

Validation of Valiantzas' Reference Evapotranspiration Equation under Different Climatic Conditions

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Abstract

Numerous daily reference evapotranspiration (ET₀) equations were developed for different climatic conditions with different performance even within the same climatic region. Their calibration and validation to the local climate usually increase their performance. The objective of this study was to evaluate Valiantzas' daily grass ET₀ equation with comparison to Penman-Monteith equation at 61 weather stations across 10 countries in Africa for the period of 1980-2012. The results showed good performance of Valiantzas' ET₀ equation with very low RMSE varying from 0.03 to 0.27 mm/day, low percent error PE from 0.87 to 5.46%, MBE from -0.09 to 0.23 mm/day and MAE from 0.03 to 0.23 mm/day. For the pooled data set, RMSE averaged 0.10 mm/day, mean PE was 1.95%, mean MBE was 0.02 mm/day and the mean MAE was 0.08 mm/day. These indexes indicated the very high performance of the Valiantzas' ET₀ equation compared to the Penman-Monteith equation and its adaptation to very broad conditions from humid to semiarid climates.

Keywords: Reference evapotranspiration; Penman-Monteith; Valiantzas; Different climatic conditions

Introduction

Reference evapotranspiration (ET₀) is widely used for agricultural, hydrological, and environmental studies for sustainable water use. It is estimated by different methods from measurement through lysimeters to mathematical modeling using climatic and geographical variables [1]. Numerous equations have been developed to estimate ET₀ at different time scales across the globe. Hargreaves and Samani [2] proposed temperature based ET₀ equation which was world wise used with variable accuracy [3-5]. Other ET₀ equations [6-19], the authors provided variable performance under different climatic conditions and locations. The Penman-Monteith equation [16] in its standardized form was revealed the most accurate ET₀ method under all climatic conditions across the globe [16,20-30]. While different ET₀ methods are providing ET₀ estimated with relatively good accuracy but non-adapted to all the climatic conditions, their calibration to local climatic conditions offers the opportunity to improve the performance of these ET₀ equations under weather conditions different from the conditions under which they were developed. Droogers and Allen [31] reported suitability of very few ET₀ equation to the Iranian environment. Djaman et al. [32] calibrated the Trabert, Mahringer, Albrecht, and two of the Valiantzas equations to the Sahelian conditions in the Senegal River Valley. The Hargreaves ET₀ equation was calibrated under different climatic conditions [33]. Valiantzas [34] had lately proposed some new simplified forms of the Penman-Monteith ET₀ equation and which have been used for daily ET₀ estimation with variable performance related to the local climatic conditions. While some of these equations showed good accuracy in ET₀ estimations under some climatic conditions, others need calibration to improve their performance [32-35]. One of the Valiantzas ET₀ equations was shown suitable for ET₀ estimation across Burkina Faso [36,37], Tanzania, Kenya and Uganda [38,39]. Ahooghalandari et al. [35] indicated good performance of the calibrated forms of two of the Valiantzas equations to the Pilbara region of Western Australia. The Valiantzas ET₀ equations have also been tested by Valipour [40,41] and Kisi [42] with variable performance. Different forms for the Valiantzas ET₀ equation with full dataset gave different performance in Iran related to the geographical locations, wind speed range and the magnitude of the shortwave incoming solar radiation [40]. While, Valiantzas [34] has

suggested different equations as a function of the availability of climatic data, one with full climatic variables showed its accuracy in Uganda for the 1992-2012 period at 16 weather stations with R² of 0.9975 and simple linear regression slope of 1.0055 for the pooled data set and RMSE varying from 0.06 to 0.09 mm/day and MBE from 0.008 to 0.064 mm/day across the locations [39]. This equation was revealed adapted to the studied region and could be used without any calibration. The objective of this study was to evaluate the most performing Valiantzas equation in comparison with the Penman-Monteith equation under humid, sub-humid and semiarid conditions and across Africa for its regional adaptability.

Materials and Methods

Study area and meteorological data used

This study covers different climatic zones from the humid to semiarid climatic conditions in Africa. Meteorological data were collected from ten continental African countries and Madagascar (Grand African Island) covering different climatic conditions and different periods: Benin (1980-2010), Burkina Faso (1998-2012), Cameroun (1980-2010), Ghana (1980-2010), Kenya (1998-2012), Madagascar (1980-2010), Niger (1998-2012), Nigeria (1998-2012), Senegal (1950-2012), Tanzania (1998-2012). Daily average solar radiation (Rs), minimum temperature (Tmin), maximum temperature (Tmax), minimum relative humidity (RHmin), maximum relative humidity (RHmax) and wind speed (u) were monitored at different weather stations in these countries with long-term average climatic conditions summarized in Tables 1 and 2.

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Countries	Weather Station	Latitude DDNorth	Longitude DDEast	Altitude (m)	U_2 (m/s)	Tmax (°C)	Tmin (°C)	Rhmax (%)	Rhmin (%)	Rs (MJ m ⁻²)
Benin	Glazoue	7.88	2.21	199	1.6	32.4	22.9	99.4	68.5	18.4
	Malanville	11.88	3.45	179	2.2	35.8	23.1	62.4	33.8	20.3
Burkina Faso	Bobo Dioulasso	11.17	-4.32	445	1.7	33.7	22.6	68.0	37.6	20.7
	Bromo	11.75	-2.93	243	0.6	35.5	22.6	65.1	33.3	20.8
	BurDedougou	12.35	-1.52	305	1.5	35.4	22.8	60.2	31.5	21.1
	Dori	14.03	-0.03	288	0.6	37.2	23.0	53.2	25.7	22.5
	Fada Ngourma	12.03	0.37	294	0.7	35.5	22.8	62.6	43.2	21.0
	Ouahigouya	13.57	0.2	315	1.1	36.0	23.5	51.1	26.8	21.5
	Po	11.15	-1.15	322	0.7	34.8	22.8	63.2	33.9	20.7
	Gaoua	10.33	-3.18	339	0.9	34.4	22.1	72.8	38.5	20.3
Cameroun	Koundja	5.65	10.75	1184	0.9	27.0	17.2	95.3	60.2	17.8
	Lagdo	9.33	13.38	249	2.0	35.5	22.6	61.8	35.2	20.3
	Mbam	3.83	11.52	712	0.3	28.6	20.4	99.6	72.9	17.0
	Ndop	5.95	10.44	1196	1.0	26.9	17.7	93.4	59.3	17.9
Ghana	Afife	6.12	0.8	21	1.8	31.3	24.7	97.7	70.5	18.7
	Bolgatanga	10.8	0.87	202	2.1	35.4	23.2	73.3	41.1	19.7
	Kumassi	6.67	-1.81	261	1.6	31.2	22.7	99.9	71.5	17.5
	Yendi	9.43	0	208.2	1.8	33.3	22.8	96.7	61.6	19.2
Kenya	Nakuru	-0.16	36.6	1901	1.4	29.8	17.4	94.6	45.5	22.2
	Jomo Kenyatta	-1.32	36.92	1624	1.8	25.7	13.9	93.3	45.7	21.4
	Kisumu	-0.09	34.73	1146	1.4	29.8	17.4	94.6	45.5	22.2
Niger	Nkonni	13.8	5.24	273	1.7	37.4	22.8	53.3	25.5	22.4
	Diffa	13.42	13	305	2.9	36.9	21.3	52.4	23.5	22.8
	Mainesorao	13.23	11.98	337	2.0	36.7	21.7	49.1	22.8	22.9
	Maradi	13.48	-7.08	373	2.0	35.5	21.3	54.8	36.0	22.7
	Niamey	13.48	2.17	227	2.0	37.3	21.0	53.0	23.7	22.3
	Tahoua	14.9	5.25	391	2.0	36.4	23.0	46.4	23.1	23.2
	Tollabery	14.2	1.45	210	2.0	37.8	23.5	39.9	19.7	22.6
	Zender	13.78	8.98	453	2.0	36.8	23.6	46.2	23.9	22.9
Nigeria	Bauchi	10.28	9.82	609	2.0	33.1	19.8	70.2	34.7	21.1
	Gaya	11.88	3.45	203	2.0	36.2	23.7	65.2	33.7	20.8
	Gusau	12.17	6.7	469	2.0	33.8	20.0	69.5	34.6	21.7
	Kaduna	10.6	7.45	642	2.0	33.0	19.2	82.6	39.3	20.6
	Kano	12.05	8.53	841	2.0	33.7	19.5	64.4	31.3	22.0
	Katsina	13.02	7.62	427	2.0	33.7	18.7	62.4	29.1	22.7
	Maidu	6.7	7.55	12.17	2.0	33.6	19.4	63.9	29.8	21.4
	Nguru	12.88	10.47	344	2.0	35.5	21.0	56.6	27.5	22.2
	Sokoto	13.02	5.25	302	2.0	35.8	22.7	53.6	28.3	22.4
	Yelwa	10.88	4.75	243	2.0	34.9	21.6	82.4	39.8	20.5
Senegal	Saint Louis	16.5	15.2	3	2.5	31.3	20.5	86.2	47.7	20.3
Tanzania	Dodoma	-6.17	35.77	1120	2.4	29.0	17.5	84.1	42.5	21.9
	Morogoro	-6.83	37.65	526	0.8	30.4	19.8	92.1	49.4	19.1
	Songea	-10.67	36	1036	1.8	26.8	16.6	89.5	48.5	18.9
	Kilimanjaro	-3.43	37.07	896	1.5	30.1	18.0	88.0	43.3	19.7
	Tabora	-5.08	33	1182	1.3	29.9	17.8	82.6	40.6	21.4

Table 1: Geographic coordinates and annual average climatic variables of the weather observatories in the continental Africa.

Reference evapotranspiration equations

Penman-Monteith model (PM-ETo): Daily grass-reference ET was computed using the standardized ASCE form of the Penman-Monteith (PM-ETo) equation [20]:

$$ET_o = \frac{0.408\Delta(Rn - G) + (\gamma Cnu_2 / (T + 273))(es - sa)}{\Delta + \gamma(1 + Cd u_2)} \quad (1)$$

where: ETo is the reference evapotranspiration (mm day⁻¹), Δ is the slope of saturation vapor pressure versus air temperature curve (kPa °C⁻¹), Rn is the net radiation at the crop surface (MJ m⁻² d⁻¹), G is the soil heat flux density at the soil surface (MJ m⁻² d⁻¹), T is the mean daily air temperature at 1.5-2.5 m height (C), u₂ is the mean daily wind speed at

2 m height (m s⁻¹), es is the saturation vapor pressure at 1.5-2.5 m height (kPa), ea is the actual vapor pressure at 1.5-2.5 m height (kPa), es-ea is the saturation vapor pressure deficit (kPa), γ is the psychrometric constant (kPa °C⁻¹), Cn and Cd are constants with values of 900°C mm s³ Mg⁻¹ d⁻¹ and 0.34 s m⁻¹, respectively. The procedure developed by Turc [18] was used to compute the needed parameters.

Valiantzas reference evapotranspiration equation

$$ET_o = 0.051(1 - \alpha)Rs(T_{mean} + 9.5)^0.5 - 0.188(T_{mean} + 13)(Rs/Ra - 0.194)^0.5 - 0.00015(T_{mean} + 45)^2(RH/100)^0.5 - 0.0165Rsu^0.7 + 0.0585(T_{mean} + 17)u^0.75((1 + 0.00043(T_{max} - T_{min})^2)^2 - RH/100)/(1 + 0.00043(T_{max} - T_{min})^2 + 0.0001z) \quad (2)$$

Weather stations	Latitude DDNorth	Longitude DDEast	Altitude (m)	U_2 (m/s)	Tmax (°C)	Tmin (°C)	Rhmax (%)	Rhmin (%)	Rs (MJ m ⁻²)
Ambohirsilaozana	-17.63	48.5	761	1.56	25.48	17.35	95.40	61.16	18.49
Andapa	-14.65	49.62	483.5	0.69	24.62	16.58	99.92	73.02	17.64
Ambohibary	-19.62	47.13	1657	1.82	22.49	12.93	97.13	56.54	20.11
Antsohihy	-14.88	47.98	33.82	2.55	32.39	21.42	79.16	44.90	21.80
Arrachart	-12.35	49.29	114	4.49	30.75	21.57	93.22	57.43	20.76
Amotsirabato	-15	50.32	87	3.07	28.56	22.23	99.03	72.16	17.83
Tolagnaro	-22.55	45.4	160	2.66	27.40	16.48	76.09	40.94	20.81
Toamasina	-18.11	49.39	7	0.76	28.20	21.01	88.62	59.38	16.58
Marovoay	-16.1	46.63	10	2.13	32.13	21.97	72.29	42.37	21.34
Maevatanana	-16.95	46.83	70	2.47	31.68	20.90	77.18	43.48	21.06
Maroantsetra	-15.43	49.73	5	0.53	26.93	19.27	99.43	71.29	17.50
Morombe	-21.75	43.38	5	2.50	31.76	20.65	69.07	36.92	22.61
Morndava	-20.29	44.32	8	1.76	32.11	19.64	89.64	46.63	22.07
Maintirano	-18.05	44.03	12	1.85	31.51	23.10	74.04	45.84	21.57
Mahanoro	-19.83	48.8	5	1.47	27.61	21.07	93.91	65.81	17.32
Mananjary	-21.2	48.36	0.27	1.40	27.27	20.82	93.61	64.86	17.12
Ivato	-18.8	47.48	1280	2.24	23.73	14.02	96.27	55.71	20.12
Fianarantsoa	-21.44	47.11	1200	1.19	23.83	14.56	99.47	63.65	19.39
Farafangana	-22.81	47.82	3	1.60	28.10	20.93	90.58	59.47	17.58
Beroroha	-24.22	45.32	458	2.69	29.21	18.87	70.02	39.40	20.41
Bekily	-21.67	45.17	180	2.16	32.19	19.75	73.55	38.03	21.15
Besalampy	-16.74	44.48	30	1.71	31.86	22.76	73.70	45.25	21.40

Table 2: Geographic coordinates and annual average climatic variables of the weather observatories in Madagascar (Grand African Island).

Where, T_{max} , T_{min} , and T_{mean} are daily maximum, minimum, and mean air temperature (°C), respectively; RH is daily relative humidity (%); Rs is solar radiation ($MJ\ m^{-2}\ day^{-1}$), Ra is extraterrestrial radiation ($MJ\ m^{-2}\ day^{-1}$); and $\alpha=0.25$, φ is the latitude of the weather station in radians, z is the elevation (m) of the weather station [34].

Evaluation criteria

Daily ETo estimates using the Valiantzas equation were compared with the daily ETo estimates by the Penman-Monteith equation using graphics and simple linear regression, root mean squared error (RMSE), relative error (RE), mean bias error (MBE), and mean absolute error (MAE).

$$RMSE = \sqrt{\frac{\sum_{i=0}^n (ET_0Vali - ET_0PM_i)^2}{n}} \quad (3)$$

$$RE = \frac{RMSE}{ET_0PM\ mean} \times 100 \quad (4)$$

$$MBE = n^{-1} \sum_i (ET_0Vali - ET_0PM_i) \quad (5)$$

$$MAE = n^{-1} \sum_i |ET_0Vali - ET_0PM_i| \quad (6)$$

Where, $ETo\ Vali$ is the estimated ETo with the Valiantzas' ETo equation; and $EToPMi$ is ETo estimated with PM-ETo model, at the i^{th} data point and n is the total number of data points.

Results and Discussion

The evaluation of the Valiantzas' ETo equation versus Penman-Monteith equation at country level is presented in Figure 1 and the statistics are summarized in Table 3. Perfect agreement between the two equations was shown in the Sahelian environment in Niger and Nigeria, and in humid climatic conditions in Tanzania, and Kenya. Valiantzas' ETo equation underestimated daily ETo at high daily ETo values above 10 mm/day in the sub-humid climatic conditions in

Benin, Cameroun, Ghana, and in the semiarid climate in Senegal. The Valiantzas' equation showed good agreement with Penman-Monteith equation with regression slopes that varied from 0.99 to 1.02 and the coefficient of determination varying from 0.98 to 0.99. The RMSE was low and ranged from 0.06 to 0.22 mm/day with the highest RMSE value obtained in Benin and the lowest value in Kenya, and Tanzania. At country level, the percent error values were acceptable and lower than 4.5%, Table 2 showing the very low error in the estimates of daily ETo by Valiantzas' equation. Moreover, very low MBE and MAE values were obtained and varied from -0.09 to 0.13 mm/day and from 0.04 to 0.15 mm/day, respectively (Table 3). The RMSE, PE, MBE and MAE averaged 0.10 mm/day, 1.95%, 0.02 mm/day and 0.08 mm/day, respectively.

At station level, the results of the performance evaluation of Valiantzas' ETo equation are summarized in Table 3. Very good agreement was found between Valiantzas and Penman-Monteith equations. Very low RMSE was obtained and varied from 0.03 to 0.27 mm/day. Moreover, the percent error PE was also very low and varied from 0.87 to 5.46% only. MBE varied from -0.09 to 0.23 mm/day and MAE ranged from 0.03 to 0.23 mm/day (Tables 4 and 5). PE values lower than 2% were obtained at 75% of the weather stations. The poorest performance of Valiantzas' equation was revealed across Burkina Faso with the PE values varying from 1.94 to 5.46%. However, the highest value of RMSE of 0.27 mm/day was registered at Lagdo in Cameroun under humid climate and the lowest value of 0.05 mm/day were registered at Songea in Tanzania. Average RMSE of all 61 weather stations was as low as 0.10 mm/day and the PE averaged only 1.95%. Average MBE and MAE values were 0.02 and 0.008 mm/day, respectively. The results of this study are in agreement with Gelcer et al. [43] who indicated that the Valiantzas' method performed the best among six ETo equations evaluated at 92 automated weather stations in Florida, Georgia, and North Carolina (Southeast USA). The authors reported very low percent error at 92 weather stations under humid climate in Florida, Georgia, and North Carolina. Similar results were

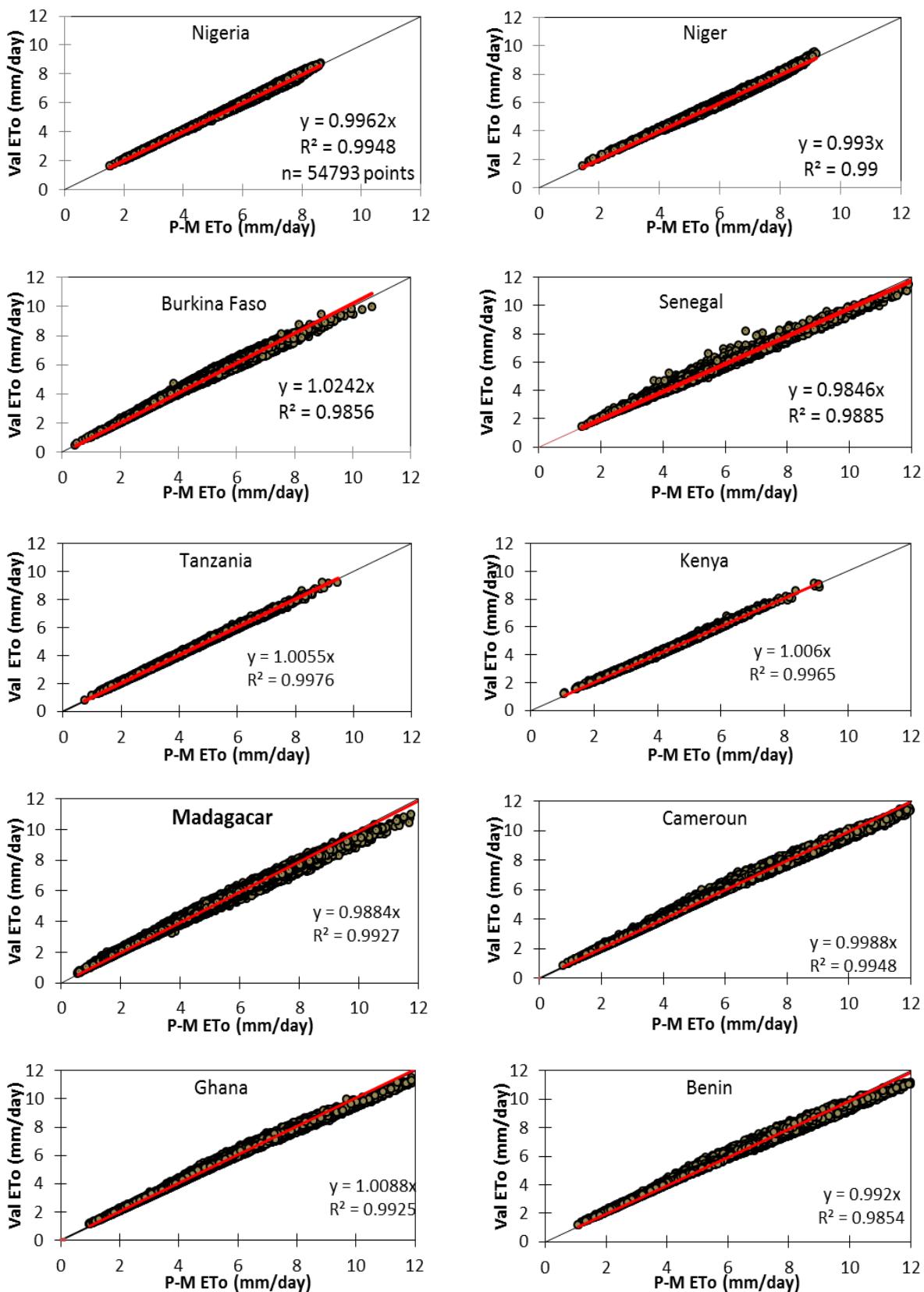


Figure 1: Valiantzas vs Penman-Monteith equations for the pooled data at country level.

Countries	RMSE (mm/day)	PE (%)	MBE (mm/day)	MAE (mm/day)
Benin	0.21	4.0	0.01	0.14
Burkina Faso	0.18	3.8	0.13	0.15
Cameroun	0.12	2.8	0.02	0.07
Ghana	0.13	2.8	0.06	0.09
Niger	0.11	1.7	-0.04	0.09
Nigeria	0.08	1.4	-0.02	0.06
Kenya	0.06	1.3	0.03	0.04
Senegal	0.22	4.3	-0.09	0.14
Tanzania	0.06	1.3	0.03	0.05
Madagascar	0.133	1.4	0.03	0.05
Average	0.12	2.3	-0.026	0.09

Table 3: Statistical Indexes for the evaluation of Valiantzas' reference evapotranspiration equation in 10 countries covering humid and semiarid climatic conditions.

reported by Kisi [42] in Turkey, Valipour [41] in Iran, Ahooghalandari et al. [35] in Australia. The Valiantzas' ETo equation performed well at 16 weather stations in Uganda for the period of 1992-2012 with a regression slope and R² of the pooled data of 1.0055 and of 0.9975, respectively, relative to the Penman-Monteith ETo equation. Moreover, RMSE varied from 0.05 to 0.09 mm/day; MBE varied from 0.008 to 0.05 mm/day and the regression slope varied from 1.00 to 1.02 indicating the applicability of the Valiantzas ETo equation across Uganda [39]. McShea [44] reported good agreement between the Valiantzas ETo estimated and Penman-Monteith ETo estimates in the Mountainous cold regions in Colorado (USA). Shalamzari and Mohammadi [45] reported that the Valiantzas' ETo equation showed the best performance under humid cold climate region of Chaharmahal and Bakhtiary province, Borujen, Shahrekord, Koohrang and Lordegan in Iran, for the period of 1994-2015. Valipour [41] reported the Valiantzas ETo equation under this study to be the most precise method for the East and South Iran. Adversely, Peng et al. [46] reported the valiantzas ETo equation to have the worst performance than the other ETo equations under their study in different sub-regions of the mainland China.

Similar to the adaptability of Valiantzas equation, Hargreaves equation is widely used for daily or monthly ETo estimation with variable degree of performance in Spain [47], in Italy [4,48], in South Korea [49], in Iran [50-52], in Canada [53], in Senegal, Kenya, and Tanzania [5,38], in Burkina Faso [37]; in China [46,54]. However, climatic variables required by the Hargreaves equation are very limited compared to the Valiantzas equation which required similar parameters as the Penman-Monteith equation. This increases the usefulness and the applicability of the Hargreaves equation across the globe, mostly under the environments where only very few climatic parameters are recorded like in the developing countries similar to the African countries.

The MBE value ranged between -0.09 and 0.13 mm/day with the highest value in Burkina Faso and the lowest value in Senegal both under the semiarid climate while the overall average MBE was -0.026 mm/day with slight underestimation of the daily ETo by the Valianstzas equation equivalent to a deficit of 0.26 m³/ha of irrigation and/or rainfall water. With %PE range of 1.3-4.3 which is relatively low, the Valiantzas equation could be applied at regional and global levels without putting crop under water stress. Thus, crops support up to 25% of deficit irrigation application without any yield reduction in maize [55-58], in soybean [59,60], and in sweet potato [61]. Even if some online resources exist to help estimating the Penman-Monteith ETo values, the accessibility and internet network coverage and intensity

Countries	Weather stations	RMSE (mm/day)	PE (%)	MBE (mm/day)	MAE (mm/day)
Benin	Glazoue	0.12	2.88	0.11	0.11
	Malanville	0.20	3.23	-0.02	0.14
Burkina Faso	Bobo Dioulasso	0.10	1.94	0.02	0.08
	Boromo	0.21	4.88	0.18	0.18
	BurDedougou	0.13	2.41	0.06	0.10
	Dori	0.26	5.46	0.23	0.23
	Fada Ngourma	0.18	4.02	0.16	0.16
	Ouahigouya	0.17	3.32	0.12	0.14
	Po	0.18	4.01	0.15	0.15
	Gaoua	0.16	3.63	0.13	0.14
Cameroun	Koundja	0.06	1.72	0.04	0.05
	Lagdo	0.27	4.54	-0.08	0.19
	Mbam	0.03	1.00	0.01	0.03
	Ndop	0.06	1.65	0.04	0.05
Ghana	Afife	0.05	1.28	0.04	0.04
	Bolgatanga	0.24	4.16	-0.04	0.15
	Kumassi	0.09	2.45	0.09	0.09
	Yendi	0.12	2.67	0.09	0.10
Kenya	Nakuru	0.08	1.63	0.04	0.06
	Jomo Kenyatta	0.04	0.99	0.00	0.03
	Kisumu	0.06	1.22	0.04	0.04
Niger	Nkondi	0.09	1.45	-0.04	0.07
	Diffa	0.10	1.58	-0.02	0.08
	Mainesorao	0.10	1.50	-0.05	0.08
	Maradi	0.12	1.98	0.02	0.11
	Niamey	0.10	1.54	-0.05	0.07
	Tahoua	0.12	1.90	-0.07	0.10
	Tollabery	0.14	1.99	-0.09	0.10
	Zender	0.09	1.39	-0.05	0.07
Nigeria	Bauchi	0.05	0.93	0.00	0.04
	Gaya	0.08	1.36	-0.03	0.05
	Gusau	0.06	1.11	-0.01	0.05
	Kaduna	0.06	1.09	0.03	0.05
	Kano	0.06	1.03	0.03	0.05
	Katsina	0.07	1.32	-0.03	0.05
	Maidu	0.13	2.21	-0.09	0.10
	Nguru	0.09	1.42	-0.04	0.07
	Sokoto	0.10	1.62	-0.06	0.07
Senegal	Yelwa	0.06	1.04	0.01	0.04
	Saint Louis	0.22	4.29	-0.09	0.14
Tanzania	Dodoma	0.05	0.87	0.00	0.04
	Morogoro	0.07	1.71	0.05	0.06
	Songea	0.05	1.19	0.01	0.04
	Kilimanjaro	0.07	1.42	0.05	0.05
	Tabora	0.06	1.31	0.04	0.05

Table 4: Statistical Indexes for the evaluation of Valiantzas reference evapotranspiration equation at the individual weather stations in 10 countries covering humid and semiarid climatic conditions in the continental Africa.

limit the use of such resources. Therefore, the use of the Valiantzas' equation might be much easier in most developing countries for aforementioned reasons in addition to numerous intermediate calculations when using the Penman-Monteith equation and which are subjected to some errors that can be detrimental to irrigation scheduling and water management under agricultural, hydrological and environmental studies and projects. The Valiantzas' ETo equation could therefore be an alternative to the Penman-Monteith ETo equation when full climatic dataset is available. However, Penman-Monteith ETo equation should overall still be adopted and applied with caution when all the required parameters by Valiantzas equation are available.

Weather stations	RMSE (mm/day)	PE (%)	MBE (mm/day)	MAE (mm/day)
Ambohirsilaozana	0.06	1.72	0.01	0.05
Andapa	0.04	1.20	0.02	0.03
Ambohibary	0.08	2.36	0.01	0.07
Antsohihy	0.19	3.31	-0.07	0.14
Arrachart	0.14	2.64	-0.01	0.11
Amotsirabato	0.09	2.36	0.05	0.07
Tolagnaro	0.18	3.64	-0.07	0.12
Toamasina	0.05	1.44	0.04	0.04
Marovoay	0.20	3.66	-0.09	0.14
Maevatanana	0.20	3.60	-0.09	0.14
Maroantsetra	0.04	1.10	0.03	0.03
Morombe	0.22	3.81	-0.11	0.15
Morndava	0.11	2.20	0.01	0.08
Maintirano	0.12	2.31	-0.03	0.08
Mahanoro	0.05	1.51	0.01	0.04
Mananjary	0.05	1.54	0.00	0.04
lvato	0.09	2.35	0.01	0.07
Fianarantsoa	0.07	1.88	-0.01	0.05
Farafangana	0.07	1.88	-0.01	0.05
Beroroha	0.19	3.65	-0.07	0.12
Bekily	0.16	3.03	-0.04	0.11
Besalampy	0.12	2.32	-0.02	0.08
Average	0.11	2.43	-0.02	0.08

Table 5: Statistical Indexes for the evaluation of Valiantzas reference evapotranspiration equation at the individual weather stations in Madagascar (Grand Africa Island).

Conclusion

The performance of Valiantzas' reference evapotranspiration equation was evaluated under this study using 61 weather stations across 10 African countries covering humid, sub-humid and semiarid climates for the period of 1980-2012. The results showed good agreement between the Penman-Monteith and the Valiantzas' equation at all weather station with RMSE values that varied from 0.03 to 0.27 mm/day, percent error PE from 0.87 to 5.46%, MBE from -0.09 to 0.23 mm/day and MAE from 0.03 to 0.23 mm/day. The Valiantzas' ET₀ equation could be an alternative to the Penman-Monteith equation without calibration to local humid, sub-humid and semiarid climatic conditions.

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