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Concentrations and health risks of particulate matter (PM2.5) and associated elements in the ambient air of Lagos, Southwestern Nigeria

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Abstract

Particulate matter (PM) exposure from ambient air has been implicated in several diseases, which necessitates periodic air monitoring in every dwelling place, particularly urban centers, to detect overexposure early. The main objective of this study was to determine the levels of PM2.5 and associated elements, namely carbon monoxide (CO), ozone (O_3), and nitrogen dioxide (NO_2) in Lagos, Nigeria. An Aerosol Mass Monitor was employed to quantify the concentrations of PM2.5, NO_2, CO, and O_3 at ten selected locations in the city, namely, Allen Avenue, Kolington, Isheri, Badagry, Opebi, Eti-Osa, Ajeniya, Awolowo, Orile, and Ajegunle. The values obtained were thereafter used to estimate the hazard quotient (*HQ*) of the average hourly dose (*AHD*) and average daily dose (*ADD*) exposures to the particles. The results revealed that PM2.5 levels in all the locations were above the 15µg/m^3 permissible level recommended by the World Health Organization (WHO), except in Badagry (5.36µg/m^3). NO_2 was above the 25µg/m^3 permissible level in all locations except in Badagry (6.11µg/m^3) and Ajeniya (0.00µg/m^3). Meanwhile, in all the locations, CO was above the tolerable level (i.e., >7µg/m^3) while O_3 was within permissible levels (i.e., <100µg/m^3). The *HQ* of the *AHD* of the pollutants was less than the threshold of 1, but the *HQ* of the *ADD* was greater than 1 in many locations. It can be inferred from the results that daily exposure to PM2.5, NO_2, and CO in the city can cause serious health consequences for residents. Agencies in charge of health and the environment in the city are advised to formulate policies towards pollution reduction.

Keywords: Carbon monoxide (CO), Hazard quotient (*HQ*), Nitrogen dioxide (NO_2), Particulate matter (PM2.5).

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INTRODUCTION

Particulate matter (PM), otherwise known as particle pollution (PP), is described as a mixture of liquid droplets and solid particles suspended in the air (USEPA, 2022). Some of the particles are released from a source, such as unpaved roads, construction sites, fires, fields, and biological material such as spores (Opara *et al*., 2021; USEPA, 2022). Some of the particles are also formed from complex chemical reactions in the atmosphere, particularly greenhouse gases such as nitrogen oxides and sulfur dioxide emitted from industries, vehicles, and power plants (USEPA, 2022). In addition, PM can absorb and adsorb a variety of harmful compounds including volatile organic compounds and polycyclic aromatic hydrocarbons (Yu *et al*., 2011). PMs are of various sizes and shapes, of which those with 2.5–10 micrometers in diameter are considered coarse and referred to as PM10, while those with a diameter of 0.1–2.5 micrometers, defined as fine particles, are designated as PM2.5 (Crinnion, 2017). There are also ultrafine particles (UFP), otherwise known as nanoparticles, which are less than 0.1 micrometers in diameter (Crinnion, 2017).

Only electron microscopes can be used to visualize PM2.5 and is produced mainly from combustive activities such as residential wood burning, industrial processes, power generation, and vehicular emissions (Cesaroni *et al.,* 2014; Samoli *et al.,* 2018). Although the compositions of various PMs differ worldwide, they all increase morbidity and mortality (Adams *et al*., 2015). However, PM2.5 is more harmful to health than PM10 (Lee *et al*., 2021). This is because while PM10 occupies the upper respiratory system, PM2.5 goes further to reach the alveolar part of the lower respiratory system (Khan *et al*., 2021). PM1, on the other hand, crosses the blood–air barrier of the lungs and enters the blood (Khan *et al*., 2021). PM exposure has been linked to lung cancer, chronic obstructive pulmonary disease, cardiovascular disease, autoimmune diseases, neoplastic diseases, and the worsening of a variety of other diseases (Crinnion, 2017; Samoli *et al*., 2018). In the upper atmosphere, PM can modify Earth radiation and cloud formation, resulting in climate change (Arideep and Madhoolik, 2017; Alani *et al.,* 2019).

Urban centers with high populations are the most affected by PM because of multiple sources of combustion such as vehicles, barbeques, and smoking, among others, as well as industrial activity (Crinnion, 2017). Thus, it is imperative to constantly monitor the atmospheric levels of PM in every urban center so as to safeguard human health and reduce health burdens. Lagos in Nigeria is one of the most populous cities in the world, with high levels of anthropogenic activity which can potentially result in high levels of PM exposure and health effects. According to Alani *et al*. (2019), PM2.5 exposure in the city caused about 11,200 premature deaths and incurred about US$2.1 billion economic burden in 2018. Moreover, Robert *et al*. (2018) hinted that air pollution in Nigeria and other African countries has become a huge problem owing to the increased industrial activities, construction, and the increased quantity of emission sources such as vehicle emissions and gas flaring, among others. However, despite these studies and a few other studies conducted in Lagos, the dangers posed by PM exposure have not been given the needed priority and so more studies are necessary to raise public awareness. Moreover, the majority of the few studies conducted on PM2.5 exposure in Lagos did not evaluate its possible health risks, which could have aroused people's interest. In view of the above, the current study was conceived to determine the levels and health risks of PM2.5 exposure in selected parts of Lagos, Nigeria. The findings in the study will provide primary data toward reducing the levels and effects of PM in the city.

MATERIALS AND METHODS

Description of study area

The study was conducted in Lagos, Southwest Nigeria (Figure 1). Lagos is located at latitude 6° 27' 55.5192 "N and longitude 3° 24' 23.2128 "E (Yahaya *et al.,* 2022). The state is bordered by Ogun State on the north and east; the Republic of Benin on the west; and the Atlantic Ocean on the south. Lagos experiences two major seasons a year, which include the wet season (April to October) and the dry season (November to March). The average atmospheric temperature is between 30 and 38 °C (Weatherspark.com, 2022).

Lagos is the smallest state in Nigeria in terms of landmass but the most populous and one of the fast-growing cities in the world. Lagos is one of Africa's economic hubs and the most industrialized city in Nigeria, which could have an adverse impact on atmospheric PM levels in the city. Yet, there is a dearth of documented information and awareness on air PM levels in the city, which necessitated the current study.

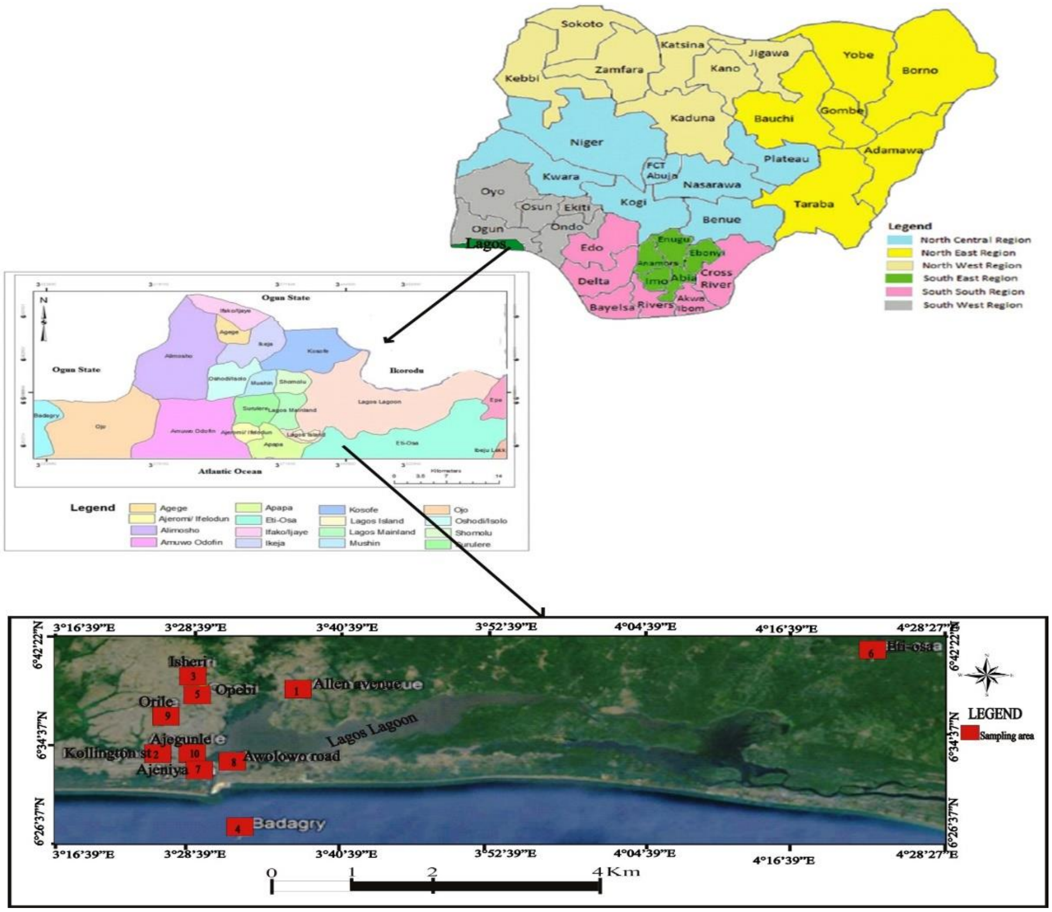

Figure 1: Locations of the study area

Measurement of particulate matter (PM)

A pre-calibrated Aerosol Mass Monitor (Elitech USA, model no PMD 351) was used to measure the concentrations of particulate matter (PM2.5), nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3) in Allen Avenue, Kolington, Isheri, Badagry, Opebi, Eti-Osa, Ajeniya, Awolowo, Orile, and Ajegunle, all in Lagos. The locations were selected randomly and readings were taken thrice monthly between July 2022 and September 2022, covering three months. Also, the coordinates of the sampling points were obtained with a hand-held automated GPS.

Health risk assessment

The health risks of the PM were calculated from their average hourly dose (*AHD*), average daily dose (*ADD*), and hazard quotient (*HQ*) using equations 1, 2, and 3 (Oyewale *et al.,* 2017).

$$AHD = \frac{Cn \times IR}{BW} \quad (1)$$

$$ADD = \frac{Cn \times ED \times IR}{ABW \times AT} \quad (2)$$

$$HQ = \frac{AHD/ADD}{RL} \quad (3)$$

Where *Cn* is the concentration of particulate matter (mg/kg); *IR* represents inhalation rate in m^3/hour per person day^{-1}, which is 1.2; *EF* denotes exposure frequency (365 days/year); *ED* stands for exposure duration (55 years, the average life span of a resident of Nigeria); *ABW* indicates average body weight (65 kg); *AT* is the average exposure time for non-carcinogenic health risk (365 days/year × *ED*); and *RL* means reference exposure level (10µg/m^3).

Data analysis

The levels of PM2.5 and elements in the air (NO_2, CO, and O_3) were presented as mean ± standard deviation (SD) using a MINITAB version 21. The values obtained for the average hourly dose (*AHD*), average daily dose (*ADD*), and hazard quotient (*HQ*) were also calculated using the software.

RESULTS

Levels of particulate matter (PM2.5) in the ambient air of Lagos

Table 1 shows the levels of PM2.5, NO_2, CO, and O_3 in the ambient air of Allen Avenue, Kolington, Isheri, Badagry, Opebi, Eti-Osa, Ajeniya, Awolowo, Orile, and Ajegunle, all in Lagos. The levels of PM2.5 (15.85, 16.83, 17.31, 17.85, 27.22, 28.48, 29.65, 31.32, and 34.63 µg/m^3) and NO_2 (25.99, 26.45, 27.05, 27.51, 27.51, 30.98, 32.06, and 36.08 µg/m3) in all the locations were above the permissible limits recommended by the World Health Organization (WHO, 2021) (15 and 25 µg/m^3), except in Badagry (5.36 and 6.11 µg/m^3) and Ajeniya (0.00µg/m^3) (NO_2 only), respectively. Meanwhile, in all the locations, CO concentrations (18.06, 22.80, 23.71, 34.10, 47.55, 48.80, 55.29, 58.05, and 67.09 µg/m^3) were above the permissible limit (7µg/m^3), while O_3 concentrations (14.06, 16.50, 20.61, 22.12, 22.19, 22.88, 25.50, 28.40, 31.13, and 32.11 µg/m^3) were within the permissible limit (100µg/m^3).

Table 1: Levels of particulate matter (PM2.5), nitrogen dioxide (NO_2,) carbon monoxide (CO), and ozone (O_3) in the ambient air of selected locations in Lagos

Location	Coordinates	PM2.5	NO_2	CO	O_3
Allen avenue	6.60ºN, 3.51ºE	16.83±0.66	27.05±0.22	34.10±0.81	28.40±1.70
Kolington	6.46ºN, 3.36ºE	15.85±1.08	36.08±1.24	47.55±2.06	25.50±2.42
Isheri	6.63ºN, 3.35ºE	27.22±0.32	26.45±0.87	49.75±2.28	22.88±1.04
Badagry	6.30ºN, 3.45ºE	5.36±2.26	6.11±0.22	18.06±0.56	22.19±1.08
Opebi	6.59ºN, 3.36ºE	17.85±2.26	25.99±1.08	67.09±2.26	31.13±0.55
Eti-osa	6.70ºN, 4.35ºE	31.32±0.65	27.51±0.55	58.05±2.46	20.61±1.12
Ajeniya	6.44ºN, 3.42ºE	34.63±0.52	0.00	22.80±0.84	14.06±1.30
Awolowo	6.44ºN, 3.42ºE	17.31±0.28	32.06±0.55	32.06±0.55	22.12±1.44
Orile	6.54ºN, 3.31ºE	28.48±0.52	30.98±1.09	55.29±1.42	32.11±2.02
Ajegunle	6.46ºN, 3.36ºE	29.65±2.33	27.51±0.82	23.71±0.45	16.50±0.62
Limits (WHO, 2021)		15µg/m^3	25µg/m^3	7µg/m^3	100µg/m^3

Values were expressed as mean ± SD and µg/m^3, WHO= World Health Organization

Health risk assessment of air pollutants

Table 2 shows the average hourly dose (*AHD*) and the average daily dose (*ADD*) of the pollutants (PM2.5, NO_2, CO, and O_3). Expectedly, the daily doses were higher than the hourly doses. The *AHD* and *ADD* of PM2.5 ranged from 0.10 and 2.37 µg/m^3 in Badagry to 0.64 and 15.34 µg/m^3 in Ajeniya. The *AHD* and *ADD* of NO_2 has the lowest concentrations in Ajeniya with 0.00 and 0.00 µg/m^3 and highest in Kolington with 0.67 and 15.99 µg/m^3. While the *AHD* and *ADD* of CO ranged from 0.33 and 8.00 µg/m^3 in Badagry to 0.93 and 22.55 µg/m^3 in Orile, those of O_3 ranged from 0.21 and 05.16 µg/m^3 in Eti-Osa to 1.08 and 26.01 µg/m^3 in Orile.

The hazard quotient (*HQ*) of the *AHD* and the *ADD* of the pollutants are revealed in Figures 1 and 2. The *HQ* of *AHD* for all the pollutants was less than 1 in all the selected locations. Meanwhile, the *HQ* of *ADD* for PM2.5 was greater than 1 in Kolington (1.7), Isheri (1.25), Ajeniya (1.5), Eti-Osa (1.3), Orile (1.2), and Ajegunle (1.3). NO_2 was greater than 1 in Kolington (1.6), Isheri (1.8), and Orile (1.1). CO was above 1 in Kolington (2.2), Isheri (1.8), Opebi (1.4), Eti-Osa (2.8), Awolowo (2.0), Orile (2.4), and Allen Avenue (1.1). O_3 was above 1 in Kolington (1.1), Isheri (1.3), Opebi (1.4), Awolowo (1.7), and Orile (2.7).

Table 2: Average hourly dose (*AHD*) and average daily dose (*ADD*) for particulate matter (PM2.5), nitrogen dioxide (NO_2,) carbon monoxide (CO), and ozone (O_3) in the ambient air of selected locations in Lagos

Locations	**PM2.5**		**NO_2**		**CO**		**O_3**	
	AHD	***ADD***	***AHD***	***ADD***	***AHD***	***ADD***	***AHD***	***ADD***
Allen Avenue	0.31	7.46	0.31	7.55	0.48	10.22	0.41	9.75
Kolington	0.27	6.59	0.67	15.99	0.88	21.07	0.47	11.29
Isheri	0.50	12.06	0.29	7.16	0.75	18.01	0.51	12.34
Badagry	0.10	2.37	0.11	2.71	0.33	8.00	0.41	9.85
Opebi	0.26	6.14	0.34	8.16	0.57	13.74	0.52	12.44
Eti-Osa	0.58	13.88	0.37	8.91	1.14	27.44	0.21	5.16
Ajeniya	0.64	15.34	0.00	0.00	0.42	10.10	0.26	6.23
Awolowo	0.13	3.24	0.26	6.26	0.81	19.32	0.67	16.00
Orile	0.53	12.62	0.44	10.62	0.93	22.55	1.08	26.01
Ajegunle	0.55	13.14	0.20	4.88	0.35	8.38	0.20	4.69

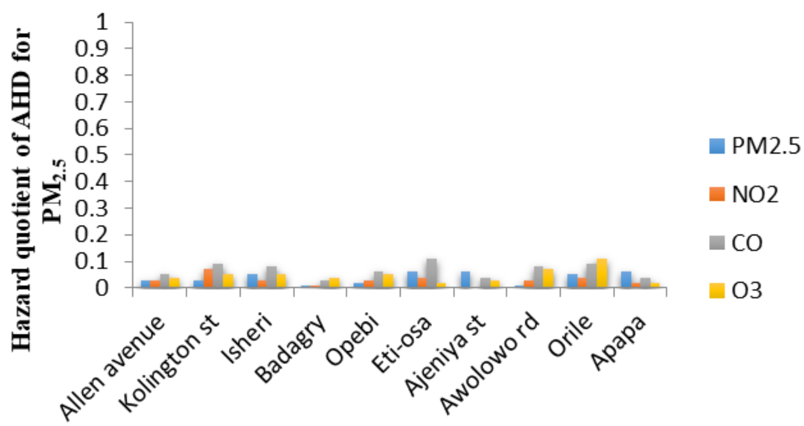

Fig 1: Hazard quotient (*HQ*) of average hourly dose (*AHD*) for particulate matter (PM2.5), nitrogen dioxide (NO_2,) carbon monoxide (CO), and ozone (O_3) in the ambient air of selected locations in Lagos

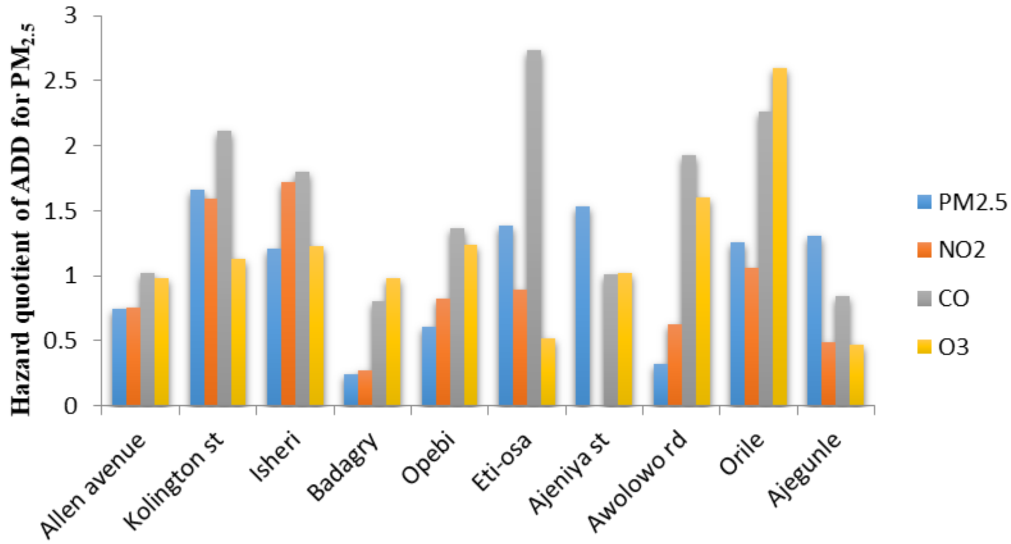

Fig 2: Hazard quotient (*HQ*) of average daily dose (*ADD*) for particulate matter (PM2.5), nitrogen dioxide (NO_2,) carbon monoxide (CO), and ozone (O_3) in the ambient air of selected locations in Lagos

DISCUSSION

The current study was conceived to evaluate the levels and health risks of particulate matter (PM2.5) and elements present in the ambient air of Lagos, Nigeria. To achieve the mentioned objectives, ambient air was measured and recorded across selected locations in the city, namely: Allen Avenue, Kolington, Isheri, Badagry, Opebi, Eti-Osa, Ajeniya, Awolowo, Orile, and Ajegunle. In all the locations, PM2.5 was above the permissible levels, except in Badagry, while NO_2 was above the permissible levels, except in Badagry and Ajeniya. On the other hand, in all the locations, CO was above the tolerable levels while O_3 was within the permissible levels. This result suggests that the air above the city is polluted. Lagos is highly populated, with lots of vehicular movements, industrial clusters, and intense anthropogenic activities, all of which could have contributed immensely to air pollution in the city. Savio *et al*. (2022) linked high vehicular emissions to increased PM and CO_2 in Srinagar, India. Perrino *et al*. (2020) also reported high PM around three industrial areas in Southern Italy. In a systematic review by Karagulian *et al*. (2015), 25% of global urban ambient air pollution from PM2.5 is contributed by traffic, 15% by industrial activities, 20% by domestic fuel burning, 22% from unspecified sources of human origin, and 18% from natural dust and salt.

The PM and associated elements in the ambient air of Lagos may cause some health hazards to residents, considering the levels at which they were detected in the current study. Short- and long-term exposure to PM2.5 may cause cardiovascular and pulmonary diseases (Lambrechtsen *et al.,* 2012). Studies also suggest that PM2.5 exposure can predispose humans to type 2 diabetes mellitus through endothelial dysfunction, immune response alterations in visceral adipose tissues, and endoplasmic reticulum stress, resulting in alterations in insulin transduction and sensitivity, and glucose metabolism (Barrett, 2016; He *et al*., 2017). Long-term NO_2 exposure worsens symptoms of bronchitis in asthmatic patients, reduces lung function, increases the risk of cardiovascular and respiratory diseases, and increases mortality among elderly people (Kowalska *et al*., 2020; Meng *et al*., 2021; Qian *et al*., 2021). NO_2 pollution can also alter immune function and thus increase vulnerability to infections (Di Ciaula *et al*., 2022). Exposure to CO may lead to reduced oxygen transport by hemoglobin (Blumenthal, 2001). Chronic CO poisoning may cause an inflammatory response, resulting in unconsciousness and neurological damage (Townsend and Maynard, 2002). The findings of the current study are consistent with those of Odekanle *et al*. (2022), who detected non-permissible levels of PM2.5, SO_2, and NO_2 in ambient air in Lagos. The results are also in line with those of Owoade *et al*. (2009) and Chiedu *et al*. (2019), who reported non-tolerable levels of PM2.5 and traces of some elements in industrialized urban areas in Lagos. Similarly, Obanya *et al*. (2018) detected non-permissible levels of PM2.5 and PM10 in Yaba Local Government Area, Lagos State.

The human hourly and daily exposures to PM and elements in the air were assessed to determine their health risks. The hazard quotient (*HQ*) of the average hourly dose (*AHD*) for the PM was less than one, but the average daily dose (*ADD*) was greater than one in many of the locations, indicating that daily exposure to PM2.5, NO_2, CO, and O_3 can have serious health consequences for residents. These results suggest that PM is significantly contributing to mortality resulting from ambient air pollution exposure in Lagos. This assertion is supported by a study carried out in Lagos by Croitoru *et al*. (2020), in which PM2.5 was estimated to cause about 11,200 premature deaths in 2018. The results of the current study are consistent with those of Odekanle *et al*. (2020), who reported non-tolerable *HQ* of PM and associated elements in the ambient air around an abattoir in Ile-Ife, Osun State, Nigeria. Seiyaboh *et al*. (2019) also detected harmful levels of PM around a football field due to vehicular emissions in Yenagoa, Bayelsa State, Nigeria. In addition, Opara *et al*. (2021) reported the non-permissible *HQ* of PM in the air above dumpsites in Owerri, Imo State, Nigeria.

CONCLUSION

The results revealed that PM2.5 was above the permissible levels in Allen Avenue, Kolington, Isheri, Opebi, Eti-Osa, Ajeniya, Awolowo, Orile, and Ajegunle but was within the permissible levels in Badagry. NO_2 was above the permissible levels in all the locations except in Badagry and Ajeniya. Meanwhile, CO levels were above tolerable levels in all locations, while O_3 levels were within acceptable limits. The hazard quotient (*HQ*) of the average hourly dose (*AHD*) of the PM was less than one, but the average daily dose (*ADD*) was greater than one. Overall, the results suggest that daily exposure to PM2.5, NO_2, CO, and O_3 in the city can cause serious health consequences for its residents.

In order to reduce PM2.5 pollution, activities that release pollutants should be controlled. In particular, residents should substitute wood fuel for biogas and use electric energy more often than generators. The government should develop pollution-reduction policies, such as prohibiting smoky vehicles from driving on the roads to reduce smoke emissions and encouraging waste recycling rather than burning.

Conflict of interest

Authors have no conflict of interest to declare

Author contribution

YT conceptualized the study and wrote the first draft of the manuscript. UFM and ZAM reviewed and edited the manuscript. AA performed health risk assessment and produced the tables and charts. IBM performed the experiments while BM and JA collected materials and data. All authors approved the final draft of the manuscript.

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