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Cross-correlation Analysis of Meteorological Indices on Global Solar Radiation Behaviour in Nigeria

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Abstract: **The study was initiated to investigate variability and change in Global Solar Radiation (GSR) penetration from climate change. Based on the meteorological data at Ile-Ife, Nigeria which is more detailed than for other stations the relations between measured GSR and other key meteorological variables namely, temperature, relative humidity, rainfall, and wind speed were established. Cross-correlation analyses methods were employed in establishing the relationship between global solar radiation and other meteorological variables influencing GSR variability. The correlation coefficient (r) between two variables, say x and y were established from the expression: The plots show that GSR has negative correlation with RH (r=0.4) and, a positive but low correlation (r=0.17) with rain. With the case of wind speed, the mode of correlation (r=0.12) appears complex. While there appears to be some positive pattern of correlation from January to August, this is reversed during the period September to December. The correlation of annual mean data for the period 2005 to 2010 shows the annual trends and associated correlations between GSR and RH, rain and wind speed during the period 2004 and 2011. The results in general show higher correlations than during the annual cycle.**

Keywords: **Cross-correlation analyses, Global Solar Radiation (GSR), meteorological data.**

I. INTRODUCTION

A wide range of parameters affect the surface penetration of global solar radiation, some of these include reflections by clouds, reflections by the atmosphere and the absorptions by clouds. In view of the fact that GSR is the principal source of energy reaching the Earth from the sun, the role played by clouds and other atmospheric parameters also affect a number of other meteorological variables measured at any place. This thus implies that correlations exist between GSR and these other meteorological parameters.

Most stations where there are no routine measurements of GSR, the common practice is to estimate global solar radiation from other measured meteorological parameters such as relative sunshine duration [9], relative humidity and temperature [7]. The numbers of rainy days, sunshine hours have also been used to estimate GSR [8]. The results of these correlation relationships are documented in literature ([1], [3], [4], [10]).

II. METHODOLOGY

Based on the meteorological data at Ile-Ife, Nigeria which is more detailed than for other stations the relations between measured GSR and other key meteorological variables namely, temperature, relative humidity, rainfall, and wind speed were established from the methods presented below. Cross-correlation analyses were employed in establishing the relationship between global solar radiation and other meteorological variables influencing GSR variability. The correlation coefficient (r) between two variables, say x and y were established from the expression:

$$r = \frac{\sum_{i=1}^{N}(y_i - \bar{y})(x_i - \bar{x})}{\left[\sum_{i=1}^{N}(y_i - \bar{y})^2 \sum_{i=1}^{N}(x_i - \bar{x})^2\right]^{1/2}}. \qquad \text{.....(1)}$$

In this study the variable, x represents meteorological parameter, while, y symbolizes global solar radiation, N is the data points available for the station in question.

Regression analyses were used to model the relationship between a response variable and one or more predictor variables. Simplest regression models involve a single response variable Y and a single predictor variable X. The regression equations obtained are presented and could be used to model daily and monthly global solar radiation. Regression analysis is used to model the relationship between a response variable and one or more predictor variables. Here, global solar radiation data is again regressed against weather parameters for any location in question.

Geo-Spatial analysis is the process of extracting or creating new information about a set of geographic features to perform routine examination, assessment, evaluation, analysis or modeling of data in a geographic area based on pre-established and computerized criteria and standards. This is done by correlation of global solar radiation in the same and different geographical locations. An XY chart was created on the mean monthly data of global solar radiation for any of two stations considering the same and different geographical locations. Excel analysis tool-kit scatter-plot was used to fit two pairs of values. Linear trend lines were added to the data point and options to display equation and R-squared value have selected. We cross-correlated global solar radiation in one station with another station within agro-ecological zone.

III. RESULTS AND DISCUSSIONS

The correlation of monthly mean data between GSR and relative humidity (RH), rain and wind speed for Ile-Ife, during the period 2005 to 2010 are presented in Figure 1. The plots show that GSR has negative correlation with RH (r=0.4) and, a positive but low correlation (r=0.17) with rain. With the case of wind speed, the mode of correlation (r=0.12) appears complex. While there appears to be some positive pattern of correlation from January to August, this is reversed during the period September to December. Similarly, the correlation of annual mean data for the period 2005 to 2010 as presented in Fig.2 shows the annual trends and associated correlations between GSR and RH, rain and wind speed during the period 2004 and 2011. The results in general show higher correlations than during the annual cycle (Fig. 1).

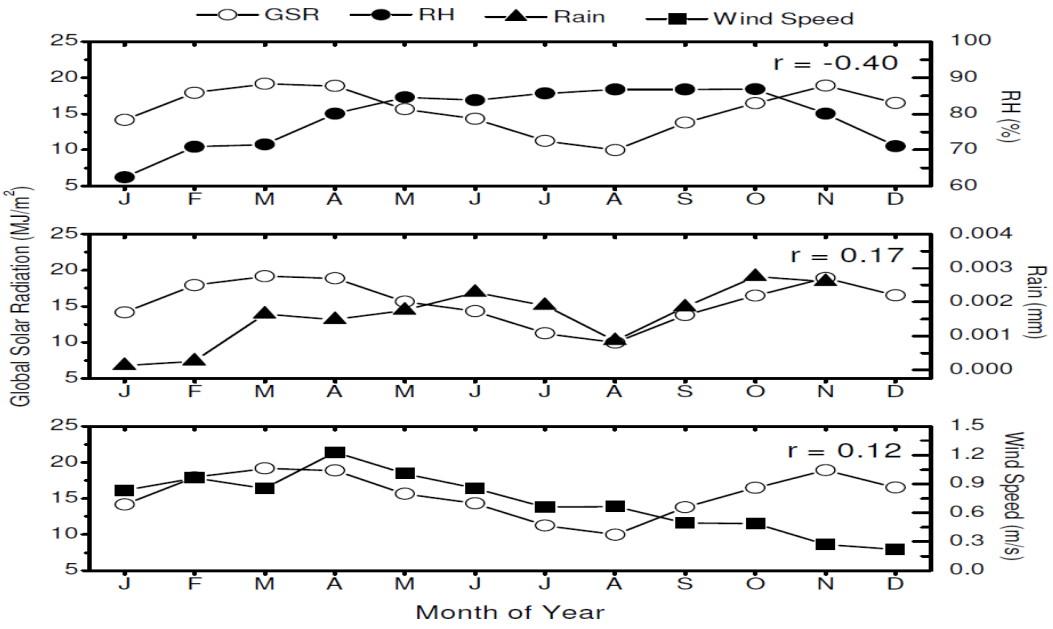

Fig 1: Correlation of Mean Monthly Global Solar Radiation (left panel) and Meteorological Parameters in Ile-Ife, Nigeria for the Period 2005 to 2010

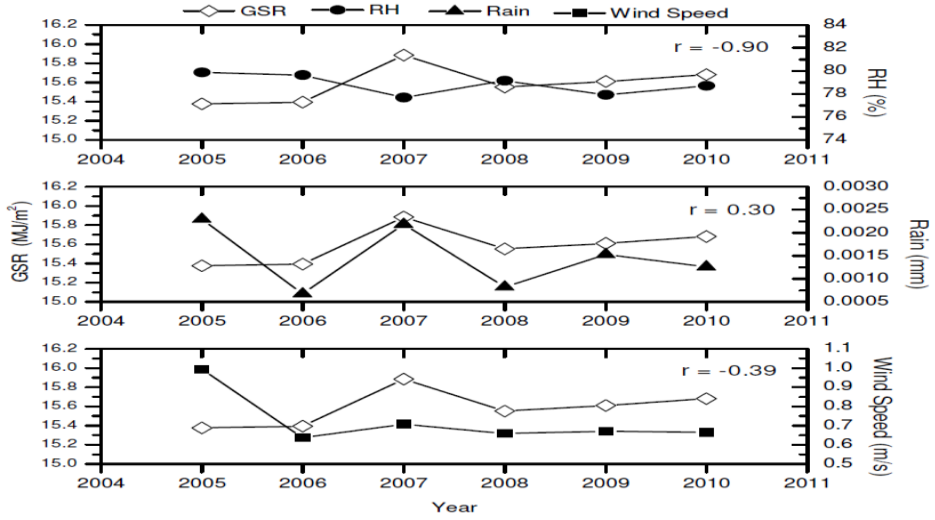

Fig 2: Correlation of Mean Annual Global Solar Radiation (left panel) and Meteorological Parameters in Ile-Ife, Nigeria for the Period 2005 to 2010

The results of the correlation of mean monthly GSR data with RH and cloud cover for Lagos, Enugu and Maiduguri are respectively presented in (Fig. 3, Fig. 4, Fig. 5). These plots indicate that RH and cloud cover have correlations. The correlation equations derived from X-Y scatter plots for Lagos, Enugu and Maiduguri are presented in Fig.6, Fig. 7, Fig. 8. The correlation coefficients for these plots were however mostly below 0.5 indicating that other meteorological parameters may also affect the GSR. The GSR and RH correlation coefficients were respectively 0.42, 0.32 and 0.45 for Lagos, Enugu and Maiduguri, while that of GSR against rainfall were 0.47, 0.61 and 0.23 respectively. The results show that with higher cloud levels in Enugu and Lagos the levels of GSR are expected to be lower in these cities when compared to Maiduguri. The observed pattern (Fig. 3, Fig. 4, Fig. 5) appears to be strongly dependent on known atmospheric conditions such as cloud, wet, clean and dusty sky in the southern and northern region of the country.

The total solar radiation received at the ground surface classified in accordance with the prevailing atmospheric conditions summarized to include clear sky (CLS), cloud sky (CLD) [2], overcast sky (OVC), and dust haze sky (DHS). However it has been possible based on the data collected to establish actual correlations between global solar radiation levels , relative humidity and these cloud conditions. Clouds play an important role as they influence vertically integrated radiative properties of the atmosphere by cooling through reflection of incoming shortwave radiation and heating through trapping of outgoing longwave radiation [11] first pointed out the possibility that processes by which the ionization effects due to gala tic cosmic rays affect surface aerosol formation and cloud nucleation would lead to changes in the distribution of cloudiness.

There are several factors which affect the global solar radiation behaviour and its variability. Injection of aerosol into the stratosphere and troposphere is one of the major factors that can affect the magnitude of solar-radiation at the surface. Aerosol is believed to be major driver of regional to global climate variability on inter-annual and longer timescales [5].

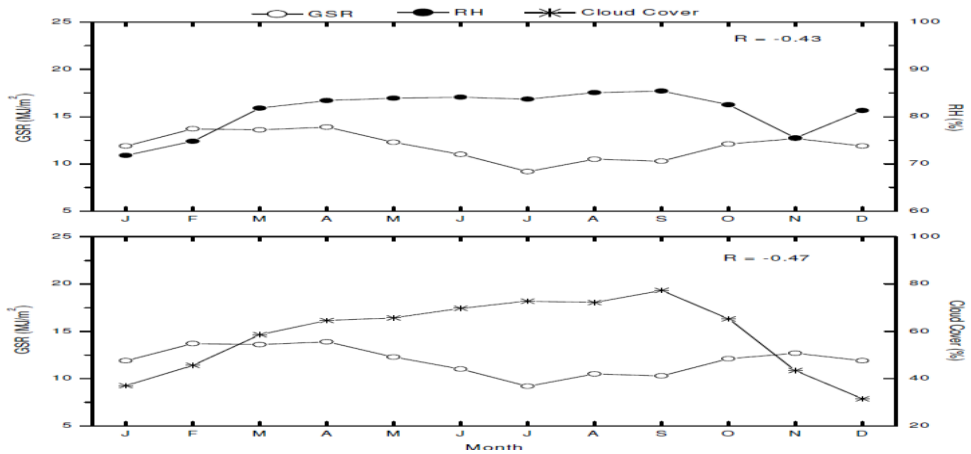

Fig 3: Monthly Correlation of GSR with Relative Humidity (top) and with Cloud Cover (bottom) over Lagos for the Period 1985 - 1994

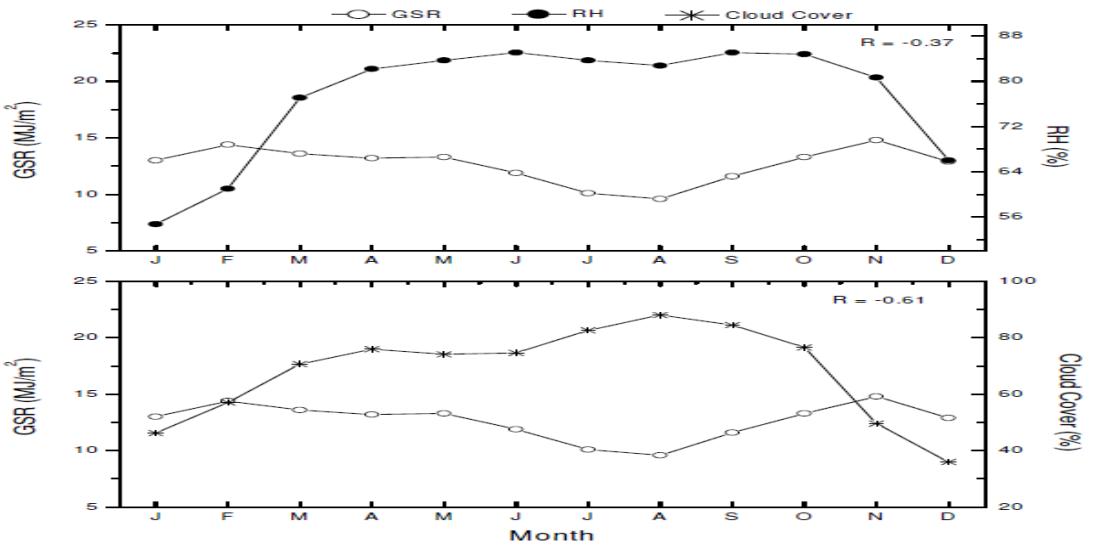

Fig 4: Monthly Correlation of GSR with Relative Humidity (top) and with Cloud Cover (bottom) over Enugu for the Period 1985 - 2005

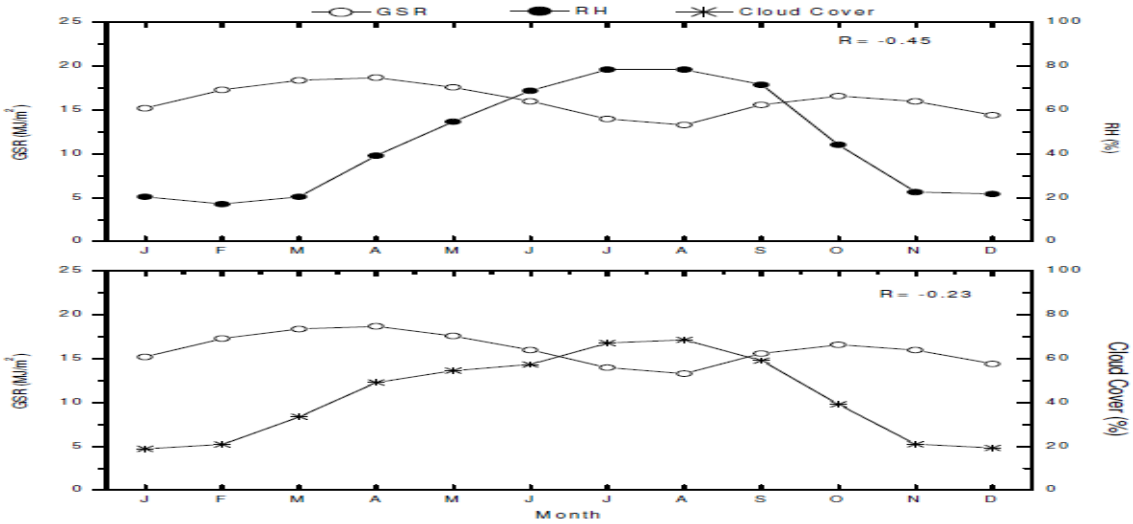

Fig 5: Monthly Correlation of GSR with Relative Humidity (top) and with Cloud Cover (bottom) over Maiduguri for the Period 1985 - 2005

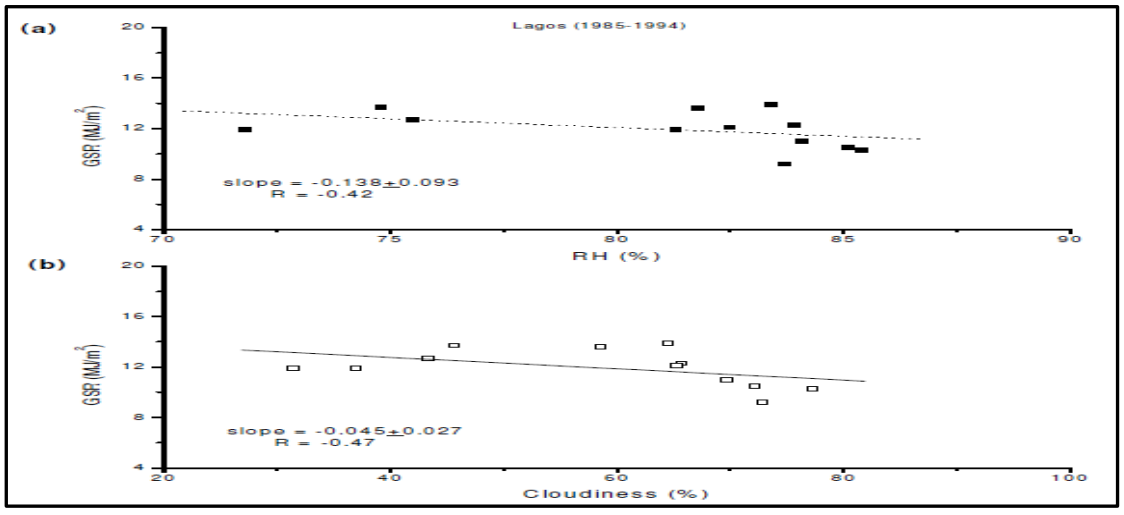

Fig 6: Correlation of GSR with (top) Relative Humidity and (bottom) with Cloud Cover over Lagos for the Period 1985 - 1994

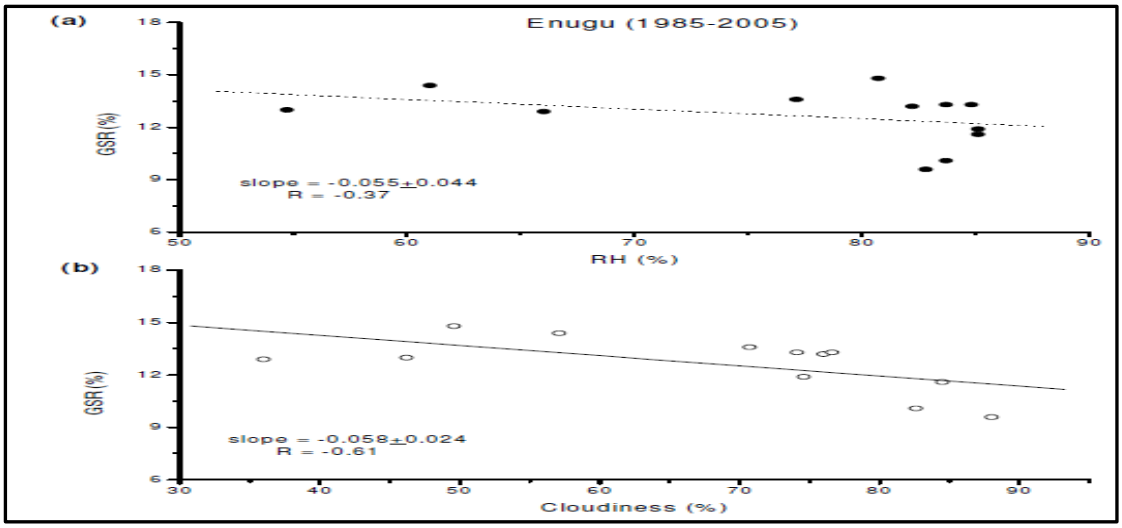

Fig 7: Correlation of GSR with (top) Relative Humidity and (bottom) with Cloud Cover over Enugu for the Period 1985 - 2005

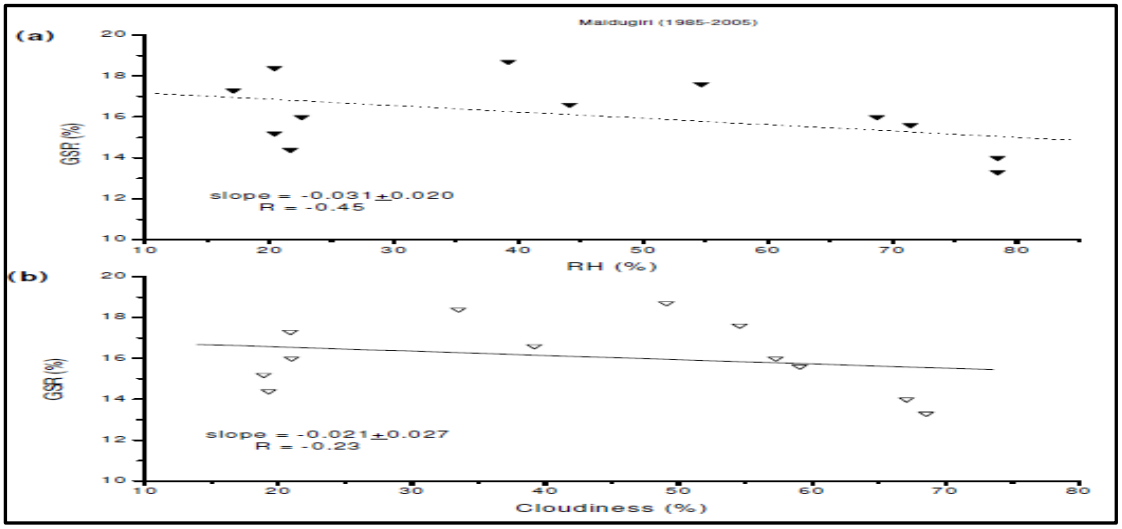

Fig 8: Correlation of GSR with (a) Relative Humidity and (b) Cloud Cover over Maiduguri for the Period 1985 - 2005

The correlations between GSR and air temperature were assessed in order to provide more insight into the role played by solar radiation in atmospheric heat generation. Based on the available observational data used for the analyses in Lagos, Ibadan and Kano, the mean monthly GSR with temperature (Fig. 9) and mean annual correlation of GSR with temperature (Fig. 10) show fairly positive correlations, with coefficients 0.58 (Lagos), 0.85 (Ibadan) and 0.82 (Kano).The degree of association between incoming solar radiation and air temperature in the tropics area is high [6].

Scatter plots were also obtained for GSR correlations with temperature using the annual mean data obtained in the three stations are as presented in Figures10. The lines of best fits are shown in each plot together with the trend values. From the results the following annual GSR and Temperature (T) trends obtained were:

(i) GSR = -0.106±0.052 MJm^{-2}/year; and T = -0.012±0.043 °C/year for Lagos

(ii) GSR = - 0.016 ± 0.014 MJm^{-2}/year; and T = - 0.010 ± 0.012°C/year for Ibadan, and

(iii) GSR = -0.008±0.029 MJm^{-2} /year; and T = +0 .012±0.023°C/year for Kano

Trends show negative progressive decline in annual GSR and temperature, except for Kano, where temperature increase is observed despite minimally declining GSR values over the period.

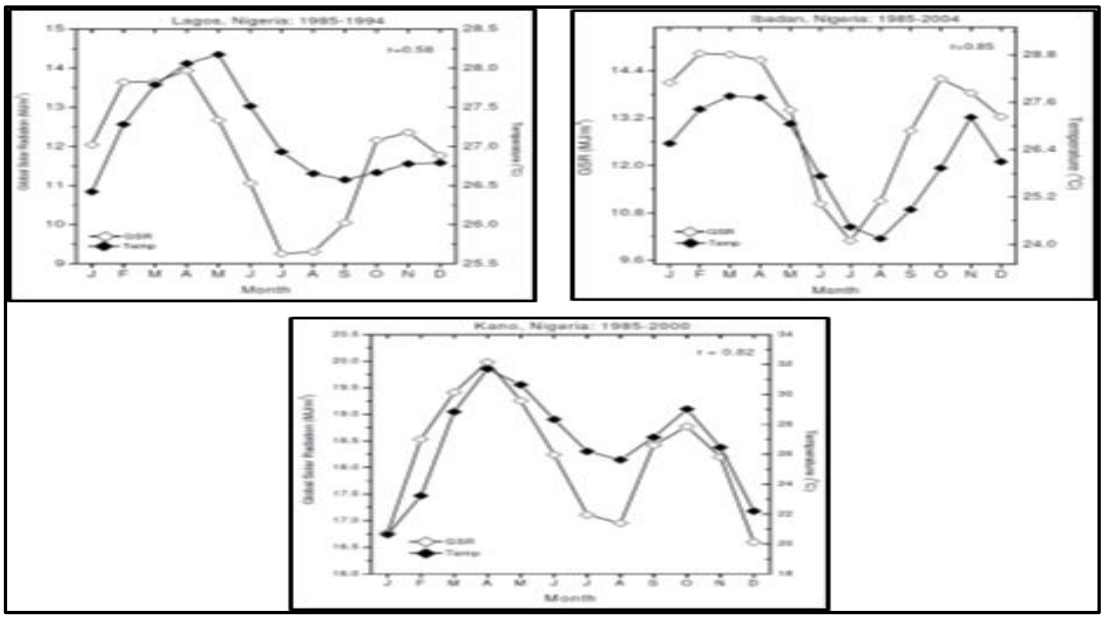

Fig 9: Correlation of monthly-averaged global radiation with temperature for Lagos (1985-1994), Ibadan (1985-2004), and Kano (1985-2000)

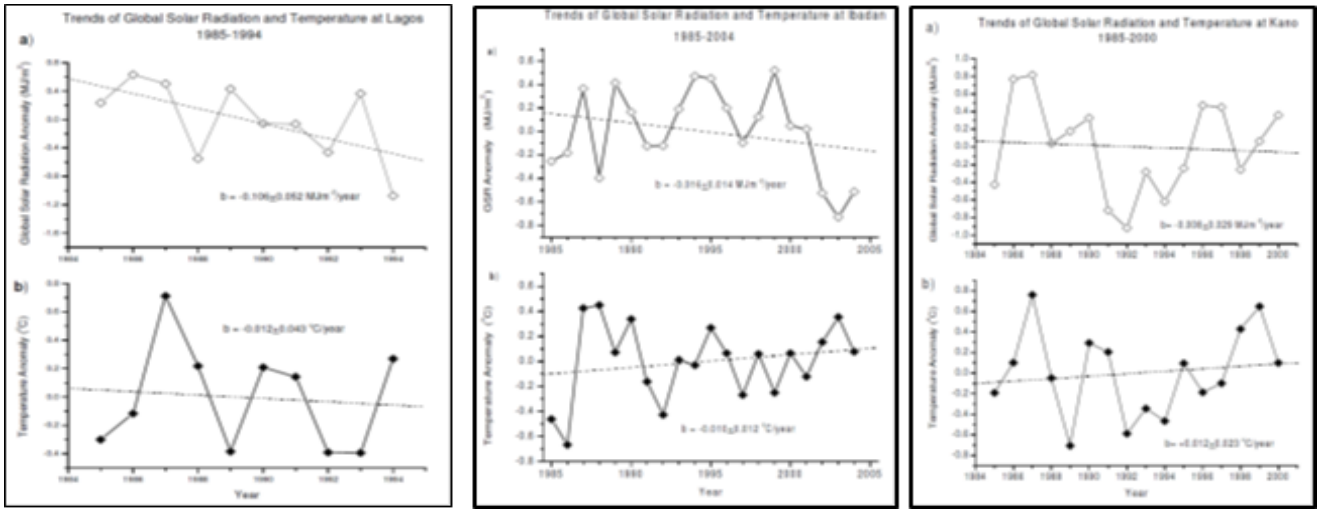

Fig 10: (a) Trends of global solar radiation and (b) concurrent trends of synoptic temperature for Lagos (1985-1994), Ibadan (1985-2004) and Kano (1985-2000)

IV. CONCLUSION

Relations between global solar radiation and some meteorological indices in selected stations in Nigeria were established. Meteorological indices affect the global solar radiation behaviour and its variability. The degree of association between incoming solar radiation and air temperature in the tropics area is high.

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