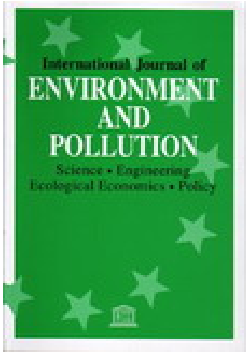

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Spatial and seasonal variation of CO_2 concentration within some selected areas of Owerri: Nigeria

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Spatial and seasonal variation of CO_2 concentration within some selected areas of Owerri: Nigeria

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Abstract: Emission-driven climate variability continues to receive great interest worldwide. Due to its negative impacts on human health and welfare, an accurate carbon dioxide (CO_2) estimate is needed. There is a great need to control concentrations, and to monitor the environment and industrial processes of Owerri metropolis. This comparative study presents the measured concentration of CO_2, relative humidity, temperature and wind speed. We concentrate on stations that have green plants and those of non-green plants over seven sites from January to April 2016. The results are compared with sixteen weeks of measurements from the suburb environment at Uratta in Owerri North LGA. Concentrations of CO_2 were approximately 42.38 ppm higher during the rainy season than during the dry season over the non-green plant area. The results are representative of the biological surroundings and indicate the importance of intra-urban selection when characterising spatial and seasonal variation in surface characteristics of CO_2.

Keywords: metropolis; Nigeria; Owerri; seasonal variation; urban CO_2; vegetated surroundings.

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1 Introduction

The rapid increase in atmospheric carbon dioxide (CO_2) has prompted intense research efforts to explain and quantify the sources and sinks of CO_2 (Conway et al., 1994). In particular, significant attention has been directed to CO_2 concentration and its contribution to climate change. There are, however, large uncertainties in greenhouse gas trends in suburban areas. These regions have great potential for contributing to global concentrations (Velasco et al., 2014). Similarly, seasonal variations of carbon dioxide in Tokyo have been reported (Imasu and Tanabe, 2018).

Therefore, it is critical to improve suburban atmospheric greenhouse gas measurements. Some studies (Leemans et al., 1996; Edmonds et al., 1996; Ishitani et al., 1996) have already attributed a good method in reducing carbon concentration. This agrees with Brown et al. (1996) and well captured in IPCC (1996).

The monitoring and assessment of spatiotemporal concentration of carbon is critical. Doing so will help validate violations of air quality standards. Also, this knowledge will give a specific mitigation strategy (Oke, 1995). In this study, we compare urban and suburban carbon dioxide concentrations. Finally, we find a need to support city greening in order to mitigate carbon dioxide concentration.

1.1 Atmospheric CO_2 increase and consequences

Ndoke et al. (2006) identified Kaduna and Abuja as high CO_2 concentration areas due to traffic congestion. This prompted Osuntogun and Koku (2007) to carry out a feasibility study over Lagos, Ibadan, and Ado-Ekiti in validating urban transportation pattern. Their results exceeded the maximum of 450ppm recommended by the Federal Ministry of Environment. Also, a similar study was performed by Ndoke and Jimoh (2007) over Niger state and Calabar (Abam and Unachukwu, 2009). Their results were in agreement. In quantifying regional measurement with satellite, Kort et al. (2012) estimated satellite strength in validating urban CO_2 concentrations.

According to the IPCC TAR report in 2001, a depiction of the global carbon budget, consider anthropogenic as most CO_2 release. This effect causes changes in land use. There is increasing interest now in applying atmospheric techniques to investigate questions of greenhouse gas concentration. The regional and local environment is not left out (Ciais et al., 2010). Air quality degradation towards CO_2 concentration in the urban environment is increasing. This is a result of an increasing number of people. Additionally, seasonal amplitude of carbon dioxide has been noticed in semi-urban environment of India responding to increase in fossil fuel applications (Metya et al., 2021).

This effect has a significant impact on human health. Understanding regional carbon sources and sinks has a great potential to predict the future trend. The strategic action plan is using urban greening (Bulkeley, 2013; Rosenzweig et al., 2010; Pincetl et al., 2012). Weissert et al. (2014) argued that the scientific absorption potentials of urban greening are uncertain, and have to be understood.

The variability of surface cover and roughness in urban areas poses particular challenges to carry out studies. The choice of spatial and vertical sites of the measurement equipment affects measurements. This prompted researchers to often use multiple urban sites to cover variations in spatial and vertical sites (Offerle et al., 2006). Evidence of urbanisation alters ecosystem function by regulating biogeochemical cycles and driving forces like temperature, carbon, and precipitation (Koerner and Klopatek, 2002). This, in turn, affects the city air quality and energy balance at large

(Forster et al., 2007). The temperature of the city varies both spatially and temporally (Oke and Maxwell, 1975). The temporal variation is dependent on minimum temperature (Brazel et al., 2000) and carbon concentration (Neftel et al., 1994; Keeling and Whorf, 2005; Barnola et al., 2003; Trenberth et al., 2007).

2 Data and method

The field monitoring of atmospheric carbon dioxide, temperature, wind speed, and relative humidity was undertaken daily and diurnally, from January to April 2016. The measurement covers Nigeria's wet and dry seasons. The data on ambient air quality and meteorological parameters were monitored at the seven selected remote sites of Owerri metropolis. Also, a correlation on control measurement at seven selected sites within Uratta, Owerri North, was further applied to the analysis.

This idea is to investigate the transportation modes of carbon dioxide concentrations between these environments. The correlation analysis was used to give information about the independent variables of pollutant distribution. In situ measurements were maintained diurnally and compared.

A measurement error was limited by optimising the analyser to avoid any interference with the measured properties and exhalation from the nostril. Measurements always begin by 8 am and 4 pm in the seven selected sites of Owerri, as well as in control. The main scope of pollutant transportation was obtained with a statistical time series diagram (IPCC, 2001). Several statistical tools were also applied to find the characteristics of transportation mode between the two environments. These include standardised anomalies, test statics, skewness, correlation analysis, average factor, and root mean square error described in Tables 1–8.

Table 1 Summary of the study locations and description (Owerri)

S/N	*Station*	*Latitude* (N)	*Longitude* (E)	*Altitude* (m)	*Site description*
1	IMSU junction	05°30′26.6″	007°02′16.6″	78	CO_2 prone site
2	IMSU gate	05°30′29.6″	007°02′32.4″	87	Less concentration station
3	Rockview roundabout	05°29′35.0″	007°01′57.8″	68	Minimal sink station
4	MCC junction	05°29′09.7″	007°02′24.4″	73	Low concentration site
5	Mbaise roundabout	05°28′53.6″	007°01′59.9″	72	Industrious station
6	New market plaza	05°28′29.4″	007°02′04.6″	80	High concentration
7	Ekeonuwa plaza	05°29′04.5″	007°01′55.6″	89	CO_2 prone station

Table 2 Summary of the locations (Uratta)

S/N	*Station*	*Latitude* (N)	*Longitude* (E)	*Altitude* (m)
1	Toronto junction	05°29′47.0″	007°05′09.0″	121
2	Factory junction	05°29′29.1″	007°05′04.8″	123
3	27 Casmir ibest.	05°29′24.6″	007°04′49.8″	125
4	Factory	05°29′16.0″	007°04′41.2″	132
5	1 Casmir ibest.	05°29′28.5″	007°04′56.2″	125
6	Umuchima uratta	05°29′54.2″	007°05′11.2″	132
7	Mechanic new road	05°29′47.0″	007°04′52.7″	128

Table 3 Daily average CO_2, water vapour, temperature and wind speed for January 2016

S/N		CO_2 (ppm)	*Temperature* (°C)	*Relative humidity* (%)	*Wind speed* (ms^{-1})
1	IMSU junction	484.33	33.14	29.14	1.54
2	IMSU gate	499.75	32.52	29.29	1.09
3	Rockview rd.	489.75	32.15	30.68	1.08
4	MCC junction	496.16	31.33	31.07	1.05
5	Mbaise rd.	501.75	31.84	30.34	1.07
6	New market plz.	491.10	31.67	30.32	1.29
7	Ekeonuwa plz.	543.25	31.60	30.50	1.05

Table 4 Statistical characteristics of observed CO_2 variance with elevation in January 2016 over the selected stations

Station		A_o	σ_o	Z_o	$\vec{Z}_o$	Υ_o	*RMSE*	*R*
1	IMSU junction	484.33	27.86	–3.02	23.64	1.26	20.39	0.60
2	IMSU gate	499.75	35.47	–2.79	21.79	1.19	27.74	0.10
3	Rockview roundabout	489.75	23.69	–3.78	29.58	0.94	22.34	0.60
4	MCC junction	496.16	24.89	–3.86	30.17	0.71	25.47	0.46
5	Mbaise road roundabout	501.75	31.67	–3.21	25.09	0.43	25.41	0.47
6	New Market Plaza	491.12	33.97	–2.68	20.94	1.68	28.16	0.26
7	Ekeonuwa Plaza	543.25	66.57	–2.15	16.80	1.20	28.02	0.17

A_o = average, σ_o = standard deviation, Z_o = standardised anomalies, $\vec{Z}_o$ = test statistic, Υ_o = skewness, $RMSE$ = root mean square error between observation and stipulated, R = correlation coefficient between observation and stipulated.

Table 5 Statistical characteristics of observed CO_2 over February 2016 for the selected stations

Station		A_o	σ_o	Z_o	$\vec{Z}_o$	Υ_o	*RMSE*	*R*
1	IMSU junction	505.37	55.99	–1.88	14.33	2.58	20.28	0.17
2	IMSU gate	498.39	25.63	–3.83	29.23	1.19	21.88	0.26
3	Rockview roundabout	512.44	37.04	–3.03	23.11	1.32	23.78	0.14
4	MCC junction	513.22	42.82	–2.64	20.13	1.91	26.92	0.004
5	Mbaise road roundabout	527.36	41.74	–3.05	23.23	1.89	22.84	0.42
6	New Market Plaza	499.20	31.77	–3.12	23.77	2.07	26.14	0.10
7	Ekeonuwa Plaza	646.89	156.86	–1.57	11.98	1.49	24.07	0.06

Table 6 Statistical characteristics of observed CO_2 in March 2016 for the selected stations

Station		A_o	σ_o	Z_o	$\vec{Z}_o$	Υ_o	*RMSE*	*R*
1	IMSU junction	540.70	73.34	–1.91	14.98	3.03	14.35	0.06
2	IMSU gate	544.56	56.33	–2.56	20.04	2.25	15.14	0.37
3	Rockview roundabout	574.02	85.93	–2.71	15.81	1.27	14.35	0.26
4	MCC junction	578.05	83.69	–2.12	16.61	1.47	17.32	0.10
5	Mbaise road roundabout	569.37	60.43	–2.80	21.88	1.86	15.53	0.44
6	New Market Plaza	560.62	60.51	–2.65	20.73	1.35	16.19	0.22
7	Ekeonuwa Plaza	756.94	131.59	–2.71	21.18	–0.112	15.25	0.10

Table 7 Statistical characteristics of observed CO_2 in April 2016 for the selected stations

Station		A_o	σ_o	Z_o	$\vec{Z}_o$	Υ_o	*RMSE*	*R*
1	IMSU junction	530.55	61.72	–2.11	16.38	3.99	15.02	0.14
2	IMSU gate	544.50	50.63	–2.85	22.10	2.97	14.40	0.20
3	Rockview roundabout	558.91	50.55	–3.14	24.35	3.51	14.47	0.04
4	MCC junction	574.55	61.76	–2.82	21.89	2.46	13.69	0.14
5	Mbaise road roundabout	585.48	70.20	–2.64	20.46	3.19	14.53	0.14
6	New Market Plaza	573.83	95.70	–1.81	14.06	2.72	15.49	0.01
7	Ekeonuwa Plaza	702.18	118.17	–2.55	19.80	0.23	13.45	0.22

Table 8 Sixteen weeks of statistical characteristics of observed CO_2 variance in Uratta

Station		A_o	σ_o	Z_o	$\vec{Z}_o$	Υ_o	*RMSE*	*R*
1	Toronto junction	523.64	44.15	–2.80	4.03	0.95	52.31	0.17
2	Factory junction	498.28	30.19	–3.25	1.22	0.45	24.03	0.09
3	27 Casmir ibest.	485.71	29.16	–2.93	2.35	1.34	27.06	0.75
4	Factory	491.85	32.07	–2.86	1.48	1.09	33.15	0.83
5	1 Casmir ibest	502.42	34.46	–2.97	2.57	0.57	19.32	0.86
6	Umuchima Uratta	491.28	36.96	–2.46	1.23	1.65	34.99	0.22
7	Mechanic new road	489.14	24.06	–3.70	1.16	1.63	29.13	0.10

A_o = average, σ_o = standard deviation, Z_o = standardised anomalies, $\vec{Z}_o$ = test statistic, Υ_o = skewness, *RMSE* = root mean square error between observation and stipulated, *R* = correlation coefficient between observation and stipulated.

The concentrations of atmospheric pollutants were examined from a variety of sources, including anthropogenic and biogenic sources. A specific method for the calculation and understanding of carbon dioxide concentrations is presented together with examples and applications. In situ measurements over the selected areas offer valuable information. This knowledge provided specific processes and depicts the atmosphere's characteristics and air composition at specific space and time intervals.

2.1 Regional description

Nigeria in West Africa covers an area of 923,768 km^2. In the far South Eastern region of Nigeria is located Owerri, Imo State, defined by a tropical rainforest climate. The annual rainfall ranging from 2032 mm to 1524 mm per year. Nigeria's rainy season begins in March and lasts until the end of July with a peak in June. The second phase of the rainy season has its peak in October. This rainy season is followed by a short dry break in August and lasts for two to three weeks.

The selected locations aimed to compare the non-point source to point source pollutants. Field campaign observations of atmospheric CO_2, wind speed, temperature, and relative humidity were carried out at seven selected sites in Owerri metropolis (Table 1) and were compared with a control measurement at seven selected sites at Uratta Owerri North (Table 2). These meteorological in-situ measurements show diurnal (Morning and Afternoon) January, February, March and April 2016.

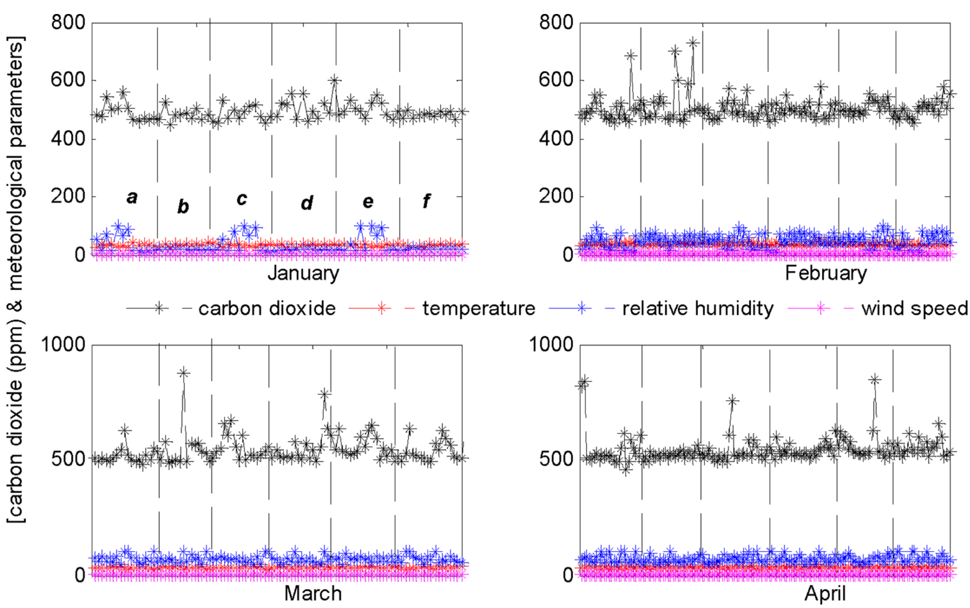
3 Results and discussion

The result highlights the value of greening in residential areas towards mitigating local CO_2 concentrations. Vehicles are the largest contributor to carbon dioxide documented from the presented results (Tables 3–7). A different result was observed in the suburb (Table 8). The possible method of counteracting urban CO_2 concentrations is adopting greening by urban planners. Further research is recommended on quantifying the photosynthetic CO_2 uptake potential of tree species. This will certainly validate species choice for climate change mitigation (Bakwin et al., 1995). Great consequences arise from the unplanned city as detailed in Koerner and Klopatek (2002). Also, Lv et al. (2020) reported using vegetation dynamics to control variations observed in carbon dioxide.

The results in Table 3–8 shows the analysis performed on the seven selected locations. The table examines carbon dioxide, wind speed, temperature, and relative humidity. Average analyses were performed on the dataset, and it was observed that the selected measurement of urban locations has more CO_2 concentrations with minimal wind speed due to clustering settlement. This confirms that wind speed is a major dispersal of anthropogenic gas concentration. As urban areas grow, urban planners need to consider the importance of urban greening to counteract urban CO_2 concentrations.

Figure 1 shows the concentration of CO_2 when compared with atmospheric constituents over the measurement sites. The concentrations were investigated maintaining strong wet (March and April) and dry (January and February) seasons. It is observed that the concentration deeply depends on seasons. Additionally, more concentrations are observed during morning hours over urban areas, indicating action of transportation. It is seen that wind speed are major pollution dispersal, but the distribution of wind speed depicts a lower variation observed in Ekeonuwa plaza. This simply indicated that it wasn't well planned during construction. Table 4 shows the statistical results of the analyses over January for the selected station. The standard deviation, average and test statistic results indicated that there are more concentrations in Ekeonuwa plaza. CO_2 concentration at Ekeonuwa plaza has mean concentration of 543.25 ppm.

Figure 1 Carbon dioxide concentration over urban study areas and interactions with meteorological parameters. (a) IMSU, (b) IMSU gate, (c) Rockview, (d) Mbaise, (e) New market and (f) Ekeonuwa (see online version for colours)



The standard deviation represents the dispersion and concentration over the 31 days at a given time. The day time concentrations show little variability with the coefficient of variation as low as 0.56%. The low temporal variability suggests that the range of atmospheric and meteorological conditions meet throughout the measurements have only a minor influence on the CO_2 concentrations. The carbon dioxide variation over the month of February over Newmarket plaza shows high daily concentrations. From the data, a peak concentration of carbon dioxide occurs from February 5th to 21st. This may be caused by the fact that there is more activity in the market as people buy gifts for the event known as the 'Lovers Day' celebration that usually occurs annually on February 14th. During this activity, occupants of shops make use of generator sets, indicating more concentration of carbon dioxide. This result indicates an increase in carbon dioxide through rise in temperature, indicating no carbon sink. This clearly shows a non-photosynthetic process as already discussed and calls for urban greening.

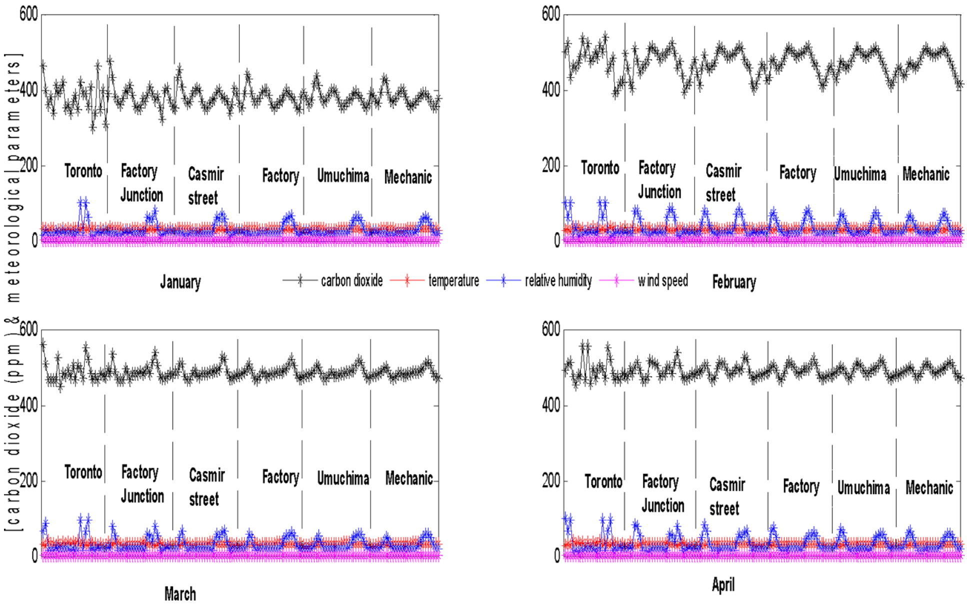
The results depicted in Table 6 shows the statistical analyses of CO_2. The results indicated high precipitation during March 2016 in Owerri. Ekeonuwa plaza has a correlation coefficient of 0.10 over wind speed and indicates a high concentration of carbon loading. In Table 7, Ekeonuwa plaza has a correlation coefficient of 0.22, most mean of 702.18 ppm and a least mean of 530.55 ppm. The result signifies settlement clustering at Ekeonuwa plaza. It is observed that traffic from Douglas road also contributes towards the high records of CO_2 trends and being trapped due to poor air convention. The Douglas road is a popular road mainly for transportation and always busy.

In Table 8, a clear statistical result depicts the characteristics of carbon dioxide concentration over Uratta. From the analyses, a significant result is observed from Tables 3–7. The study location has trees all over the surroundings which enables low retrieval of carbon dioxide despite the traffic at Toronto Junction. The values obtained are significant such that a lower outcome is recorded mostly in all the locations other than that obtained at urban sites. Photosynthesis is the process by which green plants, in the presence of light combine water and carbon dioxide to form carbohydrates. The concentrations of carbon dioxide in 27 Casmir show low values in this region. Unlike the results obtained at the measurement sites in urban environs. This is the fact that human activities like deforestation raise concerns about imbalances in the carbon concentrations and their implications. The drift confirms the month as dry season and more carbon sink due to the presence of green plants.

In Figure 2, there are low concentrations of carbon dioxide which varies with sites. The estimation of concentrations was focused on diverse space of dense green sites and less dense sites. The results of concentrations differ from that of urban sites. The concentration of relative humidity indicated high values showing much moisture in the measurement sites. This clearly indicated low values of temperature making the areas conducive. At the Factory measurement site, there is a still moderate concentration of carbon dioxide in the site. The factory is still under construction, and a generator set being mounted outside.

The 16 weeks diurnal measurements were made at 5m distance apart. From the statistical result, mean carbon dioxide concentrations at the sites are 491.85 ppm. This show the benefits of greening when the result is compared with that of Mechanic new road and at urban sites.

Figure 2 Carbon dioxide concentration over suburban study areas and interactions with meteorological parameters (see online version for colours)



4 Conclusion

In this experimental research, spatial and seasonal variation of CO_2 concentration over Owerri metropolis has been assessed. The surface CO_2 concentration and rate of absorption by green plants were investigated by applying a comprehensive and consecutive field measurement method (FMM). The anthropogenic contributions to regulating the spatiotemporal distribution and seasonal patterns of atmospheric carbon dioxide load over seven selected locations of Owerri metropolis were addressed.

The experimental results of the sensitivity experiment showed that anthropogenic concentration and increase are important in shaping spatial distributions of CO_2 over Owerri metropolis (Oke, 1982). The contribution of anthropogenic CO_2 imprint varies much due to season (Fan and Sailor, 2005; Imasu and Tanabe, 2018). However, some studies has also integrated CO_2 concentrations with wind data and similar results has been obtained (Feng et al., 2016; Hirano et al., 2015). There shows an increasing level of CO_2 during the wet season. The 584.61 ppm CO_2 concentrations are observed in March and April. However, during the dry season, there is a great reduction of 8.33% obtaining 486.50 ppm during January and February CO_2 mean. Since there is a prediction for an increase in industrial production and economic growth in general, the concentrations of air pollutants in the atmosphere will increase. The results obtained suggested that urban cities which represent an area where there are more industrial activities, share towards climate change by burning of fossil fuel (Taha et al., 1991). This is indicated from the implications of the result in Tables 3–7. To mitigate local CO_2 concentrations, particularly in cities, there is a need to adopt a plan to support high photosynthetic rates during the rainy season. Climate variability from the onset has been attributed to atmospheric CO_2 concentrations. This has provided significant information from urban settlement experimental analysis observed in this research work. It is seen from the results of this experimental statistics that cities contribute the most to anthropogenic global climate variability.

4.1. Policy recommendations and economic implications

i Climate variability through emissions of pollutants such as CO_2 from fossil fuel combustion causes air pollution, which urban areas has continued to receive at great interest. There is great need to control these carbon emissions and monitor the environmental and individual processes of Owerri metropolis, because these pollutant emissions have negative impacts on human health and welfare.

ii Since there is a prediction for an increase in industrial production and economic growth in general, the emissions of air pollutants in the atmosphere will increase. Therefore there is an urgent need for the study of air pollution characteristics and dynamics and its transport in the atmosphere at various spatial and time scales.

iii The results of this study highlighted the importance of vegetation in residential areas to mitigate local CO_2 emissions, particularly in cities with a climate that allows evergreen vegetation to maintain high photosynthetic rates over rainy season. As urban areas grow, urban planners need to consider the importance of urban greenspace to counteract urban CO_2 emissions..

iv Planners and policymakers should take into account the potential and actual impacts of climate change on human settlements both at the national and local levels, and ensure the effective implementation of urban development plans and enforcement of rules and regulations. Capacity building and raising awareness among relevant stakeholders about the impact of climate change is also essential.

v Local and municipal governments should create conducive environment for the urban population and industry to have access to clean and affordable energy. Strategies should therefore emphasise local and appropriate technologies, renewable energy, cost-effectiveness, and energy efficiency.

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References

Abam, F.I. and Unachukwu, G.O. (2009) 'Vehicular concentration s and air quality standards in Nigeria', *European Journal of Scientific Research*, Vol. 34, pp.550–560.

Bakwin, P.S., Tans, P.P., Zhao, C.L., Ussler, W. and Quesnell, E. (1995) 'Measurements of carbon dioxide in a very tall tower', *Tellus Series B-Chemical & Physical Meteorology*, Vol. 47, pp.535–549.

Barnola, J-M., Raynaud, D., Lorius, C. and Barkov, N.I. (2003) 'Historical CO_2 record from the Vostok ice core', *Trends: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., USA, pp.408–413.

Brazel, A., Selover, N., Vose, R. and Heisler, G. (2000) 'The tale of two climates–Baltimore and Phoenix urban LTER sites', *Climate Research*, Vol. 15, pp.123–135.

Brown, S.J., Sathaye, M., Cannell, P., Kauppi, P., Burschel, A., Grainger, J., Heuveldop, R., Leemans, P., Moura Costa, M., Pinard, S., Nilsson, W., Schopfhauser, R., Sedjo, N., Singh, M., Trexler, J., van Minnen, S. and Weyers, C. (1996) 'Management of forests for mitigation of greenhouse gas concentrations', in Watson, R.T., Zinyowera, M.C., Moss, R.H. and Dokken, D.J. (Eds.): *IPCC Climate Change 1995 – Impacts, Adaptations, and Mitigation of Climate Change: Scientific-Technical Analyses, Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, New York, 773-797.

Bulkeley, H. (2013) *Cities and Climate Change*, New York, Routledge, Vol. 5, pp.122–124.

Ciais, P., Paris, J., Marland, G., Peylin, P., Piao, S., Levin, I., Pregger, T., Scholz, Y., Friedrich, R., Houwelling, S. and Schulze, D. (2010) 'The European carbon balance revisited. Part 1: fossil fuel concentrations', *Global Change Biology*, Vol. 16, pp.1395–1408.

Conway, T.J., Tans, P.P., Waterman, L.S. and Thoning, K.W. (1994) 'Evidence for interannual variability of the carbon cycle from the national oceanic and atmospheric administration/climate monitoring and diagnostics laboratory global air sampling network', *Journal of Geophysical Research-Atmospheres*, Vol. 99, pp.22831–22855.

Edmonds, J.A., Wise, M.A., Sands, R.D., Brown, R.A. and Kheshgi, H.S. (1996) *Agriculture, land use, and commercial biomass energy: a preliminary integrated analysis of the potential role of biomass energy for reducing future greenhouse related concentrations. PNNL 111555*, Pacific Northwest National Laboratory, Washington, DC, USA.

Fan, H. and Sailor, D.J. (2005) 'Modeling the impacts of anthropogenic heating on the urban climate of Philadelphia: a comparison of implementations in two PBL schemes', *Atmospheric Environment*, Vol. 39, pp.73–84.

Feng, S., Lauvaux, T., Newman, S., Rao, P., Ahmadov, R., Deng, A., Diaz-Isaac, L.I., Duren, R.M., Fischer, M.L., Gerbig, C., Gurney, K.R., Huang, J., Jeong, S., Li, Z., Miller, C.E., Keeffe, R., Patarasuk, R., Sander, S.P., Song, Y., WongShow, K.W. and Yung, Y.L. (2016) 'Los Angeles megacity: a high-resolution land- atmosphere modelling system for urban CO_2 emissions', *Atmos. Chem. Phys.*, Vol. 16, pp.9019–9045.

Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Nganga, J., Prinn, R., Raga, G., Schulz, M. and Van Dorland, R. (2007) 'Changes in atmospheric constituents and in radiative forcing', in Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L. (Eds.): *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Chapter 2, Cambridge University Press, Cambridge, UK and New York, NY, USA.

Hirano, T., Sugawara, H., Murayama, S. and Kondo, H. (2015) 'Diurnal variation of CO_2 flux in an urban area of Tokyo', *Sola 2015*, Vol. 11, pp.100–103.

Imasu, R. and Tanabe, Y. (2018) 'Diurnal and seasonal variations of carbon dioxide (CO_2) concentration in urban, suburban, and rural areas around Tokyo', *Atmosphere*, Vol. 9, p.367.

IPCC (1996) 'Climate change: impacts, adaptations, and mitigation of climate change: scientific-technical analyses', in Watson, R.T., Zinyowera, M.C., Moss, R.H. and Dokken, D.J. (Eds.): *Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, New York, pp.663–745.

IPCC (2001) *Climate change: The Scientific Basis*, New York, USA, Cambridge University Press, Cambridge, New York, p.892.

Ishitani, H., Johansson, T.B. and Al-Khouli, S. (1996) 'Energy supply mitigation options', in Watson, R.T., Zinyowera, M.C. and Moss, R.H. (Eds.): *Climate Change 1995. Impacts, Adaptations*, *and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, New York, pp.87–648.

Keeling, C.D. and Whorf, T.P. (2005) Atmospheric CO_2 records from sites in the SIO air sampling network', *Trends: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tenn., USA, pp.83–113.

Koerner, B. and Klopatek, J. (2002) 'Anthropogenic and natural CO_2 concentration sources in an arid urban environment', *Environmental Pollution*, Vol. 116, pp.S45–S51.

Kort, E.A., Frankenberg, C., Miller, C.E. and Oda, T. (2012) 'Space-based observations of megacity 1 carbon dioxide', *Geophysical Research Letters*, Vol. 39, pp.1–5.

Leemans, R., van Amstel, C., Battjes, E., Kreileman, A. and Toet, S. (1996) 'The land cover and carbon cycle consequences of large-scale utilization of biomass as an energy source', *Global Environmental Change-Human and Policy Dimensions*, Vol. 6, pp.335–357.

Lv, Z., Shi, Y., Zang, S. and Sun, L. (2020) 'Spatial and temporal variations of atmospheric CO_2 concentration in China and its influencing factors', *Atmosphere*, Vol. 11, p.231.

Metya, A., Datye, A., Chakraborty, S., Tiwari, Y.K., Sarma, D., Bora, A. and Gogoi, N. (2021) 'Diurnal and seasonal variability of CO_2 and CH4 concentration in a semi-urban environment of western India', *Scientific Reports*, Vol. 11, p.2931.

Ndoke, P.N. and Jimoh, O.D. (2007) *Impact of Traffic Concentration on Air Quality in a Developing City of Nigeria*, Department of Civil engineering, Federal University of Technology, Minna, Niger State.enginpro.blogspot.com/2007/07/impact-of-traffic-concentration-on-air

Ndoke, P.N., Akpan, U.G. and Kato, M.E. (2006) 'Contributions of vehicular traffic to carbon dioxide concentration s in Kaduna and Abuja, Northern Nigeria', *Leonardo Electronic Journal of Practices and Technologies* (online).

Neftel, A., Friedli, H., Moor, E., Lötscher, H., Oeschger, H., Siegenthaler, U. and Stauffer, B. (1994) 'Historical CO_2 record from the Siple Station ice core', *Trends: A Compendium of Data on Global Change*, Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, US Department of Energy, Oak Ridge, Tenn., USA, pp.11–26.

Offerle, B., Grimmond, C.S.B., Fortuniak, K. and Pawlak, W. (2006) 'Intraurban differences of surface energy concentration in a central European city', *Journal of Applied Meteorology and Climatology*, Vol. 45, pp.125–136.

Oke, T.R. and Maxwell, G.B. (1975) 'Urban heat island dynamics in Montreal and Vancouver', *Atmospheric Environment*, Vol. 9, pp.191–200.

Oke, T.R. (1982) 'The energetic basis of the urban heat island', *Quarterly Journal of the Royal Meteorological Society*, Vol. 108, pp.1–24.

Oke, T.R. (1995) *Boundary Layer Climates*, Routledge, UK, p.435.

Osuntogun, B.A. and Koku, C.A. (2007) 'Environmental impacts of urban road transportation in the Southwestern states of Nigeria', *Journal of Applied Sciences*, Vol. 7, p.2358.

Pincetl, S., Gillespie, T., Pataki, D.E., Saatchi, S. and Saphores, J-D. (2012) 'Urban tree planting programs, function or fashion? Los Angeles and urban tree planting campaigns', *Geophysics Journal*, doi:10.1007/s10708-012-9446-x.

Rosenzweig, C., Solecki, W., Hammer, S.A. and Mehrotra, S. (2010) 'Cities lead the way in climate-change action', *Nature*, Vol. 467, pp.909–911.

Taha, H., Akbari, H. and Rosenfeld, A. (1991) 'Heat Island and Oasis effects of vegetative canopies: micrometeorological field measurements', *Theoretical and Applied Climatology*, Vol. 44, pp.123–138.

Trenberth, K.E., Jones, P.D., Ambenje, P., Bojariu, R., Easterling, D., Klein Tank, A., Parker, D., Rahimzadeh, F., Renwick, J.A., Rusticucci, M., Soden, B. and Zhai, P. (2007) 'Observations: surface and atmospheric climate change', in Solomon, S., Qin, D., Manning, M., Chen, M.Z., Marquis, K.B., Averyt, M., Tignor, A. and Miller, H.L. (eds.): *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, UK and New York, NY, USA, pp.237–336.

Velasco, E., Perrusquia, R., Jiménez, E., Hernández, F., Camacho, P., Rodríguez, S., Retama, A. and Molina, L.T. (2014) 'Sources and sinks of carbon dioxide in a neighborhood of Mexico City', *Atmospheric Environment*, Vol. 97, pp.226–238.

Weissert, L.F., Salmond, J.A. and Schwendenmann, L. (2014) 'A review of the current progress in quantifying the potential of urban forests to mitigate urban CO_2 concentrations', *Urban Climate*, Vol. 8, pp.100–125.