Impact of Criteria Air Pollutant from Diesel Combustion by Industries on Ibadan Metropolis, Nigeria

Olu-Arotiowa, O. A[a], Olafimihan, E.O[b*], Alade, A.O[a], Ogunsola, A.D[b], Orowole, I.A[b]. and Akande, O. G[a]

[a]*Department of Chemical Engineering, LadokeAkintola University of Technology. P.M.B. 4000, Ogbomoso, Nigeria*
[b]*Department of Mechanical Engineering, LadokeAkintola University of Technology. P.M.B. 4000, Ogbomoso, Nigeria*

ABSTRACT: *The use of diesel as fuel by major industries in Ibadan Metropolis to run heavy duty generating set has increased drastically due the sporadic electricity supply by Electricity Distribution Company. The combustion of diesel results in the emission of Criteria Air Pollutant (CAPs), which are hazardous to human health. This study examined the consumption rate of diesel by the minor and major industries in Ibadan Metropolis between 2015 and 2019, while the Air quality implications were compared with the standards. The study was carried out in a three-step process (emission inventory, estimation of the rate of emission and dispersion modelling to predict the ground level concentration of the CAPs) for the industries within the period. The emission rate of CO, NOx, PM, SOx and VOC is 77.132, 358.053, 25.170, 23.545 and 5.683 g/s, respectively and their corresponding predicted ground level concentration were 984.89, 4571, 321, 297 and 72.6 µg/m^3. This research work will proffer information for the government in policy-making as regards the prompt and most effective method to control air pollution in near future for the citizens of Ibadan.*
Key Words: *Diesel, combustion, emission, pollution and heating value.*

INTRODUCTION

Air pollution is increasingly becoming a global challenge due to the release of air emissions from human activities and ineffective environmental policy (Komolafe*et al*., 2014; Motesaddi*et al*., 2017; Von Schneidemesser*et al*., 2019). Larger portion of the air pollution is traceable to indoor (e.g. for cooking) or outdoor combustion processes (Frederica, 2018). The common air pollutants in the atmosphere include an oxide of sulphur, (SOx); oxides of nitrogen, (NOx), carbon monoxide, (CO), and volatile organic compounds, (VOCs) (Komolafe*et al*., 2014). The common air pollutants such as oxide of sulfur (SOx), oxides of nitrogen (NOx), carbon monoxide (CO), and volatile organic compounds (VOCs) found in the atmosphere are classified as Criteria Air Pollutant (CAPs) (Komolafe*et al*., 2014). Carbon dioxide emission from combustion source as well as oxides of nitrogen such as NO_2 and NO produce from thermal power plants, vehicles, industrial processes and, coal-burning processes enters into the air at a steep rate (Vaz AIF *et al*., 2009). This development endangers human health and existence as well as the that of the living things on earth (Wang *et al*., 2014). Polluted air can cause various health discomfort such as sneezing and coughing, eye discomfort, headache, and dizziness (Lawrence *et al*., 2019).A wide range of health challenges ranging from infertility, cancer, respiratory diseases, pulmonary and cardiovascular diseases have been attributed to exposure to Particulate Matter and gaseous fuel combustion products (Adeniran et al., 2017; Akintunde et al., 2017; Olatunji et al., 2015). Particles matters, particularly the PM_{10} or $PM_{2.5}$ can be breathed deeply into the lungs and interfere with the bloodstream (Idarraga*et al*., 2020), thereby resulting in fatal health consequences such as ischemic heart disease, stroke, chronic obstructive pulmonary disease, and lung cancer (Burnett*et al*., 2014).

Ibadan($7^0$23'47 North and longitude $3^0$55'0) is the capital city of Oyo State, Nigeriaand it is the third-most populated city in Nigeria, with an estimate of 3,649,000 people as of 2021 according to the report from the United Nations-World Population Prospects.The city hosts major industries being the next important city to Lagos and a major political seat in the Southwestern Nigeria. Ibadan and its environ have not enjoyed stable electricity supplied in recent past and this he economic and social activities of its inhabitant. The hard hit are the major industrieswithin the metropolis and some of these industries has fold up while those that remain have resulted to the use of diesel-operated heavy duty generating sets to operate their industries. The diesel engine has high efficiency due to its high compression ratio, thus it has a low specific fuel consumption, and this makes the use of diesel engine very economical (Reif, 2014). However, the air pollution resulting from the exhaust of the diesel operated generating sets of the industries within he metropolis has attracted concern. Thus the goals of this work is to quantify the amount of diesel fuel consumed from 2015 to 2019 and quantify the criteria air pollutant (CO, NOx, PM, SOx and VOCs) from the diesel combustion. The ground level concentrations of these emissions were quantified using AERMOD software and their air quantity implications with the standard were determined, with a view that the research work will proffer information for the government in policy-making.

DATA COLLECTION AND METHODS

Monitoring sites and data sources

Forty industries in Ibadan metropolis are being located and illustrated in fig.1 which is subdivided into 24 minor industries and 16 major industries. The map generated from Google Earth was cropped out using Arc-GIS to show the major and minor industries in Ibadan, this is shown in fig. 2. The small-scale industries and shopping malls are classified as minor industries since they consume less than 1000 liters of diesel per week while the food processing and clothing industries are categorized as major industries since they use over 1000 liters of diesel per week. The predicted ground-level concentrations of five pollutants in the industries in Ibadan were obtained using AERMOD software. The amount of diesel consumed between 2015-2019 was collated from the statistics of the National Bureau for Oyo State.

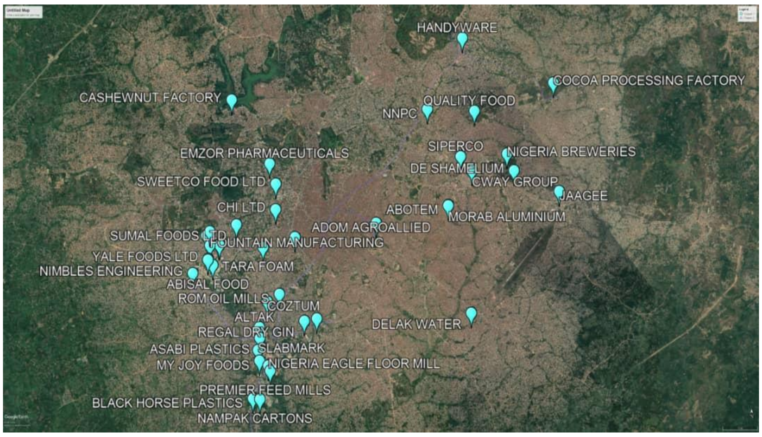

Fig 1: Location of 40 industries in Ibadan metropolis using Google Earth Map

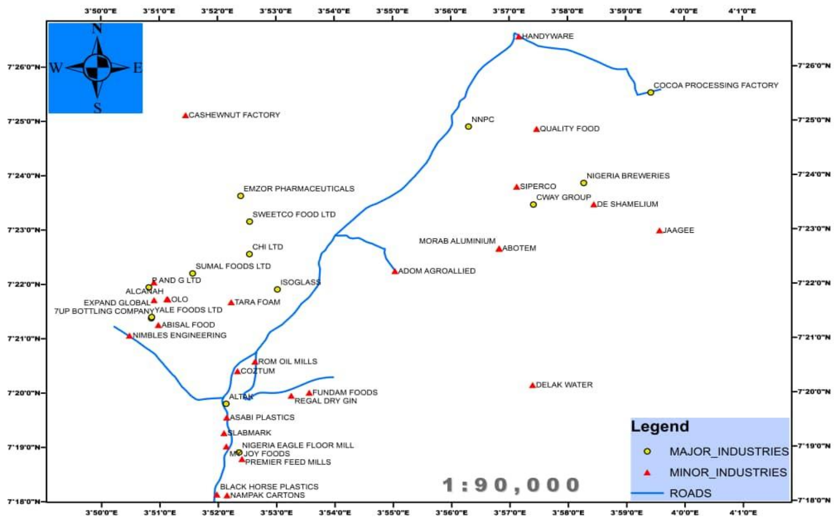

Fig 2: Map of Ibadan metropolis showing the major and the minor industries using Arc-GIS

2.2 Meteorological data and emission inventory

The data from the National Bureau of Statistics (NBS) for Oyo State (Table 1) from the year 2015 to 2019 used in this study, was downloaded from: http:// www.nigerianstat.gov.ng, were used to derive the emission rate of the pollutants. The data in table 1 shows that there was increase in the amount of diesel consumed in the year 2016 than every other years and 2015 has the least volume of diesel consumed compared to other years.

Table 1: Volume of Diesel Consumed by Oyo State from 2015- 2019

Month	The volume of Diesel Consumed by Oyo State (Litres)				
	2015	**2016**	**2017**	**2018**	**2019**
January	16,060,317.00	37,337,475.00	15,183,377.00	7,625.037.00	15,920,214.00
February	12,952,796.00	29,350,436.00	16,477,287.00	10,216,362.00	15,922,200.00
March	16,680,231.00	31,367,831.00	12,432,987.00	14,563,876.00	15,936,230.00
April	13,022,404.00	41,688,220.00	16,584,485.00	14,012,128.00	20,454,453.00
May	21,582,828.00	28,523,262.00	20,487,583.00	28,907,957.00	15,355,466.00
June	13,345,950.00	45,864,378.00	17,385,934.00	30,530,685.00	16,661,424.00
July	9,773,589.00	54,660,946.00	22,844,493.00	16,789,359.00	20,520,564.00
August	12,847,241.00	53,121,356.00	21,347,998.00	14,668,201.00	13,625,763.00
September	11,314,667.00	42,919,154.00	23,374,384.00	22,048,952.00	13,625,763.00
October	13,875,944.00	34,567,523.00	16,247,347.00	15,081,131.00	22,465,236.00
November	13,116,270.00	22,789,132.00	15,347,453.00	17,945,797.00	14,166,383.00
December	18,241,397.00	33,454,456.00	16,473,344.00	16,587,218.00	13,825,616.00
Total	**172,813,594.00**	**418,124,769.00**	**193,626,572.00**	**208,976,703.00**	**200,277,786.00**

Source: National Bureau of Statistics (NBS)

The emission rate was determined when the emission factor and the activity had been known. Emission factors are important in estimating and characterizing emission sources of air pollution (Pouliot*et al*, 2012). The emission factor relates the quantity of substances emitted from a source to some common activity associated with those emissions (Sabah, 2006). Emission factor of the Criteria Air Pollutants (CAPs) is given as: NOx – 4.41, CO – 0.95, PM – 0.31, SOx – 0.29 and VOC – 0.07 (EPA, 1996).

$$E = A \; x \; EF \; x \, \frac{1-ER}{100} \qquad (1)$$

$$E = A \; x \; EF \qquad (2)$$

Where E is the Emission in g/s, A is unit activity in g/s, EF is the emission factor, in grams/grams, ER is the overall emission reduction efficiency %. Equation (1) is used to estimate emission rate with control devices in place while equation (2) is to estimate emission rate when there is no control device in place. The sources of emission were the equipment used in the industries.

$$\frac{Ib}{10^6} Btu \; x \, \frac{19300 \, Btu}{Ib} \, x \, \frac{7.1 Ib}{gal} = \; 0.137 Ib/gal \qquad (3)$$

$$\frac{0.137 \, Ib}{gal} \; x \, \frac{1 ton}{2200 \, Ib} = \; 0.000062 ton/gal \qquad (4)$$

$$365 \; days = 31536000 \; seconds \qquad (5)$$

$$1 \; gal = 3.78 \; litres \qquad (6)$$

$$1 \; tonnes = 907184.43 \; gram \qquad (7)$$

The diesel heating value and the density of diesel were found to be 19300 and 7.1Ib/gal respectively (EPA,1996). Equations 3-7 show the conversion to the appropriate units. The total amount of diesel consumed for 2015, 2016, 2017, 2018 and 2019 were summed up to calculate the amount of diesel consumed per year. An assumption of 75% diesel consumption was made for the industries since Ibadan is the largest town in Oyo State.

$$\frac{156732527.25 L/yr}{31536000 \; s} \; x \, \frac{Yr}{s} = 4.97 \; L/s \qquad (8)$$

$$\frac{0.000062 \, ton}{gal} \; x \, \frac{907184.74 gram}{ton} = 56.2455 g/gal \qquad (9)$$

$$\frac{56.2455 g}{gal} \, x \, \frac{1 gal}{L} \; x \, \frac{4.97 L}{s} = 74 g/s \qquad (10)$$

$$Activity = \frac{74g}{s}\ x\frac{6}{7} = 63.43g/s \qquad (11)$$

It can be deduced from the calculation in Equation (10), for the year 2015, that the activity is 74 g/s. It was assumed that the industries work for 6 days in a week. This is shown in equation (11). This calculation is repeated for the year 2016, 2017, 2018 and 2019 to calculate the activity.

$$Emission\ rate = 63.43\ x\ 0.95 = 60.26g/s \qquad (12)$$

Equation (12) shows the emission rate of CO for the year 2015. The activity of the other years is calculated and multiplied by the emission factor of CO. The average emission rate for the year 2015, 2016, 2017, 2018 and 2019 will give the overall emission rate for CO. The calculation step was repeated for the other Criteria Air Pollutants (CAPs) to determine the Emission rate. The result of the emission rate of the CAPs was then inputted into AERMOD in other to predict the ground level concentration.

2.3 Prediction of the ground level concentration

The ground level concentration was predicted using AERMOD. It is an acronym for American Meteorological Society/Environmental Protection Agency Regulatory Model. According to Brode (2006), AERMOD atmospheric dispersion modeling system is an integrated system that includes three modules, which includes; steady-state dispersion model designed for short-range (up to 50 kilometers) dispersion of air pollutantemissions from stationary industrial sources, meteorological data preprocessor and terrain preprocessor. The ISCST3 interface of the ISC-AERMOD was used in this study. The pathways considered in this work are the control, source, receptor, metrological, terrain grid and the output pathway.

The control source used are the point and line sources. The point source includes the diesel generator and construction equipment because they contribute to a huge amount of emission and cannot be moved easily from one place to another. The line source are the mobile sources like vehicles which can move or can be moved from one place to another. These sources are shown in Table 2.

Table 2: Parameters used in the dispersion model (Point source and Line source)

	Parameters				
	Height (m)	Diameter (m)	Temperature (^{0}K)	Exit Velocity (m/s)	Gas Flowrate (m^3/s)
Diesel Generator	2.0	0.1	783	8.27	0.065
Construction Equipment	3.0	0.1	430	2.0	0.0157
Line Sources	1.0	9.0			

The output results necessary to meet the needs of the air quality modeling analysis were defined. The resultant output is the ground level concentration of the pollutant modeled. All these pathways were specified in the model. A uniform Cartesian coordinate was considered for the receptor pathway. A scaled map of each interested location was imported from jpeg format to the site domain where the size of domain was specified as the X and Y coordinates for the two points (14.6 cm, 27.3 cm), the southwest (SW) point (Min.) and the Northeast (NE) point (Max.) of the domain on a scale of 1cm to 0.9 km. The projection used was UTM and a UTM zone of 31 was used. The receptor locations obtained from the map, emission sources and the stack parameters estimates were input in the source box. Then, the model was run to obtain the ground level concentrations of the emission dispersion. The modeled output result was exported from bitmap format and saved appropriately.

2.4 Determination of Air Quality Impact Assessment

The predicted ground level concentration of the Criteria Air Pollutants from the major and minor industries will be compared with the standards of ambient air quality (Table 3) derived from World Bank environmental guidelines and World Health Organization (WHO) standards to ascertain their level of compliance.

Table 3: Standard of Ambient Air Quality

Air Pollutants	Averaging Period	Maximum Concentration (μg/m^3)	
		WHO	World Bank
CO	1 hour	-	30,000
	8 hours	-	10,000
	24 hours	-	-

NOx	1 hour	200	200
	24 hours	40	-
	Annual	-	40
PM	1 hour	80	-
	24 hours	50	-
TOC	24 hours	160	-
SOx	24 hour	20	125

Source: World Bank (1991), Source: WHO (2005, 2007)

3 Results and discussion

3.1 Emission Inventory Result

The emission inventory results consist of the activity and the emission rate of five different criteria air pollutants which include CO, NOx, PM, SOx and VOC. The results show the varying emission rates obtained for the years 2015, 2016, 2017, 2018 and 2019. From the result of emission, inventory was carried out on the industries in Ibadan metropolis. Table 4 shows the emission factor of the Criteria Air Pollutants (CAPs) and activity in g/s of the diesel consumed in 2015, 2016, 2017, 2018 and 2019 to be 63.387, 126.827, 58.731, 96.261, 60.749 respectively. The result shows that 2016 has the highest amount of diesel consumed while 2017 has the least amount of diesel consumed.

Table 4: 75% of diesel consumed, the emission factor and the Activity of the diesel consumed between 2015-2019

Year	Assume 75% diesel consumption	DIESEL (L/s)	CO	NOx	PM	SOx	VOC	ACTIVITY (g/s)
2015	156732527	4.970	0.95	4.41	0.31	0.29	0.07	63.387
2016	313593577	9.944	0.95	4.41	0.31	0.29	0.07	126.827
2017	145219929	4.605	0.95	4.41	0.31	0.29	0.07	58.731
2018	129610196	7.547	0.95	4.41	0.31	0.29	0.07	96.261
2019	150208340	4.763	0.95	4.41	0.31	0.29	0.07	60.749

The emission rate of CO, NOx, PM, SOx and VOC are represented on the histogram as shown in Fig. 3. The result shows that the emission rate of Carbon monoxide in 2015, 2016, 2017, 2018 and 2019 are 60.218, 120.485, 55.795, 91.448 and 57.711g/s respectively. The emission rate of Nitrogen Oxide in 2015, 2016, 2017, 2018 and 2019 are 279.538, 559.305, 259.005, 424.512 and 267.902g/s respectively. The emission rate of Particulate matter in 2015, 2016, 2017, 2018 and 2019 are 19.650, 39.316.841, 18.207, 29.841 and 18.832g/s respectively. The emission rate of Particulate matter in 2015, 2016, 2017, 2018 and 2019 are 19.650, 39.316, 18.207, 29.841 and 18.832g/s respectively. The emission rate of Sulphur oxide in 2015, 2016, 2017, 2018 and 2019 are 18.382, 36.780, 17.032, 27.916 and17.617g/s respectively. The emission rate of Volatile Organic Compound in 2015, 2016, 2017, 2018 and 2019 are 4.437, 8.878, 4.111, 6.7738, and4.2524g/s respectively.

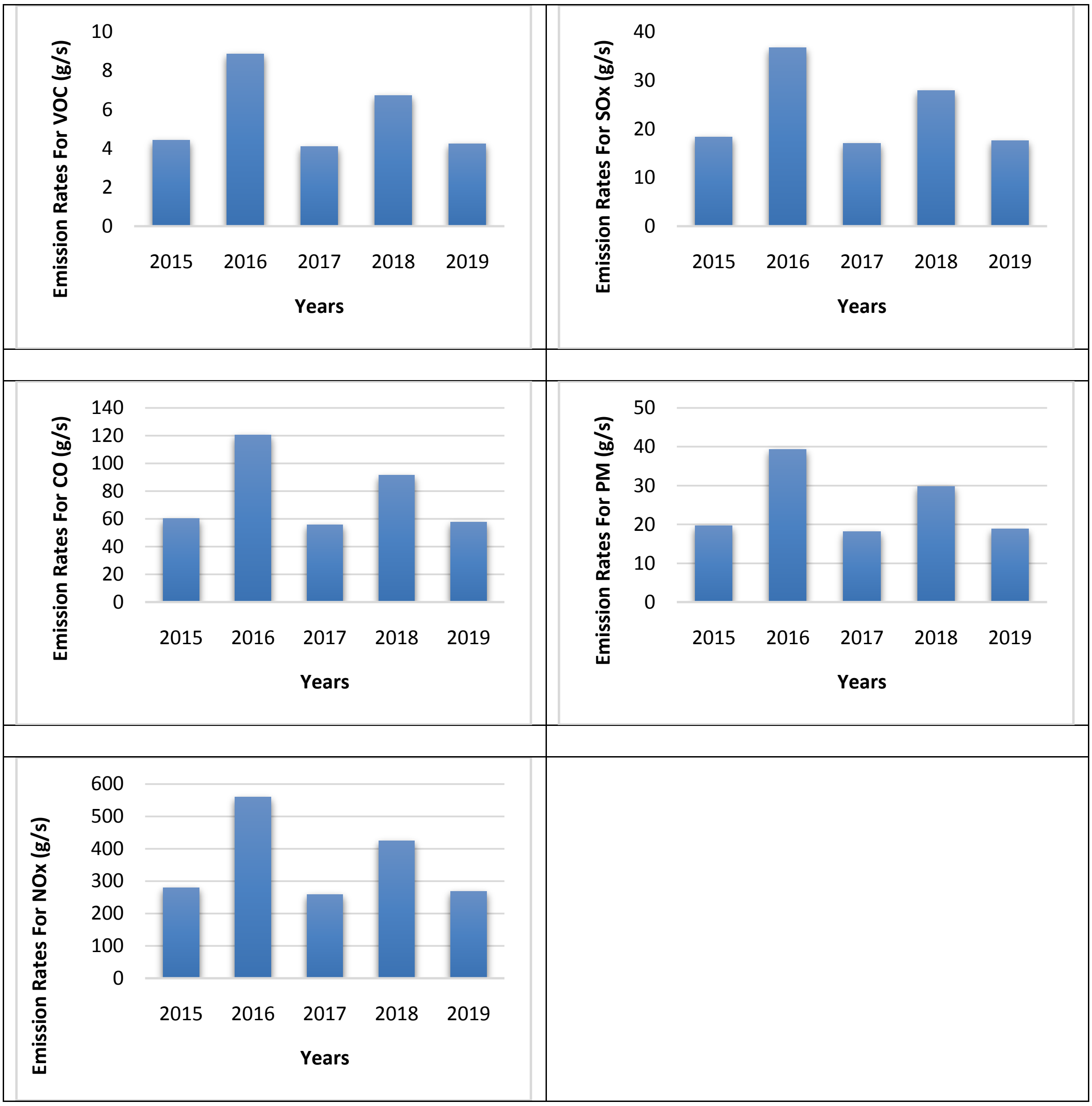

Fig. 3: A histogram showing the emission rate of the industries in Ibadan metropolis against the years

The average emission rate of the Criteria Air Pollutant is shown in fig. 4. The result shows that NOx has the highest average emission rate and VOC has the least average emission rate.

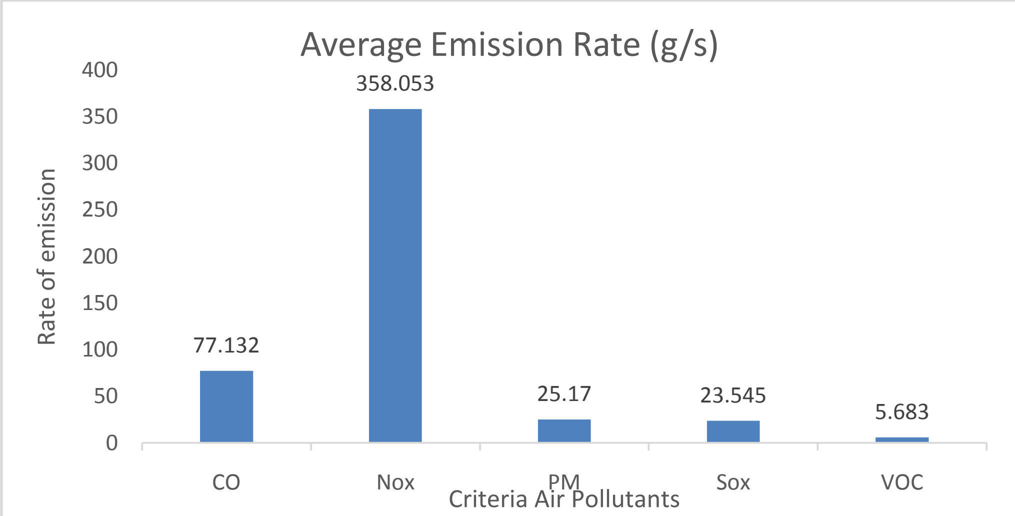

Fig. 4: Average Emission rate of the Criteria Air Pollutants (CAPs)

3.2 Ground level concentration

The average emission rate between 2015-2019 for all the criteria air pollutants was calculated (Fig.4) in other to predict the ground level concentration of the pollutant using AERMOD. The dispersion modelling outputs for a year averaging period ground level concentrations from all the emission sources of the industries in the Ibadan metropolis under consideration are reported and summarized. Fig. 4 shows the results of the predicted ground level concentration of the pollutants. Carbon monoxide (CO) was predicted to be between the ranges of 9.8-984.89.8µg/m^3, Volatile Organic Compound (VOC) was predicted to be between the range of 0.7-72.6µg/m^3, Particulate Matter (PM) was predicted to be between the range of 7.0-321µg/m^3. Sulphur Oxide (SOx) was predicted to be between the range of 3-297µg/m^3 and Nitrogen Oxide (NOx) emissions from industries in Ibadan metropolis was predicted to be between the range of 46-4571 µg/m^3. The dispersion modelling results show that the predicted maximum ground-level concentrations of Carbon monoxide (CO) is 984.8 µg/m^3 and the Volatile Organic Compound (VOC) is 72.6 µg/m^3. The predicted maximum ground-level concentrations of Carbon monoxide (CO) and Volatile Organic Compound (VOC) from industries in Ibadan metropolis are below World Bank and WHO standard limit as shown in table 2. This implies that the emission will have minimal effect on the residents of the area. It can also be observed from the dispersion modelling result that the predicted ground-level concentrations of Oxide (SOx) is 207 µg/m^3. The predicted maximum ground-level concentrations of Nitrogen Oxide is 457 µg/m^3, Particulate matter (PM) is 321 µg/m^3, and Sulphur (NOx), Particulate matter (PM) and Sulphur Oxide (SOx) from industries in Ibadan Metropolis are above World Bank and WHO standard limit Prolonged exposure of the residents to the emission of this compound is hazardous to their health and is, therefore, most likely to develop into serious health implications such as respiratory or lung disease, asthma, poor visibility as the case may be. It can be further observed that when comparing the ground-level concentrations of all the five pollutants, Nitrogen oxide (NOx) has the highest predicted maximum ground-level concentrations of 457µg/m^3 which is above the threshold value of 150µg/m^3 while Volatile Organic Compound has the least predicted maximum ground-level concentrations of 72.6µg/m^3 which is below the threshold value of 160µg/m^3.

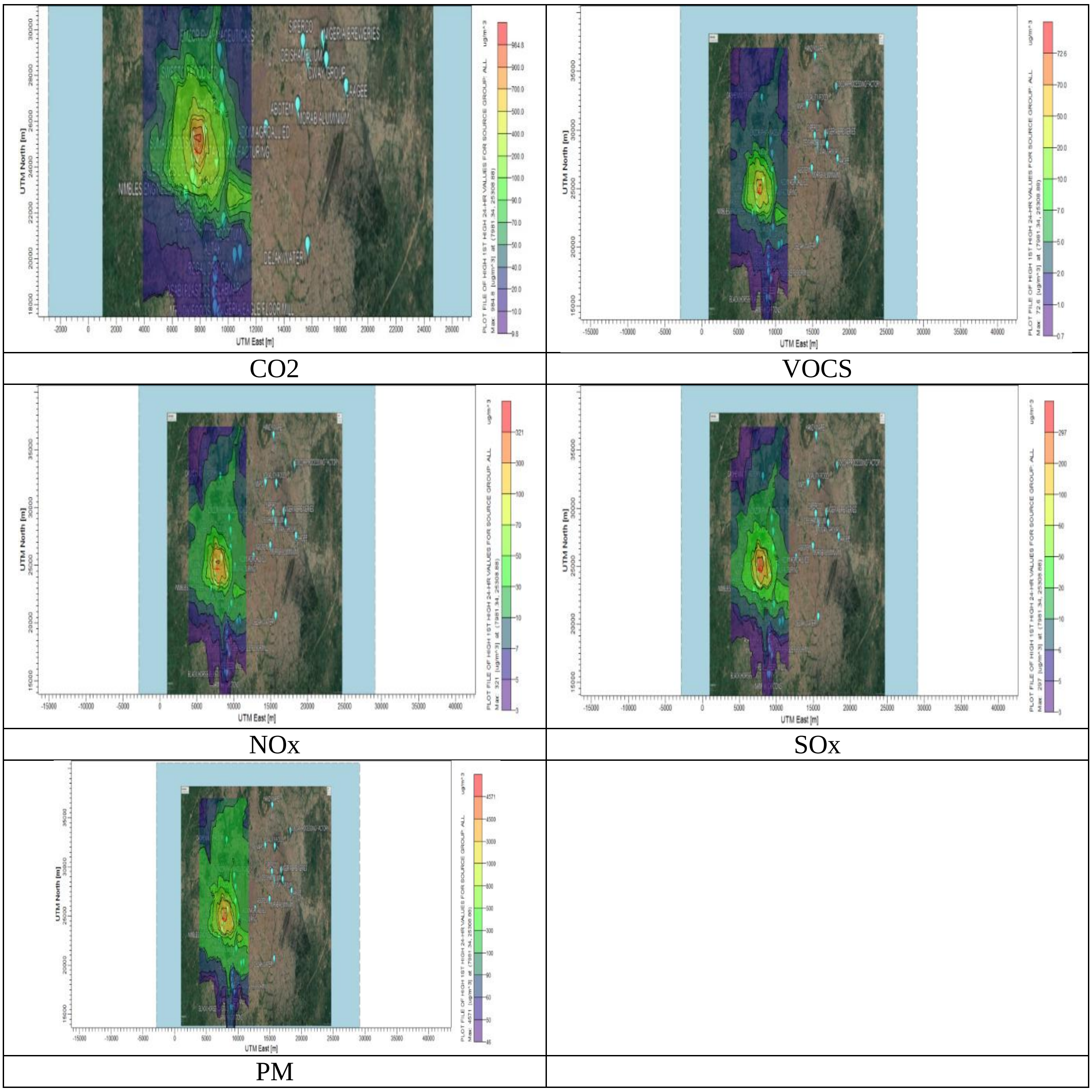

Fig.4 Predicted ground level concentration of Carbon monoxide (CO), Volatile Organic Compound (VOC), Particulate Matter (PM), Sulphur Oxide (SOx) and Nitrogen Oxide (NOx) respectively.

3.3 Health risk of the five Criteria Air Pollutants (CAPs)

Long term health effects from air pollution includes heart disease, lung cancer and respiratory diseases such as emphysema. Air pollution can also cause long term damage to people's nerves, brain, kidneys, liver and other organs. Exposure to air borne particles shows an increase in mortality and morbidity. The particles can easily penetrate deep into the tissues like alveoli in the respiratory system and cause severe cardiovascular problems. Exposure of the eyes to liquid of SOx can cause severe burns, resulting in the loss of vision. It produces burns on skin as well as headache and general discomfort.

Conclusion

AERMOD software was used to determine the predicted maximum ground level concentration of CO, NOx, PM, SOx and VOC in the major and minor industries in Ibadan metropolis. The result showed that the maximum ground level concentration of Carbon monoxide (CO) is 984.8$\mu g/m^3$, Nitrogen Oxide is 4571$\mu g/m^3$, Particulate Matter (PM) is 321$\mu g/m^3$, Sulphur Oxide (SOx) is 207$\mu g/m^3$and Volatile Organic Compound (VOC) is 72.6$\mu g/m^3$. The predicted maximum ground-level concentrations of Carbon monoxide (CO) and Volatile Organic Compound (VOC) from industries in Ibadan metropolis are below World Bank and WHO standard limit which makes these pollutants less hazardous to human health. The predicted maximum ground-level concentrations of Nitrogen Oxide (NOx), Particulate matter (PM) and Sulphur Oxide (SOx) from industries in Ibadan Metropolis are above World Bank and WHO standard limit which makes the pollutant very hazardous to human health. Nitrogen oxide (NOx) has the highest predicted maximum ground-level concentrations of 457µg/m^3 which is above the threshold value of 150µg/m^3 while Volatile Organic Compound has the least predicted maximum ground-level concentrations of 72.6µg/m^3 which is below the threshold value of 160µg/m^3. Industries should be situated far from residential areas to reduce the risk of harmful emissions. Also, I recommend that individuals should be taught about the adverse effect of these pollutants and their implications in the body system.

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