Journal of Geoscience and Environment Protection, 2017, 5, 41-56
http://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Trend Analysis in Annual and Monthly Pan Evaporation and Pan Coefficient in the Context of Climate Change in Togo

Koffi Djaman[1*], Komlan Koudahe[2], Komla Kyky Ganyo[3]

[1]Department of Plant and Environmental Sciences, New Mexico State University, Agricultural Science Center at Farmington, Farmington, NM, USA
[2]ADA Consulting Africa, Lomé, Togo
[3]Institut Togolais de la Recherche Agronomique (ITRA), Lomé, Togo
Email: *kdjaman@nmsu.edu

How to cite this paper: Djaman, K., Koudahe, K. and Ganyo, K.K. (2017) Trend Analysis in Annual and Monthly Pan Evaporation and Pan Coefficient in the Context of Climate Change in Togo. *Journal of Geoscience and Environment Protection*, **5**, 41-56.
https://doi.org/10.4236/gep.2017.512003

Received: October 26, 2017
Accepted: December 3, 2017
Published: December 6, 2017

Abstract

Trend analysis was performed for the long-term measured pan evaporation and estimated pan coefficient for 4 meteorological stations during 1976-2011 in Togo. Measured pan evaporation was recorded at four meteorological stations in Togo for the global period of 1976 to 2011 at Lome, Tabligbo, Atakpame, and Sokode. ETo was estimated using the Penman-Monteith model. The Mann-Kendall test was used for trend analysis. The results showed that annual Epan varied from 1803 to 2081 mm at Lome, from 1294 to 1496 mm at Tabligbo, from 1605 to 1974 mm at Atakpame and from 1839 to 1990 mm at Sokode. It had significant increasing trend at Lome, Tabligbo, and Sokode and a negative trend at Atakpame. Monthly Epan varied from 137 to 197 mm at Lome, 89 to 149 mm at Tabligbo, 137 to 214 mm at Atakpame and from 137 to 190 mm at Sokode. At Lome, Kpan varied from 0.61 to 1.17 and averaged 0.81. At Tabligbo, Kpan varied from 0.59 to 0.98 and averaged 0.75. At Atakpame, Kpan varied from 0.5 to 2.0 and averaged 1.12. At Sokode, Kpan varied from 0.43 to 1.92 and averaged 0.98. Monthly mean Kpan is recommended for use in hydrological studies, irrigation scheduling and water management in Togo.

Keywords

Trend Analysis, Pan Evaporation, Annual, Monthly Kpan, Togo

1. Introduction

Reference evapotranspiration (ETo) is an important component of the hydrological cycle that needs to be considered during irrigation management options or watershed hydrology studies. Different ETo estimation methods have been investigated for several decades [1]-[7]; however, the existence of all dataset necessary for its estimation is usually fastidious to get because of lack of appropriate available equipment or a complete weather station, mostly in the developing countries similar to Togo. Pan evaporation method offers simple and low costly measurement of evaporation that can be converted to ETo through pan coefficient (Kpan) [8] [9]. One advantage of evaporation pans is that they incorporate all possible physical effects. Kpan is essentially a correction factor that depends on the prevailing upwind fetch distance, average daily wind speed, and relative humidity conditions associated with the sitting of the evaporation pan [1]. Allen *et al.* [10] indicated that evaporation pan provides a measurement of the integrated effect of radiation, temperature, humidity and wind on the evaporation from an open water surface. Pan evaporation incorporates therefore the effect of all climate variables, and is more accurate in estimating grass ET than empirical formulae that depend on fewer of the climatic factors. Chen and Robinson [11] reported that pan evaporation provides an integrated measurement of the effects of solar radiation, wind speed, air temperature and relative humidity. However, Intensity of Evaporation from pan is dependent on size, color and depth of pan [12]. Grass Evapotranspiration (ETo) is less than open water evaporation because of higher vegetation albedo, stomata closure at night, and the diffusion impedance of the stomata [13]. Kpan is therefore supposed to be less than unity. Several Kpan equations have been suggested using linear, nonlinear and indicator regression techniques or combinations. There are a few regression equations for predicting the Kpan values for FAO Class A pan placed in a short green cropped area based on the FAO-24 Kpan Table [8] [14]. Allen *et al.* [10] proposed Kpan equations for FAO Class A pan placed in a dry fallow area. Allen *et al.* [10] also proposed two Kpan equations for Colorado sunken pans surrounded by green and dry fetch conditions. Other Kpan equations had been proposed by Allen and Pruitt [15]. The most proper pan which is used is class A and it is set on a wooden bench about 10 cm above the ground surface for ease ventilation.

Although there are several models to estimate Kpan, few showed their precision and accuracy under different climate conditions and the assumptions made during the equations development might show some limitation in the applicability of the equations under all climate conditions. Appropriate calibration of Epan against ETo computed with the Penman-Monteith method is recommended [10]. Thus, most of the models have shown that Kpan value is highly dependent on surrounding conditions. Reliable estimate of ETo using Pan evaporation method depends on the accuracy of Kpan. The aims of this study were to: 1) perform trend analysis in Epan, 2) estimate monthly and annual average Kpan from the Penman Monteith estimated ETo and the measured pan evaporation and 3) propose Kpan that could be used in Togo for water management for resource sustainability and conservation.

2. Materials and Methods

The study was conducted in Togo where four weather stations at Lome (6˚9'56''N, 1˚15'16.24''E, elevation 22 m), Tabligbo (6˚34'59''N, 1˚30'00''E, Elevation: 76 m), Atakpame (7˚31'37''N, 1˚7'36''E Elevation 250 m), and Sokode (8˚58'59''N, 1˚07'59''E, Elevation: 417 m) were selected for the reliability and the long term dataset without missing data during the study period. A record of monthly average climatic parameters including, air maximum and minimum temperature, minimum and maximum relative humidity, wind speed, solar radiation, were used to estimate monthly evapotranspiration. Class A pan evaporation values were also recorded for the study period that covered 1981-2010 at Lome, 1991-2002 at Tabligbo, 1991-2011 at Atakpame, and 1976-2011 at Sokode.

2.1. Reference Evapotranspiration Estimation

Daily grass-reference ET (ETo) was computed using the standardized ASCE form of the Penman-Monteith (ASCE-EWRI PM) equation [5]. The Penman-Monteith reference evapotranspiration equation with fixed stomatal resistance values for grass surface is:

$$\mathrm{ETo} = \frac{0.408\Delta(\mathrm{Rn} - \mathrm{G}) + \gamma \mathrm{Cn}\ \mathrm{u2}/(\mathrm{T} + 273)(\mathrm{es} - \mathrm{ea})}{\Delta + \gamma(1 + \mathrm{Cd}\ \mathrm{u2})} \quad (1)$$

where: ETo is the reference evapotranspiration (mm/day), Δ is the slope of saturation vapor pressure versus air temperature curve ($kPa \cdot {}^\circ C^{-1}$), Rn = net radiation at the crop surface ($MJ \cdot m^{-2} \cdot d^{-1}$), G = soil heat flux density at the soil surface ($MJ \cdot m^{-2} \cdot d^{-1}$), T = mean daily air temperature at 1.5 - 2.5 m height (˚C), u2 = mean daily wind speed at 2 m height ($m \cdot s^{-1}$), es = the saturation vapor pressure (kPa), ea = the actual vapor pressure (kPa), es-ea = saturation vapor pressure deficit (kPa), γ = psychrometric constant ($kPa \cdot {}^\circ C^{-1}$), Cn = 900˚C mm s3 $Mg^{-1} \cdot d^{-1}$ for grass and 1600˚C mm s3 $Mg^{-1} \cdot d^{-1}$ for alfalfa, Cd = 0.34 $s \cdot m^{-1}$ for grass and 0.38 $s \cdot m^{-1}$ for alfalfa, γ is the psychrometric constant ($kPa \cdot {}^\circ C^{-1}$). All parameters necessary for computing ETo were computed according the procedure developed in FAO-56 by Allen *et al.* (1998).

2.2. Pan Coefficient Estimations

Pan coefficient was estimated as the ratio of reference evapotranspiration over Pan evaporation. Reference evapotranspiration was estimated using the standardized ASCE form of the Penman-Monteith (ASCE-EWRI PM)

$$\mathrm{Kpan} = \frac{\mathrm{ETo}}{\mathrm{Epan}} \quad (2)$$

where ETo is the reference crop evapotranspiration ($mm \cdot day^{-1}$), Epan the measured class A pan evaporation ($mm \cdot day^{-1}$) and Kpan the pan coefficient [8].

2.3. Temporal Trends Analysis

For the analysis of temporal trend in annual and monthly pan evaporation and pan coefficient, the Mann-Kendall test [16] [17], a nonparametric method for trend analysis, was used. It should be noted that the Mann-Kendall test statistic is non-dimensional, and it does not offer any quantification of the scale of the trend in the units of the time series under study, but is rather a measure of the correlation of a variable with time and, as such, simply offers information as to the direction and a measure of the significance of observed trends. The Mann-Kendall test statistic S is given as follows:

$$S = \sum_{j=1}^{n-1} \sum_{i=j+1}^{n} \operatorname{sign}\left(x_i - x_j\right) \tag{3}$$

where x_i is the data value at time i, n is the length of the dataset and sign( ) is the sign function which can be computed as:

$$\operatorname{sign}\left(x_i - x_j\right) = \begin{cases} 1 & \text{if } \left(x_i - x_j\right) > 0 \\ 0 & \text{if } \left(x_i - x_j\right) = 0 \\ -1 & \text{if } \left(x_i - x_j\right) < 0 \end{cases} \tag{4}$$

For $n > 10$, the test statistic Z approximately follows a standard normal distribution:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases} \tag{5}$$

in which $Var(S)$ is the variance of statistic S.

A positive value of Z indicates that there is an increasing trend, and a negative value indicates a decreasing trend. The null hypothesis, Ho, that there is no trend in the records is either accepted or rejected depending on whether the computed Z statistics is less than or more than the critical value of Z statistics obtained from the normal distribution table at the 5% significance level [18]. If $|Z| > Z_{(1-\alpha/2)}$, the null hypothesis of no autocorrelation and trend in dataset is rejected, in which $Z_{(1-\alpha/2)}$ is corresponding to the normal distribution with α being the significance level.

If the data has a trend, the magnitude of trend can be denoted by trend slope ß [19]:

$$\beta = \text{Median}\left(\frac{x_i - x_j}{i - j}\right), \quad \forall j < i \tag{6}$$

where x_i and x_j are data values at time t_i and t_j ($i > j$), respectively.

3. Results and Discussion

3.1. Trend in Annual Pan Evaporation

Pan evaporation is an indication of the evaporative demand of the atmosphere resulting from the vapor pressure deficit of the air. Pan evaporation varied with time and had different tendency depending on location. Pan evaporation varied from 1803 to 2081 mm at Lome, from 1294 to 1496 mm at Tabligbo, from 1605 to 1974 mm at Atakpame and from 1839 to 1990 mm at Sokode (Figure 1). It had significant increasing trend at Lome (Z = 2.43) with Sen's slope of 3.7 mm/year (Table 1). Pan evaporation increased with years at Tabligbo, however, the Mann-Kendall test revealed non-significant increasing trend with Sen's slope of 3.9 mm/year. Epan increased significantly (p < 0.001) at the rate of 2.1 mm/year from 1976 to 2011 at Sokode. In contrast to the three locations, Atakpame obtained a decreasing pan evaporation trend (Sen's slope = −3.6 mm/year). Pan evaporation's increase rate was the highest at Tabligbo and the lowest rate was registered at Sokode (Table 1). Brusque drop in pan evaporation was noticed in 1999 at Lome and Tabligbo while similar drop was observed in 2009 at Atakpame and 1994 at Sokode. During the study period uniformed to 30 year period, there were increases of 110, 118 and 64 mm in pan evaporation at

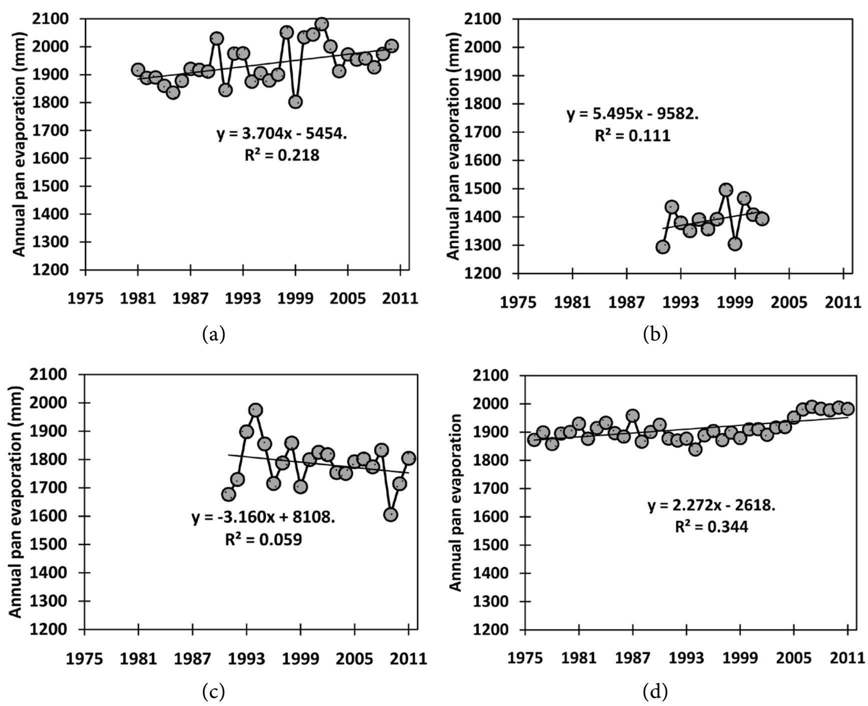


Figure 1. Trend in annual evaporation at (a) Lome; (b) Tabligbo; (c) Atakpame and (d) Sokode.

Table 1. Mann-Kendall test of the annual pan evaporation trends.

Location	Number of years	Test Z	Significance.	Sen's slope
Lome	30	2.43	*	3.670
Tabligbo	12	1.30	n.s	3.922
Atakpame	21	−0.63	n.s	−3.612
Sokode	36	3.42	***	2.136

n.s. Non-significant. *Significant at 1%. ***Significant at 0.01%.

Lome, Tabligbo and Sokode, respectively, while there was a decrease of 108 mm in pan evaporation at Atakpame. The increase in evaporation at 75% of the research stations is not surprising because one of the expected consequences of global warming is an increase in the rate of evaporation due to the increased air temperature [20]. Koudahe *et al.* [21] also found increasing Standardized Anomaly Index in the same location due to an increasing trend in air temperature. Increasing trend in pan evaporation has been reported in West Africa [22]. Similar trend in evaporation was also reported in Israel's central coastal plain [23], northeast of Brazil [24]. Global temperature is increasing due to increasing concentration of Greenhouse gases and an expected consequence is increase in non-water limited evaporation rates [25]. The decreased in evaporation at Atakpame is expressed as pan evaporation paradox [26]. The decreases in vapor pressure deficit, wind speed and solar radiation which leads to decreasing rates of Epan explains the paradox [27]. Depending on moisture availability in the region around the pan, these ETo and Epan may be nearly identical or very different, but they are nevertheless related and to understand the changes in ET-pan, one must look at changes in actual evapotranspiration (ETa), or at the variables influencing ETa [28]. In fact, Djaman and Ganyo [29] reported the influence of air temperature, mostly maximum air temperature and the thermal amplitude (Tmax-tmin) on the reference evapotranspiration at Lome, Tabligbo and Sokode. In the light of Hobbins *et al.* [28], attribution of trends in pan evaporation might be due to changes in air temperature, relative humidity and thermal amplitude through the vapor pressure deficit expressing the evaporative demand of the environing air. Whenever Graham *et al.* [30] argued that pan evaporation is not directly sensitive to changes in average air temperature, the results of this study are supported by Yin *et al.* [31] who stated that water evaporation is more sensitive to relative humidity than to other climatic variables according to the physical theory, and a small change in relative humidity could result in a large change in potential evaporation. The increase in pan evaporation is synonym of increase in irrigation water demand. Similar results were found in Benin by Obada *et al.* [32] who revealed an increase in annual ETo under Representative Concentration Pathways (RCP4.5 and RCP8.5) scenarios. Agricultural and environment actors should plan for using more water in food production and recreation parks in Togo. However, deficit irrigation strategies are promising and food can be produced at 75% ETo with no significant yield difference with the full irrigated crop [33]. Crop growing seasons should be adjusted as proposed by Djaman and Ganyo [29] to increase water productivity under rainfed systems in Togo where about 90% of crops are produced without irrigation.

3.2. Trends in Monthly Pan Evaporation

The monthly average pan evaporation at the four sites is presented in **Figure 2** and the trends analysis results are summarized in **Table 2**. Monthly Epan varied from 137 to 197 mm at Lome, 89 to 149 mm at Tabligbo, 137 to 214 mm at

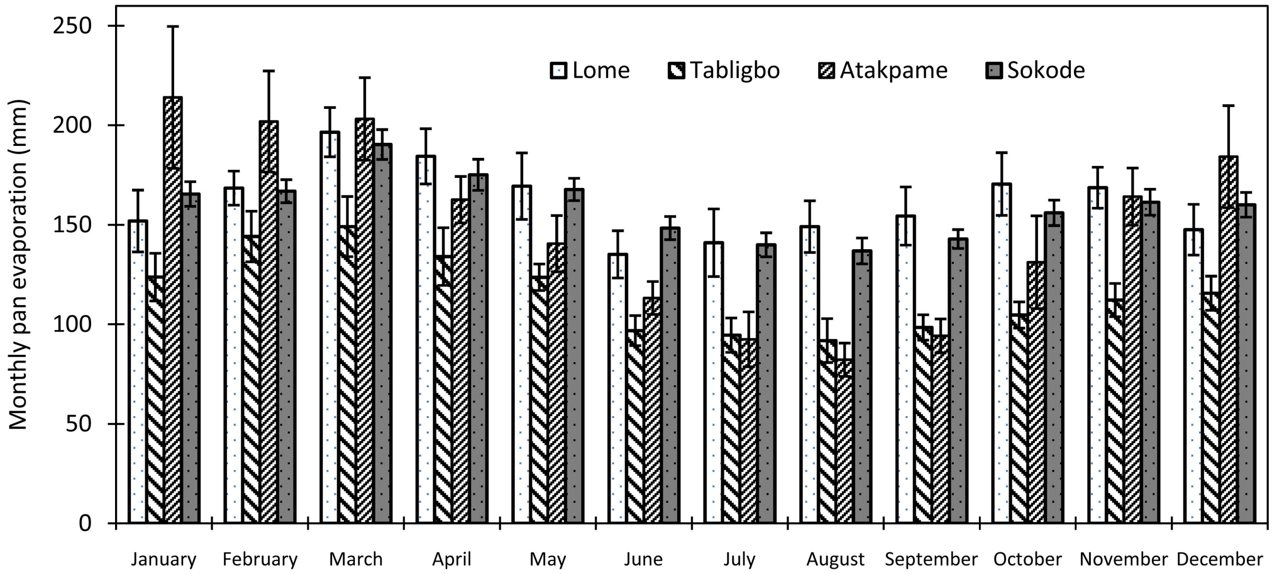


Figure 2. Monthly average pan evaporation at Lome, Tabligbo, Atakpame and Sokode.

Table 2. Mann-Kendall test of the monthly pan evaporation trends at Lome, Tablogbo, Atakpame and Sokode.

Time series	Lome			Tabligbo			Atakpame			Sokode		
	Test Z	Signif.	Sen's slope	Test Z	Signif.	Sen's slope	Test Z	Signif.	Sen's slope	Test Z	Signif.	Sen's slope
January	0.61	n.s.	0.253	−0.48	n.s.	−0.762	1.06	n.s.	1.405	1.4	n.s.	0.149
February	1.23	n.s.	0.257	0.34	n.s.	0.556	−0.73	n.s.	−0.839	1.24	n.s.	0.109
March	−0.25	n.s.	−0.071	1.71	+	1.542	−0.94	n.s.	−0.789	2.77	**	0.272
April	0.62	n.s.	0.180	−0.55	n.s.	−0.123	0.36	n.s.	0.228	0.45	n.s.	0.065
May	1.55	n.s.	0.656	0.89	n.s.	0.629	−1.12	n.s.	−0.828	2.23	*	0.2
June	−0.21	n.s.	−0.094	0.07	n.s.	0.2	−1.99	*	−0.483	2.52	*	0.25
July	2.14	*	0.817	0.89	n.s.	1.208	0.18	n.s.	0.088	2.37	*	0.274
August	0.00	n.s.	0.000	0.34	n.s.	0.608	−2.2	*	−0.682	0.93	n.s.	0.078
September	0.09	n.s.	0.028	0.07	n.s.	0.194	−0.88	n.s.	−0.261	1.16	n.s.	0.082
October	0.73	n.s.	0.230	0.07	n.s.	0.1	−2.63	**	−1.128	1.69	+	0.188
November	2.37	*	0.560	0.21	n.s.	0.408	−0.63	n.s.	−0.48	2.93	**	0.304
December	4.46	***	1.150	1.03	n.s.	0.989	1.36	n.s.	1.213	3.9	***	0.375

n.s. Non-significant. +Significant at 5%. *Significant at 1%. **Significant at 0.1%. ***Significant at 0.01%.

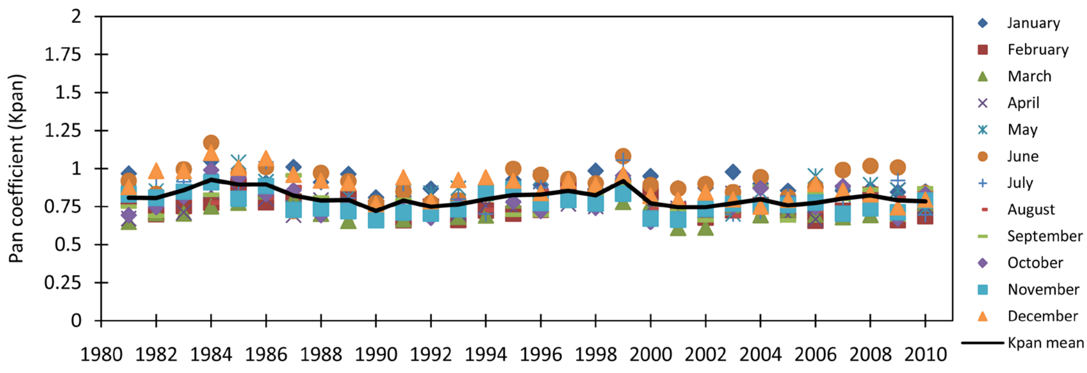
Atakpame and from 137 to 190 mm at Sokode. Across the year, Tabligbo obtained the lowest monthly average Epan. Overall monthly Epan decreased from January to August and increased thereafter up to December with the maximum values registered in March (Figure 2). The trend in Epan follows the trend in air temperature. In fact, the period of November to March coincides with the dry season across the country with extreme temperatures in March. In addition, a weaker dry and hot northeasterly Harmattan which is the dusty trade wind-blowing off the Sahara Desert across the Gulf of Guinea and the Cape Verde Islands increased water evaporation. During the dry season, from December to March, temperatures are cool at night and very hot during the day. Many small streams dry up, many big rivers shrink, and vegetation senescence is observed. The Harmattan season typically begins late November by the north side of the country and can persist until February or March. Epan decreased with rainy season establishment and it is more reduced during the monsoon period late July-August. During the monsoon, the temperatures are low and it can be extremely cold from the evening to early morning and there is attenuation of solar radiation by the monsoon clouds and hence reduces air temperature and evaporation from water bodies. Oguntunde *et al.* [34] reported that Epan and solar radiation decreased significantly in all the months ($p < 0.01$) and the reduction ranged from 5.1% *per* decade in March to 9.3% *per* decade in August in Nigeria. Similarly Badarinath *et al.* [35] found that the decline in solar radiation over Hyderabad in India was more intense during the period 1993-2005 compared to 1980s and attributed this to an increase in cloudiness mainly in monsoon.

The Mann-Kendall test revealed increasing trend in monthly Epan except in March and June when Epan non-significantly decreased with year at Lome. Epan significantly increased during July, November and December with more severe emphasis during December ($p < 0.0001$). At Lome, Epan was stable in August and the Sen's slope was zero. At Tabligbo, whenever the Epan has increasing trend about 83% of the year, the change in Epan was significant only in March. ($p < 0.05$). At Atakpame, Epan has decreasing trend during February-March, May-June and August-November (**Table 2**). The decreasing change in Epan was significant only in June, August and highly significant in October. The increasing trend observed during the rest of the months was not significant. The Sen's slopes presented in **Table 2** represent the rate of change in Epan. At Sokode, Epan had an increasing trend during all the months however; the trend is significant during 58% of months (**Table 2**). At this location, increasing trend in monthly Epan was very highly significant in December ($p < 0.0001$) and highly significant in November and March ($p < 0.001$).

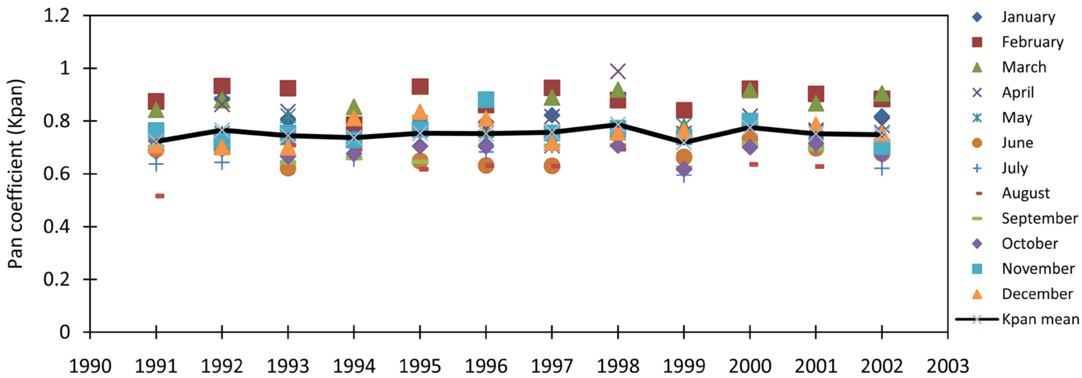
3.3. Trend in Annual Mean Kpan

Kpan showed monthly and annual variation at all the sites (**Figure 3**). At Lome, Kpan varied from 0.61 in April 2001 to 1.17 in June 1984 with long term average Kpan of 0.81. At Tabligbo, Kpan varied from 0.59 in July 1999 to 0.98 in April 1998 with annual mean Kpan of 0.75. At Atakpame, Kpan varied from 0.5 in January 2008 to 2.00 in 2007 with long term average of 1.12. At Sokode, Pan coefficient varied from 0.43 in July 2005 to 1.92 in February 1997 with annual average Kpan equal to 0.98. Kpan varied therefore with location, month and year.

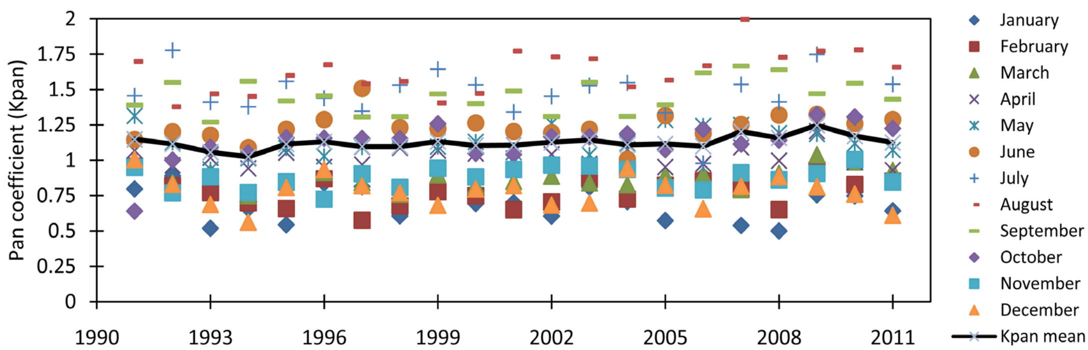
The trend analysis revealed significant decreasing trend in Kpan at Lome with Sen's slope of −0.002 that represented decrease of 0.06 during 30 years. Annual average Kpan increased from 0.8 in 1981 to 0.9 in 1984 and decreased thereafter up to 0.70 in October 1990. The trend changed from 1990 to 1999 and the an-



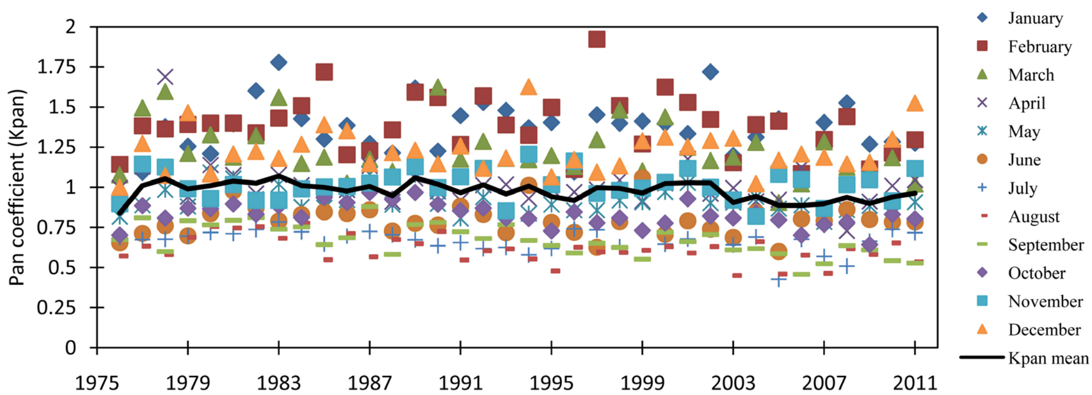
(a)



(b)



(c)



(d)

Figure 3. Trends in long term Kpan at (a) Lome; (b) Tabligbo; (c) Atakpame and (d) Sokode.

nual mean Kpan reached its maximum value of 0.92; decreased within the three following years and became more stable thereafter with non-significant increasing trend (**Figure 3(a)**). At Tabligbo the study period was shorter (1991-2002) and the annual Kpan showed an increasing trend (Sen's slope = 0.002) however, the trend analysis revealed non-significant increasing trend in the annual Kpan (**Table 3**). Kpan at Atakpame decreased from 1.15 in 1991 to 1.02 in 1994 and thereafter was more stable but showed increasing tendency from 2006 to 2009 (**Figure 3(c)**). Overall, Kpan significantly increased from 1991 to 2011 and the increase in Kpan during the 21 year period was 0.084. At sokode, annual mean Kpan varied from 1.02 to 1.07 and averaged 0.98 (**Figure 3(d)**). There was highly significant decrease in Kpan during the 1976-2011 period ($p < 0.001$) that represented 0.108 reduction in Kpan over the 36 years period. The results of this study are close to the estimates of [36] who reported annual Kpan of 0.78 for the warm arid climate in Iran. At the reservoir of the Saveh Dam in Iran Kpan varied between 0.48 for 2000 and 0.66 for 1998 and averaged of 0.55 [37]. Spatio-temporally averaged Kpan values for the Loess plateau (China) varied from 0.44 in April to 0.65 in late summer [38]. In Canada, Kpan coefficients varied from 0.78 to 0.94 [39]. For US Class A pan over a seven year period, for annual totals, the pan coefficient was 0.7, with a strong monthly variation in the pan coefficients which varied between 0.47 and 1.18 [40]. The variability in annual mean Kpan revealed that it might be better to use monthly mean Kpan for water resources management accuracy and sustainability.

Table 3. Z statistics and Sen's slope for long term monthly Kpan at Lome, Tabligbo, Atakpame and Sokode.

Month	Lome				Tabligbo				Atakpame				Sokode			
	Kpan mean	Test Z	Signif.	Sen's slope	Kpan mean	Test Z	Signif.	Sen's slope	Kpan mean	Test Z	Signif.	Sen's slope	Kpan mean	Test Z	Signif.	Sen's slope
January	0.886	−1.14	n.s.	−0.0023	0.780	−0.21	n.s.	−0.0013	0.6983	−0.82	n.s.	−0.0049	1.366	0.31	n.s.	0.0008
February	0.753	−1.71	+	−0.0026	0.889	−0.48	n.s.	−0.0013	0.7740	0.82	n.s.	0.0045	1.385	−0.43	n.s.	−0.0019
March	0.727	−0.21	n.s.	−0.0003	0.846	1.30	n.s.	0.0064	0.8782	1.24	n.s.	0.0040	1.227	−1.65	+	−0.0030
April	0.762	0.04	n.s.	0.0001	0.809	−0.21	n.s.	−0.0011	1.0199	0.21	n.s.	0.0005	1.011	−2.22	*	−0.0041
May	0.844	−1.18	n.s.	−0.0023	0.764	−0.21	n.s.	−0.0003	1.1342	1.24	n.s.	0.0061	0.914	−1.65	+	−0.0017
June	0.913	0.04	n.s.	0.0001	0.684	0.21	n.s.	0.0021	1.2343	1.96	*	0.0051	0.793	0.00	n.s.	−0.0001
July	0.819	−1.89	+	−0.0041	0.684	0.34	n.s.	0.0046	1.4663	−0.45	n.s.	−0.0017	0.676	−1.62	n.s.	−0.0020
August	0.776	−0.93	n.s.	−0.0014	0.656	0.62	n.s.	0.0021	1.6267	2.57	*	0.0148	0.615	−2.24	*	−0.0036
September	0.781	−0.57	n.s.	−0.0013	0.687	0.48	n.s.	0.0012	1.4548	1.72	+	0.0072	0.672	−4.18	***	−0.0065
October	0.780	−0.43	n.s.	−0.0007	0.694	−0.07	n.s.	−0.0005	1.1274	2.81	**	0.0106	0.830	−2.78	**	−0.0036
November	0.768	−1.68	+	−0.0028	0.763	0.16	n.s.	0.0012	0.8769	1.00	n.s.	0.0041	1.014	−0.09	n.s.	−0.0001
December	0.888	−3.93	***	−0.0075	0.758	0.62	n.s.	0.0051	0.7812	−0.82	n.s.	−0.0022	1.224	0.06	n.s.	0.0003

n.s. Non-significant. +Significant at 5%. *Significant at 1%. **Significant at 0.1%. ***Significant at 0.01%.

3.4. Trend in Monthly Kpan

Kpan varied with months and locations (**Figure 4**). The monthly mean Kpan, the Mann-Kendall statistics and Sen's slopes are summarized in **Table 3**. At Lome, monthly Kpan varied from 0.73 (March) to 0.913 (June) and had a decreasing trends except in April and June however, the decreasing trend was significant for February, July and November ($p < 0.05$) and highly significant in December ($p < 0.0001$) with the highest decreasing rate of −0.075. At Tabligbo, Kpan was much lower and varied from 0.66 in August to 0.89 in February. Kpan decreased with the establishment of the rainfall and was at its lowest value during the monsoon in August and it increased thereafter. Different trends were obtained at Tabligbo however there was no significant increase or decrease in the monthly Kpan. At Atakpame, Kpan increased progressively from 0.70 in January to 1.63 in August and decreased up to 0.78 in December (**Figure 4**). The highest values observed at Atakpame might be relevant to the particular topography and aspect of the site that could influence reference evapotranspiration, pan evaporation and finally Kpan. The Mann-Kendall test showed non-significant decreasing trend in Kpan in January, July and December while positive trend was noticed during the rest of the months with significance in June, August and September. The highest changing rate in Kpan was registered in August. Opposite Kpan tendency to Atakpame was observed at Sokode. Kpan decreased from 1.37 in January to 0.62 in August and it increased thereafter up to 1.22 in December. The monsoon and Harmattan both impacted the Kpan.

Epan decreased with rainy season establishment and it more reduced during the monsoon period late July-August because of monsoon clouds and reduction in solar radiation [34]. The results of our study are in agreement with Kaboosi [41] who reported Kpan decreasing from higher values of about 1.5 in December to lower one of 0.6 in June and that increased thereafter. Sepaskhah and Kamgar-Haghighi [42] reported that Kpan varied from 0.37 to 0.84 at Saffron in Iran with registered lowest Kpan in May and the highest Kpan in January. Lapworth [43] also found a strong monthly variation in the pan coefficients which varied between 0.47 and 1.18 for the US Class A pan. Similar to our study, Chen *et al.*

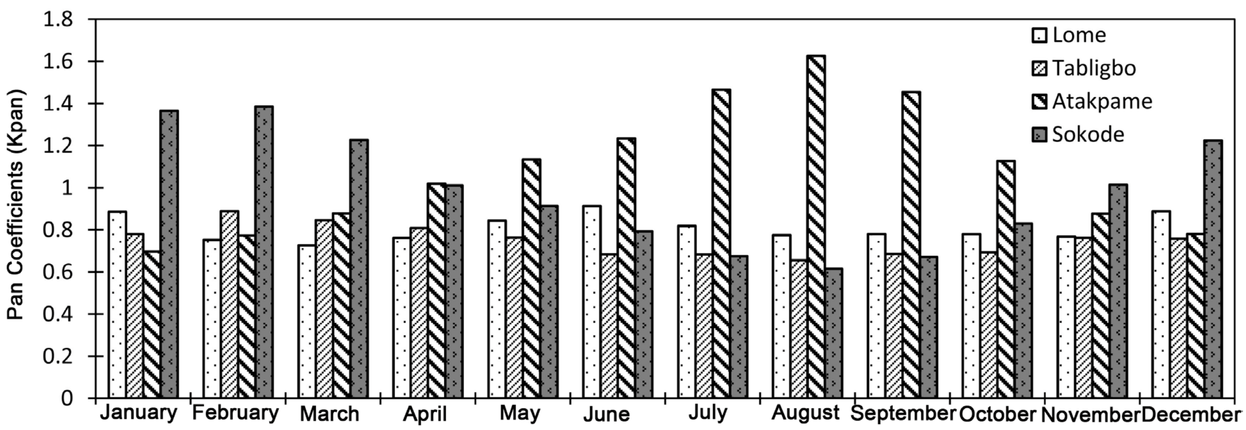
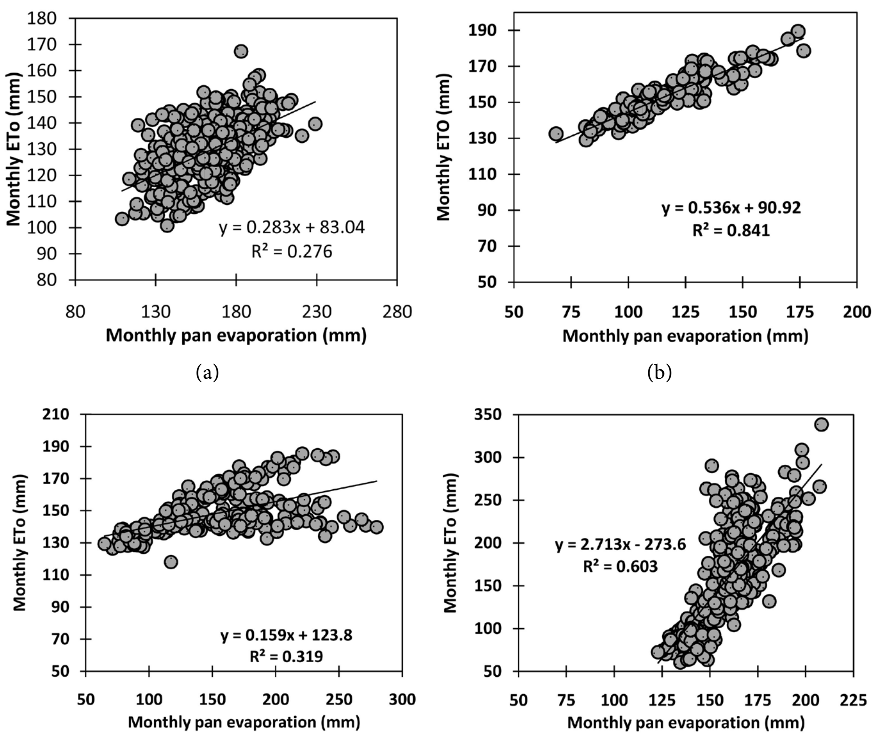


Figure 4. Monthly average Kpan at Lome, Tabligbo, Atakpame and Sokode.

[44] reported that average Kpan value laid between 0.6 and 0.8 with a seasonal and regional difference. The high Kpan values obtained at Atakpame were similar to the one observed by Koerselman and Beltman [45] who have suggested different values ranging from 0.67 to 1.7. The relationships between monthly Epan and monthly ETo (**Figure 5**) revealed that there is no annual single Kpan that could be used at any location. Due to the high dependence of Kpan with months, the monthly mean Kpan values presented in **Table 3** are recommended in place of annual mean Kpan for agricultural water management in Togo.

4. Conclusion

In this study, we performed the trend analysis in measured pan evaporation and estimated pan coefficient for four meteorological sites in Togo: Lome, Tabligbo, Atakpame and Sokode for the global period of 1976-2011. The results showed the dependence of pan evaporation on location. Annual pan evaporation varied from 1803 to 2081 mm at Lome, from 1294 to 1496 mm at Tabligbo, from 1605 to 1974 mm at Atakpame and from 1839 to 1990 mm at Sokode. A significant increasing trend of Epan was obtained at Lome, Tabligbo, and Sokode while a negative trend was registered at Atakpame. Monthly Epan varied from 137 to 197 mm at Lome, 89 to 149 mm at Tabligbo, 137 to 214 mm at Atakpame and from 137 to 190 mm at Sokode. Epan was influenced by the Harmattan and the monsoon seasons. The pan coefficient, Kpan varies both regionally and seaso-



(c) (d)

Figure 5. Relationship between monthly ETo and monthly pan evaporation at (a) Lome; (b) Tabligbo; (c) Atakpame and (d) Sokode.

nally. Kpan showed monthly and annual variation at all the sites. Kpan varied from 0.61 to 1.17 at Lome with long-term average Kpan of 0.81. At Tabligbo, Kpan was within the range of 0.59 - 0.98 and averaged 0.75. At Atakpame, Kpan varied from 0.5 to 2.0 with an average of 1.12. At Sokode, Kpan varied from 0.43 to 1.92 with annual average Kpan of 0.98. Kpan was high during the Harmattan season at Lome, Tabligbo and Sokode and it was at its lowest value during the monsoon when solar radiation is attenuated and the temperatures are low with highly relative humidity. Monthly mean Kpan is recommended for use instead of annual mean Kpan due to the highly dependence of Kpan on month and the seasonal patterns in Kpan. It should be important to carry out a sensitivity study of Kpan to all climate variables in order to determine their relative influence on the variability of Kpan. Similar study should be also conducted for all the agroecological zones of the country for accurate and spatial Kpan estimates.

References

[1] Doorenbos, J. and Pruitt, W.O. (1977) Guidelines for Predicting Crop Water Requirements. FAO Irrigation and Drainage. Paper, 24, FAO, Rome.

[2] Watson, I. and Burnett, A.D. (1995) Hydrology: An Environmental Approach. CRC Press, Boca Raton.

[3] Thornthwaite, C.W. (1948) An Approach towards a Rational Classification of Climate. *Geographical Revue,* 38.

[4] Hargreaves, G.L. and Samanim, Z.A. (1985) Reference Evapotranspiration from Temperature. *Applied Engineering in Agriculture*, **1**, 96-99. https://doi.org/10.13031/2013.26773

[5] ASCE-EWRI (2005) The ASCE Standardized Reference Evapotranspiration Equation. In: Allen, R.G., Walter, I.A., Elliot, R.L., *et al*., Eds., *Standardization of Reference Evapotranspiration Task Committee Final Report*, Environmental and Water Resources Institute (EWRI) of the American Society of Civil, Engineers, ASCE, American Society of Civil Engineers (ASCE), Reston, 213 p.

[6] Irmak, A. and Irmak, S. (2008) Reference and Crop Evapotranspiration in South Central Nebraska. II: Measurement and Estimation of Actual Evapotranspiration. *Journal of Irrigation and Drainage Engineering*, **134**, 700-715. https://doi.org/10.1061/(ASCE)0733-9437(2008)134:6(700)

[7] Djaman, K. and Irmak, S. (2013) Actual Crop Evapotranspiration and Alfalfa- and Grass-Reference Crop Coefficients of Maize under Full and Limited Irrigation and Rainfed Conditions. *Journal of Irrigation and Drainage Engineering*, **139**, 433-446. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000559

[8] Snyder, R.L. (1992) Equation for Evaporation Pan to Evapotranspiration Conversions. *Journal of Irrigation and Drainage Engineering*, **118**, 977-980. https://doi.org/10.1061/(ASCE)0733-9437(1992)118:6(977)

[9] Martínez-Alvarez, V., González-Real, M.M., Baille, A. and Molina Martínez, J.M., (2007) A Novel Approach for Estimating the Pan Coefficient of Irrigation Water Reservoirs Application to South Eastern Spain. *Agricultural Water Management*, **92**, 29-40. https://doi.org/10.1016/j.agwat.2007.04.011

[10] Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998) Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper No. 56, FAO, Rome.

[11] Chen, F. and Robinson, P.J. (2009) Estimating Reference Crop Evapotranspiration with ET Gages. *Journal of Irrigation and Drainage Engineering*, **135**, 335-342. https://doi.org/10.1061/(ASCE)IR.1943-4774.0000005

[12] Alizadeh, A. (2002) Irrigation System Design. 8th Edition (Revised), Ferdowsi University Press, 655 p. (In Persian)

[13] Penman, H.L. and Schofield, R.K. (1951) Some Physical Aspects of Asimilation and Transpiration. *Symposia of the Society for Experimental Biology*, **5**, 15-129.

[14] Raghuwanshi, N.S. and Wallender, W.W. (1998) Converting from Pan Evaporation to Evapotranspiration. *Journal of Irrigation and Drainage Engineering*, **124**, 275-277. https://doi.org/10.1061/(ASCE)0733-9437(1998)124:5(275)

[15] Allen, R.G. and Pruitt, W.O. (1991) FAO-24 Reference Evapotranspiration Factors. *Journal of Irrigation and Drainage Engineering*, **117**, 758-773. https://doi.org/10.1061/(ASCE)0733-9437(1991)117:5(758)

[16] Mann, H.B. (1945) Non-Parametric Test against Trend. *Econometrica*, **13**, 245-259. https://doi.org/10.2307/1907187

[17] Kendall, M.G. (1975) Rank Correlation Methods. 4th Edition, Charles Griffin, London.

[18] Some'e, B.S., Ezani, A. and Tabari, H. (2013) Spatio-Temporal Trends of Aridity Index in Arid and Semi-Arid Regions of Iran. *Theoretical and Applied Climatology*, **111**, 149-160. https://doi.org/10.1007/s00704-012-0650-x

[19] Sen, P.K. (1968) Estimates of the Regression Coefficient Based on Kendall's TAU. *Journal of the American Statistical Association*, **63**, 1379-1389. https://doi.org/10.1080/01621459.1968.10480934

[20] Stocker, T.F., Clarke, G.K.C., Le Treut, H., Lindzen, R.S., Meleshko, V.P., Mugara, R.K., Palmer, T.N., Pierrehumbert, R.T., Sellers, P.J., Trenberth, K.E. and Willebrand, J. (2001) Physical Climate Processes and Feedbacks. In: Houghton, J.T., Ding, Y., Griggs, D.J., Nouger, M., van der Linden, P.J., Dai, X., Maskell, K. and Johnson, C.A., Eds., *Climate Change* 2001: *The Scientific Basis*, Cambridge University Press, Cambridge, 417-470.

[21] Koudahe, K., Adewumi, J.K., Awokola, O.S., Adekunle, A.A. and Djaman, K. (2017) Trend Analysis in Standardized Precipitation Index and Standardized Anomaly Index in the Context of Climate Change in Southern Togo. *Atmospheric and Climate Sciences*, **7**, 401-423. https://doi.org/10.4236/acs.2017.74030

[22] Oguntunde, P.G., Friesen, J., van de Giesen, N. and Savenije, H.H.G. (2006) Hydroclimatology of the Volta River Basin in West Africa: Trends and Variability from 1901 to 2002. *Physics and Chemistry of the Earth*, **31**, 1180-1188. https://doi.org/10.1016/j.pce.2006.02.062

[23] Cohen, S., Ianetz, A. and Stanhill, G. (2002) Evaporative Climate Changes at Bet-Dagan Israel, 1964-1998. *Agricultural and Forest Meteorology*, **111**, 83-91. https://doi.org/10.1016/S0168-1923(02)00016-3

[24] da Silva, V.de.P.R. (2004) On Climate Variability in Northeast of Brazil. *Journal of Arid Environments*, **58**, 575-596. https://doi.org/10.1016/j.jaridenv.2003.12.002

[25] Liu, X.M., Luo, Y.Z., Zhang, D., Zhang, M.H. and Liu, C.M. (2011) Recent Changes in Pan-Evaporation Dynamics in China. *Geophysical Research Letters*, **38**, L13404. https://doi.org/10.1029/2011GL047929

[26] Brutsaert, W. and Parlange, M.B. (1998) Hydrologic Cycle Explains the Evaporation Paradox. *Nature*, **396**, 30. https://doi.org/10.1038/23845

[27] Roderick, M.L., Hobbins, M.T. and Farquhar, G.D. (2009) Pan Evaporation Trends

and the Terrestrial Water Balance. I. Principles and Observations. *Geography Compass*, **3**, 746-760. https://doi.org/10.1111/j.1749-8198.2008.00213.x

[28] Hobbins, M.T., Ramírez, J.A. and Brown, T.C. (2004) Trends in Pan Evaporation and Actual Evapotranspiration across the Conterminous US: Paradoxical or Complementary. *Geophysical Research Letters*, **31**, L13503. https://doi.org/10.1029/2004GL019846

[29] Djaman, K. and Ganyo, K.K. (2014) Trend Analysis in Reference Evapotranspiration and Aridity Index in the Context of Climate Change in Togo. *Journal of Water and Climate Change*, **4**, 848-864.

[30] Gifford, R.M., Farquhar, G.D., Roderick, M.L. and Nicholls, N. (2004) Pan Evaporation: An Example of the Detection and Attribution of Trend in Climate Variables. *Proceedings of a Workshop*, Shine Dome, Australian Academy of Science, Canberra, 22-23 November 2004, 20-21.

[31] Yin, Y.H., Wu, S.H., Chen, G. and Dai, E.F. (2010) Attribution Analyses of Potential Evapotranspiration Changes in China Since the 1960s. *Theoretical and Applied Climatology*, **101**, 19-28. https://doi.org/10.1007/s00704-009-0197-7

[32] Obada, E., Alamou, A.E., Chabi, A., Zandagba, J. and Afouda, A. (2017) Trends and Changes in Recent and Future Penman-Monteith Potential Evapotranspiration in Benin (West Africa). *Hydrology*, **4**, 38. https://doi.org/10.3390/hydrology4030038

[33] Djaman, K., Irmak, S., Rathje, W.R., Martin, D.L. and Eisenhauer, D.E. (2013) Maize Evapotranspiration, Yield Production Function, Biomass, Grain Yield, Harvest Index, and Yield Response Factors under Full and Limited Irrigation. *Transactions of the ASABE*, **56**, 273-293.

[34] Oguntunde, P.G., Abiodun, B.J., Olukunle, O.J. and Olufayo, A.A. (2011) Trends and Variability in Pan Evaporation and Other Climatic Variables at Ibadan, Nigeria, 1973-2008. *Meteorological Applications*, **19**, 464-472.

[35] Badarinath, K.V.S., Sharma, A.R., Kaskaoutis, D.G., Kharol, S.K. and Kambezidis, H.D. (2010) Solar Dimming over Tropical Urban Region of Hyderabad, India: Effect of Increased Cloudiness and Increased Anthropogenic Aerosols. *Journal of Geophysical Research*, **115**, D21208. https://doi.org/10.1029/2009JD013694

[36] Sabziparvar, A.A., Tabari, H., Aeini, A. and Ghafouri, M. (2010) Evaluation of Class A Pan Coefficient Models for Estimation of Reference Crop Evapotranspiration in Cold-Semi Arid and Warm Arid Climates. *Water Resources Management*, **24**, 909-920. https://doi.org/10.1007/s11269-009-9478-2

[37] Hassani, A., Tajrishi, M. and Abrishamchi, A. (2008) Comparison of Several Evaporation Models Applied to the Reservoir of Saveh Dam, Iran. *Proceedings of the* 3*rd International Conference on Water Resources and Arid Environments* (2008) *and* 1*st Arab Water Forum*, King Fahd Cultural Centre, Riyadh, 16-19 November 2008, 25 p.

[38] McVicar, T.R., Van Niel, T.G., Li, L., Hutchinson, M.F., Mu, X. and Liu, Z. (2007) Spatially Distributing Monthly Reference Evapotranspiration and Pan Evaporation Considering Topographic Influences. *Journal of Hydrology*, **338**, 196-220. https://doi.org/10.1016/j.jhydrol.2007.02.018

[39] Xing, Z.S., Chow, T.L., Meng, F., Rees, H.W., Monteith, J.O. and Stevens, L. (2008) Testing Reference Evapotranspiration Estimation Methods Using Evaporation Pan and Modeling in Maritime Region of Canada. *Journal of Irrigation and Drainage Engineering*, **134**, 417-424. https://doi.org/10.1061/(ASCE)0733-9437(2008)134:4(417)

[40] Finch, J. and Calver, A. (2008) Methods for the Quantification of Evaporation from

Lakes. Prepared for the World Meteorological Organization's Commission for Hydrology, Oxfordshire, UK, 41 p.

[41] Kaboosi, K. (2012) The Investigation of Error of Pan Evaporation Data, Estimation of Pan Evaporation Coefficient by Pan Data and Its Comparison with Empirical Equations. *International Journal of Agriculture and Crop Sciences*, **4**, 1458-1465.

[42] Sepaskhah, A.R. and Kamgar-Haghighi, A.A. (2009) Irrigation Department, Shiraz University, Shiraz, I.R. of Iran. *International Journal of Plant Production*, **3**, 1-16.

[43] Lapworth, C.F. (1965) Evaporation from a Reservoir near London. *Journal of the Institute of Water Engineers*, **19**, 163-181.

[44] Chen, D., Gao, G., Xu, C.Y., Guo, J. and Ren, G. (2005) Comparison of the Thornthwaite Method and Pan Data with the Standard Penman-Monteith Estimates of Reference Evapotranspiration in China. *Climate Research*, **28**, 123-132. https://doi.org/10.3354/cr028123

[45] Koerselman, W. and Beltman, B. (1988) Evapotranspiration from Fens in Relations to Penman's Potential Free Water Evaporation (E_O) and Pan Evaporation. *Aquatic Botany*, **31**, 307-320. https://doi.org/10.1016/0304-3770(88)90019-8