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Characterization and Identification of Sources of Air Pollutants in Ogoni area in the Niger Delta of Nigeria

Yorkor, B[1*], Leton, T.G[1] and Ugbebor, J.N[1]
[1]Department of Civil and Environmental Engineering, Faculty of Engineering, University of Port Harcourt, Nigeria.
*Corresponding author's email: yorkor.banaadornwi@uniport.edu.ng

Abstract
This study characterized and identified sources of air pollutants in Ogoni area. Measurement of air pollutant concentrations was carried out at selected locations in the four local government areas (LGAs) of Ogoni area. Traffic volume was determined using traffic count method. Data were analyzed using XLSTAT-2020 software. Space borne imaging was used to detect artisanal oil refining and gas flaring sites. Pairwise comparison and ratio techniques were used to rank identified sources of air pollutants. Computed air quality rating index (AQRI) was used to evaluate air pollution levels. SO_2 maximum mean values were 1.33mg/m^3, 2.48mg/m^3, 2.78mg/m^3 and 3.3mg/m^3 for Tai, Gokana, Khana and Eleme LGAs respectively. NO_2 maximum mean values were 0.63mg/m^3, 0.67mg/m^3 each and 0.81mg/m^3 for Tai, Gokana, Khana and Eleme LGAs respectively. CO maximum mean values were 2.54mg/m^3, 3.17mg/m^3, 4.23mg/m^3 and 9.78mg/m^3 for Tai, Gokana, Eleme and Khana LGAs respectively. O_3 maximum mean values were 1.28mg/m^3, 1.63mg/m^3, 1.73mg/m^3 and 1.97mg/m^3 for Tai, Gokana, Eleme and Khana LGAs respectively. PM_{10} maximum mean values were 140.59µg/m^3, 175.63µg/m^3, 194.58µg/m^3 and 214.43µg/m^3 for Gokana, Tai, Khana and Eleme LGAs. $PM_{2.5}$ maximum mean values were 93.61, 120.61µg/m^3, 127.19µg/m^3 and 158.46µg/m^3 for Gokana, Tai, Khana and Eleme LGAs respectively. Minimum traffic volume was 21, 853; maximum traffic volume was 64,548; while average traffic volume was 42,894. Dominant air pollution sources included artisanal refineries, transportation and industrial activities. The study revealed serious air pollution in Ogoni area, which is hazardous to human health with critical health concern and thus requires government intervention.

Keywords: *Artisanal refineries, Daily traffic volume, Air quality rating indices, Domestic activities, Critical health concern*

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1. Introduction

The air people breathe strongly influences their state of health as almost every human being requires approximately 12kg of air in a day compared with water that a person can survive without for about 3 days (Grandjean, 2004; Arcado, 2006). Which means that on the average, a person inhales approximate 9-20m^3 of air per day and requires approximately 2.2-3.2liters of water per day. However, breathing poor or polluted air quality causes sicknesses and premature deaths (Arcado, 2006; Park, 2009; Majra, 2011). The air quality is polluted when chemical/toxic substances or contaminants/pollutants are introduced into the atmosphere in such concentrations and duration that are dangerous to human health and the environment (Elawej, 2014; Bhagat, 2016; Leton, 2020). The atmosphere contains various types of air pollutants emanating from either natural sources or anthropogenic activities, which are associated with a variety of deleterious health effects (United States Agency for International Development [USAID], 2019). Atmospheric pollution affects human health and the environment globally and locally at different levels (World Health Organization [WHO], 2016; Health Effects Institute [HEI], 2019; McNeill, 2019). Studies have shown that air pollution has deleterious effects on human health and is responsible for the death of millions of people worldwide every year, among whom are children (Kampa and Castanas, 2008; Khan and Siddiqui, 2014; Giadom, 2018; Hosie, 2019). It is estimated that more than 90 percent of the world's population breathe polluted air every year (Hosie, 2019).

Lately, most air pollution studies have concentrated on air quality in the urban cities only; while air quality in rural areas are most often neglected (Majra, 2011). Many of these studies addressed concerns over the health effects of air pollution in urban cities such as Port Harcourt, but very little has been done in the suburban and rural areas. Generally, it is commonly believed that the air quality in rural areas is very clear and free of pollution (Majra, 2011). However, contrary to this belief, air quality in some rural areas particularly in the Niger Delta region of Nigeria may be more polluted than some of the urban areas in the world. Presently, developing countries such as Nigeria are faced with major air pollution problems and the Niger Delta is reported as one of the worst affected region due to oil and gas related activities such as gas flaring (Tawari and Abowei, 2012; Azid et al., 2015; Ugbebor and Yorkor, 2018; Yakubu, 2018).

Rural areas may suffer from both indoor and outdoor air pollution (Majra, 2011; USAID, 2019). Indoor sources may include household air pollution (HAP) that originates from domestic activities such as cooking and heating (USAID, 2019); while outdoor sources may originate from vehicular emissions, electricity generation, and agricultural activities. Domestic activities such as cooking can also be a major contributor to air pollution in rural areas where burning solid fuels or kerosene for household energy is widely practiced (USAID, 2019). To better understand the broader problem of air pollution on human health and the environment, there is need to conduct a regional air quality study in suburban and rural areas, especially in Ogoni area. Therefore, this research aimed to carry out an air pollution study of Ogoni area. The study attempted to characterize and identify sources of air pollutant concentrations in Ogoni area. The determination of the air quality of Ogoni area is necessary for the understanding of its potential impacts on the health and the environment of the Ogoni people.

2. Materials and methods

2.1 Description of the study area

Ogoni area (Figure 1) lies between Latitude 4.7798^{0}N and Longitude 7.1528^{0}E along the coastal area of Rivers State in the Niger Delta region of Nigeria. It occupies an area of about 100,000 square kilometers in the Niger Delta basin on the coast of the Gulf of Guinea (Cousins and Karlsson, 2015; Yakubu, 2017). The study area comprises of four local government areas (LGAs), namely Khana, Gokana, Tai and Eleme (UNEP, 2011; Yakubu, 2017) as shown in Figure 1. The area is situated on low-lying land fringing the swamp forest. It is a typical rainforest belt dominated by secondary vegetation, which are mainly light bushes and farmlands with varied species. Thick bushes and swamps also characterized most parts of the area. The area is also traversed by the East-West highway (Figure 1) and as a result it often experiences heavy vehicular movement causing traffic congestion. The area is also an oil producing area that hosts several major national and multinational oil and gas industrial facilities. It also hosts other chemical industries including refineries, petrochemical plants and fertilizer plants (Yorkor et al., 2017).

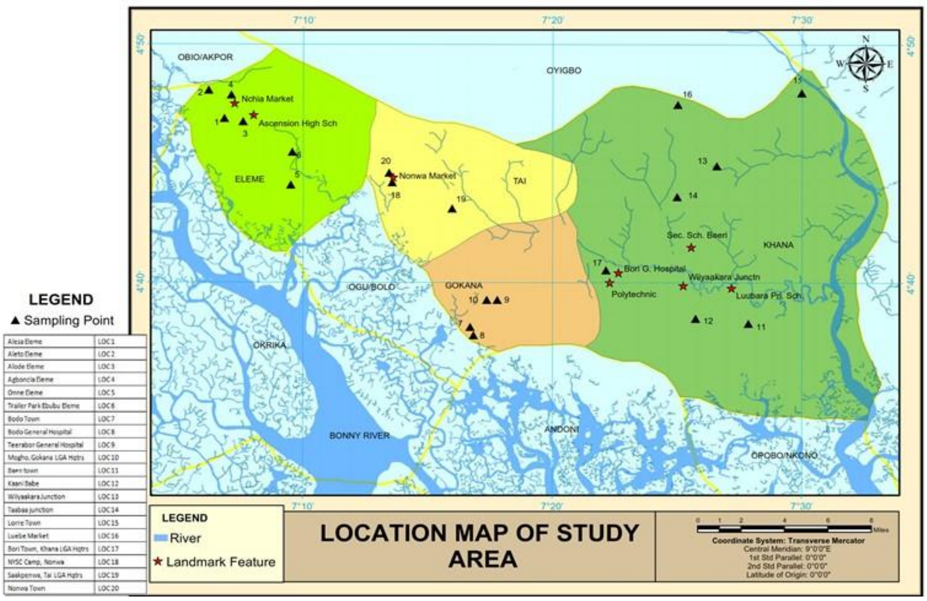

Fig. 1: Map of study area showing sampling locations

2.2 Identification of sources of air pollutants

The identification of sources of air pollutants in this study was carried out using visual survey and digital image processing techniques. Pictures of identified potentials sources of air pollutants in the area were taken using cameras; while remote sensing method of space borne imaging was used to detect artisanal oil refining and gas flaring sites, which are potential sources of air pollutants in the study area. The captured images were digitalized and processed to show the locations of artisanal oil refining and gas flaring sites in the area.

2.3 Method of data collection

The air quality data for this study was acquired via field measurement using air quality monitoring instruments. Real time in-situ measurements of air pollutant concentrations were conducted at the selected locations as shown in Figure 1. Measurement was carried out on monthly basis for 12 months and data were recorded at one-hour interval between 7:00am and 4:00pm. The hourly values of air pollutants concentrations were then averaged up to 8 hours to give 8-hour average values. All collected data were aggregated, processed and analyzed using XLSTAT-2021 premium version software developed by Addinsoft (2021). The results were compared with Federal Ministry of Nigeria (FMEnv) air quality standards and the United States National Ambient Air Quality standards (NAAQS).

2.4 Method of traffic count

The volume of traffic on the East-West highway of the study area was determined using the method recommended by Leduc (2008). The Volume of vehicles q was calculated using Equation (1) (Ugbebor et al., 2017):

$$q = \frac{N_t}{t} \qquad (1)$$

where q is the volume of vehicles passing per hour; N_t is the number of vehicles passing at time t, and t is the time (hour).

The mean volume of vehicles was computed as a ratio of the total number of vehicles counted to the total number of hours as shown in Equation (2) (Ugbebor et al., 2017).

$$q_{mean} = \frac{\sum_{t=1}^{n} N_t}{\sum_{i=1}^{n} t_i} \qquad (2)$$

2.5 Method of rating air pollutantss

Identified sources of air pollutants in the study area were ranked using pairwise comparison and ratio techniques (Rigg et al., 2004). A rank-sum weighting method was used to calculate the importance weights using the assigned ranks. The source considered most important was assigned the highest rank. The rank-sum weighting method is generally expressed as shown in Equation (3). The pollutant sources are arranged in a simple rank order as expressed in Equation (4).

$$w_i = \frac{n - r_i + 1}{\sum_{i=1}^{n}(n - r_i + 1)} \qquad (3)$$

where n is the number of pollutant sources, r is the rank of the pollutant source i and w is the importance weight for pollutant source i.

$$W_i = \frac{x_i}{\sum_{i=1}^{n} x_i} \qquad (4)$$

where x_i is the numerical weight assigned to pollutant source i relative to the least important pollutant source and W_i is the normalized weight for pollutant source i.

The Air Quality Rating Index (AQRI) for each air pollutant was computed using Equation (5)

$$AQRI_i = \frac{X_{iobs}}{X_{ref}} \qquad (5)$$

where $AQRI_i$ is the probability exceedance factor for the ith parameter, X_{obs} is the measured concentrationn of the ith pollutant and X_{re} is the air quality reference standard for the ith pollutant for the particular pollutant. AQRI > 1.5 indicates critical pollution (C); AQRI between 1.0 and < 1.5 indicates high pollution (H); AQRI between 0.5 and < 1.0 indicates moderate pollution (M); while AQRI < 0.5 indicates low pollution (L).

3. Results

Air pollutant concentrations in the study area were determined and the summary of results are presented in Table 1. The ranges of the air pollutants are shown in parentheses followed by the mean and standard deviation. Table 2 is the computed air quality rating indices for the study area. The results of traffic count on the East-West highway of the study area are shown in Fig. 2 and

3. Identified artisanal oil refining and gas flaring sites in the area are shown in Fig. 4, while the ranking of identified sources of air pollution in Ogoni area is shown in Fig. 5.

Table 1: Summary of ambient air pollutants in the study area

	Eleme	Gokana	Khana	Tai	Igbo Etche (Control)	FMEnv limit	NAAQS limit
SO_2 (mg/m^3)	(1.26-30.36) 3.3±5.01	(1.27-17.78) 2.48±2.53	(1.27-15.24) 2.78±2.69	(1.26-5.12) 1.33±1.35	(0.0-1.27) 0.14±0.36	0.26	0.2
NO_2 (mg/m^3)	(0.18-3.67) 0.67±0.82	(0.18-3.65) 0.63±0.80	(0.18-3.67) 0.81±0.92	(0.18-9.09) 0.67±1.09	(0.0-1.82) 0.09±0.13	0.11	0.19
CO (mg/m^3)	(1.11-102.63) 4.23±11.43	(1.11-55.10) 3.17±6.18	(1.11-86.24) 9.78±14.99	(1.11-13.44) 2.54±2.93	(0.0-4.9) 0.74±0.99	22.8	10.0
O_3 (mg/m^3)	(0.04-6.48) 1.73±1.35	(0.02-5.94) 1.63±1.36	(0.11-11.83) 1.97±1.72	(0.06-4.13) 1.28±1.00	(0.0-0.07) 0.01±0.01	0.12	0.15
NH_3 (mg/m^3)	(0.67-61.63) 3.05±9.36	(0.67-15.58) 0.45±2.17	(0.34-65.28) 5.25±12.31	(0.13-62.56) 6.69±14.60	(0.0-1.51) 0.02±0.03		
TVOC (mg/m^3)	(0.02-22.5) 2.05±4.80	(0.04-2.45) 0.32±0.57	(0.04-2.45) 0.32±0.57	(0.09-2.98) 0.22±0.48	(0.0-0.19) 0.01±0.02		
PM_{10} ($\mu g/m^3$)	(33.00-1045.00) 214.43±224.17	(22.00-963.00) 140.59±173.02	(30.00-981.00) 194.58±199.85	(32.00-1014.00) 175.63±192.27	(6.0-97.6) 57.23±61.43		150
$PM_{2.5}$ ($\mu g/m^3$)	(19.00-818.00) 158.46±158.82	(12.00-642.00) 93.61±121.68	(20.00-701.00) 127.19±141.86	(18.00-676.00) 120.61±135.61	(4.0-41.3) 22.91±23.67		35

The ranges of the air pollutants are shown in parentheses followed by the mean and standard deviation.

Table 2: Computed air quality rating indices for the study area

Parameter	SO_2	NO_2	CO	O_3	PM_{10}	$PM_{2.5}$	Health concern
Eleme	16.5(C)	3.5(C)	0.42(L)	11.5(C)	1.4(H)	4.5(C)	Severe and unhealthy
Gokana	12.4(C)	3.3(C)	0.32(L)	10.87(C)	0.94(M)	2.67(C)	Very Unhealthy
Khana	13.9(C)	4.3(C)	0.98(M)	13.13(C)	1.3(H)	3.6(C)	Very Unhealthy
Tai	6.7(C)	3.5(C)	0.25(L)	8.5(C)	1.2(H)	3.4(C)	Very Unhealthy
Igbo Etche (control)	0.7(M)	0.47(L)	0.07	0.07	0.38(L)	0.65(M)	Good and Acceptable

C = Critical pollution; H = pollution; M = Moderate pollution; L = Low pollution

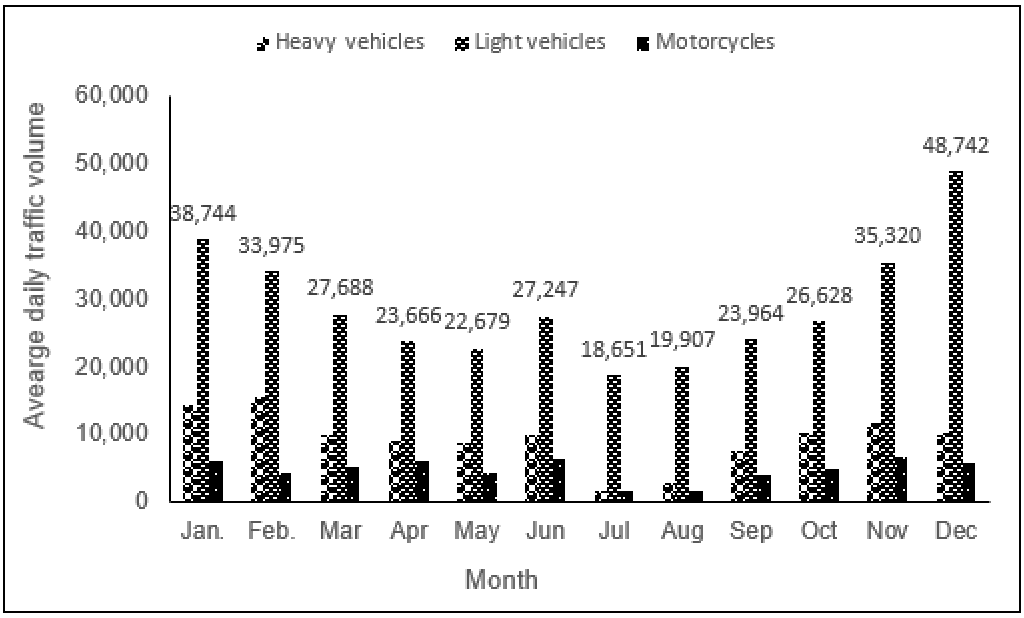

Fig. 2: Mean daily traffic volume along East-West highway

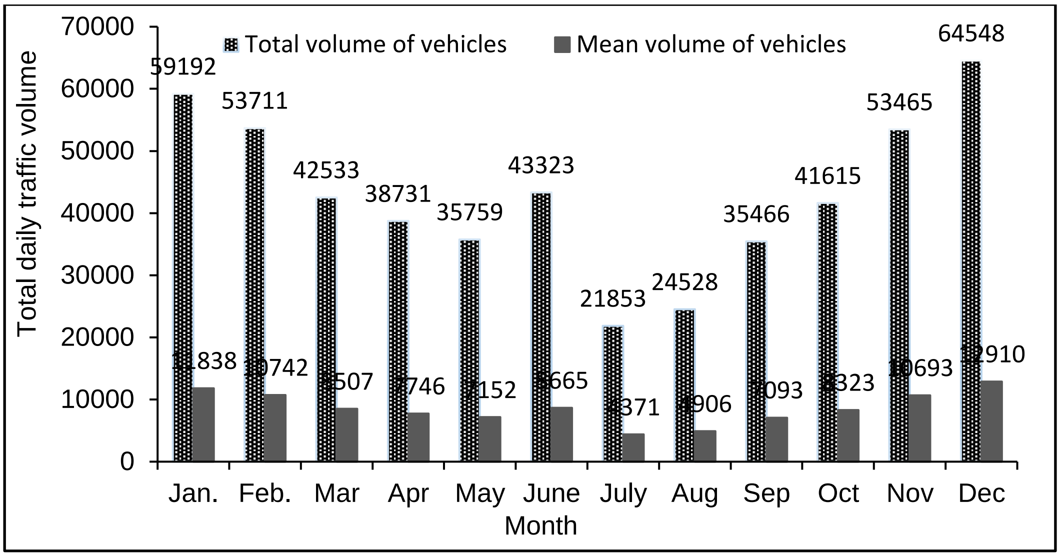

Fig. 3: Monthly total daily traffic volume (MTDTV)

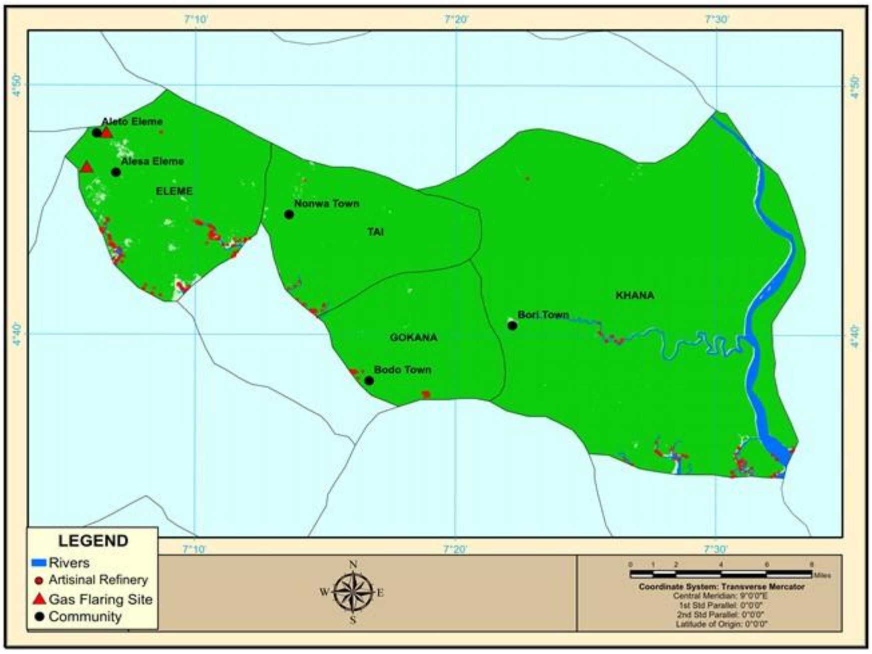

Fig. 4: Identified artisanal oil refining and gas flaring sites in Ogoni area

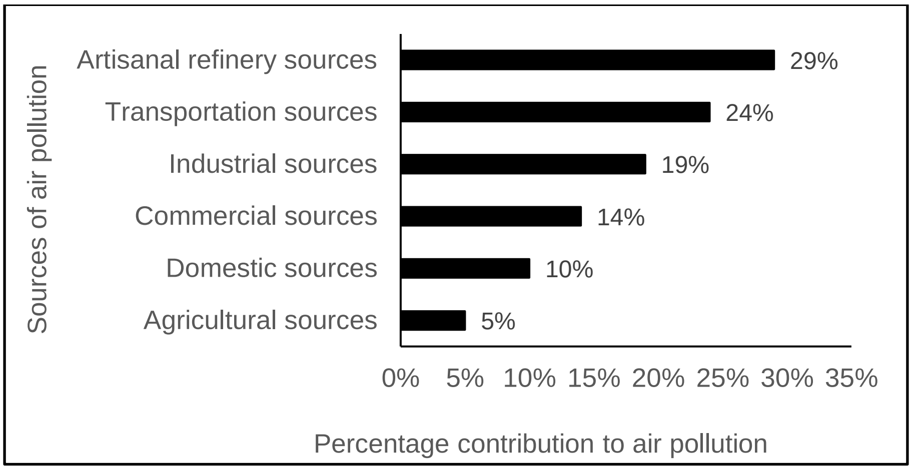

Fig. 5: Ranking of identified sources of air pollution in Ogoni area

4. Discussion

4.1 Concentrations of criteria pollutants

As observed in Table 1, the maximum mean value of 3.3mg/m^3 for SO_2 was obtained in Eleme LGA, followed by Khana and Gokana LGAs with mean values of 2.78mg/m^3 and 2.48mg/m^3 respectively, while the control location shows the lowest SO_2 mean concentration of 0.14mg/m^3, which falls within the prescribed limits. This result strengthens the study of Antai et al. (2018) who reported SO_2 concentrations as high as 3.1mg/m^3 in the study area, which was attributed to the combustion of sulphur laden imported fuel and industrial activities (Ana, 2011; Tawari and Abowei, 2012). NO_2 showed the highest mean value of 0.81mg/m^3 in Khana LGA, followed by Eleme and Tai LGAs with mean values of 0.67mg/m^3 each. The lowest NO_2 mean value of 0.09mg/m^3 was obtained at the control location. In a similar study Antai et al. (2018) obtained mean NO_2 concentrations as high as 1.7mg/m^3, which was attributed to the combustion of fossil fuels. The highest mean value of CO (9.78mg/m^3) was obtained in Khana LGA, followed by Eleme and Gokana LGAs with mean values of 4.23mg/m^3 and 3.17mg/m^3 respectively. The concentrations of CO were observed to be low below permissible limits. This is contrary to the result of Antai et al. (2018) who reported CO concentrations as high as 31.89mg/m^3 in the study area, which were attributed to vehicular exhaust emissions, industrial activities and gas flaring.

The maximum mean value of 1.97mg/m^3 of ground level ozone (O_3) was in Khana LGA, followed by Eleme and Gokana LGAs with mean concentrations of 1.73mg/m^3 and 1.63mg/m^3 respectively. Mean concentrations ammonia was highest in Tai LGA and lowest in Gokana LGA, while mean TVOC concentrations was highest in Eleme LGA and lowest in Tai LGA. In a similar study, Antai et al. (2018) reported NH_3 and TVOC concentrations as high as 4.2mg/m^3 and 9.5mg/m^3 respectively in the study area, which were attributed to vehicular emissions, fugitive emissions or leakages from fertilizer plants, and industrial stack gas emission in Eleme LGA. Similarly, the mean concentration of PM_{10} was highest in Eleme LGA (214.43µg/m^3), followed by Khana (194.58µg/m^3) and Tai (175.63µg/m^3), while the mean concentrations of $PM_{2.5}$ was also highest in Eleme LGA (158.46), followed by Khana (127.19µg/m^3) and Tai (120.61µg/m^3). These results corroborated the study of Antai et al. (2018) who reported PM_{10} and $PM_{2.5}$ concentrations as high as 554.09µg/m^3 and 92.19µg/m^3 respectively in the study area, which were also attributed to harmattan dust, artisanal refineries, transportation, and industrial activities. Analysis of the significance indicated that the difference between air pollutant concentrations in the study area and the control location is highly significant ($P > 0.05$, 95% CI). Implying that the air environment of the Ogoni area is more polluted compared to the control location in Etche LGA. According to Health Effects Institute, short-term exposure to polluted air may result in respiratory diseases, lung cancer and heart disease, which may lead to early death (HEI, 2019).

The result in Table 1 indicated that the mean concentrations of SO_2, NO_2, O_3 and $PM_{2.5}$ exceeded both FMEnv and NAAQS permissible limits in Eleme, Gokana, Khana and Tai LGAs. PM_{10} mean concentrations exceeded both limits in all the LGAs except in Gokana LGA where the mean falls below the limit. The mean concentrations of the air pollutants recorded at the control location were all within both FMEnv and NAAQS permissible limits. Computed air quality rating indices shown in Table 2 indicated that SO_2, NO_2, O_3 and $PM_{2.5}$ constitute critical pollution in all the four LGAs of Ogoni area. CO showed moderate pollution in Khana LGA, while PM_{10} showed high pollution in Eleme, Khana and Tai LGAs, and moderate pollution in Gokana LGA. Judging from health concern shown in Table 2, the air quality in Eleme LGA can be described as severe and unhealthy for human health, while the air quality in Khana, Gokana and Tai can be described as very unhealthy for human health. Computed AQRI indicated that the air quality at the control location showed little or no health concern. AQRI analysis revealed serious air pollution in Ogoni area, which is hazardous to human health and poses critical health concern. According to the Department for Environment, Food and Rural Affairs [DEFRA], 2017 and Hosie, 2019, the degree of air pollution in Ogoni area portends serious health hazards to the public. Consequently, people with lung or heart diseases are at greater risk (HEI, 2019), while high mortality rate from the diseases associated with air pollution is envisaged in the area (HEI, 2019). Hence air pollution effect is a major public health concern in Ogoni area of the Niger Delta.

4.2 Identified sources of air pollution in the study area

Air pollution due to Domestic activities

Domestic sources of air pollution found in the study area include the burning of firewood for cooking and open burning of trash. These contribute about 10% to air pollution in the area (Figure 5). This finding confirms the studies by Ana (2011) and Tawari and Abowei (2012) who identified firewood and waste burning as a major source of air pollution in the rural area of the Niger Delta. Also, Majra (2011), USAID (2019) and Sofia et al. (2020) stated that domestic sources contribute significantly to air pollution in developing countries, which according to USAID (2019) constitute a major health risk to the exposed population.

Air pollution due to Commercial activities

Commercial activities in the study area involve the use of electric generators for power supply, which emit harmful air pollutants into the atmosphere. This was found to contribute about 14% to air pollution in the area (Figure 5). Ubong and Osaghae (2018) in their study also found high concentration levels of air pollutants such as SO_2, NO_2, CO and particulate matter in some commercial areas of Port Harcourt. The emission of SO_2 may be due to the use of imported fuel laden with sulphur impurity as Nigerian fuel has been found to be sulphur free (Akinpelu, 2021).

Air pollution due to Agricultural activities

Agriculture was found to contribute approximately 5% to air pollution in the area (Figure 5). It was found that the burning of vegetation and crop residues as well as the use of fertilizer results in the release of hazardous air pollutants into the atmosphere. This corroborates similar studies carried out in the Niger Delta by Ana (2011) and Tawari and Abowei (2012). Other studies have also associated NH_3, NO_2, CO and particulate emissions with agricultural activities (Majra, 2011; USAID, 2019; Sofia et al. 2020). Velthof et al. (2012) specifically attributed 80% of NH_3 emissions in Europe to agricultural activities.

Air pollution due to Industrial activities

Industrial sources were found to contribute approximately 19% to air pollution in Ogoni area (Figure 5). Industrial activities, which are concentrated mostly in Eleme LGA on the North-West of the study area, are major emitters of air pollutants such as SO_2, NO_2, CO, NH_3, VOC, PM_{10} and $PM_{2.5}$ in the area. A study by Ana (2011), Tawari and Abowei (2012) and Antai et al. (2018) also attributed sources of air pollution in Eleme LGA to industrial activities. Also, stack flue gas emissions from refinery and petrochemical plants are potential sources of SO_2, CO, NO_2, particulate matter, black carbon and VOC as well as secondary pollutants such as ozone (Ana, 2011; Tawari and Abowei, 2012). These account for the high concentration levels of the air pollutants observed in the study area, especially in Eleme LGA, which are also dispersed to other parts of the study area. In addition, gas flaring in Eleme LGA and Oil well blow-outs in Tai, Khana and Gokana LGAs were found to release dense smoke of harmful gaseous pollutants, hydrocarbons particulate and black carbon into the atmosphere, which were dispersed to nearby communities by the meteorological vectors. These may have adverse effects on residents of the area and the environment. Studies have shown that SO_2, NO_2, VOC and particulate matter increased the risk of respiratory, lung, heart and cardiovascular diseases (European Environment Agency [EEA], 2019; HEI, 2019)

Air pollution due to transportation activities

Transportation sources of air pollution in Ogoni area were identified as fuel tankers, heavy trucks, buses, cars, motorcycles and tricycles, these were found to contribute about 24% to air pollution in the area (Figure 5). The minimum total daily traffic volume of heavy vehicles, light vehicles and motorcycles along the East-West highway was 21, 853, the maximum total daily traffic volume was 64,548, while the average daily traffic volume was 42,894 (Figures 2 and 3). The average monthly daily traffic (AMDT) indicates that heavy vehicular traffic on the East-West Highway (Figures 2 and 3) contributed significantly to the high levels of air pollution in the area. Transportation systems in Ogoni emit noxious gases such as SO_2, CO, NO_2, VOC, particulate matter, and black carbon directly into the atmosphere, which undergo mixing in the air and get dispersed into the surroundings. This finding agreed with the studies by of Ana (2011) and Tawari and Abowei (2012) who reported that transportation activity is a major contributor to air pollution in the Niger Delta and that vehicular exhaust emissions is on the increase in the Niger Delta including Ogoni area.

Air pollution from Artisanal oil refining activities

Many artisanal refineries were found located along the coastline on the Northeast, Southwest and Southeast part of the study area. This affirms the findings of Giadom (2018) who reported that there are illegal oil refining activities around the coastal areas of Rivers State. Fifteen (15) artisanal oil refining sites were found in Ogoni area (11 along the coastal line and 4 in the hinterland). Five sites were observed in Eleme LGA, six in Khana LGA and two each in Tai and Gokana LGAs. The artisanal oil refining sites in Eleme LGA are located between 4.2 and 9.6 kilometers from human settlements; the sites in Gokana LGA are located between 1.2 and 4.2 kilometers from human settlements (Bodo); the sites in Tai LGA are located between 2.7 and 5.1 kilometers from human settlements; while the sites in Khana LGA are located between 5.2 and 21 kilometers from human settlements. These artisanal oil refining activities release high levels of gaseous and particulate matter air pollutants into communities in Ogoni area and contribute approximately 29% to air pollution in the study area (Fig. 4). Artisanal oil refining activities were found to be the major sources of principal air hazards (PAH) such as VOC, CO, NO_2, SO_2, particulate matter and secondary pollutant like ozone (Onakpohora et al., 2020). Giadom (2018) and Ogele and Egobueze (2020) reported that artisanal oil refineries are the main sources of black carbon (black soot) in Rivers State and the entire Niger Delta region.

4. Conclusions

The mean concentrations of SO_2, NO_2, O_3, PM_{10} and $PM_{2.5}$ were found to exceed both FMEnv and NAAQS permissible limits. The study showed that air pollution in Ogoni area emanated from a variety of sources, with artisanal refineries contributed the highest to air pollution in the area followed by transportation and industrial/commercial activities. The study revealed serious air pollution in the area, which is hazardous to human health and poses critical health concern. The degree of air pollution in Ogoni area portends serious health hazards to the public. People with lung or heart diseases are at greater risk. High rate of mortality associated with air pollution is envisaged in the area. Conclusively, the study showed empirical evidence of air pollution in Ogoni area, which may adversely affect public health and the environment and thus requires government intervention.

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