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ORIGINAL RESEARCH ARTICLE

SENSITIVITIES OF SOME REFERENCE EVAPOTRANSPIRATION MODELS TO THE KEY CLIMATIC VARIABLES IN NORTHEASTERN NIGERIA

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ABSTRACT

Reference evapotranspiration (ETo) models are fundamental tools in decision-making in agricultural water management. They have potential spacio-temporal variations due to climatic variability that challenges their individual reliability in decision-making. The sensitivities of five ETo models were examined using the factor perturbation simulation approach (FPSA). The examined models were Penman-Monteith (PM), Hargreaves-Samanni (HS), Blaney-Criddle (BC), Jensen-Haise (JH) and Thornthwaite (TW) to alteration of climatic variables (wind speed (U2), maximum and minimum air temperatures (Tmax and Tmin), vapor pressure deficit (VPD), and Solar radiation (Rn). The study utilized ten years meteorological data obtained from Nigerian Meteorological Agency (NIMET) offices in Maiduguri between (2002-2011) for Borno State, Potiskum between (2005-2014) for Yobe State and from the Upper Benue River Basin Development Authority, Yola (UBRBDAY) between (2005-2014) for Adamawa, Taraba, Gombe, and Bauchi states respectively. Thus covering the entire northeastern region of Nigeria. The region was fractionalized in to three zones namely Borno State (zone A), Yobe State (zone B) and Adamawa, Taraba, Gombe, and Bauchi States (zone C). The results from zones A and B showed some distinctive similarities. Additionally, Blaney-Criddle, Hargreaves-Samanni and Jensen-Haise models outperformed Thorntwaite model, signifying that Thornwaite model is not suitable for application in this region. On an annual average, PM model was most sensitive to U2 and least sensitive to Tmean. BC model was highly sensitive to n/N with sensitivity coefficient (S.C.) of 3.640 in Borno and 3.611 in Yobe, and it was least sensitive to RH. The temperature difference (Tmax-Tmin) was found to have affected HS more than Ra. The Thorntwaite model was most sensitive to solar radiation. Similarly, it was observed that U greatly influenced the performances of the studied ETo models. For accurate and reliable output from any ETo model, emphases need to be placed on accurate measurement, documentation and systematic handling of the climatic variables and calibration

1.0 Introduction

Mathematical models usually contain input variables, parameters and/or series of equations that express some course of actions under investigation. Quite often, some or all of the model inputs are subject to sources of uncertainties, including errors of measurement, lack of up-to-date information and poor or partial understanding of the driving forces and mechanisms. Furthermore, some models may be highly complex in structure, thereby posing obscurity in running it and in comprehending the input/output relationships of the model. Such uncertainties and quandaries inflict some limit on user's confidence in model's output (Bakhtiari and Liaghat, 2011). Also, some natural spacio-temporal variability of the input variables occurs in response to events such as climate change and geological actions, among others. Planas and Depoutot (2000) showed that a good model is expected to present minimal uncertainty and a high degree of confidence to its users. Weighing up the level of uncertainty in a model thus becomes an essential ingredient of model building and quality assurance.

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Sensitivity analysis (S.A.) is technique involving series of computational procedures that project the performance or the outcome of models as affected by changes in the assumptions or the values of the input variables of a model (Ambas and Baltas, 2011). It also weighs up how much each input is contributing to the output uncertainty.

Among others, sensitivity analysis is often used to compare different scenarios and their potential outcomes based on changing condition and/or values of input variables and hence decisions become more effective. Furthermore, sensitivity analysis directs the study of how the uncertainty in the output of a model or system (numerical or otherwise) could be doled out to different sources of uncertainty in its variables; increase understanding of the relationships between input and output variables in a system or model. Sensitivity analysis also reduces uncertainty by identifying model inputs that cause significant uncertainty in the output; and be able to focus attention on variables that gravely impinge on the model (Gong et al., 2006). Additionally, it is used in identifying critical control points that will prioritize additional data collection or research, and in verifying and validating a model to reduce the its complexity by identifying and removing variables that least affects the final output of a model (Aydin and Keçecioğlu, 2009).

Sensitivity analysis can be achieved by several approaches (Rana and Katerji, 1998; Saltelli, 2002; Irmak et al., 2006; Bormann, 2011), however, the factor perturbation simulation approach (FPSA) also referred to as one-at-a-time (OAT) approach is mostly preferred by modelers and analysts due to its straightforwardness and other practical reasons (Irmak et al., 2006; Bakhtiari and Liaghat, 2011). The factor perturbation simulation approach (FPSA) involves calculating the sensitivity of a model by monitoring changes in its output in response to changes in one factor at a time while all other factors are kept fixed to their central or baseline values. Thus, any change observed in the model output will unequivocally be due to the single variable changed. This method of analysis usually is accomplished using partial derivative or regression analysis. The quantitative value of changes in the model output due to changes in input variables is referred to as sensitivity coefficient (S.C) (Michael et al., 2000). Under FPSA, when there is any model malfunction, the modeler immediately knows which input factor is the source for the malfunction. S.A. generally enhances the comparability of models and minimize the probability of computer programme crashes that commonly happens when several input factors are changed simultaneously

Evapotranspiration is the rate at which water, if readily available, would be removed from the soil and plant surfaces (James, 1993). The reference evapotranspiration (ET_o) is the evapotranspiration from a reference surface, not short of water. Crop evapotranspiration (ET_c) is the rate at which water, when readily available, would be removed from a specific crop and soil surfaces surrounding it (Hobbins et al., 2001). The most common procedure for estimating ET_c is to adjust the ET_o values with the crop coefficient (K_c), which in turn is a function crop's stage of development.

Water resources particularly in the arid and semi-arid regions commonly experience increasing pressure from competing users consequential to the usual limited availability of water resources. Efficient water use, especially in irrigated and other hydrological fields thus became a watch word (Hatfield et al., 1996). Precision estimation of ET_c thus becomes practically crucial due to its close link to hydrology and agro-ecosystem design and management (Allen, 2000). Hobbins et al. (2001) stressed that ET_o is one of the most important hydrological variables for scheduling irrigation systems, preparing input data to hydrological water-balance models, and calculating actual crop evapotranspiration (ET_c) for a region and/or a basin and general field water management. The computation of reference evapotranspiration (ET_o) using regularly recorded climatological data is

Corresponding author's e-mail address: jibrinmd01@gmail.com usually the first step involved in estimating the ET_c of agricultural crops. The term ET_c is thus a very important parameter for accurate hydrology and agro-ecosystem design and management.

Evapotranspiration being a quantitative measure of the evaporative demand of the atmosphere is independent of crop type and/or management practices, but is a function of climatic factors that can be computed from meteorological data (Allen, 2000). The success of the use of most ET_o models lies in the transferability of the K_c from one location to another, a situation many researchers found to be nearly impractical (Bakhtiari and Liaghat, 2011).

Tegos et al. (2013) provided a great number of methods for estimating ET_o including the combination (Penman, 1948), mass transfer (Harbeck, 1962), energy budget (Fritschen, 1966), water budget (Guitjens, 1982) empirical (Kohler et al., 1995), and the FAO Standard Penman-Montieth method (Allens et al., 2000).

Further, given the variability of the performances of different models with different local climatic conditions and the varieties of methods and/or equations that exist, adopting a specific method as a standardized model should become the central point of attention. For a reliable performance, it is expected that ET_o should be calibrated, verified, and validated and this necessitate establishment of the sensitivity of ET_o to the local climatic variables and evaluating is performance statistically (Steiner et al., 1991). The S.A. avails the model user the chance to gain understanding of the relative importance of each of the variables to the model solution. Bakhtiari and Liaghat (2011) performed the S.A. of Penman equation with respect to each climatic variable and concluded that the equation was most sensitive to net radiation. Piper (1989) showed that errors in measurement of sunshine hours, wind speed, and wet bulb temperature had the same relative effect on the estimated ET_o. Ley et al. (1994) analyzed the sensitivity of the Penman-Wright ET_o model to errors in parameters and weather data. They found that the model was most sensitive to error in the maximum and minimum air temperatures in Washington State. The sensitivity of the original Penman-Monteith equation to climatic and parametric factors in a semi-arid climate for a reference grass surface, grain sorghum, and sweet sorghum was analyzed in Italy (Rana and Katerji, 1998). They found that for grass, available energy and aerodynamic resistance played a major role. For sweet sorghum, the model was most sensitive to vapor pressure deficit. For grain sorghum under water stress, the most sensitive term was canopy resistance. Such works were also conducted on ASCE-Penman-Monteith equation in different climates of the United States. For ecosystem simulation and models uses, the required data for single-stand simulations are often available and possible to measure, but such functional data progressively became unavailable as spatial resolution increases. Sensitivity analysis would be needed by engineers, hydrologists, and agronomists to gain a better understanding of the meteorological systems in the Nigerian Northeastern region particularly to designate the physical meaning of each meteorological parameter used in the estimation of ET_o and other related hydrological problems. Nevertheless, work done in this region on sensitivity analysis of FAO-56 Penman Montieth, Balney-Criddle, Thornwite, Jensen-Haise, and Hargreaves-Samanni models are scarce. This limits their uses in resolution to many hydrologic and agro-ecosystem problems. In consequence, in this study, we conducted the sensitivity analysis of above-mentioned model

This limits their uses in resolution to many hydrologic and agro-ecosystem problems. In consequence, in this study, we conducted the sensitivity analysis of above-mentioned models in Northeast Nigeria using wind speed, maximum and minimum air temperatures, vapor pressure deficit, and Solar radiation.

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2. Materials and Methods

2.1 Study Area

The study utilized ten-years meteorological data obtained from Nigerian Meteorological Agency (NIMET) offices in Maiduguri (2002-2011) representing Borno State, Potiskum (2005-2014) representing Yobe State, and from the Upper Benue River Basin Development Authority, Yola (UBRBDAY) (2005-2014) representing Adamawa, Taraba, Gombe, and Bauchi States thus covering the entire Northeastern region of Nigeria. The region was fractionalized into three zones namely Borno State (zone A), Yobe State (zone B) and Adamawa, Taraba, Gombe, and Bauchi States (zone C). The meteorological data collected and used for the analysis were maximum (T_{max}) and minimum (T_{min}) air temperatures at 2 m height, wind speed measured at 2m height (U_2), relative humidity (RH) and daily sunshine duration (SSH). The region domicile about nine Universities, many tertiary institutions and research institutes, thus it is heavily occupied with substantial academic and research activities. Agriculture generally dominates the area, but flood that occurs nearly every rainy season is one of the chief hydrological challenges of the area**.** The climate of the region is semi-arid characterized by a high inter-annual variability in rainfall.

2.2 Computation of Reference Evapotranspiration (ET_o)

2.2.1 FAO-56 Penman-Monteith Model

The FAO-56 Penman-Monteith Model is given in (Eqn 1).

$$ET_O = 0.408\Delta R_n - G + 900T + 273U_2\,(\rho_s - \rho_a)\Delta + (1 + 0.34U_2) \qquad (1)$$

where:

ET_o= reference evapotranspiration (mmday^{-1}), R_n= net radiation at the crop surface (MJm^{-2}day^{-1}), G= soil heat flux (MJm^{-2}day^{-1}), T= mean daily air temperature at 2m height (°C), U_2= wind speed at 2m height (ms^{-1}), e_s= saturation vapor pressure (kPa), e_a= actual vapor pressure (kPa), Δ= slope of vapor pressure curve (kPa °C^{-1}), γ= psychrometric constant (kPa °C^{-1}). The details of equations associated with the calculation of the required parameters in Eqn. (1) have been standardized and described in Allens et al. (2000). Table 1 presents the monthly mean daily meteorological data for the study area that was used in the study.

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Table 1: Monthly mean daily meteorological data for the study area

		Months of the Years											
Climatic variables	Zones	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T_{max} (°C)	A	32.725	35.208	40.151	41.870	40.519	36.758	33.419	31.407	33.330	36.190	35.967	33.000
	B	32.170	35.910	37.800	40.340	39.280	36.580	32.190	30.750	32.700	35.180	35.610	32.450
	C	33.300	36.600	39.300	38.300	34.800	32.800	31.100	29.900	30.300	32.900	34.000	30.300
T_{min} (°C)	A	13.402	17.829	20.068	25.171	26.489	25.474	23.989	23.124	23.567	22.161	16.826	13.355
	B	13.770	17.480	20.790	24.700	26.050	24.630	23.050	22.020	22.420	22.380	16.490	13.880
	C	17.500	22.200	25.300	27.100	25.100	23.700	22.500	22.000	22.600	22.500	20.800	15.400
T_{mean} (°C)	A	15.635	19.840	23.045	25.900	25.575	24.165	22.775	22.010	22.510	22.440	18.645	14.640
	B	22.970	26.695	29.295	32.520	32.665	30.605	27.620	26.385	27.560	28.780	26.050	23.165
	C	20.900	20.200	20.000	18.600	17.850	17.550	17.300	16.950	16.850	18.200	19.600	20.450
RH (%)	A	31.800	24.800	19.600	26.800	40.700	57.800	70.000	78.300	72.400	50.600	36.200	33.800
	B	23.940	19.000	20.670	28.330	41.820	55.630	71.220	78.900	71.940	55.910	32.980	28.370
	C	38.364	31.364	26.164	41.800	62.800	70.200	75.500	80.180	79.300	71.700	46.400	40.364
U_2 (ms^{-1})	A	2.023	2.162	2.237	2.407	2.526	2.493	2.476	2.301	1.879	1.832	1.773	1.771
	B	1.502	1.548	1.636	1.636	1.579	1.574	1.466	1.307	1.528	1.379	1.512	1.523
	C	1.419	1.313	1.711	2.101	2.272	1.761	1.578	1.337	1.248	1.471	1.108	1.052
SSH (hrs)	A	7.770	8.640	9.650	9.850	9.140	8.250	7.640	6.900	8.350	8.340	8.420	7.690
	B	7.201	8.071	9.081	9.281	8.571	7.681	7.071	6.331	7.781	7.771	7.851	7.121
	C	8.791	7.557	7.996	7.714	7.680	6.954	6.610	5.009	6.381	8.457	10.029	9.049

2.2.2 Thornwaite Model

The monthly ET_o according to Thornthwaite (1948) were estimated using Equation (2)

$$ET_o = ET_{OSC}\left(\frac{N}{12}\right)\left(\frac{dm}{30}\right) \qquad (2)$$

where: ET_o= reference evapotranspiration, N= maximum number of sunny hours as a function of the month and latitude, dm = number of days per month, ET_{osc}= is the gross ET (without correction) and was calculated from Equation (3).

$$ET_{osc} = 1610Tia \qquad (3)$$

where: T = mean daily temperature (°C), a = an exponent as a function of the annual index defined by Equations (4) and (5).

$$a = 0.49239 + 1792 \times 10^{-5}\, I \_ 771 \times 10^{-7} I^2 + 675 \times 10^{-9} I^3 \qquad (4)$$

where I is the annual heat index obtained from monthly heat indices from equation 5.

$$I = T \times 51.514 \qquad (5)$$

where: I is the annual heat index obtained from monthly heat indices and T is as defined above (James, 1993).

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2.2.3 The Hargreaves-Samani Model

Equation (6) presents the Hargreaves-Samani's model (Allen et al, 2000)

$$ET_O = 0.0023\,(T + 17.78)(T_{Max} - T_{Min}){}^\wedge 0.5\,R_a \qquad (6)$$

where: R_a= extraterrestial radiation (mm day^{-1}), T= mean daily temperature (°C), T_{max}= mean dialy maximum temperature, T_{min}= mean daily minimum temperature. The R_a from Penman calculation were in (MJ m^{-2} day^{-1}), so they were multiplied by 0.408 convert them to (mm day^{-1}), as provided by Allen et al. (2000).

2.2.4 Jensen-Haise Model

The Jensen-Haise model takes the form of Equation (7)

$$ET_O = C_T(T - T_x)R_s \qquad (7)$$

where: C_T = air temperature coefficient for the location being considered, T= mean daily air temperatures (°C), T_x= constant for the location being considered, R_s= total solar radiation for period (mmday^{-1}). The coefficients C_T and T_x were determined using the equations (8) and (9). Rs values from Penman calculations were also converted from (MJ m^{-2} day^{-1}) to (mmday^{-1}) by multiplying them with 0.408 (Allen *et al.*, 1998).

$$C_T = 145 - h137 + 365\,\rho T_{max} - \rho T_{min} \qquad (8)$$

$$T_X = -2.5 - 0.14\rho T_{max} - \rho T_{min} - \frac{h}{500} \qquad (9)$$

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where: C_T = air temperature coefficient for the location being considered, T = mean daily air temperatures (°C), T_x = constant for the location being considered, R_s = total solar radiation for period (mmday^{-1}). Rs values from Penman calculations were also converted from (MJ m^{-2} day^{-1}) to (mmday^{-1}) by multiplying them with 0.408 to have a uniform units (Allen et al., 2000). The coefficients C_T and T_x in Equation (7) were determined using the Equations (8) and (9) in which h = attitude of the location (m), ρ_{Tmax}, and ρ_{Tmin}= saturation vapor pressure at the mean maximum and minimum air temperature during the warmest month of the year respectively (kPa).

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2.3 Sensitivity Analysis and Determination of Sensitivity Coefficients (S.C.s)

The Sensitivity of the models to T_{meam} , U_2 , VPD and SSH , was analyzed using the factor perturbation simulation approach (Smajstrla *et al*., 1987; Irmak *et al*., 2006). Sensitivity coefficient for each climatic variable was derived from Equation (10)

$$S.C. = \frac{CH_{ETO}}{CH_{CV}} \tag{10}$$

where: S.C= sensitivity coefficient, CH_{ETo}= change in ET_o with respect to change in climatic variable, and CH_{cv}= the change in climatic variable.

3.0 Results and Discussion

3.1 FAO-56 Penman-Monteith Model

Tables 2 presents the average daily sensitivity coefficients (S.Cs) computed on a monthly basis for each of the climatic variable considered in the Northeast region of Nigeria. The trends of the S.Cs showed similarities in all climatic variables. In most cases the response of ET_o to factor perturbation was linear on seasonal basis but the monthly basis, and both locations, the increase in each climatic variable resulted in a corresponding increase in ET_o except in the case of T_{mean}.

In zone A, the S.C. of T_{mean} increased somewhat linearly from January through May where it attained its peak value. The least SC was found in July. This shows that the ET_o calculated from PM model in July will be least affected by T_{mean}. The SC of Rn raged between 0.318 in December to 0.352 in October, while the S.C. of U_2 was highest (1.793) in March and least (0.299) in August. VPD got the highest SC (0.969) in July and least (0.354) in November. Generally, in zone A, the S.C. of U_2 (1.793) in March signifies it had the greatest contribution to the accuracy of POM model, and thus the need to pay greater attention while measuring U_2.

Table 2: Average sensitivity coefficients of climatic variables for Penman Monteith model in zones A, B, and C

Climatic variables	Zone A											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T_{mean}(°C)	-0.023	-0.039	-0.060	-0.080	-0.064	-0.028	-0.003	0.013	0.008	-0.012	-0.017	-0.013
Rn(MJ mm^{-1} day^{-1})	0.319	0.331	0.348	0.355	0.358	0.351	0.338	0.336	0.343	0.352	0.337	0.318
U_2(ms^{-1})	1.295	1.480	1.793	1.661	1.294	0.805	0.484	0.299	0.434	0.983	1.299	1.193
VPD(kPa)	0.894	0.857	0.781	0.747	0.813	0.888	0.967	0.955	0.596	0.588	0.354	0.681
	Zone B											
T_{mean}(°C)	-0.029	0.078	-0.045	-0.062	-0.023	-0.003	0.009	0.017	0.017	0.006	-0.008	0.007
Rn(MJ mm^{-1} day^{-1})	0.212	0.351	0.270	0.343	0.224	0.137	0.095	0.071	0.068	0.108	0.157	0.128
U_2(ms^{-1})	2.728	1.646	2.130	1.509	1.328	0.000	0.333	2.232	2.404	2.151	2.935	4.188
VPD(kPa)	0.601	0.529	0.541	0.676	0.695	0.569	0.485	0.380	0.369	0.476	0.451	0.478
	Zone C											
T_{mean}(°C)	0.566	0.771	0.932	1.138	0.866	1.119	0.947	0.801	0.864	1.025	0.479	0.624
Rn(MJ mm^{-1} day^{-1})	0.300	0.364	0.431	0.423	0.280	0.341	0.372	0.211	0.220	0.350	0.207	0.304
U_2(ms^{-1})	1.633	0.985	1.275	0.903	0.795	0.052	0.199	1.336	1.439	1.288	1.757	2.507
VPD(kPa)	1.727	2.257	1.788	2.124	2.577	4.315	4.576	4.396	4.556	4.889	1.519	2.146

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The S.C. of the climatic variables with respect to Blaney-Criddle B.C. model is presented in Table 3. In zone B, the highest SC (4.188) is that of U_2 in December and the least (0.003) came from T_{mean} in June. This means the magnitude of variability of PM's ET_o with respect to U_2 would be greatest in the dry windy months of the year.

It also points that T_{mean} would have the list influence on ET_o. It thus implies that sufficient precaution need to be taken during the measurement and recording of U_2 to avert faulty ET_o results. Similar results were observed in zone C where the S.C. of U_2 exhibited nearly linear trend from 1.336 in June to its highest value (2.507) in December.

But the overall peak value of S.C. (4.889) is that of VPD in October. Bakhtiari and Liaghat (2011) showed that due to the behavior of the term $1/(\gamma + \Delta)$ in Equation (1), the effectiveness of vapor pressure deficit on evapotranspiration is greater in the low temperatures months because this term decreases as temperature increase. Thus, the divergence in ET_o with respect to increase in VPD would be larger during wet months. This lowest S.Cs of T_{mean} in June and July tallies with the report of Audu *et al.* (2015).

Table 3: Average S.Cs. of climatic variables to Blaney Criddle ET Model

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
						Zone A						
Tmean	0.160	0.182	0.196	0.193	0.170	0.147	0.129	0.111	0.124	0.144	0.157	0.157
	-	-	-	-	-	-	-	-	-	-	-	-
RH	0.038	0.045	0.053	0.061	0.057	0.053	0.048	0.043	0.047	0.047	0.043	0.036
U_2	0.224	0.293	0.335	0.305	0.289	0.203	0.168	0.125	0.138	0.166	0.220	0.254
SSH	3.279	4.081	4.654	4.925	4.466	3.723	3.067	2.527	2.776	3.406	3.472	3.299
						Zone B						
Tmean	0.165	0.172	0.149	0.154	0.128	0.120	0.110	0.103	0.103	0.118	0.154	0.164
	-	-	-	-	-	-	-	-	-	-	-	-
RH	0.041	0.046	0.046	0.052	0.048	0.045	0.041	0.038	0.039	0.044	0.046	0.039
U_2	0.254	0.310	0.333	0.263	0.175	0.143	0.118	0.111	0.096	0.126	0.207	0.235
SSH	3.657	4.522	4.205	4.295	3.262	2.973	2.647	2.364	2.371	2.598	3.258	3.352
						Zone C						
Tmean	0.478	0.310	0.268	0.277	0.231	0.216	0.198	0.185	0.185	0.213	0.277	0.296
	-	-	-	-	-	-	-	-	-	-	-	-
RH	0.075	0.082	0.083	0.093	0.086	0.081	0.074	0.069	0.070	0.079	0.083	0.069
U_2	0.459	0.558	0.601	0.474	0.315	0.258	0.213	0.200	0.173	0.227	0.372	0.424
SSH	4.317	5.337	4.963	5.070	3.850	3.509	3.124	2.790	2.799	3.067	3.845	3.956

It is evident from the model that the S. C. of the studied variables took a sinusoidal trend with the lowest around the months August. The Table also shows that SSH of 4.925, 4.295 and 5.07 in zones A, B. and C respectively all occurring in the month of April has a dominant influence on the overall performance of the model in this region. The influence of R.H. on the performance of the model is apparently insignificant, not only due to is negative values of S.Cs, but also by the account of low S.C. values in the all the zones.

Similar results were reported by Ambas and Baltas (2011) which showed low and negative S.Cs of R.H in Blaney Criddle model. The term R.H. can thus be safely be replaced with the energy terms that have greater influence on the model.

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Table 4 elucidates that the Thorn White (T.W) ET model was found to be more sensitive to sunshine hours (SSH) which is also one of the energy terms of the model. In zones A, B and C respectively, the highest S.C values of the SSH were 0.4155, 1.095 and 1.424. This call for cautious and accurate instrumentation of SSH term to arrive accurate ET values with T.W. model. It also points that minimal emphasis can be placed on temperature measurement.

The Hargreave – Samani (H.S.) model as with other models, exhibited a non-linearity in its sensitivity to changes in its parameters (Table 5). The model is most sensitive to perturbation in temperature, especially in the rainy seasons irrespective of the zones. The highest S.C of 0.381 for T_{mean} was found in the month of September in zone C. Apparently, the response of this model to changes in its building parameters has no defined trend, however, T_{mean} should be prudently recorded for accurate ET computation with H.S. model.

The Jensen Haise model exhibited greater sensitivity to vapor pressure deficit (VPD) irrespective of the zones (Table 6). This was followed by the solar radiation in equivalent depth of evaporation (R_s). (Table 6) In zone A, the highest S.C. (1.147) for VPD was found in the month of July. The least values were found in zone C. this means the effectiveness of J.H. model in predicting ET relies on the accuracy of VPD. The Table also showed that T_{mean} holds the least position in the performance of the model, this challenges the proclamation that the Jensen Haise model depends on solar radiation in equivalent depth of evaporation (James, 1993). This study shows that efficiency of J.H. model in ET prediction is a function of its building parameters that are also in turn a function of location.

The result implies that in the dry season, greater emphasis should be on Ra than (T_{max} - T_{mean}) while in the wet season reverse is the case. Although this result shows that the effects of both parameters on the model have no significant difference, both parameters requires greater emphasis in determining ET_o if this model is to be used in such locations.

Table 4: Average S.Cs. of climatic variables to Thorn White ET Model

						Zone A						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T_{mean}	0.0598	0.0754	0.1016	0.1205	0.1119	0.0913	0.0756	0.0646	0.045	0.084	0.0758	0.0587
N (SSH)	0.3629	0.3785	0.4155	0.4538	0.4497	0.4279	0.4018	0.3928	0.3952	0.4053	0.3848	0.3615
						Zone B						
T_{mean}	0.0669	0.0718	1.0723	0.085	0.073	0.0633	0.0541	0.0392	0.0525	0.0726	0.0872	0.06
N (SSH)	0.3741	0.4096	1.095	0.4444	0.415	0.4006	0.3853	0.3783	0.3842	0.394	0.391	0.355
						Zone C						
T_{mean}	0.08697	0.09334	1.39399	0.1105	0.0949	0.08229	0.07033	0.05096	0.06825	0.09438	0.11336	0.078
N (SSH)	0.48633	0.53248	1.4235	0.57772	0.5395	0.52078	0.50089	0.49179	0.49946	0.5122	0.5083	0.4615

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Table 5: Average S.Cs. of climatic variables to Hargreaves-Samani ET Model

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
						Zone A						
Ra	0.169	0.173	0.202	0.198	0.180	0.162	0.134	0.123	0.134	0.165	0.181	0.169
(T_{mean})	0.132	0.164	0.181	0.220	0.237	0.263	0.262	0.272	0.252	0.212	0.158	0.131
						zone B						
Ra	0.152	0.159	0.165	0.158	0.108	0.137	0.125	0.117	0.118	0.141	0.163	0.148
(T_{mean})	0.151	0.182	0.214	0.261	0.203	0.270	0.260	0.266	0.281	0.245	0.194	0.158
						zone C						
Ra	0.207	0.216	0.225	0.215	0.147	0.186	0.170	0.159	0.161	0.191	0.222	0.201
(T_{mean})	0.206	0.247	0.290	0.354	0.276	0.367	0.354	0.361	0.381	0.333	0.264	0.215

Table 6: Average S.Cs. of climatic variables to Jansen-Haise ET Model

						Zone A						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T_{mean}	0.124	0.147	0.209	0.212	0.178	0.130	0.098	0.079	0.108	0.145	0.158	0.126
Rs	0.181	0.212	0.297	0.320	0.284	0.209	0.152	0.124	0.155	0.218	0.227	0.184
VPD	0.683	0.855	0.882	1.012	1.075	1.143	1.147	1.130	1.231	1.033	0.808	0.691
						Zone B						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T_{mean}	0.122	0.131	0.166	0.100	0.101	0.085	0.073	0.066	0.068	0.104	0.135	0.108
Rs	0.187	0.230	0.296	0.227	0.175	0.147	0.126	0.110	0.112	0.157	0.187	0.147
VPD	0.853	0.913	0.910	1.160	1.143	1.088	1.045	1.057	1.108	1.154	1.126	0.872
						Zone C						
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T_{mean}	0.110	0.119	0.150	0.090	0.092	0.077	0.066	0.060	0.062	0.095	0.123	0.098
Rs	0.152	0.159	0.165	0.158	0.108	0.137	0.125	0.117	0.118	0.141	0.163	0.148
VPD	0.151	0.182	0.214	0.261	0.203	0.270	0.260	0.266	0.281	0.245	0.194	0.158

4. Conclusions

Model sensitivity analysis in response to the perturbation to its building parameters is an essential element in the study of model's performance and user's confidence. This is only true when the output under consideration is a time dependent function of the input parameters. In all the models studied here, the energy and the aerodynamic terms played some major roles. However, in Jensen-Haise model, the VPD was found to be more fundamental. Whereas some of the results and interpretations appeared fairly straight- forward and logical from physiological perception, majority of the results were non-linear and may be artifact of model design or field data instrumentation. In all the zones studied, all the ET models would be recommended to be used in estimating ET_o based on the availability of meteorological data, but adequate calibration of the models should be conducted to eliminate spacio-temporal errors. However, it is believed that accurate predictions of the spatial distribution of several key parameters would produce the greatest reduction in the uncertainty to a large-scale. Further, adequate, and salient attention should be given during instrumentation and documentation of the most sensitive meteorological parameters of any chosen model to ensure a great level of accuracy in estimating ET_o. It is also recommended that the scarcity of meteorological data and stations need to be overcome to simplify and improve hydro-meteorological research that may be performed in all the zones. Further research on sensitivity analysis should be expanded to include representative climatic distribution of the agro-climatic zones of Nigeria.

References

Allen, RG. 2000. The FAO-56 Dual Crop Coefficient Method over an Irrigated Region as Part of an Evapotranspiration Inter-Comparison Study. Journal of Hydrology, 1& 2: 27-41.

Ambas, VT. and Baltas, E. 2012. Sensitivity Analysis of Different Evapotranspiration Methods Using a New sensitivity Coefficient. Global NEST Journal, 14(3): 335-343.

Audu, MO., Isikwue, BC. and Eweh, EJ. 2015. Evaluation of Seasonal and Annual Variations of Evapotranspiration with Climatic Parameters in Ibadan, Nigeria. Journal of Earth Sciences and Geotechnical Engineering, 5(2): 69-79.

Aydin, M., and Keçecioğlu, SF. 2010. Sensitivity Analysis of the Evaporation Module of the E-DiGOR Model. Turkish Journal of Agriculture 34: 497-507. doi:10.3906/tar-0909-398.

Bakhtiari, B. and Liaghat, AM. 2011. Seasonal Sensitivity Analysis for Climatic Variables of ASCEPenman-Monteith Model in a Semi-arid Climate. Journal of Agricultural Science Technology, 13: 1135-1145.

Bormann, H. 2011. Sensitivity analysis of 18 different potential evapotranspiration models to observed climatic change at German climate stations. Climate Change 104, 729–753.

Fritschen, LJ. 1966. Energy balance method. Proceedings, American Society of Agricultural Engineers Conference on Evapotranspiration and its role in Water resources Management, December 5, Chicago, I. St. Joseph, MI., pp. 34-37.

Gong, LB., Xu, CY., Chen, DL., Halldin, S. and Chen, YQ. 2006. Sensitivity of the Penman–Monteith reference evapotranspiration to key climatic variables in the Changjiang (Yangtze River) basin. Journal of Hydrology, 329: 620–629.

Guitjens, JC. 1982. Models of alfalfa yield and evapotranspiration. Journal of the Irrigation and Drainage Division, the American Society of Civil Engineers, 108(IR3): 212-222.

Harbeck, GE. Jr. 1962. A Practical Field Technique for Measuring Reservoir Evaporation Utilizing Mass Transfer Theory, US Geological Survey, Paper 272-E. 101-105.

Hatfield, JL., Prueger, JH. and Reicosky, DC. 1996. Evapotranspiration effects on water quality. In: Proceedings of the ASAE International Conference on Evapotranspiration and Irrigation Scheduling, 3–6 November, San Antonio, TX, pp. 536–546.

Hobbins, MT., Ramirez, JA. and Brown, TC. 2001. The complementary relationship in estimation of regional evapotranspiration: an enhanced advection-aridity model. Water Resource Research, 37(5): 1389–1403.

Irmak, S., Payero, JO., Martin, DL., Irmak, A. and Howell, TA. 2006. Sensitivity analyses and sensitivity coefficients of standardized daily ASCE-Penman-Monteith equation. Journal of Irrigation and Drainage Engineering, 132(6): 564–578.

James, LG. 1993. Principles of Farm Irrigation System Design. Florida, Krieger Publishing Company., pp1-35.

Kohler, MA., Nordenson, TJ. and Fox, WE. 1955. Evaporation from pans and lakes. Weather Bureau Research Paper 38.US Department of Commerce, Washington, D.C.

Ley, TW., Hill, RW. and Jensen, DT. 1994. Errors in Penman-Wright alfalfa reference evapotranspiration estimates. II: Effects of weather sensor measurement variability. Transactions of ASAE, 37(6): 1863– 1870.

Michael, A., White, PE., Thornton, SWR. and Ramakrishna, NR. 2000. Parameterization and sensitivity analysis of the BIOME–BGC Terrestrial Ecosystem Model: Net primary production controls. Earth Interactions, 4(3):1-85.

Penman, HL. 1948. Natural evaporation from open water, bare soil and grass. Proceedings of the Royal Society. London, A193: 120–146.

Piper, BS. 1989. Sensitivity of Penman estimates of evaporation to errors in input data. Agricultural Water Management, 15: 279–300.

Planas, C. and Depoutot, R. 2000. Sensitivity analysis as a tool for time series modeling. In Sensitivity Analysis (A. Saltelli, K. Chan and M. Scott, eds.). Wiley, New York., pp. 293–310.

Rana, G. and Katerji, N. 1998. A measurement-based sensitivity analysis of the Penman Montieth actual evapotranspiration model for crops of different heights and contrasting water stress. Theoretical and Applied Climatology, 60: 141-149.

Saltelli, A. 2002. Sensitivity Analysis for Important Assessment. Risk Analysis, 22(3): 1-12.

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D., Saisana, M. and Tarantola, S. 2008. Global Sensitivity Analysis. New York: The Primer, John Wiley & Sons.

Smajstrla, AG., Zazueta, FS. and Schmidt, GM. 1987. Sensitivity of potential evapotranspiration to four climatic variables in Florida. Soil and Crop Science Society of Florida, 46: 21-26.

Steiner, L., Howell, TA. and Schneider, AD. 1991. Lysimetric evaluation of daily potential evapotranspiration models for grain sorghum. Agronomy Journal, 83: 240-247

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