African Journal of Engineering and Environment Research Vol.5(2) 2024
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The link to this publication is https://ajoeer.org.ng/otn/ajoeer/2024/qtr-1/02.pdf

Spatio-temporal Analysis and Air Quality Index Levels of Selected Air Pollutants in Yenagoa, Nigeria

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Abstract

Air pollution has been identified as a significant environmental problem often experienced in rapidly developing built-up cities in developing countries. This study analyzed the dry season spatio-temporal variation of air pollutants (SO_2, NO_2, CO, PM_{10} and $PM_{2.5}$) pollutants and meteorological parameters (ambient temperature, humidity, wind speed and wind direction) and air quality indices (AQI) in Yenagoa, Bayelsa State, Nigeria. Based on land use, three sampling location were selected for the study at Igbogene, Tombia-edepie roundabout, Swali market with Otuogori as control. Measurement was carried out on weekly (Monday, Wednesday and Saturday) from 9:00am and 5:00pm (8 hours daily) on each monitoring day for four weeks. Spatial interpolation of air pollutants was performed using Inverse Distance Weighted (IDW). SO_2, NO_2, PM_{10} and $PM_{2.5}$ concentration exceeded permissible limits. The study showed that northeast wind sector contributed about 40% of the overall dry season variations of air pollutants concentration in the area. Spatial analysis indicated that interpolated average values of air pollutants exceeded permissible limits, Air quality indices of the study area indicate that Swali market and Tombia- Edepie have high to very high air pollution, suggesting increased risk of human health and the environment. To mitigate the effects of air pollution in the study area the study recommends scaling up the use of sustainable transport systems, especially mass transit. We also recommend the strengthening and enforcement of regulatory and economic tools for land use and waste management.

Keywords: Air Pollutants, Spatial Analysis, Air Quality Index, Human Health.

Introduction

One of the major global environmental issues is air pollution from anthropogenic activities (Lavanya, *et. al*., 2017). Air pollution problem was identified as far back as 1300s in London (Mosley, 2009). According to (Smith and Ezzati, 2005) air pollution represents a key social problem to the ever-evolving environment and humanity. Considering the importance of air quality, attention was given to air pollution issues among other deliberations during the United Nations Conference on Environment and Development (UNCED) in Rio de Jenairo in 1992 for global cooperation. Therefore, air quality management is one issue facing authorities in the fast-growing cities, especially in developing countries. In Africa, urban areas experience explosive population growth rates, with corresponding increases in the generation of air pollutants. These pollutants include harmful gases from exhaust of motor vehicles, industrial sources and improper waste disposal (Olatunde, *et. al*., 2017). Ambient air pollution is a serious threat to public health causing respiratory diseases, chronic obstructive pulmonary disease (COPD) and asthma as well as cardiovascular disease (Lavanya *et al.,* 2017; McNeill 2019; WHO, 2020; Yorkor et al., 2021).The WHO estimated that in 2019, seven of ten leading causes of deaths were; cardiovascular and respiratory diseases (WHO, 2020). Currently, because of the importance attached to air pollution, there is a global public health approach for addressing and preventing Non-communicable diseases (NCDs) which centers on the WHO's Global Action Plan on the prevention of NCDs(WHO, 2021).

The concentration of air pollutants released from various sources in urban areas, vary both in time and in space (Yorkor et al., 2021). Time variations of air pollutants are strongly influenced by changes in human activities and the meteorological conditions of the area (McNeill, 2019). The study area is a rapidly developing urban centre given its status as a capital city of a State hosting oil and gas infrastructure and operations. Increasing population and motor vehicle number and use, expanding commercial and industrial activities, with the attendant waste generation, are the major sources of air pollution in the study area. Spatio-temporal distribution and air quality indices of the study area have not been assessed. Understanding spatio-temporal changes in air quality and an assessment of air quality indices of an area are important in evaluating effects of air pollution on human health. To this end, this study assessed air quality indices and spatio-temporal variation of air pollutants during the dry season in Yenagoa. This is necessary for future health impact assessment and the development of air quality management plans and for the protection of public health. Thus, the result of this study can be used by decision maker to decide on locations to install air quality monitoring stations (AQMS) and to conduct health impacts assessment in the area based on the spatial distribution of air pollutants in the area.

2. Materials and methods

2.1 Description of the Study area

Yenagoa is the capital of Bayelsa State, Nigeria. It is located in the oil rich Niger Delta region and lies between Latitudes 4.86^0 and 5.023^0 North, and between Longitudes 6.207^0 and 6.459^0 East (Fig. 1). It occupies an area of about 700 square kilometers and is situated on low-lying coastal environment fringing the Atlantic Ocean. The climate is humid tropical and vegetation type is the tropical mangrove forest. According to the National Bureau of Statistics (NBS, 2017), the population of Yenagoa is projected to be about 524,400 at estimated annual population growth rate of 2.5 percent (https://citypopulation.de/en/nigeria/admin/bayelsa/). The coordinates of the sampling locations are shown in Table 1.

Table 1: Sampling locations

	Location	Coordinates	
		Latitude (deg.)	Longitude (deg.)
1	Igbogene	5.04	6.40
2	Tombia-edepie roundabout	4.95	6.36
3	Swali market	4.92	6.25
4	Otuogori (control)	4.82	7.00

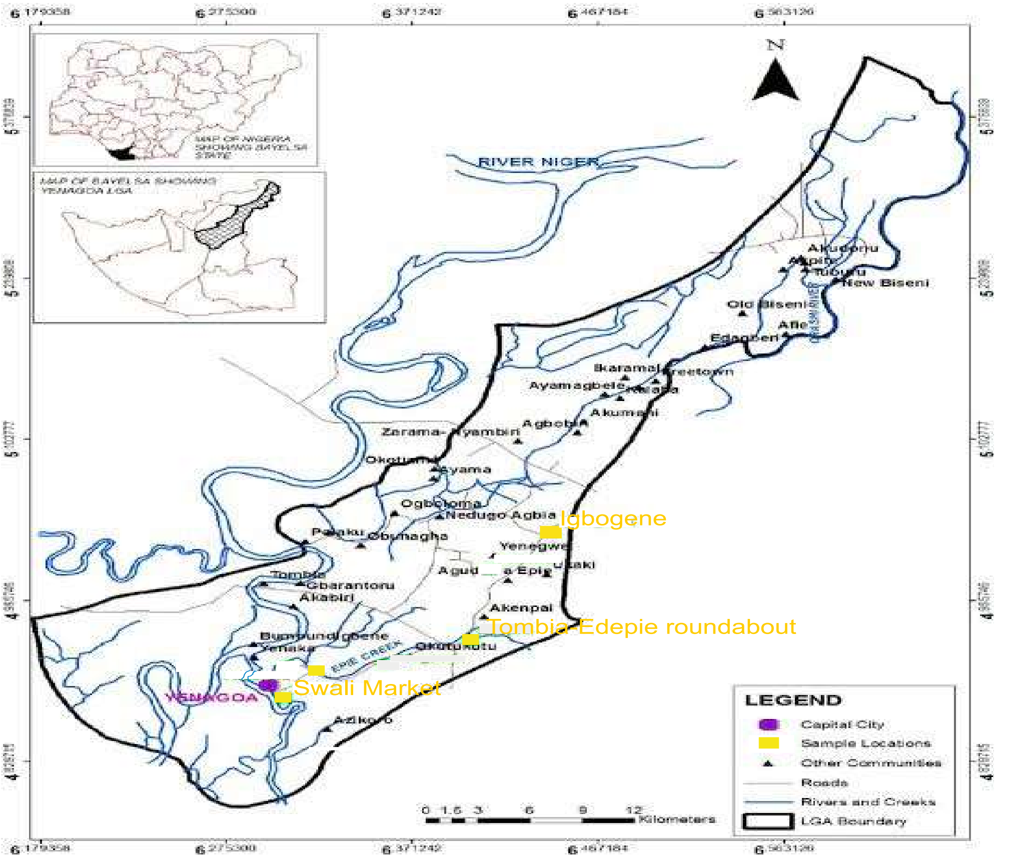


Fig. 1: Map of Yenagoa, showing sampling locations.

2.2 Data Collection Procedure

Air quality and meteorological data were collected in -situ from five selected sampling locations through field measurement carried out from December, 2021 to March, 2022. The air pollutants measured were sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), PM_{10} and $PM_{2.5}$ particulate matter while meteorological data covered wind speed and direction, temperature and relative humidity. Data collection was carried out on weekly basis (Monday, Wednesday and Saturday) from 9:00am and 5:00pm (8 hours daily) on each monitoring day for four weeks.

Aeroqual multi-gas detector (series 200) and Bosean portable multi-gas detector (model K-600) were used to monitor ambient air pollutants in the area. A Kestrel weather tracker (model 4500) and a 3-cup Scholab digital anemometer were used to measure meteorological parameters; while a BHCnav NAVA 600 Global Positioning System (GPS) was used to take coordinates of the sampling locations.

2.3 Data Analysis

Collected data were aggregated, processed and analyzed using Microsoft Excel descriptive statistic approach; the range, mean and standard deviation of the data were determined. Time series and pollutant variations with meteorological parameters were determined using R programming software version 3.5.3 (Carslaw, 2019; R Core Team, 2019). Box-whisker plots were used to visually assess monthly variations in air pollutant concentration in the area. The concentration of the gaseous air pollutants were compared with the Federal of Ministry of Environment (FMEnv); while particulate air pollutants were compared with the World Health Organization (WHO) standards.

This study employed Inverse Distance Weighting (IDW) method in ArcGIS software for the analysis of spatial distribution air pollutant concentration based on land use of the area. The purpose of the spatial analysis was to estimate or predict the concentration of air pollutant at unmeasured locations within the study area using the field data measured at the nearest locations. Geospatial analysis of air quality has rapidly become an integral part of air quality studies globally (Dilip et al., 2011; Kumar et al., 2016). This is due to its ability to estimate near accurate spatial interpolation over a wide area, most especially in areas with limited monitoring points. The expression for the IDW method is given in Equation (1):

$$Z_x = \frac{\left(\frac{1}{d_i}\right)p}{\sum_{i=1}^{N}\left(\frac{1}{d_i}\right)p} \tag{1}$$

Where Z_x is the location where the estimates will be made, p is the measured value at location i, d_i is the distance between the location x and the location i, N is the total number of known nearest location for location i, and k is a positive power parameter

2.4 Determination of Air Quality Index (AQI)

The air quality index adopted in this study area was determined using the United States Environmental Protection Agency [USEPA], 2014) model shown in Equation (2). The breakpoints used to calculate each of the pollutant sub-indices were obtained from Table 2, while the computed air quality index based on health effects was rated and categorized using Table 3.

$$I = \frac{I_{high} - I_{low}}{C_{high} - C_{low}}(C - C_{low}) + I_{low} \tag{2}$$

where:

I = the (Air Quality) index,
C = the pollutant concentration,
C_{low}= the concentration breakpoint that is ≤ C,
C_{high}= the concentration breakpoint that is ≥ C,
I_{low} = the index breakpoint corresponding to C_{low}, and
I_{high}= the index breakpoint corresponding to C_{high}.

Table 2: Pollutant standards index breakpoints

Index	24-hr SO_2 µg/m^3	1-hr NO_2 µg/m^3	8-hr CO mg/m^3	24-hr PM_{10} µg/m^3	$PM_{2.5}$ (µg/m^3)
0-50	0	-	0	0-50	0-12
51-100	80	-	5	51-150	13-55
101-200	365	-	10	151-350	56-150
201-300	800	1130	17	351-420	151-250
301-400	1600	2260	34	421-500	251-350
401-500				501-600	351-600

Source: Federal Register (1998)

Table 3: Air Quality Index Rating and Categorization

Air Quality Index (AQI) values	Air Quality Index (AQI) category
0 -50	Good
51 – 100	Moderate
101-150	Unhealthy For Sensitive Groups
151-200	Unhealthy
201-300	Very Unhealthy
301-500	Hazardous

Source: USEPA (2003)

3. Results and discussion

The summary result of the concentration of air pollutants and meteorological parameters observed in the study area is shown in Table 4. The variation of wind speed, temperature and relative humidity of the study is shown in Fig. 2; while the dry season wind flow pattern of the study area is shown in Fig. 3.
The result (Table 4) shows that mean levels SO_2 ranged between 0.18ppm at the control and 2.0ppm at Swali Market; mean levels NO_2 ranged between 0.21ppm at the control and 0.48ppm at Swali Market; mean levels of CO ranged between 0.58ppm at the control and 2.17ppm at Tombia-edepie; mean levels of PM_{10} ranged between 88.29μg/m^3 at the control and 220.39μg/m^3 at Tombia-edepie; while mean levels of $PM_{2.5}$ ranged between 37.28μg/m^3 at the control and 77.69μg/m^3 at Tombia-edepie. The result (shown in Table 4) indicates that mean values of SO_2, NO_2, PM_{10} and $PM_{2.5}$ exceeded permissible limits at Tombia-edepie, Swali Market and Igbogene.

Similarly, meteorological result (Table 4) indicates that mean wind speed varies from 2.08m/s at Igbogene to 2.3m/s at Swali Market; mean temperature levels vary from 30.22^{0}C at the control to 33.02^{0}C at Igbogene; relative humidity varies from 60.59% at Tombia-edepie to 67.22% at Swali Market; while the wind direction was predominantly northeast (NE).

Table 4: Air pollutant concentration in the study area

Location/Parameter		**SO_2 (ppm)**	**NO_2 (ppm)**	**CO (ppm)**	**PM_{10} (μg/m^3)**	**$PM_{2.5}$ (μg/m^3)**	**Wind spd. (m/s)**	**Temp (^{0}C)**	**Rel. hum. (%)**	**Wind dir.**
Tombia-edepie	Min	0.00	0.00	0.00	65.00	12.00	0.60	26.00	43.70	SE
	Max	2.00	2.00	8.00	532.00	226.00	4.10	41.10	84.60	NE
	Mean	0.60	0.36	2.17	220.39	77.69	2.10	32.96	60.59	NE
	Stdv.	0.66	0.53	1.88	76.62	41.53	0.63	2.61	6.74	
Swali Market	Min	0.00	0.00	0.00	15.00	3.00	0.80	26.50	42.30	SW
	Max	2.00	3.00	7.00	356.00	268.00	4.20	33.60	82.10	NE
	Mean	0.63	0.48	1.15	177.49	60.01	2.30	32.98	67.22	NE
	Stdv.	0.69	0.67	1.44	75.01	29.24	0.70	2.10	8.46	
Igbogene	Min	0.00	0.00	0.00	21.00	8.00	0.80	26.10	41.90	SE
	Max	2.00	1.00	5.00	313.00	99.00	4.00	33.80	82.20	NE
	Mean	0.42	0.39	1.14	175.3	59.43	2.08	33.02	65.09	NE
	Stdv.	0.52	0.49	1.22	58.4	20.04	0.60	2.12	9.13	
Control	Min	0.00	0.00	0.00	19.00	5.00	0.70	20.20	42.30	SE
	Max	1.00	1.00	4.00	210.00	82.00	4.00	33.60	87.20	NE
	Mean	0.18	0.21	0.58	88.29	37.28	2.14	30.22	64.52	NE
	Stdv.	0.38	0.4	0.76	22.4	10.93	0.51	4.43	9.79	
	FMEnv limit	**0.1**	**0.06**	**10**						
	WHO limit	**0.14**	**0.1**	**9**	**150**	**35**				

Fig.2 shows high wind speed and temperature with moderate relative humidity in the area. Wind direction was observed to be mostly from the northeast direction of the study area (Fig. 3). The Wind speed and wind direction influence pollutant concentration in the ambient air of the study area as well as determined transport and dispersion of air pollutants along the prevailing wind direction. The high temperature level of the area is caused by high sun intensity during the dry season period. Temperature is an important weather variable that determines the movement of water vapour. It also affects the chemistry of air pollutants as well as their emissions (Adejuwon, 2012). The moderate relative humidity of the magnitude observed in the study area during the dry season period of the year is expected, given the dominance of tropical maritime (mT) air-mass from the Atlantic Ocean (Adejuwon, 2012).

The monthly wind roses (Fig. 3) clearly indicates that about 40.0% of wind flow in the area was in the northern direction, This suggests the prevalence of northeast wind direction in the area during the dry season. This trend has been reported by Yorkor et al. (2017) in a study in nearby Rivers State with similar meteorological conditions. The northeast wind direction is associated with the dry harmattan wind that blows dust particles from the Sahara desert across the study area.

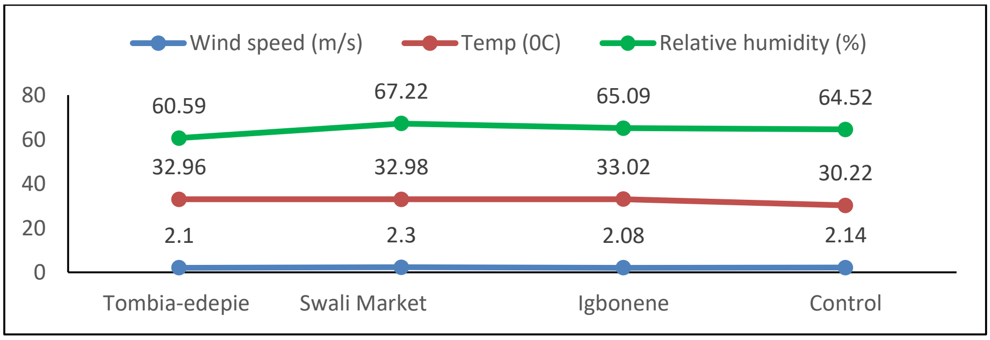


Fig. 2: Variation of wind speed, temperature and relative humidity of the study

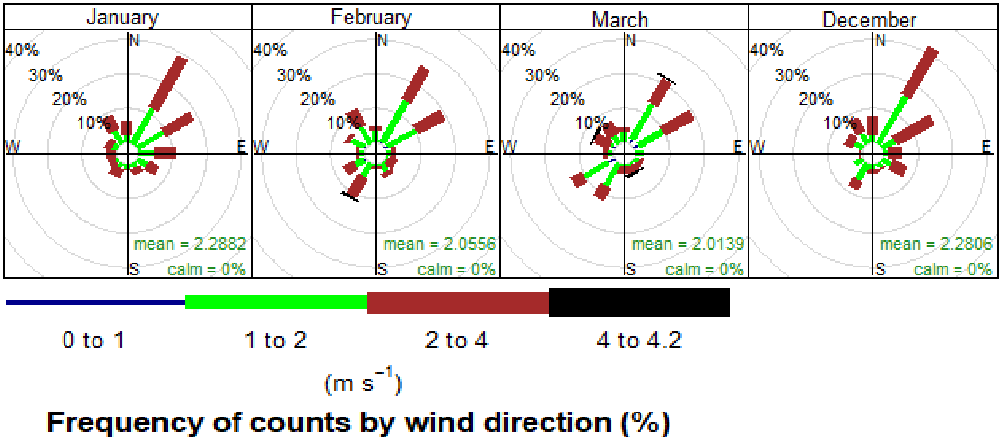


Fig. 3: Dry season wind flow pattern of the study area

3.1. Temporal variation of air pollutant concentration

Figs 4 and 5 describe monthly variation in air pollutant concentration in the study area. SO_2 and NO_2 varied evenly across the months, suggesting that they are likely emitted steadily from a common source, possibly transportation activities. The variation of CO shows monthly peak with the highest concentration in December (Fig. 4). PM_{10} (Fig. 5) has a monthly peak in January and highest concentration in February, while $PM_{2.5}$ (Fig. 5) has a monthly peak in January and highest concentration in December. The high concentration of air pollutants during the dry season may be attributed to sources such as vehicular exhaust emissions and harmattan wind that transports air pollutants from different sources around the area. Similar high concentration of air pollutants in the dry season has been reported by Angiamowei et al. (2019) in a study carried out on gas processing plant in the area. SO_2 and NO_2 may emanate from the same source, which in this case, could be transportation activities in the area.

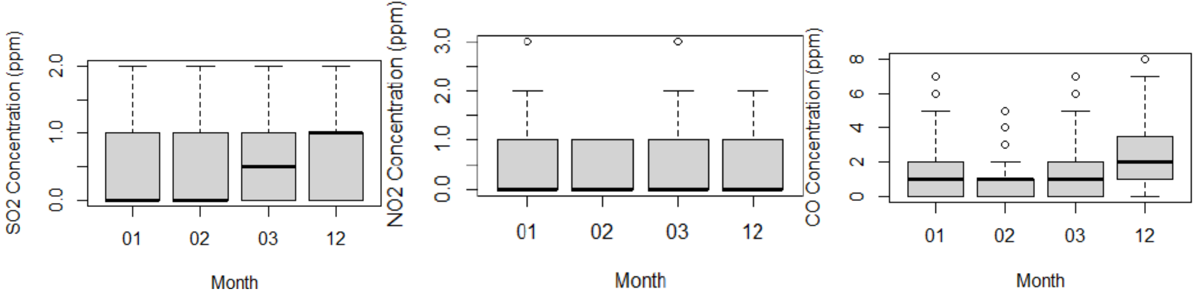


Fig. 4. Monthly box-whisker plot of gaseous air pollutants concentration

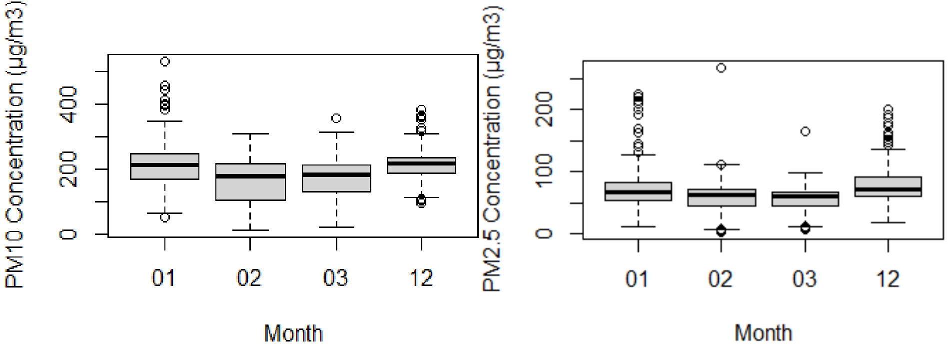


Fig. 5. Monthly box and whisker plots of particulate air pollutants concentration

Monthly time series variations of air pollutants concentration (Figs 6 and 7) indicate that concentration of gaseous and particulate air pollutants are high in December, January and February compared to March. This is expected because December, January and February are the driest months of the year in the study area.

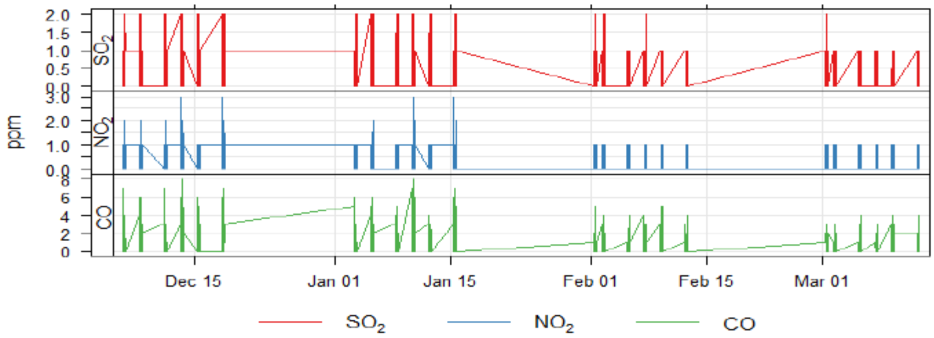


Fig. 6: Time series of of SO_2, NO_2 and CO

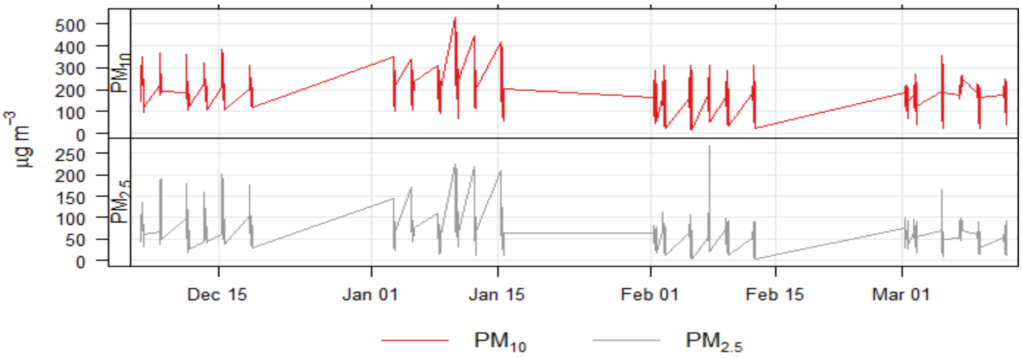


Fig. 7: Time series of of PM_{10} and $PM_{2.5}$

Simulation of temporal variation in air pollutants with meteorological vectors using pollution roses (Figs 8 to 12) shows that air pollutants concentration varied northeasterly with wind speed and wind direction during the dry season. Figs 8 to 12 indicate that northeast wind sector contributed up to 40% of the overall variations of air pollutants concentration in the area in the dry season. This wind pattern governs the general dry season dispersion of air pollutants in the area. This finding agrees with similar studies carried out in part of nearby Rivers State by Yorkor et al., (2017) and Antai et al., (2020). The finding also agrees with the studies by Angiamowei et al. (2019), Njoku et al., (2019) and Abulude et al. (2022). This is suggests that the harmattan wind plays important role in the levels of air pollutants, especially suspended particulate air pollutants, in the area during the dry season period. The harmattan dust is a common characteristic of the study area in the dry season. They are suspended particles carried from the Sahara desert by the northeast wind (Adejuwon, 2012).

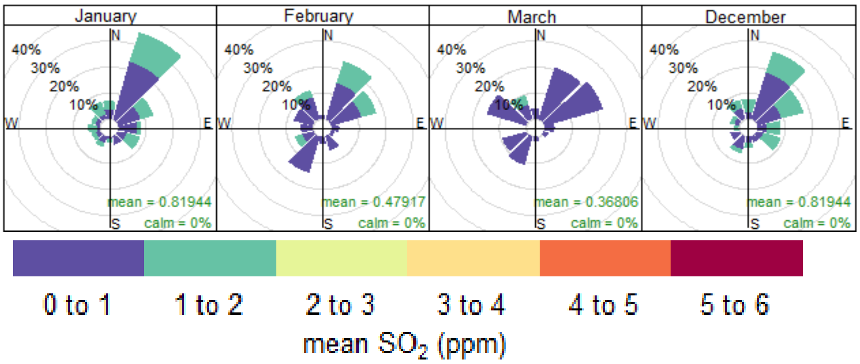


Fig. 8: Dry season variations of the concentration of SO_2 in the study area

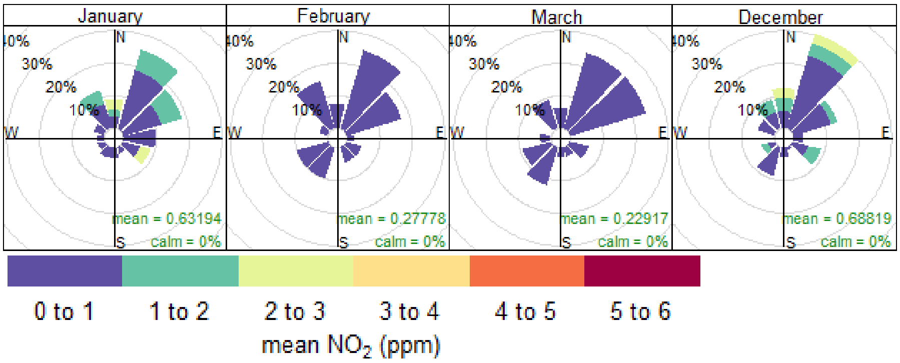


Fig. 9: Dry season variations of the concentration of NO_2 in the study area

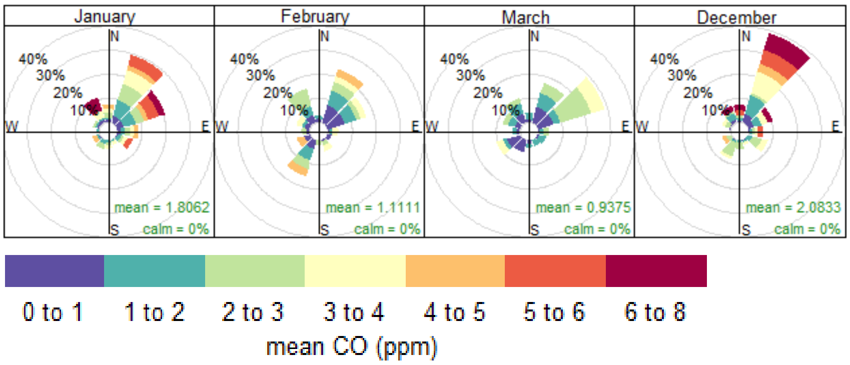
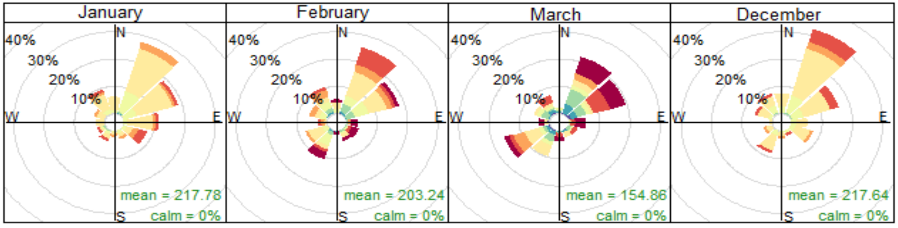


Fig. 10: Dry season variations of the concentration of COin the study area



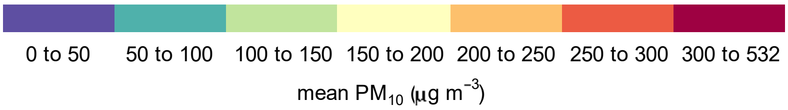


Fig. 11: Dry season variations of the concentration of PM_{10}in the study area

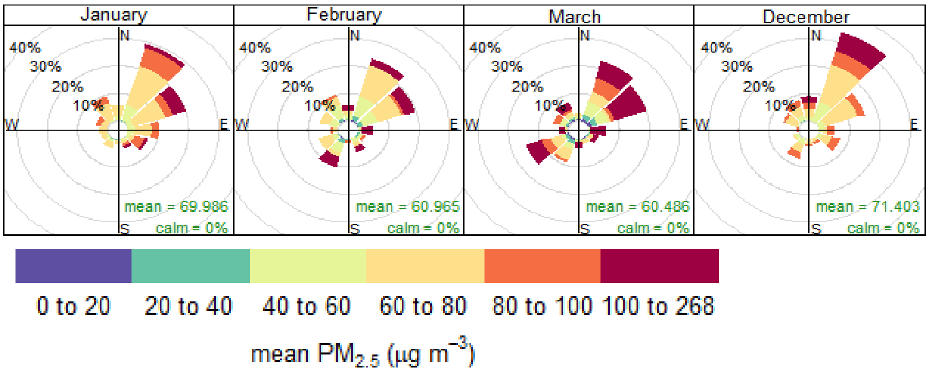


Fig. 12: Dry season variations of the concentration of $PM_{2.5}$ in the study area

3.2. Spatial distribution of air pollutants concentration in the study area

Geospatial analyses and interpolation of SO_2, NO_2, PM_{10} and $PM_{2.5}$ distribution in the study area are presented in Figs 13 to 16. Fig. 13 indicates that SO_2 has the highest concentration around Swali Market junction with interpolated mean values ranging from 0.595ppm to 0.63ppm. It extends to about 7,320 meters towards Ikolo, Yenaka, Youndgbene, Famgbe and reduces gradually towards Anyama, Opuama and Bumadi. SO_2 concentration was also very high around Tombia-Edepie with interpolated mean values ranging from 0.589ppm to 0.604ppm (Fig. 13). It has an aerial coverage of about 10,900 meters towards Edepie, Okutukutu, Yenizue-gene, Biogbolo, reducing gradually towards Akenfa. Fig. 13 further indicated that SO_2 has high concentration around Igbogene, with interpolated mean values ranging from 0.42ppm to 0.54ppm. It has an aerial coverage of about 7,487 meters towards Yenegwe, and gradually dispersed towards Epie-zarama, Agbobi.

Fig. 14 shows that NO_2 also has highest concentrations at Swali Market Junction, with interpolated mean values ranging from 0.411 to 0.480ppm. It covers an area of about 7.32meters towards Ikibiri, Anyama, Ikolo, Yenaka and reduces gradually towards Opuama. NO_2 also has high concentration at Tombia-Edepie with interpolated mean values ranging from 0.360ppm to 0.379ppm. It occupies extended aerial coverage of about 7,535 meters towards Opolo-Epie, Edepie and reduces gradually towards Akenfa. Similarly, Fig. 14 further indicates that NO_2 shows high concentrations around Igbogene (Fig. 14), with interpolated mean values ranging from 0.384ppm to 0.392ppm. It covers an aerial of about 6,928meters towards Yenegwe, reducing gradually towards Okolobiri, Epie-zarama.

Fig. 15 shows that the concentration of PM_{10} was highest around Tombia-Edepie with interpolated mean values ranging from 203.129 to 220.390ppm. It has an aerial coverage of 7,490 meters towards Opolo-Epie, Edepie and reduces gradually towards Akenfa, Akenfa-Epie, and Obunagha. Fig. 15 also shows that PM_{10} concentration is high around Swali market, with interpolated mean values ranging from 177.23 to 183.35$\mu g/m^3$. It occupies an elongated area coverage of approximately 7,168meters towards Ikibiri, Ikolo, Yenaka and reduces gradually towards Anyama, Opuama, Okaka and Bumadi. It is further indicated in Fig. 15 that PM_{10} also has high concentration around Igbogene, with interpolated mean values ranging from 175.300 to 177.229$\mu g/m^3$. It has an aerial coverage of about 7,262 meters towards Yenegwe and reduces gradually towards Yenagoa City, Okofama, Okolobri, Epie-zarama, Agbobi.

Fig. 16 shows that the concentration of $PM_{2.5}$ is highest around Tombia-Edepie with interpolated mean values ranging from 70.829ppm to 77.690$\mu g/m^3$. It has an aerial coverage of approximately 19,200 meters and disperses gradually towards Ojogbolo, Opolo-Epie, Edepie, Yenizue-gene and Biogbolo, Okaki, Akenfa, Akenfa-Epie and Obunagha. Fig. 16 also shows that $PM_{2.5}$ concentration is high around

Swali Market, with interpolated mean values ranging from 59.430 to 62.320µg/m^3 bordering Ogbia. It occupies an area of approximately 7,168 meters towards Ikibiri, Ikolo, Yenaka and reduces gradually towards Anyama, Opuama, and Bumadi. It is further indicated in Fig. 16 that $PM_{2.5}$ also has high concentrations around Igbogene, with interpolated mean values ranging from 59.430 to 60.074µg/m^3. It occupies an aerial coverage of about 7,262 meters towards Yenegwe and reduced gradually towards Yenagoa City, Okofama, Okolobri, Epie-zarama.

Generally, the spatial interpolation maps show that air pollutants in the area are widely dispersed. The values of air pollutants in hotspot areas (Figs 13 to 16) indicated by red contours exceeded permissible limits. These are areas with high levels of anthropogenic activities. Vehicular exhaust emissions, harmattan blown dust are common in these areas in the dry season period. Biomass burning for cooking, burning of refuse due to poor waste disposal, open burning of animals for meat, and bush burning during the dry season period also contribute to potential sources of air pollutants in these areas. These areas require the installation of air quality monitoring stations. The interpolation maps can be used by decision maker to conduct health impacts assessment in these areas based on the spread of air pollutants.

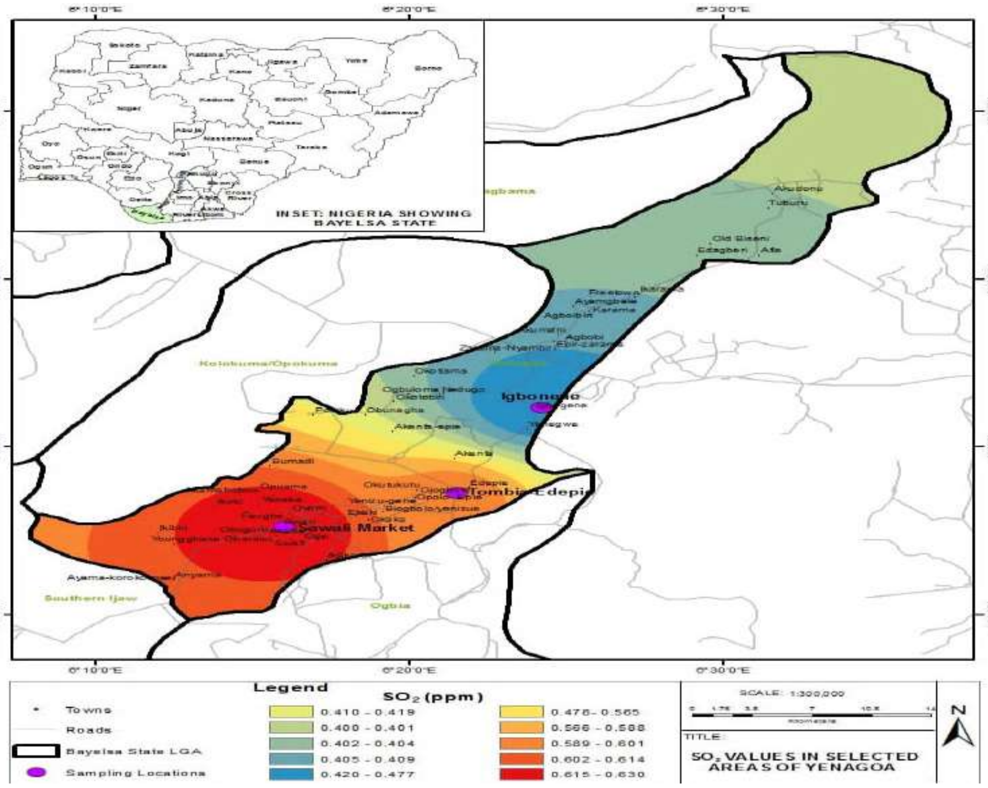


Fig. 13: Spatial interpolation of SO_2 in the study area

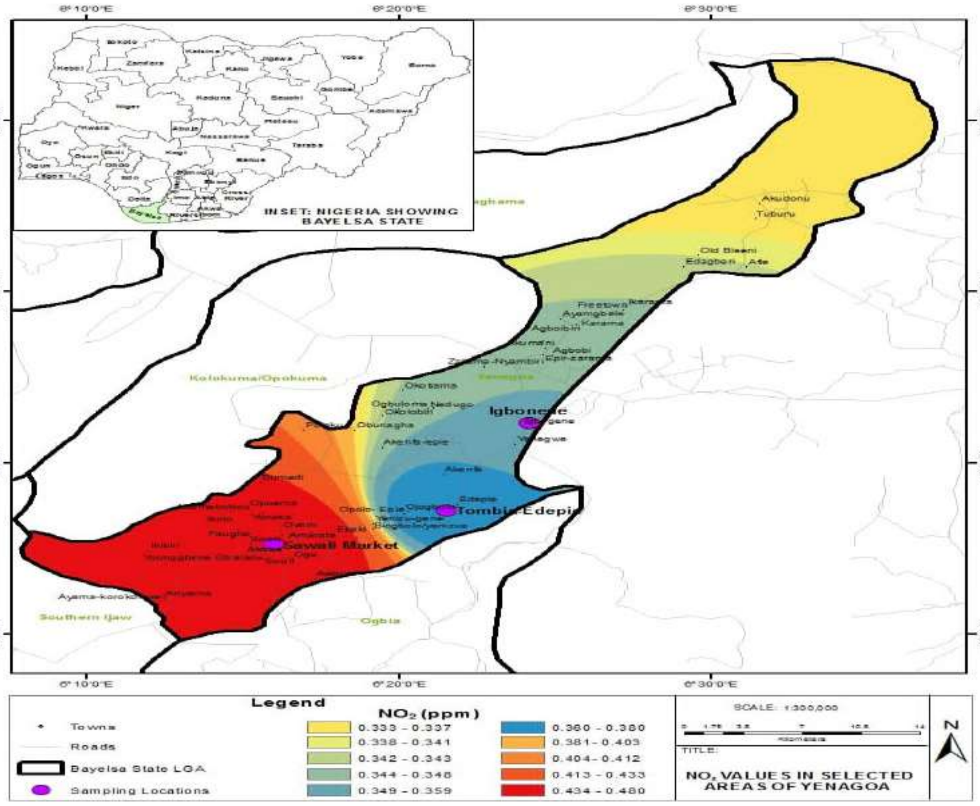


Fig. 14: Spatial interpolation of NO_2 in the study area

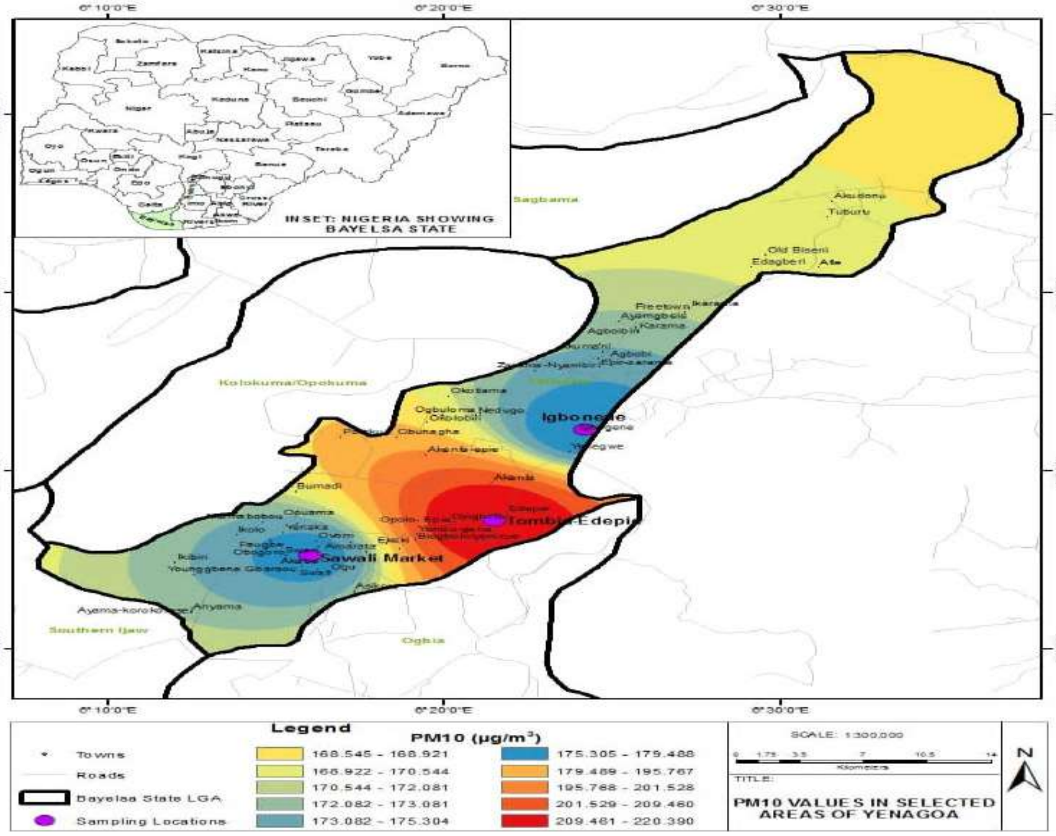


Fig. 15: Spatial interpolation of PM_{10} in the study area

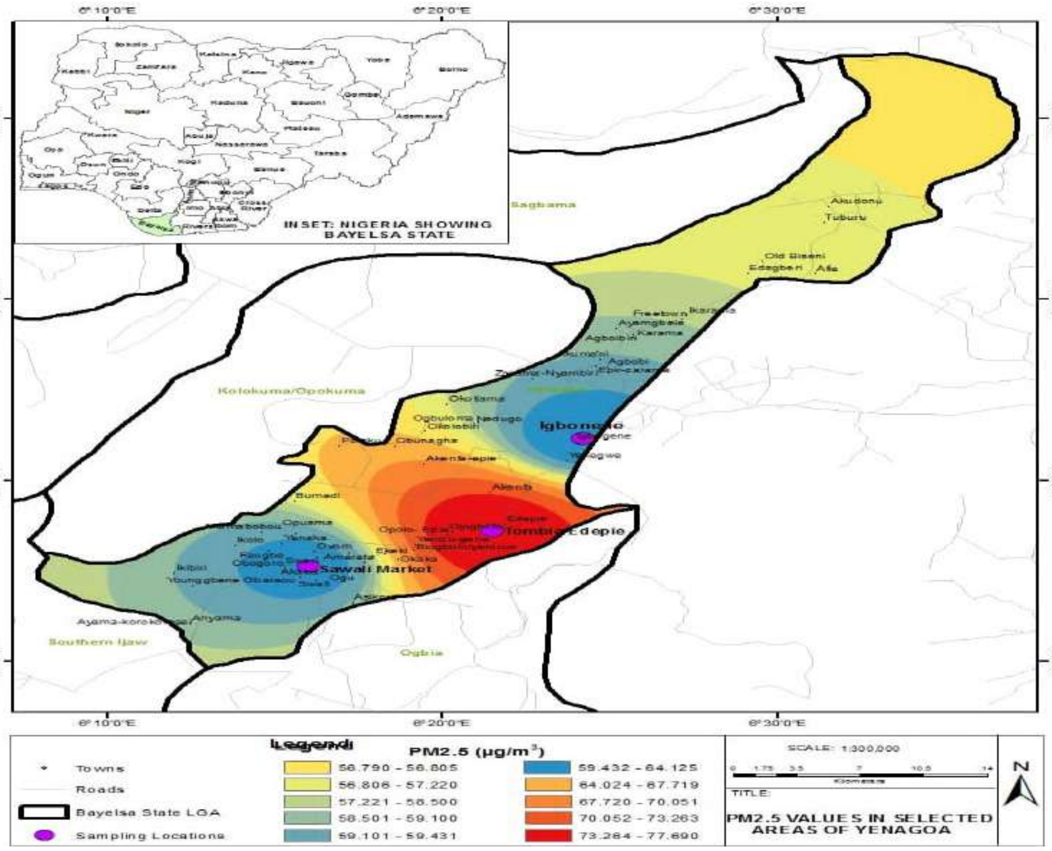


Fig. 16: Spatial interpolation of $PM_{2.5}$ in the study area

3.3. Air quality index

The health implication of air pollution in the study area was evaluated using air quality index. The air quality index of the study area was determined using the procedure of USEPA (2014). Air quality indices in selected locations in the study area (Table 5) indicate very unhealthy air quality around Tombia-Edepie and Swali Market locations (AQI = 236 and 247 respectively), which is classified as very high air pollution. This level of air pollution may adversely affect the general public and can be attributed to land use, since both locations are have very high levels of commercial and transport related activities. Similarly, air quality indices around Igbogene location is rated as unhealthy air quality (AQI = 198), which is classified as high air pollution. This suggests that the air quality around Igbogene is poor and poses health risk to residents of the area. Computed AQI indicates that the control location has good air quality (AQI = 24), which is classified as good air pollution, indicating clean air. This implies that the quality of air around the control location poses no risk to public health. Abulude et al. (2022) obtained an air quality index of moderate air pollution in a part of Yenegoa based on $PM_{2.5}$ only. Contrarily, the AQI obtained in this study is computed based on four criteria air pollutants (SO_2, NO_2, PM_{10} and $PM_{2.5}$). This may have accounted for the difference in the AQI obtained in this study and that reported by Abulude et al. (2022).

Table 5: Air quality indices of Sampled Locations

Location	AQI	AQI Classification	AQI Rating
Tombia-Edepie	236	Very unhealthy	Very high air pollution
Swali Market	247	Very unhealthy	Very high air pollution
Igbogene	198	Unhealthy	High air pollution
Control	24	Good	Clean

Generally, computed air quality index for the study area indicates unhealthy to very unhealthy air pollution, which is harmful to human health and the environment (WHO, 2016; Hosie, 2019 and McNeill, 2019). Short term exposure may cause irritation of the nose, eyes, and throat; while long term exposure may trigger health conditions such as asthma attacks, lung cancer and cardiovascular diseases in susceptible people (Khan and Siddiqui, 2014; WHO, 2016; Health Effects Institute [HEI], 2019). Inhabitants of the study area may potentially suffer from severe respiratory symptoms such as bronchial and pulmonary diseases amongst others (HEI, 2019). Children and older people who are vulnerable are more likely to be admitted to hospitals (WHO, 2016; McNeill, 2019; Hosie, 2019). Deaths due to air pollution may potentially increase in the area while vegetation, animals, fisheries, materials and properties in the study area may be adversely affected (Rao and Rao, 2005). Although, the quality of air at the control location poses no or negligible risk to public health, sensitive groups may still experience some respiratory symptoms.

4. Conclusions

The study indicated that dry season mean concentration of SO_2, NO_2, PM_{10} and $PM_{2.5}$ exceeded permissible limits. The Northeast wind sector contributed about 40% of the overall variations of air pollutants concentration and influences dry season dispersion pattern of air pollutants in the area. The study revealed that SO_2 and NO_2 concentration are emitted from a common source. Gas flaring, harmattan dust, commercial and transportation activities were the major sources of air pollution in the area during the dry season. Spatial analysis indicated that interpolated average values of air pollutants exceeded permissible limits, which was attributed to harmattan dust, commercial, industrial activities, biomass burning and bush burning.

The quality of air in the study area varied from unhealthy to very unhealthy air pollution, which is harmful to human health and the environment. Short-term and long-term exposure may result in adverse health effects. Inhabitants of the study area may likely suffer from severe respiratory symptoms, bronchial asthma, and pulmonary disease amongst others.

To mitigate the effects of air pollution in the study area the study recommends scaling up the use of sustainable transport systems, especially mass transit. In addition, polluters should be made to pay for the externalities they create through the use and enforcement of appropriate regulatory and economic tools.

Conflict of interest

The authors have declared that no competing interests exist.

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