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Spatiotemporal distribution model of air quality parameters within Federal University of Technology Owerri (FUTO)

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ABSTRACT

Introduction: Air pollution in cosmopolitan cities is increasingly becoming unprecedented with attendant effects on human and biophysical attributes.

Materials and methods: The study was carried out at Federal University of Technology (FUTO) and environs in the southeastern Nigeria. Some ambient air quality parameters (CO, CO_2, NO_2, CH_4 and noise) were sampled and measured at seven unique locations (OR, ER, FR, EJ, IM, FM and FJ) with multi sampler devices, using air differential technique during the morning, midday and evening periods.

Results: The average pollutant results show increased concentrations at the different locations when compared to Occupational Safety and Health Administration (OSHA) than Federal Ministry of Environment (FMEnv) thresholds (FMEnv>CO_2<OSHA; FMEnv>NO_2<OSHA; FMEnv>CH4<OSHA). However, concentrations of CO and Noise in FR and FJ were relatively higher than concentrations observed in other locations (CO: FR [6.4 mg/m^3] and FJ [4.2 mg/m^3]; Noise: FR [96.8 dB] and FJ [95.7 mg/m^3]) respectively.

Conclusion: The significant increase could be attributed to continuous vehicular emissions and presence of make-shift activities in these locations. However, predictive model suggests that given the meteorological conditions and perceived anthropogenic activities over time, OSHA threshold could be evidently compromised.

Introduction

Over the decades, industrialization, urbanization and increased vehicular traffic have become a recurring decimal and precursor to air pollution menace. This anomaly is usually propagated from point and non-point sources with significant influence on environmental conditions, especially in urban areas. Air pollution is a phenomenon that occurs when a mixture of particles and gases reach concentrations that are harmful to the biosphere [1]. Such harmful particles and gases in the air can harm humans and

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the environment [2]. Hence, the release of air pollutants above certain regulatory threshold presents an environmental problem of significant proportion and induced multiplier threat of changing dynamics both locally and globally [3]. Most of these air pollutants are airborne and hence can be dispersed over very long distances thereby having a widespread effect on ecosystems, including human health [4]. Studies have attributed pollutants dispersed from anthropogenic sources to induce myriad health challenges like infertility, cancer, respiratory diseases, pulmonary and cardiovascular diseases, and in some cases these health challenges have led to many deaths [5, 6]. About 1.8 million deaths worldwide between the years 2000 and 2017 have been linked to pollution-related health issues [7]. Besides, pollutants can reduce visibility and contribute to acid precipitation, also known as acid rain. Stationary combustion processes and road traffic streams have also been linked to noise pollution. A study in New York city established a relationship between noise level and the amount of traffic-emitted air pollutants as synergetic and a major source of environmental pollution [8]. Other impacts of air pollution have been linked to climate change, which in turn has become an issue of global discuss in recent decades [9-11]. The criticality of this anomaly is being considered a topical issue in the just concluded United Nations (UN) climate change conference of Parties 26th (COP26) which held in Glasgow, Scotland. The pertinent issue of discuss was anchored on the reduction of air-polluting emissions of Greenhouse Gases (GHGs), which is proven to play a key role in global temperature rise (1.1^{o}C), and the need to push efforts to limiting it to a threshold of 1.5^{o}C as impacts are already being felt in every region of the world [12].

In Nigeria, stationary combustion processes and other industrial production processes have been a concern for some years now and the aggravated concentrations of criteria pollutants pose constant threat to human health and environment. At Federal University of Technology (FUTO), ambient air pollution traced to gas flaring has been found to be the cause of corrosion of corrugated galvanized steel roofing sheets as well as other associated impacts [13]. In a recent study conducted within the FUTO campus, it was revealed that domestic solid waste materials generated in the institution were managed using unsustainable strategies like burning; open dumping and burying, which also contribute to the release of gaseous pollutants [14]. There is also an influx of automobiles and make-shift electricity-generating sets used to power offices, laboratories, workshops and business centers, since public power supply is rarely available or erratic at best. These activities/practices no doubt release noxious gases and generate noise, and hence contribute to air pollution at FUTO. This anomaly is not perceived as a welcome development as these pollutants potentially affect the psychological and wellbeing of students who ordinarily should expect a clean and serene environment for academic learning. In order to manage this pollution quagmire, it is expected that a functional telemetry station should be strategic to monitor and measure the trend of pollutants emission for the purpose of implementing control strategies. However, these studies have scanty data to leverage on and to validate physicochemical models essential for air pollution measurements.

Prediction modeling has proven to be effective in understanding the severity of pollutants as well as obtaining the spatial and temporal variations of pollutant concentrations [15]. As such, the primary objective of this study is to investigate the variability of concentration levels of pollutants associated with activities at FUTO and its environs. Some ambient air quality parameters (selected criteria pollutants and GHGs, as well as environmental noise) will be monitored, followed by their spatiotemporal distribution and modeling.

Fig. 1. Google earth satellite imagery showing the study area and sampling sites/locations for in-situ monitoring

Materials and methods

Description of sampling location

The Federal University of Technology, Owerri (FUTO) is located 25 km south of Owerri, southeastern Nigeria, with an area of about 4,048 ha [16]. FUTO is located between longitude 6059^0E and 6058^0E and latitude 5023^0N and 5024^0N, lying on altitude of 55 m above sea level within the southeastern humid tropic, and is characterized by heavy rainfall and a mean monthly temperature of 23.8 to 29^oC [13]. Currently, it has a student population of about 25,000 and staff strength of around 3,000.

Field sampling instruments

Aeroqual series 500 hand-held air quality and gas monitor with interchangeable sensor heads; used for ambient air quality monitoring. Sensor heads used include: NO_2, CO, CH_4 and CO_2.

The series 500 air quality and gas sensor enables accurate real-time surveying of air pollutants species, all in an ultra-portable hand-held monitor. The monitoring device can be used for: wide area air quality surveys; checking pollution hotspots; personal exposure monitoring; and short term fixed monitoring networks. Sensors are housed within an interchangeable cartridge (head) that is attached to the monitor base. The sensor head can be removed and replaced in seconds, allowing users to measure as many gases as possible on one device. The sensor heads features active fan sampling which ensures a representative sample is taken and therefore increases measurement accuracy.

etrexGarmin GPS device was used for the determination of coordinates of the selected sampling locations. Gas monitoring and evaluation/sampling is a spatial phenomenon, thus it is very essential to determine the accurate geographical coordinates for the sampling points using a Global Positioning System (GPS) [17, 18].

All the devices used were calibrated before taken to the sampling locations. This is to ensure they were in good working condition and would produce results of very high level of accuracy.

Safety helmet and high visibility jacket; used for precautionary safety purposes owing to the fact that the field work was going to be on busy locations, with high human and vehicular movements and other activities.

Sampling design

For the purpose of this study, the randomized method of sampling was adopted with the average values for respective parameter readings recorded at each sampling point using calibrated sampling devices. Seven sampling locations were chosen and monitoring was carried out on the following parameters: Carbon monoxide (CO), Carbon dioxide (CO_2), Nitrogen dioxide (NO_2), methane (CH_4) and noise during the morning hours, the afternoon hours and evening hours. There were a total of 105 experimental runs (each pollutant species conducted in triplicates) for the five air pollution indices in seven (7) locations to be monitored. The monitoring was conducted in one hour triplicates (i.e. repeated three times; mornings, afternoon and evening).

Sampling locations

A total of seven sampling points within the FUTO community and its environs were selected for the study. The locations selected were within the FUTO campus and its three (3) entry points, and their selection was based on high work/business activities, residential clusters (on-campus hostels and other residential buildings) and traffic considerations. The selected locations were code-named Old Registry (OR), Eziobodo Road (ER), FUTO Roundabout (FR), Eismann Junction (EJ), Ihiagwa Market (IM), FUTO Market (FM) and FUTO Junction (FJ). The seven sampling points were collected to reflect the scope and clusters of anthropogenic activities dominant in the area under investigation. The reason for this is because physical presence of this nature promotes the development of local circulation that impact on the wind regime of the atmospheric environment [19, 20]. Hence, measurements were sampled in key locations within sources and direction of local prevailing meteorological conditions. The main purpose of the experimental study was to evaluate the pollution load emanating from the clusters and how they impact on the environment, as well as public health and safety.

Air quality measurement

A GPS device etrexGarmin was raised for some minutes above the head (over 2 m height) using the hand in order to receive the co-ordinates of each of the locations from GNSS satellite and the received co-ordinates, and the longitudinal, latitude and altitude were recorded. To determine the concentration of each of the gaseous air pollutants monitored, gas sensors of the respective gaseous pollutants monitored were attached to an Aeroqual Series 500 gas monitor. The assemblage was hand-held over the head to about 2 m height to get the ambient concentration of each polluting gas covered in the study. Each gas was monitored for the three periods outlined in field study section and the concentration values recorded to calculate the average concentration value. A digital noise level Extech 407730 was hand-held for up to 2 m height at each of the sampling points for the three sampling periods to measure the respective noise levels, after which the values were recorded in order to get an average value.

Results and discussion

In order to demonstrate how pollution associated with traffic and domestic heating affects the urban environment, the selected pollutants results obtained and displayed in Figs. 2a-e are critically discussed. The air sampling operation indicated varying air quality parameters for the various sampling points as indicated in Fig. 2a-e, while Table 1 shows the overall air quality parameters in relation to conventional and national statutory limits.

Evolution of carbon dioxide (CO_2) in the study area

The results from in-situ assessment of air quality around the various sampling locations indicated that values of CO_2 were below the statutory threshold for Occupational Health and Safety Administration (OSHA), whereas the values were extremely higher when compared to limits stipulated for Federal Ministry of Environment, Nigeria (FMEnv) (Fig. 2a). The detected values for the respective locations are such that OR, EJ, FR, ER, IM and FJ all had relatively close values of 1182, 1237, 1139, 1164, 1198, 1140 and 1201 (mg/m^3) respectively. However, slight increase in the magnitude of tens was significantly observed within the respective locations under review. The reasons for the slight variations may be attributable to the peculiarities observed both in demography, naturally or artificially enhanced-green spaces and other anthropogenic related activities.

Evolution of methane (CH_4) in study area

The air quality parameter of CH_4 showed a wide range (by factor 10) of concentration values for each of the locations as depicted in Fig. 2b. The concentration values observed for these locations are arbitrarily heterogeneous with highest concentration being observed at OR (384 mg/m^3), followed by EJ (247 mg/m^3), with the least observed at FR (205 mg/m^3). However, ER (236 mg/m^3) and FJ (238 mg/m^3) did not differ significantly in their concentrations. These values were also observed to be higher than FMEnv but lower than OSHA as in the case of pollution episode demonstrated by CO_2.

Evolution of Nitrogen dioxide (NO_2) in study area

The concentration level for NO_2 across the sampling locations shows that the measured values were all below the threshold limits set for OSHA and FMEnv (Fig. 2c). Although, these values are relatively heterogeneous for the different locations with FM (0.18 mg/m^3) having the highest concentration. This pollution trend is practically dissimilar when compared to the other pollutants investigated. The observed dissimilarity may be attributed to the pollutant behavioural tendencies observed during changes in meteorological conditions.

Evolution of Carbon monoxide (CO) in the study area

The results of the air quality parameters around FR and FJ showed a wide range of values which depend on the typical vehicular density and makeshift power-generating systems observed at each location. The CO levels at FR and FJ measured at 6.4 mg/m^3 and 4.2 mg/m^3 respectively. These values were significantly higher than the threshold limit set for FMEnv but lower than that stipulated by OSHA. However, the other locations (OR, EJ, ER, IM and FM) had their values (0.8, 1.4, 0.9, 0.7 and 2.1 respectively in mg/m^3) below the FMEnv and OSHA limits (Fig. 2d). The peculiarities associated with FR and FJ may be partly responsible for the substantial increase in the pollution load observed.

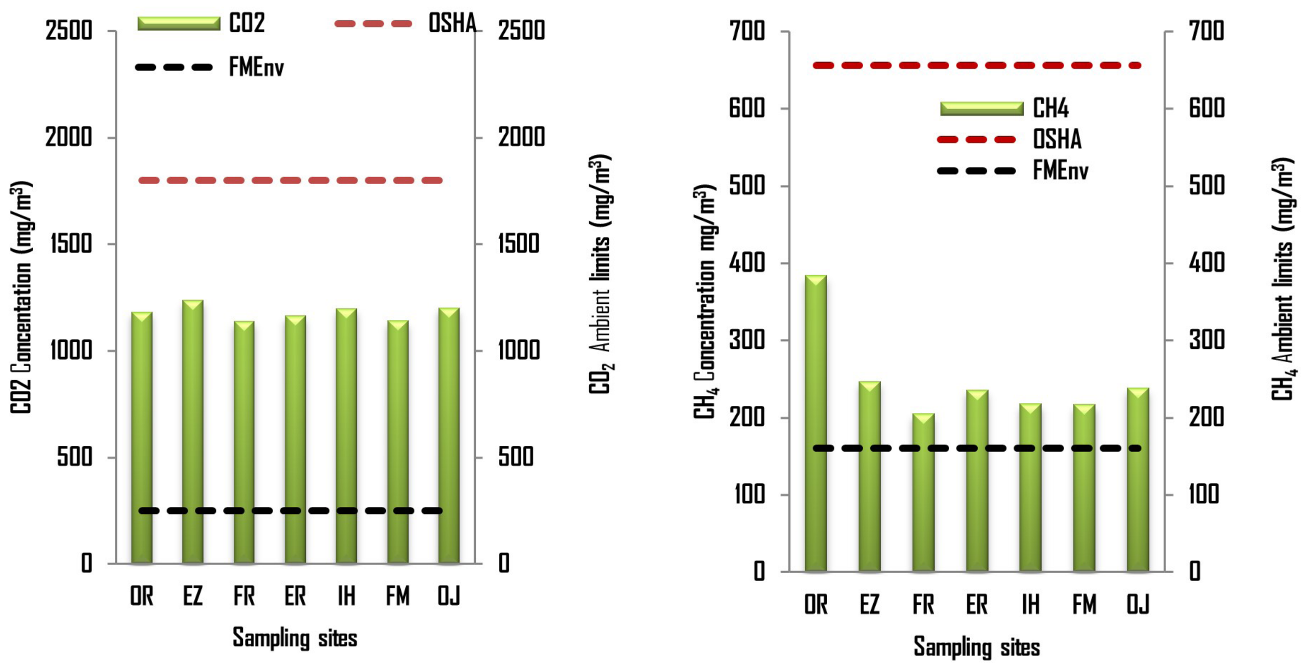
Noise pollution exposure in study area

The level of noise pollution exposure for the different sampling locations as observed in Fig. 2e did not differ significantly following the trend of exposure in the order of increasing concentration FM>ER>IM≥EZ>OR>FJ>FR

However, values at other locations were slightly higher than regulatory limits for FMEnv and slightly below statutory limit for OSHA except for FR (96.8 [dB]) and FJ (95.7 [dB]) that were higher than OSHA limit. The abnormal noise exposure at the various locations could be attributed to the university's buildings being in proximity to one another or to clustering of the residential/business properties in the university's environs.

Table 1. Results of air pollutants monitored across the seven (7) sampling locations

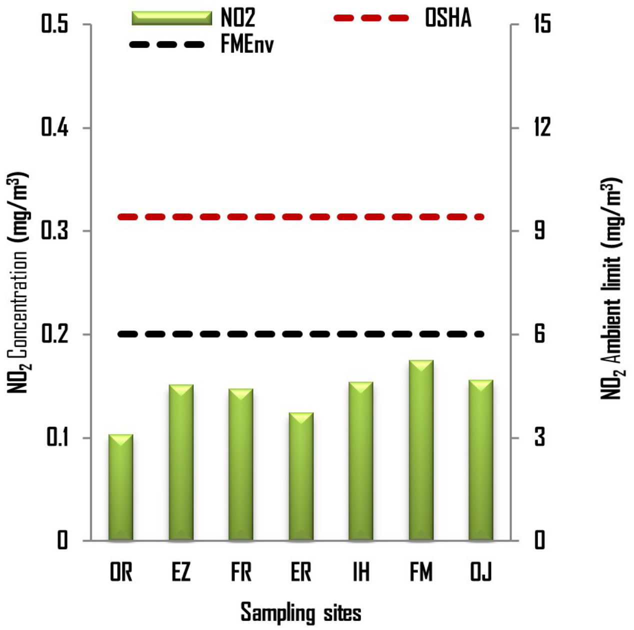
Pollutant / Location	CO_2 (mg/m^3)			CO (mg/m^3)			NO_2 (mg/m^3)			CH_4 (mg/m^3)			Noise (dB)		
	MV	OS	FM	MV	OS	FM	MV	OS	FM	MV	OS	FM	MV	OS	FM
OR	1182	1800	250	0.8	57.3	10	0.10			384	656	160	90	90	85
EJ	1237	1800	250	1.4	57.3	10	0.15			247	656	160	89.5	90	85
FR	139	1800	250	6.4	57.3	10	0.15			205	656	160	96.8	90	85
ER	1164	1800	250	0.9	57.3	10	0.12			236	656	160	88.7	90	85
IH	1198	1800	250	0.7	57.3	10	0.15			218	656	160	89	90	85
FM	1140	1800	250	2.1	57.3	10	0.18			217	656	160	86.6	90	85
FJ	1201	1800	250	4.2	57.3	10	0.16			238	656	160	95.7	90	85



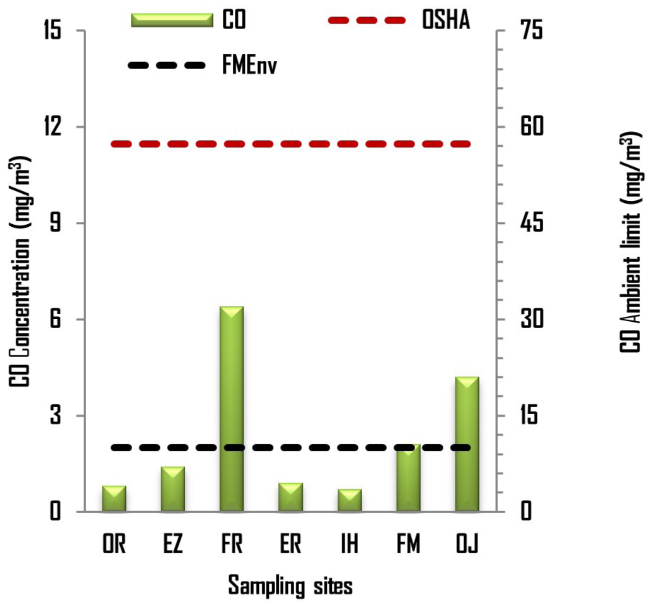
a) CO_2 comparison chart

b) CH_4 comparison chart

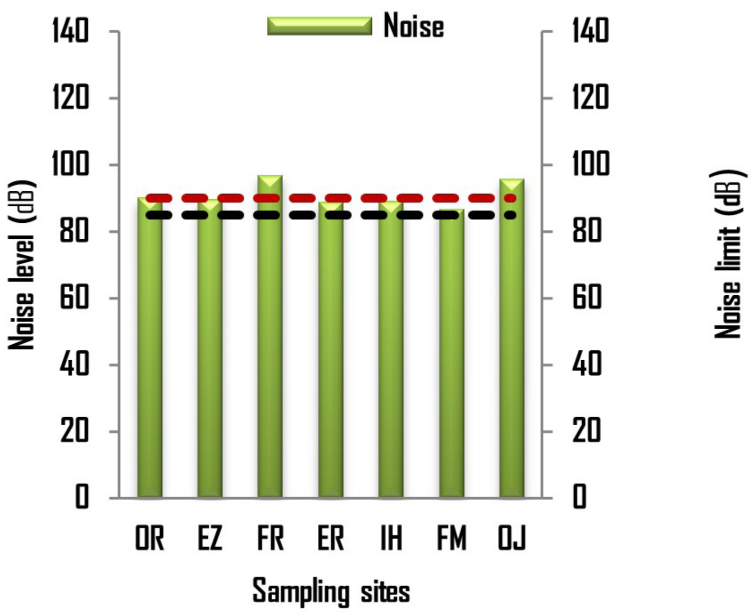
Fig. 2. Comparison chart of CO_2; CH_4; NO_2; CO and noise level comparison chart



c) NO_2 comparison chart



d) CO comparison chart



e) Noise level comparison chart

Fig. 2. Comparison chart of CO_2; CH_4; NO_2; CO and noise level comparison chart (continued)

Fig. 2a-d show the evolution of selected pollutants emission at various sampling sites measured in relation to FMEnv and OSHA standards.

Fig. 2e shows evolution of noise measured across the various sampling sites measured in relation to FMEnv and OSHA standards.

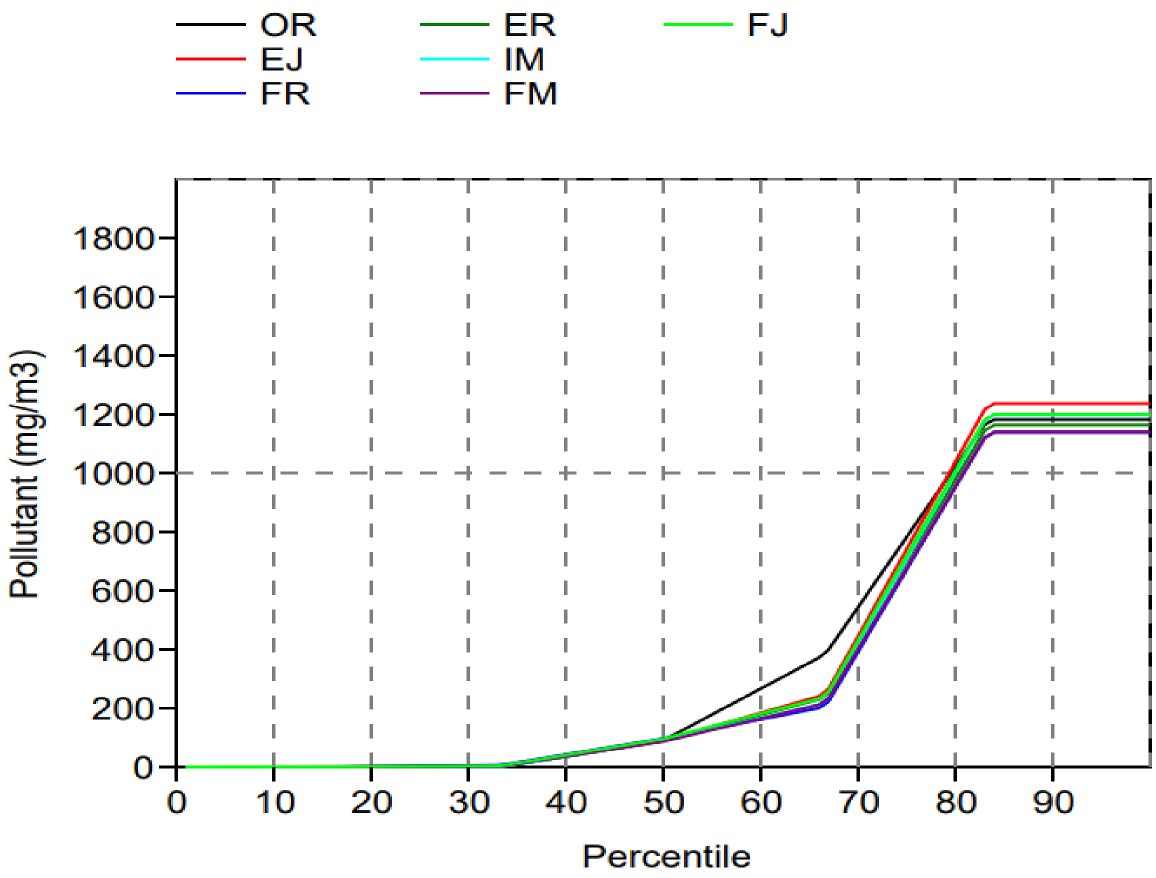


Fig. 3. A model plot of cumulative pollutant dispersion across the investigated locations over a period of time

According to Fig. 3, the cumulative frequency curve was highest at 84th percentile before it progressively flattened out. This is because significant results of the study reported medium or high concentration levels due to air pollution in the various locations (Fig. 2a-e) with slight exception observed in locations sampled for CO (Fig. 2d). Our results suggest a linear relationship between CH_4 and CO_2 pollution exposure. This implies that more methane emission results to more air pollution plume engendered by CO_2 production. However, CO which is also a precursor and a by-product of incomplete combustion of CH_4 emission was significantly low in this study. The presence and influence of socio-demographic and vegetal characteristics also played significant roles in the pattern and distribution of pollutants as observed in densely clustered locations, especially locations (FJ, FR & OR) in close proximity to traffic, business clusters and frequency of vehicles plying the locations, as should be expected [21-25]. However, in comparison with regulatory limits, most of the air pollution concentrations reported in our study (about 95%)were below OSHA threshold limit values, except for those reported for in FJ and FR locations (about 5%) which were slightly higher.

Prevalence of pollution load reported in this period was at variance with the mean value of similar pollutants concentration reported by a previous study conducted in the FUTO campus [13]. This may be due to changes in the roofing sheets currently used for the institution's buildings, changes in the type of waste now generated in the institution as well as the institution's expansion. However, a recent assessment of vehicular emissions conducted at major markets within nearby Owerri municipal environment (about 25 km from study area) shows increased concentrations in the three pollutants “CO (387), CO_2 (57.3) and NO_2(1237) mg/m^3” measured when compared to the present study [26]. The increased variation in concentration could be largely due to higher density in vehicular traffic and other perceived human activities common in market places.

Furthermore, we found that noise exposure was relatively significant and extremely abnormal, exceeding the conventional threshold (90dB) in virtually all the locations investigated, especially areas that are in proximity to clusters and volume of traffic (FR & FJ). This phenomenon suggests that distances away from certain clusters and/or the amount of green space available could help ameliorate excessive exposures observed during peak periods. Thus, estimation of individual measurement of noise exposure will be very useful in future studies that allow the characterization and considerations of complex interaction that are commonly envisaged between noise, annoyance and health. Our findings suggest that noise is a function of a pollutant as well as a function of subjective factors which may vary across population regimes. The combined effect of exposure to air pollution and noise can result to unimaginable health consequences, both directly from exposure and indirectly from stress and psychological distress, in addition to preterm delivery and deficient prenatal development of the respiratory or neuro-endocrine system [27-30]. These forms of complications can pose significant public health concerns if allowed to progressively accumulate over time, thus, the need to implement effective environmental policies that will drive technical Risk Assessment (RA) and Control of Substances Hazardous to Health (COSHH). This work also leveraged on the use of model plot to predict the cumulative impact of pollutants across the investigated locations over time as shown in Fig. 3. The profile plume exceeded the 50th percentile score which is an indication that given the prevailing meteorological conditions and perceived increase in anthropogenic activities, the potential for pollutant plume will be expected to increase unimaginably beyond the threshold of regulatory limits over time. This information is in line with the assertion that a predictive model can be designed to use seasonal climatological and anthropogenic attributes to explain how such attributes can influence background concentration at the sampling locations over time [31].

The escalation of noise within the University environment can pose a significant effect on the general wellbeing and environmental sensitivity of students as they are continuously exposed to cumulative environmental stressors that could potentially trigger annoyance and impact on living conditions [32-34].

A major limitation of our study is that we did not consider the calculation of Hazard Quotient (HQ) to enable us understand the angle of safety requirement as applicable to some of these air pollutants. However, most of the selected pollutants exceeded the FMEnv threshold limits in the various locations investigated, and as such could be used for precautionary advocacy. Hence, it can function as a guide and also promote caution when evidence is absent, uncertain or ambiguous regarding possible harm to humans or the environment.

Conclusion

Assessment of air pollution around the seven sampling locations within FUTO and environs showed that vehicular and make-shift activities are the major sources that are responsible for significant emission of CO_2, CO, NO_2, CH_4 and psycho-nuisance variable called noise. Amongst the investigated locations, FR and FJ had the highest average concentrations of pollutants which are higher than both FMEnv and OSHA regulatory limits. The predicted model plot suggests that the pollution plume can become unimaginably evident over time owing to the meteorological conditions and perceived anthropogenic activities frequently observed within the cosmopolitan milieu. Consequently, a more robust model that can generate flows, turbulence, plume transport and dispersion of pollutants within the urban setting is desired for better prediction and to provide more precise cause-effect results associated with pollutant burden that can accumulate over time. However, the present study will serve as a baseline resource for further investigations.

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Competing interests

The authors declare that there are no conflicts of interest.

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Ethical considerations

The authors declare that ethical issues such as plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc, have been completely avoided.

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