Haith DA, Shoemaker LL (1987). Generalized watershed load functions for stream flow nutrients. Water Resour. Bulletin 23:471-478.

Hargreaves GH (1994). Defining and using reference evapotranspiration. J. Irrig. Drain. Eng. ASCE 120(6):1132-1139.

Irmak A, Irmak S (2008). Reference and crop evapotranspiration in south central Nabraska: II. Measurement and estimation of actual evapotranspiration. J. Irrig. Drain. Eng. ASCE 134(6):700-715.

Irmark S, Irmark A, Allen RG, Jones JW (2003). Solar and net radiation-based equations to estimate reference evapotranspiration in humid climates. J. Irrig. Drain. Eng. ASCE 129(5): 336-347.

Knox JW, Rodriguez-Diaz JA, Hess TM (2011). Estimating evapotranspiration by using atmometers for irrigation scheduling in humid environment. J. Irrig. Drain. Eng. 137(11):685-691.

McVicar TR, Roderick ML, Donohue RJ, Li LT, Van Niel TG, others (2012). Global review and synthesis of trends of trends in observed terrestrial near-surface wind speeds: implications for evaporation. J. Hydrol. 416:182-205.

Papadopoulou E, Varanou E, Baltas E, Dassaklis A, Mimikou M (2003). Estimation of evapotranspiration and its spatial distribution in Greece using empirical methods. Proc. 8th Int. Conf. Environ. Sci. Technol. Lemnos Island, Greece, 8-10 September 2003.

Sanchez-Lorenzo A, Vicente-Serrano SM, Wild M, Calbo J (2014). Evaporation trends in Spain: A comparison of Class a pan and Piche atmometer measurements. Clim. Res. 61:269-280

Shahidian S, Serralheiro R, Serrano J, Teixeira J, Haie N, Santos F (2012). Hargreaves and other reduced-set methods for calculating evapotranspiration. In: Evapotranspiration-Remote Sensing and Modeling. A. Irmark (Ed.) In Tech. 4:59-80.

Subburayan S, Murugappan A, Mohan S (2011). Modified Hargreaves equation for estimation of ETo in a hot and humid location in Tamilnadu State, India. Intl. J. Eng. Sci. Tech. (IJEST) 3(1):592-600

Temesgen B, Eching S, Davidoff B, Frame K (2005). Comparison of some reference evapotranspiration equation for California. J. Irrig. Drain. Eng. 131(1):73-84.

Trajkovic S (2007). Hargreaves verses Penman-Monteith under humid conditions. J. Irrig. Drain. Eng. 133(1):38-42.

Trajkovic S, Kolakovic S (2009). Evaluation of reference evapotranspiration equations under humid conditions. Water Resour. Manage. 23:3057-3067.

World Meteorological Organization (WMO) (2008). Guide to meteorological instruments and methods of observation. WMO, Geneva (Chapter 10).