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Spatial Distribution of NO_2 Concentration in Southeastern Region of Nigeria

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Abstract: The aim of this study is to examine the characteristics of the tropospheric Nitrogen Dioxide (NO_2) concentrations over the five states of South Eastern Nigeria retrieved from Ozone Monitoring Instrument (OMI) data from 2010 – 2015. The mean concentration ranges from $\bar{x} = 0.99 \times 10^{15}$ molecules/cm^2 in Abakaliki (with the least commercial, industrial and vehicle activities) to $\bar{x} = 1.32 \times 10^{15}$ molecules/cm^2 in Aba, the industrial and commercial centre with coefficients of variation of 17.7% and 15.8% respectively. Results using non-parametric Mann-Kendall (MK) tests show a significant ($p < 0.05$) increasing levels of NO_2 columns in the region. For each of the seven studied cities, there is a significant seasonal cycle of NO_2 columns. NO_2 maximum was observed in dry (harmattan) season (December – March) and minimum in wet (rainy) season (May, June, October). On the average, the annual change rate for the entire Southeast was 1.72% while the 5% uncertainty interval for the region was $(1.2285 + 0.0375) \times 10^{15}$ molecules/cm^2, which indicates a highly polluted region.

Keywords: NO_2 Concentration; OMI; Pollution; Troposphere; Monotonic Trend.

1. Introduction

Atmospheric pollution is the release of deadly gases, particulate matter, and other species into the Earth's atmosphere. This affects the air quality of the global environment since there are no borders in the atmosphere. Poor air quality is the result of a number of factors from both natural and anthropogenic (human) sources.

Lu, *et al.* [1] describes nitrogen oxides ($NO_x = NO + NO_2$) as one of the six criteria pollutants recognized by the US EPA (United States Environmental Protection Agency) under the requirements of the Clean Air Act. NO_x plays a key role in tropospheric chemistry processes such as the formation of ground-level ozone and secondary inorganic and organic aerosols. It is also associated with other criterion pollutants including ozone, particulate matter, carbon monoxide, and sulfur oxides. For that reason, NO_x is not only harmful to human health but also concerned in a number of environmental problems, such as acid rain, smog, eutrophication, and climate change. NO_x emissions come from both anthropogenic (e.g., man-made combustion of fossil fuels, biofuel, and biomass) and natural sources (e.g., lightning, microbial processes in soils, and wildfires). Inventories of NO_x emissions can be quite unclear because the emission factors of anthropogenic sources strongly depend on the fuel type, technology, and combustion condition, while natural sources are in actual fact not easy to put a figure on.

One of the most essential air pollutants in the troposphere is Nitrogen dioxide (NO_2). The lifetime of NO_2 varies from one hour at the surface to several days high in the atmosphere. Owing to the strong absorption of NO_2 molecules in the visible wavelength range of the spectrum [1], satellite instruments based on the standard of optical absorption spectroscopy serve as great tools to detect NO_2 signals from space [2]. In order to boost our knowledge of tropospheric chemistry, it is imperative to get a quantitative understanding of the impact of NO_2 emission variations on the chemical balance of both the source area and the surrounding area [3].

Health regulations concerning air quality require regular monitoring, usually on an hourly basis, of surface concentrations of several species including NO_2 [4].

Recently, a number of studies in Nigeria have highlighted the impact of local and regional air quality. Ede and Ede and Edokpa [5] used a manual method to determine NO_2 with diazolizing-coupling agents such as Sulphanilic acid and N-(I-naphthyl)-ethylene diamine dihydrochloride) to produce a deeply coloured azo dye whose intensity was measured spectrophotometrically. Their study showed that laws on environment especially air quality are very weak in the Niger Delta region of Nigeria.

It is interesting to observe that while the trend in NO_2 concentration has been on the decline in the developed Europe in the last decade, the reverse is the case in the developing countries of Asia [6]. The increase in

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concentration in Asia has been attributed to rapid industrialization, for example, Sun, *et al.* [7], and the rapid growth in human population [8]. As a consequence, both factors jointly contributed to the rise in vehicular traffic and the corresponding amount of exhaust fumes in the atmosphere.

A preliminary survey of NO_2 concentration was conducted recently in Owerri, Imo state of Nigeria for a period of six months. It was observed from this survey that the levels of NO_2 concentration in the area of 29.10 ppm exceeded WHO standard for 1-hour mean of 4.89 ppm and there is an urgent need for serious awareness campaign on air pollution, regular air quality studies and enforcement of air quality guidelines in Owerri Ibe, *et al.* [9]. Motivated by these studies in Europe and Asia and the preliminary reports in Owerri, we examine in this investigation the temporal and spatial distribution of monthly averages of NO_2 concentration in seven cities in the southeast geopolitical zone of Nigeria.

2. Materials and Methods

2.1. Measurement of tropospheric NO_2

Ozone Monitoring Instrument (OMI) is one of four instruments on board NASA's EOS-Aura satellite, launched on 15 July 2004. The aim of the Aura satellite is to observe atmospheric chemistry and particularly to monitor the ozone layer, the Earth's climate and air pollution. The EOS-Aura satellite circles the world in a polar orbit, which enables daily global NO_2 measurements. OMI measures the total amount of NO_2 in the troposphere, i.e., from the surface to about 11 km above ground level (http//aura.gsfc.nasa.gov/scinst/omi.html for more information). Globally, OMI retrievals have proved to be capable to describe air quality features and variability to ground-based measurements. It boosts the assurance in using satellite observations for monitoring air quality [10]. Retrievals of tropospheric column NO_2 from OMI are available for the width of the atmosphere observed along the viewing track (or swath) of the instrument. OMI tropospheric column NO_2 is calculated by subtracting the stratospheric signal from the observations of total column NO_2 [11]. Column NO_2 measurements are only considered for the gridding procedure when solar zenith angle is less than 85^0 and effective cloud fraction is less than 30% [12]. The column amount of NO_2 used in this study is in the order of 10^{15} molecules/cm^2.

2.2. Study Area

Southeast Nigeria (see shaded area in Fig. 1; Lat. 4.5^0 – 7^0N, Long. 6.45 – 8.25^0E) has a tropical continental climate and tropical rainforest vegetation. It covers about 29,095 square kilometers and constitutes 3.15% of Nigeria's land mass. The region has a yearly rainfall between 2400 mm and 4000 mm [13, 14]. These cities are characterized by huge activities ranging from small-to-large scale manufacturing, farming, transportation, oil exploration, power generation and high rate of vehicular traffic. The population of the cities is about 16.38 million.

Figure-1. Map of Nigeria showing southeast region

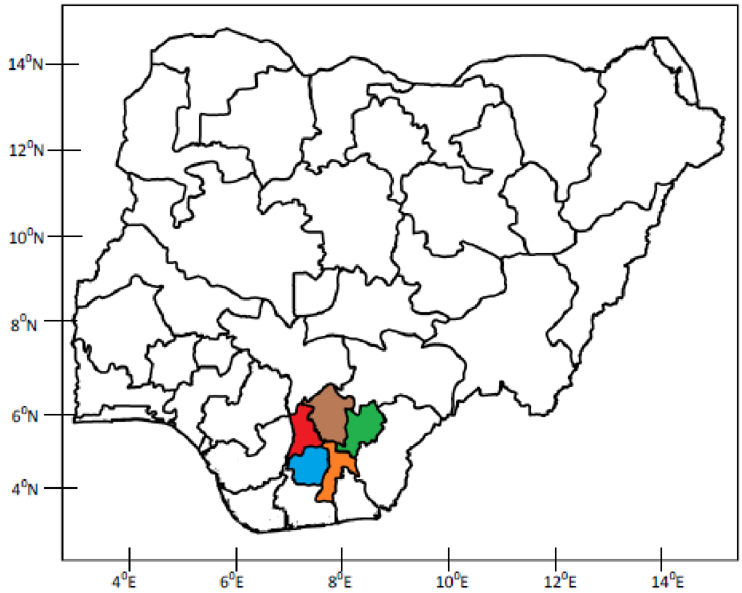


Table-1. Stations and their respective coordinates

Station	Lat.(^{0}N)	Lon.(^{0}E)	Elevation (m)
Aba	5.112	7.372	205
Abakaliki	4.750	7.000	65
Awka	6.200	7.730	105
Enugu	6.500	7.500	192
Onitsha	6.133	6.793	106
Owerri	5.480	7.030	73
Umuahia	5.530	7.480	148

3. Data and methodology

NO_2 column data were sourced from the National Aeronautics and Space Agency (NASA) USA, available on http://avdc.gsfc.nasa.gov/ and processed with Microsoft Excel and R software. The data were recorded at daily intervals and data on column NO_2 were obtained for each station. All stations fall in the southeast region of Nigeria (see Fig. 1). The summary statistics, the analysis of variance (ANOVA) for comparison of means of concentrations, analysis of time series for the study of underlying mechanism of the process and the nonparametric methods for estimation and testing the existence of trend will be adopted. Specifically, the Mann-Kendall trend test, (see, e.g., Mann [15] and Kendall [16]) for detecting and estimating a trend in time series of monthly/annual values of observations will be employed on the data sets to detect the presence of positive or negative trends in the time series data. It is the nonparametric statistical method for testing the presence of monotone increasing/decreasing trend. The test statistic, S, which is based on the sign differences and not directly on the values of the random variable, is expected to be less affected by outliers [17]. The method is well suited for analyzing trends in data over period of time, it does not require any assumptions as to the statistical distribution of data. The basic principle of Mann-Kendall (MK) test based on the statistic, S, is given by

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign}(x_j - x_i), \qquad i < j \tag{1}$$

where x_i is the value of the *i*-th time point. S can assume any of three values: negative, zero or positive value. The statistic S is tested for significance using the criteria in Helsel and Hirsch [18]. The magnitude of the slope of the time series data is necessary if the value of the S statistic is nonzero. The Sen's slope estimator, which is a simplenonparametric test developed by Sen [19] and presented by Gilbert [20] measures the magnitude of the increase/decrease and tests for its significance in the series is given by

$$Q_i = \frac{x_j - x_k}{j - k} \tag{2}$$

where x_j and x_k are the data values at time points *j* and *k*, respectively.

To evaluate and describe the changes in the series, we employ a simple year-over percentage change defined as

$$T(\%.yr^{-1}) = 100(y_{t-1} - y_t)/y_t \tag{3}$$

where y_t is the average annual concentration at year *t* over the six years.

The procedure is: calculate annual percent changes for each pair (adjacent observations, y_t, y_{t+1}) of sequential data points in the series; take the median of these computed year-over rates of change, and the resulting single number is the desired change.

The general hypothesis of interest here is H_0: There is no significant monotonic trend in NO_2 concentration in the Southeast between 2010 and 2015. This hypothesis will be rejected if the Mann-Kendall statistic, *S*, is greater or equal to the critical value, S_α, Hirsch, *et al.* [21] developed such a test by computing the Kendall score separately for each month.

4. Results and Discussions

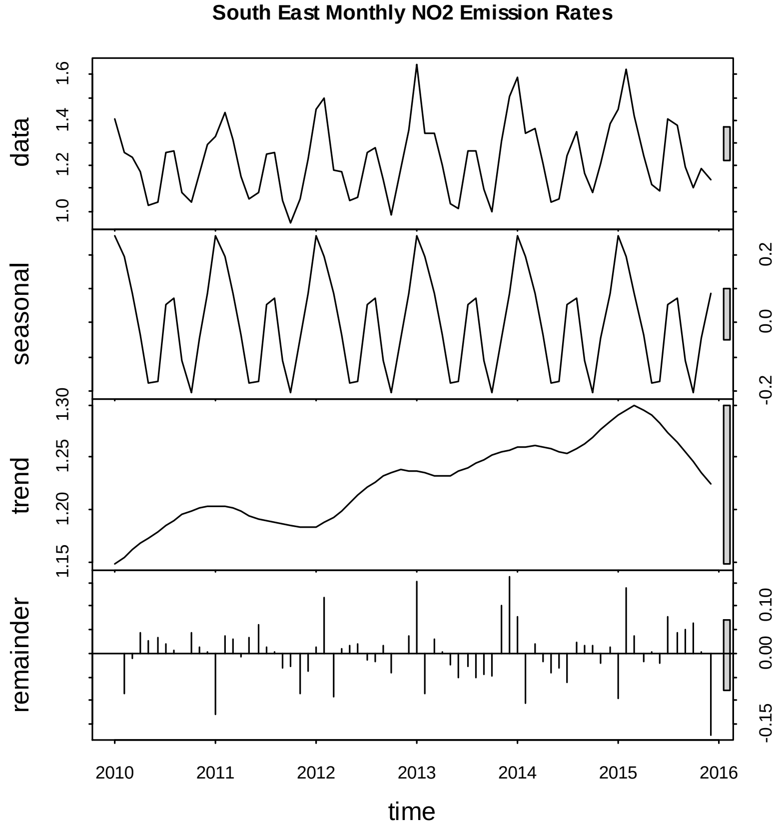
Table 2 shows the summary statistics for SE and all the state capitals and other big cities in the survey. Abakaliki, the capital of Ebonyi state, has the lowest NO_2 concentration (mean = 0.9992, median = 0.9500), see also, Fig. 4) while Aba, the industrial and commercial "capital" city in the southeast recorded the highest (mean = 1.3182, median = 1.3000). The distribution of the 72 data points over the six years show that besides each city being uniquely identifiable, Abakaliki displays some heavy tail properties. The city's skewness and kurtosis parameters are the highest (Skew = 1.2400, kurtosis = 1.7200).

Table-2. Summary Statistics of NO_2 $(10^{15}\text{molecules/cm}^2)$ concentration data

Parameter	*SE*	*Aba*	*Abakaliki*	*Awka*	*Enugu*	*Onitsha*	*Owerri*	*Umuahia*
Mean	1.2285	1.3182	0.9992	1.2196	1.2183	1.2744	1.2914	1.2788
Standard Error	0.0188	0.0246	0.0208	0.0161	0.0182	0.0186	0.0232	0.0219
Median	1.2186	1.3000	0.9500	1.2150	1.2050	1.2650	1.2700	1.2750
Standard Deviation	0.1596	0.2084	0.1764	0.1369	0.1541	0.1581	0.19699	0.1857
Kurtosis	-0.1604	-0.3069	1.7200	0.1797	0.9117	-0.2449	-0.3994	-0.5872
Skewness	0.5163	0.5587	1.2410	0.5690	0.7189	0.4252	0.4689	0.3572
Minimum	0.9500	0.9700	0.7500	0.9500	0.9600	1.0100	0.9200	0.9600
Maximum	1.6443	1.8700	1.6500	1.6100	1.7500	1.6700	1.7600	1.7100
Confidence Level (95.0%)	0.0375	0.0490	0.0415	0.0322	0.0362	0.0372	0.0463	0.0436

A time series (Fig. 2) shows the behavior of the original data for the SE (panel 1), the estimated seasonal components (panel 2), the nature of its trend and random components (panels 3 and 4, respectively).

Fig-2. SE average monthly NO_2 concentration



Seasonal variation is evident in the time series and a monotonic increasing trend can be found. Further analysis of the original data using ANOVA showed that there were significant differences (p = 0.0000) among months but year effect was not significant (p > 0.05). From Table 3 and Fig. 3, concentration rates are highest in January and February, and lowest in May, October and June. The large dot in each bar indicates the monthly mean value while the entire bar shows $\bar{x} \pm se$ (standard error) for the month over the six years under consideration. The shorter (longer) the bars, the lower (higher) the variability on emission/concentration within the month. For example, fluctuations in NO_2 is most in the months of December – February and least in April – June. Also from Table 3, only Awka differed from others by having high concentration of NO_2 in the month of April while Abakaliki recorded the lowest in July and August. Besides, this SE profile actually represents the situation in the entire sub-region. Estimation and tests for trend using MK S statistic, Helsel and Hirsch test criteria and Sen-Thiel's nonparametric regression method are displayed in Table 4. The *S* statistic was applied in two ways; on the 72 data points (*S**), and that based on yearly averages (*S*).

Table-3. Effect of season on the region

Month	Aba	Abakaliki	Awka	Enugu	Onitsha	Owerri	Umuahia	SE
Jan	0.3658	0.3446	0.1215	0.2512	0.1520	0.3357	0.2517	0.2604
Feb	0.1494	0.2093	0.1735	0.2008	0.2279	0.2619	0.2724	0.2136
Mar	0.1393	0.0612	0.0637	0.0639	0.0664	0.1066	0.1230	0.0892
Apr	-0.0538	-0.1168	0.0478	-0.0274	-0.0253	-0.0488	-0.0658	-0.0415
May	-0.2212	-0.1218	-0.1393	-0.1799	-0.1805	-0.1960	-0.2224	-0.1802
Jun	-0.2148	-0.2212	-0.1284	-0.1533	-0.1791	-0.1675	-0.1893	-0.1791
Jul	0.0198	-0.0188	0.0827	0.0947	0.0254	0.0195	0.0414	0.0378
Aug	0.0324	-0.0666	0.1517	0.0778	0.0927	0.0669	0.0836	0.0626
Sep	-0.1617	-0.0261	-0.1042	-0.1122	-0.1344	-0.1662	-0.1428	-0.1211
Oct	-0.2580	-0.1617	-0.1558	-0.2138	-0.2228	-0.2842	-0.2501	-0.2181
Nov	-0.0007	-0.0273	-0.0993	-0.0737	0.0109	-0.0717	-0.0519	-0.0448
Dec	0.1836	0.1454	-0.0139	0.0719	0.1668	0.1440	0.1503	0.1212

Fig-3. Effects of seasons on NO_2 concenteation in the SE

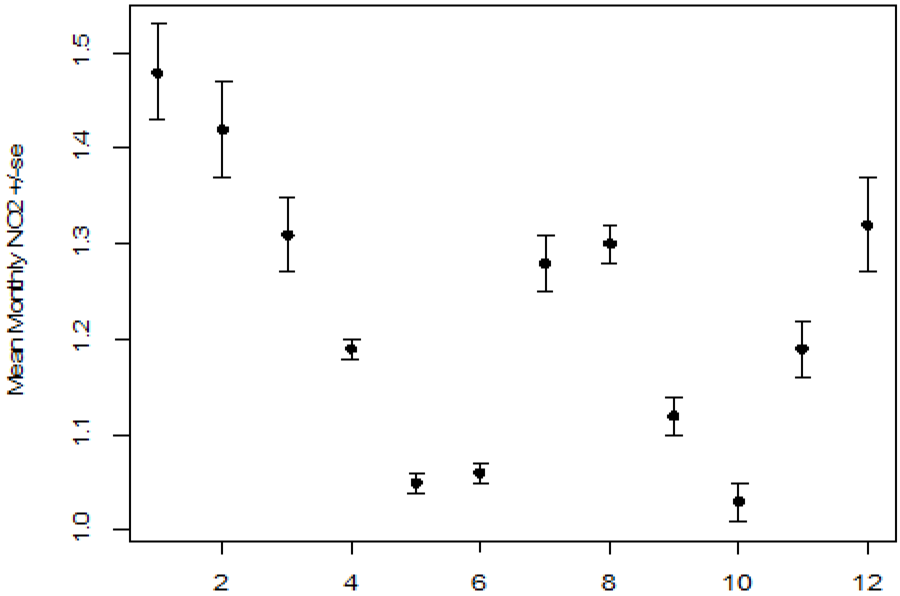
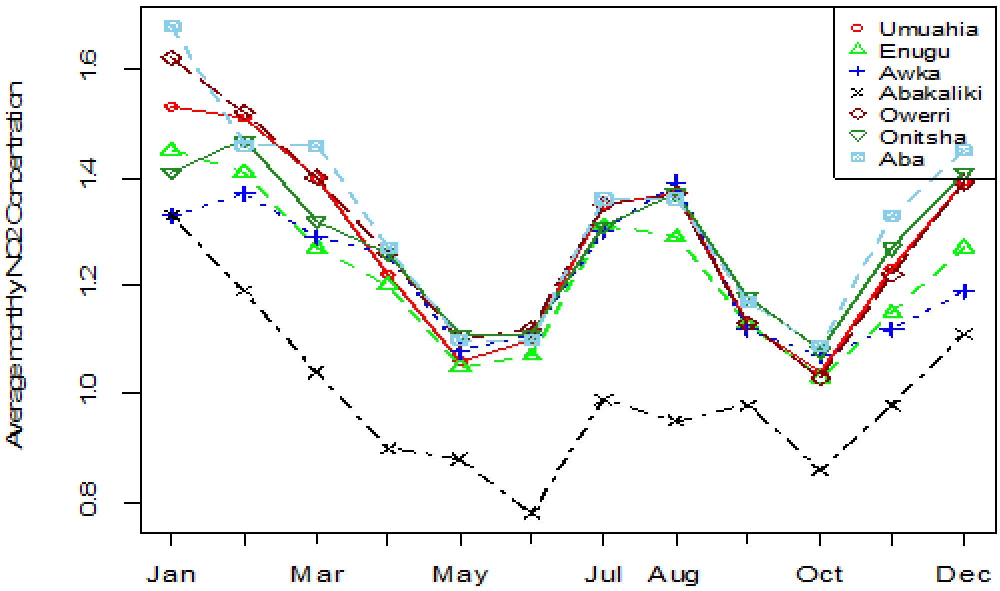


Fig-4. Seasonal vaeiation in NO_2 concentration across cities



The positive values of the statistic (*S* or *S**) indicate a positive trend in all cities. All Q values in Table 4 are positive which is indicative of positive slope and which we test for the significance of trend. A comparison of S and S_a showed that there was a significant trend in all cities ($p < 0.05$) which implies that NO_2 emission was increased in the area. For example, the positive trend observed in Aba was significant $S = 15 > 7 = S_a$. Thiel's method was used for the estimation of linear trend (regression) lines for each city over six years; where *y* represents value of NO_2 concentration and *t* is time (in years). The results in Table 4 showed that all the trend lines have positive and significant ($p < 0.05$) slopes, indicating an increase trend of NO_2 concentration over the years. The year-over percentage change, T, showed that Owerri has the highest with T = 3.08 and Enugu the lowest with T = 1.10.

Table-4. Results of trend analyses of NO_2 emission by city (2010 – 2015)

Site	S^*	Q	Thiel's Trend Line	S	S_α		T(%)
Aba	299	0.00156	$y_t = 1.2463 + 0.0229t$	15	7		1.57
Abakaliki	254	0.00097	$y_t = 0.9223 + 0.0193t$	13	7		2.12
Awka	155	0.00066	$y_t = 1.1600 + 0.0200t$	11	7		1.61
Enugu	124	0.00047	$y_t = 1.1700 + 0.0133t$	11	7		1.10
Onitsha	253	0.00115	$y_t = 1.2133 + 0.0142t$	12	7		0.81
Owerri	137	0.00081	$y_t = 1.2250 + 0.0150t$	11	7		3.08
Umuahia	212	0.00111	$y_t = 1.2000 + 0.0200t$	13	7		1.54
SE	254	0.00105	$y_t = 1.1700 + 0.0167t$	14	7		1.72

5. Conclusions

The NO_2 data for six years (2010 – 2015) obtained from NASA over five states in the south eastern region of Nigeria were used for this study. Data on each state capital and two other commercial and industrial hub of the region were investigated. The analysis of the OMI data was through both parametric and non-parametric methods and results presented in both numerical and graphical displays.

Results showed that the annual mean NO_2 concentration (AMNC) in the south eastern states of Nigeria increased. It was highest in Aba (1.3182 ± 0.0188) and lowest in Abakaliki (0.9992 ± 0.0208), being the busiest and the least busy cities respectively in terms of commercial and industrial activities. The monthly mean NO_2 concentration showed seasonal variation pattern; higher during dry season (December to March) and lower during wet season (May, June, September and October). As a result, seasonal variations were prominent in the region during the period of our study.

Trend analyses showed the significant positive trend ($p < 0.000$) in all cities, indicting continuously increasing NO_2 concentration in the region. It has an upward trend in NO_2 concentration (2010 – 2015) and a year-over changing rate from 0.81% to 3.08%. Thiel's nonparametric trend method was used to show how predictable the trend was in the region. This upward trend showed that a 5% uncertainty interval from (1.2285+0.0375) ´ 10^{15} molecules cm^{-2} / year. This phenomenon is worrisome because of its health and environmental implications.

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