Air quality impact of carbon monoxide emission from diesel engine electric power generators

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RESEARCH ARTICLE

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Air quality impact of carbon monoxide emission from diesel engine electric power generators

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Abstract

An emissions inventory and the AERMOD View dispersion model were used to estimate the concentrations and the potential effects of carbon monoxide (CO) from diesel engine electric power generators operated by and providing electricity to a textile factory in Nigeria on its host air shed. The CO emissions from simultaneous operations of all of the electric power generators in the factory resulted in: 1-hr average CO emissions of 4.2 to 54.5 micrograms per cubic meters ($\mu g/m^3$) and 24-hr average CO emissions of 0.3 to 20.9 $\mu g/m^3$. The estimated 1-hr averaging period maximum ground-level concentrations of CO were deposited within the factory, while the 24-hr maximum ground-level concentrations are estimated at a distance 90 meters (m) from the factory in a southeast direction. The ground-level concentrations of CO emanating from the textile factory are within the stipulated ambient air quality standards.

KEYWORDS
diesel, emission inventory, energy, ground-level concentration, textile industry

1 | INTRODUCTION

In developing countries such as Nigeria, energy demand is growing rapidly due to urbanization and industrialization. This trend is likely to continue as the country's industrial development increases. Energy has a major impact on every nation's socioeconomic life and development. An inadequate supply of energy will restrict socioeconomic activities, limit economic growth, and adversely affect the quality of life (Ugwu, Nwankwojike, Ogbonnaya, & Ekoi, 2012). The inadequate supply of energy from the power sector in Nigeria has led to a loss of faith among citizens, causing them to resort to the self-generation of electric power through the use of diesel engine generators in order to meet their required energy needs (Adegbola, Kolawole, & Olabiyi, 2012). In regard to the operation of diesel engines, gaseous emissions are of great concern. A major component of the criteria air pollutants emitted by generators is carbon monoxide (CO) (Idiata, Omoruyi, & Aiwize, 2010), which is the focus of this study.

The environmental impacts of air pollutants cannot be overemphasized, and their impacts on agriculture have been established (Lieffering, Kim, Kobayashi, & Okada, 2004). Water in the atmosphere serves as sink for sulfur dioxide (SO_2) (Johnson & Fegley, 2002), and the resulting water can be harmful to vegetation (Cape, 2003) and aquatic life (Havens, Yan, & Keller, 1993). Other impacts may be human health based (Adler, 2010). CO is readily absorbed from the lungs into the blood stream, resulting in competitive binding between it and oxygen to hemoglobin in the red blood cells, forming carboxyhemoglobin and oxyhemoglobin, respectively. Carboxyhemoglobin causes a decrease in the oxygen carrying capacity of the blood, thus inducing toxic effects that are dangerous to human health (World Health Organization [WHO], 1999). Furthermore, several health effects associated with NO_x have created a need for a threshold level in the atmosphere (WHO, 2000).

The impacts of pollutants released to the atmosphere are not always restricted to the point of release. Contaminants discharged into the air are transported over long distances by large-scale airflows and dispersed by small-scale airflows or turbulence, which serve to mix contaminants with clean air (Gilmore, Adams, & Lave, 2010). Emission rates, wind speed, and wind direction are strong factors influencing the transport of these pollutants away from their sources. Atmospheric dispersion models are widely used to make predictions and/or to solve problems associated with the emission of pollutants into the atmosphere (Zannetti, 1990).

The focus of this study is on the nearby environmental impact of CO emissions from the diesel power generating facilities of a textile factory located in one of the industrial estates in Lagos State, Nigeria.

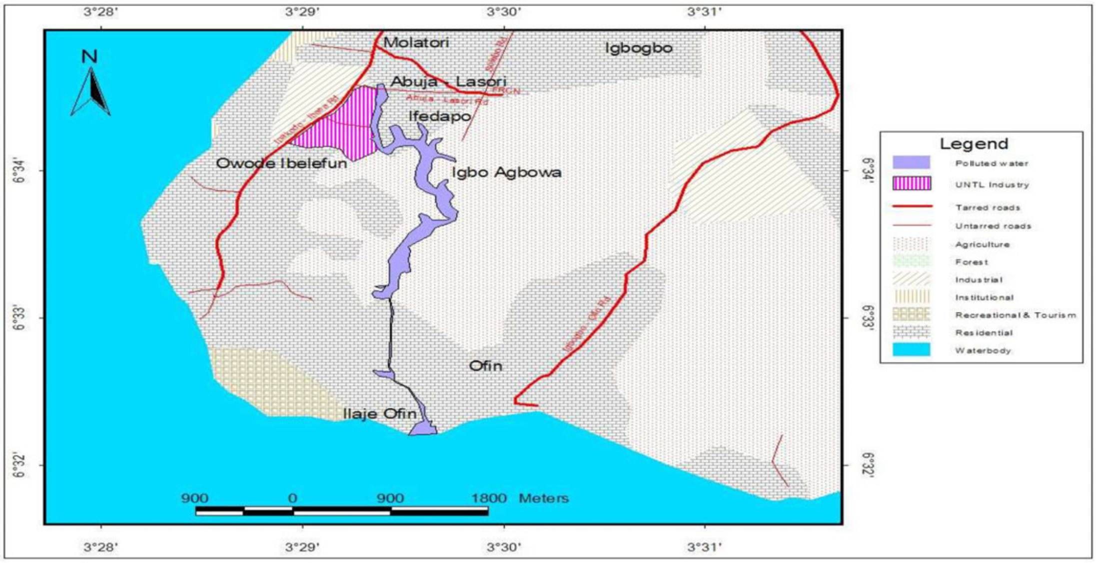

EXHIBIT 1 The study area, Ikorodu, Lagos Nigeria [Color figure can be viewed at wileyonlinelibrary.com]

2 | METHODOLOGY

2.1 | Study area

The study area for this research is a factory located at Ikorodu Local Government, Lagos State—the industrial and commercial hub of Nigeria (**Exhibit 1**). The factory is located in an area with geographical coordinates of 6°34′19″N and 3°29′9″E. Because of rapid growth in urbanization and industrialization, the need for electricity as a source of energy has been on the increase. As a result of this growth in demand, the national grid supply of electricity in Nigeria does not currently have the required capacity to service the needs of both industry and the populace. Hence, CO emissions from the diesel engine power generators that are employed in the studied factory to generate electricity are the subject of this study.

2.2 | AERMOD modeling system

The Industrial Source Complex (ISC) AERMOD View software used in this study is a user-friendly interface for three air dispersion models: the Industrial Source Complex Short Term model 3 (ISCST3) from the United States Environmental Protection Agency (US EPA); Industrial Source Complex-Plume Rise Model Environments (ISC-PRIME) developed by the Electric Power Research Institute (EPRI); and AERMOD, developed by the US EPA and the American Meteorological Society, in a version developed specially for Microsoft Windows and that runs under Windows 95/98/Me/NT/2000 and XP. The ISC-AERMOD View uses pathways that compose the run-stream file as the basics for its functional organization. These pathways include:

- Control Pathway (CO), where the modeling scenario and the overall control of the modeling run is specified;
- Source Pathway (SO), where the sources of pollutant emissions are defined;
- Receptor Pathway (RE), where the receptors considered to determine the air quality impact at specific locations are defined;
- Meteorology Pathway (ME), where the atmospheric conditions of the area being modeled are defined so they can be taken into account when determining the distribution of air pollution impacts for the area;
- Terrain Grid Pathway (TG), where the option of gridded terrain data can be used to calculate dry deposition in elevated or complex terrain; and
- Output Pathway (OU), where the output results necessary to meet the needs of the air quality modeling analyses are determined (Deligiorgi, Philippopoulos, & Karvounis, 2013).

2.3 | Emission sources in the factory

The factory is divided into five sections with each having its own installed generators. These sections and their generators are listed in the following subsections.

2.3.1 | Spinning and weaving section

The spinning and weaving section of the factory is equipped with five Cummins electric power generator units (GRT1–GRT5) (as shown in the table in **Exhibit 2**), each having a capacity of 700 kilovolt-amperes (kVA); a 931 kVA Cummins electric power generator unit (GRT6), a 1405 kVA Cummins electric power generator unit (GRT7), and a 1380 kVA Cummins electric power generator unit (GRT8).

2.3.2 | Printing and dyeing section

The diesel electric generators in the printing and dyeing section include three Cummins electric power generator units with capacities of 1380 kVA (GRT9, GRT10, and GRT11) and an addition two Cummins electric power generators units with capacities of 1019 kVA (GRT12) and 1220 kVA (GRT13).

2.3.3 | Motel section

The motel section of the factory includes a Cummins electric power generator unit with a capacity of 800 kVA (GRT14), a Perkins electric

EXHIBIT 2 Emission sources characteristics and parameters used in the dispersion modeling

Emission source	Discharge temperature (°C)[b]	Exhaust flow rate (m^3/min)[b]	Release height (m)[a]	Stack diameter (m)[a]	Exit velocity (m/s)[c]	Fuel consumption (Liter/s)	Location		Emission (g/s) CO[d]
							X(m)	Y(m)	
GRT1	557.2	154.4	6	0.15	145.6	0.0000	3,149.99	5,778.07	0.0000
GRT2	557.2	154.4	6	0.15	145.6	0.0043	3,161.28	5,789.35	0.0552
GRT3	557.2	154.4	6	0.15	145.6	0.0036	3,228.99	5,789.35	0.0462
GRT4	557.2	154.4	6	0.15	145.6	0.0006	3,262.85	5,789.35	0.0077
GRT5	557.2	154.4	6	0.15	145.6	0.0039	3,307.99	5,789.35	0.0501
GRT6	516	63.3	6.8	0.15	59.7	0.0043	3,240.28	5,766.78	0.0552
GRT7	475	237.8	6	0.2	126.2	0.0082	3,217.71	5,766.78	0.1053
GRT8	520	257	6	0.2	136.3	0.0149	3,262.85	5,800.64	0.1912
GRT9	520	257	5.3	0.2	136.3	0.0193	3,138.71	5,710.35	0.2477
GRT10	520	257	5.3	0.2	136.3	0.0209	3,104.85	5,665.21	0.2683
GRT11	520	257	5.3	0.2	136.3	0.0049	3,082.28	5,653.93	0.0629
GRT12	847	63.5	5.3	0.15	59.9	0.0046	3,048.43	5,631.36	0.0590
GRT13	525	240.7	5.3	0.2	127.7	0.0081	3,037.14	5,608.79	0.1040
GRT14	574	64.3	3.7	0.22	28.2	0.0056	3,228.99	5,315.37	0.0719
GRT15	543.8	66.4	3.7	0.16	55.0	0.0048	3,228.99	5,270.23	0.0616
GRT16	513	60.46	3.2	0.22	26.5	0.0048	3,285.42	5,270.23	0.0616
GRT17	487.7	103.5	3.3	0.2	54.9	0.0024	3,285.42	5,225.09	0.0308
GRT18	499.8	378.5	11.8	0.5	32.1	0.0127	3,082.28	5,078.38	0.1630
GRT19	499.8	378.5	11.8	0.5	32.1	0.0229	3,116.14	5,078.38	0.2939
GRT20	499.8	378.5	11.8	0.5	32.1	0.0042	3,149.99	5,044.52	0.0539
GRT21	499.8	378.5	11.8	0.5	32.1	0.0150	3,183.85	5,044.52	0.1925
GRT22	500	185	4.1	0.23	74.2	0.0005	2,867.86	5,213.80	0.0064

[a]Measured in the factory.
[b]Obtained from plant manufacturers.
[c]Calculated from the provided exhaust flow rate by manufacturers and the measured stack parameter.
[d]Calculated using emission factor in AP-42 (EPA, 1995) and the provided past six months diesel consumption rates by the factory.

power generator unit with a capacity of 375 kVA (GRT15), a Cummins electric power generator unit with a capacity of 338 kVA (GRT16), and an L-Sommer electric power generator unit with a capacity of 388 kVA (GRT17).

2.3.4 | Filament section

The filament section of the factory has four A-Van Kaick (BA16M-528) electric power generator units with capacities of 2000 kVA (GRT18, GRT19, GRT20, and GRT21).

2.3.5 | Fiber section

The fiber section of the factory is powered by GRT22, an L-Sommer electric power generator unit with a capacity of 950 kVA.

Thus, a total of 22 electric power generator units are installed at the factory with a total capacity of 24,108 kVA.

The modeling effort for this study considered emissions from the stacks of the diesel generators identified as the main sources of CO in the factory. The CO emissions are the results of the combustion activities in the power plants. Emission rates and exhaust vent stack parameters (height, diameter, exhaust temperature, and exit velocity) used as model input parameters were provided from the manufacturer (see table in Exhibit 2). The modeling exercise considered six different scenarios of emissions from the point sources identified in the factory. These scenarios are the "worst case" in each of the sections, in which all of their electric power generators are in operation, while the last scenario assumed that all of the electric power generators in the factory are in operation.

EXHIBIT 3 Standards of ambient air quality for carbon monoxide

Averaging period	Limit	
	FEPA[a]	World Bank[b]
1 hr	22,800	30,000 (25 ppm)
24 hr	11,400	10,000

[a]Source: Federal Environmental Protection Agency (FEPA, 1991), Nigeria.
[b]Source: World Bank (1998).

Meteorological information is also an essential input requirement in the ISCST3 air dispersion modeling. Due to the lack of upper air observations at the Lagos airport, which would be the nearest synoptic meteorological station to the study location, the meteorological data set for the project location was compiled using meteorological observation data from the Cotonou Cadjehoun Airport in Cotonou, Benin. The prevailing winds in Cotonou are in a southeasterly direction, which is consistent with the winds observed at the factory area.

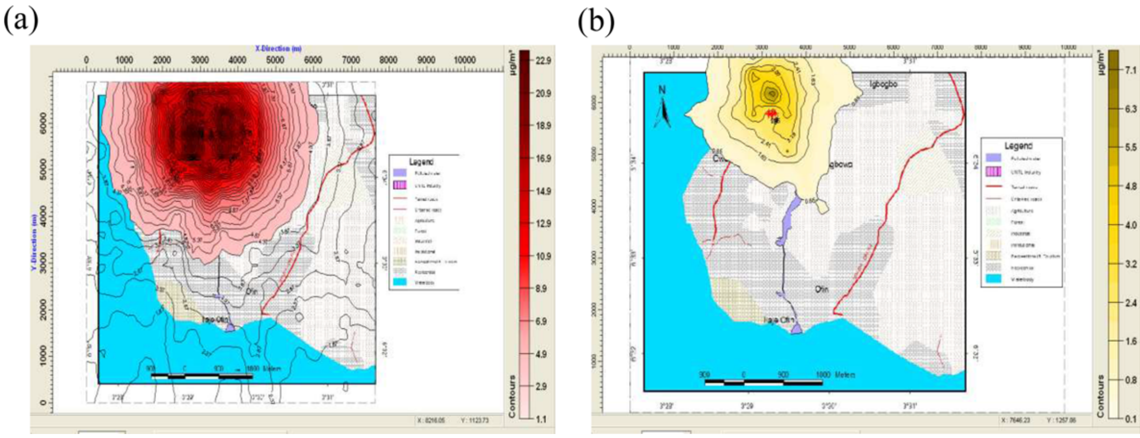

EXHIBIT 4 (a, b) 1-hr and 24-hr ground-level CO from the spinning and weaving generators [Color figure can be viewed at wileyonlinelibrary.com]

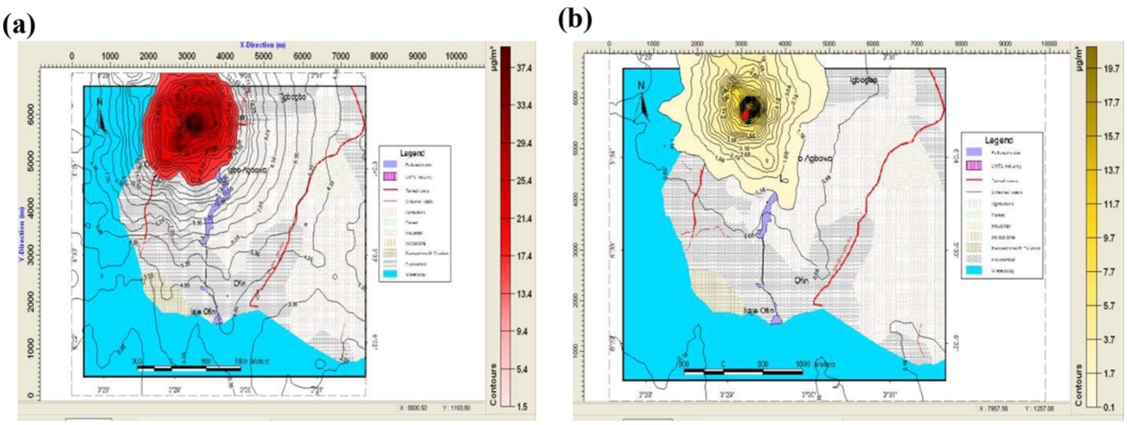

EXHIBIT 5 (a, b) 1-hr and 24-hr ground-level CO from the printing and dyeing generators [Color figure can be viewed at wileyonlinelibrary.com]

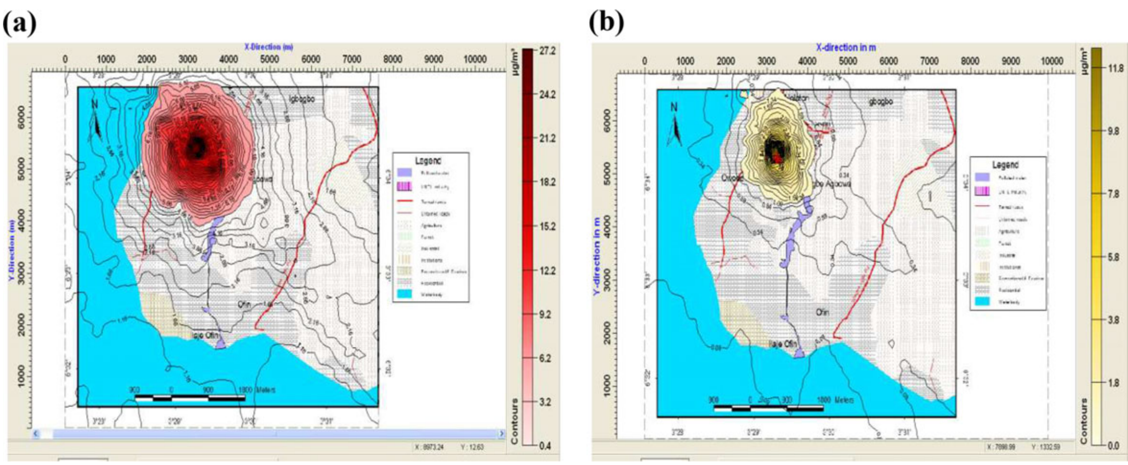

EXHIBIT 6 (a, b) 1-hr and 24-hr ground-level CO from the motel generators [Color figure can be viewed at wileyonlinelibrary.com]

3 | RESULTS AND DISCUSSION

3.1 | Modeling results

From the six scenarios considered, the key findings of the dispersion modeling are herein presented. The standards for ambient air quality for CO using the averaging periods considered in this study are shown in the table in **Exhibit 3**. The impacts on ambient air quality of the textile host environment are discussed.

3.2 | Ground-level concentrations

Exhibits 4 through 9 show the estimated ground-level concentrations of CO emissions as obtained in the modeling exercise. From the

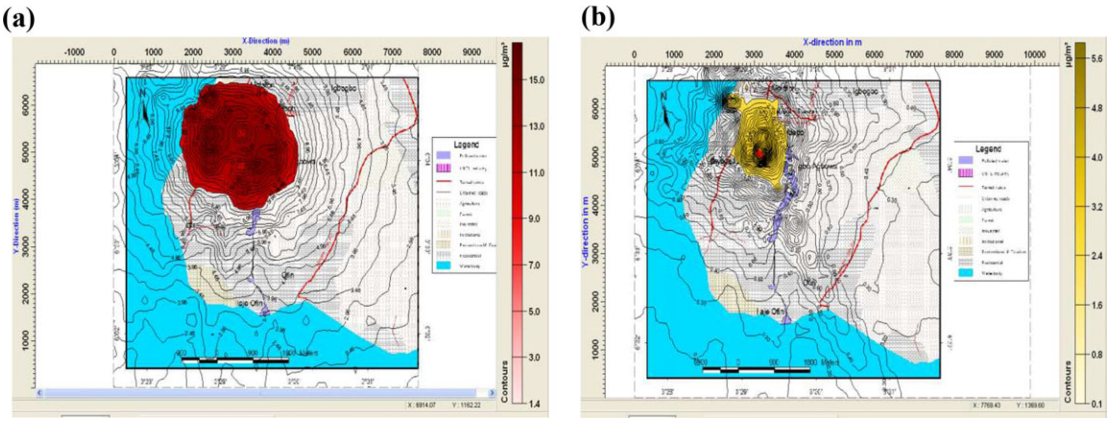

EXHIBIT 7 (a, b) 1-hr and 24-hr ground-level CO from the filament section generators [Color figure can be viewed at wileyonlinelibrary.com]

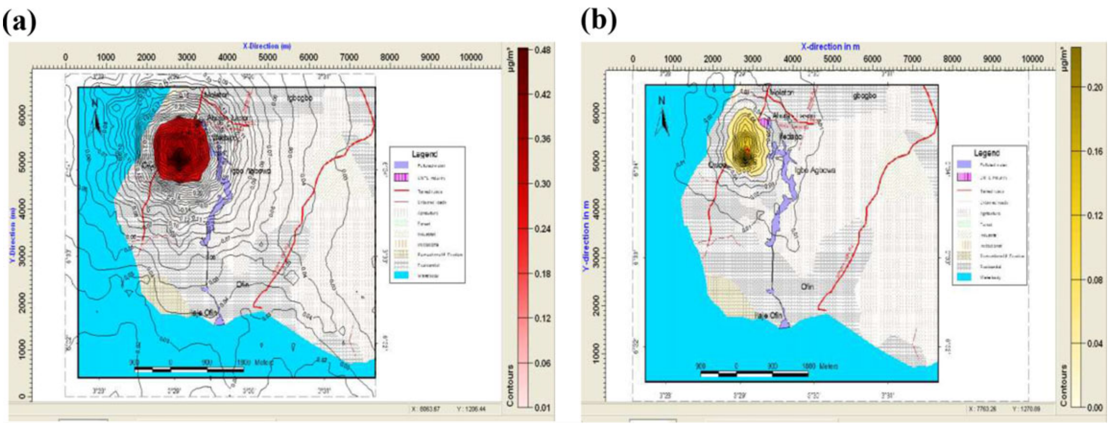

EXHIBIT 8 (a, b) 1-hr and 24-hr ground-level CO from the fiber section generators [Color figure can be viewed at wileyonlinelibrary.com]

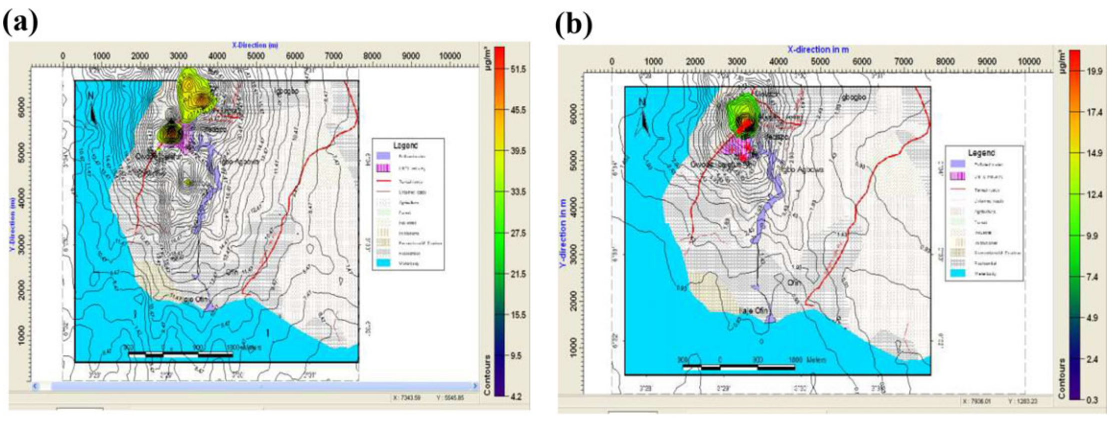

EXHIBIT 9 (a, b) 1-hr and 24-hr ground-level CO from the combined generators [Color figure can be viewed at wileyonlinelibrary.com]

spinning and weaving section electric power generators emissions in the factory, the 1-hr ground-level CO concentrations were 1.1 to 23.4 micrograms per cubic meters (μg/m^3) (**Exhibit 4**a), while their 24-hr averaging period CO concentrations were 0.1 to 7.1 μg/m^3 (Exhibit 4b). The calculated 1-hr averaging period ground-level concentrations of CO from the printing and dyeing section electric power generators emissions in the factory were 1.5 to 39.4 μg/m^3 (**Exhibit 5**a), with the 24-hr CO concentrations of 0.1 to 20.7 μg/m^3 (Exhibit 5b).

The CO Emission from the motel section of the factory resulted in 1-hr averaging period CO ground-level concentrations of 0.4 to 27.2 μg/m^3 (**Exhibit 6**a), with 24-hr concentrations of 0.0 to 12.3 μg/m^3 (Exhibit 6b). The emissions from the filament section resulted in 1-hr CO ground-level concentrations of 1.4 to 16.5 μg/m^3 (**Exhibit 7**a), but 0.1 to 5.8 μg/m^3 (Exhibit 7b) as 24-hr averaging period levels.

In the fiber section of the factory, emissions from the electric power generators resulted in 1-hr and 24-hr averaging periods ground-level CO concentrations of 0.01 to 0.48 μg/m^3 (**Exhibit 8**a) and 0.00 to 0.22 μg/m^3 (Exhibit 8b), respectively. The emissions from the simultaneous operation of all of the electric power generators in the factory resulted in 1-hr ground-level CO concentrations of 4.2 to 54.5 μg/m^3 (**Exhibit 9a**), and 24-hr ground-level CO concentrations of 0.3 to 20.9 μg/m^3 (Exhibit 9b).

3.3 | Impacts of the factory's electric generators on selected receptors

From the spinning and weaving generators' emissions, the calculated impacts on selected receptors around the factory were 0.01 to 0.02% of the CO limit, from the printing and dyeing section generators, the calculated impacts on these receptors were 0.01 to 0.18% of the CO limit. The motel section generators in the factory have an impact on the ambient air quality of the host environment of 0.01 to 0.11% of the CO limit, while from the filament section generators, the impacts were 0.01 to 0.03% of the CO limit. The impact from the fiber section generator was 0.01% of the CO limit. The cumulative impacts of CO emissions from the simultaneous operations of all of the electric power generators in the factory were 0.01 to 0.08% of the CO limit.

4 | CONCLUSIONS

The emissions inventory of the diesel electric power generators in the factory shows that the generators in the spinning and weaving section of the factory emit CO of 0.0077 to 0.1912 grams per second (g/s). In the printing and dyeing section, the emission rates of CO into the atmosphere are 0.0590 to 0.2683 g/s. The motel section of the factory's electric power generators are releasing 0.0308 to 0.0616 g/s of CO into the host environment's air shed. Emission rates of CO from the diesel electric power generators in the filament section of the factory are 0.0539 to 0.2939 g/s, but in the fiber section, the CO emission rates are 0.0064 g/s.

Generally, the ground-level concentrations of CO emanating from the textile factory in Lagos State are within the stipulated ambient air quality standards.

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