

<http://dx.doi.org/10.48198/NJPAS/20.B18>

Sensitivity of Reference Evapotranspiration Computed with FAO CropWat 8.0 Model to Weather Input Variables During Two Irrigation Seasons in Kaduna, Nigeria

N.E. Onwuegbunam¹, D.O. Onwuegbunam*¹, V.C. Ameso², U.U. Emeghara¹ and E.J. Zakka¹

Page | 3778

¹Forestry Research Institute of Nigeria, Federal College of Forestry Mechanization, PMB 2273, Afaka, Kaduna, Nigeria

²Department of Water Resources and Environmental Management, National Water Resources Institute, PMB 2309, Mando Road, Kaduna, Nigeria

ABSTRACT

The sensitivity analysis of the Food and Agriculture Organization (FAO) CropWat 8.0 model is aimed at determining the dominant variable of the model in the study area. Hence, the sensitivity coefficient and the correlation of the reference evapotranspiration (ET_o) in Afaka, Kaduna, Nigeria, with each of the climatic input variables of the model, namely, maximum temperature (T_{max}), minimum temperature (T_{min}), humidity (H), wind speed (WS) and sunshine hour (SSH), were evaluated. A perturbation method was used in the evaluation and the sensitivity coefficients were obtained in a decreasing order of 0.55, 0.42, 0.22, 0.09 and -0.08 for T_{max} , WS, SSH, T_{min} and H, respectively. Also, the correlation of ET_o with each of the input parameters, irrespective of the others, show the following correlation coefficients, r ; SSH ($r = 0.8675$), T_{max} ($r = 0.6979$), T_{min} ($r = 0.6226$), H ($r = 0.19$) and WS ($r = 0.0742$). Hence, radiation and temperature-based estimations of ET_o were recommended as useful tools for ET_o estimation in the face of limited or scarce data and are adaptable to areas with similar climate characteristics. This would also serve as a theoretical basis for future studies on the response of ET_o to climatic change in the study area and other areas with similar climate.

Keywords: Sensitivity, Reference evapotranspiration, CropWat 8.0 model, Weather input variables

Introduction

Reference evapotranspiration (ET_o) refers to the combined process of loss of water from soil due to evaporation, and from plants due to transpiration, from a reference surface, not short of water (Michael, 2008). The reference surface is a hypothetical green grass reference crop of uniform height, actively growing. ET_o is a measurement of the evaporative demand of the atmosphere independent of crop type, crop development and management practices (Allen, 2000; Hou *et al.*,

2013). ET_o is affected by only climatic factors, hence, it is a function of weather parameters and its computation is done from meteorological data (Allen *et al.*, 1998; Raes, 2012). In irrigated agriculture, evapotranspiration measurements are basically taken as tools for scheduling irrigation and for evaluation of irrigation water resource planning and distribution (Dejonge *et al.*, 2015). CropWat 8.0 is a computer programme designed to simplify the rigours involved in computing ET_o by

Corresponding Author: D.O. Onwuegbunam

Forestry Research Institute of Nigeria, Federal College of Forestry Mechanization, PMB 2273, Afaka, Kaduna, Nigeria

Phone: +2348023786572; Email: donancy2001@yahoo.com



means of the FAO Penman Monteith (FAO-PM) formula which is the most commonly used empirical approach in the estimation of ET_o (Allen *et al.*, 1998). FAO-PM has been considered by the International Scientific Society to be the best empirical model as it gives relatively accurate results when compared with other methods in several locations of the world. This is corroborated by Jensen *et al.* (1997) as the standard model adopted by international experts for defining and computing reference evapotranspiration. Hence, FAO-PM has been considered to be the standard method that can be used anywhere without the necessity of calibration (Willmott *et al.*, 1985; Allen *et al.*, 1998; Razei and Pereira, 2013). Allen *et al.* (1998) expressed the FAO-PM model as:

$$ET_o = \frac{0.408(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.034U_2)} \quad (1)$$

Where, ET_o = estimated reference evapotranspiration (mm/day), R_n = surface radiation balance (MJ/m²/day), G = sensible heat flux in the soil (MJ/m²/day), T = average atmospheric temperature (°C), U_2 = wind speed at 2 m height (m/s), e_s = saturation vapour pressure (KPa), e_a = actual vapour pressure (KPa), Δ = slope of the water vapour saturation pressure curve (KPa/°C).

Sensitivity analysis for a multi-variable model such as the FAO-PM which has different variables is aimed at determining how each of the model equation variables affects the output (Afshar and Saadatpour, 2009), thus resulting in the determination of the dominant parameters in the model (Rangel-Peraza *et al.*, 2016). The sensitivity of ET_o to its underlying factors at both regional and local levels have shown that the most important driving change variables differ from one climatic region to the other (Ali *et al.*, 2009; Fan and Thomas, 2013). Except for Emeka *et al.* (2020), reports on the sensitivity of ET_o to climatic input parameters for Kaduna, Nigeria, are not available.

The present study is an on-season assessment at smaller locational scale. Like in some studies carried out at regional levels to show the most important climatic variables that determine the ET_o , the aim here is the same but at a smaller locational scale. Hence, the objective of the study is to determine the sensitivity coefficient and the correlation of the reference evapotranspiration in Afaka, Kaduna, Nigeria, with respect to each of the weather input variables required for the FAO CropWat 8.0 model.

Materials and Methods

Study Location

The study area, Afaka, Kaduna, Nigeria lies on latitude 10°37'N and longitude 7°47'E. It belongs to the northern guinea savannah ecological zone of Nigeria. The climate of the study area is usually characterized by a clear distinction between the dry and rainy seasons. The dry season sets in late October and ends by mid-April (NIMET, 2015). Full irrigation is practiced during the dry season by means of earth-dams and streams. The climate of Afaka is similar to that of the Kaduna Central District, comprising Igabi, Kaduna North, Kaduna South, Chikun, Giwa, Birnin Gwari and Kajuru Local Government Areas (KSWB, 2015). The annual mean rainfall is 1200 mm and the temperature ranges are 28°C to 36°C for the maximum scale, and 15°C to 23°C for the minimum scale (NIMET, 2015; KSWB 2015).

Measurement Procedure

Daily values of the input parameters for CropWat 8.0 model viz. minimum temperature, maximum temperature, relative humidity, wind speed and sunshine hours were measured in the months of December to March during the 2017/18 and 2018/19 irrigation seasons at the meteorological station of the Federal College of Forestry Mechanization, Afaka, Kaduna, Nigeria. In Kaduna, these periods are characterized by complete dry spell and the absence of rainfall

(NIMET, 2015). The daily values were subsequently converted to mean monthly values for the two seasons.

Sensitivity Analysis

The sensitivity of the model to the input parameters was done using the grid perturbation method which involves the fluctuation of each of the model input parameters within defined percentages, while holding the others constant, and obtaining corresponding output values based on the variations (Kabala and Milly, 1990; Caers and Hoffman, 2006; Zakari *et al.*, 2015; Rangel-Peraza *et al.*, 2016). This is repeated for all the input parameters in turns. In this study, all the input parameters were varied between 75% and 125% of their base values in steps of 5%. The base value here are the recorded values of the input parameter during the irrigation seasons.

The CropWat model sensitivity was hence calculated using a sensitivity coefficient (SC). This arises from the differential quotient of the change in the output over that of the input parameters (Rangel-Peraza *et al.*, 2016). That is,

$$SC = \frac{\% \text{ change in the output variable}}{\% \text{ change in the input parameters}} \quad (2)$$

Input (Weather Parameters) and Output (ET_o) Correlation

Simple linear regression analyses of the estimated ET_o and each climatic parameter, in turn, were made according to equation 1 (Devore and Peck, 2001; Abarikwu *et al.*, 2019).

$$y = \alpha + \beta x \quad (3)$$

Where, y = output variable, x = predictor variable, α = constant term (intercept), β = regression coefficient (slope).

Results

Table 1 defines the base values of the input parameters. The changes in input parameter (other parameters remaining constant) resulted in

corresponding changes in ET_o. Hence, the sensitivity coefficients (SC) due to these changes were computed and presented as mean values in Table 2.

The highest sensitivity coefficient (0.55) was obtained from changes due to maximum temperature, followed in decreasing order by wind speed (0.42), sunshine hour (0.22), minimum temperature (0.09) and humidity (-0.08).

The relationship between the monthly reference evapotranspiration (ET_o) and the varied minimum temperature is shown in the regression analysis presented in Figure 1. The coefficient of determination (r^2) is 0.9848, showing an excellent positive linear correlation between ET_o and varied minimum temperature when the other input parameters are held constant. The results of the relationship of reference evapotranspiration with each of the maximum temperature, wind speed and sunshine hours are presented in Figures 2, 4 and 5. These show similarities with that of minimum temperature, the relationships being positively linear and excellent, with very high r^2 values of 0.9970, 0.9993 and 0.9981, for the maximum temperature, wind speed and sunshine hours, respectively. The relationship between the reference evapotranspiration and the humidity (Figure 3) is however different, being negatively linear but with excellent correlation ($r^2 = 0.9946$).

The linear regression analyses result of the relationship between ET_o and each of the climatic parameters is summarized in Table 3.

The performance of each varied parameter with respect to ET_o, other parameters remaining constant, increased in the order: wind speed, followed by sunshine hour, maximum temperature and then minimum temperature, for the positive relationship. A negative correlation exists between ET_o and humidity.

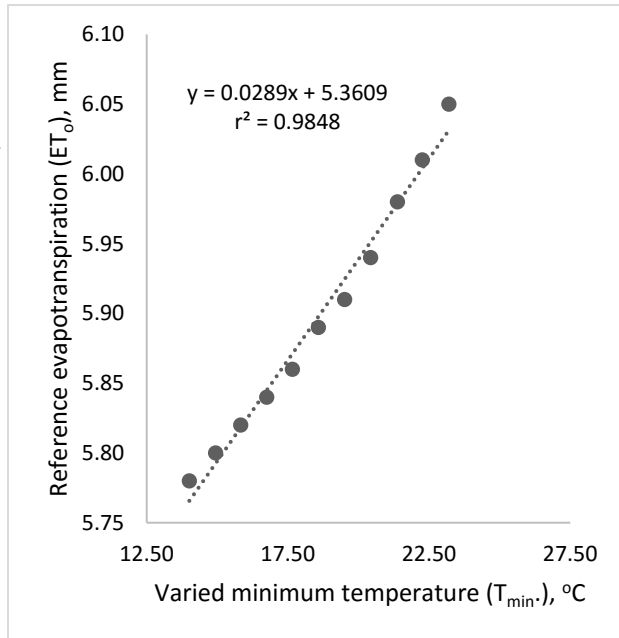


Figure 1: ET_0 at varied minimum temperature

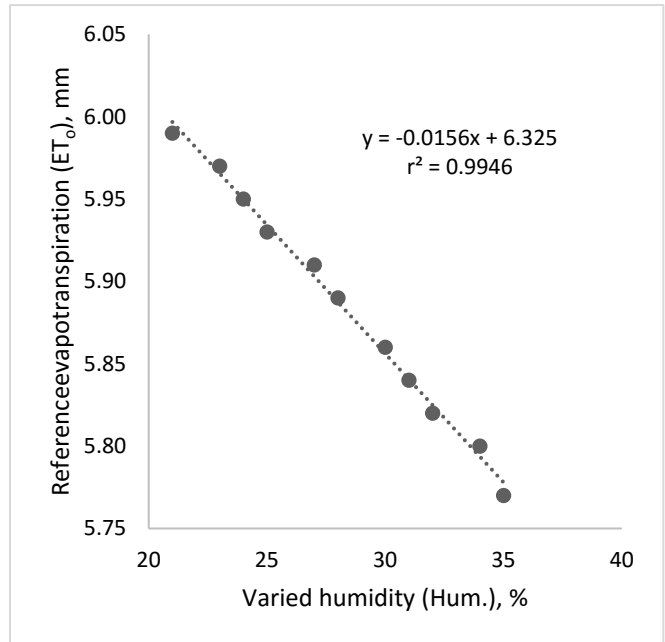


Figure 3: ET_0 at varied humidity

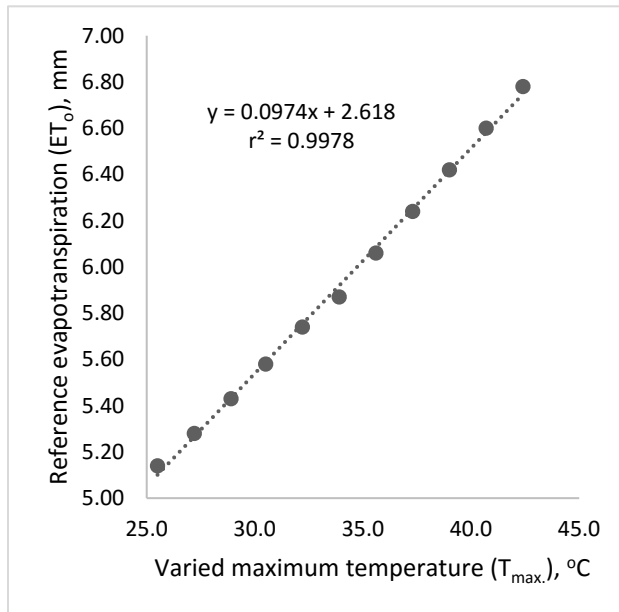


Figure 2: ET_0 at varied maximum temperature

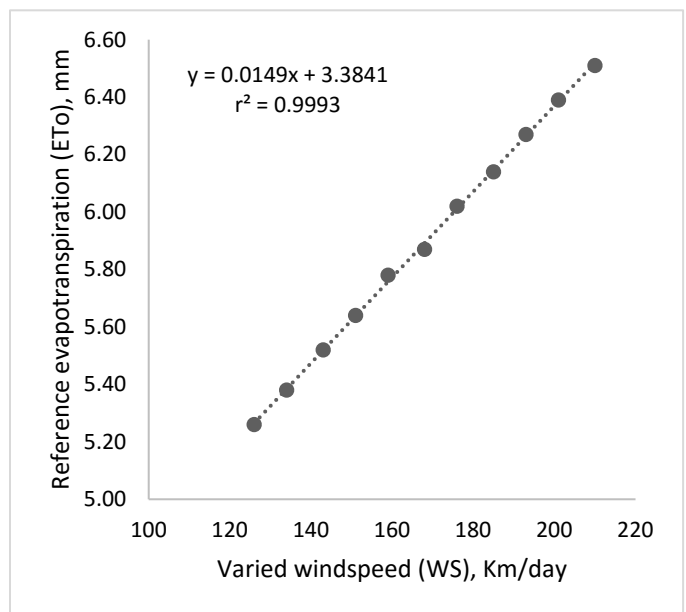


Figure 4: ET_0 at varied wind speed

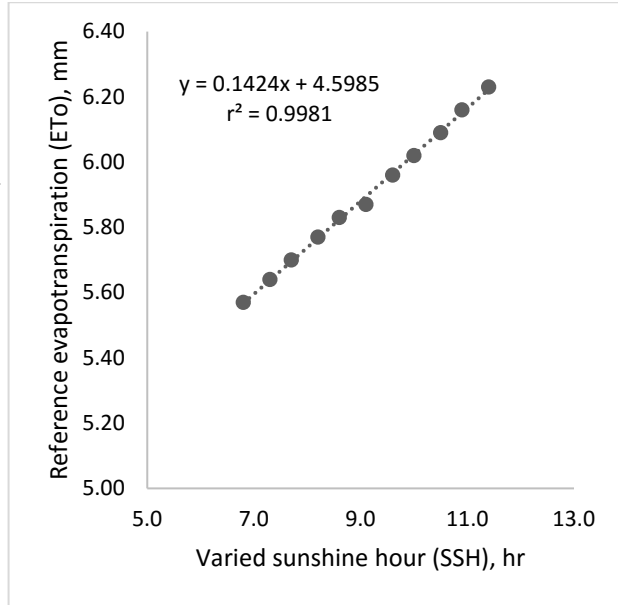


Figure 5: ET_o at varied sunshine hours

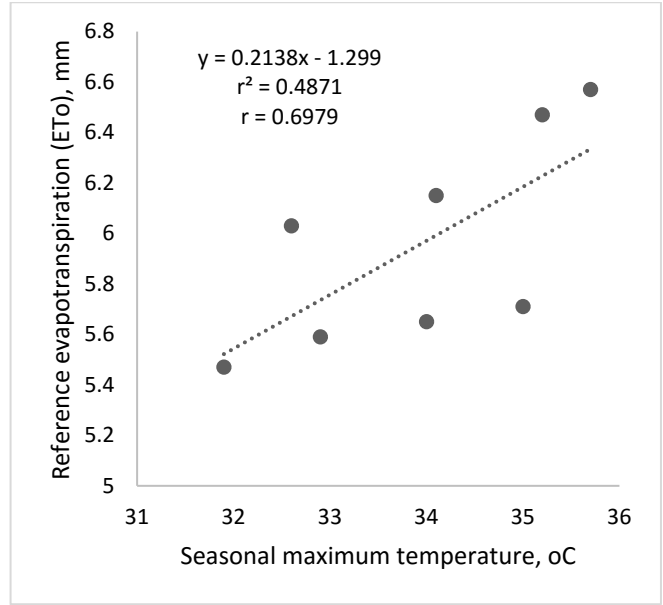


Figure 7: Correlation of seasonal maximum temperature with ET_o

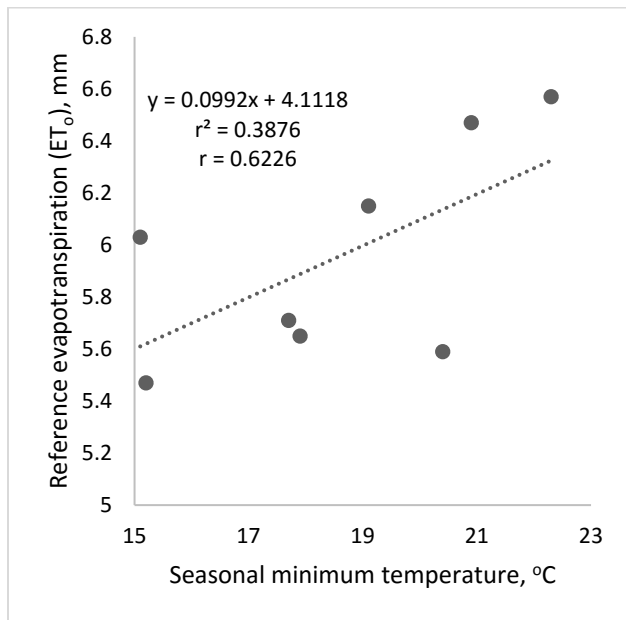


Figure 6: Correlation of seasonal minimum temperature with ET_o

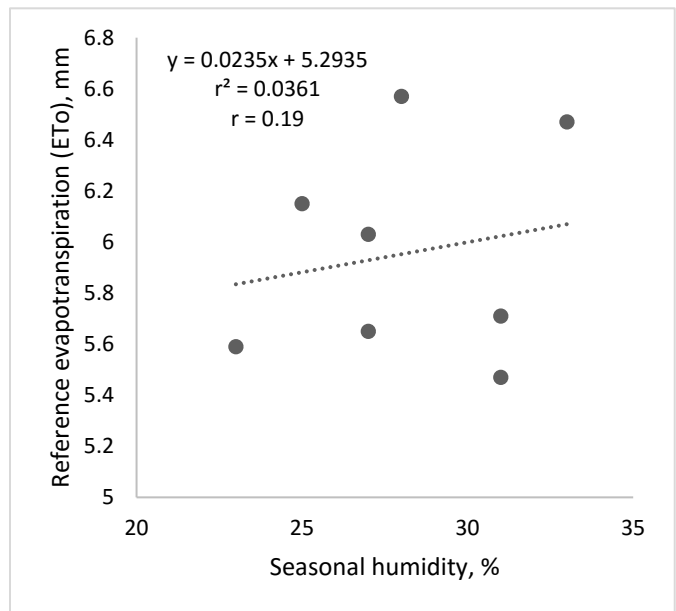


Figure 8: Correlation of seasonal humidity with ET_o

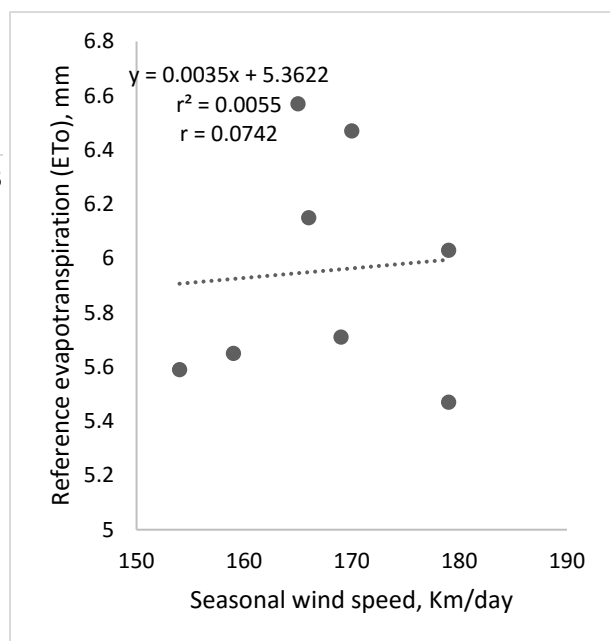


Figure 9: Correlation of seasonal wind speed with ET_o

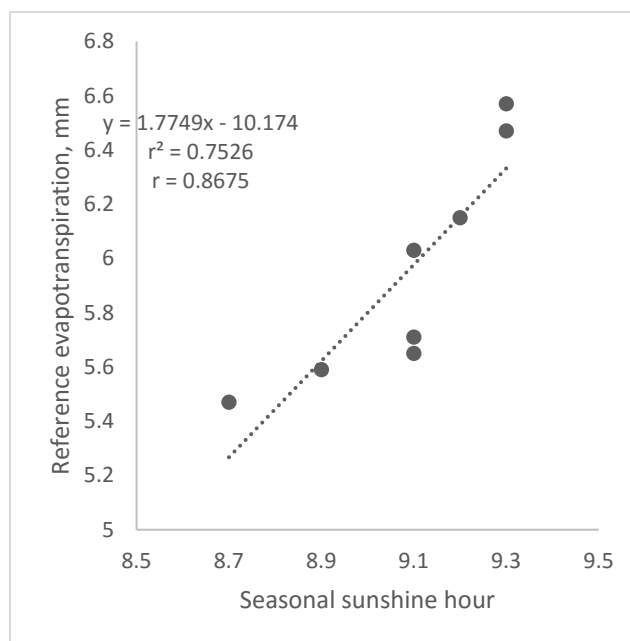


Figure 10: Correlation of seasonal sunshine with ET_o

Table 1: Base values of input parameters for CropWat 8.0 (December to March)

Period	T_{min}	T_{max}	H	WS	SSH	Rad.	ET_o
12-2017	15.2	31.9	31.0	179	9.3	20.3	5.47
01-2018	17.9	34.0	27.0	159	9.1	20.5	5.65
02-2018	19.1	34.1	25.0	166	9.1	21.9	6.15
03-2018	22.3	35.7	28.0	165	8.7	22.6	6.57
12-2018	17.7	35.0	31.0	169	9.3	20.3	5.71
01-2019	20.4	32.9	23.0	154	9.2	20.6	5.59
02-2019	15.1	32.6	27.0	179	9.1	21.9	6.03
03-2019	20.9	35.2	33.0	170	8.9	22.9	6.47

T_{min} = Minimum temperature ($^{\circ}C$), T_{max} = Maximum temperature ($^{\circ}C$), H = Humidity (%), WS = Wind speed (Km/day), SSH = Sunshine hour (Hr)

Table 2: Sensitivity coefficient (SC) of reference evapotranspiration computed with CropWat 8.0

Change in input parameter	ΔT_{\min}	ΔT_{\max}	ΔH	ΔWS	ΔSSH
	0.92	1.69	1.40	8.40	0.46
ΔET_o	0.03	0.16	-0.02	0.13	0.07
SC	0.09	0.55	-0.08	0.42	0.22

Table 3: Summary of linear regression analysis of relationship between ET_o and input parameters

Varied parameter	Constant parameters	Regression equations	r^2
T_{\min}	T_{\max} , H, WS, SSH	$y = 0.0289x + 5.3609$	0.9848
T_{\max}	T_{\min} , H, WS, SSH	$y = 0.00974x + 2.618$	0.9978
H	T_{\max} , T_{\min} , WS, SSH	$y = -0.0156x + 6.325$	0.9946
WS	T_{\min} , T_{\max} , H, SSH	$y = 0.0149x + 3.3841$	0.9993
SSH	T_{\min} , T_{\max} , H, WS	$y = 0.1424x + 4.5985$	0.9981

One implication of the regression equations in Table 2 is that the monthly value of the reference evapotranspiration increases by a value corresponding to the slope of the regression line for each unit increment in the varied parameter. In this case, for each unit increment in T_{\min} , T_{\max} , H, WS and SSH values, the ET_o increased by 0.0289, 0.00974, -0.0156, 0.0149 and 0.142 mm, respectively.

The plotting of the relationship between each climatic variable and ET_o (irrespective of the other input variables) for the two irrigation seasons, is presented in Figures 6 to 10. Maximum temperature showed the best positive correlation, with an r^2 of 0.4871, followed by minimum temperature ($r^2 = 0.3876$), humidity ($r^2 = 0.0361$) and wind speed ($r^2 = 0.0055$). Sunshine hour has

a high negative correlation ($r^2 = 0.8095$). The coefficient of correlation (r) for Figures 6, 7, 8, 9 and 10 are 0.6226, 0.6979, 0.11, 0.0742 and 0.8675, respectively. The performance ratings, thus, are follows: sunshine hour - very high; minimum temperature and maximum temperature – high; humidity - low and wind speed - poor.

Discussion

The relationship between the change in each climatic variable and the corresponding ET_o (other factors being constant) is excellent (Figures 1 – 5), however, the sensitivity coefficients (SC) of ET_o to each variable differ (Table 2). The sensitivity coefficients of the ET_o with respect to the five input parameters were found to differ in the following order: $T_{\max} > WS > SSH > T_{\min} > H$;

ET_o being most sensitive to maximum temperature. This agrees with Emeka *et al.* (2020) where ET_o was found to be most sensitive to maximum temperature in Maiduguri, Sokoto, Kaduna and Jos, Nigeria, on agro-ecological zone basis. The result also corroborates the findings of Vincente-Serrano *et al.* (2014) for meteorological parameters in Spain, except for humidity. Two major observation from the various studies findings are that temperature is prominent as a dominant variable, and, the order in which the variables influence evapotranspiration changes from period to period and from location to location (Ambas and Baltas, 2012).

The negative coefficient of sensitivity for humidity (-0.08) is an indication that high relative humidity has a reducing effect on the potential of reference evaporation. Similar reports have been given by Vincente-Serrano *et al.* (2014) and Hou *et al.* (2013) with relative humidity being a major limiting factor in evapotranspiration.

In Kaduna, Nigeria, based on this on-season study, sunshine hour, maximum temperature and wind speed have more dominance than the minimum temperature and humidity in determining the atmospheric evaporative demand during the full irrigation season (November to March). The wind speed and humidity actually had very poor correlation coefficients; 0.0742 and 0.14, respectively. In a study at Kano, about 210 Km from Kaduna, Isikwue *et al.* (2015) obtained a similar (poor: $r = 0.031$) correlation between ET_o and wind speed. The poor correlation coefficient for wind speed indicates that wind speed is not a significant factor for predicting short term in-season reference evapotranspiration in the study area. The same is true for humidity, having a correlation coefficient of -0.14. The high sensitivity of ET_o to temperature during the dry season is dominant in many study locations (Wang *et al.*, 2009; Admasu *et al.*, 2014; Abarikwu *et al.*, 2019) and this has necessitated the adoption of temperature-based models. More

so, temperature data are more available in agricultural extension services than the other parameters (Wang *et al.*, 2009).

Conclusion

The reference evapotranspiration of Afaka, Kaduna, Nigeria, was found to be sensitive to changes in each perturbed climatic variable. The change, in order of sensitivity is: $T_{max} > WS > SSH > T_{min} > H$. The on-season evaluation of relationship between ET_o and each climatic parameter (irrespective of other input parameters) reveal that ET_o has poor relationship with humidity and wind speed, and good relationship with sunshine hour, maximum temperature and minimum temperature. Hence, radiation and temperature-based estimations of ET_o can be useful in the face of limited or scarce data in the study area. The findings of this study are adaptable to areas with similar climate characteristics. It can also be used as a theoretical basis for future studies on the response of ET_o to climatic change in the study area.

Conflict of Interest

The authors declare that there is no conflicting interest in the publication. No funding was obtained from any funding agency; the research was funded by the authors.

References

- Abarikwu, O.I., Adama, J.C. and Ezeani, E.U. (2019). Relationship between reference evapotranspiration and some climatic parameters, Umudike, Nigeria. *Agricultural Engineering International: CIGR Journal*, 21(1): 28-33.
- Admasu, W., Tadesse, K., Hordofa, T. and Habte, D. (2014). Sensitivity analysis of climatic parameters on reference evapotranspiration calculated by FAO Penman-Monteith equation (CropWat Model 8.0) for sub-humid to humid areas of Arsi Zone,

Ethiopia. *International Journal of Agricultural Science Research*, 3(4): 039-051

Afshar, A. and Saadatpour, M. (2009). Reservoir eutrophication modeling, sensitivity analysis, and assessment application to Karkheh reservoir. *Iran. Environ. Eng. Sci.* 26: 1227- 1238.

Ali, M.H., Adham, A.K.M., Rahman, M.M. and Islam, A.K.M.R. (2009). Sensitivity of Penman- Monteith estimates of reference evapotranspiration to errors in input climatic data. *J. Agrometeorol.*, 11: 1-8

Allen, R.G. (2000). Using the FAO-56 dual crop coefficient method over an irrigated region as part of an evapotranspiration inter-comparison study. *J. Hydrol*, 229(1-2): 27-41.

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 56, United Nations Food and Agriculture Organization, Rome.

Ambas, V.Th. and Baltas, E. (2012). Sensitivity analysis of different evapotranspiration methods using a new sensitivity coefficient. *Global NEST Journal*, 14(3): 335-343.

Caers, J. and Hoffman, T. (2006). The probability perturbation method: a new look at Bayesian inverse modelling. *Math. Geol.*, 38(1): 81-100

Dejonge, K.C., Ahmadi, M., AscoughII, J.C. and Kinzli, K. (2015). Sensitivity analysis of reference evapotranspiration to sensor accuracy. *Computers and Electronics in Agriculture*, 110: 176-186

Devore, J.L. and Peck, R. (2001). Statistics: Exploration and analysis of data. 4th ed. Pacific Grove CA: Duxbury.

Emeka, N., Ikenna, O., Okechukwu, M., Chinenye, A. and Emmanuel, E. (2002). Sensitivity of FAO Penman-Monteith reference evapotranspiration to climatic variables under different climate types in Nigeria. *Journal of Water and Climate Change*(<https://doi.org/10.2166/wcc.2020.200>). Accessed on 12th Sept., 2020.

Fan, Z.X. and Thomas, A. (2013). Spatiotemporal variability of reference evapotranspiration and its contributing climatic factors in Yunnan Province, SW China, 1961-2004. *Clim. Change*, 116: 309-325

Hou, L., Zou, S., Xiao, H. and Yang, Y. (2013). Sensitivity of the reference evapotranspiration to key climatic variables during the growing season in the Ejina oasis Northwest China. *Proceedings of the 2010 International Conference on Combating Land Degradation in Agricultural Areas (ICCLD'10)*, Zi'An City, PR China. 11-15 October 2010.

Isikwue, B.C., Audu, M.O. and Eweh, E.J. (2015). Correlation of evapotranspiration with climatic parameters in some selected cities in Nigeria. *Journal of Earth Sciences and Geotechnical Engineering*, 5(4): 103-115.

Jensen, D.T., Hargreaves, G.H., Temesgen, B. and Allen, R.G. (1997). Computation of ET₀ under non-ideal conditions. *Journal of Irrigation and Drainage Engineering*. 123(5): 394-400

Kabala, Z.J. and Milly, P.C.D. (1990). Sensitivity analysis of flow in unsaturated heterogeneous porous media: Theory, numerical model and its verification. *Water Resources Research*, 20(4): 593-610.

KSWB (2015). Weather data for Kaduna North and South (1986-2015). Kaduna State Water Board, 2015.

Michael, A.M. (2008). Irrigation: Theory and Practice 2nd Ed., Vikas Publishing House PVT Ltd, New Delhi.

NIMET (2015). Climate of Kaduna, Nigeria, 1986-2015, Nigerian Meteorological Agency, 2015.

Raes, D. (2012). Reference Evapotranspiration. Training module 2, Food and Agriculture Organization (FAO), Land and Water Division, September 2012 (<http://indico.ictp.it/event/a12165/session/19/contribution/14/material/0/0.pdf>, Accessed on 29th October, 2020)

Rangel-Peraza, J.G., DeAnda, J., González-Farías, and Rode, M. (2016). Sensitivity and uncertainty analysis on water quality modelling of Agauamilpa reservoir. *J. Limnol.*75(1): 81-92

Vincente-Serrano, S.M., Azorin-Molina, C., Sanchez-Lorenzo, A., Revuelto, J., Morán-Tejeda, E., López-Moreno, J.I. and Espejo, F. (2014). Sensitivity of reference evapotranspiration to changes in meteorological parameters in Spain (1961-2011). *Water Resour. Res.*, 50: 8458-8480.

Wang, Y., Namaona, W., Traore, S. and Zhang, Z. (2009). Seasonal temperature-based models for reference evapotranspiration estimation under semi-arid condition of Malawi. *African Journal of Agricultural Research*, 4(9): 878-886

Willmott, C.J., Ackleson, S.G., Davis, R.E., Fedema, J.J., Klink, K.M., Legates, D.R. and Rowe, C.M (1985). Statistics for the evaluation and comparison of models. *Journal of Geoph. R.*,90: 8995-9005.

Zakari, M.D., Audu, I., Shanono, N.J., Maina, M.M., Abubakar, M.S. and Mohammed, D. (2015). Sensitivity of crop water requirements simulation model (CropWat 8.0) at Kano River Irrigation Project (KRIP), Kano, Nigeria. *Proceedings of the second international inter-disciplinary conference on global initiatives for integrated development (IICGIID)*, Chukwuemeka Odumegwu Ojukwu University, Igbariam, Nigeria, 2-5 September, 2015, Pp. 502-510.

Zazei, T. and Pereira, L.S. (2013). Estimation of ETo with Hargreaves-Samani and FAO-PM temperature methods for a wider range of climates in Iran. *Agric. Water Management*, 121:1-18.