Determination of a Reference Model for Estimating Evapotranspiration in Burkina Faso

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Abstract: - The evapotranspiration (ETo) is an important factor in the application of irrigation design and scheduling, particularly at an undeveloped rural region with limiting data information. In this study, the procedure to estimate a reliable ETo with a few data is proposed in two production sites; Ouagadougou and Banfora, in Burkina Faso, Africa. There are several methods such as Penman-Monteith, Blaney-Criddle, and Hargreaves methods may be used to calculate ETo, but the accuracy is depended on the data set of weather or temperature considered in each model. In the calculation, the statistical analysis was done to verify the differences and evaluate the performance of estimation methods. From the calculated results in both locations, the trend gives significantly highest estimates values with Blaney-Criddle, while Hargreaves underestimates the ETo. It is observed that for most of the time, the Penman-Monteith ETo value is ranged between Blaney-Criddle and Hargreaves. Therefore, the model using the mean equation of (Blaney-Criddle + Hargreaves)/2 is proposed as it may produce the best estimation when assessed by the root mean square error. That is, the present proposed model offers the most satisfactory alternatives to standard Penman-Monteith method for a reliable monthly ETo estimation, and that may provide a valuable reference for the two studied areas.

Key-Words:- Evapotranspiration, irrigation design, scheduling, estimation model, mean equation, wind factor

1. Introduction

Faced to climatic constraints, high heat and low precipitation, Burkina Faso has put priority on irrigated agriculture for a supplement production. Since 2001 under the Ministry of Agriculture, Hydraulic and Fishery Resources, the government launched the Small Scale Irrigation project (SSI) in order to overcome the food insufficiency and poverty in rural areas. Subsidized inputs, such as irrigation equipments and technical assistance were provided to farmers. SSI has been popularly adopted by farmers, but it needs to be sustained by coming up with an irrigation strategy plan [1]. The difficulties are the high cost of water pumping and the lack of appropriate planning system for an efficiency use of water. However, estimation of reference evapotranspiration (ETo) can help to carry out a standard design and management of irrigation schemes [2-3]. ETo is one of the most important hydrological variables for scheduling irrigation systems [4].

For agricultural purpose, reliable estimation of evapotranspiration is required for an efficient irrigation management [5-7]. A good estimation of ETo is vital for a proper irrigation water management, allowing high water productivity. ETo can be obtained by many estimation methods, but the factors such as data availability must be considered when choosing the ETo calculation technique [8]. The Penman-Monteith method is maintained as the sole standard method recommended by the FAO (Food and Agriculture Organization of the United Nations) for the computation of ETo from complete meteorological data [9-10]. Nevertheless, the main shortcoming of Penman-Monteith method is that it requires data for large number of climatic parameters that are not always available for many locations. Several studies done under diverse climatic conditions have revealed a widely varying performance of alternative equations which local calibration are required [11-12].

Indeed, there are many models have been proposed to predict ETo, but according to the report [13], there is no universal consensus on the suitability of any given model for a given climate. Furthermore, these alternatives models require rigorous local calibration before they can be used for the estimation of ETo in irrigation scheduling [14]. Blaney-Criddle (1990) and Hargreaves (1985) considered as temperature methods and using few weather input are suitable to the study area where the complete data required for ETo estimation is complex [15-16]. Those two temperature methods as well as Penman-Monteith have been used in this study with 10 years climate data from two production sites (Ouagadougou and Banfora) of the small scale irrigation project in Burkina Faso.

The choice of Blaney-Criddle and Hargreaves has been guided by their simplicity and accuracy [17], and the availability of minimum and maximum temperature in the study areas. A sufficient climate data to be used with Penman-Monteith equation is not always available in the agricultural extension services, and the ETo calculation is very hard. As well, large measurements errors are possible as the instruments age, and the weather stations require qualified personnel for operation and maintenance of the very sensitive instruments. Therefore, the objective of this study is to set up a simple and reliable ETo estimation model by using long term data in the condition of arid area for irrigation planning purpose.

2. Data and Estimation Model

To determine a reliable model for estimating ETo, it will depend on the availability of data base. In this study, the data sets were collected from two meteorological stations in Burkina Faso as shown in Fig. 1. In the center region at 800mm isohyets, Ouagadougou Airport Meteorological station located at 12°37'N in latitude, -15°2'W in longitude, and 306m altitude. In the Cascades region, National Sugar Company Agro-meteorological station located in Banfora, Western part of Burkina Faso at 10°63'N in latitude, -4°77'W in longitude, and 302m altitude. The annual rainfall regularly reaches slightly isohyets of 1200mm.

The weather data in decade (10 days) and month for ten years (1996-2005) were collected from both locations for this study. The data are composed of precipitation, hours of sunshine (hours), wind speed (km/day), maximum and minimum temperature (°C) and relative humidity (%). These values were used to compute ETo using (1) Penman-Monteith method, (2) Blaney-Criddle method, and (3) Hargreaves method. The climatic data including temperature, humidity, wind speed, and sunshine are required for the first method, while only temperature is required for the other two methods.

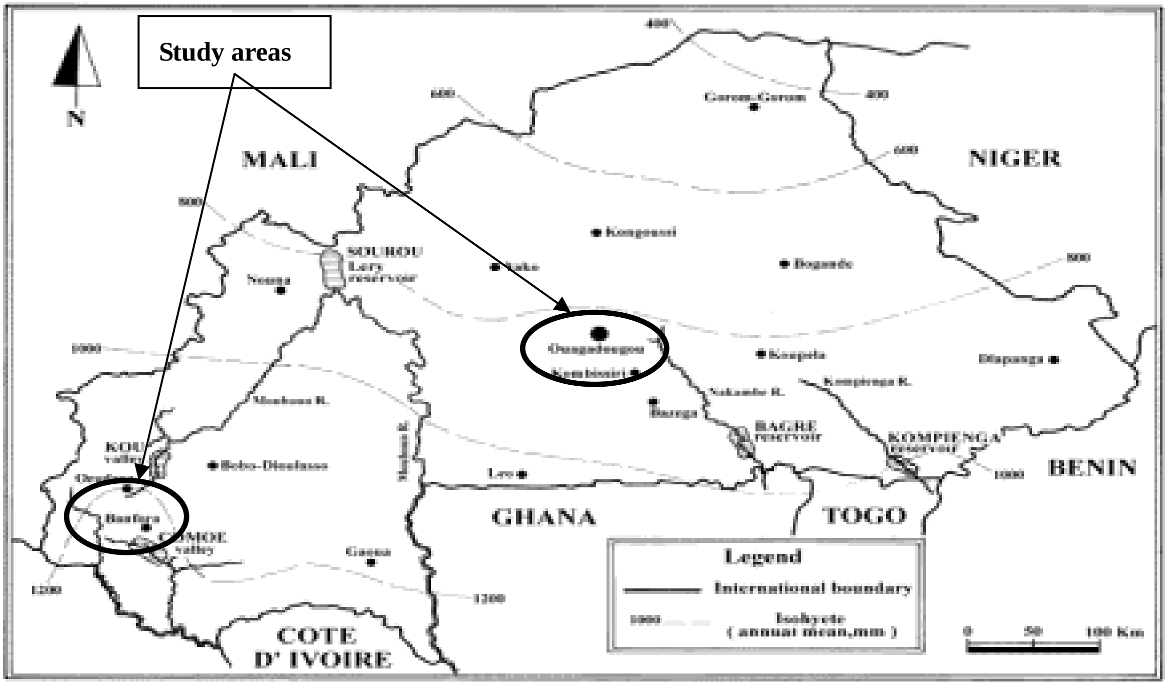

Fig. 1. Sketch of the present study areas.

The ETo values estimated for decade and month were subjected to their mean analysis by ANOVA (ANalysis Of VAriance) procedure, where each method is taken as treatments. The linear regression procedures was done by the equation $y = a + bx$, where y represents ETo computed by Penman-Monteith equation, x is the ETo estimated from alternative methods, and a and b are constants representing the intercept and slope of the regression equation, respectively.

The root mean square error (*RMSE*) can be used to test the statistical significant of the ETo estimates was calculated according to the equation $RMSE = (\Sigma_{i=1}^{n} d_i^2 / n)^{1/2}$, where d_i is the difference between *i*th predicted and *i*th Penman-Monteith estimates values and n is number of data pairs.

3. Result Discussion

Estimates ETo for decade (ten days) and month, the minimum and maximum temperature, and precipitation by using the average of ten years data from two regions (Ouagadougou in the Center and Banfora in the West called Cascades) of Burkina Faso are summarized in Fig. 2. Our results demonstrated that during the rainy season (June-October) for both locations, all those methods gave a low ETo, while the high ETo values are observed in dry season (November-May). The highest ETo is found in Ouagadougou (Figs. 2a and c) in March during the dry season with a value of 7.0mm/day and 7.3mm/day for month and decade, respectively. The lowest ETo is found in Banfora (Figs. 2b and d) in August in rainy season with a value of 4.0mm/days for month and 3.9mm/day for decade. The ETo in Ouagadougou is slightly higher (5.7mm/day, Penman-Monteith annual average) than Banfora (5.4mm/day), due probably to the difference from their isohyete. Generally as shown in the Fig. 2 (e and f), Banfora (1200mm isohyete) has abundant precipitation than Ouagadougou (800mm isohyete). The ETo derived from the Penman-Monteith, Blaney-Criddle and Hargreaves gave a similar fluctuation varying according to the season of year.

It has been observed most of the time, Penman-Monteith ETo value is ranged between Blaney-Criddle and Hargreaves. Thus, considering a fourth estimation method (Blaney-Criddle + Hargreaves)/2 proposed by this study, the mean comparison by ANOVA procedure was done to verify the difference between those estimation methods chosen (Table 1). The ETo estimates comparison across models indicated were in descending order of Blaney-Criddle > Present study > Penman-Monteith > Hargreaves regardless the location and period. In the comparison of the decade ETo estimated by those four methods for the two locations, Blaney-Criddle gives the highest estimates values followed by The present study and Penman-Monteith. The lowest estimate was by Hargreaves. The statistical analysis given in Table 1 showed that there was significant difference between Penman-Monteith when comparing with Blaney-Criddle or Hargreaves.

The comparison of monthly ETo showed the highest ETo value with Blaney-Criddle (Ouagadougou 5.9mm/day; Banfora 5.6mm/day) and the lowest with Hargreaves (Ouagadougou 5.4mm/day; Banfora 5.2mm/day). The mean comparison showed that Hargreaves was not significantly different from Penman-Monteith. There was significant difference between Blaney-Criddle and Penman-Monteith for the Ouagadougou location, while no significant difference was observed in Banfora. Blaney-Criddle overestimated significantly the ETo, exception of Banfora monthly value where this overestimation showed no significant difference to Penman-Monteith. However, we generally observed that Blaney-Criddle overestimates and Hargreaves underestimates the ETo.

The influence of those alternative methods may strongly dependent of climate conditions. More recently report [18], found that in semi-arid conditions, Hargreaves generally under-predicted ETo. Considering the dry tropical climate of Burkina Faso, the results obtained from Blaney-Criddle and Hargreaves in this study agreed with those previous studies. Blaney-Criddle in Ouagadougou (Figs. 2a, and c) underestimates not significantly the ETo between April to July. The reason of this ETo decrease is probably due to the decrease of temperature with the beginning of rainy season (Fig. 2e). According to previous study [19], the underestimation seems to correspond with the rapid decrease of air temperature. But, this underestimation did not significantly impact the global trend given by Blaney-Criddle.

Considering the present proposed model, no significant difference has been found with Penman-Monteith whatever the location and estimation period. The comparison of the present method gives a similar trend with Penman-Monteith when compared to Blaney-Criddle and Hargreaves. Blaney-Criddle is followed by the present method, but this last method for any location and period seem to be close to Penman-Monteith. It has been observed during the rainy season (June to October) for both locations, all those alternative methods agreed more closely with Penman-Monteith, and there is no significantly difference observed among them. For the supplement irrigation purpose during the rainy season in both areas, all those alternatives methods can be considered.

The linear regression between Penman-Monteith assumed as true ETo in this study versus the other methods are describes in Table 2. In general, the performance of monthly calibration was better than decade periods. The regression coefficients are ranked between r^2 (0.84-0.97) for decades, and r^2 (0.88-0.98) for months. Our results showed that the relations between ETo from alternative methods and Penman-Monteith were better for monthly value than decade in both locations. The present model showed a good relation with Penman-Monteith, followed by Hargreaves. Previous report [20] found that Hargreaves method gives similar results with Penman-Monteith, despite its limited input of temperature alone. Regarding the Blaney-Criddle method, it is poorly modeled when compared to

Hargreaves. The Blaney-Criddle method always refers to mean monthly value, both for the temperature and the ETo [21]. Under such consideration, we emphasized only on the monthly evapotranspiration value with Blaney-Criddle method.

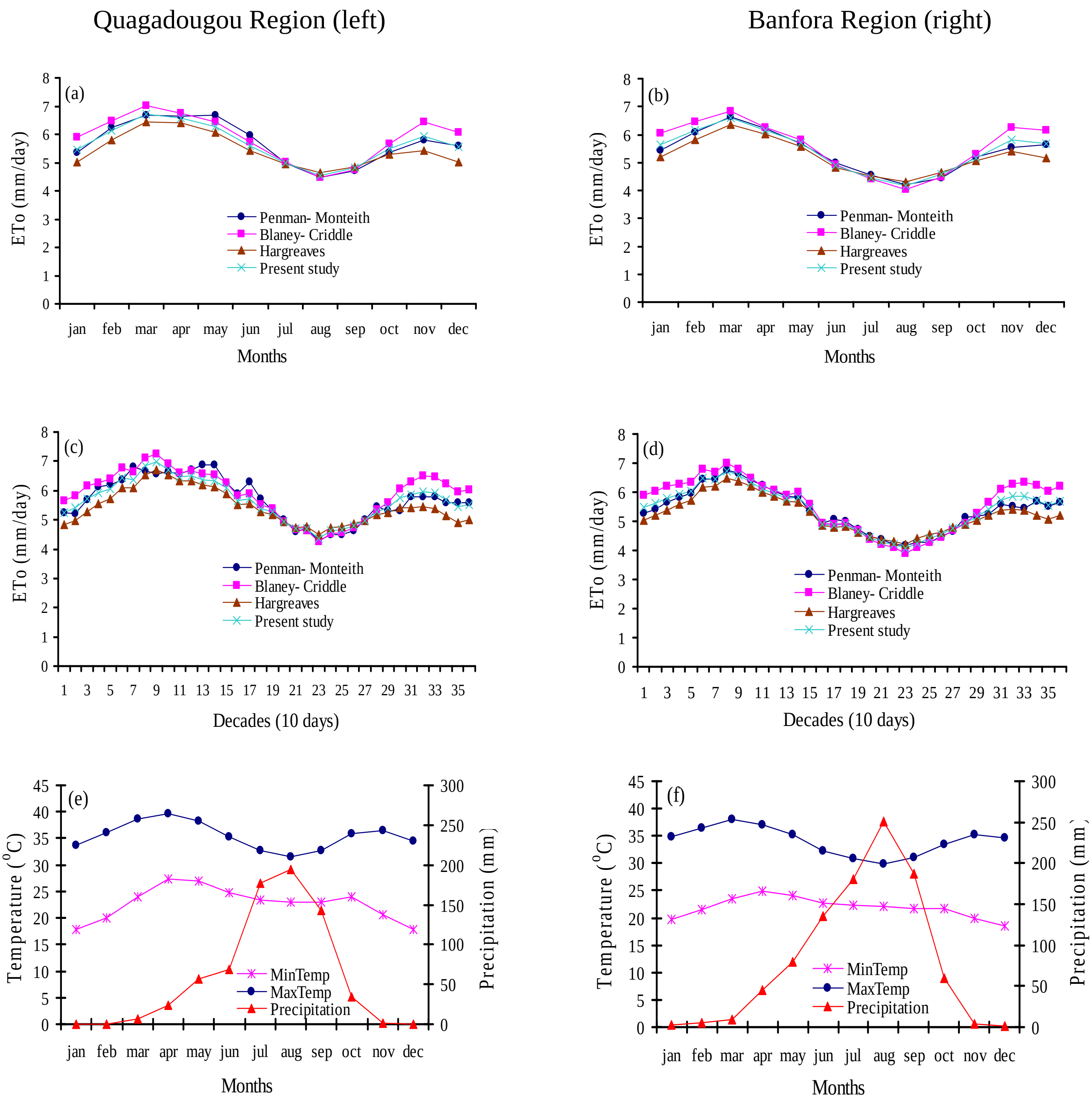

Fig. 2. Plot of reference evapotranspiration; (a),(b): month, (c),(d): decade, (e),(f): average of maximum, minimum temperature, and precipitation.

Table 1. Comparison of reference evapotranspiration (ETo) by four different methods.

Estimation Methods	Ouagadougou ETo (mm/days)		Banfora ETo (mm/days)	
	Decade	Month	Decade	Month
Blaney- Criddle	5.891	5.893	5.581	5.577
Present study	5.694	5.676	5.413	5.421
Penman-Monteith	5.604	5.598	5.383	5.401
Hargreaves	5.447	5.445	5.241	5.242

Table 2. Relationship between monthly evapotranspiration from Penman-Monteith and alternative methods.

Linear regressions	Ouagadougou			Banfora		
	a	*b*	r^2	*a*	*b*	r^2
Penman-Monteith *vs*. Blaney-Criddle	0.4043	0.8990	0.88	1.1407	0.7599	0.92
Penman-Monteith *vs*. Hargreaves	-0.6977	1.1736	0.88	-0.6669	1.1524	0.96
Penman-Monteith *vs*. Present study	-0.5407	1.1012	0.95	0.0241	0.9894	0.98

Penman-Monteith; $y=a+bx$

Further examination of regression analysis results with Penman-Monteith were similarly ranked as in the performance of the present model, Hargreaves and Blaney-Criddle. Previous study [22] found a good relation between Penman-Monteith and Hargreaves (r^2 = 0.99), and Blaney-Criddle (r^2 = 0.92). Our results showed similarity to those studies particularly for Banfora (Hargreaves r^2 = 0.96; Blaney-Criddle r^2 = 0.92), but the present study model is the most fitted to Penman-Monteith for Banfora (decade r^2 = 0.97; month r^2 = 0.98) and Ouagadougou (decade r^2 = 0.91; month r^2 = 0.95). Thus, the present study model can be considered for a reliable monthly ETo estimation in the two locations. Nevertheless regarding the decade, it can give also a reliable ETo estimation close to Penman-Monteith compared to Blaney-Criddle and Hargreaves. The *RMSE* values, ranging from 0.164 to 0.295 and from 0.113 to 0.246 for Ouagadougou and Banfora, respectively (Table 3), attributed the smallest indices to the present study model. According to previous study [23], the smaller is the value of *RMSE*, the better is the performance model. Even we found small *RMSE*, the present study model performed the best in both locations for decade and month, followed by Hargreaves and Blaney-Criddle.

Table 3. Error analysis performed on Penman-Monteith and estimates ETo values from models established for Ouagadougou and Banfora locations.

Model	Ouagadougou		Banfora	
	RMSE		*RMSE*	
	Month	Decade	Month	Decade
Present study	0.164	0.193	0.113	0.171
Hargreaves	0.230	0.294	0.136	0.219
Blaney-Criddle	0.252	0.295	0.201	0.246

4. Conclusion

The development of irrigation sector and its planning system improvement as part of the small scale irrigation project activities are a big challenge for the government of Burkina Faso. Until now, it has been noticed that the Penman-Monteith, as well as ETo application for the irrigation purpose still not used in Burkina Faso. The irrigation program in the country is done without appropriate planning system. The ETo estimation model demonstrated in this study can produce an ETo forecast, which may help in an efficient management of irrigation water and model the cropping pattern through the computer CROPWAT analysis; thereby avoiding the high cost of water pumping, crop failure and yield decrease. We have been observed in the specific condition of Burkina Faso, the ETo is sensitive to the wind speed, and this parameter could impeded to the ETo estimation with Penman-Monteith method. It could be concluded that during the rainy season, ETo from limited inputs, calculate with Blaney-Criddle, Hargreaves and The present model showed similarity to Penman-Monteith results, thus can be considered for the supplement irrigation purpose. We found that, the present study model offers the most satisfactory alternative to Penman-Monteith, appropriate particularly for estimating monthly ETo in the reported studies areas.

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