International Journal of Engineering and Emerging Scientific Discovery
ISSN: 2536-7250 (Print): 2536-7269 (Online)
Volume 3, Number 1, March 2018
http://www.casirmediapublishing.com

Percentage Empirical Modelling of Reference Evapotranspiration in a Semi – Arid Region

[1]Edebeatu, C. C., [2]Okujagu, C. U. & [2]Ononugbo, Philomina C.
[1,2]Department of Physics & Industrial Physics, Madonna University, Nigeria
[2]Department of Physics, University of Port Harcourt, Nigeria
Corresponding Author:
Email: edebeatuc@yahoo.com

ABSTRACT

Three reference evapotranspiration (ET_o) models and one measured / observed ($ET_{o(m)}$) were compared using percentage format. Among them the standardized Penman – Monteith model given by Food and Agricultural Organisation (FAO), hereby refer to as FPM 56. One empirical temperature based and one empirical radiation based is among the models used to predict reference evapotranspiration in the semi – arid region of Nigeria. The three models and the observed model were compared to the standard ETo table, alongside the ET_o modelled by the FPM 56. The results showed that percentage modelling approach could be used as an alternative to modelling ET_o, and again that the Allen's standard ET_o table is good comparison format when evaluating ET_o, apart from the normal use of the modelled value within the research work itself, which may not provide the appropriated water requirement for the agricultural field or the need that satisfies the environmental water requirements. The empirical models predicted better results for the semi – arid region closest to the standard ET_o table. The results of the percentage statistical comparisons provided a confident statistical justification for the ranking of the compared models.

***Keywords**: Reference evapotranspiration, Percentage ET_o, standard Allen table, semi – arid region, Nigeria.*

INTRODUCTION

In a semi – arid region water deficit is a major limiting factor towards agricultural crop production and plant growth. In a region of low or insufficient rainfall, irrigation is an important component of its many agricultural purposes. In an environment of rainfed agriculture, it is not all that necessary to determine or establish how much water a field requires for its agricultural crop production. In a semi – arid zone, the reverse is the case as irrigated field is necessary to establish the "when and how" much water that should be applied to any agricultural crop field. This irrigation water demand by the agricultural crop field is determined by the process called ***evapotranspiration*** modelling / estimation procedure. However, modelling / estimation of crop reference evapotranspiration require that weather stations be sited within or near the agricultural field with standardized vegetation surface such as grass or alfalfa [1]. But most regions of the world do not have vegetation sites or ET_o networks which requires high cost of installation and maintenance, and includes third world countries like Nigeria [2-4]. This led to the use of extracted online weather data for the ET_o calculations from the non – ideal sites. This has also led to the formulation and use of empirical model equations in various climate regimes to model reference evapotranspiration. These model equations have limited global validity [1]. To limit these validities and discrepancies, the FAO and the International Commission on Irrigation and Drainage Engineering (ICIDE) have recommended the standardized Penman – Monteith reference evapotranspiration equation[4,3,5] to be used in virtually every climate as the potential evapotranspiration for short grass (short crop) or tall reference crop (alfalfa). The characteristics of this standardized model are defined in [-9]. The aim of this research work is to use percentage guidance / difference to model reference evapotranspiration (ET_o) in a semi –arid of Nigeria. The objective is to provide percentage ETo guidance to irrigation engineers, hydrologist, agronomists and meteorologists in modelling reference crop evapotranspiration. This will also be beneficial for computing field evaporative water demand for both irrigated and rainfed agriculture and for modelling agricultural water consumption in agricultural and natural vegetation.

MATERIALS AND METHODS

MATERIALS

Study Area: The study is centred in the semi – arid region of the North East of Nigeria located at latitudes 10.32^{0}N, 11.83^{0}N and longitudes 9.83^{0}E and 13.15^{0}E for Bauchi and Maiduguri respectively.

Bauchi: The ambient air temperature for Bauchi varied from 28031^{0}C in the rainy season month of August to 35051^{0}C in the dry dusty atmosphere in the month of April. The minimum solar radiation of Bauchi occurred in the month of July at 14.59 MJ/m^2/d, while its maximum solar radiation occurred in the month of December at 23.44MJ/m^2/d[4].

Maiduguri: The ambient air temperature for Maiduguri varied from 32.57^{0}C in the rainy season August to 41.33^{0}C in the hot dry season of April. The maximum solar radiation is assumed to occur in February at 20.76MJ/m^2/d, while the minimum is also assumed to occur in August at 16.01MJ/m^2/d[4].

Methods

The Penman – Monteith of the FAO (FPM 56) written after[11,10,3]for tall reference as;

$$ET_{o,FPM56} = \frac{0.408\Delta(R_n - G) + \gamma\left[\frac{1600}{T+273}\right]u_{2(e_s - e_a)}}{\{\Delta + \gamma(1 + 0.34u_2)\}} \quad \ldots\ldots\ldots\ldots\ldots 1$$

Where;

$ET_{o,FPM56}$ = reference evapotranspiration calculated by the FPM 56 (mm/d);

Δ = slope of the saturation vapour pressure versus air temperature curve (KPa/^{0}C);

R_n = net solar radiation at the crop surface (MJ/m^2/d);

G = soil heat flux (MJ/m^2/d);

γ = psychrometric constant (KPa/^{0}C);

T = daily mean air temperature at 2m height (^{0}C);

U_2 = wind speed at 2m height (m/s);

e_s = saturation vapour pressure (KPa/^{0}C);

e_a = actual vapour pressure (KPa/^{0}C);

$(e_s - e_a)$ = vapour pressure deficit (KPa/^{0}C);

0.408 = conversion factor that converts (MJ/m^2/d) to (mm/d).

McGuiness – Borne (1972): This is an empirical radiation based ET$_o$ model and is written after[12,11].

$$ET_{o,MB} = \left[(0.0082T_m - 0.19)\left\{\frac{R_s}{1500}\right\}\right] 2.54 \quad \ldots\ldots\ldots\ldots\ldots 2$$

And modified in this work as;

$$ET_{o,MB} = \left[(0.82T_m - 0.19)\left\{\frac{R_s}{5}\right\}\right] \quad \ldots\ldots\ldots\ldots\ldots 3$$

Where;

$ET_{o,MB}$ = reference evapotranspiration modelled by the McGuiness – Borne (mm/d);

T_m = daily mean air temperature (^{0}C);

R_s = solar radiation at the crop surface (Mj/m^2/d);

Jensen – Haise, written after[13,14] as;

$$ET_{oJH} = \frac{R_s}{\lambda}(0.0025T_m + 0.8) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .4$$

Where;

ET_{oJH} = reference evapotranspiration (mm/d);

λ = latent heat of vapourization [λ = 2.45 MJ/Kg];

T_m = mean daily average air temperature (^{0}C);

The percentage seasonal ET$_o$ is given by the relation;

$$seasonal\ ET_o = \frac{sum\ of\ standard\ seasonal\ ET_o}{sum\ total\ of\ all\ standard\ seasonal\ ET_{os}}\, x\, \frac{100}{1}\%$$

The percentage pass mark was set at 20%. This is purely an assumption as used in this research as our benchmark.

RESULTS AND DISCUSSION

Bauchi

The results were compared on seasonal basis. Percentage ETo for the observed / predicted models for the station were recorded as follows;

ET$_{o(m)}$ = 21%; FPM 56 = 23%; M-B = 28% and J-H = 28%.

Then as compared with the Allen et al., 1998 standard table, we observed the following the recordings on the seasonal periods as;

ETo(m) recorded four (4) standard seasonal periods accounting for 21%;

FPM 56 recorded four (4) standard seasonal periods which amounted to 23%;
M-B recorded eight (8) standard seasonal periods recording 28% ETo;
J-H recorded five (5) standard seasonal periods accounting for 28% ETo;
The pictorial % chart is shown in figure 1 below using pie chart.

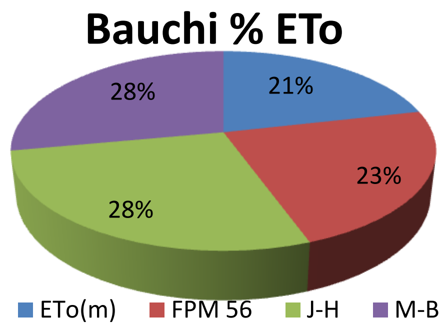

Fig1: %comparison of modelled ETos for Bauchi station

Maiduguri

The results were also compared on seasonal basis as follows;
$ET_{o(m)}$ = 20%; FPM 56 = 9%; M-B = 29% and J-H = 42%.
Thus, as compared with the Allen et al., 1998 standard table, the following seasonal observations were made and recorded as;
ETo(m) recorded four (4) standard seasonal periods amounting to 20%;
FPM 56 recorded two (2) standard seasonal periods amounting to 9%;
M-B recorded six (6) standard seasonal periods which accounted for 29%;
J-H recorded eight (8) standard seasonal periods which also accounted for 42%;
The pictorial % chart is shown in figure 2 below using pie chart

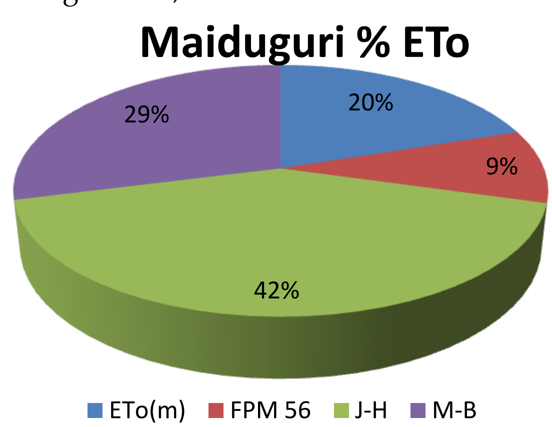

Fig 2: %comparison of modelled ETos for Maiduguri station

The modified empirical temperature and radiation models outperformed the FPM 56 in the two stations under review, followed by the observed model in the semi – arid region.

CONCLUSION

The ETo computation was carried out with three models in the semi – arid region of Nigeria which employed the percentage approach for the modelling of the reference. The models expressed in an explicit form are an indication of a new approach in predicting ETo with percentage model approach. This is basically presented by the statistical error analysis as shown by the results above. The statistical indicators pointed out a clearer evidence of the empirical percentage of the evaluated performance of the ETo models. Hence, empirical percentage, evaluation and performance of the empirical reference ET models has yielded another milestone in the quest for the analysis, evaluation, performance and comparison of empirical ETo models for the good analysis of hydrological management, water management scheme and irrigation scheduling. It has also aided the need for improved agriculture and agricultural activities, food security challenges as well as in paving for green environment and combating climate change scenario. It has its application in shaping the irrigation scheduling and management, and food crop production and combating hunger and food security challenges.

ACKNOWLEDGEMENT

The meteorological data supplied by the Nigerian Meteorological Agency Port Harcourt Rivers state branch is acknowledged.

REFERENCE

1. Alexandris, S., Stricevic, R., and Petkovic, S. (2008). Comparative analysis of reference evapotranspiration from the surface of rainfed grass in central Serbia, calculated by six empirical methods against the Penman-Monteith formula. European Water 21/22, 17-28.
2. Chineke, T. C., Okoro, U. K., Nwofor, O. K., Akunne, O. P., Emelogu, N., Chiemeka, I. U. and Nwokocha, C. O. (2008): "Candidates Equation for the Potential Evapotranspiration: Another step in Humanizing the Water Research Capacity.
3. Chineke, T. C., Idinoba, M. E., and Ajayi, O. C. (2011): "Seasonal Evapotranspiration Signatures under a Changing Landscape and Ecosystem Management in Nigeria: Implications for Agriculture and Food Security."

American Journal of Scientific and Industrial Research Science. HUB, http://www.scihub.org/AJSIR ISSN: I 53-649x, dio:10.5251/ajir.20 11.2.2.191.204.

4. Edebeatu, Chinedu Callistus (2015): "Comparison of Four Empirical Evapotranspiration Models against the Penman – Monteith in a Mangrove Zone. International Journal of Applied Sciences and Engineering Research, Vol.4, Issue 6, 2015. www.ijaser.com.
5. Okoro, U. K., Chineke, T. C., Nwofor, O. K. and A. Ibe. (2008): "Evapotranspiration Leve1s in Owerri, Imo State, Nigeria." International Journal of Natural and Applied Sciences. 4(2): 168 – 173. www.tapasinstitute.org/iournal s/ijomis.
6. 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. Rome: FAO.
7. R. G. Allen, M. Smith, A. Perrier and L.S. Perrier.(2006): "An Update For the Definition of Reference Evapotranspiration." Pages 1 — 34 and, ''An Update for the Calculation of Reference Evapotranspiration." Pages 35 – 92. ICID Bulletin 1994, Vol 43 No.2.
8. Pereira, L.S., Pereira, A., Allen, R.G. and Alves, I. (1996): Evapotranspiration: Review of concepts and future trends. Journal of Irrigation and Drainage Engineering, ASCE 25.
9. Walter, I.A., Allen, R.G., Elliott, R., Itenfisu, D., Brown, P., Jensen, M.E., Mecham, B., Howell, T.A., Snyder, R., Eching, S., Spofford, T., Hattendorf, M., Martin, D., Cuenca, R.H. and Wright, J.L. (2005): The ASCE Standardized Reference Evapotranspiration Equation. Final Report (ASCE – EWRI). Pr. Eds: Allen, R.G., Walter, I.A., Elliott, R., Howell, T., Itenfisu, D. and Jensen, M. Environmental and Water Resources Institute. 2005. Task Committee on Standardization of Reference Evapotranspiration of the Environmental and Water Resources Institute.
10. Edebeatu, Chinedu C. and Okujagu, Charity U. (2015): "New Correlation for Estimating Reference Evapotranspiration in Semi –

arid Region." International Journal of Scientific Research. Volume: 4|Issue: 12|December 2015 – ISSN No 2277 – 8179.

11. Edebeatu, Chinedu C., Okujagu, Charity U., Ozuomba, Jude O., Owate, Israel O. and Nwokocha, Cecily O. (2014): "Seasonal Calibration of the Hargreaves Equation for Estimating Monthly Reference Evapotranspiration in a Data Sparse Region." Merit Research Journal of Environmental Science and Toxicology (ISSN: 2350 – 2266) Vol.2(4) pp. 076 – 085, July, 2014. Available online. http://www.meritresearchjournals.org/est/index.htm. Subtropical Africa. International Science Research Journal 1(2): 72 — 81. ISSN: 2006 — 1730.
12. Faybishenko, Bori (2012): ''Fuzzy Probabilistic Calculations of' Evapotranspiration ET – Remote Sensing and Modeling. "Dr, Ayse Irmak (Ed). ISBN: 978 953 – 307 – 808 – 3, InTech. http://www.intechopen.com/books/ET-remote-sensing-and-modeling-and-modeling/Fuzzy-probabilistic-calculations-of-evapotranspiration
13. Madubuike, C. N. (2005). "The Sensitivity of Evapotranspiration Models to Errors in Model Parameters." Nigerian Journal of Technology, vol.24. No.2, September 2005.
14. Rosenberry, D. O., Stannard, D.I., Winter, T.C., Marge L. Martinz (2004). "Comparison of 13 Equations for Determining Evapotranspiration from a Prairie Wetland, Cottonwood Lake Area, North Dakota U.S.A. Wetlands (2004): 483.doi:1672/0277 – 5212 (2004) 024 [0483: CODEFDE]2.0.Co;2. Springer.