Tropical Environment, Biology, and Technology

Research Article
Volume 2(1), 2024, 34–43
https://doi.org/10.53623/tebt.v2i1.438

Assessment of Levels and Health Risks of Atmospheric Particulate Matter (PM10) and Associated Gaseous Elements in Selected Locations in Lagos, Nigeria

Tajudeen Yahaya[1]*, Tawakalt Fagbayi[2], Abdulmalik Abdulazeez[1], Abdulrazaq Izuafa[1], Sani Kalgo Abdulrahman[1], Caleb Obadiah[1]

[1]Department of Biological Sciences, Federal University Birnin Kebbi, PMB 1157, Kebbi State, Nigeria
[2]Department of Cell Biology and Genetics, University of Lagos, Nigeria

*Correspondence: e-mail@yahayatajudeen@gmail.com; yahaya.tajudeen@fubk.edu.ng

SUBMITTED: 20 April 2024; REVISED: 15 May 2024; ACCEPTED: 20 May 2024

ABSTRACT: Particulate matter with a size of 10 micrometers (PM10) poses health risks and thus needs to be monitored in every locality. This study assessed the health risks associated with PM10 and related gaseous elements, including nitrogen dioxide (NO_2), carbon monoxide (CO), and ozone (O_3), in the ambient air of selected locations in Lagos, Nigeria. Theselocations included Ikeja, Apapa, Idumota, Odogunyan, Yaba, Obalende, Agege, Oshodi, Oto-Awori, and Ojodu. The average hourly dose (AHD), average daily dose (ADD), and hazard quotient (HQ) of these pollutants werecalculated. The results indicated that PM10 levels (ranging from 48.05±0.97 $\mu g/m^3$ in Obalende to 115.00±1.74$\mu g/m^3$ in Apapa) and CO levels (ranging from 12.46±0.84 $\mu g/m^3$ in Obalende to 58.50±3.64 $\mu g/m^3$ in Agege) exceeded the WHO permissible limits at all locations (45$\mu g/m^3$ for PM10 and 7 $\mu g/m^3$ for CO). NO_2 levels (ranging from 0.00 $\mu g/m^3$ in Yaba and Obalende to 23.98±2.06 $\mu g/m^3$ in Oshodi) and O_3 levels (ranging from 2.25±0.20 $\mu g/m^3$ in Odogunyan to 38.71±2.41 $\mu g/m^3$ in Oshodi) remained within permissible limits (25$\mu g/m^3$ for NO_2 and 100µg/m3 for O_3) across all locations. The HQ of the ADD for both PM10 and CO (Agege and Oshodi only) exceeded the threshold, suggesting that air quality in these locations may induce toxic effects. These findings emphasize the need forpolicies aimed at controlling pollution in the city.

KEYWORDS: Average daily dose (ADD); carbon monoxide (CO); hazard quotient (HQ); nitrogen dioxide (NO_2); particulate matter 10 (PM10)

1. Introduction

PM constitutes a significant component of air pollution, consisting of exceedingly small particles and liquid droplets containing acids, organic chemicals, metals, and soil or dust particles [1, 2]. PM can originate from either direct emissions (primary particles) or atmospheric formation through chemical reactions involving gases (secondary particles) like sulfur dioxide (SO_2), nitrogen oxides (NO_2), and certain organic compounds [3, 4]. Therefore, sources of PM can be classified as either natural or anthropogenic [5]. Anthropogenic, or human-made sources, of PM encompass combustion in mechanical and industrial processes, vehicle emissions, and tobacco smoke [6, 7]. On the other hand, natural sources encompass phenomena such as volcanoes, fires, dust storms, and aerosolized sea salt [8,9]. For regulatory purposes regarding air quality, PM is categorized based on size. Particles with a diameter of 10 microns or less are referred to as PM10, whereas those with a diameter of 2.5 microns or less are categorized as PM2.5 [10, 11]. It is essential to note that PM10 and PM2.5 often originate from distinct emission sources and exhibit varying chemical compositions. PM2.5 is primarily produced by emissions from the combustion of gasoline, oil, diesel fuel, or wood. In contrast, sources of PM10 include dust from construction sites, landfills, agriculture, wildfires, industrial sources, wind-blown dust from open lands, pollen, and fragments of bacteria [12, 13]. PM has a profound impact on both human health and the environment, with effects that can be acute or chronic, contingent upon the duration and absorbed dose [14]. Exposure to PM, specifically PM10, can lead to health issues such as ischemic heart disease, inflammatory responses, DNA damage, cancer, obesity, and diabetes mellitus [14, 15]. Additionally, exposure to PM heightens the risk of developing or succumbing to cardiac, cerebrovascular, and chronic airway diseases [16, 17]. Globally, about 8.34 million people died yearly from particulate matter emissions [18]. Moreover, both PM10 and gaseous pollutants like CO, SO_2, and NO contribute to climate change and exhibit detrimental effects on rainfall, reducing its occurrence and quantity [19–21].

People in low- and middle-income countries, particularly those residing in industrialized urban areas such as the Lagos metropolis, bear the brunt of mortality and morbidity due to PM exposure [22, 23]. In 2018, PM was responsible for approximately 11,200 premature deaths and generated a health cost of US$2.1 billion in Lagos State, Nigeria, which equated to about 2.1% of the state's GDP during that year [24]. The World Health Organization (WHO) has recommended a PM limit of 45 g/m^3, but Lagos recorded levels as high as 68 g/m^3 [24–26]. Unfortunately, literature searches have revealed a significant lack of studies and awareness regarding the dangers posed by PM exposure in the city. Information and awareness are crucial to mitigating mortality, morbidity, and the expenses incurred due to PM exposure. Consequently, this study was conducted to determine the concentrations and health risks associated with PM10 in selected locations within Lagos, namely Ikeja, Apapa, Idumota, Odogunyan, Yaba, Obalende, Agege, Oshodi, Oto-awori, and Ojodu. It is hoped that the findings of this study will provide primary data on PM pollution and associated health burdenwhich policymakers in the city may strategize to reduce air pollution and its effects.

2. Materials and Methods

2.1. Description of the study area.

This research was conducted in Lagos State, located in southwestern Nigeria, as depicted in Figure 1. The geographical coordinates of the state fall within the latitude of 6° 27' 55.5192 "N and the longitude of 3° 24' 23.2128 "E. Lagos experiences a tropical wet and dry climate, characterized by two distinct rainy seasons, with the peak rainy season occurring from April to July and a dry season prevailing from December to March. The temperature in the city typically varies between 21 and 33 degrees celsius. Lagos stands as the fastest-growing city in Nigeria, boasting an annual growth rate of approximately 5.8% and an estimated population exceeding 14 million residents [27]. This dynamic urban center is host to a significant portion of Nigeria's industrial investments, accounting for 70%, and is a hub for about 65% of the country's commercial activities, with over 10,000 large-scale industrial and commercial businesses [28]. Furthermore, Lagos contends with a high density of vehicles, surpassing 222 vehicles per square kilometer [29]. It is noteworthy that many of these vehicles employ outdated emission technologies and utilize fuel with high sulfur content [30]. Given these circumstances, there exists a plausible risk of elevated levels of PM and its associated elements in the city's ambient air. Regrettably, documented information concerning PM exposure within the city is limited, underscoring the imperative need for the present study.

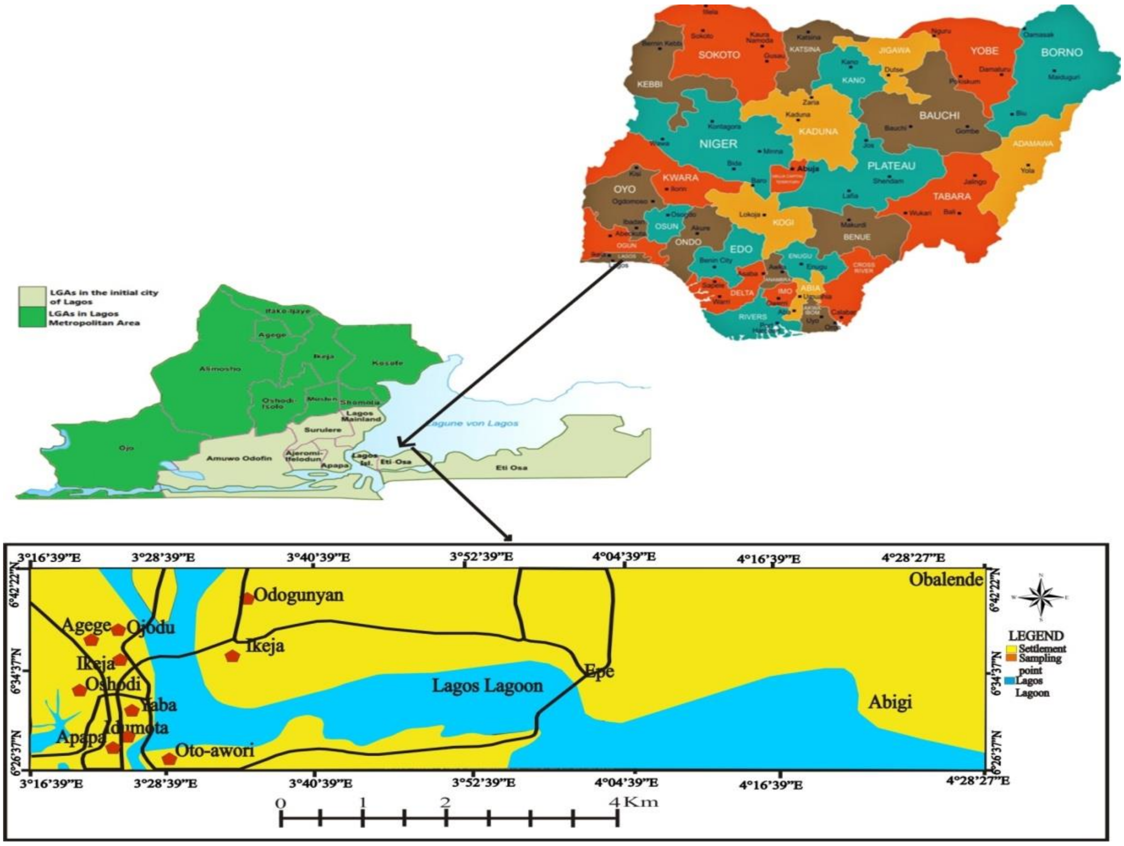

Figure 1. Locations of the study area.

3.2. Sample and data collection.

A pre-calibrated Aerosol Mass Monitor (Temtop Aerosol Dust Monitor PMD 351, USA) was utilized to measure the concentrations of PM10, NO_2), CO_2, and O_3 in the ambient air of ten carefully chosen locations in Lagos, covering the period from July 2023 to September 2023. These selected locations encompass Ikeja, Apapa, Idumota, Odogunyan, Yaba, Obalende, Agege, Oshodi, Oto-Awori, and Ojodu. The selection of these sites took into account various factors, including high population and vehicular densities, the presence of industrial clusters, and intense anthropogenic activities. Following the data collection process, the precise coordinates of each location were determined using a portable, automated GPS device.

3.3. Health risk assessment.

The potential health risks associated with PM10, NO_2, CO_2, and O_3 in the ambient air of the selected locations were assessed by estimating their AHD, ADD, and HQ using equations 1, 2, and 3, as described by Yahaya et al. [31].

$$AHD = Cn \times IR/BW \quad (1)$$

$$ADD = Cn \times ED \times IR/BW \times AT \quad (2)$$

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

In this context, the variables are defined as follows: Cn represents the concentration of particulate matter (mg/kg); IR signifies the inhalation rate, which is set at 1.2 m^3/hour per person/day; ED stands for exposure duration (55 years, which corresponds to the average lifespan of a resident of Nigeria); BW indicates the average body weight (65 kg); AT represents the average exposure time for non-carcinogenic health risk (365 days/year multiplied by ED); and RL stands for the reference exposure level (20 µg/m^3) [31].

3.4. Data analysis.

The values of PM10, NO_2, CO_2, and O_3 obtained from the selected locations were presented as means ± standard deviation (SD) using Minitab version 21. The same software was employed to calculate the AHD, ADD, and HQ for these values.

3. Results and Discussion

3.1. Levels of particulate matter (PM10) in the ambient air.

Table 1 displays the concentrations of PM10, NO_2, CO, and O_3in the ambient air across various locations in Lagos, including Ikeja, Apapa, Idumota, Odogunyan, Yaba, Obalende, Agege, Oshodi, Oto-Awori, and Ojodu. Notably, the levels of PM10 and CO exceeded the permissible limits established by the WHO [26], which were 45µg/m^3 for PM10 and 7 µg/m^3 for CO, across all the selected areas. Obalende recorded the lowest PM10 levels, measuring at 48.05±0.97 µg/m^3, while Apapa exhibited the highest PM10 concentration, reaching 115.0±1.74 µg/m^3.As for CO levels, Obalende had the lowest concentration, with 12.46±0.84 µg/m^3, while Agege had the highest, measuring at 58.50±3.64 µg/m^3. On the other hand, O_3 and NO_2 levels were found to be within the permissible limits (100 µg/m^3 for O_3 and 25 µg/m^3 for NO_2) across all the locations. Odogunyan displayed the lowest O_3 levels, registering at 2.25±0.20 µg/m^3, while Oshodi exhibited the highest O_3 concentration, measuring 38.71±2.41 µg/m^3. Regarding NO_2, Yaba and Obalende both recorded the lowest levels at 0.00µg/m^3each, whereas Oshodi had the highest NO_2 concentration, reaching 23.98±2.06 µg/m^3.

These findings imply that individuals exposed to the ambient air in the selected locations risk health hazards associated with PM10 and CO. Prolonged exposure to elevated PM10 levels can result in increased mortality due to cardiovascular and respiratory diseases, developmental defects, and mutagenic effects in children [32, 33]. Additionally, PM10 exposure can cause poor pregnancy outcomes, type 2 diabetes, dementia, and decreased life expectancy [34,35]. Acute exposure to CO can cause headache, dizziness, drowsiness, or nausea, vomiting, loss of consciousness, while chronic exposure can lead to loss of consciousness, coma, or even death [36, 37]. Moreover, excessive CO exposure aggravates respiratory, cardiovascular, genitourinary, gastrointestinal, and neuropsychiatric diseases [38]. The findings of the current study are consistent with those of Odekanle et al. [39], who detected non-tolerable levels of PM10 in Oshodi, Agege, Apapa, Ikorodu, and Maryland in Lagos, Nigeria. Njoku et al. [40] reported non-tolerable levels of CO in the ambient air of selected locations in Lagos, Nigeria.

However, unlike the current study, Njoku and colleagues reported non-tolerable levels of NO_2. Abulude et al. [41] also detected PM10, CO, and NO_2 above the permissible limit in Ojodu, Opebi, Maryland, Ikeja, and Eti-Osa in Lagos, Nigeria. Additionally, compared to a study carried out in Ibadan, Nigeria by Kolawole and Olatunji [42], PM10 concentrations in the study areas were lower; while the current study recorded maximum PM10 concentration of 115.0±1.74 µg/m^3, Kolawole and Olatunji recorded a minimum of 120 µg/m^3. However, it is higher than the maximum range of PM10 (0.065-0.172 µg/m^3) recorded in some markets in Imo, Nigeria [43]. Outside Nigeria, it is lower than the levels detected in Qena, Egypt which detected as high as 646.74 µg/m of PM10 [44]. But it is higher than the 56.243-69.425 µg/m^3 range reported in Tema, Ghana [45].

Table 1. Levels of PM10 and associated elements in the ambient air of ten selected locations in Lagos.

Locations	Coordinates	PM10 (µg/m^3)	NO_2 (µg/m^3)	CO (µg/m^3)	O_3 (µg/m^3)
Ikeja	6.60ºN, 3.51ºE	83.51±1.45	11.01±0.55	23.07±0.77	22.00±1.21
Apapa	6.46ºN, 3.36ºE	115.0±1.74	17.05±0.57	18.91±0.45	10.50±0.69
Idumota	6.46ºN, 3.38ºE	63.38±2.09	15.07±2.05	29.06±0.50	8.21±0.06
Odogunyan	6.68ºN, 3.52ºE	76.33±1.15	7.12±1.12	25.19±4.02	2.25±0.20
Yaba	6.51ºN, 3.37ºE	52.71±0.69	ND	34.51±1.15	10.02±0.68
Obalende	6.70ºN, 4.35ºE	48.05±0.97	ND	12.46±0.84	11.0±1.00
Agege	6.62ºN, 3.32ºE	89.56±0.45	21.51±2.24	58.50±3.64	35.54±1.74
Oshodi	6.54ºN, 3.31ºE	32.78±1.07	23.98±2.06	50.89±4.42	38.71±2.41
Oto-Awori	6.44ºN, 3.42ºE	104.7±4.08	14.12±0.80	43.61±2.24	36.12±1.04
Ojodu	6.63ºN, 3.36ºE	93.41±2.01	16.15±0.48	40.65±2.05	27.65±1.12
Limits [26]		**45**	**25**	**7**	**100**

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

3.2. Health risk of PM10 in the ambient air.

Table 2 presents data on the AHD and ADD of PM10, NO_2, CO, and O_3 obtained from ambient air in various locations in Lagos. As anticipated, the ADD for pollutants exceeded the AHD in all the locations. AHD and ADD for PM10 showed the highest values among the pollutants, ranging from 0.61 µg/m^3 and 14.52 µg/m^3 in Oshodi to 2.12 µg/m^3 and 50.97 µg/m^3 in Apapa, respectively. Conversely, exposure to NO_2 had the lowest values, ranging from 0.00 µg/m^3 in Yaba and Obalende to 0.44 µg/m^3 and 10.62 µg/m^3 in Oshodi, respectively. Figures 2 and 3 illustrate the HQ of the AHD and ADD of PM10 and associated elements at selected locations in Lagos. Figure 2 demonstrates that the HQ of AHD for PM10, NO_2, CO, and O_3 remained consistently below 1 in all locations. In contrast, Figure 3 reveals that the HQ of ADD for PM10 exceeded 1 in all locations, while those for NO_2, CO (except in Agege and Oshodi), and O_3 remained below 1 in all locations. The HQ of the AHD of PM10, NO_2, CO, and O_3 being less than 1, indicate lower risk, while the HQ of the ADD of PM10 being greater than 1, indicated potential risks. Additionally, the HQ of ADD of CO being greater than 1 in Agege and Oshodi, suggests that PM10 and CO could cause lasting harm to individuals in these areas.

Table 2. AHD and ADD of PM10 and associated elements in the ambient air of ten selected locations in Lagos.

Locations	**PM10 (µg/m^3)**		**NO_2** (µg/m^3)		**CO** (µg/m^3)		**O_3** (µg/m^3)	
	AHD	***ADD***	***AHD***	***ADD***	***AHD***	***ADD***	***AHD***	***ADD***
Ikeja	1.54	37.01	0.31	4.88	0.43	10.22	0.41	9.75
Apapa	2.12	50.97	0.20	7.55	0.35	8.38	0.19	4.65
Idumota	1.17	28.08	0.28	6.68	0.54	12.88	0.15	3.64
Odogunyan	1.41	33.82	0.13	3.15	0.47	11.16	0.04	0.99
Yaba	0.97	23.3	50.00	0.00	0.64	15.29	0.18	4.44
Obalende	0.78	18.63	0.00	0.00	0.23	5.52	0.20	4.87
Agege	1.65	39.68	0.39	9.53	1.08	25.92	0.66	15.75
Oshodi	0.61	14.52	0.44	10.62	0.94	22.55	0.72	17.15
Oto-Awori	1.93	46.08	0.26	6.26	0.81	19.32	0.68	16.00
Ojodu	1.72	41.39	0.29	7.16	0.75	18.01	0.51	12.34

These results are consistent with those of Obanya et al. [25], who reported potential health risks of PM10 in selected places in Lagos, Nigeria. Similarly, Abulude et al. [41] reported poor quality of air at selected places in Lagos, including Ikeja, Maryland, Opebi, Ojodu, and Eti-Osa. Furthermore, Wambebe and Duan [46] documented health risks associated with PM and associated elements in the ambient air of selected locations in Abuja, Nigeria. Potential sources of PM and CO in the city can be attributed to high population density, extensive anthropogenic activities, industrial emissions, vehicular exhaust, and the widespread use of diesel and petrol generators by households.

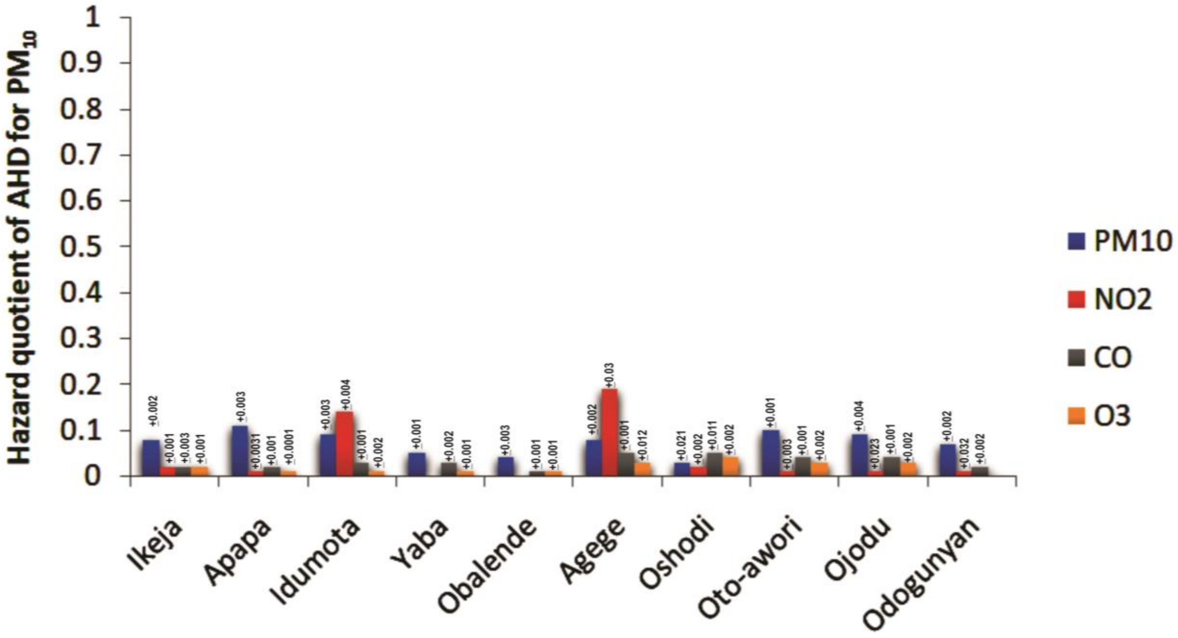

Fig 2. Hazard quotient of AHD of PM10 (values above each bar is the standard error of the triplicates results).

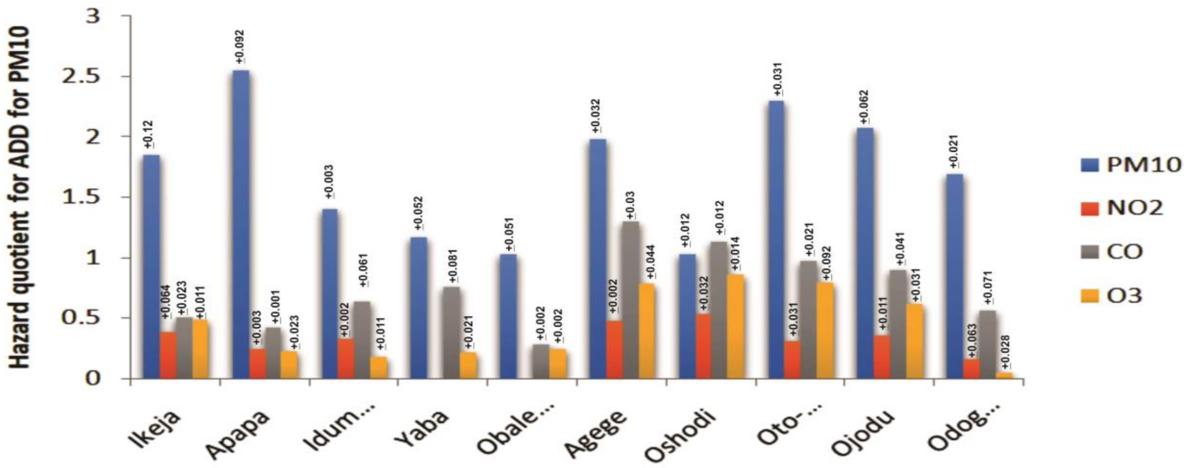

Fig 3. Hazard quotient of ADD of PM10 **(**values above each bar is the standard error of the triplicates results).

4. Conclusions

The results indicate that the levels of PM10 and CO in the ambient air of Ikeja, Apapa, Idumota, Odogunyan, Yaba, Obalende, Agege, Oshodi, Oto-Awori, and Ojodu, all situated in Lagos, Nigeria, exceeded the permissible limits recommended by the WHO. While Obalende recorded the lowest PM10 levels, measuring at 48.05±0.97 μg/m^3, Apapa exhibited the highest PM10 concentration, reaching 115.0±1.74 μg/m^3. As for CO levels, Obalende had the lowest concentration, with 12.46±0.84 μg/m^3, while Agege had the highest, measuring at 58.50±3.64 μg/m^3. However, NO_2 and O_3 remained within acceptable limits across all these locations. While the HQ for the AHD of PM and its associated elements was found to be below 1, the HQ for the ADD of PM10 exceeded 1. Additionally, the HQ for ADD of CO exceeded 1 in Agege and Oshodi. These findings suggest that the air quality above the selected locations may pose health hazards to exposed individuals, particularly in relation to PM10 and CO toxicity. Given these results, it is essential to raise awareness among residents in these areas regarding the health risks associated with PM exposure. Encouraging the use of nose covers as a preventive measure is advisable. Additionally, measures to reduce the number of vehicles on Lagos's roads, such as the introduction of metro lines and railways, should be considered. The removal of old, emissions-heavy vehicles from circulation is crucial. Furthermore, efforts to control industrial emissions are needed to mitigate air pollution. It is imperative that the government develops and implements pollution control policies. Regular, periodic studies similar to the current one should be conducted in these areas to monitor and address air quality concerns effectively.

Acknowledgments

Not applicable.

Competing Interest

All authors have no competing interest.

References

[1] Thangavel, P.; Park, D.; Lee, Y.C. (2022). Recent Insights into Particulate Matter ($PM_{2.5}$) Mediated Toxicity in Humans: An Overview. *International Journal of Environmental Research and Public Health*, *19* (12), 7511. https://doi.org/10.3390/ijerph19127511.

[2] Lala, M. A.; Onwunzo, C.S.; Adesina, O.A., Sonibare, J.A. (2023). Particulate matters pollution in selected areas of Nigeria: Spatial analysis and risk assessment. *Case Studies in Chemical and Environmental Engineering*, *7*, 100288. https://doi.org/10.1016/j.cscee.2022.100288.

[3] Manisalidis, I.; Stavropoulou, E.; Stavropoulos, A.; Bezirtzoglou, E. (2020). Environmental and Health Impacts of Air Pollution: A Review. *Frontiers in Public Health*, *8*, 14. https://doi.org/10.3389/fpubh.2020.00014.

[4] Hassan, A.; Ilyas, S.Z.; Agathopoulos, S.; Hussain, S.M.; Jalil, A.; Ahmed, S. et al. (2021). Evaluation of adverse effects of particulate matter on human life. *Heliyon*, *7*(2), e05968. https://doi.org/10.1016/j.heliyon.2021.e05968.

[5] Morantes, G.; González, J.C.; Rincón, G. (2021). Characterization of particulate matter and identification of emission sources in Greater Caracas, Venezuela. *Air Quality, Atmosphere and Health*, *14*, 1989–2014. https://doi.org/10.1007/s11869-021-01070-2.

[6] Calderón-Garcidueñas, L.; Stommel, E.W.; Rajkumar, R.P.; Mukherjee, P.S.; Ayala, A. (2021). Particulate Air Pollution and Risk of Neuropsychiatric Outcomes. What We Breathe, Swallow, and Put on Our Skin Matters. *International Journal of Environmental Research and Public Health*, *18*(21), 11568. https://doi.org/10.3390/ijerph182111568.

[7] Nnaji, C.C.; Chibueze, C.; Afangideh, C.B. (2023). The Menace and Mitigation of Air Pollution in the Built Environment: A Review. Nigerian *Journal of Technology*, *42*(1), 12–29. https://doi.org/10.4314/njt.v42i1.3.

[8] Daellenbach, K.R.; Uzu, G.; Jiang, J. (2020). Sources of particulate-matter air pollution and its oxidative potential in Europe. *Nature*, *587*, 414–419. https://doi.org/10.1038/s41586-020-2902-8.
[9] Sharma, S.K.; Mandal, T.K. (2023). Elemental Composition and Sources of Fine Particulate Matter ($PM_{2.5}$) in Delhi, India. *Bulletins of Environmental Contamination and Toxicology, 110*, 60. https://doi.org/10.1007/s00128-023-03707-7.
[10] Liu, Z.; Shen, L.; Yan, C.; Du, J.; Li, Y.; Zhao, H. (2020). Analysis of the Influence of Precipitation and Wind on PM2.5 and PM10 in the Atmosphere. *Advances in Meteorology,* Article ID 5039613. https://doi.org/10.1155/2020/5039613.
[11] Sturm, R. (2020). Modelling the deposition of fine particulate matter (PM2.5) in the human respiratory tract. *AME Medical Journal*, *5*, 14. https://doi.org/10.21037/amj.2020.03.04.
[12] Fan, H.; Zhao, C.; Yang, Y.; Yang, X. (2021). Spatio-Temporal Variations of the $PM_{2.5}/PM_{10}$ Ratios and Its Application to Air Pollution Type Classification in China. *Frontiers in Environmental Science*, 9, 692440. https://doi.org/10.3389/fenvs.2021.692440.
[13] Krupnova, T.G.; Rakova, O.V.; Bondarenko, K.A.; Saifullin, A.F.; Popova, D.A; Potgieter-Vermaak, S. et al. (2021). Elemental Composition of $PM_{2.5}$ and PM_{10} and Health Risks Assessment in the Industrial Districts of Chelyabinsk, South Ural Region, Russia. *International Journal of Environmental Research and Public Health*, *18*(23), 12354. https://doi.org/10.3390/ijerph182312354.
[14] Parker, J.D.; Kravets, N.; Vaidyanathan, A. (2018). Particulate matter air pollution exposure and heart disease mortality risks by race and ethnicity in the United States: 1997 to 2009 national health interview survey with mortality follow-up through 2011. *Circulation*, *137,* 1688–1697. https://doi.org/10.1161/CIRCULATIONAHA.117.029376.
[15] Garcia, A.; Santa-Helena, E.; De Falco, A. (2023). Toxicological Effects of Fine Particulate Matter ($PM_{2.5}$): Health Risks and Associated Systemic Injuries—Systematic Review. *Water Air and Soil Pollution, 234,* 346. https://doi.org/10.1007/s11270-023-06278-9.
[16] Li, T.; Yu, Y.; Sun, Z. (2022). A comprehensive understanding of ambient particulate matter and its components on the adverse health effects based from epidemiological and laboratory evidence. *Particle and Fibre Toxicology, 19*, 67. https://doi.org/10.1186/s12989-022-00507-5.
[17] Zhao, N.; Smargiassi, A.; Jean, S. (2022). Long-term exposure to fine particulate matter and ozone and the onset of systemic autoimmune rheumatic diseases: an open cohort study in Quebec, Canada. *Arthritis Research and Therapy*, *24*, 151. https://doi.org/10.1186/s13075-022-02843-5.
[18] Lelieveld, J.; Haines, A.; Burnett, R.; Tonne, C.; Klingmüller, K.; Münzel, T. et al. (2023). Air pollution deaths attributable to fossil fuels: observational and modelling study. *BMJ*, *383*, e077784. https://doi.org/10.1136/bmj-2023-077784.
[19] Bălă, G.P.; Râjnoveanu, R.M.; Tudorache, E. (2021). Air pollution exposure—the (in)visible risk factor for respiratory diseases. *Environmental Science and Pollution Research, 28,* 19615–19628. https://doi.org/10.1007/s11356-021-13208-x.
[20] Opio, R.; Mugume, I.; Nakatumba-Nabende, J. (2021). Understanding the Trend of NO_2, SO_2 and CO over East Africa from 2005 to 2020. *Atmosphere*, *12,* 1283. https://doi.org/10.3390/atmos12101283.
[21] Maboa, R.; Yessoufou, K.; Tesfamichael, S. (2022). Sizes of atmospheric particulate matters determine the outcomes of their interactions with rainfall processes. *Scientific Report*, *12*, 17467. https://doi.org/10.1038/s41598-022-22558-6.
[22] Mannucci, P.M.; Franchini, M. (2017). Health Effects of Ambient Air Pollution in Developing Countries. *International Journal of Environmental Research and Public Health*, *14*(9), 1048. https://doi.org/10.3390/ijerph14091048.
[23] Bikis, A. (2023). Urban Air Pollution and Greenness in Relation to Public Health. *Journal of Environmental and Public Health*, Article ID 8516622. https://doi.org/10.1155/2023/8516622.

[24] Croitoru, L.; Chang, J.; Akpokodje, J. (2020). The Health Cost of Ambient Air Pollution in Lagos. *Journal of Environmental Protection*, *11*, 753-765. https://doi.org/10.4236/jep.2020.119046.

[25] Obanya, H.E.; Amaeze, N.H.; Togunde, O.; Otitoloju, A.A. (2018). Air Pollution Monitoring Around Residential and Transportation Sector Locations in Lagos Mainland. *Journal of Health & Pollution*, *8*(19), 180903. https://doi.org/10.5696/2156-9614-8.19.180903.

[26] Global Air Quality Guidelines. Particulate matter (PM2.5 and PM10), Ozone, Nitrogen dioxide, Sulfur dioxide, and Carbon Monoxide. (accessed on 20 April 2024) Available online: https://www.who.int/publications-detail-redirect/9789240034228.

[27] Onilude, O.O.; Vaz, E. (2021). Urban Sprawl and Growth Prediction for Lagos Using GlobeLand30 Data and Cellular Automata Model. *Science*, *3*, 23. https://doi.org/10.3390/sci3020023.

[28] Oyalowo, B. (2022). Implications of urban expansion: land, planning and housing in Lagos. *Building and Cities*, *3*(1), 692–708. https://doi.org/10.5334/bc.243.

[29] Otuoze, S.H.; Hunt, D.V.L.; Jefferson, I. (2021). Neural Network Approach to Modelling Transport System Resilience for Major Cities: Case Studies of Lagos and Kano (Nigeria). *Sustainability*, *13*,1371. https://doi.org/10.3390/su13031371.

[30] Ajayi, S.A.; Adams, C.A.; Dumedah, G.O.; Adebanji, O.A.; Ababio-Donkor, A.; Ackaah, W. et al. (2023). Public perceptions of vehicular traffic emissions on health risk in Lagos metropolis Nigeria: A critical survey. *Heliyon*, *9*(5), e15712. https://doi.org/10.1016/j.heliyon.2023.e15712.

[31] Yahaya, T.; Umar, F.M.; Zanna, A.M.; Abdulmalik, A.; Ibrahim, B.A.; Bilyaminu, M.; Joseph, A. (2023). Concentrations and health risks of particulate matter (PM2.5) and associated elements in the ambient air of Lagos, Southwestern Nigeria. *Journal of Biological Research & Biotechnology*, *21*(3), 2141–2149. https://doi.org/10.4314/br.v21i3.9.

[32] Thabethe, N.N.L.; Engelbrecht, J.C.; Wright, C.Y.; Oosthuizen, M.A. (2014). Human health risks posed by exposure to PM10 for four life stages in a low socioeconomic community in South Africa. *Pan African Medical Journal*, *18*, 206. https://doi.org/10.11604/pamj.2014.18.206.3393.

[33] Khaniabadi, Y.O.; Goudarzi, G.; Daryanoosh, S.M. (2017). Exposure to PM10, NO_2, and O_3 and impacts on human health. *Environmental Science and Pollution Research*, *24*, 2781–2789. https://doi.org/10.1007/s11356-016-8038-6.

[34] Abdul Shakor, A.S.; Muhammad, A.P.; Mohamad, I.M. (2020). Effects of Population Weighting on PM_{10} Concentration Estimation. *Journal of Environmental and Public Health*, Article ID 1561823. https://doi.org/10.1155/2020/1561823.

[35] Rojas-Rueda, D.; Morales-Zamora, E.; Alsufyani, W.A.; Herbst, C.H.; AlBalawi, S.M.(2021). Environmental Risk Factors and Health: An Umbrella Review of Meta-Analyses. *International Journal of Environmental Research and Public Health*, *18*(2), 704. https://doi.org/10.3390/ijerph18020704.

[36] Hall, R.M.; Earnest, G.S.; Hammond, D.R.; Dunn, K.H.; Garcia, A. (2014). A summary of research and progress on carbon monoxide exposure control solutions on houseboats. *Journal of occupational and environmental Hygiene*, *11*(7), D92–D103. https://doi.org/10.1080/15459624.2014.895374.

[37] Gozubuyuk, A.A.; Dag, H.; Kacar, A.; Karakurt, Y.; Arica, V. (2017). Epidemiology, pathophysiology, clinical evaluation, and treatment of carbon monoxide poisoning in child, infant, and fetus. *Northern Clinics of Istanbul*, *4*(1), 100–107. https://doi.org/10.14744/nci.2017.49368.

[38] Wang, Y.; Yao, C.; Xu, C. (2019). Carbon monoxide and risk of outpatient visits due to cause-specific diseases: a time-series study in Yichang, China. *Environmental Health*, *18*, 36. https://doi.org/10.1186/s12940-019-0477-3.

[39] Odekanle, E.L.; Fakinle, B.S.; Akeredolu, F.A.; Sonibare, J.A.; Adesanmi, A.J. (2016) Personal exposures to particulate matter in various modes of transport in Lagos city, Nigeria, Cogent *Environmental Science*, *2*(1), 1260857. https://doi.org/10.1080/23311843.2016.1260857.

[40] Njoku, K.L.; Rumide, T.J.; Akinola, M.O.; Adesuyi, A.A.; Jolaoso, A.O. (2016). Ambient Air Quality Monitoring in Metropolitan City of Lagos, Nigeria. *Journal of Applied Science and Environmental Management*, *20*(1), 175–185. http://doi.org/10.4314/jasem.v20i1.21.
[41] Abulude, F.O.; Damodharan, U.; Acha, S. (2021). Preliminary Assessment of Air Pollution Quality Levels of Lagos, Nigeria. *Aerosol Science and Engineering*, *5*, 275–284. https://doi.org/10.1007/s41810-021-00099-1.
[42] [Kolawole, T.O.; Olatunji, A.S. (2023). Assessment of concentration of the potentially toxic elements and associated human health risk from particulate matter exposure along road intersections in Ibadan, southwestern Nigeria. *Discovery Environment*, *1*, 3. https://doi.org/10.1007/s44274-023-00005-1.
[43] Diagi, B.; Suzan, A.; Nnaemeka, O.; Ekweogu, C.; Acholonu, C.; Emmanuel, O. (2022) An Assessment of Vehicular Emission in the Vicinity of Selected Markets in Owerri, Imo State, Nigeria. *Journal of Geoscience and Environment Protection*, *10*, 1–12. https://doi.org/10.4236/gep.2022.101001.
[44] Adam, M.E. (2013). Suspended Particulates Concentration (PM_{10}) under Unstable Atmospheric Conditions over Subtropical Urban Area (Qena, Egypt). *Advances in Meteorology*, Article ID 457181. https://doi.org/10.1155/2013/457181.
[45] Sarpong, S.A.; Donkoh, R.F.; Konnuba, J.K.-S.; Ohene-Agyei, C.; Lee, Y. (2021). Analysis of $PM_{2.5}$, PM_{10}, and Total Suspended Particle Exposure in the Tema Metropolitan Area of Ghana. *Atmosphere*, *12*, 700. https://doi.org/10.3390/atmos12060700.
[46] Wambebe, N.; M.; Duan, X. (2020). Air Quality Levels and Health Risk Assessment of Particulate Matters in Abuja Municipal Area, Nigeria. *Atmosphere*, *11*(8), 817. http://dx.doi.org/10.3390/atmos11080817.