STOCHASTIC COMPARISON OF THE EFFECT OF RADIATION AND TEMPERATURE ON COMSUMPTIVE USE IN A SEMI – ARID REGION OF NIGERIA

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ABSTRACT
This paper focuses on the understanding of using empirical relations of radiation and temperature to model the effect of consumptive use in the semi – arid region of Nigeria, bearing in mind that the water demand of any agricultural field is determined by meteorological factors. Climate is the main stay in determining weather parameters like energy balance, humidity and vapour pressure deficit which affect the magnitude of vapour flux at the surface of the atmosphere. Some weather variables such as wind speed, relative humidity, solar radiation, temperature to a greater extent helps shape agricultural yield, hence the use of simple weather variables as radiation and temperature as an alternative in estimating evapotranspiration (ET). In this work, we modeled field consumptive use using empirical models of radiation and temperature base models and compared to the standard of the Food and Agricultural Organization (FAO) Penman – Monteith (PM) in the semi – arid region of Nigeria. The results showed that the empirical models of radiation and temperature have significant effect on the consumptive use. In Alkaleri Penman – Monteith (PM) correlated well with Baier-Robertson $(B\text{-}R)_{(a)}$ and Baier-Robertson $(B\text{-}R)_{(b)}$ at 75.0% and 88.2% respectively, whereas in Bauchi PM correlated with B-R(a), B-R(b) and J-H at 81.1%, 81.0% and 70.6% respectively. Therefore, the use of empirical models is an essential tool for modeling reference evapotranspiration in a semi – arid region in the absence of full meteorological data. Empirical models are veritable alternatives for the estimation, modeling and comparison because of its quality effect on the agricultural field.

Keywords: Radiation, Temperature models, semi – arid region, stochastic comparison, consumptive use.

INTRODUCTION

With the increasing rate of drought in the desert and sub – desert regions of the world today, water scarcity has become a major problem facing people living in the arid and semi – arid regions. This has led to the want of scarce resources. In today`s modern society, available water resource conflicts are as a result of multiple uses; industrial, agriculture, ecosystem and domestic due to increase in population growth (Daniel et al., 2010), urbanization, industrial setups and migration. The later comes in various forms such as migration by herdsmen both for

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green pasture and agriculture as well as war turn cities and other natural disasters. In an environment besieged by climate change and global warming, sea level rise, artic ice melting, drought, desertification, disappearing of streams and lakes, hunger, famine and war and other natural and man - made disasters have plagued man into a green search for a better world(Edebeatu, 2010). To utilize the available scarce commodity (water and green vegetation), civil engineers and scientists have paved way for modern irrigation giving birth to a new way of agriculture and modern farming rather than seasonal rainfed agriculture (Edebeatu et al., 2014). Good irrigation scheduling and agricultural water crop production require accurate estimates of evapotranspiration (Ahaneku, 2011).

Evapotranspiration is a complex quantity that demands a sophisticated device to measure its physical variables (Chineke et al., 2008; Edebeatu et al., 2014) or soil water balance using lysimeters (Sheikh & Mohammadi, 2013). Different methods have been developed and deployed in a bid to obtain accurate measurement of evapotranspiration in different climatic regimes. To compute evapotranspiration requires complete meteorological and climatological parameters that use the combination equation model of the Penman – Monteith. Unfortunately, weather service stations and these instruments are not readily available mostly in developing countries like Nigeria (Chineke et al., 2008; Edebeatu et al., 2014). The challenge is overcome by the use of empirical and semi – empirical equation models developed over the years in the absence of the full Penman – Monteith (PM) model. These empirical models have been tested in various geographical and climatological regions of the world varying from the tropical to the temperate regions as reported in many literatures (Aheneku, 2011; Chineke et al., 2008; Davide & Baiyeri, 2011; Fotios & Andreas, 2011; Edebeatu, 2015).

Evapotranspiration is a crucial factor in determining agricultural field requirement as well as management of irrigation scheduling, irrigated areas, crop production, and environmental and urban assessment (Irmak et al., 2003; Temesgen et al., 2005; Hossein and Hosseinzadeh, 2010).

We modeled consumptive field use by using radiation and temperature – based empirical equations in the semi – arid region of Nigeria. Therefore, the objective of this study is to compare the effects of the empirical models in two different locations within the semi – arid Sahel Savanna of Nigeria. To estimate this, we employed minimum and maximum air temperature and solar radiation as well as atmospheric moisture content.

MATERIALS AND METHOD

Study Location:

Alkaleri: Alkaleri is in Bauchi State, North East Nigeria at latitude 10.32°N and longitude 10.25°E and at an elevation of 757m above mean sea level (MSL).

Bauchi: Bauchi is located at latitude 10.32°N and longitude 9.83°E, mean sea level altitude of 622m. Bauchi is the capital of Bauchi State in North East Nigeria.

Data set extraction: The measured/observed ETo model for temperature and evapotranspiration data were obtained from the website of the International water managementinstitute (http://dw.iwmi.org/IDIS_DP/clickandplot.aspxbhttp://dw.iwmi.org/clickplot/Parameteraspx?).The meteorological parameters extracted are:

Mean daily minimum and maximum air temperature (0C);

Mean daily average air temperature (0C);

Measured mean daily average evapotranspiration; the PM ETo(mm/d).

The data range is from 1980 – 2010 (30 years).

Method

Baier - Robertson (1965) ET_0 model (B-R)$_{(a)}$: The 1965 Baier-Robertson ET_0 model uses minimum and maximum temperature in addition to atmospheric variables and saturation vapour pressures(e_s) and the actual vapour pressure (e_a). This is given in Boris, (2012) as;

$$ET_{0(BRa)} = 0.0039T_{max} + 0.1844(T_{max} - T_{min}) + 0.1136R_a + 2.811\,(e_s - e_a) \quad (1)$$

Where (e_s - e_a) is the pressure deficit.

Baier - Roberson (1971) ET_0 model (B-R)$_{(b)}$: This is an empirical ET_0 model that requires only the difference in the monthly daily mean air temperature and the extraterrestrial radiation to estimate the reference evapotranspiration for a given climate. This is given in Boris, (2012) as:

$$ET_{0(BRb)} = 0.157\,T_{max} + 0.158(T_{max} - T_{min}) + 0.109R_a \quad (2)$$

Where;

T_{max}= Maximum temperature (^{0}C);

T_{min}=Minimum temperature (^{0}C);

R_a=Extraterrestrial Radiation (MJ/m^2/d).

2.2.3Jensen - Haise: The Jensen – Haise (1963) ET_0 model used in this work is given by (Maduike, 2005; Rosenberry *et al.,* 2004) as;

$$ET_{oJH} = \left[\frac{R_s}{\lambda}\right]\{0.25T_{mean} + 0.08\} \quad (3)$$

Where,

λ = latent heat of vapourization (MJ/kg) = 2.501 – (2.361x10^{-3}).

T_{mean} = 2.54 (MJ/kg).

Caprio (1966): The Caprio ETo model is given by Edebeatu and Okujagu, (2017) as;

$$ET_o = \frac{8.1}{10^8}\{1.8T_{mean}\}R_s \quad (4)$$

RESULTS

Alkaleri Station.

Table 1: ETo values for Alkaleri

Months	PM (mm/d)	B-R(a)	B-R(b)	J-H	Caprio
Jan	5.83	9.01	9.90	4.76	6.93
Feb	6.71	9.35	**10.23**	5.27	7.70
Mar	6.97	9.46	10.14	5.57	8.13
Apr	6.38	9.11	9.31	5.30	7.73
May	5.42	8.60	8.46	4.81	7.01
Jun	4.61	8.06	7.72	4.32	6.28
Jul	3.69	7.51	7.04	3.85	5.59
Aug	3.31	7.34	6.89	3.75	5.44
Sep	3.73	7.79	7.60	4.25	6.18
Oct	4.75	8.64	8.97	5.17	7.54
Nov	5.63	9.39	10.49	5.86	8.56
Dec	5.57	9.25	10.47	5.66	8.26

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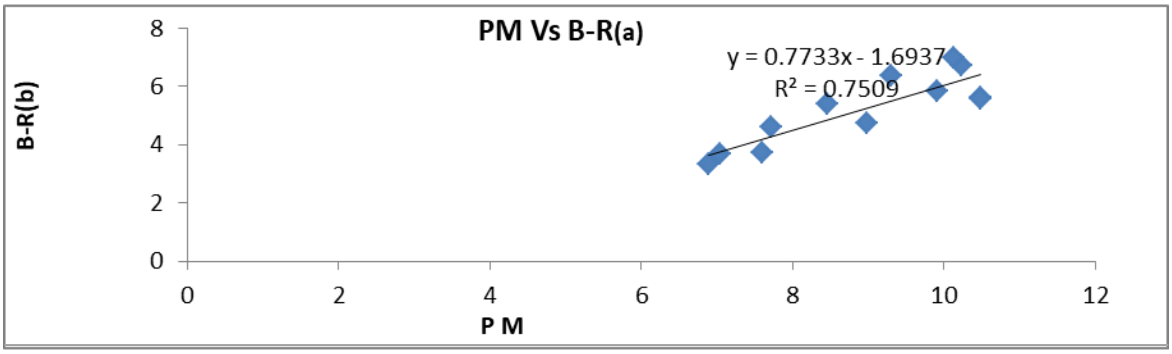

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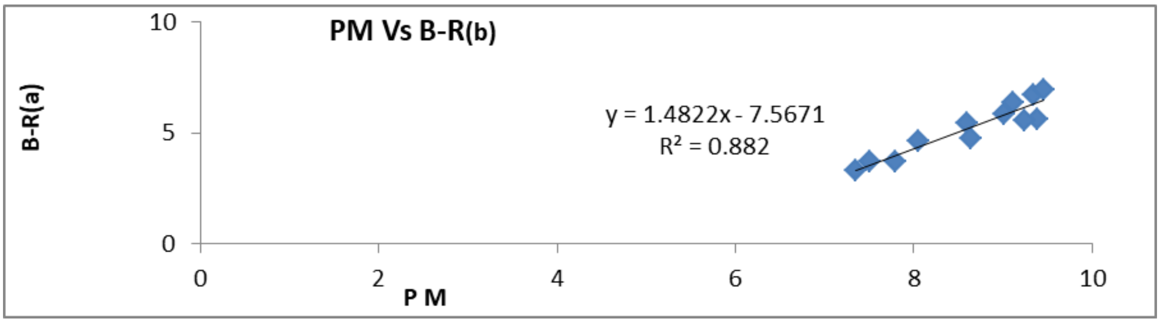

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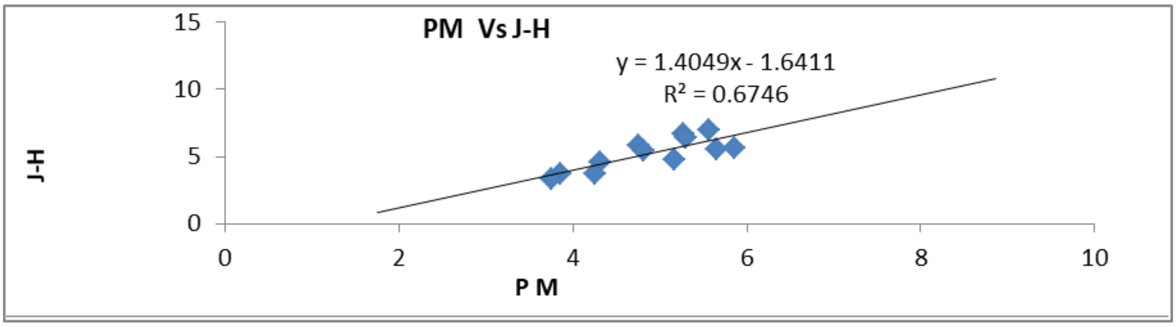

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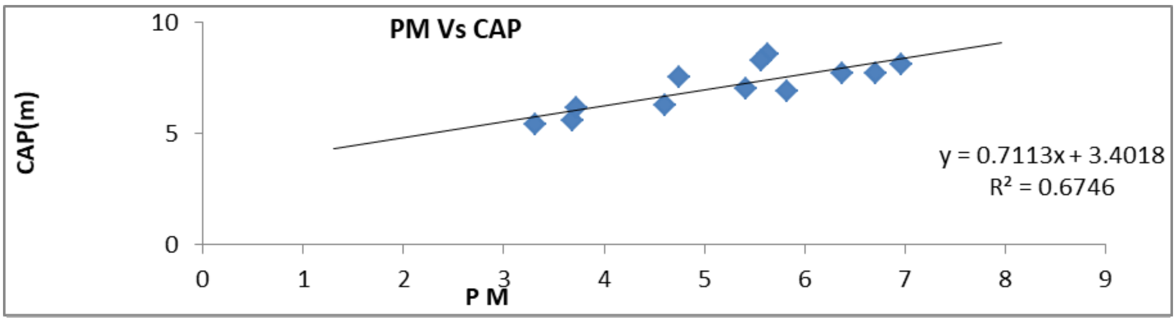


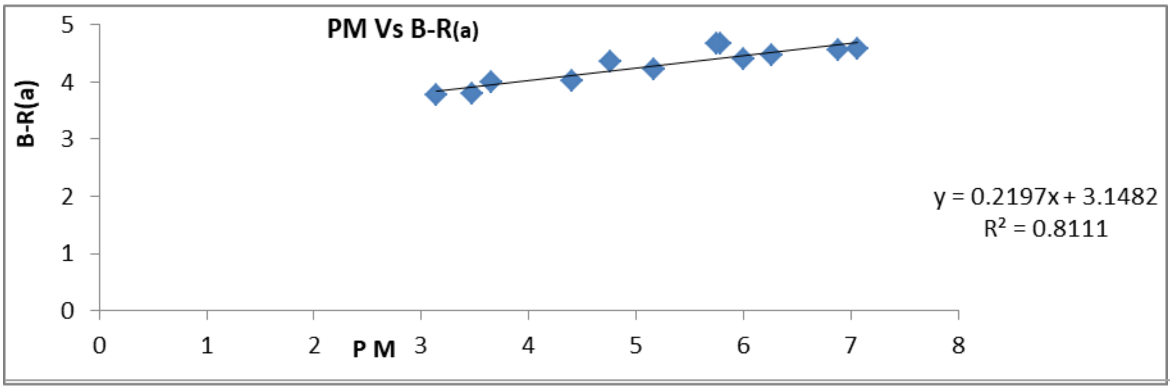
(d)

Figure 2: R^2 for Alkaleri

Bauchi Station.

Table 2: ETo values for Bauchi station

Month	PM (mm/d)	B-R (a)	B-R (b)	J-H	Caprio
Jan	6.00	4.41	9.63	4.48	6.59
Feb	6.89	4.55	9.98	4.98	7.33
Mar	7.06	4.57	9.75	5.24	7.72
Apr	6.26	4.46	9.14	5.06	7.45
May	5.17	4.21	8.15	4.50	6.62
Jun	4.41	4.02	7.55	4.08	5.99
Jul	3.47	3.80	6.86	3.60	5.28
Aug	3.14	3.78	6.77	3.54	5.20
Sep	3.65	4.00	7.49	4.06	5.96
Oct	4.76	4.35	8.75	4.89	7.20
Nov	5.79	4.67	10.17	5.52	8.13
Dec	5.75	4.66	10.24	5.37	5.96



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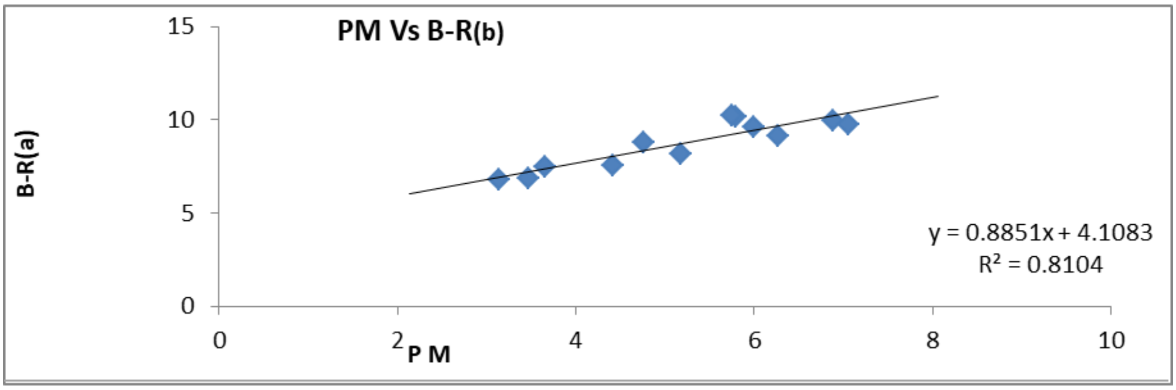

(b)

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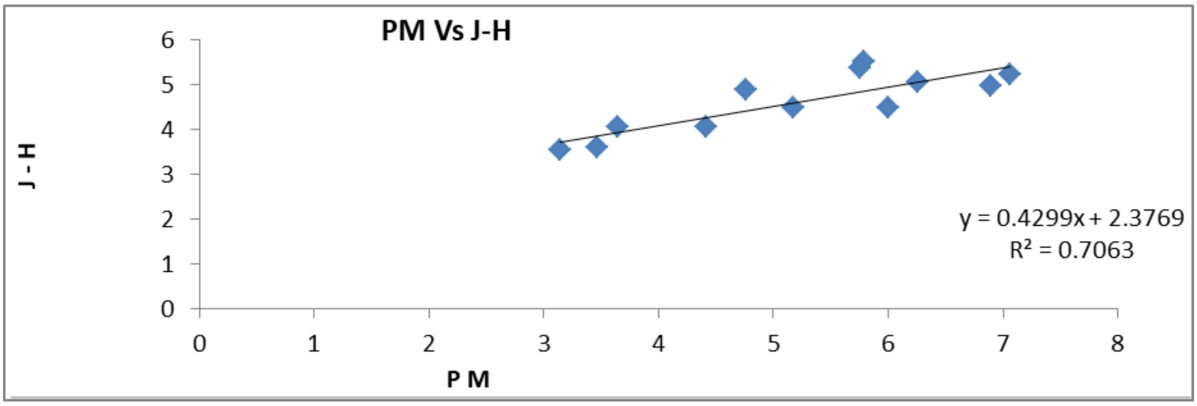

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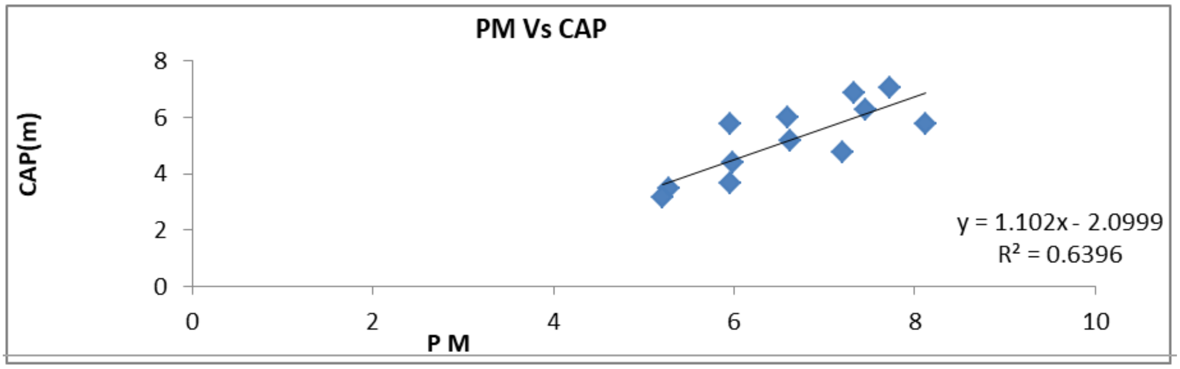

(d)

Figure4: R^2 for Bauchi.

DISCUSSION

Alkaleri Station. The result of the estimated reference evapotranspiration in the station ofAlkaleri is displayed in theTable1 above.The maximum observed ET_0 at this site occurred at 6.97mm/d in March while the minimum occurred at 3.31 mm/d in August. The B-$R_{(b)}$ was a little bit above normal to the extreme right for the months of October to June. B-$R_{(a)}$ overestimated between October to march. Both were normal at the peak of rainy season between July and September for B-$R_{(b)}$, and between June and September for B-$R_{(a)}$. B-$R_{(a)}$ had an overestimation of 10.48mm/d in December. The J-H model underestimation occurred only in July and August. The Caprio (Cap)had a standard value estimate of the reference evaporative demand of the field as given by the FAO of UN for a semi – arid region.

The comparison of the graphical result displayed a wave – like pattern which showed that in Alkaleri, differences in analysis had significant effect during the dry season. The lines were far dispersed in the early part of the season and ETo values were recorded above standard for the models of B-$R_{(a)}$ and B-$R_{(b)}$, but slightly dropped below standard during the rainy season. Cap and PM recorded standard ETo values during the dry season with Cap having some significant drop during the rainy season, while PM had more pronounced drop below standard from the month of May to the end of the year. J-H recorded below standard no significant improvement in all seasons of the year under review. It rather dropped more during the rainy season.

The comparative analysis of the modeled ETo to the measured PM showed that B-R(a) had 75.0%, B-R(b) recorded 88.2%, whereas J-H and Cap recorded water use of 67.4% respectively.

The mean annual observed values are; PM = 5.22mm/yr; T_{max} = 32.97^{0}C; T_{min} = 20.26^{0}C, while the corresponding mean annual estimated ET_O values are recorded as follows: $B\text{-}R_{(a)}$ = 8.63 mm/yr; $B\text{-}R_{(b)}$ = 8.94 mm/yr; J-H = 4.88mm/yr; The annual diurnal temperature is 12.71^{o}C, whereas the corresponding solar radiation is 18.37MJ/m^2/yr.

Bauchi Station. The Bauchi ET_o isas analyzed and presentedin Table 2above.

Observations were made of reference evapotranspiration as well as calculated ET_omodel value at this site. The maximum PM ET_o of 7.06mm/d occurred in March whereas the minimum value is at 3.14mm/d and occurred in August. $B\text{-}R_{(b)}$ model had greater frequency of over estimation than normal with highest ET_oat 10.24mm/d in December while the minimum is at 6.77mm/d in August. The Caprio here again had a good estimate of the ET_o. The maximum ET_o value was found to be 8.13mm/d in the month of November which is an over estimation, while the least value occurred at 5.20mm/d under estimation in month of August. Hence, the Caprio presents a better model in the semi – arid region than the original form and can be extended to other regions with similar climate regimes.

The graphical display of modeled ETo in Bauchi also showed a simple wave – like pattern, but with some disparities in ETo values. B-R(a) estimated above standard ETo values during the dry season, but slightly dropped to standard from the month of June to the month of September and diverted above standard again. B-R(b) and J-H recorded below standard ETo values for the entire period, having no significant wave – like pattern. PM and Cap had standard records during the first phase of the dry season into the early phase of the rainfall. The drop in ETo value continued down the trend during the rainy season, though with some measures of significant increase with the Cap model in October to December.

The comparative results of Bauchi showed that PM correlated with other estimated models at 81.1% with B-R(a), 81.0% with B-R(b), 70.6% with J-H and 63.9% with Cap.

The mean annual observed values are: ET_0 = 5.19mm/d yr; T_{max} = 31.88^{0}C; T_{min} = 19.37^{0}C. Other estimated values are T_d = 12.5^{0}C; solar radiation Rs = 18.23 MJ/m^2/yr.Mean annual estimates is a resemblance of the monthly reflection and displayed as; $B\text{-}R_{(a)}$ = 4.29mm/d yr; $B\text{-}R_{(b)}$ = 8.71mm/yr; J-H = 4.61mm/yr.

Reliable estimation of reference evapotranspiration (ET_o) is important in agricultural water management and crop production, irrigation scheduling and management. Combating hunger and eradicating food security challenges around the world mostly in developing countries like Nigeria lies in the knowledge, understanding and application of evapotranspiration. The Caprio ET_o model in this work has proved a reliable method of modeling evapotranspiration and a way of contributing to the improvement of modern agricultural development, water management, irrigation scheduling and a

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boost towards agricultural yield especially in the semi – arid region of the Sudan and the Sahel savanna of Africa.

The performance evaluation of the temperature – based ET_o has been carried out with the view to ascertaining its efficacy as compared to the Penman- Monteith, and the result showed that it is strongly a reliable and efficient means of modeling reference evapotranspiration in semi – arid region of Sudan – Sahel savannas of Nigeria. However, care must be exercised when applying the empirical coefficients of any empirical (ET_o) model which is mostly determined for each region for utmost performance, as it requires recalibration or modified for effective result. It shows that temperature effect is more dominant than radiation effect in the environment. Thus, temperature is the dominant atmospheric variable and it could be regarded as the controlling weather factor for modeling consumptive use in the semi – arid zone of Nigeria for the two locations under study.

Therefore, the empirical temperature – based ET_o model is recommended as an alternative in estimating ET_o to its equivalent radiation model. The approach is a pathfinder to solving irrigation problems, water management, and crop production and opens up many other huge opportunities related to agriculture like livestock management and environmental land scaping and urbanization.

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