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Determination of Air pollutants concentration from Ground Level Sources in Abuja Metropolis, Nigeria.

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Abstract

This work focuses on measurements of concentration of gaseous emissions such as CO, SO_2, H_2S and particulate matters ($PM_{10}$and $PM_{2.5}$) released from ground level sources at specified receptor points downwind. These sources were monitored using Altair Multi-gas and HAT 200 $PM_{10}$and $PM_{2.5}$ detectors. From the selected sources monitored, Carbon Monoxide had the highest dispersion strength of 45%. An analysis of the concentrations show that refuse burning source has maximum concentrations of 111.2 mgm^{-3} for CO, 7.312 mgm^{-3} for SO_2, 5.342 mgm^{-3} for H_2S, 0.542 mgm^{-3} for PM_{10} and 0.272 mgm^{-3} for $PM_{2.5}$ respectively while minimum concentrations of 77.42 mgm^{-3} for CO, 0.52 mgm^{-3} for SO_2, 1.44 mgm^{-3} for H_2S, 0.48 mgm^{-3} for PM_{10} and 0.14 mgm^{-3} for $PM_{2.5}$ respectively were obtained from wood burning source. This shows that CO has the highest concentrations of the pollutants monitored. Correlation between modeled and measured concentrations showed that wood burning source has higher validity of the model with coefficients of regression R^2 for CO, SO_2, H_2S, PM_{10} and $PM_{2.5}$ as 0.885, 0.848, 0.574, 0.861 and 0.715 respectively while refuse burning has the least measure of validity with coefficients of regression R^2 for CO, SO_2, H_2S, PM_{10} and $PM_{2.5}$ as 0.363, 0.416, 0.416, 0.431, 0.572 and 0.284 respectively. Based on Ambient Air Quality Standards, refuse burning sources are most harmful of the sources investigated. A comparative environmental impact assessment of the sources reveals that they are unsafe for selected pollutants. For CO (1 hour time average, the safe limit is 40mg/m^3), SO_2 (1 hour time average, the safe limit is 0.35040mg/m^3) and H_2S (1 hour time average, the safe limit is 0.04240mg/m^3).

Introduction

Air pollution is an issue of interest to all neighborhoods of various income classes (Anumita *et al*., 2013). Fossil fuel utilization for energy needs and burnings during sanitation have contributed to poor ambient air quality (Irina, 2008). Despite sanitary laws one of which mandates residents to bury refuse, it is not or hardly obeyed by individuals. These combustions produce high level of pollutants like CO_x, NO_x, SO_x, particulate matters among others that cause environmental pollution (Sarmar and John, 2017). Some of the effects of air pollution include; asthma, irritation of the eyes, malfunction of the central nervous system and cancer. Apart from direct-health related issues, air pollution brings with it economic losses as well. Some of the economic losses include; travel time losses due to poor visibility, decreased productivity due to damage to crops and plants, and lost in income due to premature deaths (Irina, 2008).

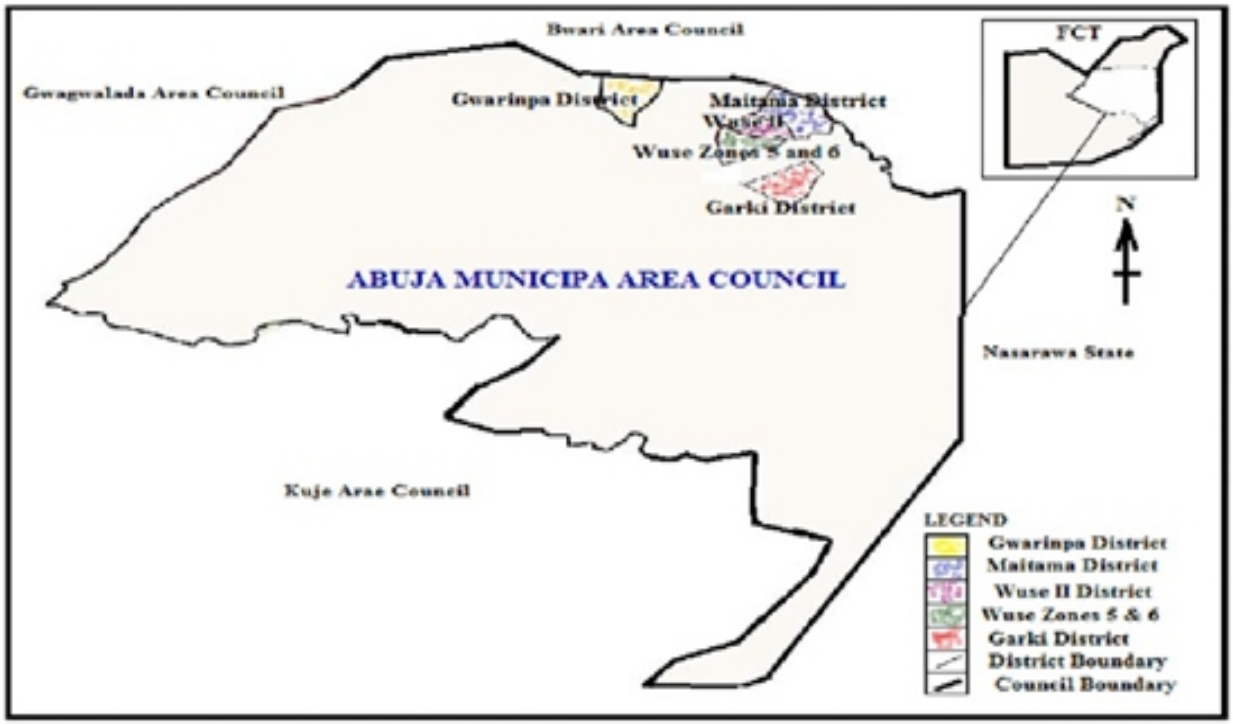
Ground level pollution comes from sources that do not have a stack height and cannot move from one point to another under their own powers but emit pollutants into the atmosphere through combustion (Enkeleda and John, 2009). These sources include wood burning for cooking, refuse burning, charcoal burning, tyre burning among others. As the emitted gases leave the combusted sources, they mix with the ambient air describing a plume. As the plume travels downwind, the plume diameter grows and it progressively spreads causing environmental hazard (Anthony *et al*., 2015).

As many cities in the country become more congested due to rural-urban migration which Abuja is not left out, there is a growing use of biomass and different fuel types as alternative energy sources which adds to poor ambient air quality and increases concern over the level of urban air pollution being generated especially from ground level sources. This work will help to provide information from direct measurement on the sources to policy makers in Environmental Management to device strategies to minimize the impact of identified emission sources on the populace as there is limited reference information for appropriate air quality policy and planning in Nigeria. It will also go a long way to predict pollutants' concentration using Gaussian Plume Model as concentrations cannot be measured directly wherever they occur due to presence of obstacles around pollution sources or plume spreading in directions that are not accessible for monitoring (Anjorin, 2017) so as to protect public health since modeling generally is an effective replacement for direct field measurement of ambient air quality and it serves to assist in the design of effective control strategies to reduce emission of harmful air pollutants.

Methodology

The Study Area

Abuja is the capital city of Nigeria located in the centre of the country within the Federal Capital Territory (FCT). Its coordinates are $9^0\ 4^1N$ and $7^0\ 29^1E$. At the 2006 census, the city of Abuja had a population of 1,406,239 (NBS, 2011) making it one of the ten most populated cities in Nigeria. Abuja is chosen primarily due to population density and knowledge of existing adverse effects of emissions from ground level sources present in literature. The sampling stations chosen are the city areas where pollution level could be high due to human activities. In these locations, wood burning for cooking and burning from refuse dumps were monitored as ground level sources. Figure 1 presents the study area of the research.



Source: Adopted from Abuja Geographic Information System Abuja FCT, Nigeria (2012).
Figure 1: Map of Abuja Municipal Area Council

Sampling Procedures

In this work, the ground level concentration of CO, SO_2, H_2S, $PM_{2.5}$ and PM_{10} from identified sources was monitored at distances of 1.0m, 2.0m, 3.0m, 4.0m and 5.0m for wood emission source and 5m, 10m, 20m, 30m, 40m, 50m, 60m, 70m, 80m, 90m, 100m for refuse burning source. These distances are chosen for refuse burning due to momentum and buoyancy of release of emissions from the source. At a distance of 1-4m near the source, the concentration is very high that the detector cannot fully measure the concentration effectively. Altair 5x Multi-Gas Detector and HAT 200 particulate monitor were held by hand along the plume centerline at a height of 1.0m from the ground. This height is chosen because of average breathing height of human beings. The concentrations of pollutants were measured at specific downwind distances within time duration of 3 minutes. The Altair 5x detector measures CO, SO_2, and H_2S while HAT 200 detector measures $PM_{2.5}$ and PM_{10}. Stations monitored were the wood burning site for beans cake beside King of Dutse Palace and a refuse dump at Dutse Central Primary School in Abuja Municipal Area Council.

Modeling Procedures

This work uses Gaussian Plume Model to simulate concentrations of identified pollutants from ground level sources to receptor points as given (Turner, 1970)

$$C(x,0,0,0) = \frac{Q}{2\pi u \delta y \delta z} \quad (1)$$

Where,
Q is the emission rate in mg/s
δy and δz are the dispersion parameters in m.
u is the surface wind speed u in m/s

In the application of the model, emission rates were determined for wood burning source using measured concentrations of the identified pollutants at 1 m while 5 m for refuse burring source. This simulation was done using meteorological data obtained under neutral atmospheric stability conditions. Data such as wind speed and temperature were obtained from Nigerian Meteorological Centre Abuja. Wind speed was obtained at a height of 4.5 m from the ground using Anemometer. However, since plume advection height from the sources is different from the Anemometer height, a wind profile equation was used in getting the wind speed at the required advection height of the plume by extrapolation. The equation is given in 2 (Anjorin, 2017).

$$\frac{U}{v_0} = \left(\frac{h}{h_0}\right)^a \quad (2)$$

Where v is the wind speed at the required height h, v_0 is wind speed at the original height h_0 and α is the surface roughness coefficient which lies in the range of 0.05 - 0.5 (Akpinar and Akpinar, 2005). Surface roughness coefficient 'α' can be determined from the expression (Ulcar and Balo, 2009):

$$a = \frac{[0.37 - 0.088In(v_0)]}{\left[1 - 0.088In\left(\frac{h_0}{10}\right)\right]} \quad (3)$$

Wind speed of 6.2 m/s was obtained by applying the wind speed profile.

Results and Discussion

As majority of people resident in these city areas of Abuja where measurements were taken burn refuse during sanitation and wood as their source of energy for cooking, Figure 2 to 6 show percentage trend in dispersion of pollutants from wood burning source. At a distance of 1m from wood source, about 45% of the concentration of CO is obtained while about 5% eventually gets to the receptor at 5m downwind. For SO_2 and H_2S, about 39% and 35% are obtained at 1.0m while 8% and 2% get to the receptor at 5m downwind respectively. This shows that CO has higher dispersion than SO_2 and H_2S (Okobia and Hassian, 2015). This analysis is corroborated with Table 1 which reflects high values of CO for the source. For particulates, it is observed that about 42% of the concentration of PM_{10} is obtained at 1.0m from a wood burning source while 2% eventually gets to the receptor at 5m. Similarly 38% of $PM_{2.5}$ is obtained at 1.0m while 5.0% gets to the receptor at 5.0m. This indicates that wood burning source emits PM_{10} pollutants more than $PM_{2.5}$. The average monitored data from Refuse Burning Source as presented in Table 2 shows that concentrations decrease to their respective receptor points. It also shows that at a distance of 5m near the source, the concentration of pollutants is very high that it is somehow difficult for the detector to fully measure the concentration effectively. This is because the exit velocity of the pollutants is high due to high momentum of release. At 10 to 40m from the source, high concentration is registered. At a distance of 50m, the pollutants would have lost significant momentum thereby attaining a steady velocity with the ambient wind speed leading to low concentrations. At points beyond 70m, gravitational settling of the pollutants would have significantly taken place thereby reducing their concentrations.

Emission rate is influenced by amount of fossil fuel combusted and the volume of air in which pollutants are mixed. Extrapolation shows that refuse burning source records the highest emission rates of 89.2 mg/s, 5.06 mg/s, 4.20 mg/s, 0.68 mg/s and 0.47 mg/s for CO, SO_2, H_2S, PM_{10} and $PM_{2.5}$ respectively which could be due to buoyancy of release of the pollutants while wood burring source records least emission rates of 62.07 mg/s, 0.42 mg/s, 1.15 mg/s, 0.46 mg/s and 0.11 mg/s for CO, SO_2, H_2S, PM_{10} and $PM_{2.5}$ respectively as shown in Table 3. Comparing Tables 1 and 2, 4 and 5 respectively shows that measured concentrations of pollutants are higher than modeled concentrations. This could be due to the occurrence of very complex and unpredictable atmospheric dynamics which are not accounted for by the modeling equation. Analyzing the correlation of the measured and modeled concentrations, scattered plots have been used. Figures 9 to 13 show a high degree of correlation for wood burning. The respective coefficient of regression R^2 for the gas pollutants; CO, SO_2 and H_2S are 0.885, 0.848 and 0.574 while for particulates; R^2 is 0.861 and 0.715 for PM_{10} and $PM_{2.5}$. This indicates that among the pollutants investigated, SO_2 correlates least. Since this research allows the application of Gaussian Plume Model to ground emission sources for criteria pollutants, analysis would provide a validity of the model for use in predicting ground level concentrations along centerline of CO, SO_2, H_2S, PM_{10} and $PM_{2.5}$ for wood burning. This can be concluded that Gaussian Plume Models can be used to carry out measurement of the disposal of these selected pollutants from wood burning. In the same vein, measured and modeled concentrations of pollutants from refuse burning were correlated as presented in Figures 14 to 18. Their respective coefficient of regression show that only PM_{10} records high correlation of $R^2 = 0.577$. The other pollutants correlate low with $PM_{2.5}$ having least correlation. Based on ambient air quality index, results obtained from the monitored stations were compared to the South African and European Air Quality Standards. This is because Nigeria has no set standards or a legislative network that determines air quality. Table 1 and

2 reveals that refuse burning has higher emissions while wood burning records least emissions for at least 99% of the cases. This shows that refuse burning sources are the most harmful of the sources investigated while wood burning are most conducive of all the sources monitored. A comparative environmental impact assessment of the sources reveals that they are unsafe for selected pollutants. For CO (1 hour time average, the safe limit is 40mg/m^3), SO_2 (1 hour time average, the safe limit is 0.35040mg/m^3) and H_2S (1 hour time average, the safe limit is 0.04240mg/m^3).

Table 1: Average Concentration of Pollutants from Wood Burning in mg/m^3

X(m)	CO	SO_2	H_2S	PM_{10}	$PM_{2.5}$
1.0	77.4	0.52	1.44	0.48	0.14
2.0	45.75	0.30	1.05	0.32	0.11
3.0	27.95	0.29	1.00	0.22	0.07
4.0	14.20	0.13	0.60	0.10	0.03
5.0	8.30	0.11	0.07	0.02	0.02

Table 2: Average Concentration of Pollutants Emitted from Refuse Burning source in mg/m^3

Sources	Pollutants				
	CO	SO_2	H_2S	PM_{10}	$PM_{2.5}$
Wood burning	62.07	0.42	1.15	0.46	0.11
Refuse burning	89.2	5.86	4.20	0.68	0.47

Table 3: Emission Rate of Pollutants in mg/s

Sources	Pollutants				
	CO	SO_2	H_2S	PM_{10}	$PM_{2.5}$
Wood burning	62.07	0.42	1.15	0.46	0.11
Refuse burning	89.2	5.86	4.20	0.68	0.47

Table 4: Modeled Concentration of Pollutants from Refuse Burning.

	Modeled concentration in mg/m^3				
X(m)	CO	SO_2	H_2S	PM_{10}	$PM_{2.5}$
5.0	41.53	2.729	1.956	0.317	0.219
10.0	0.416	0.027	0.020	0.003	0.002
20.0	0.104	0.007	0.005	0.002	0.001
30.0	0.046	0.003	0.002	0.001	0.001
40.0	0.026	0.002	0.001	0.001	0.001
50.0	0.017	0.001	0.001	0.001	0.000
60.0	0.012	0.001	0.001	0.000	0.000
70.0	0.009	0.001	0.001	0.000	0.000
80.0	0.007	0.001	0.001	0.000	0.000
90.0	0.005	0.001	0.001	0.000	0.000
100.0	0.004	0.001	0.000	0.000	0.000

Table 5: Modeled Concentration of Pollutants from Wood burning

	Modeled concentration mg/m^3				
X(m)	CO	SO_2	H_2S	PM_{10}	$PM_{2.5}$
1.0	28.901	0.196	0.535	0.214	0.051
2.0	7.225	0.050	0.130	0.050	0.013
3.0	3.210	0.020	0.060	0.020	0.006
4.0	1.805	0.010	0.030	0.010	0.003
5.0	1.155	0.005	0.020	0.005	0.002

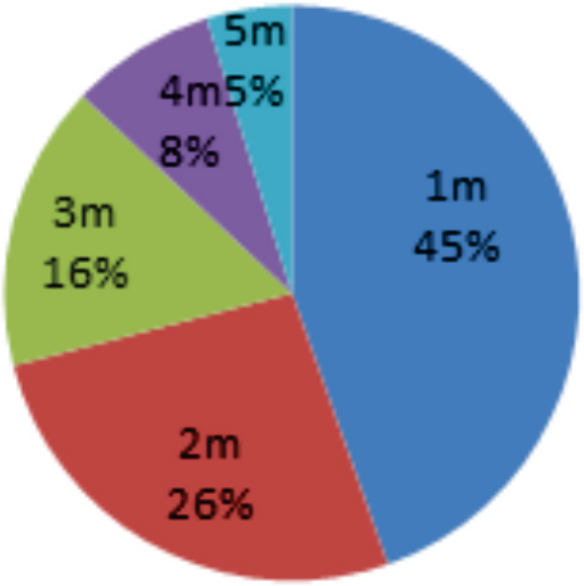


Figure 2: Percentage Trend of Dispersion of CO from Wood Burning for Cooking at Specified Locations Downwind.

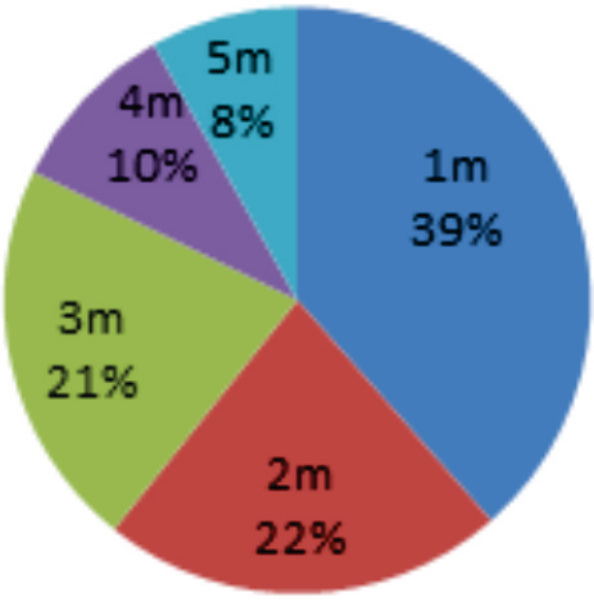


Figure 3: Percentage Trend of Dispersion of SO_2 from Wood Burning Cooking at Specified Locations Downwind.

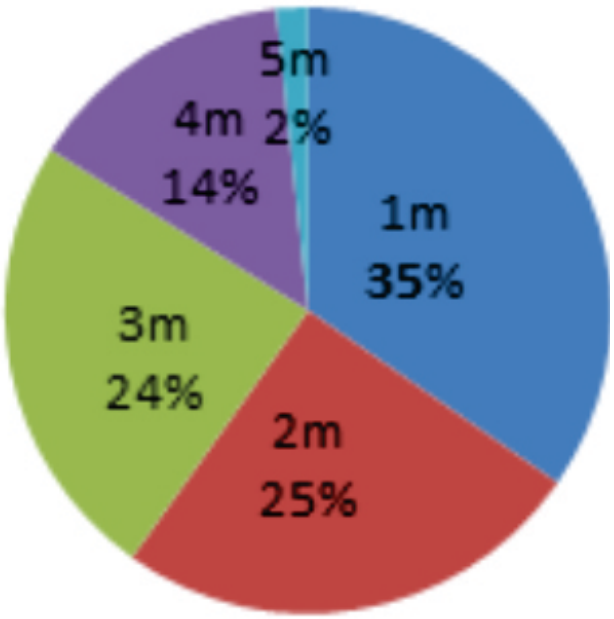


Figure 4: Percentage trend of dispersion of H_2S from wood burning for Cooking at specified locations downwind

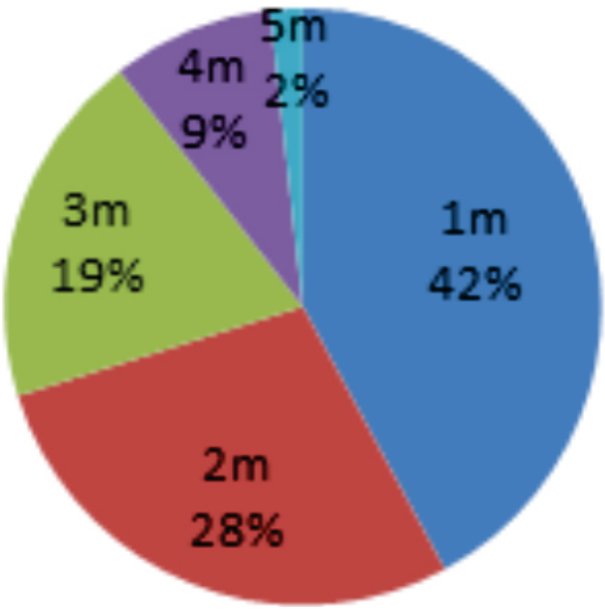


Figure 5: Percentage trend of dispersion of PM_{10} from wood burning for cooking at specified locations downwind.

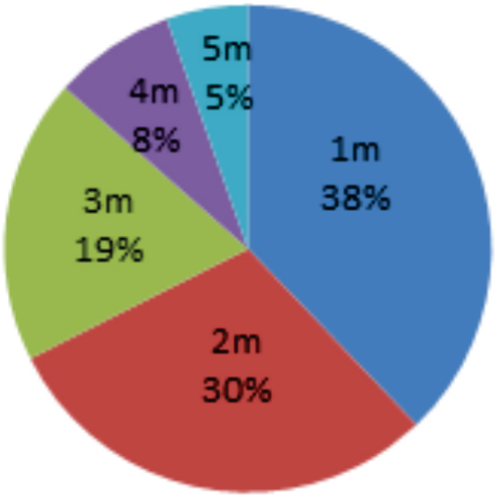


Figure 6: Percentage trend of dispersion of $PM_{2.5}$ from wood burning for cooking at specified locations downwind.

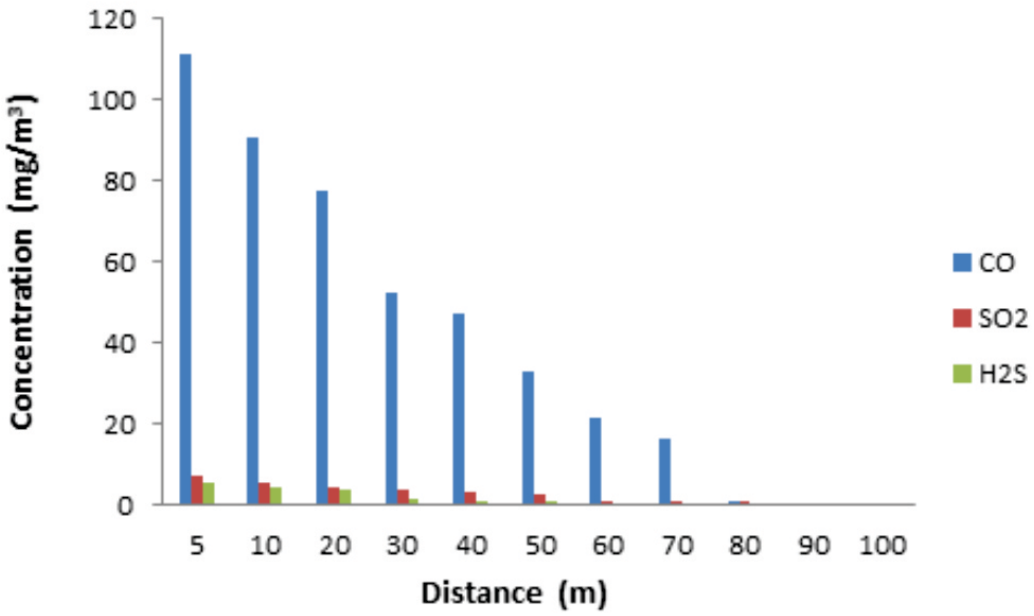


Figure 7: Concentration of gas pollutants emitted from refuse burning source

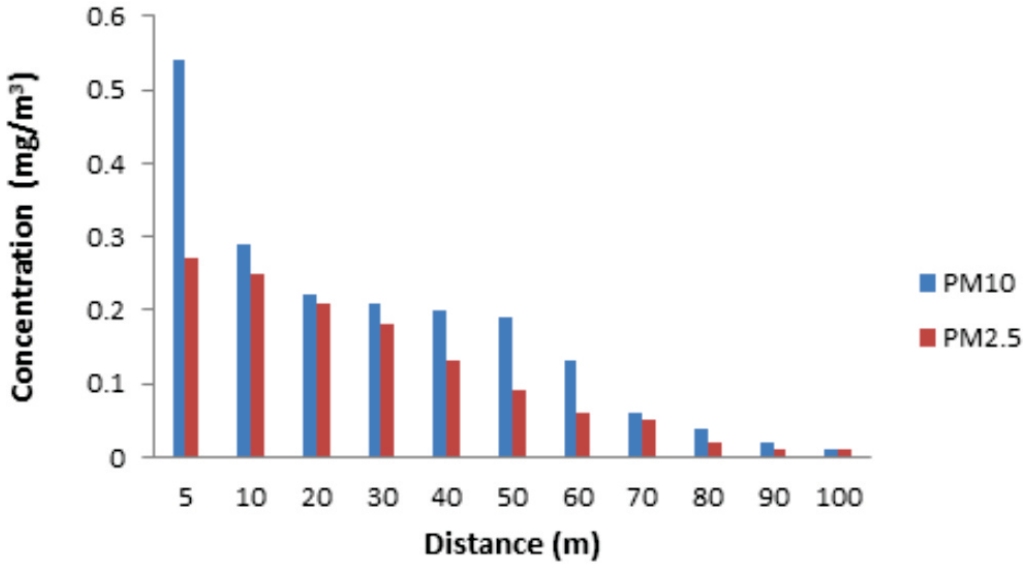


Figure 8: Concentration of particulate matters emitted from refuse burning source.

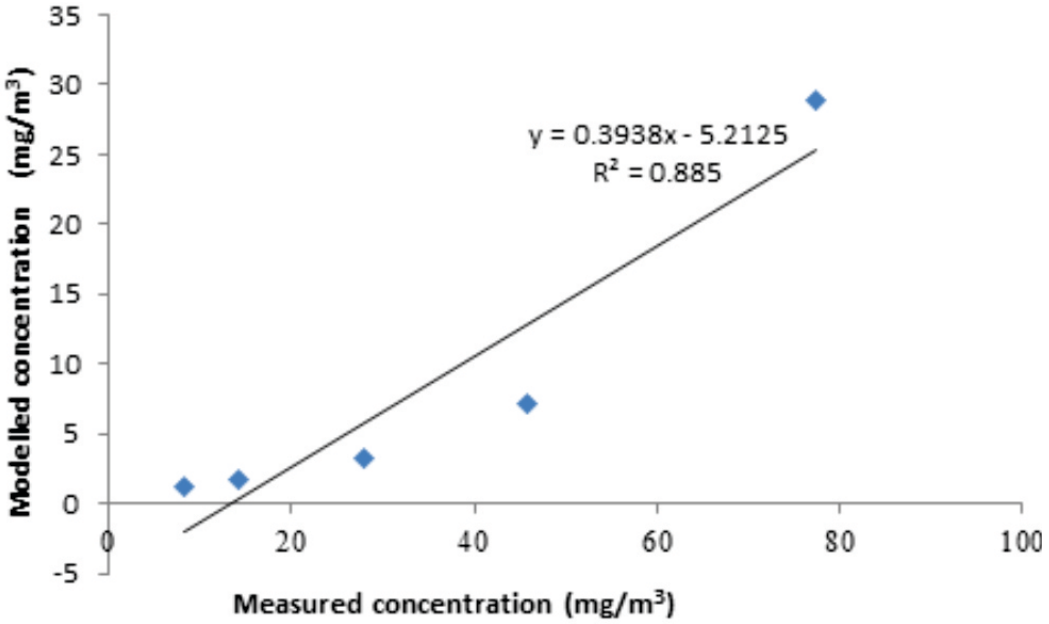


Figure 9: Scatter plot of modeled and measured concentration of CO from wood burning.

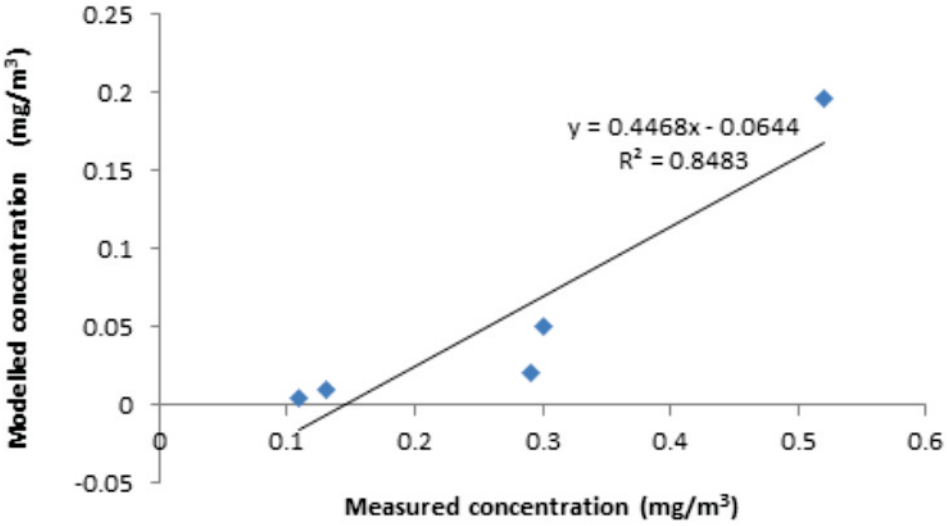


Figure 10: Scatter plot of modeled and measured concentration of SO_2 from wood burning.

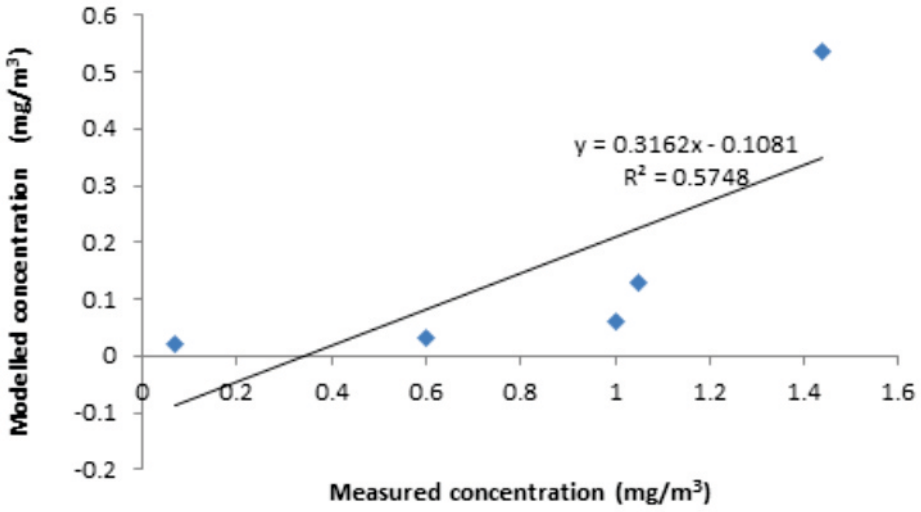


Figure 11: Scatter plot of modeled and measured concentration of H_2S from wood burning.

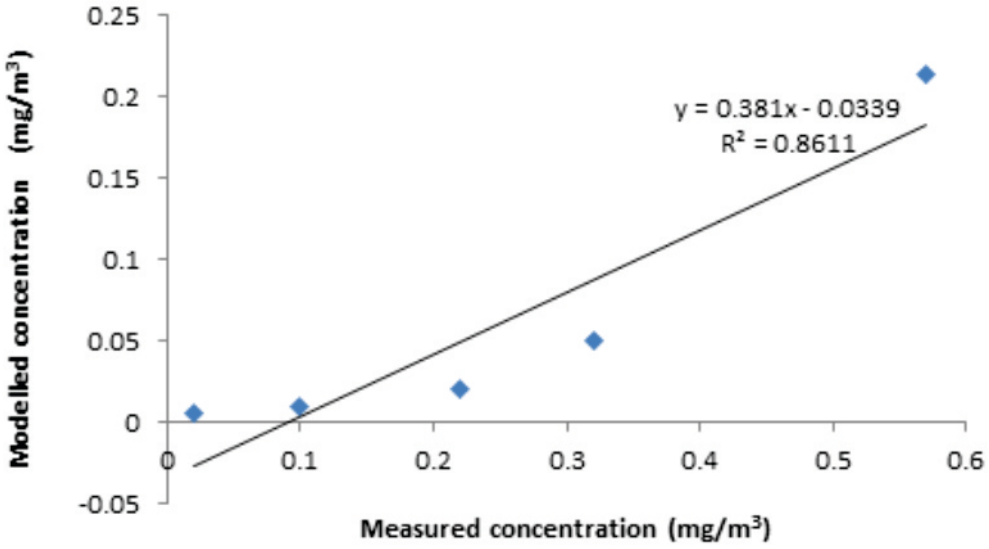


Figure 12: Scatter plot of modeled and measured concentration of PM_{10} from wood burning.

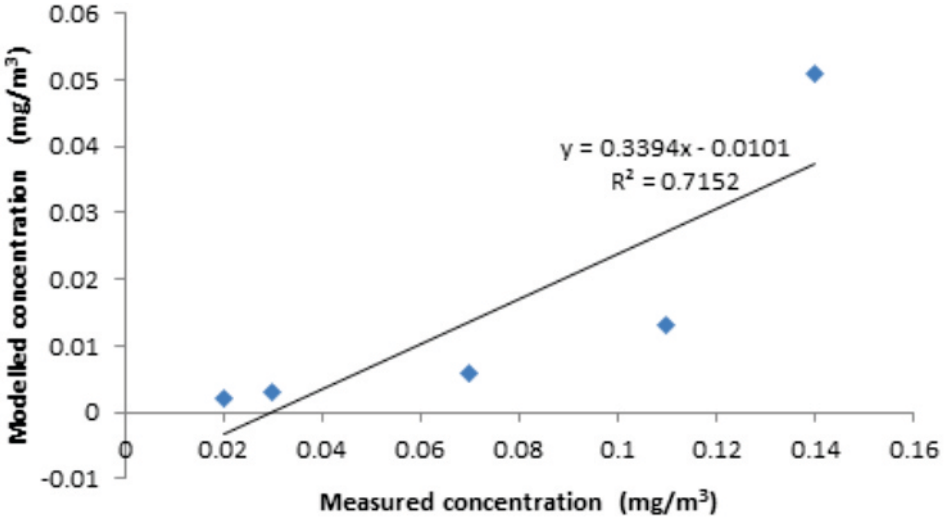


Figure 13: Scatter plot of modeled and measured concentration of $PM_{2.5}$ from wood burning

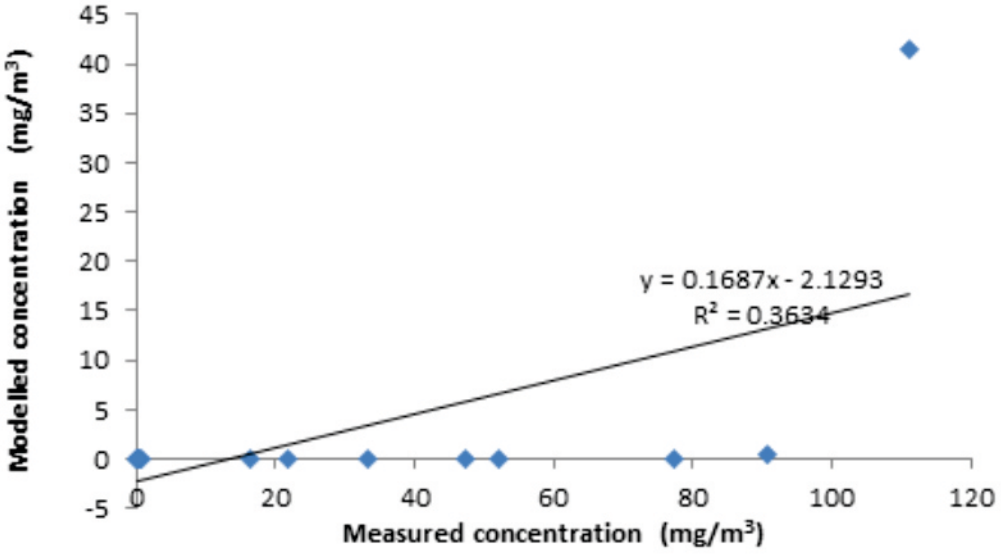


Figure 14: Scatter plot of modeled and measured concentration of CO from refuse burning.

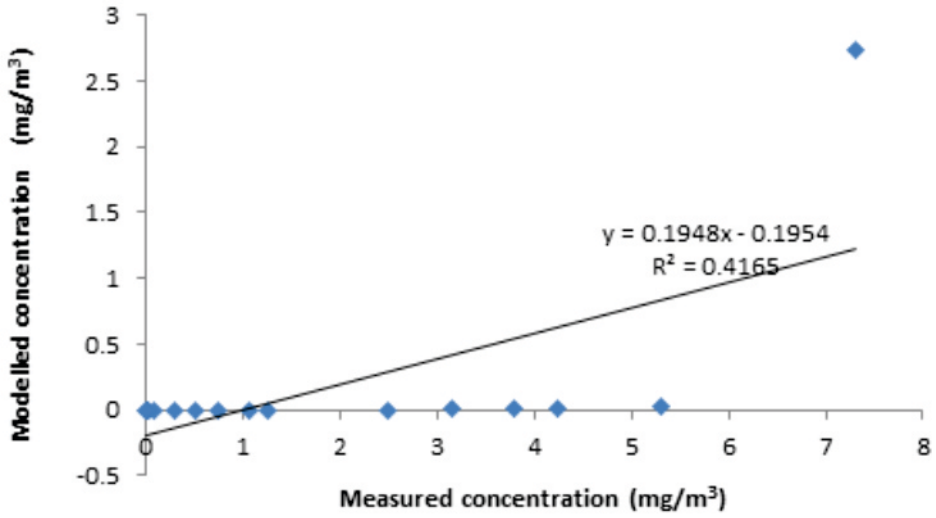


Figure 15: Scatter plot of modeled and measured concentration of SO_2 from refuse burning.

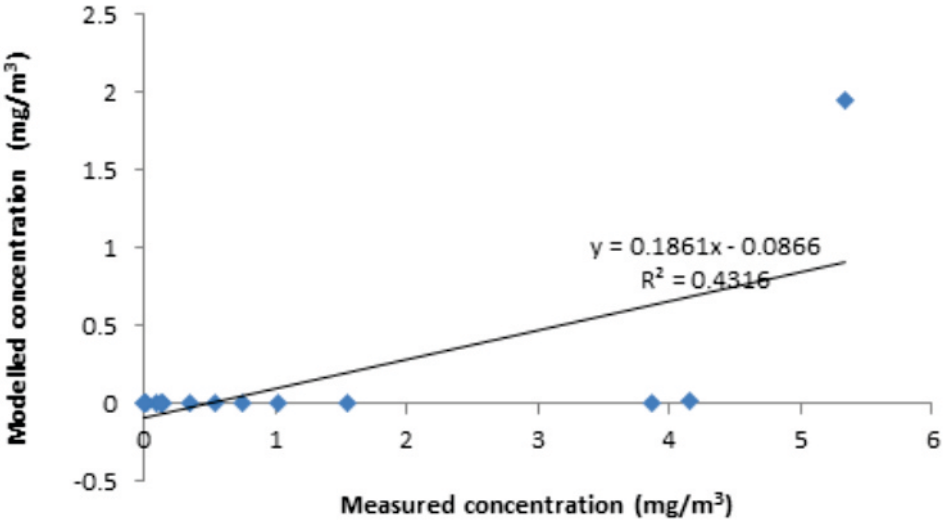


Figure 16: Scatter plot of modeled and measured concentration of H_2S from refuse burning.

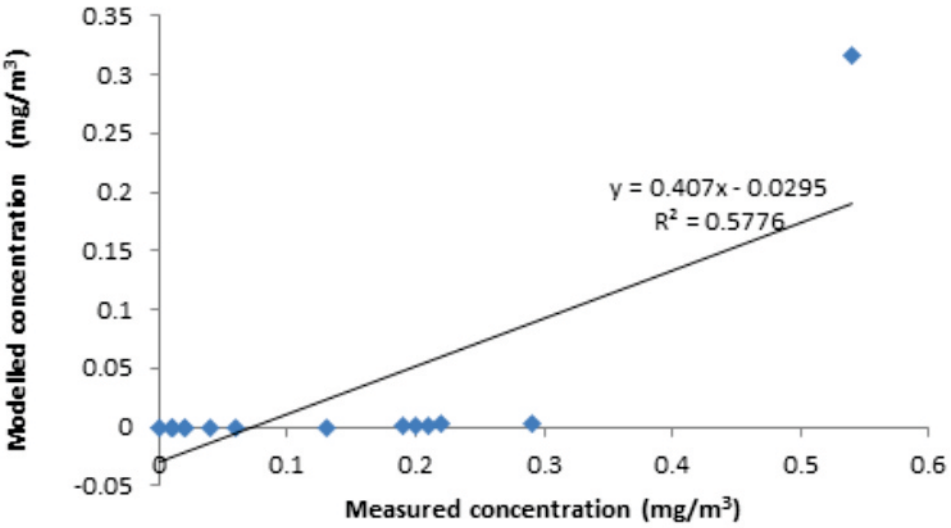


Figure 17: Scatter plot of modeled and measured concentration of PM_{10} from refuse burning.

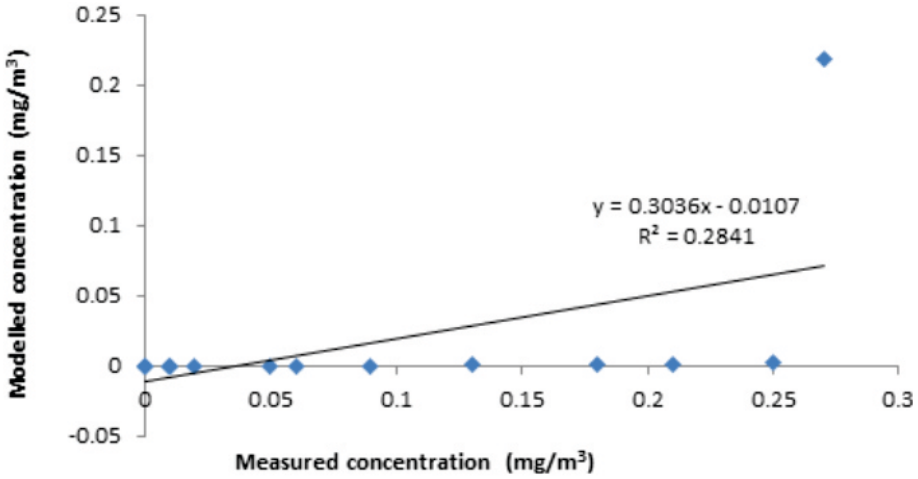


Figure 18: Scatter Plot of Modeled and Measured Concentration of $PM_{2.5}$ from Refuse Burning.

Conclusion

Fuel type, amount of fuel being burnt and wind speed were seen to affect the emission rates from the sources. Dispersion of pollutants was observed to vary between sources and for different pollutants. The more the buoyancy of emission from the source, the higher the vertical distance and the farther the emission moves away from the source. That is why dispersion of pollutants from refuse burning is higher than wood source. From the selected sources monitored, Carbon Monoxide has the highest concentration and dispersion strength. This could be attributed to its non reactivity and low molecular weight. On the other hand, particulates have least dispersion which is due to heavy molecular weight which encourages more deposition and gravitational settling.

It is observed that measured concentration of the pollutants investigated is higher than the modeled concentration. This is due to the occurrence of very complex and unpredictable atmospheric dynamics which are not accounted for by the modeling equation. This complex atmospheric dynamics is as a result of wind shearing and turbulence. However, this work has given measure of validity to Gaussian plume model for application to ground level emission sources for some criteria pollutants. Correlation between modeled and measured concentrations shows that wood burning source has higher validity of the model with coefficients of regression R^2 for CO, SO_2, H_2S, PM_{10} and $PM_{2.5}$ as 0.885, 0.848, 0.574, 0.861 and 0.715 respectively while refuse burning has the least measure of validity with coefficients of regression R^2 for CO, SO_2, H_2S, PM_{10} and $PM_{2.5}$ as 0.363, 0.416, 0.416, 0.431, 0.572 and 0.284 respectively. It is observed that the lower the measured concentrations the more effective the model and the higher the measured concentrations the less the applicability of the model as it will not present data at respective receptor points downwind the sources if used in simulating the concentrations. Based on Ambient Air Quality Standards, the immediate environments of these sources are unsafe for gas pollutants while particulates are more conducive in the sources investigated.

Recommendations

Nose mask should be worn by people exposed directly to these sources so as to reduce hazards arising from inhalation of pollutants. People working with wood burning source can sit in anti-plume direction in other to reduce the impact of the emissions from the source. Exposure to these sources should be grossly reduced by enacting environmental policies that regulates the duration of exposure to these sources so as to reduce the health impact of the emissions.

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