IOSR Journal of Applied Physics (IOSR-JAP)
e-ISSN: 2278-4861.Volume 11, Issue 2 Ser. II (Mar. – Apr. 2019), PP 16-21
www.iosrjournals.org

Variability of Clearness Index Over Lagos A Selected Location in South West Nigeria

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Abstract: *Global solar radiation changes and climatic variation are the most of the world's environmental problems. Solar radiation received at the earth's surface under different atmospheric conditions obviously affect the amount and quality of radiation obtained at the ground during the course of the day. The variation in climatic parameters like pressure,temperature,rainfall,humidity,wind, precipitation, turbidity, transparency and distribution of cloud cover have been suggested to exert depleting influence on solar radiation data. This paper is focused on the development of graphical polygon method based on the extraterrestrial and terrestrialsolar irradiation amount and the interpretation concerning the clearness index of Lagos south west part of Nigeria with solar irradiation measurement.*

Keywords: *Radiation, extraterrestrial, terrestrial, clearness index.*

Date of Submission: 11-03-2019 Date of acceptance: 27-03-2019

I. Introduction

The sun our singular source of renewable energy, sits at the center of the solar system and emits energy as electromagnetic radiation at an extremely large and relatively constant rate, 24 hours per day, 365 days of the year.The rate at which this energy is emitted is equivalent to the energy coming from a furnace at a temperature of about 6,000 ^{0}K.The sun is sphere of intense hot gaseous matter with a diameter of $1.39x10^9$m and is about 1.5 $x10^{11}$m away from the earth (Falayi*et al.*, 2011).The rate at which solar energy reaches a unit area at the earth is called the "*solar irradiance*" or "*insolation*". The units of measure for irradiance are watts per square meter (W/m^2). Solar irradiance is an instantaneous measure of rate and can vary over time. The maximum solar irradiance value is used in system design to determine the peak rate of energy input into the system.The radiation from the sun is the primary natural energy source of the planet Earth. Other natural energy sources are the cosmic radiation, the natural terrestrial radioactivity and the geothermal heat flux from the interior to the surface of the Earth (Falayi*et al.*, 2011).Sun's energy is generated in its nucleus mainly through thermonuclear reaction of hydrogen fusion into helium. The sun's energy is generated in its core. Gravitational pressures compress and heat the material in the core to over 15 million degree Celsius or about 17 million degree Fahrenheit.Not all of the sun's energy comes to the Earth. The sun's energy is emitted in all directions with only a small fraction being the direction of the Earth. The average energy of the sun of the whole earth's surface is 2 calories (cal) per square centimeter (cm^2) per minute (min). It is also called the solar constant while 34% of the sun's energy is reflected back into space by snow and clouds. This reflective quality of a planet is called its "Albedo"(Che, H.Z., et al 2007).Only the half-billionth part of the sun energy reaches the earth. Only about 5 percent of all available sun's energy is considered as chemical energy in the biomass of planet. A theoretically optimal 80 percent of the energy can be used by organisms of the next higher trophic level.Sun energy is clean; inexhaustible and can be transformed into other forms of energy: thermal, electric, chemical, mechanical, etc. the solar energy that energizes the plants goes on to become the fuel that allows animals to live and grow.(Bocco,*et al.*, 2010).

II. Experimental

The raw data collected from meteorological station were processed into required formats with information on year, month, day, time measured parameters.The monthly means of the daily values of the meteorological parameters were evaluated by taking the average of all the days in every month for each month for each year of the data. The daily average temperature was evaluated by taking mean value of the maximum and minimum temperature for any day and its monthly means evaluated alongside the other parameter. (Angstrom, 1924).

III. Data Source And Description

The data uses in the research consist of daily values of some meteorological variables. The meteorological parameters that span through a period of one year (2010) include solar radiation and temperature both minimum and maximum. The meteorological data were obtained from Center for Atmospheric Research (CAR), sited at KogiState University campus, Anyingba Nigeria. The center is under the supervision of NationalSpace Research and Development Agency (NASRDA). The data were collected from observing project (NECOP). The metrological variable dealing with the research is solar radiation, and temperature T. These parameters are used to calculate for the use of clearness index. The results are shown in table 1 below and subjected to simple statistical analysis to enable the view of the characteristics of solar radiation and temperature in the study area. The data are obtained through the electronic format to enable effective analysis in Microsoft excel, MATLAB and surfer software.

IV. Clearness Index

Often, solar radiation levels are plotted in order to gain insight into local and to permit extrapolation between sites where accurate databases exist. Examples of these are available on the NREL solar energy data site. A concept used to normalize these maps, and to present location specific solar radiation data is the clearness index; which is the ratio of global horizontal solar radiation at a site to the extraterrestrial horizontal solar radiation above the site where $H_{0,h}\left(J/m^2\right)$ is defined as,

$$H_{0,h} = \frac{86,400 I_0}{\pi}\left(\omega_s \sin\phi \sin\delta + \cos\delta \cos\phi \sin\omega_s\right) \qquad 1$$

V. Method Of Model Evaluation

Radiation Modeling

In a period of rapidly growing deployment of solar energy systems, solar resource assessment, or in other words acquisition of solar data is imperative.It allows assessment of a solar system's performance in relation to the technicalities, local geography and energy demand. The need for modeling the solar data is necessary for solar resource assessment. This section reviews some of the major landmark models (correlations or regressions as one may call it) in the history of solar radiation.

VI. Angstrom-Type Model

Average daily global radiation at a specific location can be estimated by the knowledge of the average actual sunshine hours per day and the maximum possible sunshine hour per day at the location. This is achieved by a simple linear relation given by Angstrom (1924) and modified by (Prescott, 1940).

$$\frac{G}{G_0} = a + b\left(\frac{S}{S_{\max}}\right) \qquad 2$$

In Nigeria, the hourly global solar radiations were obtained through Gun Bellani distillate, and were converted and standardized after Folayan (1988), using the conversion factor computed from the following equations.

$$G = \left(1.35 \pm 0.176\right) H_{GB} \frac{KJ}{M^2} \qquad 3$$

where G is the monthly average of the daily global solar radiation on a horizontal surface at a location (KJ/m^{2-}day), G_0 is the average extraterrestrial radiation (KJ/m^{2-}day). S is the monthly average of the actual sunshine hours per day at the location. $S_{\max}$ monthly average of the maximum possible sunshine hours per day, n is mean day of each month (Falayi, *et al.*, 2011).Where a and b are the model parameters. From a mathematical point of view, a is theintercept and b is the slope parameter of a linear equation. When the sky is completely clear,the sunshine duration hour become equal to day length $\left(S = S_{\max}\right)$. For completely overcast sky,the sunshine duration hour, S, is equal to zero. H_{GB} in equation (3) is the data measured using the Gun-Bellani distillate (Yusuf, 2017). At any point in time, the solar radiation outside the atmosphere incident on a horizontal plane is given by,

$$G_0 = G_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]\cos\theta_z \qquad 4$$

where G_{sc} is the solar constant and n is the day of the year. For a horizontal surface at any time between sunrise and sunset G_0 becomes,

$$G_0 = G_{sc}\left[1+0.033\cos\left(\frac{360n}{365}\right)\right]\left(\sin\phi\sin\delta+\cos\phi\cos\delta\cos\omega\right) \quad 5$$

The daily extraterrestrial radiation on a horizontal surface is given by,

$$G_0 = \frac{24x3600G_{sc}}{\pi}\left[1+0.033\cos\left(\frac{360n}{365}\right)\right]x\left[\cos\phi\cos\delta\sin\omega_s+\frac{2\pi\omega_s}{360}\sin\phi\sin\delta\right] \quad 6$$

where ω_s is the sunset hour angleDuffie and Beckman (1980).

$$S_{\max} = \frac{2}{15}\cos^{-1}\left(-\tan\theta\tan\delta\right) \quad 7$$

The value of the solar radiation was calculated based on Angstrom method of prediction:

$$\frac{H_m}{H_0} = a+\frac{bn}{N} = K_T \quad 8$$

where, H_m is a measure of monthly mean daily global solar radiation falling on horizontal surface of each location. H_0 is the monthly mean daily extraterrestrial radiation falling on horizontal surface in the absence of atmosphere. n is the monthly mean value of observed sunshine hour. N is the monthly mean value of day length of a particular location a = 0.3j and b = 0.47j are climatologically determined regression constant using the relationship given as

$$a = 0.110+0.235\cos\theta+0.323\left(n/N\right) \quad 9$$

$$b = 1.449-0.553\cos\theta-0.694\left(n/N\right) \quad 10$$

where, n/N is called the percentage of possible sunshine hour.The value H_o which is the monthly mean daily extraterrestrial radiation measured in MJ/m^2 is determined as,

$$H_0 = \frac{24x3600}{\pi}G_{sc}\left[1+0.033\cos\left(\frac{360n}{365}\right)\right]x\left[\cos\phi\cos\delta\sin\omega_s+\frac{2\pi\omega_s}{360}\sin\phi\sin\delta\right] \quad 11$$

Where, Gsc = solar constant = 1367W/m^2

ω_s = sunset hour angle for the typical day n for each month in degrees

$$\omega_s = \cos^{-1}\left(-\tan\phi\tan\delta\right) \quad 12$$

ϕ = latitude angle for the location in degrees

δ = declination angle for the month in degree.

$$\delta = 23.45\sin\left[\frac{360}{365}\left(284+Cj\right)\right] \quad 13$$

where C_j is the day number of the year with January 1st as 1 and December 31st as 365. K_T is known as clearness index defined as the ratio of the global solar radiation to extraterrestrial radiation.

VII. Estimation of Solar Radiation Components from Global Radiation

This class of models is commonly known as “decomposition models of global into diffuse and direct beam irradiance”. Models have extensively been developed based on inter-correlations between ratios such as K_T : clearness index (global/extraterrestrial horizontal radiation), k: diffuse ratio (diffuse/global radiation) or k_d: diffuse transmittance index (direct/extraterrestrial radiation).

VIII. Diffuse Ratio-Clearness Index Regression

One of the most common and popular estimation techniques in literature and for practical use in solar resource assessment has been the use of global radiation to estimate diffuse radiation. In this regards, the first regression model based on K_T was proposed by Liu and Jordan (1960). Since then, this correlation relationship has evolved over the time and its coefficients have been modified for different locations and also different time scales, that is, monthly-average, daily or hourly radiation models.

IX. Variation of diffuse solar radiation

Several models for estimating the diffuse component based on the pioneer works of Argstrom (1924) and Liuand Jordan (1960) and developed by Klein, (1977). These models are usually expressed in either linear or polynomial fittings relating the diffuse fraction (H_d) with the clearness index and combining both clearness index K_T) and sunshine duration (Orgill and Hollands, 1977;Erbs et al, 1982; Trabea, 1992; Jacovides, 2006;Hamdy, 2007, Falayi et al 2011) established hourly correlations. Ulgen and Hepbash (2002) correlated the ratio of monthly average hourly diffuse solar radiation to monthly average hourly global solar radiation with the monthly average clearness index inform of polynomial relationship for the city of Izmir, Turkey. Oliveira et al, (2002) used measurement of global and diffuse solar radiation in the city of Sao Paulo (Brazil) to drive empirical model to estimate hourly, daily and monthly diffuse solar from value of the global solar radiation, based on the correlation between the diffuse fraction and clearness index. The diffuse solar radiation H_o can be estimated by an empirical formular which correlates the diffuse solar radiation component H_o to the daily total radiation G. The ratio H_o/H therefore, is an appropriate parameter to define a coefficient, that is cloudiness or turbidity of the atmosphere.

$$\frac{H_0}{H} = 1.00 - 1.13K_T \qquad 14$$

Another commonly used correlations is due to Liu and Jordan (1960) and developed by Klein (1977) and is given by,

$$\frac{H_0}{H} = 1.390 - 4.027K_T + 5.53\left(K_T\right)^2 - 3.108\left(K_T\right)^2 \qquad 15$$

Large variations in the intensities of diffuse solar radiation due to cloudiness have been indicated as stated earlier.

X. Geographical Location Of Lagos

Lagos is one of the largest urban agglomerations, currently counting 9.5 million inhabitants.Since the late 70ies Lagos experiences an enormous population explosion and has a growth rate of 5.7percent per year.This means, Lagos is growing 2000 inhabitant per day. As the city's growth rate and the slum growth rate are mostly the same, the city development is not able to connect and to build at that speed. Lacking infrastructure and the emergence of informal settlements and at first glance chaotic conditions are resulting effects.

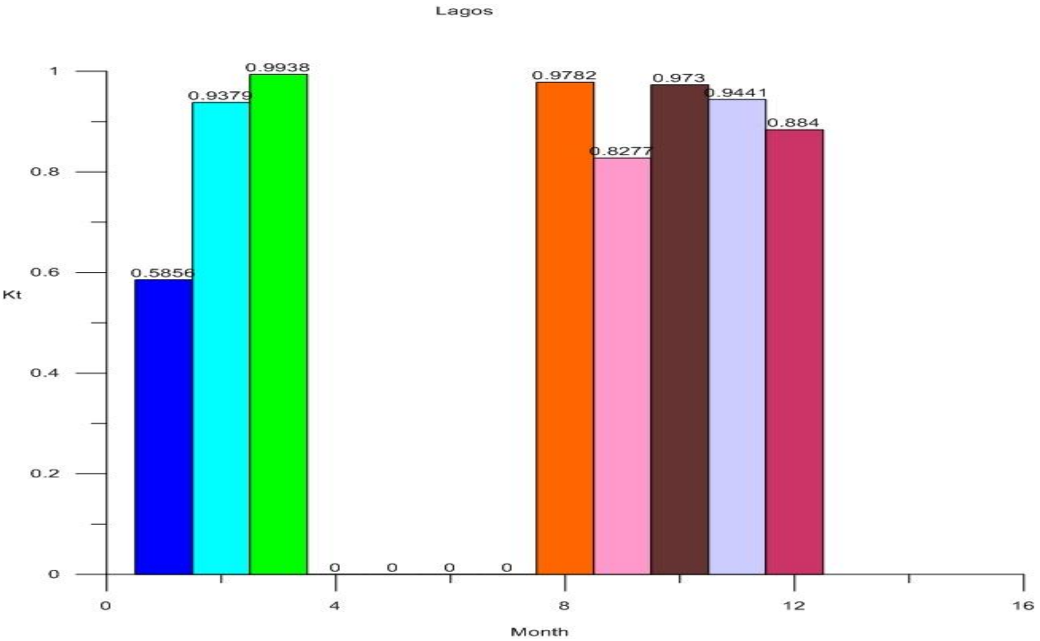
Lagos state Nigeria latitude	**6.523276500000000000**
Lagos state Nigeria longitude	**3.340790900000047300**

Lagos	Latitude	6.6667
	Longitude	3.4500E
	Altitude	39.35m
	N	181
	Ho	97.2352

Month	**H**	$K_T = H/H_0$
January	56.9395	0.585585
February	91.1944	0.937874
March	96.6312	0.993788
April	0	0
May	0	0
June	0	0
July	0	0
August	95.113	0.978175
September	80.4847	0.827732
October	94.6052	0.972952
November	91.7997	0.944099
December	85.9523	0.883963
Total	692.72	7.124169
Average	86.59	0.890521

XI. Result and Discussion

The clearness index of Lagos station as at January 2010 has value of 0.585,February, March, August, October and November recorded the highest values of clearness index. This shows that high clearness index was experienced in Lagos during the period. In April through to July, there are no records of clearness index K_T . From August to December, 2010, there is an average value of high clearness index value K_T = 0.93.



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XII. Conclusion

From the empirical results, the clearness index of Lagos station as at January, 2010 was 0.585 {58.5%} while February, March, August, October and Novemberrecorded the highest values of clearness index.The knowledge of the variability of clearness index can be of the following importance: It can be used to forecast the future disasters cause by climatic variation of the weather parameters.Climatic variation and solar radiation can be studied to improve the agricultural practices and food production.

XIII. Recommendation

Based on the conclusion, the following recommendations are made:

Effort should be put in place by experts in atmospheric and Space Physics to under study trend of clearness index of various states in the six geopolitical zones in Nigeria. Also there should be general enlightenment from the professionals on the risk and possible implications of clearness index and its impact on climate change and greenhouse effect.

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IOSR Journal of Applied Physics (IOSR-JAP) is UGC approved Journal with Sl. No. 5010, Journal no. 49054.

Olugotun, O. O. "Variability of Clearness Index Over Lagos A Selected Location in South West Nigeria." IOSR Journal of Applied Physics (IOSR-JAP) , vol. 11, no. 2, 2019, pp. 16-21.