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DISPERSION MODELLING OF PARTICULATE EMISSION FROM OFF-GRID DIESEL ENGINE ELECTRIC POWER GENERATORS

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ABSTRACT

Emission inventories and ISC-Aermod dispersion modeling tool were used to investigate the impacts of particulate matter (PM) emission from off-grid electric power generators used by a textile factory on ambient air quality (AAQ) of the immediate and distant environment of the plant. Information on diesel consumption obtained from the factory was combined with emission factor of diesel powered generators to obtain the emission rates of PM. The emission rates, meteorological parameters, terrain grid and output pathways were inputed into the ISC-Aermod dispersion modeling tool to obtain the ground level concentrations (GLC) of PM. The maximum GLCs were compared with AAQ limit of 250 µg/m^3 set for PM by Nigeria's Federal Ministry of Environment to establish their impacts. Results showed that worst case scenario (WCS) gave PM concentrations of 1.4 – 17.8 µg/m^3 and 0.1 – 6.8 µg/m^3 for 1-hr and 24-hrs averaging period respectively. The predicted impact using the WCS showed that the ambient PM of the host air shed changed by 0.1 - 1.2% of FMENV standard. It was concluded that emissions from factory would not significantly affect the ambient PM of the host air shed.

Keywords: Emission inventory, point sources, ISC-AERMOD, worst case scenario, ground level concentration

INTRODUCTION

Despite the huge potential of Africa to generate energy due to the abundance of natural resources, it is the poorest continent in terms of energy utilization with a total energy consumption of less than 3% of global primary energy demand (Agboola, 2011). Many communities in Nigeria have no or limited access to large scale or integrated electricity through the national grid (Stephen *et al.,* 2012). The erratic state of electricity supply in Nigeria has necessitated the need for industries to operate fossil fuel generators to meet the short fall in their energy demand. Use of generator has been a more stable supplement to the national grid that is characterized by frequent and persistent outages. According to World Bank (2005), well over 90% of Nigerian businesses have generators as backups. The most common form of off grid supply for industries in the country are generators running on diesel. However, operation of utilities such as diesel generators will emit particulates (Xing *et al*., 2012). Particulate matter from energy production systems have been of concern due to their impacts on human health and environment (Sacks *et al*., 2010). Either by intrinsic or extrinsic toxicities, they have been known to pose severe health hazards (Lu *et al*., 2008).

The particles can remain suspended in air and transported to air shed outside of the plant. The possibility of transportation of pollutants to some far distances necessitated the need for dispersion modeling. Air dispersion modeling uses mathematical formulations to quantify the atmospheric processes that disperse a pollutant emitted by a source. Based on emissions and meteorological inputs, dispersion models can be used to predict concentrations at some selected downwind receptor locations. Such models are widely used in the management of impact of pollutant emissions on the environment.

In this study, emission inventory and AERMOD dispersion modeling tool (version 4.8 serial number ISCAY0002488) were used to predict the emission rates, ground level concentrations of TSP emitted by factory generators and their impacts on the host airshed.

MATERIALS AND METHODS

Study Area Description

The study area was a factory in Ikorodu area of Lagos State, Nigeria (Fig.1). It is located along the Lagos Lagoon, and shares boundary with Ogun State, Nigeria. Ikorodu, being a part of Lagos, is among the fastest growing urban centre in Nigeria. Rapid population and industrial growth in Ikorodu has affected the demand for electricity as a major source of energy. Based on 2006 Census figures (Nigeria's last official Census figures), Ikorodu had an enumerated population of 535,619 (NPC, 2006). Diesel engine electric power generators are engaged in the factory to privately generate electricity for its activities. This is to meet up with the electric power requirements in the factory since there is presently heavy shortage of electricity from the national grid. The factory has five sections and each of these has dedicated diesel engine electric power generators. In all, there is a total 22 units of electric power generators with total installed capacity of 24,108 kVA.

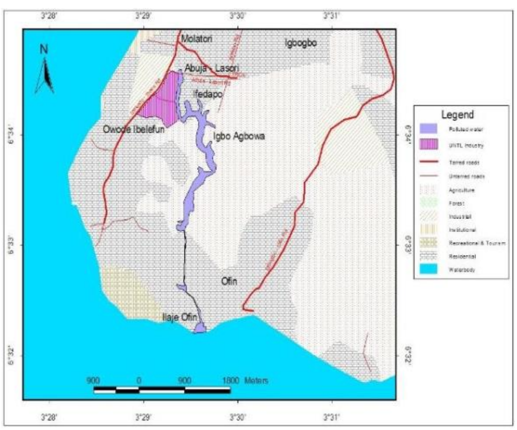

Fig. 1: Study area and its host

Emission Sources in the Factory

The sources of particulate emission were the 22 units electric power generators installed for smooth production activities. These are: G1, G2, G3, G4, G5, G6, G7 and G8 in the Spinning and weaving section; G9, G10, G11, G12 and G13 in the Printing and Dyeing section; G14, G15, G16 and G17 in the Motel section; G18, G19, G20 and G21 in the Filament section; and G22 in the Fiber section.

Emission Rate Determination

The point sources in the factory were identified and information on fuel usage was obtained from the factory and combined with emission factor of point sources (EPA, 1995). PM emission for each section was determined as the sum of emissions from point source(s) in that section while the overall emission from the factory was determined as sum of emissions from all sections in the factory. The PM emission rate was calculated with Equation 1.

$$\text{Emission rate (g/s)} = \text{Fuel Consumption(l/s)} \times \text{TSP emission factor} \quad (1)$$

Dispersion Modeling

The ISC-AERMOD View air dispersion modeling tool was employed in the dispersion modeling exercise. It takes as input PM emission rates, meteorological and land surface characteristics data. To predict the 1 hour and 24 hours ground level concentrations of PM emitted by point sources in the factory and their impacts on the neighbourhood, six emission scenarios based on worst cases from each section were created. Unavailability of upper air observations in the Lagos airport, the nearest synoptic meteorological station to the study location, necessitated the use of meteorological dataset from Cotonou meteorological observation. Cotonou (Benin) shares boundary with Lagos (Nigeria) and is about 106 km from Lagos on the west coast of Africa. The meteorological station is located at Cotonou airport on coordinate 6.36^{O}N and 2.38^{O}E and has winds having prevalence in the southwesterly direction which is consistent with the winds observed at the project area (Sonibare and Ede, 2009; NIMET, 2011). The study area has predominantly overland wind source with tree heights ranging from 10 - 15 m. The value used for the roughness length in this study was 0.16 for overland fetch as recommended by U.S. EPA for these types of terrain. Using land use pattern classification by Auer (1978), the study area is classified as rural.

RESULTS AND DISCUSSION

The PM emission rates obtained are as summarized in Table 1. The estimated TSP emission rates from the five sections of the factory were 0.1666, 0.2420, 0.0738, 0.2295 and 0.0021 g/s for scenarios 1, 2, 3, 4 and 5 respectively while the overall TSP emission associated with the diesel power generators in the factory was 0.714 g/s. Due to atmospheric dispersion processes, the emitted particulate will be transported downwind. It is thus important to consider the ground level concentrations of the emitted particulate matter and their impacts on the host air shed. In scenario 1, the ground level concentrations of total suspended particulate from the factory were predicted for 1-hour and 24-hour averaging period to be 0.3 – 7.6 µg/m^3 (Figure 4a) and 0.0 – 2.3 µg/m^3 (Figure 4b) respectively while in scenario 2, they were 0.5 – 12.8 µg/m^3 (Figure 5a) and 0.0 – 6.5 µg/m^3 (Figure 5b).

Table 1: Emissions sources and emission rate

Factory Section	Source/fuel consumption (Liter/s)	Location (m)		Emission rate (g/s)
		X	Y	
Spinning and Weaving (Scenario 1)	G 1/ 0.0000	3149.99	5778.07	0.0000
	G 2/ 0.0043	3161.28	5789.35	0.0180
	G3/ 0.0036	3228.99	5789.35	0.0151
	G 4/ 0.0006	3262.85	5789.35	0.0025
	G 5/ 0.0039	3307.99	5789.35	0.0163
	G 6/ 0.0039	3240.28	5766.78	0.0180
	G7 / 0.0082	3217.71	5766.78	0.0343
	G 8/ 0.0149	3262.85	5800.64	0.0624
Printing and Dyeing (Scenario 2)	G 9/ 0.0193	3138.71	5710.35	0.0808
	G 10/ 0.0209	3104.85	5665.21	0.0875
	G 11/ 0.0049	3082.28	5653.93	0.0205
	G 12/ 0.0046	3048.43	5631.36	0.0193
	G 13/ 0.0081	3037.14	5608.79	0.0339
Motel (Scenario 3)	G 14/ 0.0056	3228.99	5315.37	0.0235
	G 15/ 0.0048	3228.99	5270.23	0.0201
	G 16/ 0.0048	3285.42	5270.23	0.0201
	G 17/ 0.0024	3285.42	5225.09	0.0101
Filament (Scenario 4)	G 18/ 0.0127	3082.28	5078.38	0.0532
	G 19/ 0.0229	3116.14	5078.38	0.0959
	G 20/ 0.0042	3149.99	5044.52	0.0176
	G 21/ 0.0150	3183.85	5044.52	0.0628
Fiber (Scenario 5)	G 22/ 0.0005	2867.86	5213.80	0.0021
Scenario 6	All generators			0.714

In scenario 3, these were predicted to be 0.1 – 8.9 µg/m^3 (Figure 6a) and 0.0 – 4.0 µg/m^3 (Figure 6b) while in scenario 4, they were 0.5 – 5.4 µg/m^3 (Figure 7a) and 0.0 – 1.8 µg/m^3 (Figure 7b). In scenario 5, the 1 and 24-hour ground level concentrations of TSP from the power plant ranged between 0.0 – 0.2 µg/m^3 (Figure 8a) and 0.0 – 0.1 µg/m^3 (Figure 8b). In scenario 6 which implied emissions from simultaneous operations of all the electric power generators in the factory, the ground level concentrations of TSP were 1.4 – 17.8 µg/m^3 (Figure 9a) and 0.1 – 6.8 µg/m^3 (Figure 9b) for 1-hr and 24-hrs averaging periods respectively.

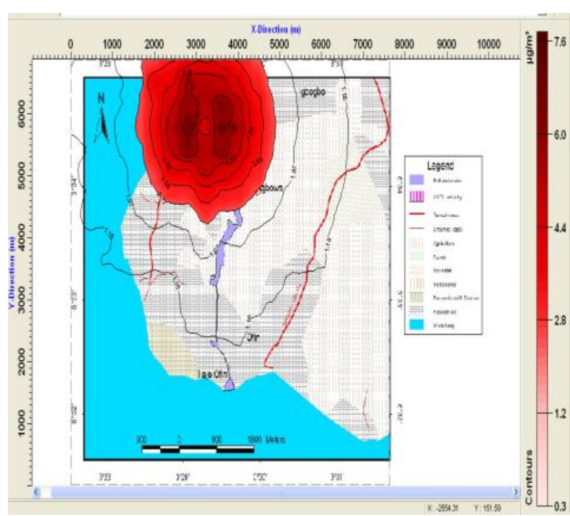

Figure 4a: 1-hour ground level TSP concentration from scenario 1

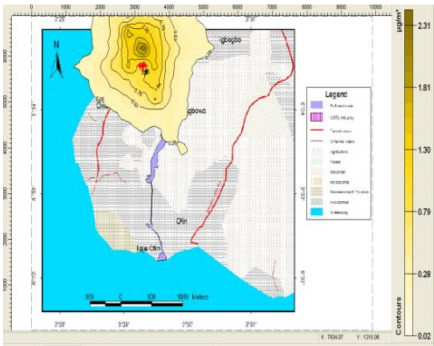

Figure 4b: 24-hour ground level TSP concentration from scenario 1

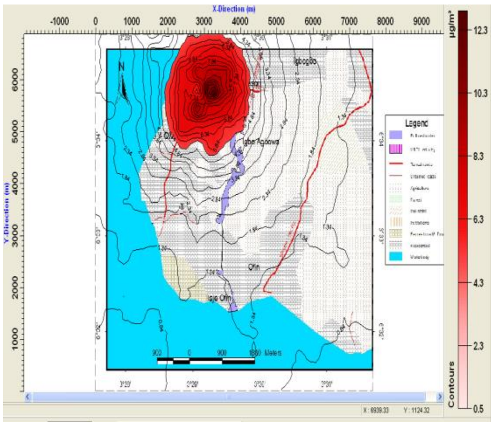

Figure 5a: 1-hour ground level TSP concentration from scenario 2

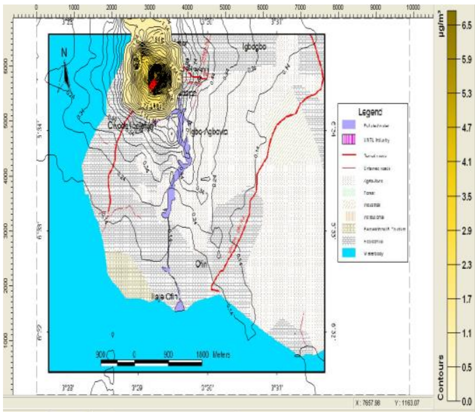

Figure 5b: 1-hour ground level TSP concentration from scenario 2

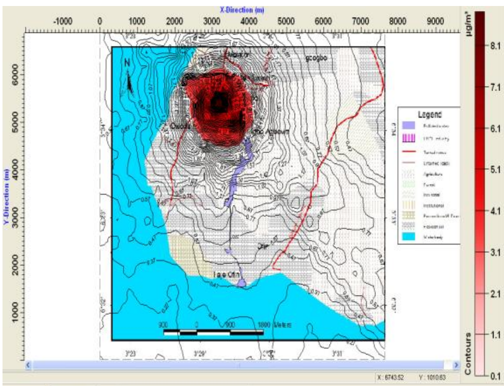

Figure 6a: 1-hour ground level TSP concentration from scenario 3

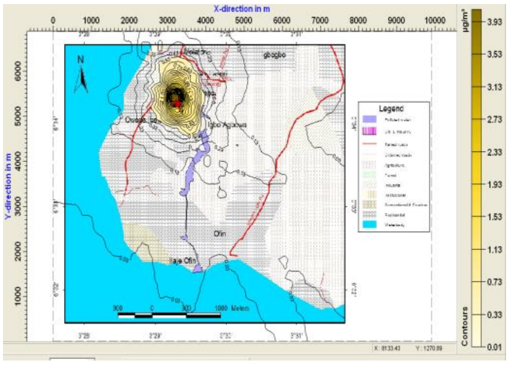

Figure 6b: 24-hour ground level TSP concentration from scenario 3

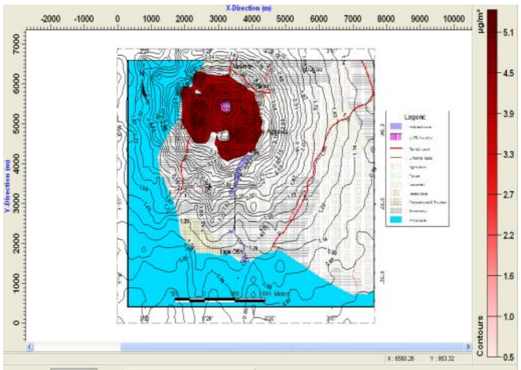

Figure 7a: 1-hour ground level TSP concentration from scenario 4

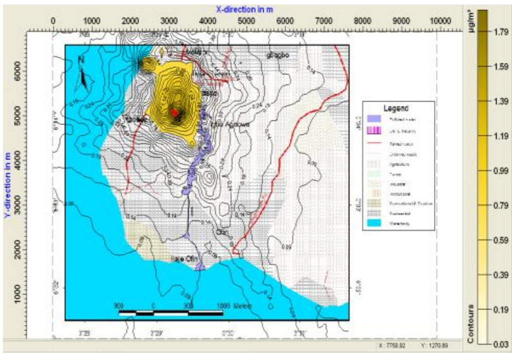

Figure 7b: 24-hour ground level TSP concentration from scenario 4

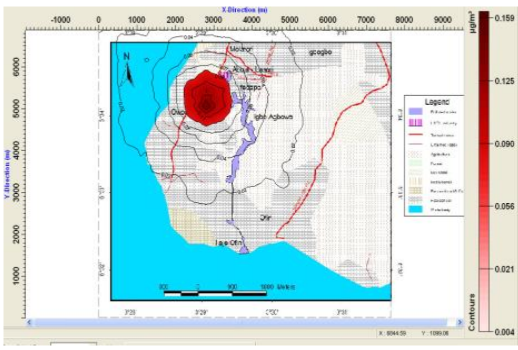

Figure 8a: 1-hour ground level TSP concentration from scenario 5

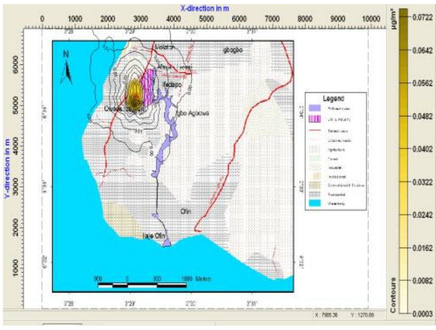

Figure 8b: 24-hour ground level TSP concentration from scenario 5

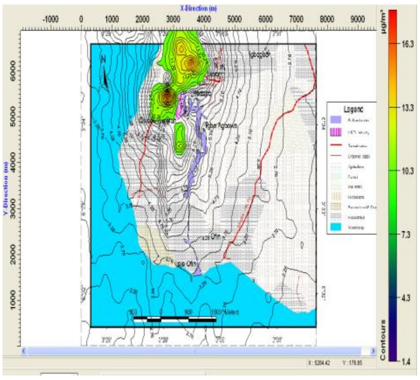

Figure 9a: 1-hour ground level TSP concentration from scenario 6

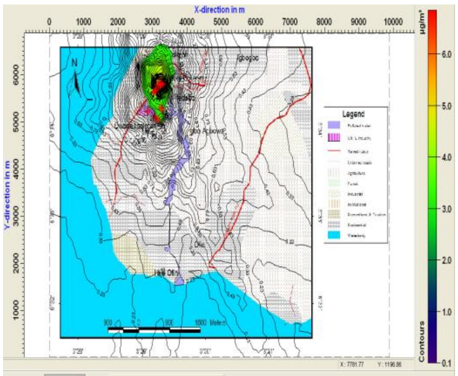

Figure 9b: 24-hour ground level TSP concentration from scenario 6

The locations of the emitted PM as predicted by the ISC-Aermod view dispersion modelling tool are summarized in Table 2. The maximum 1-hour averaging period ground level concentrations of PM from the Spinning and Weaving Section generators were within the perimeter fence of the Textile Mill but their 24-hour averaging period maximum ground level concentrations were at about 315 m northeast of the factory. The maximum 1-hour and 24-hour averaging periods ground level concentrations of PM emitted from the Printing and Dyeing Section generators were at the Factory's East Flank.

S	1-hr ($\mu g/m^3$)	Designation	24-hr ($\mu g/m^3$)	Designation
1	7.6	Within factory	2.3	315 m North East
2	12.8	East Flank	6.5	East Flank
3	8.9	East Flank	4.0	East flank
4	5.4	180 m South	1.8	180 m South East
5	0.2	187 m South	0.1	187 m South
6	17.8	Within factory	6.8	90 m South East

This same trend was observed for emissions from the Motel Section electric generators of the factory as both the 1-hour and 24-hour averaging period maximum ground level concentrations of TSP emanating from there were all at the Factory's East Flank. From the Filament Section generators, the associated 1-hour and 24-hour averaging period TSP maximum ground level concentrations were at about 180 m to the south of the factory. The 1-hour and 24-hour averaging period maximum ground level concentrations of TSP are at 187 m south of the factory. Whenever all the electric power generators in the factory are simultaneously operating, the predicted 1-hour averaging period maximum ground level concentrations of TSP were deposited within the factory while its 24-hour averaging period maximum ground level concentrations were deposited at 90 m away from the factory in the southeast direction.

The spread of emissions is affected by climatic conditions which determine their deposition rates that influence ground level concentrations. To investigate the impacts of particulate matter emission from the factory on the host air shed, Nigeria's ambient TSP standard for 24-hr averaging period was used as the basis for impact assessment. Summarized in Table 3 are the impacts of all the emissions from the factory in all the scenarios. Based on the worst case scenario (scenario 6) in which all the factory generators were in use, the TSP of the ambient environment will change by 0.1-1.2% of the standard with minimum and maximum impacts at Ofin and the factory, respectively.

Sensitive Receptor	Scenario 1 Conc. (μg/m³)	Scenario 1 % of Limit	Scenario 2 Conc. (μg/m³)	Scenario 2 % of Limit	Scenario 3 Conc. (μg/m³)	Scenario 3 % of Limit	Scenario 4 Conc. (μg/m³)	Scenario 4 % of Limit	Scenario 5 Conc. (μg/m³)	Scenario 5 % of Limit	Scenario 6 Conc. (μg/m³)	Scenario 6 % of Limit
Factory	0.8	0.3	6.5	2.6	4.0	1.6	1.1	0.4	0.0	0.0	2.9	1.2
Molatori	1.1	0.4	1.6	0.64	0.2	0.1	0.8	0.3	0.0	0.0	2.6	1.0
Igbogbo	0.2	0.08	0.3	0.1	0.9	0.4	0.2	0.1	0.0	0.0	0.5	0.2
Ifedapo	1.2	0.5	1.1	0.4	1.1	0.4	1.8	0.7	0.0	0.0	2.2	0.9
Owode Ibelefun	0.2	0.1	0.4	0.2	0.1	0.0	0.5	0.2	0.0	0.0	1.1	0.4
Igbo Agbowa	0.5	0.2	0.5	0.2	0.3	0.12	0.5	0.2	0.0	0.0	1.1	0.4
Ilaje Ofin	0.1	0.0	0.5	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.4	0.2
Ofin	0.1	0.0	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.3	0.1

CONCLUSION

The impacts particulate matter emission from off grid diesel engine electric power generators run by a textile factory on host environment have been investigated using emission inventory and dispersion modeling technique. The predicted concentrations of particulate matter at all receptor locations were in compliance with Nigeria's ambient TSP standard of 250 μg/m³. Based on the WCS, the PM of the ambient environment will change by 0.1 - 1.2% of the Nigeria's standard with minimum and maximum impacts at Ofin and the factory, respectively. Although, the ambient PM standard for 24-hour averaging period in Nigeria was not breached even in the worst scenario and the impacts of emissions from the factory appeared insignificant, the host ambient air may not be healthy if the contributions of other factories in the vicinity are factored into the study.

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