

Seasonal Levels of Evapotranspiration, Solar Radiation, and Rainfall for Climate Variability Studies at a Subtropical Site.

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ABSTRACT

The levels of climate parameters such as evapotranspiration (ET_o), global solar radiation, and rainfall must be ascertained because of their importance in ecosystem modeling. However measuring evapotranspiration and other water balance parameters in lysimeters constructed around monoliths of undisturbed soil and mature vegetation can be expensive and difficult to maintain, especially in developing countries. In Nigeria, ET_o and global solar radiation measurements are very sparse, yet the data are invaluable for climate variability studies.

We have estimated the reference evapotranspiration at the subtropical site of Ilorin, Nigeria (longitude 4° 34" East and latitude 8° 32" North) using the Blanney-Criddle and Hargreaves methods and the global solar radiation with the temperature-based Hargreaves equation. How far these two simple methods of deriving reference ET_o and solar incidental radiation are realistic estimates is being investigated. Nonetheless, the results capture the signatures of the expected climate scenarios at this site.

An interesting development is that rainfall amount seems to be varying at the site since 2002 which may be dodgy for agriculture in view of the fact that it may exacerbate poverty and promote urbanization and migration with unemployment. The implication of these in climate variability and predictability studies has been underscored with the attendant applications in crop-climate exploration trumpeted.

(Keywords: evapotranspiration, solar radiation, climate variability, rainfall, crop climate studies)

INTRODUCTION

The availability of surface incoming solar radiation observations is necessary for applications such as evapotranspiration estimation or plant growth and developmental and yield simulation models. These, however, are not observed at many locations, preventing the application of such models (Abraha and Savage, 2008). Hence, other routinely observed meteorological data must be analyzed to simulate the on-site surface solar radiation (Chiemeka, 2008; Chineke, 2008; Fortin et al., 2008).

Evapotranspiration (ET_o) is a major component of the hydrological balance climate and land use change (Brooks et al., 1997, Dow and DeWalle, 2000, Yanling et al., 2008). It is also an indicator of ecosystem productivity; in fact, it is the only variable that links hydrology and biological processes in most current ecosystem models and a measure of available environmental energies and can be used as an indicator of biodiversity. For example, Currie (1991) found that in the four vertebrate classes studied, 80 to 93% of the variability in species richness could be statistically explained by a monotonically increasing function of a single variable, reference evapotranspiration. Daily radiation is required by most models that simulate crop growth because growth is primarily based on the photosynthetic processes which involve the utilization of radiation and its conversion to chemical energy. However, solar radiation is an infrequently measured meteorological variable, compared to temperature and rainfall (Liu and Scott, 2001).

The aim of this work is to evaluate the reference evapotranspiration and global solar radiation (GSR) level at a test site Ilorin (latitude 8.48°N) to guide us in our ongoing work of downscaling global circulation model (GCM) and regional

climate model (RCM) products over Nigeria, a first step towards improving their model physics and for impact assessment studies. Testing the accuracy of methods under a new set of conditions is laborious, time-consuming and costly, and yet evapotranspiration data are frequently needed at short notice for project planning or irrigation scheduling design.

Part of our mandate is using solar energy for photovoltaic applications which underscores our estimating the global solar radiation (GSR) data from minimum data in the face of paucity of actual measurements using instruments like pyrheliometers for measuring the direct radiation from the solar disk, pyranometers for measuring the combination of direct solar radiation and diffuse radiation from the sky, and instruments for measuring the fraction of daylight hours when the sun is not hidden by clouds (duration of sunshine) like the Campbell Stokes Recorder. In extension, we have included rainfall levels in the site for impact studies and variations inherent in the observed data and how they relate to ETo and GSR.

MATERIALS AND METHODS

Different methods are used to estimate the reference ETo and GSR from climate data (Mbagwu, 1988; Pereira and Camargo, 1989; Mahmood and Hubbard, 2005; Vicente-Serrano et al., 2007).

ETo Methods

We used two temperature-based methods to estimate the reference evapotranspiration at the site

Hargreaves Equation: The equation was presented by Hargreaves and Samani (1985) and has been tested and found suitable for tropical Africa (Jagtap, 1991; Chineke, 1993). It is a simple equation that requires temperature values to compute the reference evapotranspiration estimate. It is found to be favorable or gives better results in drier regions (Hargreaves, 2003; Fooladmand and Haghighat, 2007). The equation needs as input data the daily temperature range (maximum – minimum temperature) and the extraterrestrial solar radiation which depends on the latitude of the location.

The equation is:

$$ETo \text{ (mm/day)} = 0.0021Ra(Ta+17.8)\sqrt{Td} \quad (1)$$

The extraterrestrial solar radiation, Ra in mm/day was computed by a computer routine from Chineke (2002).

The Modified Blanney – Criddle Method: This is the modification of the original Blanney – Criddle method (Palutikof et al., 1994; Allen et al., 1998). The equation for calculating reference evapotranspiration with this method is:

$$ETo \text{ (mm/day)} = p (0.46Ta + 8) \quad (2)$$

Where Ta is the mean air temperature (maximum + minimum)/2 and p is a local constant (0.27) for Nigeria.

Global Solar Radiation Estimating

In any solar energy conversion system, the knowledge of global solar radiation is extremely important for the optimal design and the prediction of the system performance. The best way of knowing the amount of global solar radiation at a site is to install pyranometers at many locations in the given region and look after their day-to-day maintenance and recording, which is a very costly exercise (El-Sebaai and Trabea, 2005). It is, therefore, necessary to approximate radiation from commonly available climate parameters such as sunshine hours, relative humidity, maximum and minimum temperatures, cloud cover and geographic location (Kuye and Jagtap, 1994; Akpabio and Etuk, 2003; Skeiker, 2006; Chiemeka, 2008; Sabziparvar, 2008).

However, most of the models require weather parameters which may not be available at many sites (Chineke, 2008). In this work therefore, we used an equation that requires only temperature difference (maximum minus minimum) data at the site. The equation is presented below. The results were compared with National Aeronautic and Space Administration (NASA) surface solar radiation in our attempt to check the accuracy of the estimated data. This is done because the best understanding will result from a comparative analysis of satellite and ground-based data (see Pinker et al., 2006).

Hargreaves Global Solar Radiation Equation:

The equation we used to estimate the global solar radiation (R_s) is written by Hargreaves and has been tested over tropical Africa (Kuye and Jagtap, 1994; Chineke and Jagtap; 1995; Chineke, 2008; Dike et al, 2010). It is a simple equation that requires temperature values to compute the daily global solar radiation (GSR) Hargreaves (2003).

$$\text{GSR (KWh)} = 0.16R_a\sqrt{T_d} \quad (3)$$

Where T_d is the temperature difference (maximum-minimum). R_a is the extraterrestrial solar radiation which was computed with the routine in Table 1 and can be used to compute R_a and N when the latitude is supplied in degree radian.

Note that $180^\circ = \pi$ radian. We chose our unit for global solar radiation as Kilowatt hours (KWh) which is convenient for evaluating the solar power potential especially for solar photovoltaic applications. It is the power output (kW) and the number of hours of sunshine (hrs) that comes into play in any solar home system or related photovoltaic application.

DATA ACQUISITION AND RESULTS

The site studied in this work is Ilorin in Nigeria located on longitude $4^\circ 34''$ East and latitude $8^\circ 32''$ North. Like most locations in West Africa, the climate system is governed by the "West African Monsoon" which is characterized by fluctuations of tropical maritime air mass (south-westerly wind) and the tropical continental air mass (north-easterly wind) (Peter and Tetzlaff 1988). The

monsoon circulation, accommodates the primary rainfall-producing systems during summer months, provides West African countries with more than 75% of their annual rainfall (Omotosho 1985). The rain-producing systems include the African easterly jet (AEJ), tropical easterly jet (TEJ), African easterly waves (AEWs), and mesoscale convective systems (MCSs). These phenomena interact in a complex way with the low-level monsoon flow, which transports moisture inland from the Atlantic Ocean providing West Africa with most of its moisture for rainfall. Over the past four decades, rainfall in West Africa exhibited a pronounced change in variability based on intensity, duration, spatial distribution and annual amount. Several studies based on observational data have documented this change in variability on interannual and longer time scales (e.g., Lamb and Pepler 1991; Hulme 1992; Nicholson 1993; Rowell et al. 1995; Afiesimama et al. 2006).

At Ilorin, it is obvious that the increased monsoon flow strengthens the low-level circulation that helps maintain the mid-tropospheric easterlies over West Africa. The strengthened circulation produces stronger easterlies south of the African Easterly Jet. The stronger easterlies transport more moisture away from West Africa (Abiodun et al., 2008). However, this is resultant to two seasons; the wet and dry seasons, which differ by the levels of precipitation, temperature and humidity, with the wet season recording higher precipitation, higher humidity and lower temperature than the dry season. The wet season usually spans from April to September while the dry season lasts from October to March of the succeeding year.

Table 1: Equations for Computing Theoretical Radiation (R_a) and Maximum Daylight Duration (N) at any site Worldwide (Chineke, 2002).

Location Specific Functions

$$PH1 = \text{Latitude} * \pi / 180.0$$

$$DEL = (23.45 * \pi / 180.0) * \sin(2.0 * \pi * (284.0 + \text{Julian Day} / 365.0))$$

$$WS = \arccos(-\tan(PH1) * \tan(DEL))$$

$$N = (2.0 / 15.0) * WS$$

$$DF = 1.0 + 0.033 * \cos(2.0 * \pi * (\text{Julian Day} / 365.0))$$

$$R_a = (\text{calories/cm}^2/\text{day}) = (1440.0 / \pi) * S_c * DF * (\cos(PH1) * \cos(DEL) * \sin(WS) + WS * \sin(PH1) * \sin(DEL))$$

Constants

Solar constant (S_c) = 1.96 cal/cm²/minute or 1367 kW/m² (Eddy et al, 1982; Akpabio and Etuk, 2003)

$$\pi = 4.0 * \text{ATAN}(1.0)$$

The temperature data used for computing the GSR and reference ETo were collected from the meteorological department of the Federal Ministry of Aviation (FMA) at Ilorin while the NASA surface solar radiation data was obtained from their online data store; <http://eosweb.larc.nasa.gov/sse>.

The estimated GSR and ETo levels for the site are plotted in Figures 1-3 for the daily GSR and ETo estimates for the three years (2002-2004). For clarity, month 1 is Jan 2002, month 12 is December 2002, month 13 is January 2003, month 24 is December 2003, and month 36 is December 2004.

In Figure 1, we see the daily GSR and ETo for 2002 at Ilorin. The GSR values ranged from 3.22 KWh on day 184 (July 3) to 6.49 KWh on day 69 (March 10). This is in line with expected values for Nigeria (Akpabio and Etuk, 2003; Chineke, 2008; Chineke and Dike, 2010).

For the ETo values, we see the Blanney-Criddle method having signatures that have the similitude of expected patterns at a subtropical site. The values ranged from 4.95 mm on day 357 (December 23) to 6.13mm on day 91 (April 1).

The Hargreaves temperature-difference method had ETo values that were consistently lower than the Blanney-Criddle estimates ranging from 2.65 mm on day 184 (July 3) to 6.09 mm on day 69 (March 10) as can be seen from Figure 1. The scenario is not far-fetched for the year 2003 as is listed in Figure 2.

The global solar radiation ranges from 3.26 KWh on day 263 (September 20) to 6.74 KWh on day 74 (March 15). For the ETo results, the Blanney-Criddle values ranged from 4.95 mm on day 184 (July 3) to 6.26 mm on day 78 (March 19). The Hargreaves ETo surrogates ranged from 2.63 mm on day 263 (September 20) to 6.13 mm on day 84 (March 25).

For the year 2004 (Figure 3), we also see patterns that are similar to those of other years (Figures 1-2). The GSR values ranged from 3.26 KWh on day 265 (September 22) to 6.62 KWh on day 172 (June 20) which is an extreme weather event since June should be typically be a rainy period although the reverse was the case that year. Actually, there was a period of dry spell from June 9 – June 30 (days 161 – 182), a scenario that was not good for farmers in the city of Ilorin and its environs.

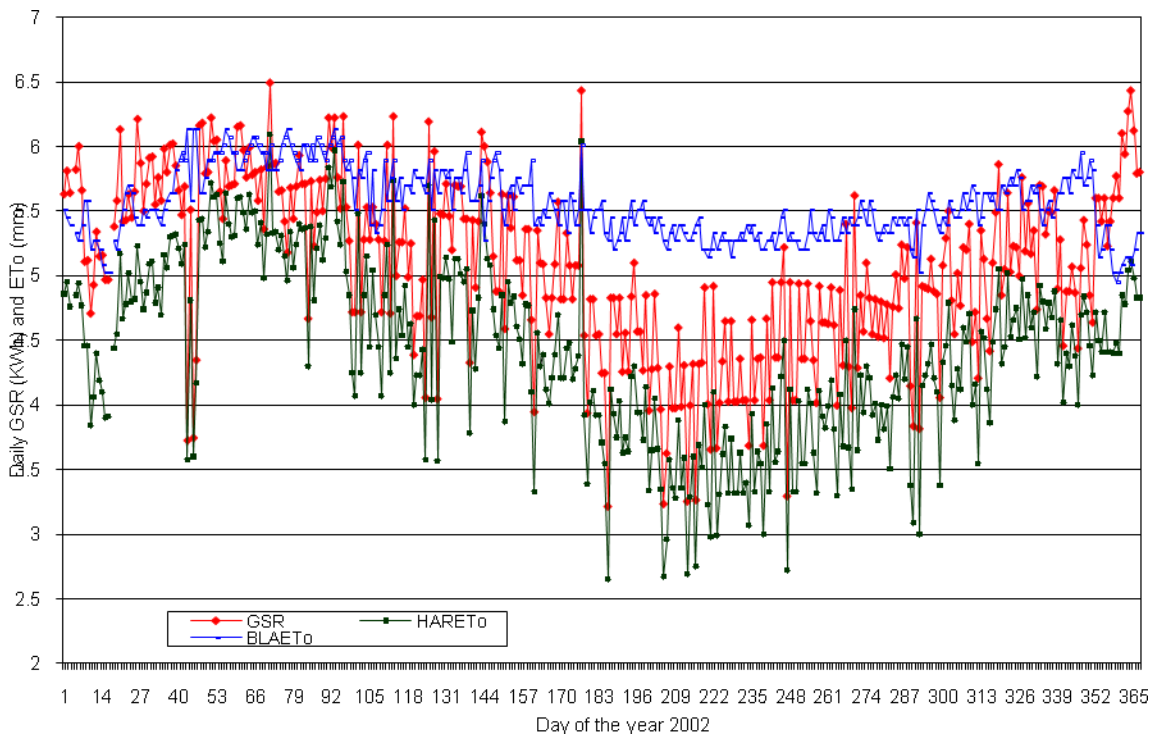


Figure 1: Daily Global Solar Radiation ($\text{kWh/m}^2/\text{day}$) and Reference Evapotranspiration at Ilorin for 2002.

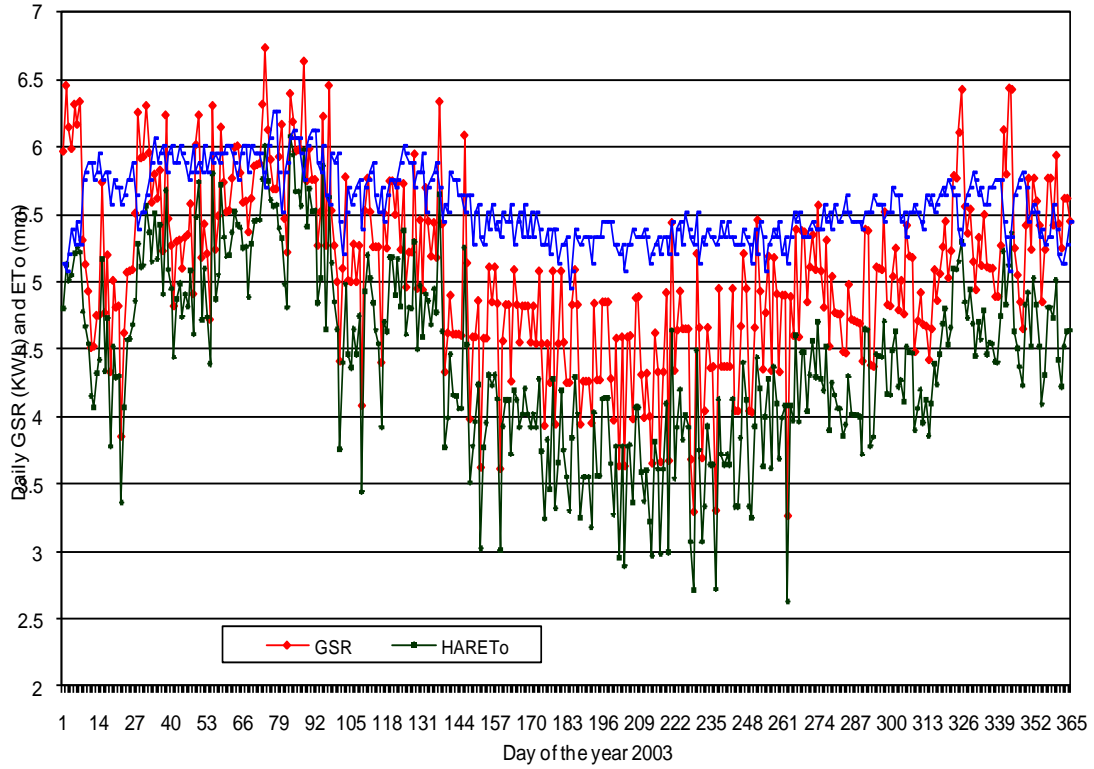


Figure 2: Daily Global Solar Radiation ($\text{kWh/m}^2/\text{day}$) and Reference Evapotranspiration at Ilorin for 2003.

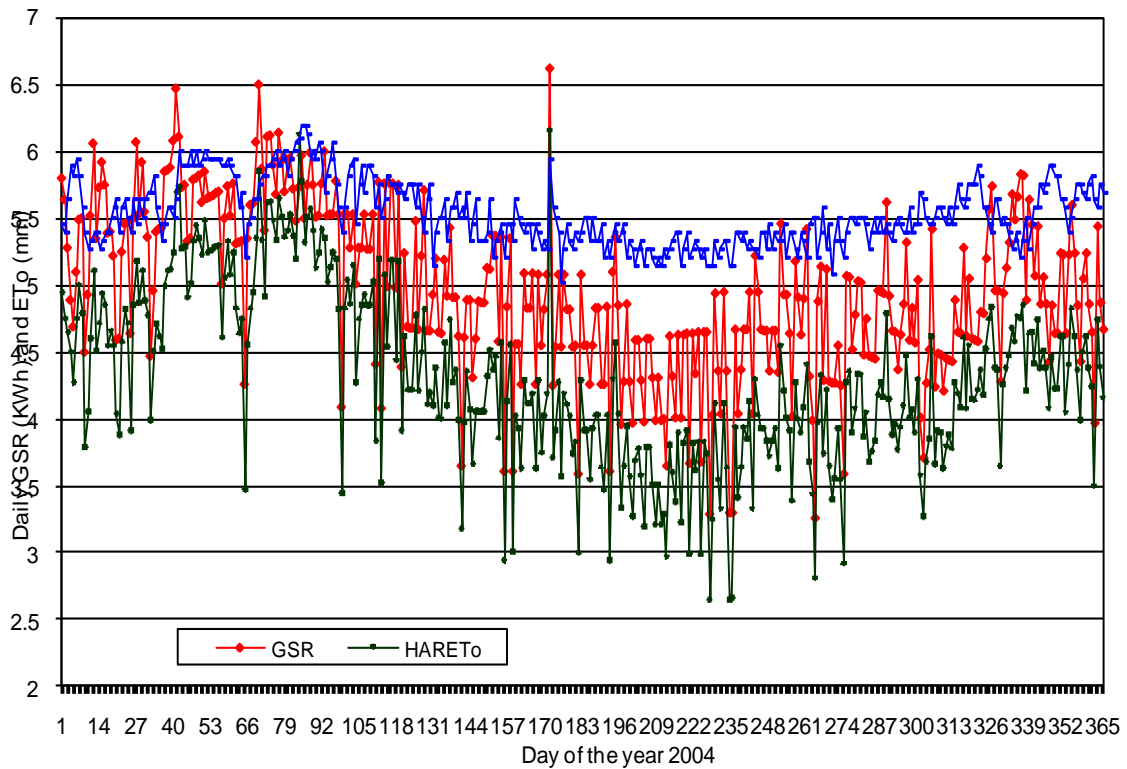


Figure 3: Daily Global Solar Radiation ($\text{kWh/m}^2/\text{day}$) and Reference Evapotranspiration at Ilorin for 2004.

The Blanney-Criddle ETo values ranged from 5.02 mm on day 176 (June 26) to 6.2 mm on day 86 while the Hargreaves ETo ranged from 2.65 mm on day 235 (August 22) to 6.16 mm on day 172 (June 20) as can be seen in Figure 3.

In Figure 4 we show the monthly mean climatology of the GSR and ETo values for the 36 study months (2002-2004). The global solar radiation ranged from 4.25 KWh in August 2002 to 5.89 KWh in March 2003 while the Hargreaves ETo estimates had its minimum as 3.51 mm/day in August 2002 and 5.48 mm/day in March 2003 which is expected since the months of March to April is the peak of the dry season in Nigeria.

The situation is similar with the Blanney-Criddle equation that computed ETo values with a range of 5.27 mm in August 2004 to 5.97 mm in March 2002. This shows that Figures 1-3 maintained the same pattern, except the variations seen at different peaks which are mainly a function of

temperature swings and the performance of the model used. This however underscores partly the essence of this paper to show case the variability of ETo in this site and to ascertain how much the used models differ and to what extent they agree; this is shown in Table 2. The percentage difference between Hargreaves ETo (Har ETo) and Blanney Criddle ETo (BC ETo).

The difference is generally lower during the dry season months and consequently higher in the wet season months. Although the key difference between the Hargreaves and Blanney-Criddle methods is that the former takes care of the diurnal variation in the temperature, which includes temperature difference, which definitely tells something about the cloudiness of a place. This method therefore captures more humid days for the 2002-2004 period than the Blanney-Criddle method, thus Blanney-Criddle equation is not as accurate in regions with higher humidity's (Hanson, 1991).

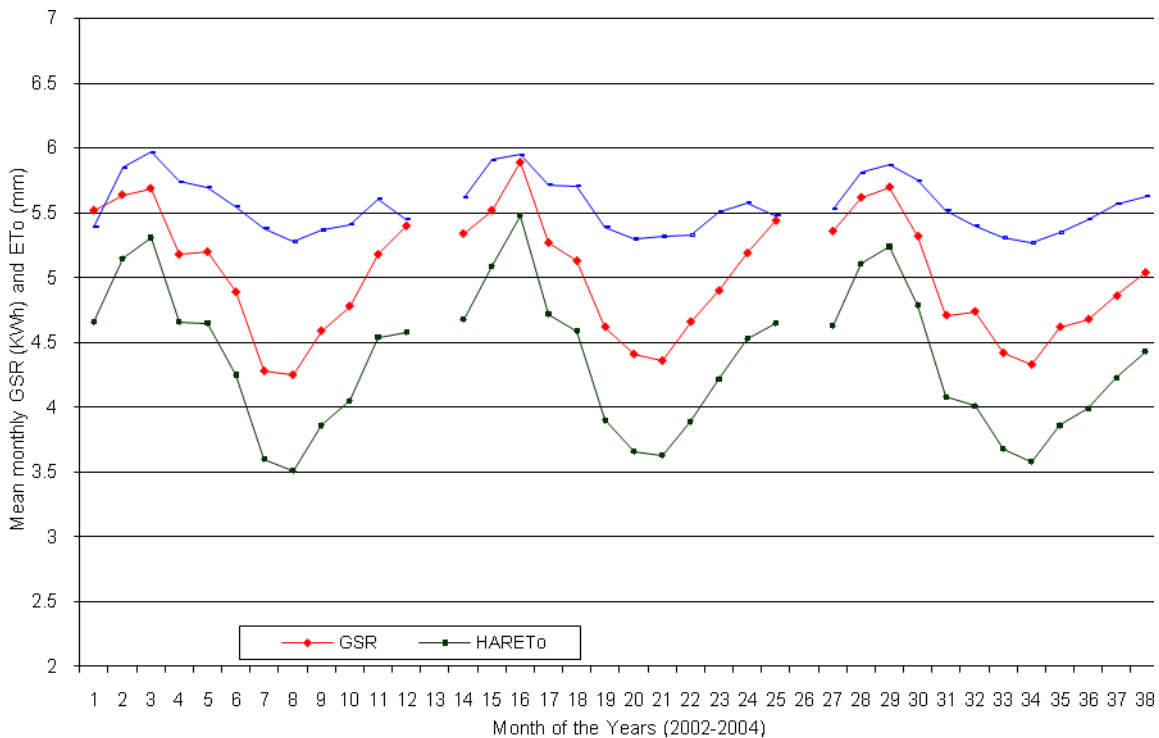


Figure 4: Seasonal Variation of Global Solar Radiation (kWh/m²/day) and Reference Evapotranspiration at Ilorin for 2002-2004.

Table 2: Percentage Difference and Correlation Analysis.

Months	2002 % Diff	2003 % Diff	2004 % Diff
Jan	13.5436	16.72598	16.27486
Feb	11.96581	13.87479	12.04819
Mar	11.05528	7.89916	10.73254
Apr	18.81533	17.48252	16.69565
May	18.42105	19.61471	26.08696
Jun	23.42342	27.64378	25.74074
Jul	33.0855	30.9434	30.6968
Aug	33.52273	31.76692	32.06831
Sept	28.11918	27.01689	27.85047
Oct	25.13863	23.41198	26.78899
Nov	19.07308	18.8172	24.05745
Dec	15.9633	15.14599	21.31439
Correlation of HarETo and BC ETo	0.865	0.949	0.965

It should be noted that the Blanney-Criddle method on the other hand is based on the mean air temperature and it uses mean air temperature and therefore averages the noise that may be inherent due to instrument errors. The temperature difference is less when cloud cover is greater. This is because the day temperatures remain high and the heat is conserved so that the night temperature is also high, resulting in less temperature range during the day. The temperature difference (Td) takes into account changes in radiation due to proximity to oceans, mountains, and the altitude of the location (Chineke, 2002).

We also plotted the monthly rainfall climatology which is shown in Figure 5. For the year 2002, the peak rainfall was recorded in August which dropped in September increasing in October.

In 2003, we see the months of June and September recording the maximum amounts of 370.8 mm and 400.1 mm of rainfall respectively which we may attribute to the local phenomenon of "little dry season" or the August break (Adeniyi and Oladiran, 2005; Adejuwon and Odekunle, 2006; Salako, 2008) which associates a clear and distinct bimodal rainfall pattern in Nigeria. In 2004, it is obvious that the bimodal pattern in rainfall (see Figure 5) may be vacillating with the extreme rainfall amount of 210.3 mm recorded in May.

To investigate the features more clearly, we analyzed the daily rainfall series for the years 2002-2004 since daily weather and climate series

is more suited for impact studies in that monthly values smoothens out the daily variations inherent in the observed data.

Precipitation is a key component of the climate system as well as a key phenomenon for human activities, in particular through floods, droughts and water resources. The rainfall data used in this study shows an increased annual average from 2.46mm in 2002 to 3.45mm in 2003 and a decrease to 3.07mm in 2004. The extreme values recorded for each year decreased from 87.9 mm (on day 240) in 2002 (Figure 6) to 84.4 mm on day 156 in 2003 (Figure 7) and further to 70.3 mm on day 135 in 2004 (Figure 8).

The annual inception of extreme rainfall is shown to shift towards earlier periods of the year. Whereas it was by August 28 in 2002 (87.9 mm) the 2003 extreme was on June 5th (84.4 mm) and the 2004 extreme in May 14 (70.3 mm) in all cases, the traditional "August break" or little dry season (Adejuwon and Odekunle, 2006) in rainfall seem to be "quasi-static".

We had days without rainfall or "breaks" in 2002 from July 21-27 and August 16-19 (Figure 6). In the year 2003, the breaks were observed between July 20-29, August 1-8 and 13-17th (Figure 7). For the year 2004, we had a semblance of the "little dry season" from July 26 – August 3, but again there were days without rain from August 9-12 and from the 14 – 20 August 2004 (Figure 8).

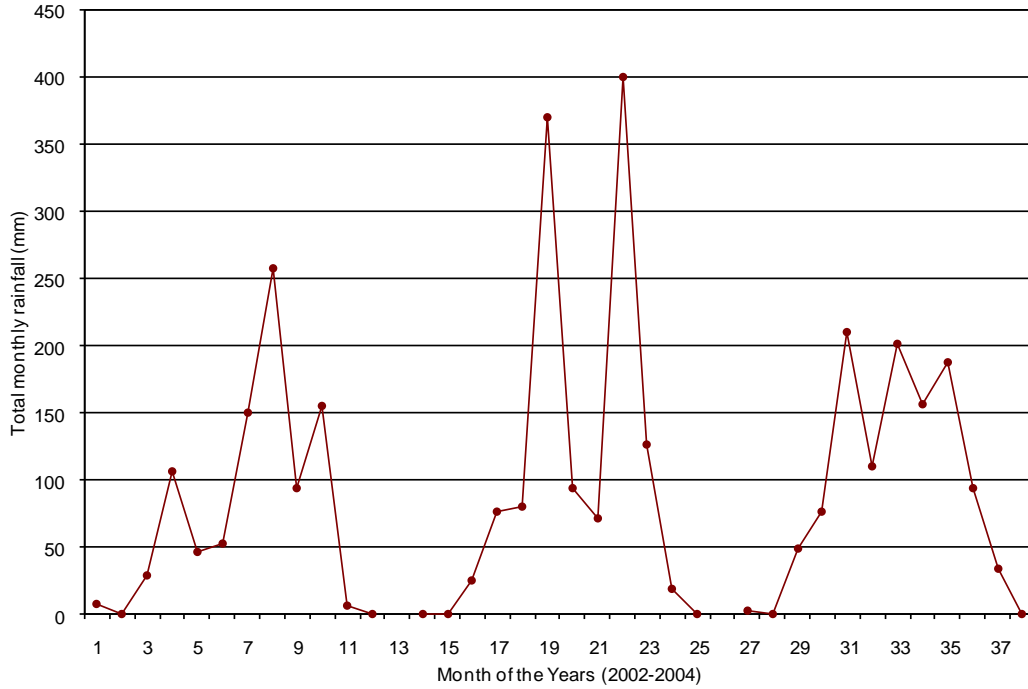


Figure 5: Seasonal Variation of Rainfall Amount (mm/day) at Ilorin for 2002-2004.

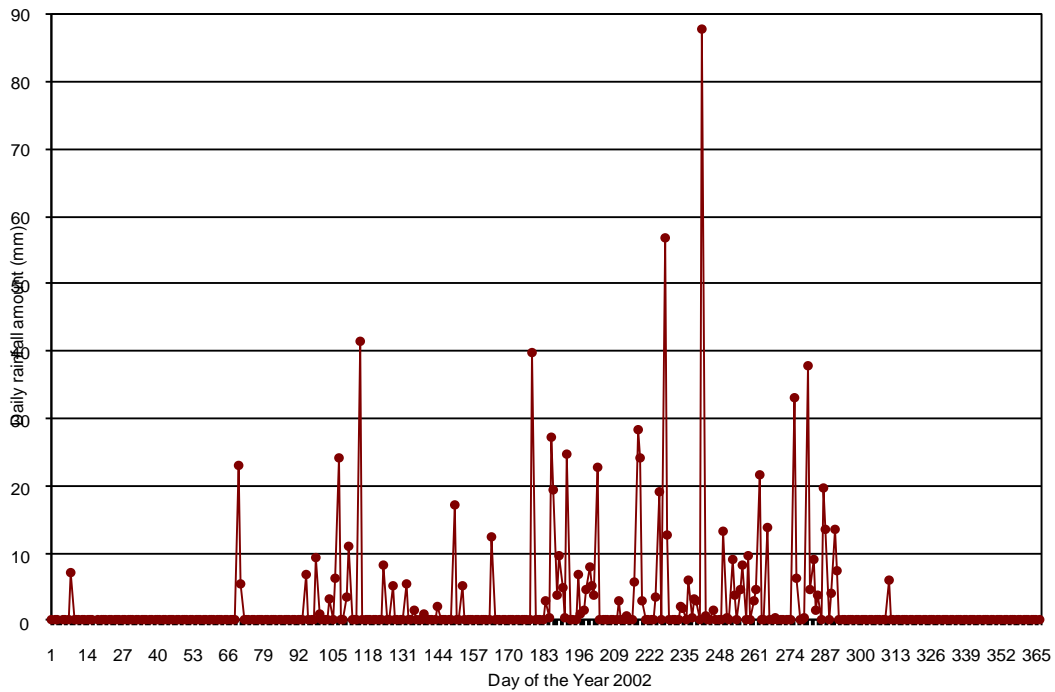


Figure 6: Daily Rainfall Series at Ilorin for 2002.

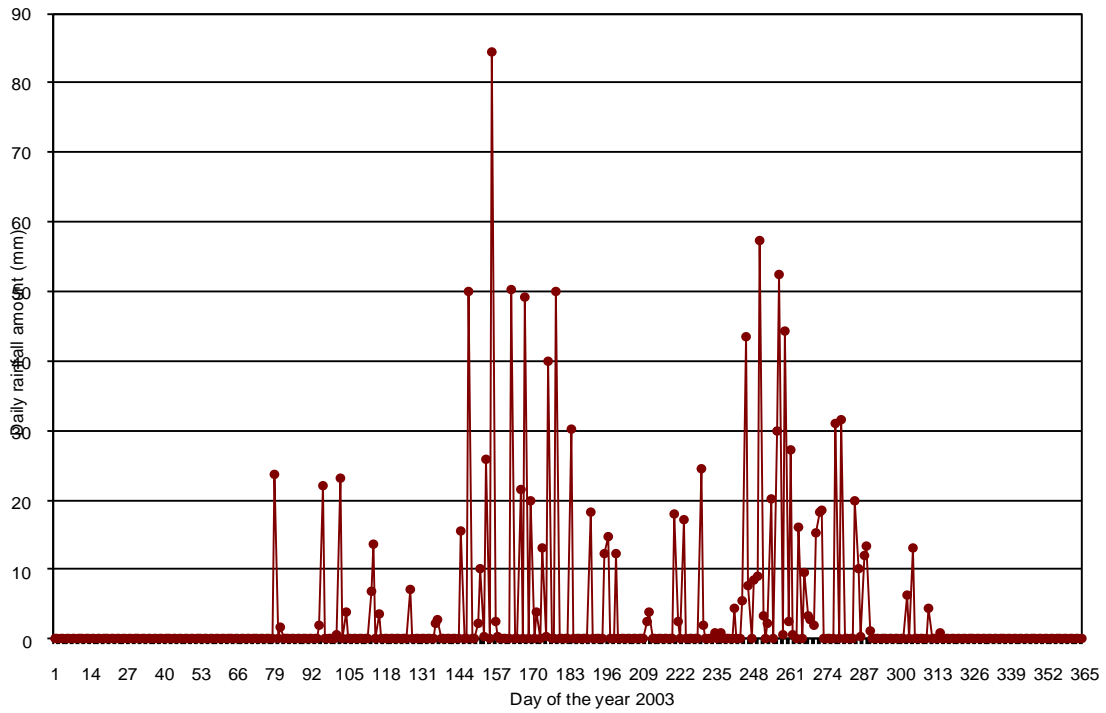


Figure 7: Daily Rainfall Series at Ilorin for 2003.

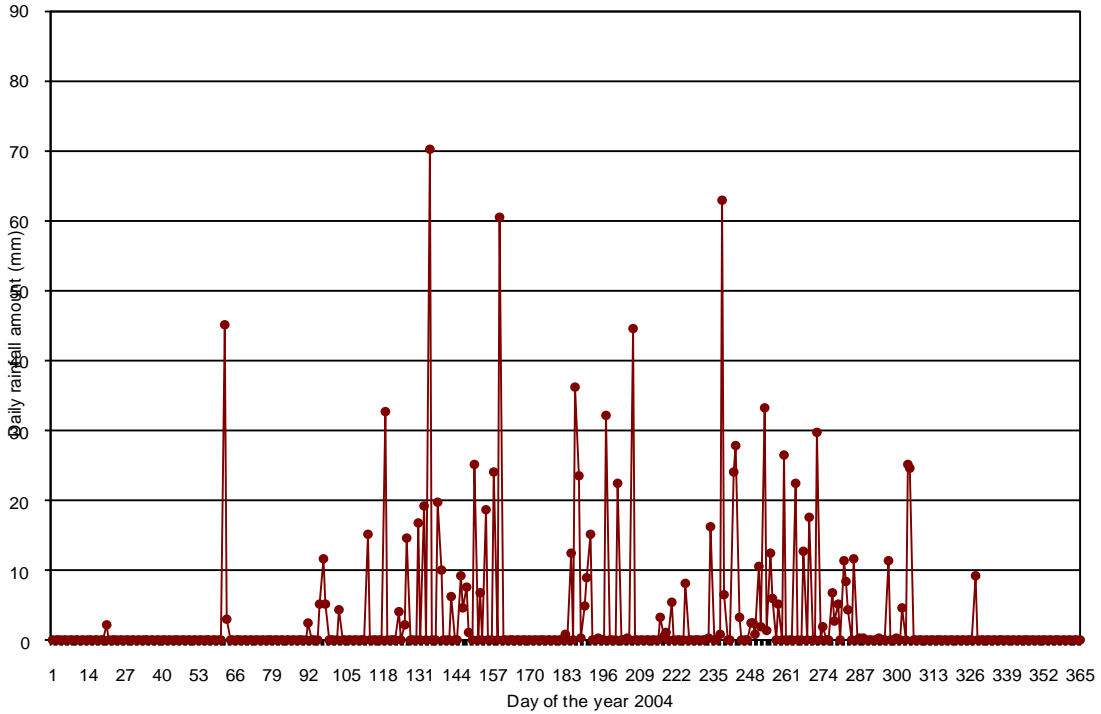


Figure 8: Daily Rainfall Series at Ilorin for 2004.

In order to check performance accuracy of the used data and the applied algorithms we have compared the estimated global solar radiation (Hargreaves) obtained with measured temperature data with the global solar radiation obtained from NASA for the study site (based on 22-year average).

The correlation analysis shows that they estimates agree to a high degree 0.969 which is an indication that they results can be accepted as close to reality. This comparison is clearly elucidated in Figure 9, however the estimates of the NASA global solar radiation level of accuracy as compared with most ground-based measurements for latitudes below 60° equatorward is ~ 9% which we have assumed for this work (<http://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?+505#s05>).

Hargreaves and Samani (1985), Hargreaves (2003) had shown accuracy of the order of ± 15

% in either evapotranspiration or solar radiation estimates.

IMPLICATION OF THE RESULTS

In Nigeria, agriculture and natural resources provide livelihoods for over 80% of the population which mostly live in the rural areas. The agricultural systems depend heavily on inception and levels of rainfall. The observed changes in inception, extremity and frequency of rainfall within the short period investigated have enormous socio-economic implications if they persist. An increase in annual rainfall amount will for instance increase incidence of water logging of farmlands and flooding which would reduce agricultural yield and forestry growth. The apparent shift in rainfall inception will likely affect the well known traditional crop cycles and in the absence of appropriate scientific knowledge and technology such as irrigation, would also reduce agricultural productivity and forestation.

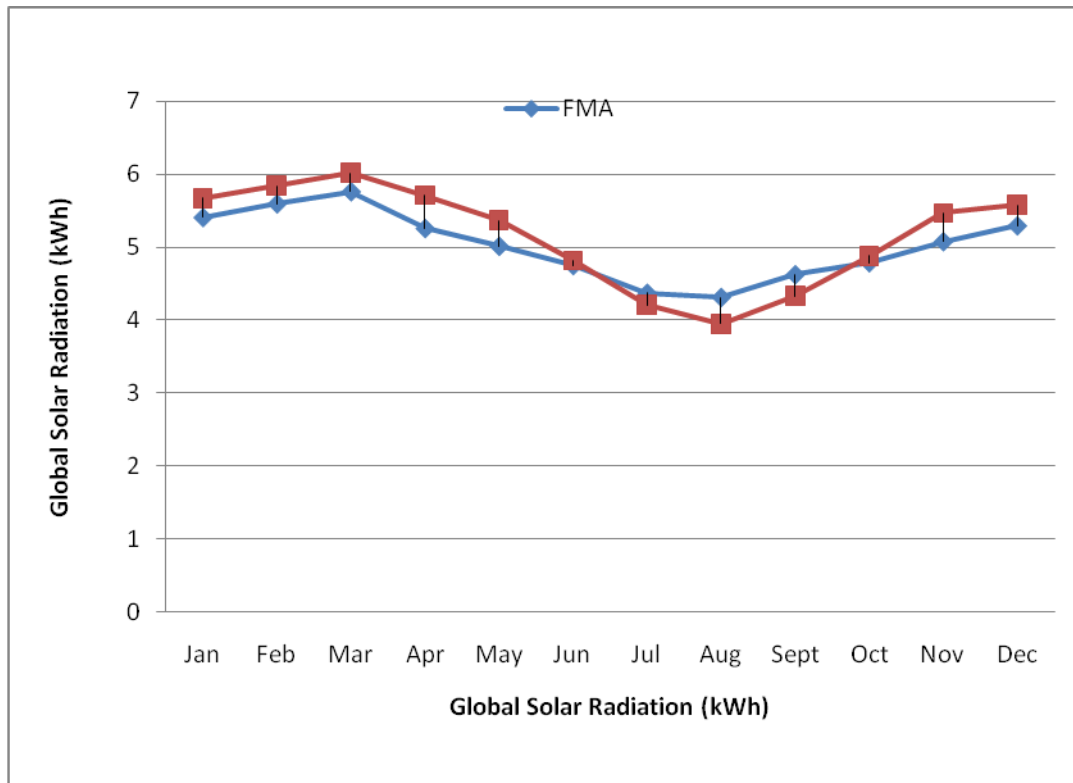


Figure 9: Comparative Plot of Global Solar Radiation (kWh/m²/day) from Two Data Sources at Ilorin.

It should be noted that forests particularly affect the water cycle and climate through a range of reciprocal feedback processes (Crutzen, 1994). Although the data examined in this work is short to draw major climatological conclusions, this work has revealed the need for continuous examination of GSR, ETo and rainfall levels at the site to provide more evaluation of the apparently changing trends.

There is also need to raise efforts towards improving the capacity of the predominantly agricultural populace for adapting to a most probable change in the weather and climate system. These will require development of more weather resilient crop varieties, improvement in weather forecasting capabilities, and deployment of efficient irrigation systems. Irrigated agriculture is facing new challenges that require refined management and innovative design. Meeting these challenges requires improved prediction of irrigation water requirements vis-à-vis, better estimates of evapotranspiration and the driving solar radiation. Irrigation water requirements can be defined as the quantity, or depth, of irrigation water in addition to precipitation required to produce the desired crop yield and quality and to maintain an acceptable salt balance in the root zone. This quantity of water must be determined for such uses as irrigation scheduling for a specific field and seasonal water needs for planning, management, and development of irrigation projects.

Scholes and Walker (2004) argue that climate is a first order "determinant" of ecosystem character, with edaphic factors second, followed by human intervention and other natural disturbances. This hierarchical determination of the constraints on ecosystem structure provides a useful model for characterizing agricultural environments. Beginning with the climate surfaces for monthly minimum and maximum temperature, mean rainfall, and mean evapotranspiration, the foundation is prepared for a scale-integrated and dynamic mechanism for supporting agricultural research efforts. Minimum evapotranspiration rates generally occur during the wet months of the year, maximum rates generally coincide with the dry season, when water may be in short supply, also depend on the availability of soil moisture and plant maturity. This shows that evapotranspiration reduces during wet season.

CONCLUSIONS

Precipitation is highly variable in space and time. In mountainous regions, this variability is amplified because of the complex interactions between the atmosphere and the rugged topography. The land-surface scheme, an important driver in the physics of global and regional climate models has one of its key components as evapotranspiration modulated by the incoming solar radiation. This is a key scientific area that is still poorly understood especially in the West African monsoon region. The results of our work on evapotranspiration, global solar radiation and Rainfall variability studies will aid in this research that will tend to answer an important scientific question, thereby complementing the work of the global climate circulation and regional climate models developed mainly in the North for use in the South.

It is important for agriculture to start focusing on proactive solutions and adaptive responses to climate change. Adapting to climate change will involve everything from changes in crop varieties, through to improve seasonal forecasting, up to revised national policies and programs. A key message we are passing is the importance of building adaptive capacity among farm managers, agro-businesses and industry groups. The past climate, which even skeptics will agree is changing, is no longer a good guide to the future climate, so having the skills and resources to respond flexibly will be essential. This preliminary study has evaluated some methods for estimating the daily reference evapotranspiration and global solar radiation at a test station in Nigeria. The methods of deriving reference ET and solar incidental radiation mentioned and how far these are realistic estimates is being investigated by the research groups in the three collaborating institutions where the authors are involved in teaching and research.

Global solar radiation data are often required in agrometeorological calculations, e.g. to compile a water budget for irrigation or to run a crop growth simulation model, but these are not usually measured in Nigeria, except at isolated stations like Onne, Ibadan and Kano by the International Institute of Tropical Agriculture (IITA), a member of the CGIAR consortium <http://www.iita.org/>. From the results of this study, our formulation of estimating solar radiation, from only temperature is beautiful especially in rural applications of photovoltaic applications.

Estimating evapotranspiration from minimum data will help the local agricultural extension workers to advise the local farmers on scheduling irrigation. In addition, the information from this work will be very useful to studies in other areas like crop- climate modeling, vegetation-climate classification and regional climate changeability studies. Solar radiation drives the energy balance at the earth's surface, and any changes in this quantity will tend to influence the hydrological cycle as well as other components of the climate system.

While global studies are important to get a general picture, regional and local studies provide more detailed information on the response of surface solar radiation to variables such as clouds and aerosols, evapotranspiration as well as circulation changes (Roderick and Farquhar, 2005; Stjern et al., 2008). The deliverables at the end of the day from the holistic climate research will be sustainable food production, climatic change effects will be mitigated, and rural-urban migration with the negative consequences of armed conflicts, hunger and disease will be flagged. Finally, water resource managers must as a matter of urgency study the emerging hydrological budget in order to allocate and manage water resources effectively. In line with this water reservoir/dams should be constructed at strategic locations to take care of floods, which may occur during rainy season. At the same time these water will be used for irrigation of the farmland during dry season.

REFERENCES

- Abiodun, B.J., J.S. Pal, E.A. Afiesimama, W.J. Gutowski, and A. Adedoyin. 2008. "Simulation of West African Monsoon using RegCM3 Part II: Impacts of Deforestation and Desertification". *Theor. Appl. Climatol.* 93:245–261.
- Abraha, M.G. and M.J. Savage. 2008. "Comparison of Estimates of Daily Solar Radiation from Air Temperature Range for Application in Crop Simulations". *Agricultural and Forest Meteorology.* 148:401-416.
- Adejuwon, J.O. and T.O. Odekunle TO. 2006. "Variability and Severity of the "Little Dry Season" in Southwestern Nigeria". *Journal of Climate.* 19: 483-493.
- Adeniyi, M.O. and E.O. Oladiran. 2006. "Recent Results on Atmospheric Radioactivity at Ibadan, Nigeria". *Radiation Measurements.* 41:330-336.
- Afiesimama, E.A., J. Pal, B.J. Abiodun, W.J. Gutowski, and A. Adedoyin. 2006. "Simulation of West African Monsoon using the RegCM3. Part I: Model Validation and Interannual Variability". *Theor Appl Climatol.* 82:23–38.
- Akpabio, L.E. and S.E. Etuk. 2003. "Relationship between Global Solar Radiation and Sunshine Duration for Onne, Nigeria". *Turkish Journal of Physics.* 27:161-167.
- Allen, R.G, L.S. Pereira, D. Raes, and M. Smith. 1998. "Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements". FAO Irrigation and Drainage Paper. 56.
- Brooks, K.N., P.F. Ffolliott, H.M. Gregersen, and L.F. Deban. 1997. *Hydrology and the Management of Watersheds (Second Edition)*. Iowa State University Press: Ames, Iowa.
- Chiemeka, I.U. 2008. "Estimation of Solar Radiation at Uturu, Nigeria". *International Journal of Physical Sciences.* 3:126-30.
- Chineke, T.C. and V.N. Dike. 2010. "Correlation of PVGIS Data with other Solar Radiation Estimates in the Niger Delta Region of Nigeria". *International Journal of Natural and Applied Sciences.* 6(2): 173-180.
- Chineke, T.C. 2002. "A Robust Method of Evaluating the Solar Energy Potential of a Data Sparse Site". *The Physical Scientist.* 1:59-69.
- Chineke, T.C. 2008. "Equations for Estimating Global Solar Radiation in Data Sparse Regions". *Renewable Energy.* 33:827-831.
- Chineke, T.C. and S.S. Jagtap. 1995. "A Comparison of Three Empirical Models for Estimating Solar Radiation in Nigeria". *African Journal of Science and Technology.* A(11): 45-48.
- Chineke, T.C. 1993. "Stochastic Simulation of Daily Weather Data in Tropical Africa". Ph.D. Thesis. University of Ibadan, Nigeria (unpublished).
- Crutzen, P.J. 1994. "An Overview of Atmospheric Chemistry". pp 63-85 In: *Topics in Atmospheric and Interstellar Physics and Chemistry.* C.F. Boutron (ed.). EDP les: Ulis, France.
- Eddy, J.A., R.L. Gilliland, and D.V. Hoyt. 1982. "Changes in the Solar Constant and Climatic Effects". *Nature.* 300:689 – 693.
- Currie, D.J. 1991. "Energy and Large-Scale Patterns of Animal-and Plant-Species Richness". *The American Naturalist.* 137:27-49.

18. Dike, V.N., T.C. Chineke, O.K. Nwofor, and U.K. Okoro . 2010. "Evaluation of Horizontal Surface Solar Radiation Levels in Southern Nigeria". *Journal of Renewable and Sustainable Energy*. 3(2):1-11.
19. Dow, C.L. and D.R. DeWalle. 2000. "Trends in Evaporation and Bowen Ratio on Urbanizing Watersheds in Eastern United States". *Water Resources Research*. 36:1835-1843.
20. El-Sebaei, A.A. and A.A. Trabea. 2005. "Estimation of Global Solar Radiation on Horizontal Surfaces over Egypt". *Egypt Journal of Solids*. 28:163-175.
21. Fooladmand, H.R. and M. Haghighat. 2007. "Spatial and Temporal Calibration of Hargreaves Equation for Calculating Monthly ETo based on Penman-Monteith Method". *Irrigation and Drainage*. 56:439-449.
22. Fortin, J.G., F. Anctil, L.E. Parent, and M.A. Bolinder. 2008. "Comparison of Empirical Daily Surface Incoming Solar Radiation Models". *Agricultural and Forest Meteorology*. 148:1332-1340.
23. Hanson, R.L. 1991. *Evapotranspiration and Droughts*. U.S Geological Survey: Washington, D.C. 99-104.
24. Hargreaves, G.H. 2003. "History and Evaluation of Hargreaves Evapotranspiration Equation". *Journal of Irrigation and Drainage Engineering*. 129: 53-63.
25. Hargreaves, G.H. and Z.A. Samani. 1985. "Reference Crop Evapotranspiration from Temperature". *Applied Engineering in Agriculture*. 1:96-99.
26. Hulme, M. 1992. "Rainfall Changes in Africa. 1931–1960 to 1961–1990". *Int J Climatol*.12: 685–699.
27. Jagtap, S.S. 1991. "Spatial Pattern of Reference Evapotranspiration in Africa". ASAE paper St. Joseph, MI. 91-2644.
28. Kuye, A. and S.S. Jagtap. 1994. "Correlation of Solar Radiation with Climatological Data for Port Harcourt, Nigeria". *International Journal of Climatology*. 14:815-825.
29. Lamb, P.J. and R.A. Pepler. 1991. "West Africa". In: M. Glantz, R.W. Kats, and N. Nicholson (eds). *Teleconnections Linking Worldwide Climate Anomalies*. Cambridge University Press: London, UK. 121–189.
30. Liu, D.L. and B.J. Scott. 2001. "Estimation of Solar Radiation in Australia from Rainfall and Temperature Observations". *Agricultural and Forest Meteorology*. 106:41–59.
31. Mahmood, R. and K.G. Hubbard. 2005. "Assessing Bias in Evapotranspiration and Soil Moisture Estimates due to the use of Modeled Solar Radiation and Dew Point Temperature Data". *Agricultural and Forest Meteorology*. 130: 71-84.
32. Mbagwu, J.S.C. 1988. "A Comparison of Five Empirical Models for Estimating Reference Evapotranspiration in Nigeria". *Beitrage zur Tropischen Landwirtschaft und Veterinarmedizin*. 26: 47-54.
33. Nicholson, S.E. 1993. "An Overview of Africa Rainfall Fluctuation of the Last Decade". *J. Climate* 6:1463–1466.
34. Omotosho, J. and H. Bayo. 1985. "The Separate Contributions of Squall Lines, Thunderstorms and the Monsoon to the total Rainfall in Nigeria". *J Climatol*. 5:543–552.
35. Palutikof, J.P., C.M. Goodess, and X. Guo. 1994. "Climate Change, Potential Evapotranspiration and Moisture Availability in the Mediterranean Basin". *International Journal of Climatology*. 14:853-869.
36. Pereira, A.R. and A.P. de Camargo. 1980. "An Analysis of the Criticism of Thornthwaite's Equation for Estimating Potential Evapotranspiration". *Agricultural and Forest Meteorology*. 46:149–157.
37. Peter, M. and G. Tetzlaff. 1988. "The Structure of West African Squall Lines and their Environmental Moisture Budget". *Meteorol Atmos Phys*. 39:74–84.
38. Pinker, R.T., Y. Zhao, C. Akoshile, J. Janowiak, and P. Arkin. 2006. "Diurnal and Seasonal variability of Rainfall in the Sub-Sahel as seen from Observations, Satellites and a Numerical Model". *Geophys. Rm Lett*. 33, LO7806, doi: 10.1029/2005GLO25192.
39. Roderick, M.L. and G.D. Farquhar. 2005. "Changes in New Zealand pan Evaporation since the 1970s". *International Journal of Climatology*. 25: 2031-2039.
40. Rowell, D.P., C.K. Folland, K. Maskell, and M.N. Ward. 1995. "Variability of Summer Rainfall over Tropical North Africa (106–92): Observation and Modeling". *Quart J Roy Meteor Soc*. 121:669–704.
41. Sabziparvar, A.A. 2008. "A Simple Formula for Estimating Global Solar Radiation in Central Arid Deserts of Iran". *Renewable Energy*. 33:1002-1010.

42. Salako, F.K. 2008. "Rainfall Variability and Kinetic Energy in Southern Nigeria". *Climatic Change*. 86: 151-164.
43. Scholes, R.J. and B.H. Walker. 2004. *An African Savanna: Synthesis of the Nylsvley Study*. Cambridge University Press: London, UK.
44. Skeiker, K. 2006. "Correlation of Global Solar Radiation with Common Geographical and Meteorological Parameters for Damascus Province, Syria". *Energy Conversion and Management*. 47:331-345.
45. Stjern, C.W., E.J. Kristjansson, and A.W. Hansen. 2008. "Global Dimming and Global Brightening: An Analysis of Surface Radiation and Cloud Cover Data in Northern Europe". *International Journal of Climatology*. DOI: 2008;10.1002/joc.1735.
46. Vicente-Serrano, S.M., S. Lanjeri, and J.I. López-Moreno. 2007. "Comparison of Different Procedures to Map Reference Evapotranspiration using Geographical Information Systems and Regression-Based Techniques". *International Journal of Climatology*. 27:1103-1118.
47. Yanling, S., Y. Xiaodong, and X. Deti. 2008. "A New Method of Vegetation-Climature Classification in China". *International Journal of Climatology*. 28:1163-1173.

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