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Decline in global solar radiation with increased sunshine hour in Abia state Nigeria

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Abstract

The trend of Global solar radiation and bright sunshine hour reaching Abia state were investigated in the light of climate change on annual and seasonal scale. In this connection, annual trends of global solar radiation and sunshine hour was carried out, covering 32 years (1985-2016) period. Mann-Kendell test and Sen's Estimate was used to confirm the significance and magnitude of the trend. A statistical significant decrease in mean annual global solar radiation was observed both on annual and seasonal scale. Bright sunshine hour showed an increase in trend on annual and seasonal scale. However, only dry season showed statistical significant increase in trend for bright Sunshine hour. It was also observed that dry season recorded higher bright sunshine hour and solar radiation than wet season.

Keywords: Global Radiation; Bright Sunshine Hour; Global Dimming; Mann Kendall Test; Sen's Estimate.

1. Introduction

Solar radiation arriving into the Earth–atmosphere system drives atmospheric circulation and influences climate. Surface solar radiation can be affected by both astronomical and meteorological factors (including clouds, water vapor, gas species, and aerosols, etc.). The study of surface solar radiation, besides its direct climatic significance, can also help to detect changes in atmospheric composition, such as aerosol loading, and to estimate the available solar energy. Recent investigations concerning surface solar radiation revealed significant global dimming and bright brightening trends on decadal scales, implying a profound effect on climate change [1].
Global dimming term was introduced in 1990s which means the decline in global radiation. This decline was reported in several studies across the world.
Amount of solar radiation reaching to the Earth's surface is determined by the atmospheric conditions, latitude and seasons. Solar radiation flux at the Earth's surface is the primary source of energy for life as well as a regulator of climate on our planet [2]. Solar radiation incident on the Earth's surface is very important in many applications; such as atmospheric energy balance studies, global land carbon sink studies [3], canopy gas exchange processes [4], analysis of thermal load on buildings, and solar energy collecting systems. For designing any solar energy conversion device (Solar collectors, photovoltaic, solar thermal generator), amount of insolation availability at that site is needed. A complete knowledge of solar radiation is very important for understanding the climatology of any place. But with urbanization [5], industrialization and other anthropogenic activities, atmospheric load has been increased which has caused sufficient reduction in solar radiation (global dimming) and it is reported in several studies [6]. Aerosol affect the incoming solar radiation directly by scattering and absorption of solar radiation and indirectly by acting as cloud condensation nuclei [7] which decides the fate of cloud and it also alter the reflectivity of cloud for solar radiation. Multidecadal changes in incoming global radiation are highly modulated by cloudiness at the surface [8].
Natural forcing of Earth's Climate has been observed on both global and regional scale with small variation in solar irradiance [9]. The long term trend analysis of solar radiation is very essential to understand the different changes which are occurring or have already occurred in the perspective of climate change. Many studies have been

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done to see the long term trend of solar radiation on annual scale but not much emphasis has been given on the analysis of long term seasonal trend of solar radiation. To feel this gap we have decided to see the change in solar radiation on seasonal scale. The main aim of this paper is to find whether such decreasing trend is also applicable for Abia State conditions in different seasons or not? In the present study trend analysis of solar radiation for wet and dry seasons were studied over Abia State to see the possibility of declining trend for these two seasons. Significance of trends were analyzed by using non parametric statistical test "Mann Kendall Test".

2. Methodology

Abia is a state in the south eastern part of Nigeria.

Table 1. The of geographical properties of Meteorology site

Location: Umudike, Southern Nigeria	Altitude 122 m
	Latitude 05º29'N
	Longitude 07º33'E

The area is an agrarian environment marked by dry season between November and April and wet season between May and October. Global radiation, H_m and bright sunshine hour, (*BSS*) data comprises (1985-2016), has been divided into two seasons wet and dry. The H_m and BSS was measured using Gunn-Bellani solar radiation Integrator and Campbell Stoke Sunshine Recorder respectively.
Here extraterrestrial radiation was computed using formula

$$\overline{H_0} = \frac{24}{\Pi} I_{sc} E_0 \left(\frac{\Pi}{180} w_s sin\varphi sin + cos\varphi cos\delta sin w_s\right) \quad (1)$$

Where I_{sc} is the solar constant in (MJm-2-day), expressed as

$$I_{sc} = \frac{1367*3600}{1000000} \text{ MJm}^{-2}\text{day}^{-1} \quad (2)$$

E_o is the eccentricity correction factor, expressed as

$$E_o = 1 + 0.0033\cos\left(\frac{360N}{365}\right) \quad (3)$$

N is the day number of the year /Julian day (1 Jan, N = 1 and 31st December, N = 365), φ is the latitude of the site, δ the solar declination and, ω_s the mean hour angle for the given month. The solar declination (δ) and the mean hour angle (ω_s) can be calculated as suggested by [10]

$$\delta = 23.45\sin\left(360\left(\frac{N+284}{365}\right)\right) \quad (4)$$

and

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \quad (5)$$

For a given day, the maximum possible sunshine duration (monthly values of day length, (N) can be computed by using [10]

$$\overline{N} = \frac{2}{15}\omega_s \quad (6)$$

The monthly daily mean value of global solar radiation (H_m) was normalized by dividing with monthly daily mean values of extraterrestrial radiation (H_o). Transmissivity K_T was calculated as a ratio of global radiation H_m to extraterrestrial radiation H_0. [11]

$$K = \frac{H_m}{H_o} \quad (7)$$

2.1 Significance of Trend

In this study, the Mann Kendall (MK) test was applied to ascertain the presence of statistically significant trend. The MK test checks the null hypothesis of no trend *versus* the alternative hypothesis of the existence of increasing or decreasing trend. Following [12] no pre-whitening of the data series was carried out as the sample size is large ($n \geq 5$) and slope of trend was high (>0.01). The statistics (*S)* is defined by [13], as follows

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} sgn(x_j - x_i) \quad (8)$$

Where *N* is the number of data points. Assuming $(x_j - x_i) = \theta$, the value of sgn(θ) is computed as follows

$$sgn(\theta) = \begin{cases} 1 \ \ if\ \theta > 0 \\ 0 \ \ if\ \theta = 0 \\ -1\ if\ \theta < 0 \end{cases} \quad (9)$$

This statistics represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (N >10), the test is conducted using a normal distribution with the mean and the variance as follows [14]

$$E[S] = 0 \quad (10)$$

$$Var(S) = \frac{N(N-1)(2N+5) - \sum_{k=1}^{n} t_k(t_k-1)(2t_k+5)}{18} \quad (11)$$

Where *n* is the number of tied (zero difference between compared values) groups and *tk* the number of data points in the *k*th tied group. The standard normal deviate (*Z*-statistics) is then computed as follows [15]

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \ if\ S > 0 \\ 0 \qquad\quad if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} \ if\ S < 0 \end{cases} \quad (12)$$

If the computed value of $|Z| > Z_{\alpha/2}$, the null hypothesis (H_0) is rejected at α level of significance in a two-sided test. Then values of calculated *Z* are checked at α = 0.05 level of significance.
Sen's method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in meteorological time series [16]. In this method, the

slopes (Ti) of all data pairs are first calculated by

$$T_i = \frac{x_j - x_k}{j-k} \quad \text{for} = 1, 2, 3,\ldots \tag{13}$$

where x_j and x_k are data values at time j and k ($j > k$), respectively. The median of these N values of T_i is Sen's estimator of slope, which is calculated as follows

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N \text{ is even} \end{cases} \tag{14}$$

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

3. Results and Discussions

Table 1 shows that in Abia State the annual and seasonal mean of H_m is declining significantly α = 0 while BSS is increasing 001 level of significance. The annual and dry season of BSS is increase at 0.017 and 0.033 Hour/year respectively while there is no trend for BSS wet season. Mean annual H_m is decreasing at 4.589MJyear^{-1}m^{-2} during the period under review. During the same period the wet season is decreasing fast than the dry season at 5.90 MJyear^{-1}m^{-2} and 4.103 MJyear^{-1}m^{-2} respectively. The Sen's slope is negative as show in table 1 and figure 1-3 for the annual and seasonal mean of H_m.

Table 1: MK and Sen's Test Results of H_0 and BSS

Season	Mean		Wet		Dry	
	H_m	BSS	H_m	BSS	H_m	BSS
MK	-4.59	2.53	-5.19	0.23	-4.103	2.88
Trend	↓	↑	↓	↑	↓	↑
Signific	***	*	***	¤	***	**
Sen's slope	-0.09	0.017	-0.09	0.000	-0.097	0.033

Note: *** (α) = 0.001, ** (α) = 0.01, * (α) = 0.05, ¤ (α) > 0.1.

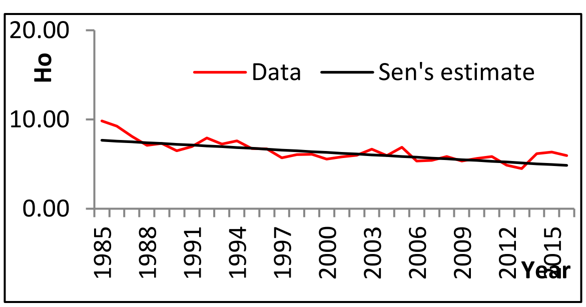

Figure 1. Trend of Annual Mean global radiation

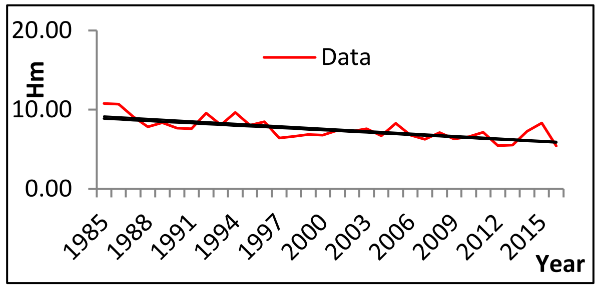

Figure 2: Trend of Wet Season Mean global radiation

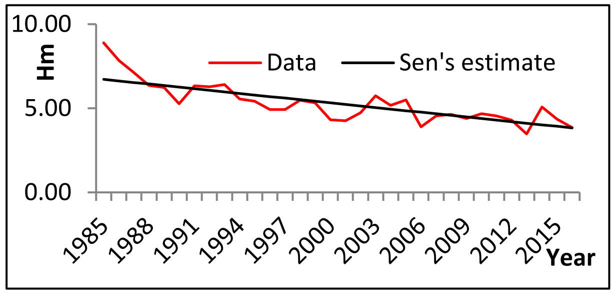

Figure 3: Trend of Dry Season Mean global radiation

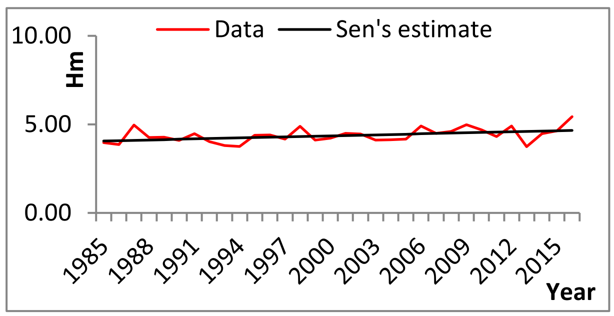

Figure 4: Trend of Annual Mean BSS

Values of H_m and BSS in dry season are more than the wet because in wet cloud cover increases which obstruct the incoming solar radiation.

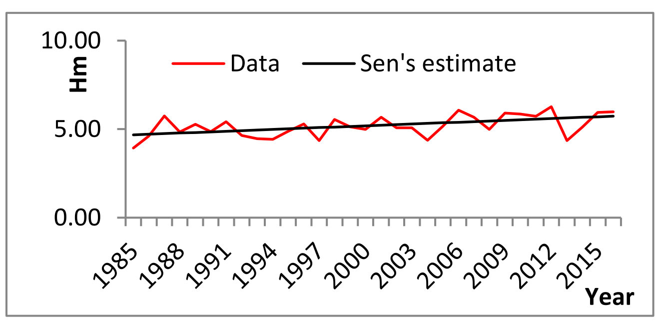

Figure 5: Trend of wet Season Mean BSS

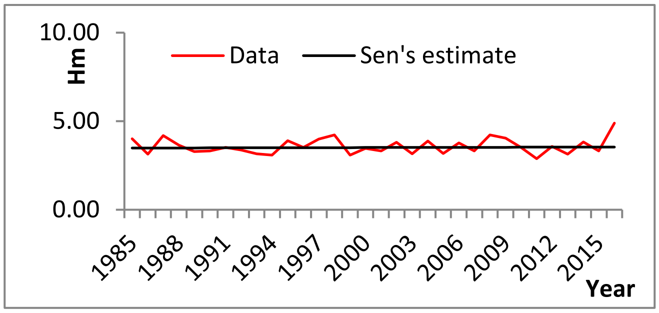

Figure 6: Trend of Dry Season Mean BSS

3.1 Possible Causes of Declining in H_m

According to [18] Aerosols and clouds are not very much independent but they interact in various ways through different processes. The only source of aerosols in the atmosphere is anthropogenic and natural in nature [19]. With increase in population and to satisfy the need of increasing population many industries are spreading day by day and these urbanizations, industrialization and other anthropogenic activities are contributing more in aerosol load in the atmosphere.

However, there other affects that may have some effect on solar radiation. This can be explain from equation 15 below

$$K_T = e^{\gamma}$$

Where $K_T = \frac{H_m}{H_0}$ and

$$\gamma = \tau_g + \tau_w + \tau_a + \tau_c - \tau_r$$

where g, w, a, c and r are the five transmissivities representing Rayleigh scattering, permanent gas absorption, absorption by water vapour, absorptions and scattering by aerosols and cloud components, respectively. According to [17], The change in 0 is often occur within 11 year solar cycle but these variations are of smaller magnitude compared to variations observed in the solar radiation. Therefore increase in Rayleigh scattering and permanent gas absorption has also little or less affect in causing any variation in H_m. It has also been confirmed that a 10% increase in atmospheric water vapour content would cause decrease in $H_m < 0.5\%$ according to [20], so it is not very sufficient to cause significant effect on τ_w.

Abia state which is a big city represents a typical urban area of with population of about 3.89 million is also surrounded by oil producing state like River, Akwa Ibom. [21]. Aerosols from transport sector, oil industries and biomass burning are the main sources of anthropogenic aerosols. In dry months concentration of aerosols from these sources increases very much in the absence of scavenging mechanism (wet deposition). So the contribution of both natural and anthropogenic aerosols explain the decreasing trend of H_m. But in wet months sky is obscured by cloud and these clouds reflects and backscatter solar radiation Srinivasan and cause a significant reduction in solar radiation in wet season. The slopes of H_m, in wet months is more negative than the dry months. In wet months concentrations of aerosols are more as compared to dry month where there decreases in the aerosols concentrations. Aerosols also contribute its effect in altering the properties of cloud *i.e.* they increase the reflectivity of cloud which is the indirect effect of aerosols. Thus, in both the months (wet and dry) aerosol play a very significant role in dimming of H_m. The trend in is not significant in dry months for sunshine hour at 99% confidence level while there is no trend for wet months.

4. Conclusion

The evaluation of annual and seasonal mean values of global solar radiation and sunshine hour at Abia state show decrease in solar radiation and increase in sunshine hour. However the increase in sunshine hour is not significant. A notable decline in the annual solar radiation has been identified which is statistically significant at 0.001 alpha level. Also, the trend is declining significantly at 0.001 alpha level for both wet and dry season. However, wet season is declining at higher rate than the dry season at 5.190 and 4.103 $MJyear^{-1}m^{-2}$ respectively.

On the other hand, the annual mean sunshine is increasing at 2.53 hour per year. The increasing rate is higher in dry season than the wet season at 2.88 and 0.23 hours per year respectively.

Thus, after the analysis of trend it is clearly visible that aerosols direct (scattering and absorption) and indirect (altering cloud properties) make it a potential candidate for becoming the main culprit of solar dimming in both the seasons. But there is still need of detailed investigation to understand the role of aerosols and clouds in dimming of solar radiation.

References

[1] G. Stanhill and S. Cohen, "Global Dimming: A Review of the Evidence for a Widespread and Significant Reduction in Global Radiation with Discussion of Its Probable Causes and Possible Agricultural Consequences," Agricultural and Forest Meteorology, **107**(4), 2001, pp. 255-278.

[2] A. S Ackerman, O. B., Toon, D. E., Stevens, A. J., Heyms-field, V. Ramanathan and E. J., Welton, "Reduction of Tropical Cloudiness by Soot," J. Science, **288** (5468), 2000, pp. 1042-1047.

[3] M. L.Mercado, N. Bellouin , S. Sitch, O. Boucher, C. Huntingford, M. Wild and P. M. Cox, "Impact of Changes in Diffuse Radiation on the Global Land Carbon Sink," Nature, 458, 2009, pp. 1014-1018.

[4] P.Alpert, P. Kishcha, Y. J. Kaufman and R., Schwarzbard, "Global Dimming or Local Dimming? Effect of Urbanization on Sunlight Availability," J. Geophysical Research Letters, 32,2005, pp. 4.

[5] A. Knohl and D. D. Baldocchi, "Effects of Diffuse Radiation on Canopy Gas Exchange Processes in a Forest Eco-system," Journal of Geophysical Research, **113**, 2008, pp. 17

[6] B. G. Liepert, "Observed Reductions of Surface Solar Radiation at Sites in the United States and Worldwide from

1961 to 1990," Geophysical Research Letters, **29**, (10), 2008, pp. 1421.

[7] J. R. Magnus B. Melenberg, and C. Muris, "Global Warming and Local Dimming: The Statistical Evidence," Journal of the American Statistical Association, **106**, (494), 2011, pp. 452-464.

[8] B. A. Albrecht, "Aerosols, Cloud Microphysics, and Fractional Cloudiness," J. Science, **245** (4923), 1989, pp. 1227-1230.

[9] J. L. Lean and D. H. Rind, "How Will Earth's Surface Temperature Change in Future Decades?" Geophysical Research Letter, **36**, 2009, pp. 5.

[10] J.A Duffie, and W.A. Beckman, Solar Engineering of Thermal Processes, 2nd (Ed). John Wiley and Sons, New York, 1999, pp. 944.

[11] E.O. Falayi, A.B. Rabiu, and R.O. Teliat, "Correlations to estimate monthly mean of daily diffuse solar radiation in some selected cities in Nigeria". Advances in Applied Science Research 2(4): 2011, pp. 480-490.

[12] M. Bayazit, and B. Onoz, "To prewhiten or not to prewhiten in trend analysis"? Hydrological Sciences Journal **52**, 2007, pp. 611–624.

[13] J. D. Salas 1993: Analysis and modeling of hydrologic time series", In Handbook of Hydrology, Maidment DR (ed). McGraw-Hill: New York, 19. 1–19.72.

[14] D. R. Helsel, and R. M. Hirsch, 1992: "Statistical Methods in Water Resources," Elsevier: New York. J. Clim. 21: 6089–6098.

[15] Hirsch, R. M., D. R. Helsel, T. A. Cohn and E. J. Gilroy,1993: "Statistical treatment of hydrologic data," In Handbook of Hydrology, Maidment DR (ed). McGraw-Hill: New York, 17. 1–17.52.

[16] Salmi T., Määttä A., Anttila P., Ruoho-Airola T. and Amnell T. (2002) Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen's slope estimates –the Excel template application MAKESENS No.3.

[17] Badarinath, K. V. S., A. R. Sharma, D. G. Kaskaoutis, S. K. Kharol and H. D. Kambezidis, "Solar Dimming over the Tropical Urban Region of Hyderabad, India: Effect of Increased Cloudiness and Increased Anthropogenic Aerosols," Journal of Geophysical Research, 115, 2011, pp. 18.

[18] V. Ramanathan, P. J. Crutzen, J. T. Kiehl and D. Rosenfeld, "Aerosol, Climate and the Hydrological Cycle," Science, 294, (5549), 2001, pp. 2119-2124.

[19] K. Singh, D. P. Singh, C.K. Dixit, N. Singh, C. Sharma, S. Sahai, A. K. Jha, Z. H. Khan and P. K. Gupta, "Chemical Characteristics of Aerosols and Trace Gas Distribution over North and Central India," Environmental Monitoring Assessment. 2011.

[20] M. Wild "The Heat Balance of the Earth in GCM Simulations of Present and Future Climate," Zuechercher Geografische Schriften, **68**, 1997, pp188.

[21] Abia State Statistics year book. "Abia State Government of Nigeria, A publication of state bureau of statistics Abia state planning commission" 2015.