production, as a clean alternative to the exploitation fossil fuel resources. Inferences drawn from climate change impacts on sunshine duration hours have provoked this study to examine the trends in sunshine duration hours as an excellent proxy measure of global solar radiation on interannual and decadal scales (e.g. Stanhill, 2003; Stanhill and Cohen, 2008; Liang and Xia, 2005). Sanchez – Lorenzo *et al* (2009)defined sunshine duration as the amount of time, usually expressed in hours, that direct solar radiation exceeds a certain threshold (usually taken at 120 Wm^{-2}). Rahimzadeh*et al*, (2014) reported that the desired minimum amount of sunshine needed to generate effective energy from solar panels is roughly 4 – 6 hours per day. It is important to understand the potential of solar energy resource in different parts of Nigeria due to prognosticated changes of major climate variable such as sunshine duration, atmospheric transmissivity and cloud-cover.

The aim of this study is to investigate the trends in the effective sunshine duration in Nigeria on the basis of the long-term measurements and observations conducted at 20 meteorological stations in Nigeria during the period 1961 – 2012.

2. Study Area and Data

Nigeria situates between longitude 2°E and 15°E and between latitude 4°N and 14°N. The monthly mean daily sunshine duration data in hours from 20 synoptic stations across Nigeria were obtained from the Nigerian Meteorological Agency, Oshodi, Lagos for the period 1961 – 2012. Fig 1 shows the map of Nigeria indicating the stations used for the study.

Figure 1: Map of Nigeria, showing the areas covered in the study.

3. Methodology

The trends, representing a general direction of changes in sunshine duration during the period 1961 – 2012 were determined. The monthly mean daily sunshine hours were used. The trend testing was based on the linear regression model, using the method of least squares. The estimation of the quality of the model fitting was carried out on the basis of the coefficient of determination and residual standard deviation.

3.1 Co-Efficient of Determination R^2

$$R^2 = \frac{\sum_{i-1}^{n}(\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad \text{.........................(1)}$$

where R^2 = coefficient of determination; n = sample size; y_i, = value of next observation i of y variable; $\hat{y}$ = value of regression function for x_i; y is the arithemetic mean of y variable.

3.2 Residual Standard Deviation

$$Se = \sqrt{\frac{1}{n-2}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \quad \text{.........................(2)}$$

where *Se* is residual standard deviation.
To estimate the signifcance of regression coefficients, the values of standard errors of parameter estimators were used. The linear regression model is represented thus:

$$\bar{y} = \beta_1.\bar{x} + \beta_o \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The null hypothesis is that the slope coefficent, $\beta_1 = 0$. The *t* – statistic on $\beta_1$is tested to determine if it is significantly different from zero. If β_1 is significantly non zero, the null hypothesis is rejected and it can be concluded that there is a linear trend in y over time with the rate = β_1. Missing values are allowed. Values of β_1 (the slope coefficient) and β_o (the intercept), and their errors were determined on the basis of the following formulae:

$$\beta_1 = \frac{\sum_{i=1}^{n}(x_i - \bar{x}).(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad \text{........................(4)}$$

$$\beta_o = \bar{y} - \beta_1.\bar{x} \; \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where x is the independent variable (time), and y is the dependent variable (Sunshine duration).

$$D(\beta_1) = \frac{Se}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}} \quad \text{........................(6)}$$

$$D(\beta_o) = Se\sqrt{\frac{1}{n} + \frac{\bar{x}^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}} \quad \text{........................(7)}$$

where $D(\beta_1)$ and $D(\beta_o)$ are standard errors of the model estimators.

The significance of model parameters were tested on the basis of the t – statistic determined by the formulae:

$$t_{stat} = \frac{\beta_1 - 0}{D(\beta_1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

$$t_{stat} = \frac{\beta_o - 0}{D(\beta_o)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

The statistics has student's t – distribution. Testing of the significance of the model parameters was done on the basis of the following hypothesis:

Null hypothesis, H_o : $\beta_1 = 0$ (lack of linear dependence):

Alternative hypothesis, H_1 : $\beta_1 \neq 0$ (Linear dependence exists).

The calculated values using eqns (8) and (9) were compared with the critical values determined from student's t – distribution at the assumed levels of confidence (α = 0.01 and α =0.05). The null hypothesis was rejected if $t_{stat} > t_{\alpha}$ (ie, $p < \alpha$), thus accepting the alternative hypothesis, H_1.

4. Results and Discussion

Table 1 is the result of linear trend estimation of the model estimators for sunshine duration hours in the stations studied. Also indicated in the table are the standard errors, the t – statistics and the p values of the model estimators.

Table 1: Results of linear trend estimation, standard errors of model estimators, t – statistics and the p-values.

	Parameter	*Estimate*	*Std. Error*	*t*	*p-value*	*Slope Estimate*	
						Hrs per yr	*Hrs per decade*
Yelwa	Slope	0.0020*	0.0010	2.0710	0.0390	0.024	0.24
	Intercept	6.0840	0.4840	12.5630	0.0000		
Sokoto	Slope	-0.0029**	0.0006	-4.9986	0.0000	-0.0348	-0.348
	Intercept	8.5090	0.2623	32.4385	0.0000		
Kaduna	Slope	-0.0007	0.0007	-0.9909	0.3226	-0.0084	-0.084
	Intercept	7.9503	0.3153	25.2135	0.0000		
Kano	Slope	0.0014*	0.0006	2.5265	0.0121	0.0168	0.168
	Intercept	7.1234	0.2531	28.1478	0.0000		
Bauchi	Slope	-0.0020**	0.0007	-2.6642	0.0082	-0.024	-0.24
	Intercept	7.3911	0.3381	21.8630	0.0000		
Maiduguri	Slope	-0.0004	0.0005	-0.7745	0.4393	-0.0048	-0.048
	Intercept	8.2004	0.2448	33.4952	0.0000		
Ilorin	Slope	0.0017**	0.0006	2.6208	0.0092	0.0204	0.204
	Intercept	5.3532	0.2911	18.3871	0.0000		
Yola	Slope	-0.0003	0.0006	-0.4241	0.6718	-0.0036	-0.036
	Intercept	7.4532	0.2678	27.8264	0.0000		
Ikeja	Slope	0.0024**	0.0007	3.6969	0.0003	0.0288	0.288
	Intercept	4.1784	0.2970	14.0672	0.0000		
Ibadan	Slope	0.0003	0.0007	0.4135	0.6796	0.0036	0.036
	Intercept	4.6746	0.3227	14.4879	0.0000		
Oshogbo	Slope	0.0003	0.0007	0.4436	0.6577	0.0036	0.036
	Intercept	5.1253	0.3180	16.1156	0.0000		
Benin	Slope	0.0011	0.0006	1.7829	0.0757	0.0132	0.132
	Intercept	4.3187	0.2762	15.6370	0.0000		
Warri	Slope	0.0040**	0.0007	6.0323	0.0000	0.048	0.48
	Intercept	2.6781	0.3007	8.9053	0.0000		
Lokoja	Slope	-0.0020**	0.0006	-3.2755	0.0012	-0.024	-0.24
	Intercept	6.7939	0.2817	24.1160	0.0000		
Port Harcourt	Slope	0.0025**	0.0007	3.5695	0.0004	0.03	0.3
	Intercept	3.1164	0.3131	9.9544	0.0000		
Owerri	Slope	0.0007	0.0006	1.1642	0.2453	0.0084	0.084
	Intercept	4.1542	0.2889	14.3791	0.0000		
Enugu	Slope	0.0004	0.0006	0.5910	0.5550	0.0048	0.048
	Intercept	5.2446	0.2758	19.0147	0.0000		
Calabar	Slope	0.0018**	0.0007	2.7044	0.0073	0.0216	0.216
	Intercept	2.8064	0.2999	9.3565	0.0000		

Makurdi	Slope	0.0001	0.0006	0.1517	0.8795	0.0012	0.012
	Intercept	6.0249	0.2802	21.5016	0.0000		
Ogoja	Slope	-0.0016*	0.0007	-2.2111	0.0278	-0.0192	-0.192
	Intercept	6.1740	0.3219	19.1811	0.0000		

** Trend is significant at the 1% level (2-tailed) * Trend is significant at the 5% level (2-tailed).

7 stations show downward trends with 4 stations having significant trends. Apart from Ogoja and Lokoja, all the stations that show downward trends fall within the Sudan and Sahelian Savanna regions of the country. 13 stations show upward trends with 7 stations showing significant positive trends.

Several explanations could account for the observed trends in sunshine duration in Nigeria. Clouds exert a dominant influence on the global energy balance and can be attributed to be the leading cause of the trend variations across Nigeria. Cloudiness can contribute to dimming, i.e. low-level clouds types linked to their high albedo, and also brightening, ie, high clouds types emit less radiation out to space than do low clouds, or the clear atmosphere (Mace *et al*, 2006). Changes in atmospheric transmissivity (aerosol optical thickness) due to changes in the concentrations and optical properties of aerosols can also cause dimming or brightening depending on the type of aerosol causing the local pollution.

Uncertainties of the indirect effects of aerosols on clouds and precipitation could also result to either induced changes in the cloud properties such as albedo and lifetime, or the modifications of precipitation forming processes. These aerosol indirect effects on clouds and precipitation are in the form of cloud-albedo effect, cloud lifetime effect, semi direct effect, glaciation effect and the thermodynamic effect. The cloud- albedo and cloud lifetime effects can be brought about by sulphate aerosols that have the tendency to produce small cloud droplets that reflect solar radiation more efficiently, decrease precipitation formation and prolong cloud lifetime. These two effects presumably contribute to the observed downward trends in sunshine duration in some of the locations. Soot aerosols (particulate black carbon) absorb solar radiaton and re-emit it as thermal radiation which consequently heats the air – mass, causing evaporation of cloud droplets. This aerosol heating within cloud layers reduce cloud fractions, and cause change in cloud amounts (Ramanathan, *et al*, 2001). This semi-direct effect, as it is known, can contribute to the increasing trends in sunshine durations in locations with large fossil fuel burning and several other manufacturing concerns such as Port Harcourt, Ikeja and Warri etc. Large aerosols have the consequences of precipitation with the formation of fewer and larger droplets. These large aerosols are efficiently scavenged by precipitation which is their main atmospheric sink, resulting in atmospheric lifetime of few days or few weeks. All things being equal, this effect will consequently increase effective sunshine hours and can also account for the upward trends observed in some stations.

Given the observed trends at the stations in Nigeria over the 52 year period, and realising the high sunshine duration experienced across the regions, Nigeria has favourable conditions for solar energy resource. Descriptive statistical analsis (not shown) shows that the monthly mean daily sunshine hours for the 52 year period (ranging from 444 – 624 months) range from over 4 hours per day in the coastal locations to over 8 hours per day in the high latitude locations. The effective sunshine duration in Nigeria is characterised by high vairation in space and time. Seasonal variation plots (not shown) indicate that maximum daily sunshine hours are observed from November to March in all the stations, exceeding 6.5hours in the southern low latitudes and having up to 9hours in the high latitude locations in the north. Minimum daily sunshine hours are observed from June to September across the stations recording about 6hours in the high latitude stations and 3 hours in the low latitude stations.

The results of this study are in agreement with eariler studies particularly Ogolo (2014), Ewona *et al*, (2014), Ewona and Udo (2011a), and Ewona and Udo (2011b).

5. Conclusion

The trends of sunshine duration hours in Nigeria for the period 1961 – 2012 have been investigated using the least sequare method of the linear regression model. The results indicate, overall regions, that the pattern of sunshine duration exhibited sinusoidal increases and decreases in seasonal variations. The trends indicate that the sign of the trends for the vast majority of the station is positive. Given the increasing trends observed at many stations and some decreasing trends that are not significant in some stations over the 52 years period, and realising the relatively high monthly mean daily sunshine duration hours, solar energy resource is a good candidate in Nigeria as alternative energy solution to offset carbon emissions. The effective sunshine duration across Nigeria is characterised by high spatial and temporal variations which could be linked to some factors such as the effects due to cloud cover, direct and indirect aerosol effects, latitudinal locations, and orographic conditions. Nevethelss, the results in some cities, intriguing as they appear, may be hinting at the possibility of an impact of anthropogenic aerosols emissions on the dynamics of the atmospheric circulation at synoptic scales, and needs to be explored further in subsequent times.

As a result of large geographical coverage of Nigeria, the 20 stations used in this study do not have the capacity to generate complete meteorological data for the Country even though they are representatives of different climatic belts and agro-ecological zones in Nigeria. Further research could improve on this by examining more stations to get finer grids especially in the north. Furthermore, the non-parametric Mann-Kendall's rank correlation test, which is more robust to missing data and outliers, could be used for analysis in further works in this regard to create room for comparison of the parametric and non-parametric tests.

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