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EVALUATION OF CONSUMPTIVE USE OF WATER FOR THE GEO-POLITICAL ZONES OF NIGERIA USING RICE AS A REFERENCE CROP

by

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Abstract

This study focused on the estimation of crop water requirement of rice to avoid over or under irrigation which may negatively affect crop yields. In this study, agro-climatic data (2013-2024) were collected and analyzed. The data obtained include; minimum and maximum temperature (°C), relative humidity (%), wind speed (km/day), sunshine (hr /day) and radiation (MJ/m^2/day). FAO Penman-Monteith model is a universal standard model used to compute the mean monthly reference evapotranspiration (ET_o) using the mean monthly weather data for six weather stations in Nigeria. The mean monthly and annual ET_o estimated for each weather station were multiplied by the average crop coefficient (K_c) of rice to determine the crop water requirements. The empirical crop growth stage coefficient is used to scale the FAO 56 Penman-Monteith model to a specific crop (Rice). The mean annual ET_c computed by FAO 56 Penman-Monteith model for all the six zones were graphically compared to identify the differences in evapotranspiration losses across the study area. The study concluded that, irrigation practices are best done by estimating the consumptive use of water in order to avoid over or under irrigation which may negatively affect crop yields.

Keywords: Consumptive use of Water, Geopolitical Zones of Nigeria & Rice.

Introduction

Estimating consumptive use of water by computing crop evapotranspiration is a widely used method (Ray and Dadhwal, 2000). There are majorly two approaches for estimating consumptive use of water by crop: direct methods and indirect methods. The direct methods involve the use of instruments such as Class A evaporation pan, Sunken Colorado pan, Drainage Lysimeter, Energy budget approach, etc.

Class A evaporation pan is a standard for the measurement of water evaporation and it provides a measurement of the combined effect of temperature, humidity, wind speed and sunshine on the reference crop evapotranspiration (ET_o). It is circular, 120.7cm in diameter and 25cm deep. The Pan is mounted on a wooden open frame platform which is 15cm above ground level. The soil is built up to within 5cm of the bottom of the pan and the pan must be leveled. Christiansen in 1968, related 'Class A' pan evaporation to meteorological variables in order to estimate reference crop evapotranspiration. Sunken Colorado pans are sometimes preferred in crop water requirements studies as these pans give a better direct estimation of the reference evapotranspiration than does the Class A pan. (Allen *et al.,* 1998).

Lysimetry determination of crop water requirement is a process whereby Lysimeter is used to determine the rate of evapotranspiration of reference crop. Lysimeter have been described as a probable instrument for determining the actual crop water requirement. However, the use of Lysimeter for the determination of reference evapotranspiration (ET_o) at various growing stages of crop would help in the computation of ET crop, (Allen and Nwa 1997). The indirect methods involve the use of evapotranspiration (ET) models. The ET models include; Blaney Criddle, Jensen Haise, Christiansen, Hargreaves, Priestley Taylor, FAO Penman Monteith, ASCE Penman Monteith, etc.

There are several models to calculate ET_o, but their performance in different environment is diverse since all of them have some empirical background (Pereira and Pruitt, 2004). The FAO Penman-Monteith model has been considered the best to estimate ET_o for more than a decade. This model accounts for aerodynamic as well as physiological parameters which requires several meteorological parameters such as net radiation, air temperature, vapour pressure deficit, relative humidity, sunshine and wind speed (Sentelhas *et al.,* 2010; Pankaj *et al.,* 2016). Reference evapotranspiration (ET_o) is 'the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12m, a fixed surface of 70 sec/m and an albedo of 0.23 closely resembling the evapotranspiration (ET) from an extensive surface of green grass of uniform height, actively growing, well-watered and completely shading the ground' (Suat and Dorota, 2014).

The ET_o estimation models can be grouped in view of their data necessities as temperature based, radiation based and combination based. The execution of the particular ET_o estimation model varies with climatic conditions and accessibility of meteorological information and the data prerequisites change from model to model (Jensen *et al.,* 1990). The number of meteorological stations where reliable data for these parameters exist is an even smaller subset. This is especially true in developing countries where reliable collection of wind speed, humidity and radiation is limited (Droogers and Allen, 2002).

The evapotranspiration process is determined by the amount of energy available to vaporize water. Solar radiation is the largest energy source and is able to change large quantities of liquid water into water vapour. The potential amount of radiation that can reach the evaporating surface is determined by its location and time of the year. Due to differences in the position of the sun, the potential radiation differs at various latitudes and in different seasons. The actual solar radiation reaching the evaporating surface depends on the turbidity of the atmosphere and the presence of clouds which reflect and absorb major parts of the radiation (FAO, 1998).

In practice, the estimation of ET_c requires first calculating reference evapotranspiration (ET_o) and then applying the proper crop coefficient (K_c) to estimate actual crop evapotranspiration

(ET_a) (Suat and Dorota, 2014). The K_c is defined as the ratio of ET_c to ET_o and is used to scale the ET model to a specific crop. This coefficient depends on several factors including crop type, stage of crop growth, canopy height and density. Consequently, different crops will have different K_c coefficients (Allen *et al.,* 1998). A fully grown rice crop will need more water than rice which has just been planted. When the plants are very small the evaporation will be more than transpiration. When the plants are fully grown the transpiration is more important than the evaporation. During the initial stage of rice, evapotranspiration is estimated at 50% of crop water requirement. At crop developmental stage, the evapotranspiration gradually increases from 50% to the maximum crop water requirement and the maximum crop water requirement is reached at the end of the crop development stage which is the beginning of the mid-season stage. With respect to the late season stage which is the period during which the crop ripens and is harvested, the crop water requirement is minimal to only some 25% (Allen *et al.*, 1998).

Study Area

Nigeria is located in the tropical zone of West Africa within Africa continent of the world between latitudes 4°N and 14°N and longitudes 2°2'E and 14°30'E, and has a total area of 923,768 km^2. It has evolved over time and space in terms of administrative structures and nature of governance. It started as an amalgamated British colony in 1914, became a federation in 1963; then became independent in 1960 as a two-unit region comprising the Northern and Southern provinces. Today Nigeria consists of 36 states and the Federal Capital Territory located at Abuja as shown below:

Figure 1: Map of Nigeria Showing the Different States and the FCT.

Source: FAO (2009)

Data Collection

Twelve years of weather data were collected (2013-2024) from the Nigerian Meteorological Agency (NIMET), Abuja, Nigeria. The data involved in this study are minimum and maximum temperature (^oC), relative humidity (%), wind speed (km/day), sunshine (hr. /day) and radiation ($MJ/m^2/day$).

Data Analysis

The daily weather data values collected were summed and averaged to obtain the mean daily and monthly values. Similarly, the mean monthly values across the period of record for each station were averaged to obtain the mean annual values used for the computation of reference evapotranspiration (ET_o) for the six geopolitical zones of Nigeria. Six different evapotranspiration (ET) models were used in this study including; FAO 56 Penman-Monteith, ASCE-Penman Monteith, Thornth-Waite, Blaney-Criddle, Priestley-Taylor and Hargreaves to estimate mean monthly Reference evapotranspiration (ET_o) for the six geopolitical zones of Nigeria (North-East, North-East, North-Central, South-West, South-East and South-South).

An Excel computer program was developed to calculate ET_o for the ET models on monthly basis using the mean monthly weather data for the six stations. The mean monthly and annual ET_o estimated for each weather station were multiplied by the average crop coefficient (K_c) of rice to determine the crop water requirements. The empirical crop growth stage coefficient is used to scale the FAO 56 Penman-Monteith model to a specific crop (Rice). The mean annual ET_c computed by FAO 56 Penman-Monteith model for all the six zones were graphically compared to identify the differences in evapotranspiration losses across the study area.

Results and Discussion

FAO Penman-Monteith model is used to compute the mean monthly total reference evapotranspiration (ET_o) and multiplied by crop coefficient (K_c) of Rice to obtain the mean monthly crop water requirement (ET_c) for the six geopolitical zones of Nigeria [North-East: NE (Yola), North-West: NW (Sokoto), North-Central: NC (Lokoja), South-East: SE (Enugu), South-West: SW (Lagos) and South-South: SS (Port-Harcourt)] using weather data from 2013-2024 collected from NIMET, Abuja, Nigeria. The mean monthly crop evapotranspiration (ET_c) values obtained by averaging the mean monthly values across the period are shown in Table 1 and are plotted against the year of record for all the six weather stations (Figure 2).

The FAO Penman-Monteith ET_c estimates across the six weather stations in the study area ranged from the lowest value of 2.58 mm/day for South-West to highest value of 15.03 mm/day for North-Central. The lowest ET_c estimates experienced at North-East, North-West, North-Central, South-East, South-West and South-South are 3.35 mm/day in 2011, 2.53 mm/day in 2011, 7.17 mm/day in 2012, 5.47 mm/day in 2010, 0.01 mm/day in 2009 and 5.92 mm/day in 2010, respectively.

Table 1: Crop Evapotranspiration (ET_c) mm/day, using FAO Penman-Monteith Model

Year	North-East	North-West	North-Central	South-East	South-West	South-South
2013	11.45	11.22	11.97	11.63	4.47	11.67
2014	15.67	13.60	14.78	15.03	5.13	12.58
2015	20.73	20.45	16.30	15.30	4.20	20.92
2016	15.95	23.62	16.28	10.53	3.12	67.50
2017	9.58	16.07	12.17	7.50	1.95	15.42
2018	4.22	10.15	9.20	6.12	0.01	7.72
2019	4.18	4.93	22.37	5.47	0.02	5.92
2020	3.35	2.53	7.38	5.75	2.03	6.38
2021	3.57	3.13	7.17	5.78	1.75	6.38
2022	5.57	9.28	8.25	6.13	1.63	7.58
2023	8.90	13.27	12.50	8.05	2.30	8.80
2024	10.22	`11.58	11.05	9.75	4.38	9.53
Average	**9.45**	**11.65**	**12.45**	**8.92**	**2.58**	**15.03**

The highest ET_c estimates recorded at North-East, North-West, North-Central, South-East, South-West and South-South are 20.73 mm/day in 2006, 23.62 mm/day in 2007, 16.30 mm/day in 2006, 15.30 mm/day in 2006, 5.13 mm/day in 2005 and 67.50 mm/day in 2007, respectively. The mean monthly average ET_c estimates by the FAO Penman-Monteith model for the North-East (Yola), North-West (Sokoto), North-Central (Lokoja), South-East (Enugu), South-West (Lagos) and South-South (Port Harcourt), are found to be; 9.45, 11.65, 12.45, 8.92, 2.58, and 15.03 respectively.

Figure 1 shows that ET_c estimates at North-East and North-West are in closest agreement followed by North-Central ET_c estimates, while the ET_c as estimated by South-East, South-West and South-South show an under-estimated trend. This may be partly due to the lower latitudes and vapour pressure deficits at these weather stations.

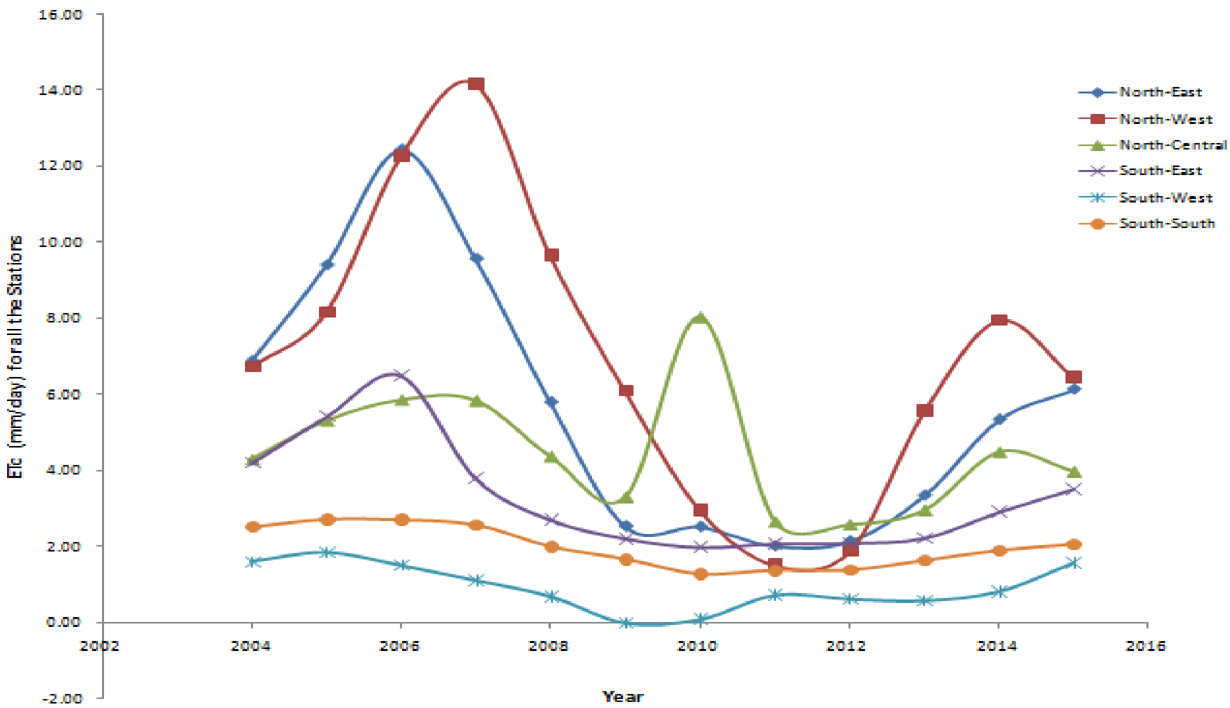

Figure 1: Mean Monthly ET_c 3Estimates by FAO Penman-Monteith Model for Six Weather Stations.

Conclusion

The FAO 56 Penman-Monteith model is well established as the accurate and robust model to estimate ET_o. The FAO Penman-Monteith ET_c estimates across the six weather stations in the study area ranged from the lowest value of 2.58 mm/day for South-West to highest value of 15.03 mm/day for North-Central. The mean monthly average ET_c estimates by the FAO Penman-Monteith model for the North-East (Yola), North-West (Sokoto), North-Central (Lokoja), South-East (Enugu), South-West (Lagos) and South-South (Port Harcourt), are found to be; 9.45, 11.65, 12.45, 8.92, 2.58 and 15.03 respectively. The ET_c estimates at North-East and North-West are in closest agreement followed by North-Central ET_c estimates, while the ET_c as estimated by South-East, South-West and South-South show an under-estimated trend.

Recommendations

The mean monthly average ET_c estimated by FAO Penman-Monteith model for Yola, Sokoto, Lokoja, Enugu, Lagos and Port Harcourt can be used in these locations for irrigation practices for rice in order to avoid over or under irrigation which may negatively affect crop yields.

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