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PREDICTING REFERENCE EVAPORTRANSPIRATION USING DRYNESS INDEX MODEL IN SOME TYPICAL HUMID REGION OF NIGERIA

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Abstract

Physics as a field of study provides basic instrument and numerical analysis of problem. This work is aimed at estimating reference evaportranspiration using Dryness Index Model in some typical humid region of Nigeria employing analytical techniques of Physics. There is a growing concern especially in Africa, about the consequences of climate change for food systems and food security. There is also concern that meeting the rising demand for food is leading to environmental degradation thereby exacerbating factors in part responsible for climate change, and further undermining the food systems upon which food security is based. This work presents Dryness Index (DI), the ration of rainfall over reference evaportranspiration (ET) in some parts of humid regions in Nigeria. The ET values were computed using the Blanney-Criddle using the maximum and minimum temperatures as input. The daily rinfall analysis showed signs of a possible climate change. The implication of this in developing a sustainable crop plan for Nigeria and in crop-climate studies

Keywords:
Evaportranspiration, Dryness Index Model, Typical Humid Region, Nigeria, Predicting.

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towards boosting the food production system in a changing climate is emphasized. An understanding of the evaportranspiration, rainfall, dryness index process and knowledge about the spatial and temporary rates of evaportranspiration is paramount for designing appropriate response to climate change. Unfortunately, knowledge about the process is limited in many African countries. In this work, we analyzed levels of evaportranspiration, rainfall and dryness index for two cities of Nigeria (Owerri and Calabar) using obtained data fron Nigeria meteorological agency (NIMET) for the period of 12 months. This work stands a chance to educate and enlighten its reader and thus, gives a suitable advice where necessary.

Introduction

Nigeria is listed by FAO (Food and Agricultural Organization) among those nations that are at the moment technically unable to meet their food needs from rain-fed production at a low level of input and appear likely to remain so even at intermediate levels of inputs at some point in time between year 2000 and 2030. Knowledge of levels of evapotranspiration and dryness index helps farmers know the adequate season and crop to sow depending on nature of plant by considering the transpiration from the plant and evaporation from soil. Evapotranspirtaion is a significant water loss from drainage basins. Types of vegetation and land use significantly affect evapotranspiration, and therefore the amount of water leaving a drainage basin. Because water transpired through leaves comes from the roots, plants with deep reaching roots can more constantly transpire water. Through evapotranspiration, forest reduce water yield, except in unique ecosystems called cloud forests. Trees in cloud forests collect the liquid water in fog or low clouds onto their surface, which drips down to the ground. These trees still contribute to evapotranspiration, but often collect more water than they evaporate or transpire.

Routine information on regional evapotranspiration (ET), rainfall and dryness index is essential for agricultural water management, drought monitoring, and studies of water cycle and climate dynamics. Formally, the knowledge of evapotranspiration, rainfall and dryness index was neglected initially and this lead to poor infrastructural development, limited agricultural product, deformation and hence low standard of living. Having adequate knowledge of evapotranspiration, rainfall and dryness index as estimated by scientist in recent times can help to checkmate and balance the activities of the agricultural sector and enhance proper development scheme because one can vividly state the rate at which water leaves the earth surface, give the level of rainfall at a particular place and tell how dry a place is at a particular time.

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As physicist we stand a better chance in helping our society, because through Physics method one can estimate and give proper information about evapotranspiration, rainfall and dryness index to improve the standard of living. Evapotranspiration (ET) is a term used to describe the sum of evaporation and plant transpiration from the Earth's land surface to atmosphere. Evaporation accounts for the movement of water to the air from sources such as the soil, canopy interception and water bodies. Transpiration accounts for the movement of water within a plant and the subsequent loss of water as vapor through stomata in its leaves. It is also the combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration which is referred to as evapotranspiration (ET). The process of evapotranspiration is one of the main consumers of solar energy at the Earth's surface. Energy used for evapotranspiration is generally referred to as latent heat flux, however, the term latent heat flux is broad, and includes other related processes unrelated to transpiration including condensation (e.g., fog, dew), and snow and ice sublimation. Apart from precipitation, evapotranspiration is one of the most significant components of the water cycle.

Rain is liquid water in the form of droplets that have condensed from atmospheric water vapor and then precipitated that is, become heavy enough to fall under gravity. Rain is a major component of the water cycle and is responsible for depositing most of the fresh water on the planet. It provides suitable conditions for many types of ecosystem, as well as water for hydroelectric power plants and crop irrigation. The major cause of rain production is moisture moving along three-dimensional zones of temperature and moisture contrasts known as weather fronts. If enough moisture and upward motion is present, precipitation falls from convective clouds (those with strong upward vertical motion) such as cumulonimbus (thunder clouds) which can organize into narrow rainbands. In mountainous areas, heavy precipitation is possible where upslope flow is maximized within windward sides of the terrain at elevation which forces moist air to condense and fall out as rainfall along the sides of mountains.

Dryness index (DI) predicts the level of dryness within the atmosphere at a particular period of time. It incorporates evapotranspiration, while evapotranspiration tells the rate at which moisture leaves the surface of the earth to the atmosphere, dryness index is the absence of moisture content within the atmosphere at a particular period of time in a particular area, that is, they give the level of dryness of a place.

Evapotranspirtaion and rainfall are the most significant component of the hydrologic budget. They vary according to weather and wind condition. Because of this variability, water managers who are responsible for planning and adjusting the distribution of water

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resources needs to have a thorough understanding of the evapotranspiration process and knowledge about spatial and temporary rates of evapotranspiration. Dryness indices of land surface provide useful information for agricultural and water resources managements. In areas that are not irrigated, actual evapotranspiration is usually no greater than precipitation, with some buffer in time depending on the soil's ability to hold water. It will usually be less because some water will be lost due to percolation or surface runoff. An exception is areas with high water tables, where capillary action can cause water from the groundwater to rise through the soil matrix to the surface.

If potential evapotranspirtaion is greater than actual precipitation, then soil will dry out, unless irrigation is used. The main objective of this research was to predict reference evapotranspiration using dryness index model in some typical humid region of Nigeria (Calabar and Owerri). Specific Objectives are: (a) present information on levels of evapotranspiration, rainfall and dryness index within the eastern region (Calabar and Owerri) from October 2024 to September 2025 (b) discuss issue of levels of evapotranspiration, rainfall and dryness index also note factors that affect them (c) compare levels of evapotranspiration, rainfall and dryness index in two cities within the eastern region.

MATERIALS AND METHODS

The sites studied in this research was Calabar, located on longitude 8° 32^{l} East and latitude 4° 95^{l} North and Owerri, located on longitude 7° 02^{l} East and latitude 5° 48^{l} North. Like most locations in West Africa, there are 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. The temperature data used for computing the reference evapotranspiration (ET) was collected from the Nigerian Meteorological Agency, Abuja.

The monthly average time series of rainfall spanning 1 year (October, 2024 to September, 2025) was also acquired by Nigerian Meteorological Agency (NIMET), Abuja. These are ground measured data that has shown to be accurate enough to provide reliable meteorological resource data over Nigeria. With these data length of 12 months average rainfall values, it is possible to observe seasonal annual cycles and decadal trend-lines.

Microsoft excel was used to analyze the data in fairly quantitative terms by plotting graphical representation of the sequence and the fitted trend line will show that the sites was captured in two obvious trend, one was the periodic variation with average period

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between extreme wetness and dryness, the other was an increasing linear trend modeled by the equation 1 and 2.

$y = 7.3112x + 162.11$ …… Equation 1

$y = 8.6599x + 138.36$ …… Equation 2

Estimation of Evapotranspiration Levels

The reference crop evapotranspiration (ET) is the rate of evaoptranspiration from a large area; covered by green grass, 8cm to 15cm tall, which grows actively, completely shades the ground and which is not short of water. Evaporation pans provide a measurement of the combined effect of temperature, humidity, windspeed and sunshine on the reference crop evapotranspiration (ET) (Chineke, 2008). If no measured data on pan evaporation are available locally, a theoretical method to calculate the reference crop evapotranspiration (ET) was used. There are a large number of theoretical methods to determine the ET (Mbagwu, 1988; Jesen *et al.,* 1990; Lemuer and Zhang, 1990; Fennessey and Kirshen, 1994; Xu and Chen, 2005; Cai *et al.,* 2007; Rim, 2008). The Penman-Monteith method (Allen *et al.,* 1998) was the benchmark but requires many climatic parameters that may not be available most of the time like the vapour pressure, relative humidity, net and global radiation amongst others. The methods used to compute the reference evapotranspiration data that was used in this study were described below:

The Modified Blanney–Criddle Method

This is the modification of the original Blanney-Criddle (Dorenboos and Pruitt, 1977; Palutikof *et al.,* 1994; Allen *et al.,* 1998). The equation for calculating reference evapotranspiration with this method is:

$ET\ (mm/day) = p\ (0.46Ta + 8)$ …… Equation 3

Where,

Ta = is the mean air temperature (maximum + minimum)/2 and

p = is a local constant (0.27).

The mean temperature takes into account changes in radiation due to proximity to oceans, mountains, and the altitude of the location (Chineke and Olemeforo, 2010).

Estimation of Dryness Index

Dryness index (DI) was computed using the method by Kulandaivelu and Jayachandran (1994) which had been used by Kassam (1976) in Nigeria who demonstrated that crop-water requirement is usually met when rainfall is only half the value of the evapotranspiration. The equation is:

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DI = Rainfall/ET …… Equation 4
Where,
Rainfall is the daily amount of precipitation (mm/month) and
ET is the evapotranspiration (mm/month).
Chineke and Olemeforo, (2010) used three sets of index, thus, (i) DI ≤ 0.5, (ii) 0.5 > DI < 1.0 and (iii) DI ≥ 1.0.

RESULTS AND DISCUSION

The Blanney-Criddle method was based on the mean air temperature and was preferable since it uses mean air temperatures and therefore averages the noise that may be inherent due to instrument errors, for example on days with maximum and minimum temperatures having a marginal 1difference, for example 3 degrees Celcius. A month is assumed to be humid if dryness index (DI) equals or exceeds 1.0. The method therefore captures more humid days for the 12 months period.

The main elements used in the Blanney-Criddle model for the analysis was very germane and suitable, especially for the humid part of Nigeria, where wind, solar radiation and temperature play a significant role in the determination of evaportranspiration and reference evaportranspiration rates. Again, the choice of the locations, which was located in the weetter Guinea Savannah belt of Nigeria, was very ideal, because a suitable and very workable "crop plan index" can be developed simultaneously for the zone, using the data from the locations. Using the Blanney-Criddle models, the October 2024 to September 2025 (monthly weather variables) reference evaportranspiration (mm) rates indicated that there are significantly fewer days of dryness in the study sites (that is fewer days of "good DI", and more for "poor DI" rates). The results are listed in Table 1 and 2.

Table 1: Distribution of DI ratios for October 2024 to September 2025 at Calabar for the Blanney-Criddle (BLAC) method

Month	DI ≤ 0.5	0.5 > DI < 1.0	DI ≥ 1.0
October 2024	2	0	10
November 2024	1	0	11
December 2024	1	0	11
January 2025	1	0	11
February 2025	0	0	12
March 2025	1	0	11
April 2025	1	0	11
May 2025	0	0	12

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Month	DI ≤ 0.5	0.5 > DI < 1.0	DI ≥ 1.0
June 2025	1	0	11
July 2025	0	0	12
August 2025	1	0	11
September 2025	0	0	12

Observations from the 12 months Rainfall/ET data indicate that there are about 0.9 "good DI days and 13.5 "poor DI days for the whole year in Calabar, observations from the one year Rainfall/ET daya indicate that there are about 0.9 "good DI" days and 13.5 "poor DI" days for the whole year in Calabar. The observed values for Owerri are 0.8 for "good DI" days and 13.6 for "poor DI" days (Table 2). Deducting from the above information, it can be observed that there was a minimum of 1 drier month and a maximum of 2 drier months in the both cities, between October 2024 and September 2025, coupled with a steady but gradual increase in rainfall. However, it is pertinent to suggest here, that caution should be exercised, so as not to adopt with error any rainfall data for this year alone without making provisions for comparisons with data from other years, which may either be wetter or drier than the present October 2025 to September 2026.

Table 2: Distribution of DI ratios for October 2024 to September 2025 at Owerri for the Blanney-Criddle (BLAC) method

Month	DI ≤ 0.5	0.5 > DI < 1.0	DI ≥ 1.0
October 2024	0	0	12
November 2024	2	0	10
December 2024	2	0	10
January 2025	1	1	10
February 2025	0	0	12
March 2025	0	0	12
April 2025	0	0	12
May 2025	0	0	12
June 2025	1	0	11
July 2025	0	0	12
August 2025	1	0	11
September 2025	0	0	12

Monthly Evaportranspiration Level at Calabar

The estimated ET levels for the site were stated in Table 3 and 4 for 12 months (October 2024 to September 2025). In Table 3 were listed the Seasonal Variations of

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evaportranspiration for Calabar, we see the estimates having signatures that have the similitude of expected patterns at a subtropical site. The values ranged from 4.07 mm in November 2024, to 6.02 mm in July 2025. The site recorded high level of evaportranspiration in the dry season months with peak in February (5.77 mm) while it recorded 6.02 mm in July, 5.77 mm in March and 5.77 mm in January.

Table 3: Seasonal Variation of Reference Evaportranspiration at Calabar for 12 months

Month	Evaportranspiration (mm)
October 2024	5.74
November 2024	4.07
December 2024	5.75
January 2025	5.77
February 2025	5.79
March 2025	5.77
April 2025	5.33
May 2025	5.32
June 2025	5.25
July 2025	6.02
August 2025	5.38
September 2025	5.39

On the other hand, the site recorded minimum estimates mostly in the month of August (5.38 mm). This scenario is expected since the months of July to August are the peak of the rainy season in Nigeria. this pattern is well elucidated in Table 5 which shows a one year average plot for the site Calabar, the dry season months recording high level of evapotranspiration (October to March) and least levels in rainy season months April to September for the one year in study.

However, a linear trend line shows a significant heavy decline in levels of evapotranspiration for the site, this linear trend in modeled by the equation y = -0.02x + 5.6873 probably suggest that the research site records more rainy days than dry days because the study has shown that evapotranspiration was high during dry season and low during wet season.

Monthly Evapotranspiration Level at Owerri

The scenario was not far-fetched for Owerri as Table 4 clearly shows the Seasonal Variations reference Evapotranspiration for Owerri, the site recorded the highest level of

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ET (mm/day) mostly in the month of Febraury (5.99 mm) and in the month of March as (5.89 mm).

Table 4: Seasonal Variation of Reference Evaportranspiration at Owerri for 12 months

Month	Evaportranspiration (mm)
October 2024	5.40
November 2024	4.20
December 2024	5.75
January 2025	5.77
February 2025	5.99
March 2025	5.89
April 2025	5.35
May 2025	5.36
June 2025	5.37
July 2025	5.39
August 2025	5.48
September 2025	5.41

While recording the minimum levels mostly in the month of August which was also captured in Table 4 as (5.48 mm) and in July as 5.39 mm and the least 4.20 mm in the monh of November. A linear trendline shows a significant heavy decline in levels of evapotranspiration for the site, this linear trend in modeled by the equation y = -0.0256x + 5.7888 which also suggests that the research site recorded high levels of evapotranspiration in the month 5.99 mm/day in February 2025 and least 5.48 mm/day in August 2025. This can be interpreted as more evapotranspiration during dry season months and less during wet season months.

Seasonal Variation of Rainfall Amount for Calabar (mm/month)

Listed in Table 5 was the rainfall variation trend for Calabar. It was observed that the site witnessed its highest rainfall level 881, 827, 647 in the months of July, August and June respectively. The month of July and August has the highest occurrence of extreme episode of heavy rainfall, while there was little or no rainfall in the months (December 2024, January 2025 and February 2025). It was obvious that it rained throughout the months of June, July and August with incidence of extreme episode of rainfall 647 mm/day, 827 mm/day and 881 mm/day respectively.

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Table 5: Seasonal Variation of Rainfall Amount for Calabar (mm/month)

Month	Rainfall amount (mm)
October 2024	536
November 2024	491
December 2024	391
January 2025	399
February 2025	400
March 2025	517
April 2025	583
May 2025	624
June 2025	647
July 2025	881
August 2025	827
September 2025	598

Seasonal Variation of Rainfall Amount for Owerri (mm/month)

Table 6 was the rainfall variation trend for Owerri. It was observed that the site witnessed its highest rainfall level 630, 560, and 538 in July, August and September, 2025 respectively. The month of July and August 2025 has the highest occurrence of extreme episode of heavy rainfall, while there was no rainfall in the months of (December 2024 and January 2025). It was obvious that rained through out the year with incidence of extreme episode of rainfall 430 mm/day and 630 mm/day respectively.
The trend line which modeled by equation 2 suggest a gradual increase in the amount of rainfall receivable at the site.

Table 6: Seasonal Variation of Rainfall Amount for Owerri (mm/month)

Month	Rainfall amount (mm)
October 2024	333
November 2024	310
December 2024	278
January 2025	289
February 2025	381
March 2025	392
April 2025	453
May 2025	507
June 2025	539

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Month	Rainfall amount (mm)
July 2025	630
August 2025	560
September 2025	538

As stated earlier, like most locations in West Africa, there are two seasons; the wet and dry seasons, which differ by the levels of precipitation, temperature and humidity, with the wet season recording higher precipitation, higer 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 (Chineke, 1993; Nwofor *et al.,* 2010; Nwofor, 2010; Dike *et al.,* 2011a and Dike *et al.,* 2011b).

Implication of the Results

With the utilization of the effective growth energy of crops (Oshodi, 2016; Kowal and Kassam, 2016) which we have modified to be in line with present climate patterns in Nigeria, suitable soil type, favourable Rainfall/ET ratio, sustainable food production systems (like reduced tillage, multi-cropping, optimal fertilizer and pesticide use, forest conservation), the basis for the development of crop plans with suitable varities that are often drought-resistant and with shorter periods of maturity can be established across the Sub-Saharan environments of Africa. For grains such as millet, sorghum, beans, rice, wheat, maize and Soya-beans, all locations in Nigeria are suitable, with the exception of the wetter Niger Delta areas, where millet, sorghum, wheat and Soya-beans which are dry weather crops cannot perform optimally (Bello, 2017).

Soil type, rainfall and evapotranspiration ratio, and other types of information can provide the basis for developing crop plans by adopting improved technology, the sites has ample justification to increase cultivation of crops, such as millets, oil seeds, pulses, vegetables and so forth. Pulses can be grown successfully in these areas. In places that are prone to moderate drought, millets such as sorghum and pearl millets are recommended (Bello, 2017).

A good crop plan to reduce the risk of crop failure includes cereals mixed with pulses or oil seeds. Suitable crops and varieties should be selected based on the degree of drought tolerence in relation to soil types. In a changing ecosystem like in Sub-Saharan Africa due to many factors like overgrazing, indiscriminate felling of trees, unsustainable food production systems, inapprpriate management of land and water resources, new crop plans and varieties must be adopted to boost food production for an ever-increasing population faced with other problems like wars and ethnic conflicts.

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CONCLUSION

The food and Agriculture Organization (FAO) Land and Water Development Division has played anactive role during the past three decades in developing and promoting guidelines and methodologies on crop water management at the field level that have becomes widely-used standards. This particularly applies to the methodologies for the calculation of crop water requirement and crop water productivity in irrigated and rain fed agriculture (Kassam and Smith, 2001). From our results, we suggest that the wetter months between May and October, can be dedicated for the growing of the following crops alone: yams, cassava, cocoyam, potato as well as maize and rice. It is believed that the growing of these crops within the wetter months would not require irrigation water which will add stress to the "lean"water ecosystem.

The ability to tell how dry, wet and the amount of water that leaves a particular place by estimating evapotranspiration and dryness index is not only important in the agricultural sector but play major role in construction of roads, bridges and other infrastructural structures because one needs the knowledge of ET and DI to tell exactly the nature of the material to be used in order harness effective structure and avoid deformation.

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