Communication in Physical Sciences, 2023, 9(4): 521-532

Investigation of the Safe Location for Private Electric Power Generators Servicing Residential Buildings in Nigeria

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Received: 11 April 2023/Accepted 29 August 2023/Published 02 September 2023

Abstract: *This study focused on the safe location for electric power generators servicing detached bungalows in the Nigerian environment via the determination of the air quality impact of primary air pollutants including carbon monoxide (CO), oxides of nitrogen (NOx), sulphur dioxide (SOx), particulate matter (PM) and volatile organic compounds (VOCs). The AERMOD view air emission dispersion modelling commercial software was used to predict the ground-level concentration of air pollutants entering buildings. These were compared with Nigeria's National Ambient Air Quality Standards (NAAQs) and WHO air quality standards to determine the indoor air quality impacts and predict the safe location for electric power operations. The results showed that predicted ground-level concentrations of CO, NOx, SO_x, PM and VOCs from electric power generators located at both 1 m and 4m from the residential building of interest at the various hours considered were within limits. However, it was observed that the location of generators at 1m or beyond from the house is relatively good and safe to limit hazards from air emissions. The findings will assist relevant authorities and individuals in developing and implementing a strategic air quality management plan for the safety of residential building occupants.*

Keywords: *Air emission, electric power generators, air quality impact, buildings*

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1.0 Introduction

The impact of energy on the socio-economic aspect of our lives cannot be overemphasized. It plays a vital role in the economic, social and political development of our nation. Inadequate supply of energy thus restricts socio-economic activities, limits economic growth and adversely affects the quality of life (Energy Commission of Nigeria, 2003). Today, industries and individuals do not rely on electricity from the national grid for high productivity despite Nigeria being energy resource abundant, this is a result of constant power outages. In the past three decades, Nigeria's electricity market has been incapable of providing minimum acceptable international standards of electricity service that can be characterized by reliability, accessibility and availability (Iwayemi, 2007). This has led the Nigerian population, which entails the industries and the domestic sector, to lose faith in the Nigerian power sector, hence, the predominance of self-generation of electricity by industries and individuals (Afam Power Station, 2011). In many countries, diesel and petrol-powered generators are used as backup or emergency power when the national grid fails or during power outages. They are also used to provide energy in remote areas. However, in Nigeria, generators have become the primary source of electricity for most residential, commercial and industrial, as supply from the national grid is still very low (Lawal *et al.,* 2017).

However, in the last two decades, the use of electric power generators including both diesel and gasoline-powered electric generators as one of the sources for the distributed generation of electricity is contributing to air quality problems as a result of increased global warming (Tong and Zhang, 2015). Air pollution remains one of the biggest environmental risks to human health in developing countries (Aung *et al.*, 2019). Changes in concentrations of air constituents have a significant effect on the quality of air in an environment (EPA, 2005). These air constituents are measured by accumulating a database for the discharge of air pollutants into the atmosphere called emission inventory (Baruch, 2008).

The emissions of air pollutants from the electric power generators give rise to deterioration of air quality and have negative effects on human health in the surrounding environment (Gilmore *et al.,* 2010). An electric power generator exhaust may contain more than forty (40) air pollutants which include various carcinogenic compounds such as arsenic, benzene and formaldehyde. It may also include the emission of primary air pollutants such as oxides of sulphur (SO_x), oxides of nitrogen (NO_x), carbon monoxide (CO), carbon dioxide (CO_2), hydrocarbons (HC) and particulate matter (PM) among others. These primary pollutants can cause poor air quality in a particular region (Brajmohan and Ahmed, 2018). In addition, about 97% of the generator-related fatalities, which included generator location information, were associated with operating carbureted generators in enclosed spaces such as a basement, garage, shed, or crawl space (Hnatov, 2008). The operation of electric power generators increases the unsafe and damaging factors such as exhaust gases, vibration and noise which break the ecological balance of an area. The gases emitted into the air from these engines can cause serious illness as well as oncological violations (Awofeso, 2011).

Furthermore, changes in climatic conditions such as temperature, water balance and direct sunshine may also lead to further deterioration of air quality that may have a high impact during heat waves (Jacobson, 2015; Papanastasiou *et al.,* 2015 and Harndy *et al.*, 2017). In many megacities, the air is already so heavily polluted with gaseous substances and particulates that it is no longer advisable to ventilate interior spaces with unfiltered outside air (Baklanov *et al.*, 2016). As people typically spend a large fraction of their time indoors, in homes, workplaces, shopping malls and restaurants the breathingbreathe clean air, and enjoy thermal comfort and visual health is critical. This right to a healthy indoor environment as a human right has been well emphasized by the constitution of the World Health Organization. (Margulis *et al.,* 2016).

In addition, electric power generators are major contributors to the aforementioned health and environmental challenges from the emissions of air pollutants, they also contribute significantly to noise pollution, which harms the quality of life of people living nearby (Tong and Zhang, 2015). In this regard, it is therefore considered necessary to identify and quantify these criteria air pollutants from common residential electric power generators servicing buildings in Nigeria. This will help to determine the ground-level concentrations of criteria air pollutants and to provide some insight into the appropriate location for the safe operation of the source of air pollutants in this study to improve indoor air quality in the country.

2.0 Materials and Methods

2.1 Study Area

The South- West Nigeria was used as the study area. South-West Nigeria lies within longitude 2º 48' – 6º0' E and latitude 5º5' – 9º12'N in the southwestern part of the country. This region consists of six states including Oyo, Ogun, Osun, Ekiti, Ondo and Lagos (Fig. 1), with Lagos representing a mega city in the South-West (Lawal *et al*., 2017). According to Nigeria Meteorological Station, the following annual weather conditions prevail in the South-West region using Lagos as reference: The temperature is usually around 28° C, the humidity is about 82%, the precipitation is around 1900 -1200 mm while the wind speed is about 10 km/h.

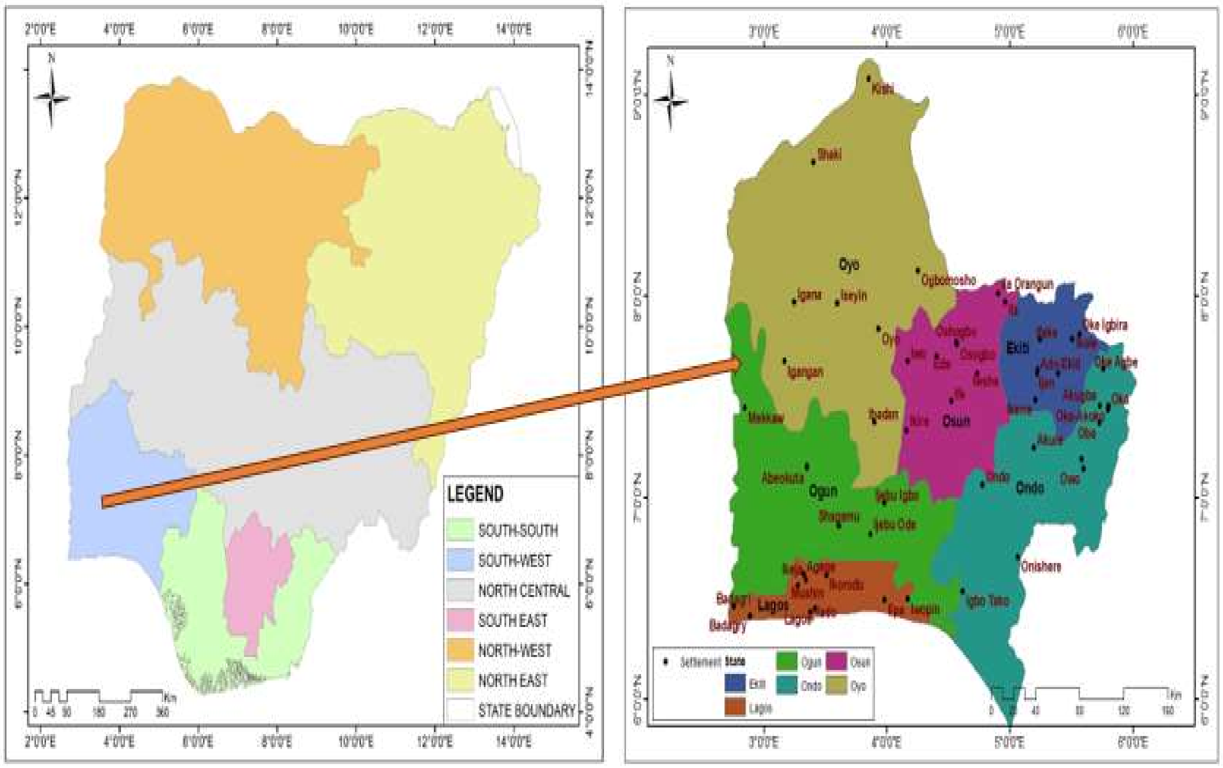


Fig. 1: South West Nigeria

2.2 Identification of relevant electric power generators

Generally, the common residential buildings identified in the Nigerian environment include duplexes, maisonettes, terrace apartments, blocks of flats, semi-detached bungalows, fully-detached bungalows and vernacular apartments. However, a fully detached bungalow is of interest in this study. The scaled floor of a detached bungalow was designed via Architectural tools such as AUTOCAD, Sketch Up and LUMION. However, the associated electric power generators used by occupants of the residential building of interest was determined by relevant information from vendors and distributors of electric power generators. Occupants of detached bungalows generally make use of a 4.5 kW gasoline electric power generator. Power usage was calculated based on the assumption that a group of house types including flats in blocks of flats, detached bungalows, and Semi-detached bungalows have similar power usage. Minimum power usage was calculated regarding regarding appliances used daily only. Table 1 shows power ratings and assumed usage in detached bungalows.

2.3 Estimation of air emission rates from electric power generators

The emissions of criteria air pollutants including CO, NO_x, SO_2, PM and VOC from residential electric power generators were quantified. Relevant assumptions were made where necessary, and Equation 1 was used in calculating the emission rates at worst-case scenario.

Table 1: Appliances categories, power ratings and usage in residential buildings

Categories	Household Appliances	Power Ratings(Watts)	Usage
Lighting	**Lamps**	**101**	
Cooking	**Freezer**	**286**	
	Dispenser	**607**	
	Refrigerator	**225**	
	Microwave oven		
	Hot plate/Cooker	**1215**	
Entertainment	**Phones**	**3**	
	TV	**205**	
	Laptop	**155**	
	Radio	**60**	
	DVD	**17**	
Cooling	**Fan**	**80**	
	AC	**1872**	
Laundry	**Washing machine**	**228**	
	Iron	**1258**	

Source: Olaniyan *et al* (2018)
Legend:

Appliances used daily

Appliances used frequently (but may not be daily)

The general equation for emissions estimation is:

$$\mathbf{E = EF \times A\left(1 - \frac{ER}{100}\right)} \qquad (1)$$

where E = Emission, in g/s, A = Unit activity, in g/s, EF = Emission factor, in grams/grams and ER = Overall emission reduction efficiency % (EPA, 2015).

2.3.1 Calculation of air emission from residential electric power generation

The power supply has not been stable in Nigeria since the 1970s (Awosipe, 2014). The use of generators as an alternative source of electricity became dominant in 1990's leading to emissions of pollutants, particularly carbon monoxide. This alongside poor ventilation has negatively influenced the indoor air quality in households (Stanley *et al.*, 2011).

It was assumed that a household operates an electric power generator for an average of 6 hours daily (2190 hrs/annum). The fuel heating value for gasoline-electric power generator was taken as 0.130 MMBtu/gal and the Emission factors in Table 2 were taken from EPA (2005).

Table 2: Emission Factors for Gasoline Electric Power Generators

	Air Pollutants				
	CO	**NO_x**	**SO_x**	**PM**	**VOC**
Emission Factors (lb/MMBtu)	62.7	1.63	0.084	0.10	2.10
Emission Factors (ton/MMBtu)	0.02822	0.00073	3.8E-05	4.5E-05	0.00095

The activity rate of gasoline-electric power generators was calculated thus;

$$\boldsymbol{Actitvity\ rate\ (Ar) = H_V \times FC} \quad (2)$$

where H_V and FC are the heating value and fuel consumption per annum respectively

2.4 Air Emission modeling procedure

The American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) version 8.9.0 was used to determine the ground-level concentration of primary air pollutants from the calculated emission rates. They use pathways that compose the run stream file as the basis for their functional organization. The pollutant type and the averaging period of 24-Hr were specified at the control pathway for all air pollutants of interest. A 1-Hr averaging period was specified for both CO and NO_x while 8-Hr was specified for CO only. In the source pathway, the sources of pollutant emissions being modelled were defined. Point source was used for the fuel combustion from electric power generators servicing residential buildings. The emission rates of the residential electric power generators were modelled at specified distances as point sources. The parameters including stack height (m), exit temperature (K), stack inside diameter(m), exit velocity (m/s), gas flow rates (m^3/s) and base elevation (m) were measured and specified in this pathway. The receptors used in determining the air quality impact at specific locations were specified. In the meteorological pathway, the atmospheric conditions of the area being modelled were defined. Flat terrain was used in the terrain grid pathway while in the output pathway, a scaled floor plan design of building types of interest was used. The model was run to obtain the ground-level concentrations of emission dispersion of air pollutants using the 1–Hr, 8–Hr and 24–Hr averaging time options as the case may be.

2.5 Parameters used for modeling

The following parameters in Table 3 were used for modelling the emissions of air pollutants.

2.6 Determination of a safe location for the operation of electric power generators near the building

The safe location for the operation of these generators was determined by examining the air quality impacts of the calculated emissions on the environment at relevant distances and directions. This was achieved by comparing the ground-level concentration and Nigeria's National Ambient Air Quality Standards (NAAQs) and WHO air quality standards, see Table 4. Generally, indoor air quality which can be affected by outdoor emissions of air pollutants from electric power generators depends on the structure of building considered, diffusion and advection. The floor plan design of these buildings was designed with varying lengths relative to the obtainable standards in the country. The size and structure of the buildings were taken into consideration during the dispersion modeling and they played an important role in the extent to which concentrations of pollutants were dispersed

Table 3: Parameters for Modeling

Stack Height (m)	Residential electric power generator 4.5 kW
Exit temperature (K)	501
Stack diameter inside (m)	0.03
Exit velocity (m/s)	7.00
Gas flow rate (m^3/s)	0.0049

The main receptors considered were the living rooms and bedroom. The electric power generators used in servicing the residential apartments in the Nigerian environment were mainly gasoline-powered electric generators with few using diesel-powered electric generators. The emphasis of this study was on gasoline-powered electric generators in fully detached buildings as it is commonly being used.

The results of the emission rates of criteria air pollutants in ton/annum from gasoline-electric power generators servicing fully detached bungalows were presented in Table 5. The quantity of gasoline consumption by electric power generators servicing detached buildings is 983 gal/annum, the CO emission was 3.6056 ton/annum, NO_x was 0.0937 ton/annum, SO_x was 0.0048 ton/annum, PM and VOCs were 0.0058 ton/annum and 0.1208 ton/annum.

Furthermore, the level of emission of air pollutants from electric power generators depends on some factors such as the age of the engine, the condition of the engine, the ambient temperature and energy demands. It was observed that CO has the highest emission rate from gasoline-powered electric generators servicing fully detached buildings (3.6056 ton/annum). The observation agrees with the report by Oguntoke and Adeyemi (2016) as CO is one of the major air pollutants emitted by portable power generators. It was also reported that emission rates decrease as the capacity of generator increases.

Table 4: Air Quality Standards

Contaminants	Average time	Air Quality Standards (µg/m^3)	
		FMENV[a]	**WHO[b]**
CO	1	–	30000
	8	22800	–
	24	11400	–
NO_x	1	–	200
	24	75-113	–
SO_2	24	260	20
PM	24	250	50
HC	24	6000	–

****Sources: [a]FEPA (1991); [b]Duh *et al.* (2008).**

The emission rate of CO is followed by that of VOCs, NO_x and PM with the least being that of SO_x for all the residential house types of interest. The high emission of CO is a function of incomplete combustion of gasoline fuel when there is insufficient oxygen near the hydrocarbon fuel molecule during combustion at a very low gas temperature or short residence time in the cylinder. High VOCs emission is a function of low cylinder temperature and poor air and fuel homogeneity resulting from incomplete mixing before or during combustion (EPA, 2005). It can be inferred from the observation that gasoline-electric power generator is a major source of emission of CO into residential buildings.

The model output results for the predicted ground level concentrations of air pollutants entering detached bungalow from electric power generators at 1-Hr, 8-Hr and 24-Hr CO, 1-Hr and 24-Hr NO_x and 24-Hr SO_x, PM and VOCs can be found in (Figs. 2-3). Table 6 shows the results of the predicted maximum ground-level concentrations of criteria air pollutants entering detached bungalows obtained using the AERMOD View Dispersion Modeling software. These were compared with the Nigeria National Ambient Air Quality Standards (FMEnv) and WHO Air Quality standards to determine the indoor air quality impact and the safe location for electric power generators servicing fully detached bungalows.

CO entering from an electric power generator servicing a fully-detached bungalow at 1 – 4 m has its predicted maximum 1-Hr concentration decreasing from 5000 – 1000 $\mu g/m^3$ (16.67 – 3.33% of limit), its 8-Hr and 24-Hr predicted maximum concentrations are constant at 1500 $\mu g/m^3$ (6.58% of limit) and 1000 $\mu g/m^3$ (8.77% of limit) respectively. The maximum 1-Hr concentrations predicted for NO_x remain constant at 200 $\mu g/m^3$ (100% of the limit), while its 24-Hr predicted maximum concentration is also constant at 30 $\mu g/m^3$ (26.55% of the limit).

The predicted maximum 24-Hr concentrations of SO_2, PM and VOCs are constant at 2 $\mu g/m^3$ (0.77% of limit), 2 $\mu g/m^3$ (0.80% of limit) and 4 $\mu g/m^3$ (0.07% of limit) respectively.

In Table 6, the data presented indicates vividly that when electric power generators are placed near the building of interest at 1 m, the predicted values for the concentrations of 1-Hr CO and NO_x, 8–Hr CO and 24–Hr CO, NO_x, SO_x, PM and VOCs entering the fully detached

Table 5: Air emission rates from electric power generators servicing residential building

House type	Residential (detached bungalow)
Power rating (kW)	4.5
Fuel type	Gasoline
Fuel consumption (gal/annum)	983
Air emission rate (ton/annum)	
CO	3.606
NO_x	0.094
SO_x	0.005
PM	0.006
VOCs	0.121

buildings were within the FEMnv and WHO limits, and therefore will not have a significant effect on the indoor air quality. The same is obtainable for a distance of 4m. Consequently, these results will ensure the safety of the occupants from health problems associated with these key air pollutants when they are above limits. In agreement with the report by Adefeso (2012), the low concentrations of these pollutants can be attributed to the fact that the speed of the wind is high enough to reduce the magnitude of the concentrations penetrating indoors and also because the concentration of pollutants entering is inversely proportional to time. A moderate value for indoor-outdoor temperature difference in the study area contributed to values which are below limits.

Table 6: Impact of predicted concentrations of air follutants on indoor air quality

Source	Duration (hour)	IMP	% of Standard- at 1m	IMPC	% of Standard at 4 m
CO	1	5000	16.67	1000	16.67
	8	1500	6.58	1500	6.58
	24	1000	8.77	1000	8.77
NO_x	1	200	100.00	200	100.00
	24	30	26.55	30	26.55
SO_2	24	2	0.77	2	0.77
PM	24	2	0.80	2	0.80
VOCs	**24**	**4**	**0.77**	**4**	**0.77**

****IMPC = Indoor Maximum Predicted Concentrations (µg/m^3) for fully detached bungalow-4 m and IMP = Indoor Maximum Predicted Concentrations for fully detached bungalow-1m**

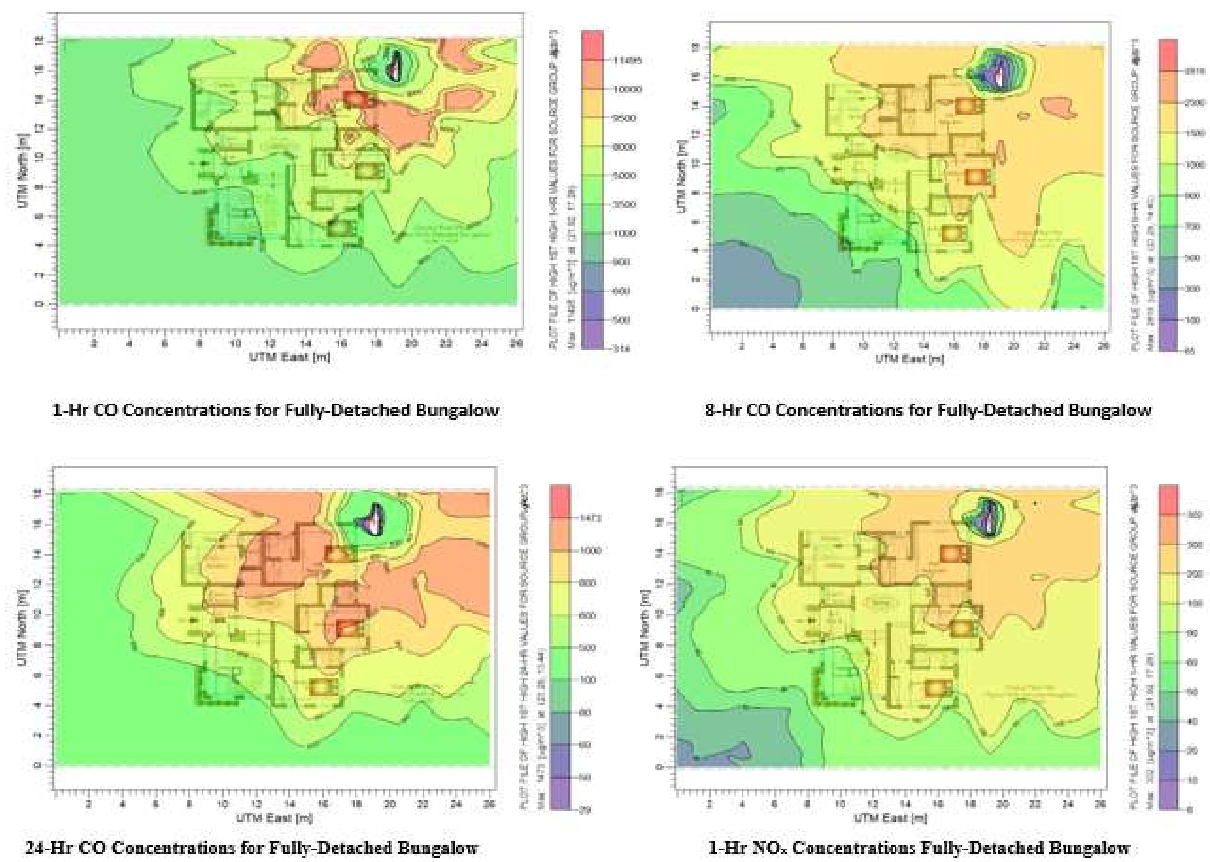
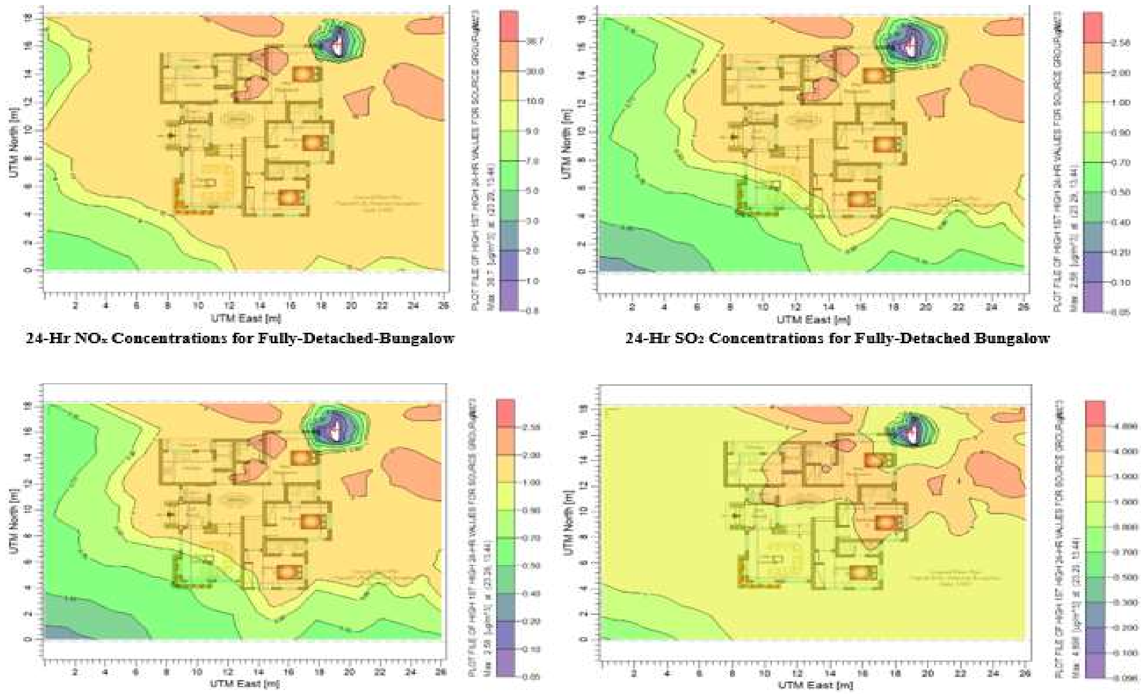


Fig. 2a: (Cont'd): Predicted Concentrations from Electric Power Generators Servicing Fully-Detached Bungalow at 1 m



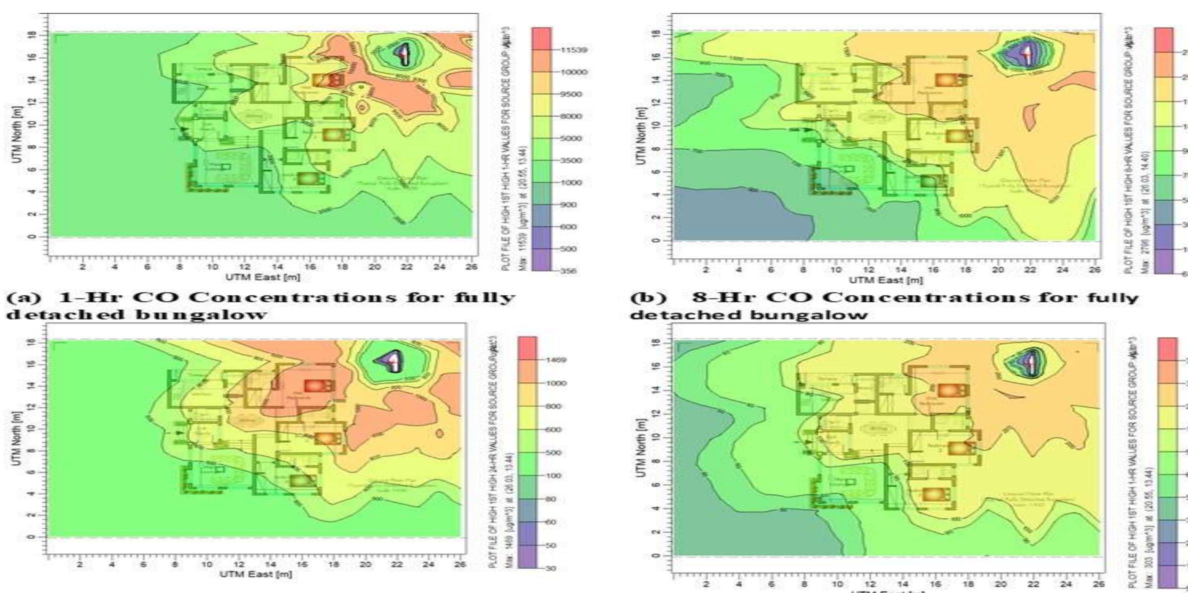
24-Hr NO_x Concentrations for Fully-Detached-Bungalow

24-Hr SO_2 Concentrations for Fully-Detached Bungalow

24-Hr PM Concentrations for Fully-Detached Bungalow

24-Hr VOCs Concentrations for Fully-Detached Bungalow

Fig. 2b: (Cont'd): Predicted Concentrations from Electric Power Generators Servicing Fully-Detached Bungalow at 1 m



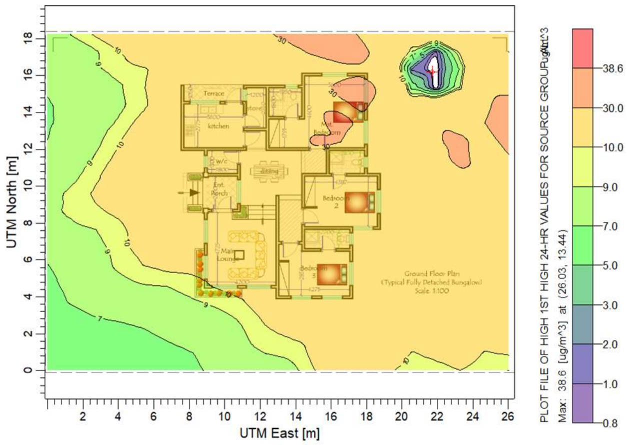
(a) 1-Hr CO Concentrations for fully detached bungalow

(b) 8-Hr CO Concentrations for fully detached bungalow

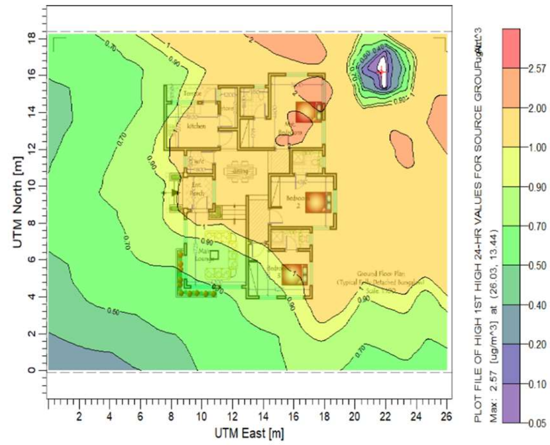
(c) 24-Hr CO Concentrations for fully detached bungalow

(d) 1-Hr NO_x Concentrations for fully detached bungalow

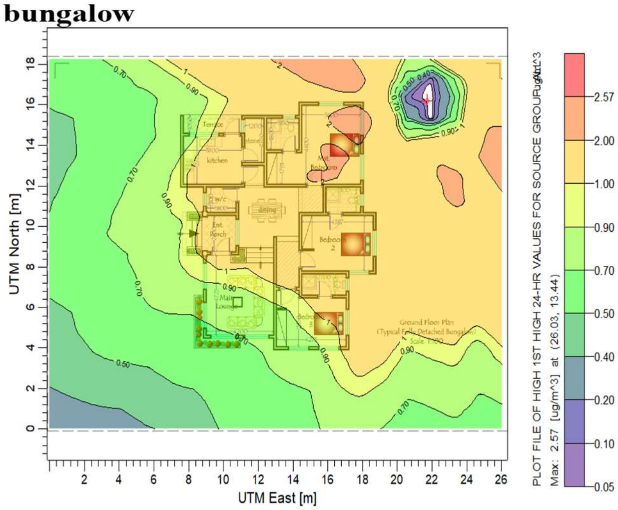
Fig. 3a: Predicted Concentrations from Electric Power Generators Servicing Fully-Detached Bungalow at 4 m



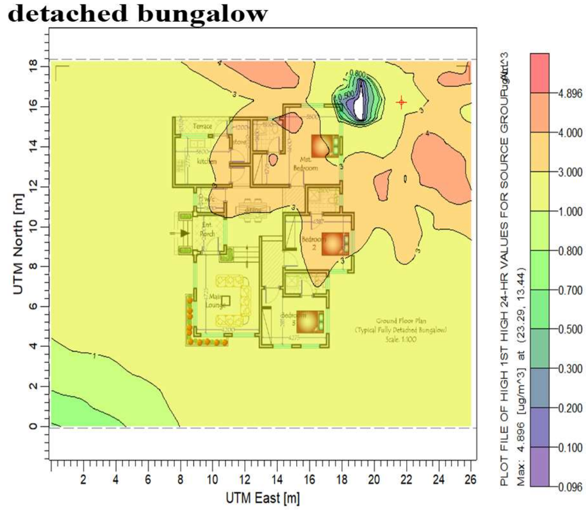
24-Hr NO_x concentrations for fully detached bungalow



24-Hr SO_2 concentration for fully detached bungalow



24-Hr PM concentrations for Fully-Detached Bungalow



24-Hr VOCs concentrations for fully detached bungalow

Figure 3b (Cont'd): Predicted Concentrations from Electric Power Generators Servicing Fully-Detached Bungalow at 4 m

4.0 Conclusion

This study showed that a safe distance of private electric power generators from residential buildings limits the negative impact of emitted criteria air pollutants on indoor air quality in the Nigerian environment. Amidst many factors that affect the decision of the location of electric power generators, consideration of the safe location for the operation of electric power generators near the building is very vital. This source of emissions releases criteria air pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), particulate matter (PM) and volatile organic compounds (VOCs) into the atmosphere which consistently and significantly affects the ambient air quality in residential buildings.

Gasoline electric power generators are commonly used in fully detached bungalow with common power ratings of 4.5 kW. Emission rates of criteria air pollutants determined from these electric power generators showed that gasoline power generator is a major source of emission of CO. This study established that placement of gasoline electric power generators can be achieved near fully detached bungalow and similar house types at distances of 1 m or beyond and this is safe enough to ensure good indoor quality and wellness of occupants in these buildings.

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Declarations

The authors declare that they have no conflict of interest.

Data availability

All data used in this study will be readily available to the public.

Consent for publication

Not Applicable.

Availability of data and materials

The publisher has the right to make the data public.

Competing interests

The authors declared no conflict of interest

Funding

There is no source of external funding.

Authors’ contribution

The entire work was done by the author