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Evaluation of Spatial Distribution and Seasonal Variations of Total Ozone Column and its Relationship with Atmospheric Parameters

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Abstract:- From literature, evidence exist that ozone and climate have influence on one another. Understanding the dynamism for this interaction is however, an open research area. In this paper, attempts have been made to study this dynamical effect; employing daily data of Total Ozone Column (TOC) and atmospheric parameters for some stations in Nigeria. The period under study spanned through 12 year (1998 – 2009). Descriptive and bivariate statistics were used in data analyses employing XLSTA and ArcGIS software. Results revealed that TOC varied spatially from the coastal region to the northern region, having similar distribution with maximum temperature, sunshine hour and wind speed, in contrast to rainfall and relative humidity. The observed spatial distribution exhibited elevation and latitudinal dependence. Seasonally, TOC recorded high values between April – October which coincided with the period of rainy season; when rainfall and relative humidity recorded high values, while maximum temperature and sunshine hour were very low during this period. The reverse is the case during dry season (November – March). This depicts that TOC has similar variation pattern with rainfall and relative humidity while it varied in opposite direction with maximum temperature and sunshine hour. We tend to attribute our observation to rain producing mechanism and atmospheric phenomena. The findings of this study suggests that two parameters can varies spatially, having similar spatial pattern but varies seasonally in opposite direction. Generally, significant relationship was observed between TOC and atmospheric parameters, depicting the interconnectivity between ozone and climate. This study has confirmed the results of previous findings and has equally given more information which is useful to climatologists and meteorologists.

Keywords:- *Atmospheric Parameters; Earth's Atmosphere; Spatial and Seasonal Variations; Total Ozone Column; Nigeria.*

I. INTRODUCTION

The Earth, a planet in the solar system is composed of an atmosphere which is divided into different layers (troposphere, stratosphere, mesosphere and thermosphere); based on temperature distribution [1]. Generally, the atmosphere is classified into the lower atmosphere (troposphere), the middle atmosphere (stratosphere and the mesosphere) and upper atmosphere (i.e the region above the middle atmosphere). Extending from the mesosphere to the thermosphere is the ionosphere, while the region above the ionosphere is the magnetosphere. Each of these regions has unique components, features and characteristics that differentiate it from the others.

Despite the uniqueness of each layer, there is an interaction between each layer/region either directly or indirectly due to the dynamic nature of the atmosphere. For example, the greenhouse gases from human activities in the troposphere affects the ozone layer in the stratosphere, while the ozone layer on the other hand protects lives on earth by absorbing harmful ultraviolet radiation from penetrating to the lower atmosphere.

Many studies have been carried out on the interaction of the different layers of the atmosphere [2]. Many researchers have studied the Earth's atmosphere and ionosphere [2], coupling of the lower atmosphere and the ionosphere [3], stratosphere- troposphere coupling [1], among others. The emphasis of this study is on the stratospheric- tropospheric interaction using measurable parameters from each region. This is because the dynamical effect of the stratosphere on the troposphere and vice versa is an open research area.

Several research works have been carried out using different parameters to study the relationship between stratosphere and troposphere [4].The dynamical mechanisms in the coupling of stratosphere-troposhpere have also been reported. For details see [1], [5].

Working on total ozone variability over West Africa stations [5], observed significant positive and negative correlation between TOC and zonal temperature and precipitation over four latitudinal zones in Africa. Similarly, [6] reported strong positive correlation of 0.99 between annual coefficient of relative variability (ACRV) of ozone and temperature while precipitation was negatively correlated (-0.99) with ozone over West Africa. Furthermore, maximum ozone was observed during dry season (December - February) with minimum value in rainy season (June-August).

Reference [7] reported significant negative correlation (-0.6305) between TOC and sunshine hour in Lagos Nigeria (1997-2005). She also observed maximum TOC during the rainy season (June-September). Similarly, [8] reported maximum and minimum TOC of 287.8DU and 192.7DU during rainy season (July-August) and dry season (December-March) respectively. Other scholars have reported maximum and minimum TOC during rainy/summer season (JJA) and dry season/winter season (DJF) respectively [9], [10]. Reference [11] observed both positive and negative correlation between ozone and temperature, while relative humidity was positively correlated with ozone.

In all these studies, none has considered the relationship between TOC and atmospheric parameters on the basis of their spatial and seasonal variations in recent time. This study is very significant as it hopes to provide information on the relationship between TOC and atmospheric parameters which will be useful especially to climatologists and meteorologists.

II. SOURCES OF DATA AND METHOD OF DATA ANALYSIS

Daily TOC and atmospheric parameters (maximum temperature, sunshine hour, rainfall, relative humidity and wind speed) data spanning for 12 year (1998 – 2009) for some stations in Nigeria were obtained from the Earth Probe Total Ozone Mass Spectroscopy (EPTOMS) and the Nigeria Meteorological (NIMET) Agency, Lagos respectively. Descriptive and bivariate statistics were used in data analyses. The ArcGIS software was employed in the analysis of spatial distribution of TOC and atmospheric parameters over Nigeria using Inverse Distance Weighting method. Eight stations representing the zones in the country were used to study the seasonal variations (Table 1). Bivariate analysis was then performed at 0.05 level of significant to confirm the relationship.

Correlation coefficients are often used at the exploration stage of bivariate statistics. The Spearman's rank correlation coefficient is most widely used in practice among others. The Spearman's rank correlation coefficient denoted by r, of two variables x and y is given by the expression [12]:

$$r_{xy} = 1 - \frac{6\sum_{i=1}^{n} d_i^{\,2}}{n(n^2-1)} \quad (1)$$

III. RESULTS AND DISCUSSION

Spatial distribution of TOC and atmospheric parameters

It could be observed from Fig. 1 that TOC increases from the coastal region to the northern region. The lowest and highest values range between 259.1-260.3 DU and 263.6-264.4DU respectively. Rainfall and relative humidity decreases from the coastal region with the maximum values ranging between 207.5-254.8mm and 76.1-82.6%, to the northern region with minimum values of 57.0-88.8mm and 39.5-46.9% respectively (Figs. 1b & c). Thus, the spatial distribution of rainfall and relative humidity varied in opposite direction to TOC.

On the other hand, maximum temperature and sunshine hour increase from the coastal region to the northern region (Figs.1d & 2a). Similarly, wind speed increases from the coastal region to the northern region. The lowest and highest values of wind speed ranges from 3.2-4.5 m/s and 7.5-8.6 m/s respectively (Fig. 2b).

It is very clear from Fig. 1 and 2 that TOC, maximum temperature, sunshine hour and wind speed have similar pattern of spatial distribution in contrast to rainfall and relative humidity across the country; based on elevation and latitude. Thus, the observed spatial distribution of TOC and atmospheric parameters exhibited elevation and latitudinal dependence. References [5] and [6] separately observed similar results over Africa and West Africa respectively. Our observation is consistence with the findings of [10] who observed that over West Africa, temperature and ozone tend to increase across latitude while rainfall decreases across latitude. Reference [13] also observed that sunshine hours increasing with altitude and latitude of the location across Nigeria.

Seasonal variations of TOC and atmospheric parameters

Figure 3 depicts the variation of monthly mean daily TOC and atmospheric variables from 1998-2012 for some stations representing the different zones in Nigeria. It could be observed from Figure 3a that TOC varied from January to December in all the stations. The lowest and highest values were recorded for the period under study between November – March and April – October which coincided with the period of dry and rainy season respectively. This is consistence with previous findings [7], [8], [9], 10]. The minimum, maximum and mean values range between 245.33DU and 246.2DU, 264.6 and 277.1DU and 259.1 and 264.4 DU respectively.

Similarly, rainfall increases steadily from January to its maximum value from July to September (the peak of rainy season); depending on the location of the station and later decreases to December (Fig. 3b). The lowest rainfall was recorded in Maiduguri and Kano (northern region) while the highest value was observed in Port-Harcourt (coastal region). Relative humidity also varied from January to December and was very high during the rainy season but low during the dry season (Fig.3c).

The variation of maximum temperature and sunshine hour show that they are very low during the period of rainy season (peak of cloud activity) when little solar radiation reaches the Earth's surface, but high during the dry season (Figs. 3d & e).

It is interesting to note from Figure 3 that TOC, rainfall and relative humidity have similar variation pattern. That is, high during rainy season and low during dry season, in contrast to maximum temperature and sunshine hour. This suggests possible relationship between TOC and rainfall, since humidity is the function of rainfall, but inverse relationship between TOC and maximum temperature and sunshine hour.

To further confirm this observation, bivariate analysis was performed using spearman rank correlation at 0.05 level of significant. Rainfall and relative humidity were strongly and positively correlated with TOC (Table 2). Some authors have reported positive correlation between TOC and rainfall based on seasonal variations [14], which is in line with our findings.

Maximum temperature was positively but weakly correlated with TOC in Kano and Maiduguri located in northern region of Nigeria. However, it was negatively but strongly correlated with TOC in other region (Table 2).We tend to suggest that the statistical relationship between maximum temperature and TOC depend on the location of the study area. Sunshine hour was negatively correlated with TOC in all the regions (Table 2). Significant negative correlation of -0.6305 was reported between TOC and sunshine hour in Lagos by [7].

The spatial distribution and seasonal variations of TOC and atmospheric parameters observed in this study were attributed to rain producing mechanism and atmospheric phenomena that influence both ozone and atmospheric parameters. Atmospheric phenomenon such as Quasi-biennial Oscillation (QBO) influenced ozone formation and Brewer-Dobson circulation [15].

From the aforementioned, the spatial distribution of TOC and atmospheric parameters differs from their seasonal variations; we observed that TOC, maximum temperature, sunshine hour and wind speed have similar variations pattern in contrast to rainfall and relative humidity. However, seasonally, TOC, rainfall and relative humidity have similar variation patterns opposite to maximum temperature and sunshine hour. This suggests that two parameters can vary spatially with similar patterns, but differ on seasonal basis.

It is interesting to note that, significant relationship was observed between TOC and atmospheric parameters which could be direct or inverse. This depicts that TOC and atmospheric parameters affect each other. This may probably be due to the influence of atmospheric parameters on the formation, transport and distribution of ozone, and ozone, in turn on the climate. Ozone level was reported to change periodically and these changes have implication especially on the climate. According to [16], increased temperature is associated with higher ozone level. He also observed that wind direction plays a significant role on how much ozone is transported.

Furthermore, [17] observed that ozone is mostly formed at the equator having high sunshine but it is transported to high altitude by wind. These are clear indications that relationship exist between ozone and atmospheric parameters. This is consistent with the result of [18] who reported that atmospheric parameters influence ozone formation and transport, while ozone on the other hand affect the atmospheric constituents.

Our findings which are in conformity with the results of earlier researchers at different temporal and spatial scales across the globe have contributed to the understanding of the dynamical effect of the ozone on the climate and vice versa.

Table 1: Meteorological stations and their location

S/N	Station	Station code	Longitude (°)	Latitude (°)	Altitude (m)
1.	Kano	Kan	8.300	12.000	472
2.	Maiduguri	Mai	12.815	11.708	350
3.	Ilorin	Ilo	4.687	8.586	306
4.	Ikeja	Ike	3.437	6.712	46
5.	Port Harcourt	P/H	7.187	4.839	206
6.	Enugu	Enu	7.812	6.088	114
7.	Calabar	Cal	8.32	4.95	62
8.	Makurdi	Mkd	8.437	7.649	122

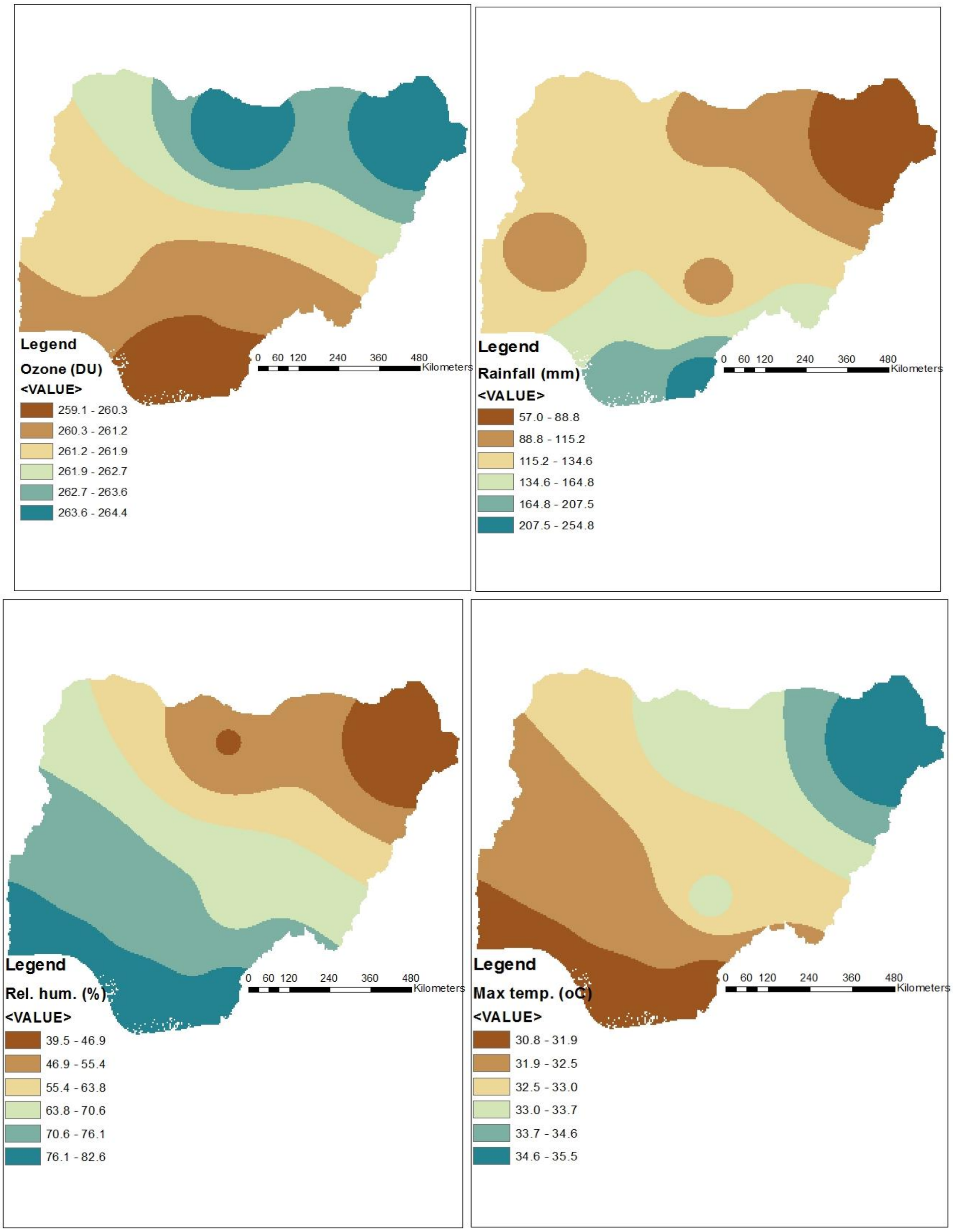


Fig. 1: Spatial distribution of overall average of (a) Total Ozone Column (b) Rainfall(c) Relative humidity and (e) Maximum temperature over Nigeria (1998-2012)

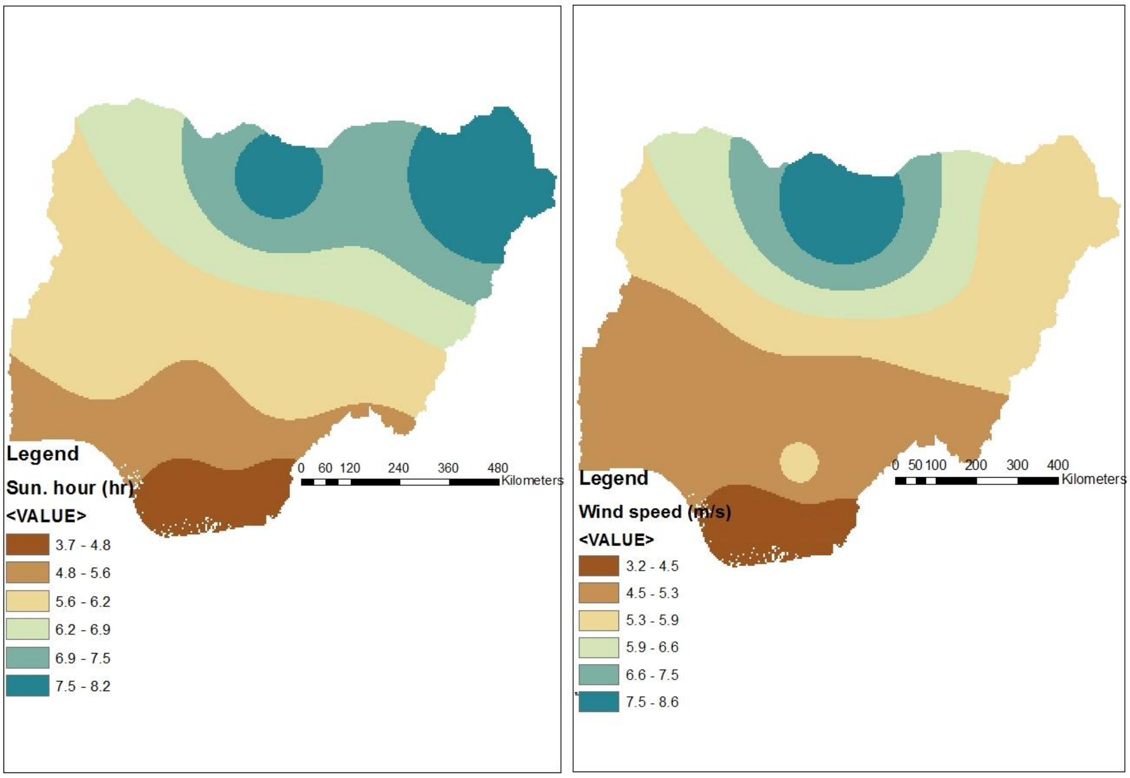
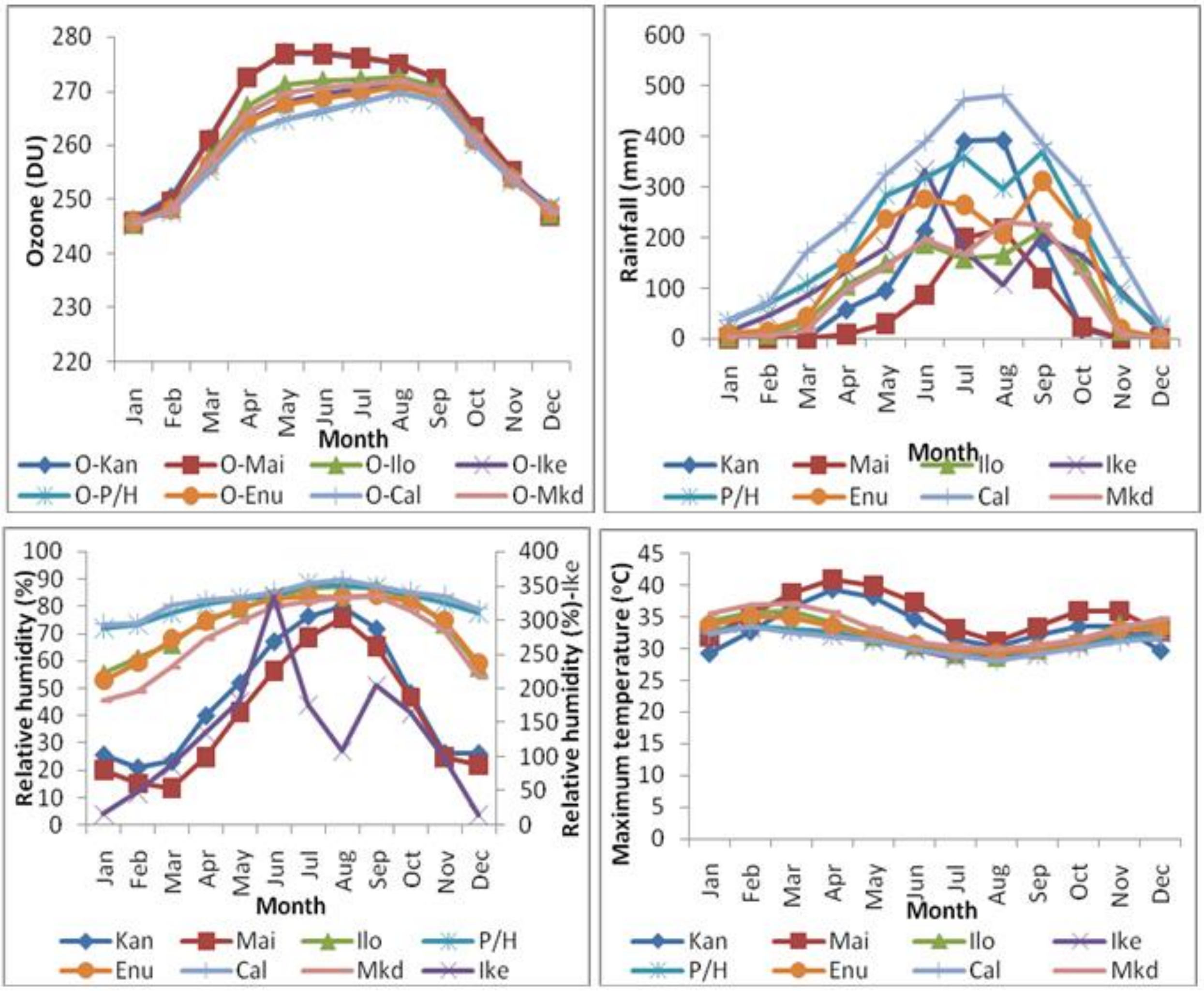


Fig. 2: Spatial distribution of overall average of (a) Sunshine hour and (b) wind speed in Nigeria (1998-2012)



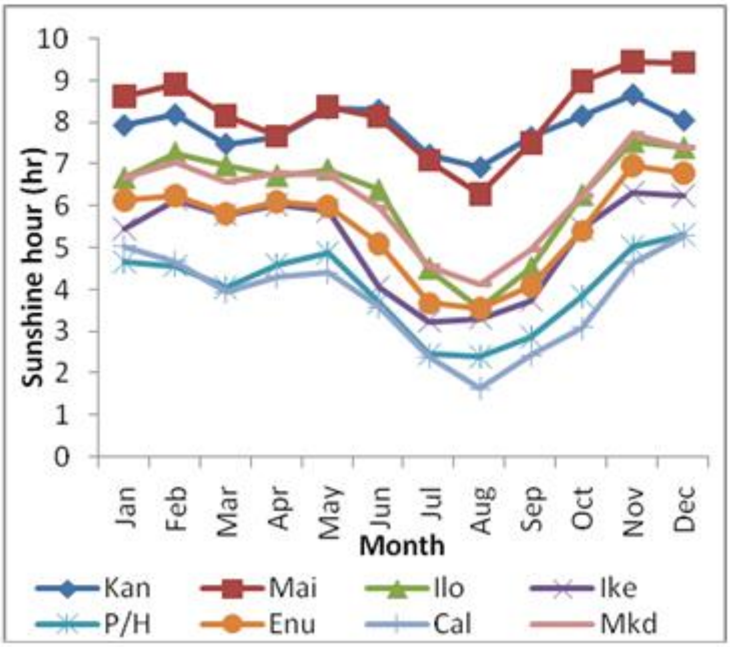


Fig. 3: Variations of monthly mean (a) Total Ozone Column (b) Rainfall (c) Relative humidity (d) Maximum temperature, and (d) Sunshine hour in selected stations in Nigeria (1998 – 2012)

Table 2: Correlation coefficient (r) of TOC with atmospheric parameters in selected stations in Nigeria (p<0.05)

S/N	Atmospheric parameters	Ozone							
		Kan	**Mai**	**Ilo**	**Ike**	**P/H**	**Enu**	**Cal**	**Mkd**
1.	Rainfall	0.868	0.805	0.895	0.769	0.930	0.853	0.951	0.958
2.	Relative humidity	0.769	0.713	0.935	0.755	0.895	0.923	0.895	0.902
3.	Maximum temperature	0.496	0.377	-0.790	-0.888	-0.853	-0.846	-0.839	-0.783
4.	Sunshine hour	-0.069	-0.636	-0.720	-0.720	-0.748	-0.881	-0.888	-0.783

IV. CONCLUSION

The spatial distribution of TOC, maximum temperature, sunshine hour and wind speed have similar variations pattern in contrast to rainfall and relative humidity based on elevation and latitude of the location. This is in conformity with the findings of [6], [10], [13].

Seasonally, TOC, rainfall and relative humidity have similar variation patterns, opposite to maximum temperature and sunshine hour. We tend to suggest that two parameters may vary spatially having similar patterns, but differ on seasonal basis. Relationship exists between TOC and atmospheric parameters which is consistent with previous findings.

The observed relationship may contributed to the understanding of the dynamical effect of ozone on climate and vice versa, which will be useful to climatologists and climatologists.

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