Journal of Advanced Research in Medical Science & Technology
Volume 8, Issue 1 - 2021, Pg. No. 19-28
Peer Reviewed & Open Access Journal

Research Article

Outdoor Air Quality Index of Biomass Combustion in the Niger Delta, Nigeria: A Health Impact Perspective

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DOI: https://doi.org/10.24321/2394.6539.202108

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How to cite this article:
Richard G, Sawyer WE, Izah SC. Outdoor Air Quality Index of Biomass Combustion in the Niger Delta, Nigeria: A Health Impact Perspective. J Adv Res Med Sci Tech. 2021;8(1):19-28.

Date of Submission: 2020-08-18
Date of Acceptance: 2021-03-31

A B S T R A C T

Background: Pollutant gases such as Carbon Monoxide (CO), Nitrogen Dioxide (NO_2) and Sulphur Dioxide (SO_2) are released during certain anthropogenic activities including cooking with biomass. This study evaluated the air quality index of CO, NO_2 and SO_2 emissions during outdoor biomass combustion in the Niger Delta region of Nigeria.
Materials and Methods: Triplicate sampling was carried out at 3 distances in 4 different states for one Calendar year across the two distinct seasons viz: dry (November, January and March) and wet (May, July and September) in the Niger Delta. A portable multiprobe AEROQUAL meter with head-probe of varying detection range of 0 - 100 ppm for CO and NO_2, and 0 - 10ppm for SO2 was used.

Result: The results showed that CO, NO_2 and SO_2 ranged from 0.00 - 1.58 ppm, 0.00 - 0.08 ppm and 0.00 - 0.06 ppm, respectively. There was statistical variation $p<0.05$ across the different months for CO and SO_2, locations for NO_2 and distances for all the gases, and most of their interactions. The concentrations of the pollutant gases decreased as distances away from the emission source increased. The concentration of CO, NO_2 and SO_2 were ≤ Nigerian Ambient air quality guidelines. The air quality index showed slight to severe contamination at 10ft distances in both seasons of study.

Conclusion: The air quality index indicates deleterious health impacts at 10ft emission source. Hence there is need for routine monitoring of these gases in the ambient air to obtain indices that are relevant in preventing risks related to human exposure.

Keywords: Air Quality, Environmental Health, Biomass, Pollutant Gases

Introduction

Air pollution is a major global concern in both developed and developing nations. Air pollution is caused by anthropogenic and natural sources leading to alteration in the ambient air quality of an area. Emissions released into the atmosphere are predominantly particulate matter, PM_1, $PM_{2.5}$, PM_4, PM_7 PM_{10} and total suspended particulates.[1,2] Of these $PM_{2.5}$ and PM_{10} are widely studied because they pose health risk to humans.[3] Other air pollutants that are frequently studied include Sulphur Dioxide (SO_2), Nitrogen Dioxides (NO_2), Carbon Monoxide (CO), volatile organic compounds, hydrogen sulphide, ammonia,[4-7] hydrogen fluoride, ozone, among others.[8] Health impacts of particulates and heavy metal concentration[9-12] have been reported in the atmosphere[13,14] and in dusts.[15] The anthropogenic sources of these air pollutants include use of fossil fuel, emissions from fired power plants, smelters, industrial boilers, petroleum refineries, manufacturing facilities,[8] biomass combustion, and domestic heating and cooking as well as gas flaring.

Noxious gases are source of concern because some have the tendency to undergo physicochemical changes to substances that are detrimental to both biotic and abiotic components of the environment. For instance, ozone which is a major component of smog is formed when NO_2 and volatile organic compounds are assorted in the presence of sunlight.[8] The authors further reported that ozone in the troposphere/ atmosphere is close to the ground, and should not be confused with beneficial ozone found in the stratosphere/ atmosphere.

Some other gases such as oxides of nitrogen and sulphur can combine with moisture, oxygen, and other chemicals in the atmosphere to form acidic gases that causes acid rain. Sulphur dioxide and NO_2 readily dissolves in water. Acid rain is known to cause several effects on humans as well as infrastructures including buildings.[16]

Carbon monoxide in the atmosphere often results from incomplete combustion of hydrocarbons and other organic compounds, in addition to SO_2 and NO_2 they are noxious gases with varying health impacts.[8] Nitrogen oxide is another important pollutant gas that exists as nitrogen monoxide (NO) and NO_2 in the atmosphere, and they are mainly from fossil and biomass combustion.[8] Nitrogen dioxide is formed in the reaction between nitric oxide and atmospheric oxygen or ozone.[17] Pagadala et al.[8] reported that SO^2 reflects the amount of suphur emitted indirectly (from combustion) into the atmosphere. This implies that SO^2 could serve as a marker index to the sulphur content of a substance eg petroleum products and its derivatives. The distribution of these pollutant gases in the atmosphere is influenced by seasons[4] as well as meteorological parameters such as wind speed, relative humidity and temperature.[5,6]

Exposure to complex mixture of organic and inorganic chemicals from industrial activities poses a great risk to the environment and health of humans in such vicinity.[18] Through the act of breathing, air pollutants enter the lungs where it causes deleterious effects dependent on their chemical composition as well as dosage. Most importantly air pollutants tend to affect the respiratory channels of the body (viz: bronchi, bronchioles and alveoli), cardiovascular functions, with acute or chronic consequences or even death.[8]

Air pollutants occur in many urban and rural areas in developing and developed nations. These pollutants of public health importance occur either outdoor or indoor depending on the pollutant source. Many instances of indoor and outdoor air pollution are due to the combustion of wood (biomass) fuel. The dispersal/ dilution of noxious gases is faster in outdoor compared to indoor, hence cross ventilation and other technological methods are advised when biomass combustion is carried out indoors. Fromme[19] described outdoor air pollutants as a complex mixture originating from natural and anthropogenic sources and comprising particles, chemicals and biogenic materials with well-known health implications.

In The Niger Delta region of Nigeria, wood fuel is used for cooking especially in rural areas in both indoor and outdoor settings. Several studies have been carried out with respect to air pollution in Nigeria but most of the study focused on industrial areas. These other less studied emission sources may have concentrations exceeding the desirable limits. Therefore, this study focused on air quality index of outdoor exposure to biomass combustion in the Niger Delta, Nigeria. The health implications of the air quality index were discussed.

Materials and Methods

Study Area

The Niger Delta is often defined as the oil and gas producing States in Nigeria comprising 6 States in the South-South, 1 in the South-West and 2 in South-East geopolitical zones. However, this study was carried out in 4 states (viz: Delta, Bayelsa, Rivers and Abia) (Figure 1) in the South-South geo-political zone. Several human activities are carried out in the area. Wood fuel (biomass) is a major source of cooking energy in the area especially among residents who lives in the rural area. Some use biomass indoor while several others cook out in a well-ventilated area. The wood fuel is from diverse plant species which depends on its availability. The region is characterized by two distinct season viz: wet (comprising 7 months i.e. April to October) and dry season (comprising of 4 months i.e. November to March). The characteristics of common meteorology of the area have been documented by Richard et al.,[1,4] Ohimain et al.[5]

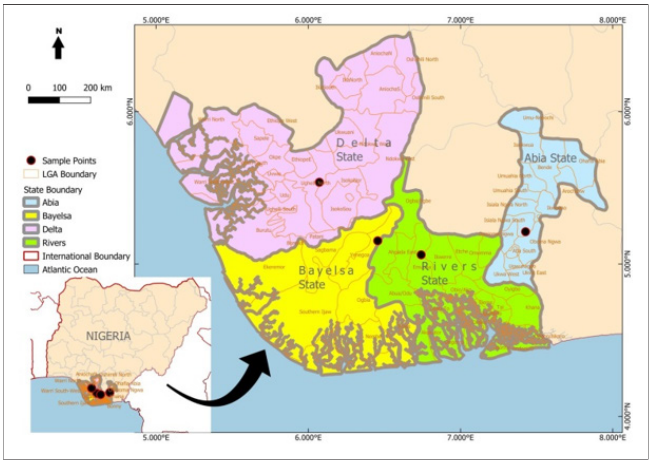


Figure 1.Map of the study area showing the sampling locations

Sample Collection

Triplicate samples was collected at 3 distances (viz: 10ft, 25ft and 50ft from the emission source) in 4 locations viz: A (Delta State), B (Bayelsa state), C (Rivers State) and D (Abia state) for 6 months spanning 1 Calendar year cutting across 3 months of wet (May, July and September) and dry (November, January and March) seasons. The study was carried out from November 2016 to September 2017.

Measurement of Pollutant Gases and Meteorological Indicators

The pollutant gases were measured with a portable multiprobe AEROQUAL meter (Aeroqual Limited Auckland-New Zealand-Series 300) as described by Richard et al.[4] Each of the pollutant gases head probe was attached to the AEROQUAL meter and switched on. The range of detection was between 0 -100 ppm for CO and NO_2, and 0 - 10 ppm for SO_2. For each of the parameters, measurements were taken by holding the sensor in the direction of the prevailing wind until the reading stabilizes.

The meteorological parameters (temperature, relative humidity and wind speed) were measured with a portable multi- meteorological indicator Kestrel (model: 4500 NV).

Air Quality Index

Air quality index developed by US Oak Ridge National Laboratory previously described by Tiwari[20] was adopted for this study due to the ability to combine all the pollutant parameters to give overall value.[21,22]

Air quality index = $[5.7\sum I]^{1.37}$

Where I is the ratio of the observed concentration of the measured gases to their standard limits. The Nigerian Ambient air quality index by Federal Environmental Protection Agency was adopted as the standard viz: 10 - 20 ppm for 8 hourly average (CO), 0.01 - 0.06 ppm for 1 hourly average (NO_2) and 0.01 - 0.10ppm for 1 hourly average (SO_2).[5,23,24] The lower value for each of the gases was used for the calculations. The air quality index was classified as: 00 $<$AQI≤25 (Clean air), 25 $<$AQI≤50 (slight contamination), 50 $<$AQI≤75 (moderate contamination), 75 $<$AQI≤100 (heavy contamination), and AQI$>$100 (severe contamination).[21]

Statistical Analysis

SPSS version 20 was used to carry out the statistical analysis. A three-way analysis of variance was carried out at p=0.05 and Duncan statistics was used to discern the source of observed variations. Microsoft excel was used to plot the charts. Spearman's rho was used to show the correlation between the pollutant gases and meteorological indicators studied.

Result

The concentrations of some pollutant gases and meteorological indicators of outdoor biomass combustion during cooking in the Niger Delta region of Nigeria are shown Tables 1-3. Carbon monoxide concentration from outdoor combustion of biomass among the various months, locations and distances studied ranged from 0.13 - 0.86 ppm (Table 1), 0.33 - 0.47 ppm (Table 2) and 0.03 - 0.98 ppm (Table 3), respectively. There was significant variations at $p<0.05$ across the months, locations, interactions of months and locations and between months and distances, but there was no significant variation ($p>0.05$) across the locations, interactions of distance and locations, and between months, locations and distances. The overall concentration of CO decreased with increase in distance from the emission source. The highest concentration of CO concentrations occurred in the wet season (Figure 2).

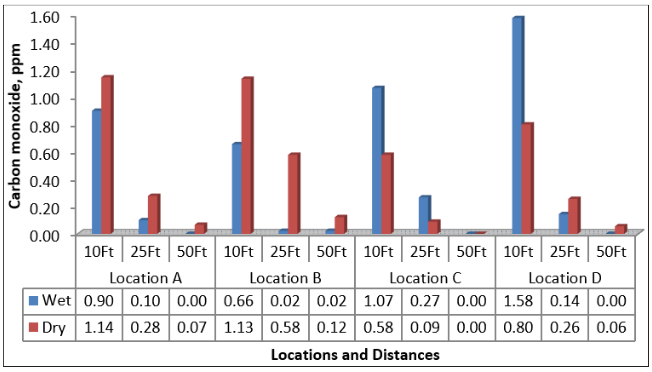


Figure 2.Overall seasonal distribution of carbon monoxide during outdoor combustion of biomass during cooking in the Niger Delta, Nigeria

The level of sulphur dioxide during outdoor combustion of biomass in the various months, locations and distances studied ranged from $<$0.01 - 0.04 ppm (Table 1), 0.01 - 0.02 ppm (Table 2), and $<$0.01 - 0.05 ppm (Table 3), respectively. There was statistical variations at $p<0.05$ among the various months, distances, and interaction between months and distances, but no significant variations (P>0.05) across the locations, interactions between months and locations, distances and locations, and months, distances and locations. The overall level of SO2 is slightly higher in wet season at 10ft distances (Figure 3).

The level of nitrogen dioxide during outdoor combustion of biomass in the Niger Delta States ranged from <0.01 – 0.01 ppm, which differs significantly at p<0.05 among the various months (Table 1). Based on spatial-temporal distribution, the concentration was in the range <0.01 - 0.01 ppm, which is statistically different at p<0.05 among some locations (Table 2). The concentration ranged from <0.01 – 0.01 ppm based on distance and showed significant decline at p<0.05 as the distances away from the emission source increased (Table 3). Based on interactions, nitrogen dioxide showed significant interactions at p<0.05 between months and location, months and distance, distance and location, and months, distance and locations. The nitrogen dioxide was only recorded in 10ft distance in Location C for both season and Location D for only wet season (Figure 4).

Table 1.Bimonthly distribution of some pollutant gases and meteorological indicators in outdoor biomass combustion during cooking in the Niger Delta region of Nigeria

Parameters	Months					
	November	January	March	May	July	September
CO, ppm	0.31a	0.81b	0.15a	0.20a	0.86b	0.13a
SO_2, ppm	0.03c	<0.01a	0.01abc	0.04bc	0.03 c	0.01ab
NO_2,ppm	0.01a	<0.01a	<0.01a	0.01b	0.01a	<0.01a
Wind speed, m/s	0.87c	0.89c	0.88c	0.63a	0.79bc	0.71ab
Temperature, ºC	31.77d	31.55c	32.29e	29.30ab	29.25a	29.39b
Relative humidity, %	60.11b	61.75c	57.86a	71.03d	72.78f	71.78e

Means (36) with Different superscript letters across the row indicate significant difference at p<0.05 according to Duncan multiple range test statistics.

Table 2.Spatial distribution of some pollutant gases and meteorological indicators in outdoor biomass combustion during cooking in the Niger Delta region of Nigeria

Parameters	Locations			
	A	B	C	D
CO, ppm	0.42a	0.42 a	0.33a	0.47a
SO_2, ppm	0.02a	0.02 a	0.02a	0.01a
NO_2,ppm	<0.01a	<0.01a	0.01b	0.01b
Wind speed, m/s	0.79 a	0.86a	0.76a	0.79 a
Temperature, ºC	31.53d	31.06c	29.83a	29.93b
Relative humidity, %	61.76 a	63.63b	69.72d	68.43c

Means (54) with Different superscript letters across the row indicate significant difference at p<0.05 according to Duncan multiple range test statistics.

Table 3.Distance-based distribution of some pollutant gases and meteorological indicators in outdoor biomass combustion during cooking in the Niger Delta region of Nigeria

Parameters	Distance, feet		
	10	25	50
CO, ppm	0.98c	0.22b	0.03a
SO_2, ppm	0.05b	<0.01a	<0.01a
NO_2,ppm	0.01b	<0.01a	<0.01a
Wind speed, m/s	0.737a	0.828a	0.825a
Temperature, ºC	30.62a	30.57a	30.58a
Relative humidity, %	65.58a	66.03a	66.04a

Means (72) with Different superscript letters across the row indicate significant difference at p<0.05 according to Duncan multiple range test statistics.

ISSN: 2394-6539
DOI: https://doi.org/10.24321/2394.6539.202108

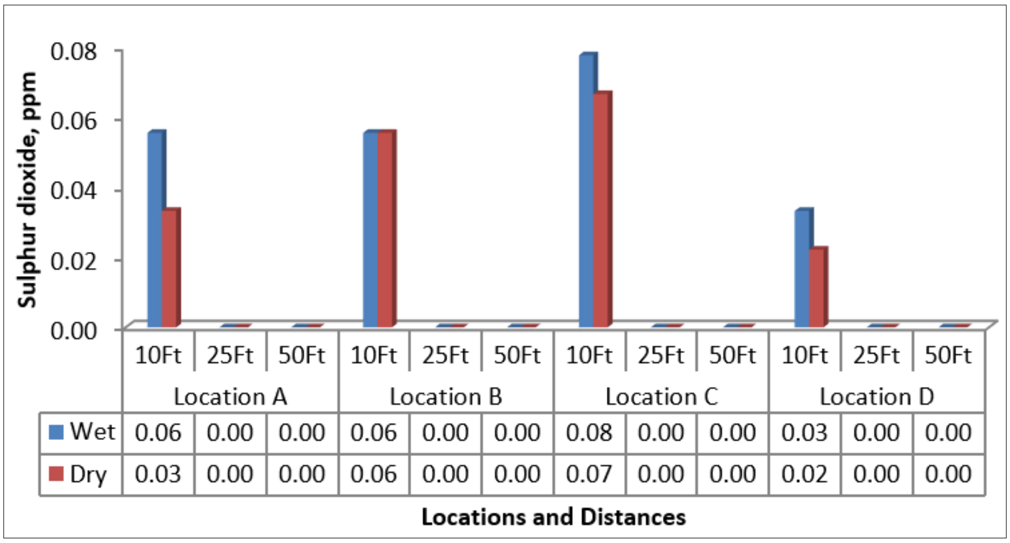


Figure 3.Overall seasonal distribution of sulphur dioxide during outdoor combustion of biomass during cooking in the Niger Delta, Nigeria

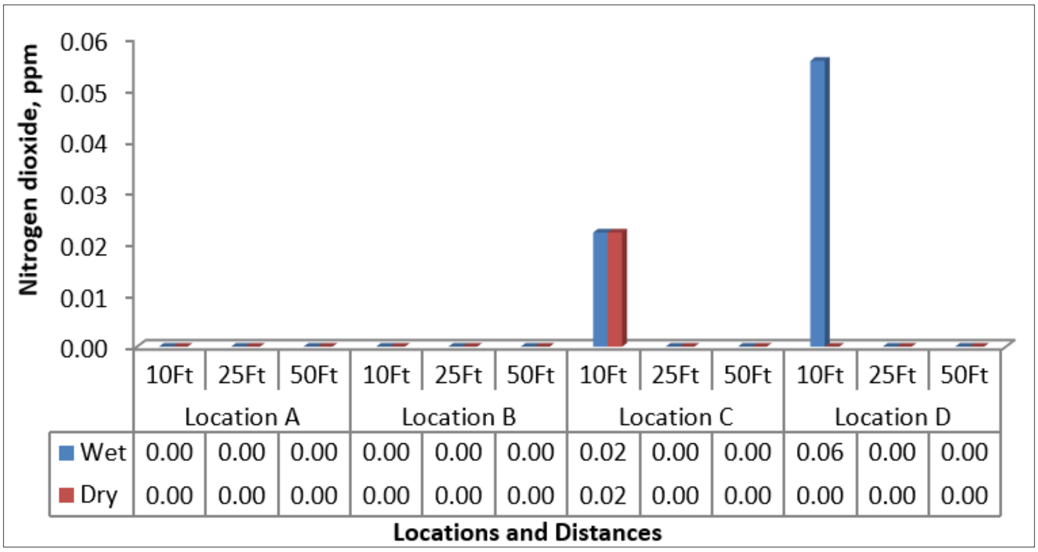


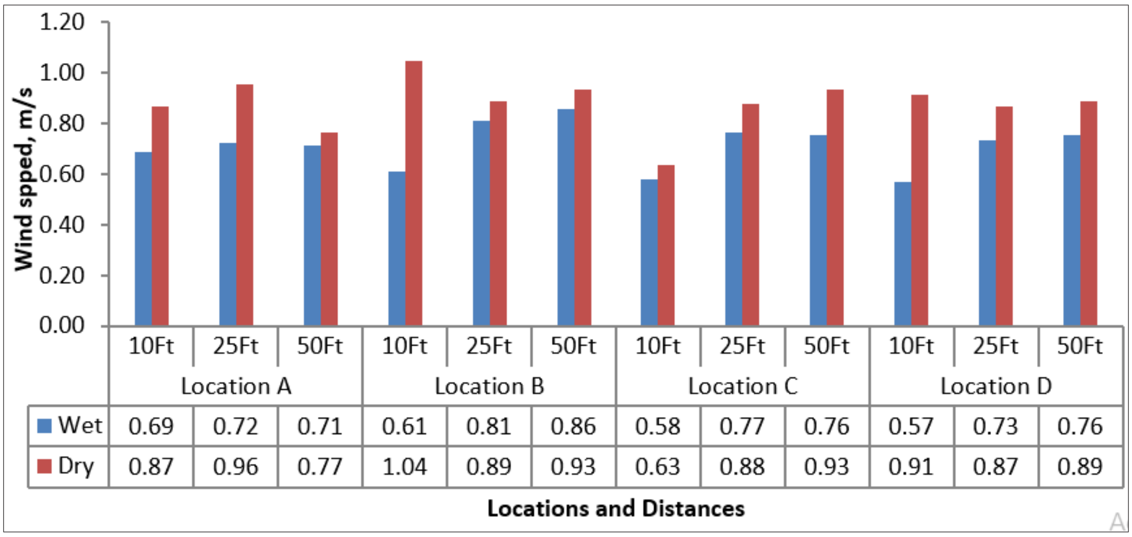
Figure 4.Overall seasonal distribution of nitrogen dioxide during outdoor combustion of biomass during cooking in the Niger Delta, Nigeria

In the study, the wind speed across the various months, locations and distances ranged from 0.63 – 0.89 m/s (Table 1), 0.76 – 0.86 m/s (Table 2) and 0.74 – 0.84 m/s (Table 3), respectively. Statistically, there was variations at $p<0.05$ among the various months, interactions between distances and locations, but not significantly different ($p>0.05$) across the locations, distances, interactions between months and locations, distances and locations, and between months, locations and distances. On the overall the wind speed were higher in wet season as compared to wet season (Figure 5).

The atmospheric temperature across the various months, locations and distances during the study ranged from 29.25 – 32.29 ºC (Table 1), 29.83 – 31.53 ºC (Table 2) and 30.57 – 30.62 ºC (Table 3), respectively. There was significant variation ($p<0.05$) across the months, locations, interactions between months and locations, and between months, locations and distances, and no statistical variation ($p>0.05$) across the distances, interactions between months and distances, and distances and locations. On the overall the temperature was higher in dry season than wet season (Figure 6).

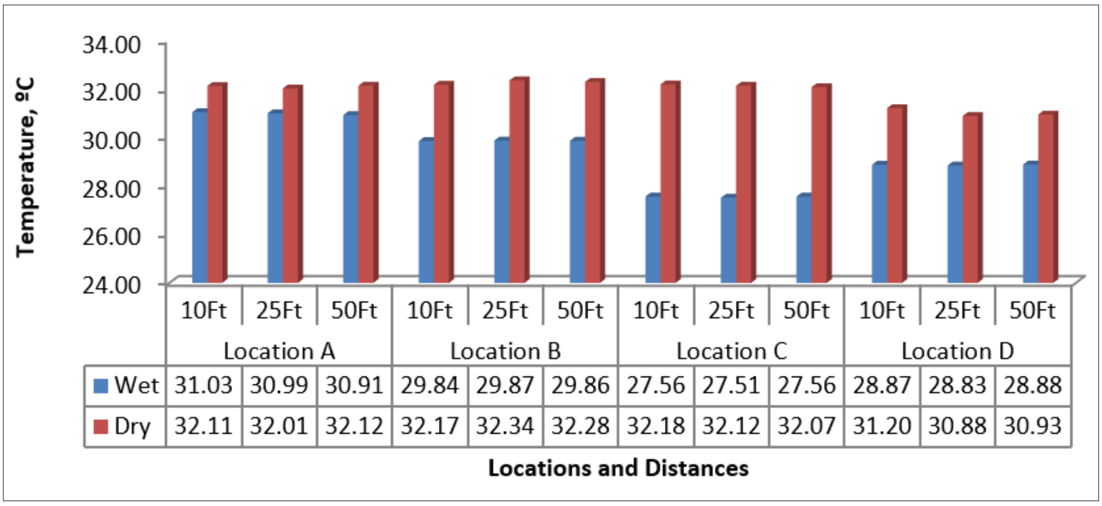
The relative humidity across the various months, locations and distances during the study period ranged from 57.86 – 72.82 % (Table 1), 61.76 – 69.72 % (Table 2) and 65.58 – 66.04 % (Table 3), respectively. There was significant variation ($p<0.05$) across the months, locations, interactions between months and locations, between distances and locations, and between months, locations and distances, and not statistical variation ($p>0.05$) across the distances, interactions between months and distances. On the overall the relative humidity were higher in wet season as compared to wet season (Figure 7).

ISSN: 2394-6539
DOI: https://doi.org/10.24321/2394.6539.202108



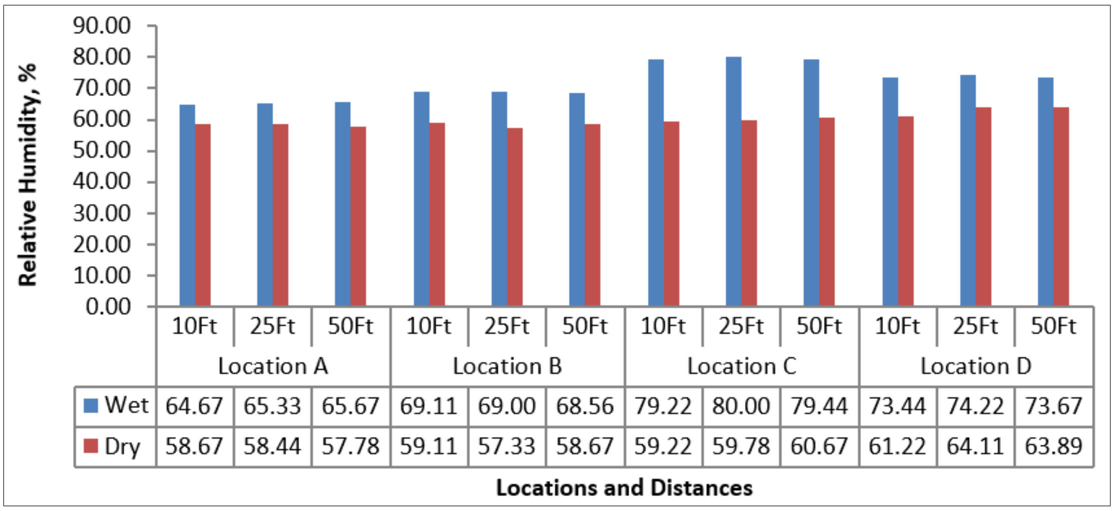
	10Ft	25Ft	50Ft	10Ft	25Ft	50Ft	10Ft	25Ft	50Ft	10Ft	25Ft	50Ft
	Location A			Location B			Location C			Location D		
Wet	0.69	0.72	0.71	0.61	0.81	0.86	0.58	0.77	0.76	0.57	0.73	0.76
Dry	0.87	0.96	0.77	1.04	0.89	0.93	0.63	0.88	0.93	0.91	0.87	0.89

Figure 5.Overall seasonal distribution of wind speed during outdoor combustion of biomass during cooking in the Niger Delta, Nigeria



	10Ft	25Ft	50Ft	10Ft	25Ft	50Ft	10Ft	25Ft	50Ft	10Ft	25Ft	50Ft
	Location A			Location B			Location C			Location D		
Wet	31.03	30.99	30.91	29.84	29.87	29.86	27.56	27.51	27.56	28.87	28.83	28.88
Dry	32.11	32.01	32.12	32.17	32.34	32.28	32.18	32.12	32.07	31.20	30.88	30.93

Figure 6.Overall seasonal distribution of temperature during outdoor combustion of biomass during cooking in the Niger Delta, Nigeria



	10Ft	25Ft	50Ft	10Ft	25Ft	50Ft	10Ft	25Ft	50Ft	10Ft	25Ft	50Ft
	Location A			Location B			Location C			Location D		
Wet	64.67	65.33	65.67	69.11	69.00	68.56	79.22	80.00	79.44	73.44	74.22	73.67
Dry	58.67	58.44	57.78	59.11	57.33	58.67	59.22	59.78	60.67	61.22	64.11	63.89

Figure 7.Overall seasonal distribution of relative humidity during outdoor combustion of biomass during cooking in the Niger Delta, Nigeria

ISSN: 2394-6539
DOI: https://doi.org/10.24321/2394.6539.202108

Table 4.Spearman's rho of some pollutant gases and meteorological indicators within outdoor biomass combustion during cooking in the Niger Delta region of Nigeria

Parameters	CO	SO2	NO2	W/S	TEMP	RH
CO	1.000					
SO2	.403**	1.000				
NO2	.172*	.362**	1.000			
W/S	-.052	-.192**	-.226**	1.000		
TEMP	.059	-.052	-.033	.178**	1.000	
RH	-.084	.039	.042	-.196**	-.979**	1.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

N=218 (months =6, Location =4, distance = 3, replicate=3).

Table 5.Air quality index of pollutant gases and meteorological indicators within outdoor biomass combustion during cooking in the Niger Delta region of Nigeria

Locations	Distances, Feet	Air quality index (AQI)			
		Wet		Dry	
		Values	Air description	Values	Air description
Location A	10	116.37	Severe contamination	59.07	Moderate contamination
Location B	10	115.68	Severe contamination	117.03	Severe contamination
Location C	10	201.72	Severe contamination	164.78	Severe contamination
Location D	10	95.15	Heavy contamination	33.97	Slight contamination
Location A	25	0.02	Clean air	0.08	Clean air
Location B	25	0.00	Clean air	0.22	Clean air
Location C	25	0.08	Clean air	0.02	Clean air
Location D	25	0.03	Clean air	0.07	Clean air
Location A	50	0.00	Clean air	0.01	Clean air
Location B	50	0.00	Clean air	0.03	Clean air
Location C	50	0.00	Clean air	0.00	Clean air
Location D	50	0.00	Clean air	0.01	Clean air

00 <AQI≤25 (clean air), 26 <AQI≤50 (slight contamination), 51 <AQI≤75 (moderate contamination), 76 <AQI≤100 (heavy contamination), and AQI>100 (severe contamination).

Table 4, shows the spearman's rho of some pollutant gases and meteorological indicators within outdoor biomass combustion in the Niger Delta region of Nigeria. Carbon monoxide showed positive correlation with sulphur dioxide (r=0.403; p<0.01) and nitrogen dioxide (r=0.172, p<0.05). Sulphur dioxide showed positive relationship with nitrogen dioxide (r=0.362, p<0.01) and negatively correlates with wind speed (r=-0.192, p<0.01). Nitrogen dioxide negatively correlates with wind speed (r=-0.226, p<0.01). Wind speed positively correlates with temperature (r=0.178, p<0.01), and negatively correlates with relative humidity (r=-0.196, p<0.01). Temperature negatively correlates with relative humidity (r=-0.979, p<0.01).

Table 5, showed air quality index of pollutant gases and meteorological indicators within outdoor biomass combustion during cooking in the Niger Delta region of Nigeria. The index ranged from clean air to severe contamination. The index at 25ft and 50ft distances showed that the air is clear. Generally, the air quality index were higher (with air description of slight to severe contamination) at 10ft distances across both seasons.

Discussion

Wood fuel is used for cooking by many rural families in the rural area in the Niger Delta region of Nigeria. The combustion of biomass has deleterious effect on ambient

ISSN: 2394-6539
DOI: https://doi.org/10.24321/2394.6539.202108

air quality as well as human health especially women.[25] The significant difference observed in the level of noxious gases (CO, NO_2 and SO_2) studied suggests variations in the dynamics of emission and distribution across the months, locations and distances under consideration. The observed variations could be due to moisture content and type of biomass combusted in the various locations. Seasonal distributions are affected by the meteorological characteristics which may account for the variations across the various months of study. These trends have been reported in pollutant gases concentration around waste dumpsite in the Niger Delta.[4]

The concentrations of the CO is within the Nigerian Ambient air quality value of 10-20ppm as stipulated by Federal Environmental Protection Agency, FEPA.[23] Nitrogen dioxide was only detected at 10ft distance in a Location C and D with concentration ≤0.06ppm across both seasons. The concentration is within 0.01 - 0.06 ppm for 1 hourly average specified by FEPA. Sulphur dioxide was only detected at 10ft distance in all the location at a concentration of 0.01 - 0.10ppm for 1 hourly average widely specified by authors.[5,23,24]

The concentration of pollutant gases in this study is less than values recorded in some other activities in Nigeria. For instance, Ana et al.[25] reported CO, NO_2 and SO_2 concentration in the range of 11.00-31.70 ppm, 0.20-1.50 ppm and 0.03 - 1.30, respectively during the use of firewood for cooking in in Olorunda community, Ibadan. Njoku et al.[26] reported CO, NO2 and SO2 concentration of 2.00 - 42.00ppm, 0 - 3.00 ppm and 0 ppm, respectively in emissions in vehicular intersection, dumpsite, industrial and residential area in Metropolitan City of Lagos. Richard et al.[4] reported CO, SO2 and NO2 concentration in the range of 0.03 - 1.22ppm, 0.14 - 0.30 ppm, 0.02 - 0.30ppm, respectively around waste dumpsite in the Niger Delta. Ohimain et al.[5] reported NO_2, CO and SO_2 concentration of <0.01 - 1.167 ppm, <0.01 - 27.167 ppm and <0.01 - 2.033 ppm, respectively around boiling of palm fruits using oil palm processing biomass as energy source in smallholder oil palm processing mill in the Niger Delta. The variation may be due to the difference in the type of biomass being combusted as well as their moisture content.

The meteorological indicators recorded in this study suggest seasonality in the distribution of the gases. This is because the indicators such as temperature and wind speed, and relative humidity is consistently higher and lower, respectively in dry season. Basically as the temperature increased the relative humidity drops. These trends have been recorded in several studies in the Niger Delta.[4-6,27] The values recorded have some similarity with previous studies in the Niger Delta. For instance, the values of wind speed, temperature and relative humidity around waste dumpsite waste dumpsite ranged from 0.27-2.97 m/s, 27.17 – 33.20ºC and 52.67 - 80.13% respectively,[4] 0.42 – 1.20m/s, 28.56 - 31.97°C and 58.67 - 76.33%, respectively, around smallholder gari processing facility.[27]

The correlational analysis revealed significant relationship between the three gases under investigation. This suggests that the emissions are from a common source. Also, the significant relationship between temperature and wind speed further indicates seasonal influence.

The air quality index showed some potential health concern within 10ft of emission source which could be due to higher concentration of noxious gases around emission source. This trend is in accordance with studies from dumpsites,[4] gari processing,[27] oil palm processing facility.[5,6] These research findings imply that there may have been health impacts over prolong exposure in the area which may have been under-reported.

The symptoms of health concerns associated with exposure to biomass combustion include runny nose, sinusitis, sore throat, wet cough, dry cough, cold, head ache, red eyes and fever (upper respiratory) and wheezing, phlegm, chest discomfort and shortness of breath (lower respiratory).[8,28] The authors further indicated that exposure to biomass fumes could aggravate other respiratory diseases such as asthma and chronic obstructive pulmonary diseases. The adverse effect of biomass fuel on lungs due to exposure may be due to exposure to pollutant such CO, SO_2 and NO_2, particulate matter, polyhydroxy aromatic hydrocarbons liberated by biomass fuel combustion and inadequate ventilation.[8,28]

Conclusion

Air quality index is often used to estimate the impact of human activities on the health of the environment and human that resides in such vicinity. This study evaluated the health risk index of some pollutant gases (CO, SO_2 and NO_2) from outdoor combustion of biomass in the Niger Delta at different locations and distances. The study found that higher concentration of the pollutant gases were recorded at 10ft distances, and the concentration decreased as distance away from the emission source increased. Significant variations occurred across the months and distances in different Locations which is an indication of seasonal influence. The air quality index showed slight to severe contamination at 10ft distances and no contamination at 25ft and 50ft distances. Hence, there is need to include this pollutant gases while monitoring human activities such as biomass combustion. Also there is need to sensitize the populace on the hazard associated with combustion of biomass.

ISSN: 2394-6539
DOI: https://doi.org/10.24321/2394.6539.202108

Authors Contribution

The lead author conceived the ideal, carried out the field data gathering and statistical analysis, while the second and third authors introduced the air quality index and wrote the initial draft. All authors approved the final manuscript.

Conflicts of Interest: None

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ISSN: 2394-6539
DOI: https://doi.org/10.24321/2394.6539.202108