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Variation of Solar Radiation and its Correlation with Weather Parameters using Statistical Analysis at Yola, North-Eastern Nigeria

[1]Said R.S., [2]Gabriel F. I, [3]Garba M. B and [4]Najib, G.Y

[1]Department of Physics, Bayero University, Kano. Nigeria
[2] School of Computer Science, Mathematics and Information Technology, Houdegbe North American University, Benin Republic
[3]Hussaini Adamu Federal Polytechnic, Kazaure, Jigawa State, Nigeria
[4]Centre for Atmospheric Research, Kogi State University, Ayingba, Nigeria.

Abstract

Solar radiation plays a major role in meteorology. Solar radiation is a major contributor for stability in the weather-system and climate-atmosphere mechanism. Keeping a tab on its variability therefore helps in understanding the weather and climate conditions of an environment and ultimately at a global scale. In this paper, the data used were employed from an Automatic Weather Stations Network installed across Nigeria under the umbrella of Tropospheric Data Acquisition Network (TRODAN). These data were collected from YOL Station located at the Federal University of Technology Yola (latitude $9^0 12'$N and longitude$12^0 29'$E and an altitude 260m). The data which was recorded at five minutes intervals was filtered and then averaged hourly values and averaged for the second time to obtained daily values and the finally averaged to monthly values for the sunshine hours between 07.00hours and 18.00 hours local time. The yearly variations of solar radiation for 2010, 2011 and 2012 have been analyzed. The variations follow seasonal patterns and the results revealed (that, there is continues fluctuations in the trend of solar radiation within the considered period. The peak solar radiation was found to be 465.79 W/m^2 , 437.43 W/m^2, 456.32 W/m^2 for the year 2010, 2011 and 2012 respectively. The correlation coefficient and coefficient of determination of solar radiation with other atmospheric parameters (relative humidity, temperature and wind speed) were also investigated to determine all round variability.

Keywords: Potential well, Bohr- sommerfeld quantization, bound states energy, wave function.

1.0 Introduction

Weather is generally considered as the state of the atmosphere at a given time at any given location [1]. It may also be referred to as the aspects of the atmospheric state which is visible and, experienced and which affect human activities. The weather conditions of any given location is often described in terms of the meteorological elements which include the state of the sky, temperature, winds, pressure, precipitation, and humidity. These factors initiate and influence the atmospheric processes [2].

Solar radiation is the energy that sustains life on the Earth for all plants and animals. The Earth receives this radiant energy from the Sun in the form of electromagnetic waves, which the Sun continually emits into space. The Earth is essentially a huge solar energy collector receiving large quantities of this energy, which manifests itself in various forms other than those mentioned earlier, like heated air masses causing wind and tapped directly as solar energy (thermal and photovoltaic), and indirectly as wind, biomass and hydroelectric energy. It is clean energy, a renewable resource that allows for local energy independence [3].

Over the universe, the atmosphere also responds to other phenomenon like direct and indirect energy releases into the atmosphere by human activities and effects of burning of fossil fuel, industrial releases and atmospheric pollution. All these result in the spatial and time variation of weather [4, 5]. The profound influence of climate and weather over man's activities

Corresponding author: Said R.S, E-mail: rssaidu.phy@buk.edu.ng, Tel.: +2348033976393

can be seen from his everyday life. Forces of nature have regulated to a very great extent the sort of food we eat, what we wear, how we live and our mental alertness, our physical characteristics and even our radical differences when closely examined have at least some relationship with climate.

Climate and weather are vitally important in agriculture. For instance, some climatic effects such as frosts at critical times can wipe out crops, while shortage of rain will hinder pasture and crops from growing. This will in turn bring about food scarcity in the affected regions and may further have an unbearable impact on world economy. Therefore, a better understanding of climatic variability is essential in the agriculture of today.

Climate change refers to changes in climate that are attributed directly or indirectly to human activities that alter the composition of the global atmosphere and which is in addition to natural climate variability. In other words, this term refers to changes that are brought about by human activities [6]. In recent usage, however, the term "climate change" often refers to changes in modern climate especially in the context of environmental policy. Baxter *et.al* [7] referred to climate change as any long term significant change in the average weather that a given region experiences, average weather in this case may include average temperature, precipitation, wind patterns and relative humidity. It includes changes in the variability or average state of the atmosphere over durations ranging from decades to millions of years and these changes can be caused by dynamic processes on earth including external forces such as variations in sunlight intensity and more recently human activities [7]. Other factors which influence climate change include distance from the sea, ocean currents, direction of prevailing wind, relief, proximity to the equator among others. Non climatic factors such as the greenhouse gas, volcanism plate technics and orbital variation also affect climate change. Climate change has continued throughout the entire history of the earth. The field of pale climatology has provided information on climate change in the ancient past, supplementing modern observations of climate.

The earth absorbs radiation from the sun (which is the radiant energy emitted by the sun as a result of its nuclear fusion reactions) mainly at the surface. This energy is then redistributed by the atmospheric and oceanic circulations and reradiated back to space at longer wave length. The incoming solar radiation energy is balanced approximately by the outgoing terrestrial radiation. Any factor that alters the radiation received from the sun or lost to space or alters the redistribution of energy within the atmosphere, land and the ocean can affect climate [8].

Any changes in the radiative balance the earth including those due to an increase in greenhouse gases or in aerosols will alter the global hydrological cycle and atmospheric and oceanic circulation thereby, affecting weather patterns, regional temperatures and precipitation. Also any human induced changes in the climate will be embedded in the back ground of natural climate variations.

In most studies carried out in recent years with respect to climate change, for example, on temperature, analyses as conducted by the Intergovernmental Panel on Climate Change (IPCC), have found a 0.3^0C to 0.6^0C rise in global mean temperature during the last century [9] and a somewhat larger temperature increases have been projected in the IPCC's Third Assessment Report [10] results of projections that Sulphur Dioxide emissions are likely to be controlled.

2.0 Instrumentation and Data Source

The meteorological data were obtained from Centre for Atmospheric Research (CAR), sited at Kogi State University Campus, Anyigba, Nigeria; the centre is under the supervision of National Space Research and Development Agency (NASRDA). The data were collected from a network of automatic weather stations located at Federal University of Technology, Yola, and this is under a project with an acronym TRODAN which means Tropospheric Data Acquisition Network, initiated to provide data to the atmospheric and earth science communities in Nigeria as well as world at large.

3.0 Campbell Scientific Automatic Weather Station

The standard station is a fully configured, solar powered, automated weather station. It consists of a weatherproof enclosure which contains a highly reliable Campbell scientific datalogger, barometric pressure sensor, 12V battery and charge controller. The weather station is equipped with a standard set of sensors which takes records of: air temperature, relative humidity, wind speed and direction, soil temperature and moisture etc. The data logger is programmed using CR basic for the sensors supplied, when completely connected the weather station will automatically start to take measurements through each of the parameter sensors outside of the box. Additional sensors especially dual-sensor can be added as options. It is designed for long term unmanned or unattended operation and is ideal for meteorological, weather monitoring and climate study applications. The CR1000 datalogger type is used for measurement and data storage in this station at five-minute update cycle. Different choices of communication options are available which includes GSM and GPRS, fixed line phone, phone modem, and direct RS232 connection using RS232 port.

Fig 1a: Image of the LI200X Pyranometer Sensor

Fig 1b: Image of the CR1000 Datalogger

4.0 Data and Methodology

The data which was recorded at five minutes intervals was averaged to hourly values and from hourly values to daily values and then to monthly values for sunshine hours between 07.00 and 18.00 hours local time, this is achieved using Microsoft Excel spread sheet. From the computed result, the early variation in solar radiation for the three years period was plotted. Equation (1) was applied to determine the correlation coefficient and coefficient of determination between the solar radiation and related weather parameters such as Relative Humidity, Air Temperature and Wind Speed for the periods considered in this work (2010, 2011, and 2012).

$$r = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{\sqrt{n\left(\sum x^2\right) - \left(\sum x\right)^2}\sqrt{n\left(\sum y^2\right) - \left(\sum y\right)^2}} \qquad (1)$$

r = correlation coefficient
x = relative humidity, temperature, wind speed.
y = solar radiation.
n = month

5.0 Results and Discussions

Table 1: Monthly Weather parameters for the year 2010

Months	Relative Humidity %	Temperature ^{0}C	Wind Speed m/s
January	16.5908	30.7210	0.9213
February	11.6797	32.3493	1.0050
March	12.2815	35.2041	1.0896
April	32.5243	37.6772	1.6078
May	45.4153	36.5051	1.6448
June	62.3901	31.4210	1.2531
July	64.5998	30.6514	1.3448
August	69.5905	28.9863	1.1676
September	64.5568	29.4587	1.1003
October	59.4545	30.6897	1.0745
November	15.8593	32.5654	1.0209
December	14.7100	32.0582	0.9687

Table 2: Monthly Weather Parameters for the Year 2011

Months	Relative Humidity %	Temperature ^{0}C	Wind Speed m/s
January	15.1001	29.8607	0.9272
February	21.8861	33.0805	1.0611
March	10.1418	35.8323	1.1803
April	36.8213	38.0027	1.7578
May	55.6041	33.0176	1.0478
June	61.3637	31.3080	1.3007
July	73.0340	29.6527	1.1645
August	73.3636	28.5473	1.2007
September	72.4478	29.0156	0.8778
October	62.0026	30.9644	0.9150
November	15.7115	32.5398	1.0213
December	16.8016	30.8774	0.7867

Table 3: Monthly Weather Parameters for the Year 2012

Months	Relative Humidity %	Temperature ^0C	Wind Speed m/s
January	13.4574	31.0497	0.9180
February	21.1505	34.8264	1.0381
March	07.7900	35.7757	1.0163
April	38.5022	37.2556	1.2788
May	55.3781	34.1350	1.3430
June	64.9129	30.7850	1.3342
July	77.9601	28.6788	0.9771
August	73.2931	28.7235	0.7340
September	65.5462	30.4205	0.7255
October	54.0144	29.3211	0.8891
November	15.8778	32.5297	1.1667
December	15.6335	31.0978	0.8681

Table 4: Monthly Solar Radiation over Yola, Nigeria (2010, 2011, 2012)

Months	Solar Radiation (2010) W/m^2	Solar Radiation (2011) W/m^2	Solar Radiation (2012) W/m^2
January	371.2374	378.8712	423.5567
February	411.0274	390.5540	392.9274
March	465.7974	437.4291	456.3136
April	473.0210	466.0571	465.7298
May	443.0189	357.7815	382.3252
June	360.5554	362.5341	330.3837
July	324.4618	307.6567	314.8814
August	331.5239	330.6440	304.7469
September	375.0344	386.2368	395.6407
October	448.0067	415.4123	421.4506
November	465.7662	407.8519	432.0453
December	443.0246	378.4439	419.8678

Table5: Correlation coefficient of solar radiation with relative humidity, temperature, and wind speed for 2010, 2011 and 2012

Year	r_1	r_2	r_3
2010	-0.6115	0.7230	0.0936
2011	-0.5425	0.7739	0.3191
2012	-0.7701	0.6646	0.1425

r_1 = Correlation coefficient of solar radiation with relative humidity for each year
r_2 =Correlation coefficient of solar radiation with temperature for each year
r_3 = Correlation coefficient of solar radiation with wind speed for each year

Table 6: Coefficient of determination of solar radiation with relative humidity, temperature, and wind speed for 2010, 2011 and 2012

Year	r^2_1	r^2_2	r^2_3
2010	0.373932	0.522729	0.008761
2011	0.294306	0.598921	0.101825
2012	0.593054	0.441693	0.020306

r^2_1 =Coefficient determination of solar radiation with relative humidity for each year
r^2_2 =Coefficient determination of solar radiation with temperature for each year
r^2_3 = Coefficient determination of solar radiation with wind speed for each year

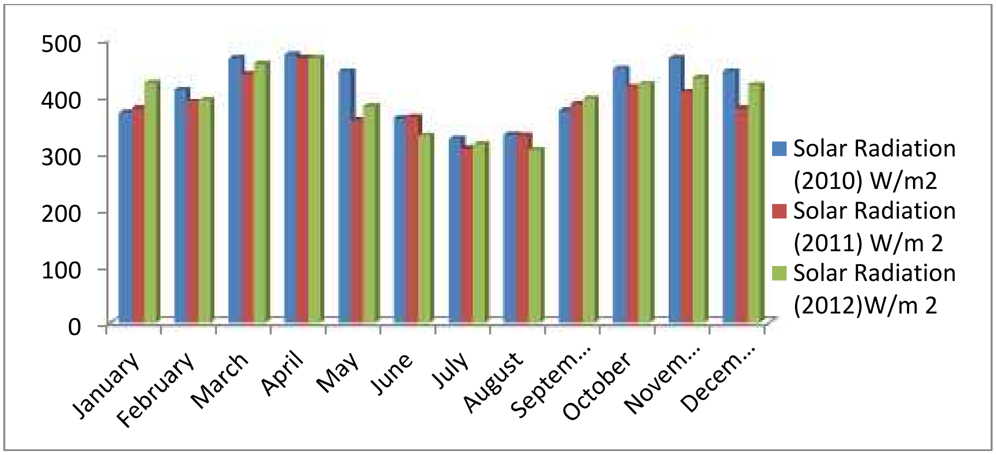

Figure 2: Graphical Bar Representation of Solar Radiation of 2010, 2011 and 2012

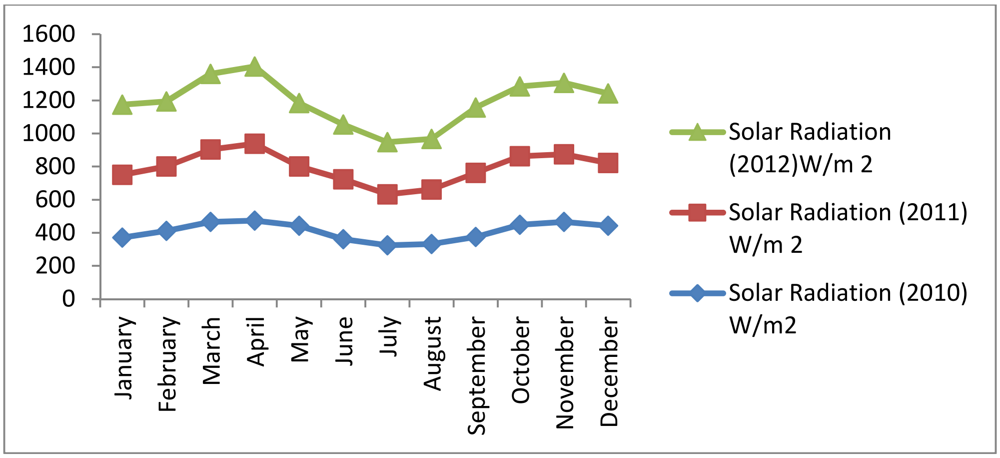

Figure 3: Graphical Line Representation of Solar Radiation of 2010, 2011 and 2012

Figures 2 and 3show the variability of solar radiation for 2010, 2011 and 2013 respectively. The variations follow seasonal patterns of the zone and the profiles show the same trend in the three year period. From figure 1, it can be deduce that in January for the three years, year 2012 has the higher value while in February, March, April and May the values are higher in 2010 for each month. The values of 2010 solar radiations are also higher in October, November and December. The values of 2010 solar radiation are significantly notice in May, October, November and December.

The two figures clearly show that the solar radiation values are low in May, June, July and August which indicates the presence of rainfall while the low values in January and February could bean indication of Harmattan. The lowest value is noticed to be in July and August which also indicates heavy rainfall in the zone at these months.

Overall, the results show a month-to-month variation of solar radiation, which signify the dynamic nature of the Earth's atmosphere, with almost a similar pattern in the years considered in this work. However, the variability of solar radiation could be as a result of solar activity which has less priority as the radiation undergo a lot of processes before it reaches the lower atmosphere, compared to the influence of human activity resulting from anthropogenic substances and emissions.

The quantity r, called the linear correlation coefficient, was used to measures the strength and the direction of a linear relationship between solar radiation and relative humidity, temperature, wind speed independently, while coefficient of determination r^2 was used to determine how certain these variable can be in making prediction of solar radiation. Again, $r^2$is useful because it gives the proportion of the variance (fluctuation) of one variable that is predictable from the other variable. The coefficient of determination was also applied because it represents the percent of the data that will be closest and better for the predictions. Table 5 shows that in 2010, the correlation between solar radiation and temperature is strong since the value is closer to one. It also shows that there is strong correlation between solar and relative humidity and statistically insignificant correlation with wind speed. 2011 also show that temperature has a stronger linear correlation while relative humidity shows weak correlation but has a better correlation if compared with the correlation of wind speed. It was also noticed that correlation of relative humidity is negative. Finally, the correlation of relative humidity is negative in 2012 but has strong correlation and temperature also has a strong correlation while wind speed has weak correlation.

Table 6 shows that coefficient of determination of temperature is 0.5227, which mean that 52% of the total variation in solar radiation can be explained by the linear relationship between solar radiation and temperature while the remaining percent remain unexplained. Again, the table also shows that the coefficient of determination of relative humidity is 0.373932 which mean 37% while less than 1% is the value of coefficient determination of wind speed in 2010 respectively.

In 2011, the coefficient of determination for temperature is 0.598921 meaning 60%, coefficient of determination relative humidity is 0.294306 and wind speed is 0.101825 which indicate 29% and 1% respectively. Also, the coefficient of determination for relative humidity, temperature and wind speed are 0.593054, 0.441693 and 0.020306 in 2012, meaning 59%, 44% and 1% respectively.

6.0 Conclusion

In this research work the variation of solar radiation in Yola, within the period from January 2010 to December 2012 shows that variations follow seasonal pattern of the zone and the profiles show the same trend in the three year period. The correction coefficient and coefficient of determination of solar radiation and relative humidity, temperature, wind speed respectively were also analyzed.

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