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Estimation of Reference Evapotranspiration of Ussa, Taraba State

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ABSTRACT
The determination of the reference evapotranspiration for Ussa local government area of Taraba state has been carried out. For effective irrigation management, plant water estimation, and irrigation system design in a semi-arid area, reference evapotranspiration assessment must be accurate. Due to the connection between climate change and water scarcity, research on evapotranspiration is also crucial and timely. The reference evapotranspiration for Ussa (latitude 7°10′60N, longitude 10° 01 ′ 60″E) was estimated and analyzed using the Hagreaves – Samani Model for the period of 11 years (2011-2021) to observe it trends and variation. Data for the research were collected from the National Aeronautics and Space Administration with the resolution of 0.5 x 0.625 lat-long. The results of this work show that the reference evapotranspiration is generally high from January (9.06 mm/day) to March (8.64 mm/day) and drops gently from April (7.89 mm/day) to August (4.77 mm/day) with a gradual rise from September (5.41 mm/day) to December (8.08 mm/day), which is consistent with the annual pattern of solar radiation intensity. This result is timely for farmers in this area to help in determining when to farm and irrigate their farms in order to maximize the use of available water for a bumper harvest.

Keywords:
Evapotranspiration,
Model,
Irrigation,
Irradiance.

INTRODUCTION

Global food security will be further burdened by the world's continually growing population, particularly in regions where freshwater has not been sufficient for both drinking and food production (Barrett, 2021). The growing reliance of irrigated agriculture on crop output to meet food demand is even more worrisome (Viviroli et al., 2020). Improvements in water use efficiency and the operation of big irrigation systems are sought after due to considerations such as competition for water, high pumping costs, the difficulty of storing and delivering water, and environmental concerns (Koech and Langat 2018Agricultural managers have relied primarily on evapotranspiration (ET) measurements or estimates for the aim of timely and effective water application (Pôças et al., 2020). Accurate reference evapotranspiration (ETo) estimation is indispensable, particularly in arid regions where fresh water supplies are scarce and water resources are limited (Belay et al., 2019). Its area of application includes scheduling of irrigation design, agricultural water management, crop growth simulation and modeling, and drought assessment (Hussain, et al., 2019).

The word 'Evapotranspiration (ET)' is a collective term, whereby Water is lost to the atmosphere from plant through transpiration and from the soil surface evaporation. Evaporation in its context means a process whereby water molecules in its liquid state turn into vapour and while transpiration involves the removal of water droplets found in plant tissues to the atmosphere (Singh et al., 2018). Such water molecules need energy to change from a liquid to a gas, and during the transition, a quantum of energy is required. Energy from the sun (solar energy) is the main source of this energy and, to a lesser extent, air temperature are both responsible for supplying this energy (Zhao et al., 2018). There is no simple method to distinguish between evaporation and transpiration because they happen concurrently (Islam et al., 2022).

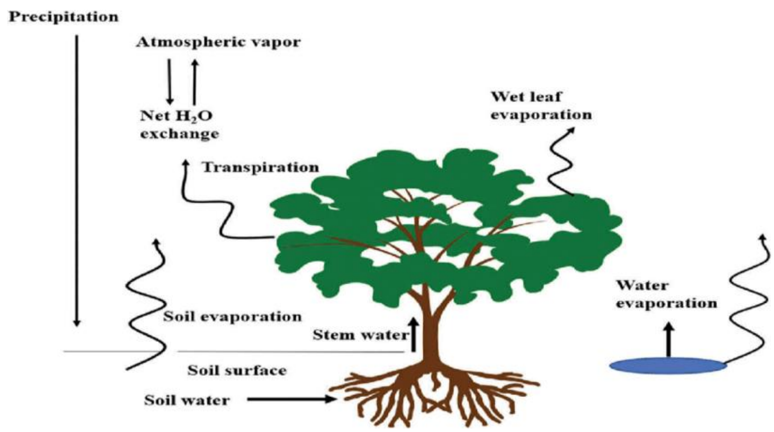

Figure 1: Evapotranspiration (Zhang *et al.*, 2020)

The word 'reference evapotranspiration' means the evapotranspiration from a proposed reference crop, which is grass of height 0.12 m, albedo 0.23 and surface resistance 70 sm^{-1} (Patle and Singh, 2015). Lysimeter or evapotranspirometer is the device used that can be employed to measure evapotranspiration, but they are often enormous, expensive to acquire, and difficult to find, as claimed by Gurski et al. (2018). Due to these facts, meteorologists and climatologists have agreed to estimating this atmospheric parameter using empirical models from relationships that exist between measured atmospheric variables at the surface. Such parameters that are primarily connected to ET are air temperature, wind speed, humidity, and solar radiation (Khoshravesh et al., 2017). In an effort to produce a standardized and widely accepted technique for estimating reference evapotranspiration for the precise computation of crop water requirements, numerous models had been put out by numerous authors (Majidi *et al.*, 2015; Tabari and Talaee, 2011; Olmos- Gimenez, and García-Galiano, 2018; Moratiel *et al.*, 2020). Some of these models include these (1) the Temperature based model (Blaney−Criddle 1950; Thornthwaite 1948; and Hargreaves and Samani, 1982), (1) Solar Radiation based model which comprises the FAO-24 model (Makkink, 1957) and the Priestley-Taylor model (Priestley and Taylor 1972), (3) the mass-transfer models which is based on vapour pressure or relative humidity by Rohwer (1931) and Harbeck (1962) and (4) a combination models which is based on the energy balance and mass transfer principles comprises the Penman model (Penman 1948) and the modified Penman model (Doorenbos and Puritt, 1977). The equation of some of these models are presented the table 1.

Where R_n is net radiation (MJ $m^{-2}day^{-1}$), Δ is slope of the vapour pressure curve (kPa $°C^{-1}$), α is PT coefficient, γ is psychrometric constant (kPa $°C^{-1}$), λ is latent heat of vaporization ($MJkg^{-1}$), *RH* is daily mean relative humidity (%) and u_{2d} is mean wind speed of daylight hours at 2m height (ms^{-1}), , r_a is aerodynamic resistance (sm^{-1}), *G* is soil heat flux (MJ $m^{-2}day^{-1}$) , $u_{2\,d}$ is daily mean wind speed at 2m height (km day^{-1}), r_c is canopy resistance (sm^{-1}), e_s is saturation vapor pressure (kPa) and e_a is actual vapor pressure (kPa), ET_0 is monthly reference evapotranspiration (mm day^{-1}), T_a is monthly mean air temperature (°C) T_{max} is mean monthly maximum temperature (°C), and T_{min} is mean monthly minimum temperature.

Table 1: Some selected Evapotranspiration models

Model name	Model Equation	Reference
FAO-24	$ET_o = a_2 + b_2\left(\frac{\Delta}{\Delta+\gamma}\right)\frac{R_n}{\lambda}$ $a_2 = -0.3$ $b_2 = c_0 + c_1RH + c_2u_{2d} + c_3RHu_{2d} + c_4RH^2 + c_5u_{2d}$ $\Delta = \frac{4098e_s(T_a)}{(T_a+237.3)^2} = \frac{2504\left(\frac{17.27T_a}{T_a+237.3}\right)}{(T_a+237.3)^2}$, $\lambda = 2.501 - (2.361 \times 10^{-3})T_a$	Makkink, 1957

Priestley-Taylor-model	$ET_0 = \frac{\alpha \frac{\Delta}{\Delta+\gamma}(R_n - G)}{\lambda}$	Pereira *et al.*, (1995)
Pereira model	$T_0 = E_{pan} - K_1$ $K_1 = \frac{0.85(\Delta+\gamma)}{[\Delta+\gamma(1+0.33u_2)]}$	Pereira *et al.*, (1995)
Mass-transfer Model	$ET_0 = 0.1572.\sqrt{3.6u_2}.(e_s - e_a)$	Mahringer (1970)
Hargreaves-Samani Model	$ET_0 = 0.0023R_n\,(T_a + 17.8)\sqrt{(T_{max} - T\_min)}$	Hargreaves and Samani (1982)

Therefore, this research work employed the Hargreaves Samani model because of its less meteorological inputs and high performance when compared with other models in arid and semi-arid regions (Er-Raki *et al.* 2010, Sabziparvar and Tabari 2010, Mohawesh, 2011,).

The main aim of this study is to estimate the crop reference evapotranspiration for drought assessment in Ussa using the Hargreaves Samani model.

MATERIALS AND METHODS

Materials

The primary materials employed for this study are set of meteorological data collected from the archive of NASA (National Aeronautics and Space Administration) as the solar radiation, the minimum and maximum temperatures as well as the mean temperature for estimating the reference evapotranspiration (ET0) for USSA, which is at latitude 7°11'00" N and longitude 10°02'00" E (figure 2). The data covered the 11 years (2011-2021).

Method

The Hargreaves-Samani Model was used to estimate the reference evapotranspiration (ET_o) by incorporating the necessary meteorological parameters.

$$ET_0 = 0.0023R_n\,(T_a + 17.8)\sqrt{(T_{max} - T\_min)} \quad (1)$$

Where R_n is extra-terrestrial radiation ($MJm^{-2}\ day^{-1}$)
T_a is monthly mean air temperature (°C)
ET_0 is monthly reference evapotranspiration ($mmday^{-1}$);
T_{max} is mean monthly maximum temperature (°C) and
T_{min} is mean monthly minimum temperature.

Other necessary conversions were made like converting the solar radiation from kW-hr/m²/day to MJ/m²/day.

RESULTS AND DISCUSSION

The following are the results and the graphs for the reference evapotranspiration (ET_o) for the study area using the HGS Model.

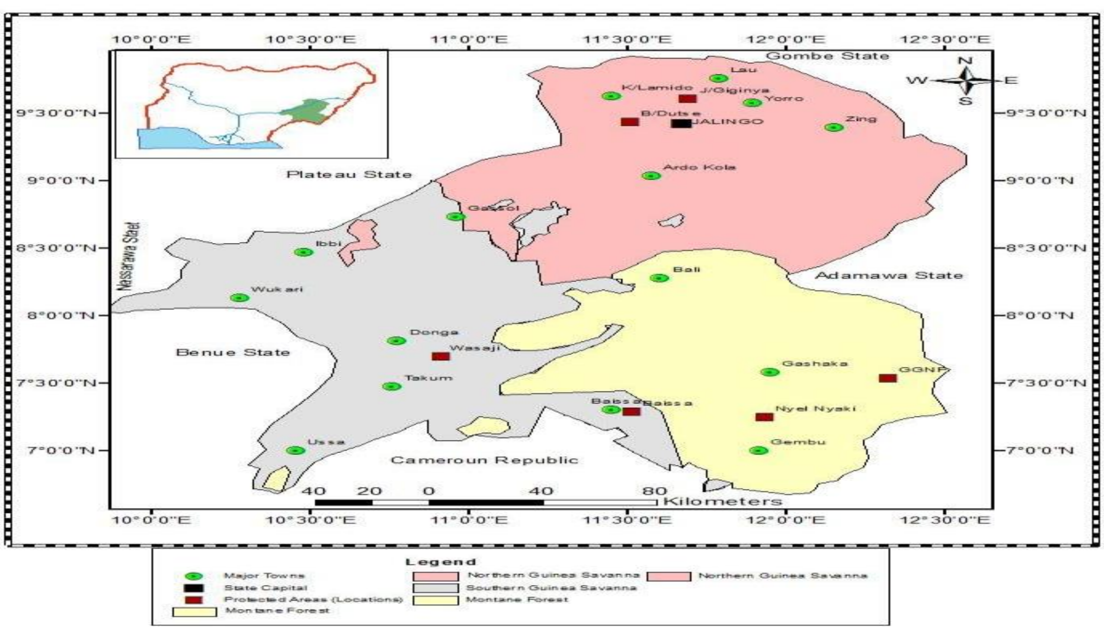

Figure 2: Map of Taraba state showing the major ecological zones and the study area source: GIS MAUTEH Yola, 2017

Table 2: Determination of Monthly *ETo* using Hargreaves-Samani Model for 2011

Month	T_{max}	T_{min}	Ra (kW-hr/m²/day)	Ra (MJ/m²/day)	T_a = T_{mean}	Ta+17.78	T= T_{max}-T_{min}	T^0.5	ET_o
JAN	32.11	11.87	6	21.6	21.99	39.77	20.24	4.4989	8.8888
FEB	31.98	19.46	5.38	19.368	25.72	43.5	12.52	3.5384	6.8565
MAR	34.62	21.22	6.34	22.824	27.92	45.7	13.4	3.6606	8.7819
APR	32.82	21.23	5.55	19.98	27.025	44.805	11.59	3.4044	7.0096
MAY	31.82	21.4	5.15	18.54	26.61	44.39	10.42	3.2280	6.1102
JUN	30.76	20.55	4.53	16.308	25.655	43.435	10.21	3.1953	5.2057
JUL	29.62	20.19	4.33	15.588	24.905	42.685	9.43	3.0708	4.6995
AUG	28.67	19.55	4.08	14.688	24.11	41.89	9.12	3.0199	4.2736
SEP	29.12	19.81	4.51	16.236	24.465	42.245	9.31	3.0512	4.8135
OCT	29.83	20.37	5.21	18.756	25.1	42.88	9.46	3.0757	5.6894
NOV	30.55	17.02	5.98	21.528	23.785	41.565	13.53	3.6783	7.5702
DEC	30.21	15.42	5.82	20.952	22.815	40.595	14.79	3.8458	7.5233
ANN	34.62	11.87	5.24	18.864	23.245	41.025	22.75	4.7697	8.4899

Table 3: Monthly Averages of the *ETo* using Hargreaves-Samani Model from 2011 – 2021

Month	ET_o 2011 (mm/day)	ET_o 2012 (mm/day)	ET_o 2013 (mm/day)	ET_o 2014 (mm/day)	ET_o 2015 (mm/day)	ET_o 2016 (mm/day)	ET_o 2017 (mm/day)	ET_o 2018 (mm/day)	ET_o 2019 (mm/day)	ET_o 2020 (mm/day)	ET_o 2021 (mm/day)	$\overline{ETo}$ (mm/day)
JAN	8.89	8.23	8.26	8.31	9.19	9.60	8.31	9.88	8.62	10.52	9.87	9.06
FEB	6.86	7.07	9.06	9.26	7.81	10.47	10.14	8.98	9.09	10.70	10.51	9.09
MAR	8.78	9.25	7.74	8.04	7.66	7.15	9.58	8.30	9.80	9.18	9.57	8.64
APR	7.01	6.73	6.92	6.64	9.34	7.39	8.35	7.60	9.01	8.04	9.74	7.89
MAY	6.11	6.08	5.95	6.94	8.30	6.99	7.67	7.86	8.63	7.18	8.02	7.25
JUN	5.21	5.67	5.27	5.85	5.44	6.30	6.00	6.29	7.15	6.50	6.98	6.06
JUL	4.70	4.56	4.65	4.73	5.56	4.96	4.76	5.28	5.35	4.77	5.45	4.98
AUG	4.27	4.33	4.12	4.62	4.99	4.70	4.61	5.07	4.86	5.68	5.19	4.77
SEP	4.81	5.53	5.74	5.39	5.43	5.36	5.18	5.86	5.08	5.10	6.02	5.41
OCT	5.69	5.95	6.15	6.61	6.07	6.49	6.27	6.82	5.55	6.62	7.23	6.31
NOV	7.57	6.61	7.08	7.40	7.72	7.47	7.40	7.69	7.65	7.96	8.49	7.55
DEC	7.52	7.83	7.66	7.70	8.25	7.96	7.45	8.05	8.82	8.71	8.96	8.08
ANN	8.49	8.71	8.18	8.48	9.38	9.49	9.01	9.28	9.30	10.14	9.72	9.11

The results in table 1 show the mean monthly ET_0 for the study area within the period of study. The results reveal that the reference evapotranspiration is generally high from January to March and decreases gently from April to August with a gradual rise from September to December (as seen in figure 3), which is in accordance with the intensity of solar radiation pattern for the year. The maximum temperature of 39.48°C and radiation of 22.1MJ/m²/day occurred from February to March while the minimum temperature of 29.63 °C and radiation of 15.68MJ/m²/day occurred from July to August. Generally, February is the driest month with highest average ET_0 of 9.09 mm/day while August is the wettest month of the year with the least average ET_0 of 4.77mm/day in Ussa. According to Rácz *et al.,* (2013), the value of ET_0 increases when global radiation levels rise. On the account of the annual trend, the year 2013 has the lowest recorded ET_0 with the highest in the year 2020 as depicted in figure 4.

The regression analysis showed a positive trend in ET_0 with an R^2 value of 0.696 during the study period. This is similar to the work of Ochoche and Odeh (2019) and Isikwue *et al.*, 2014. The implication of this is that there is an increasing trend of ET_0 in Ussa Local government of Taraba state.

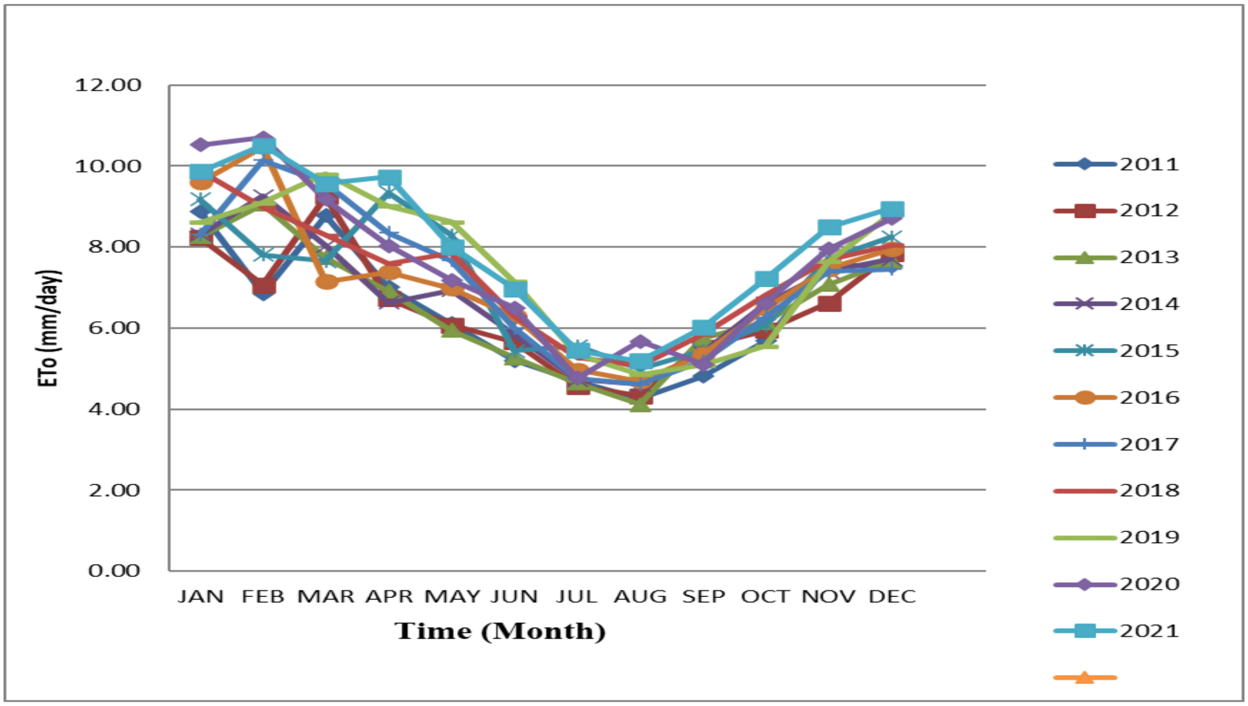

Figure 3: Monthly ET_o Variation from 2011-2021

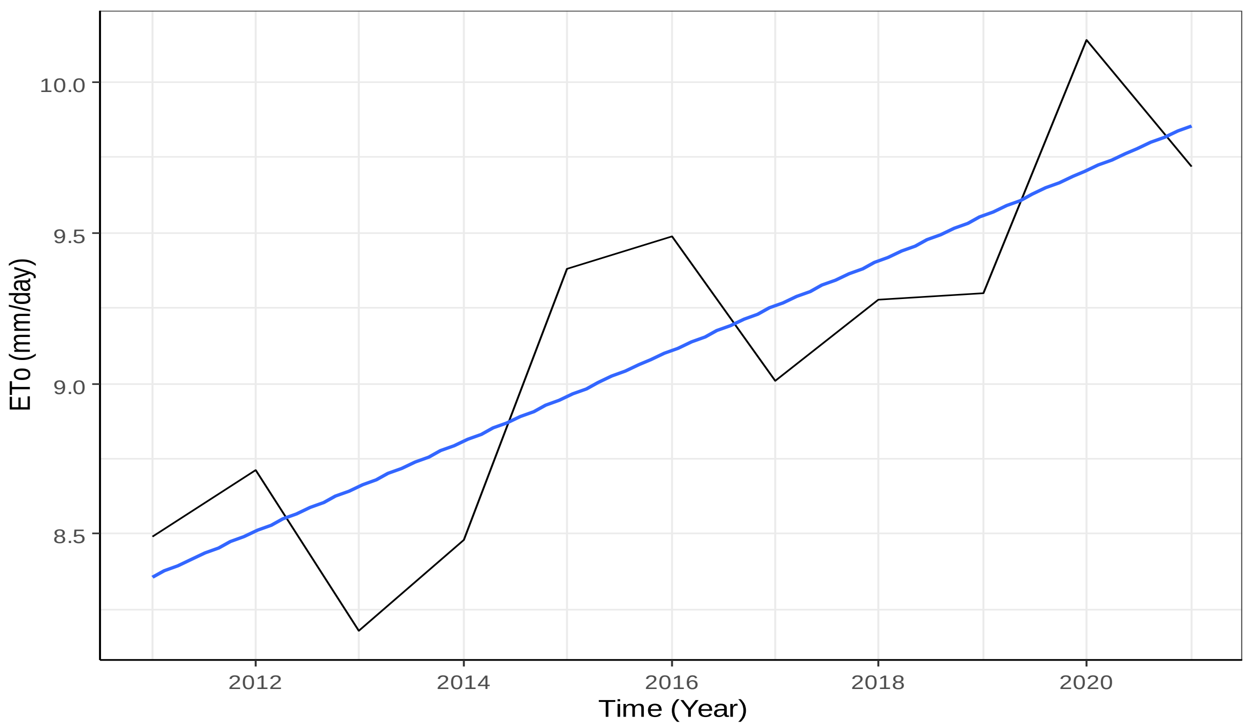

Figure 4: Inter-annual trends of ET_o from 2011-2021

CONCLUSION

The HGS model has been used to evaluate the reference evapotranspiration for Ussa from 2011 to 2021. The highest values observed from February to March can be accounted for by the high solar radiation received during this period of the year (dry season) while the low values from April to September are likely due to high humidity. It was also revealed that ET_0 is on its increasing trend in the study area. Farmers can use this finding to plan their planting and irrigation schedules.

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