Spatio-Temporal Analysis of Air Quality in Yola Metropolis, Adamawa State, Nigeria

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Abstract

Air pollution is a significant public health concern, particularly in urban areas. This study investigated the outdoor spatio-temporal variation of pollutants concentration within the study area. The commercial land-use has the highest concentration of pollutants with CO measuring 17.04ppm, $P.M_{2.5}$ (27.9ug/m^3), PM_{10} measured 59 ug/m^3. As per diurnal variability, CO (12.49ppm), PM2.5 (22.57ug/m^3) and PM_{10} (47.15 ug/m^3) were averagely highest in the evening as commercial activities peaked in the evening. The identified hazardous locations were Jimeta Market, which measured an average of 33.17ppm CO level, and By-pass Market with $PM_{2.5}$ and PM_{10} reading 95.3ug/m^3 and 199.9ug/m^3 respectively. Findings of the study revealed that land-users were not aware of the implications of their activities. Findings also showed that there was no instrument stationed at the highly polluted locations various human activities are the major causes of air pollutants as pollutants concentration was more at the commercial centres, transportation centres as well as the abattoir where emissions are high. Based on the findings, the study recommended that pollutants monitoring instruments be installed, and people should be educated on the topic of air quality. While it is advisable to use cleaner energies, enforcement should be ensured to cut down emissions.

Keywords: Pollutants concentration, Land-uses, season, pollutant gases, emissions.

Introduction

The terrestrial environment where humans live and the atmosphere are inseparable. Therefore, the wellbeing of humans is related to the level of atmospheric pollution and sundry anthropogenic activities with resultant negative environmental impacts. Air pollution is the contamination of the air we breathe; both indoors and outdoors, by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. Atmospheric pollution is therefore a major determinant of health even at relatively low concentration. For instance, Particulate Matter (PM) can produce adverse effects on health with no evidence of a safe exposure (World Health Organization [WHO], 2018). It is important to note that much of the pollutants come from the activities of humans like the commercials, transportation, industrial, etc. Bakshi (2001) studied the roadside air quality of some of the areas of Jammu city in terms of suspended particulate matter (SPM) and reported higher levels of SPM at all the places and attributed this to the high automobile density on the road. Air pollution has emerged as a global challenge, posing significant risks to public health and the environment. Despite efforts to mitigate this issue, it continues to prevail in many parts of the world, which includes Yola Metropolis, Adamawa State, Nigeria. As a capital city, it serves as hub for social, economic and some industrial activities, hence, we considered air pollutant concentration variability in Yola Metropolis in space and time. Hazardous zones were identified, and they were examined based on the activities at the sampled locations

Literature Review

Since the industrial revolution and widespread urbanization, air pollution has risen to the top of the environmental concerns list in both developed and developing nations (Anwar *et al.,* 2021; Wei *et al,* 2021; Zhang *et al,* 2022). The key source of pollutants that contribute to the degradation of air quality are various human activities, such as fossil fuel combustion to drive production processes, motor vehicles, and industrial plants (Pachon *et al,* 2018; Rajput *et al.,* 2021; Munsif *et al.,* 2021; Molina *et al,* 2021). Also, the primary factors contributing to the degradation of air quality are tremendous expansion of the urban population and the changes in land use (Liang *et al.,* 2019; Surya *et al.,* 2020). This implies that many urban inhabitants are continually exposed to an unhealthy amount of air pollution (Chen *et al.,* 2020). For instance, due to an increase in industry, population concentration, anthropogenic influences and automobile usage, India's air quality has been worse over time (Jat & Gurjar, 2021). Studies conducted in Kaduna and Abuja, Nigeria, show higher values of CO_2 concentration in heavily congested areas: 1,840 ppm for Sambo Kaduna, 1,780 ppm for Stadium round-about, Kaduna, and 1,530ppm for A.Y.A, Abuja, 1,160 ppm for Asokoro, Abuja (Akpan & Ndoke, 1999). Similar work was done by Jimo and Ndoke (2000) when they discovered that in Minna, a city in Nigeria shows a maximum value of 5,000ppm for CO_2 in congested areas. It was discovered that the reason for Minna low emission was due to low traffic and industrial activities in the city. Also, a comparative study of emission figures in Lagos and the Niger Delta area was reported by Jerome (2000). Two major cities in the Niger Delta were considered (Port Harcourt and Warri). The research shows that the concentrations of total suspended particles, NOx, SO_2 and CO in the two locations were above recommended limits. Apart from the fact that there is not much work done with regards to pollutants concentration in the north-eastern part of Nigeria, there is also a gap of estimating the exposure of people to the pollutant concentration

Description of the Study Area

Yola Metropolis is the capital of Adamawa State, Nigeria and it covers Yola North (Jimeta) and Yola South local government areas. It is situated on the bank of the Benue River. Yola Metropolis, being the capital city is also the administrative centre of Adamawa State and is an economic hub for the region. It is located between latitude 9^0 13' – 9^0 19'N and longitude 12^0 19' – 12^0 28'E and has a population of 282,785 as at 2018 with population density of 2,528 per km^2. As a metropolis, Yola has witnessed some significant growth in recent times with an increasing population and urban development. In terms of population, according to the 2006 national census, Yola had a population of 196,197 (NPC, 2006). However, recent estimates put the population over 400,000 (Citypopulation.de, 2021). The increasing population of Yola Metropolis indicates an increase in commercial activities, automobile movements, Increase in industrial activities, more waste and higher number of residents per house among other things. It should be noted that this will have some influence in gas emission in Yola if not well managed.

Methodology

Data Types and Sources

Primary data was collected from sixteen different locations in Yola metropolis. The primary data were six pollutant gases, and the selection of these gases was based on two factors which were the calibration of the instruments used and the guideline of WHO. The WHO's new guidelines recommend air quality levels for 6 pollutants, which evidence has the most negative health effects from exposure such as Particulate Matter$_{2.5}$ ($PM_{2.5}$), Particulate Matter$_{10}$ (PM_{10}), Ozone (O_3), Nitrogen dioxide (NO_2), Sulfur dioxide (SO_2) and Carbon Monoxide (CO). The pollutants that were considered were $PM_{2.5}$,(PM_{10}), CO, and SO_2. The identified gasses are called classical pollutants which also have an impact on other damaging pollutants (WHO, 2021). Also, Hydrogen dioxide (H_2S) was included since the instrument used could measure it alongside the classical pollutants considered in this research. Pollutant concentration data was collected in the year 2022 at 16 different locations across three seasons (Rainy, Dry-cold, Dry-hot seasons) and at three times daily (Morning, Afternoon, Evening). Thirty different morning readings, afternoon readings and evening readings were taken at each season (Rainy, dry cold (Harmattan) and Dry Hot) in the space of one year (Year 2022). Rainy season data were taken in the month of September, dry cold season data were taken in the month of January and Dry hot season data were taken in March when temperature was at its peak. It is worthy of note that the locations which were selected was as result of the prevailing activities that occur in them (Balogun & Orimogunje, 2015) and were also categorized based on their respective land-uses as shown in Table 1. Also, farmlands, where there are fewer human activities, were selected to serve as control sites as shown in Table 1 below.

Data Collection Instruments

Hinaway CW-HAT200 Handheld Portable Particulate Counter $PM_{2.5}$ and PM_{10} unit Microgram Cubic Meter air quality instrument was used to collect particulate matter data (2.5 and 10 diameter). Altier 5X has four sensors which can display four separate gases. The gases monitored were CO, H_2S, and SO_2.

Table 1: Sampled Locations and land-uses

Transportation	**Commercial**	**Abattoir**	**Institutional**	**Residential**	**Agricultural**
Fire Service	Bypass Market	Abattoir	SPY	80 units	Rumde
Jippu Jam	Jambutu		FMC	Demsawo	
Mubi Roundabout	Jimeta Market				
Police Roundabout	Shopping complex front				
Target Junction	Yola Market				

Result of findings

ANOVA was used to examine the variability of pollutant concentration across all land-uses and locations. Also, hazardous locations were identified. This section examined the result of the findings of the variability of pollutants concentration at the sampled locations, variability at various land-use types, variability during the times of the day, and variability across the season.

Pollutants Concentration at Various Locations in Yola Metropolis

According to the US EPA (2018), CO value between 15.5 and 30.4ppm is very unhealthy. Across the three seasons, locations like Mubi Roundabout (15.84ppm), Jambutu (16.39ppm), By-Pass Roadside (19.77ppm) and Yola Market (17.36ppm) fall under this category. Abattoir (13.16 ppm) is lower than the above-mentioned locations, but it is categorized as unhealthy. The bye pass market was unhealthy for sensitive groups at 11.32ppm. Other locations are moderate except Jimeta Market, (33.17ppm), which recorded the highest CO, and it is categorized as hazardous. As shown in Figure 3, Jimeta market, a commercial centre has the highest level of CO concentration while Bye-Pass market (a commercial centre) has the highest concentration of Particulate matter. The least concentration of pollutants concentration is found at Rumde being an agricultural area.

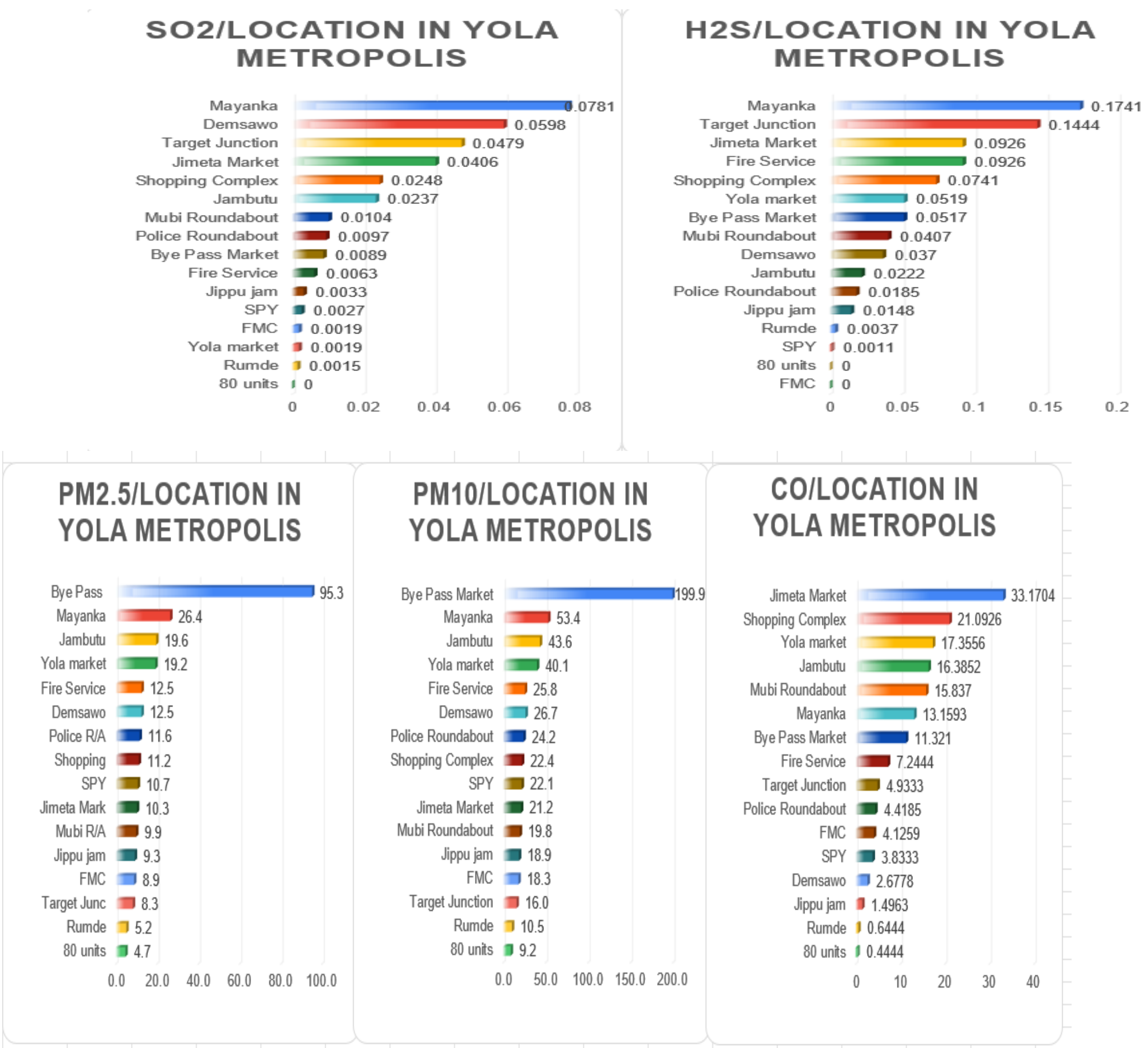

Figure 1: Pollutants Concentration at the sampled locations in Yola Metropolis

Pollutants Concentration across the Seasons Based on Land-use Types (Year 2022)

As shown in Table 2, the mean concentration of CO is at the highest at the commercial land-use type (17.04ppm) while it is 8.63ppm for transportation land-use. Apart from the various commercial activities going on at the commercial centres, it should be noted that a lot of vehicular emissions were prominent around the commercial areas which constituted a very large portion of the CO around the commercial centres. Moreover, abattoir centre also showed high value of CO at 13.16ppm and then, agricultural land-use, which involves low commercial activities, transportation and industrial has CO as low as 0.644ppm. Based on Land-use type, the level of $PM_{2.5}$ in the study area ranged between 5.2 and 27.9ug/m^3 across the land-uses with the highest from commercial land-use (27.9ug/m^3) which was attributed to activities, like cooking, burning, vehicular movements and other commercial related activities. The next to commercial land use was Abattoir (26.4ug/m^3) which can be attributed to the intense burning activity. Residential went as high as 14.9ug/m^3 which was due to cooking activities where low-income residents, who do not use cooking gas, are prevalent. PM_{10} across the land use types was measured and it was at the highest at the commercial centres (59ug/m^3) followed by Abattoir (53.3ug/m^3). SO_2 and H_2S were highest at abattoir.

Table 2: Overall Mean concentration of pollutant in different land-use types (Year 2022)

Land use	CO	SO_2	H_2S	$PM_{2.5}$	PM_{10}
Transportation	8.6304 ±13.87789^e	0.0242 ±0.14476^a	0.0579 ±0.32388^a	10.8363 ±7.41601^{bc}	22.0111 ±15.20861^b
Commercial	17.0392 ±20.6776^d	0.0173 ±0.05308^a	0.0529 ±0.22392^a	27.8524 ±56.94602^d	58.9993 ±123.5278^c
Abattoir	13.1593 ±31.92522^c	0.0781 ±0.1784^c	0.1741 ±0.38954^c	26.4444 ±37.42674^d	53.3519 ±75.29663^c
Institutional	3.9796 ±6.4691^a	0.0023 ±0.01476^b	0.0006 ±0.00744^b	9.7889 ±6.85497^b	20.2074 ±14.36825^b
Residential	4.688 ±12.11855^a	0.0039 ±0.01919^b	0.0222 ±0.14741^b	14.8705 ±15.43363^c	28.9088 ±31.2396^b
Agricultural	0.6444 ±1.5423^b	0.0015 ±0.0121^b	0.0037 ±0.06086^b	5.1704 ±2.92417^a	10.5444 ±6.58458^a
Mean	9.8447 ±17.36585	0.0183 ±0.09925	0.048 ±0.25059	16.963 ±34.17262	34.9914 ±73.54283
F	32.421	30.515	8.724	83.234	79.974
P	0.000	0.000	0.000	0.000	0.000

Values are the means ± standard deviations. Different superscripts in the same column indicate significant differences at $p < 0.05$ according to the Duncan multiple range test (DMRT)

Diurnal Pattern of Pollutants Concentration

From the average data collected across all seasons, CO is highest in the evening (12.49ppm) followed by afternoon (8.92ppm), then morning (8.12ppm). The value in the morning was due to high vehicular movement when people were going to work. $PM_{2.5}$ (22.57 ug/m^3) and PM_{10} (47.15 ug/m^3) are also at the highest level in the evening, followed by morning (18.93 and 38.76ug/m^3)

respectively. The values are at the lowest in the afternoon at 9.39 and 19.06ug/m^3 respectively, also, at the highest level in the evening, followed by morning (18.93 and 38.76ug/m^3) respectively.

Table 3: Mean concentration of pollutant in different times of the day across the season (Year 2022)

Time of the day	CO	SO_2	H_2S	$PM_{2.5}$	PM_{10}
Morning	8.1187 ±15.87213[a]	0.0226 ±0.0834[a]	0.0673 ±0.25286[a]	18.9316 ±36.40978[a]	38.762 ±74.3031[a]
Afternoon	8.9223 ±12.70932[a]	0.0129 ±0.0672[b]	0.03 ±0.17013[b]	9.3869 ±9.49379[b]	19.0602 ±19.65597[b]
Evening	12.4921 ±21.92595[b]	0.0194 ±0.13436[ba]	0.0468 ±0.30804[c]	22.5716 ±44.6786[c]	47.1543 ±99.54163[c]
Mean	9.8447 ±17.36585	0.0183 ±0.09925	0.048 ±0.25059	16.963 ±34.17262	34.9914 ±73.54283
F	9.704	36.95	8.57	64.71	70.155
P	0.000	0.000	0.000	0.000	0.000

Values are the means ± standard deviations. Different superscripts in the same column indicate significant differences at $p < 0.05$ according to the Duncan multiple range test (DMRT)

Air Pollutant Variation across the Seasons

The highest value of CO occurred in the rainy season (11.64) which is just slightly higher than the value of dry hot season (8.91) while Particulate matters are highest during dry hot season with $PM_{2.5}$ having 21.44 value and PM_{10} at 44.62. SO_2 and H_2S have the highest value during the rainy season. Also, it was observed that CO and H_2S were highest during the rainy season with values 11.64 and 0.0795 respectively as well as SO_2 at 0.026 highest value. Particulate matters were at the highest point during the dry hot season followed by the dry cold. In summary, CO, SO_2 and H_2S have the highest value during the rainy season while PM_{10} and $PM_{2.5}$ have the highest value during the dry hot season. This pattern is observed across land uses. Particulate Matter is at the highest value at the commercial land use during dry hot season with $PM_{2.5}$ and PM_{10} at 21.44 and 44.62 respectively.

Table 4: Air Pollutants variation across the seasons (2022) in Yola Metropolis

CO			SO_2		
Rainy	Dry-cold	Dry - hot	Rainy	Dry-cold	Dry - hot
11.64	3.47	8.91	0.026	0.01	0.03

H_2S			$PM_{2.5}$		
Rainy	Dry-cold	Dry - hot	Rainy	Dry-cold	Dry - hot
0.08	0.02	0.06	8.8	16.9	21.44

PM_{10}		
Rainy	Dry-Cold	Dry-hot
16.9	34.73	44.62

High Air Pollutants Concentration Spots in Yola Metropolis

Table 5 shows the AQI categories of the unhealthy spots in Yola metropolis. The categories were analysed using US EPA indices (2018). It should be noted that any pollutants concentration type that exceeds the atmospheric healthy limit in any location, such location is considered unhealthy for breathing. This means that even if CO is normal for the location but $PM_{2.5}$ is above the limit for the same location, such location is considered not healthy irrespective of the acceptable CO concentration. The consideration is since there is no pollutant that is safe for humans to be exposed to.

High Pollutants Concentration Locations in Yola Metropolis

Table 5: Hazardous locations in Yola Metropolis categorized using US EPA, 2018 Standard

Locations	**Pollutants**	**AQI Categories**
Bye Pass Market	CO (11.32ppm) $PM_{2.5}$ (95.3ug/M^3) PM_{10} (199.9ug/M^3)	Unhealthy for Sensitive Groups
Abattoir	CO (13.16ppm)	Unhealthy
Mubi Roundabout	CO (15.84ppm)	
Jambutu	CO (16.39ppm)	Very Unhealthy
Yola Market	CO (17.36ppm)	
Jimeta Market	CO (33.17ppm)	Hazardous

Discussion

The least concentration of pollutants concentration found at Rumde being an agricultural area was due to low emission at the location and this was corroborated by the study done by Maitera, *et al* (2018) who affirmed lowest concentration at a farmland beside Federal government Girl's college (FGGC) Yola which represented an agricultural area. Rumde, an agricultural area, recorded 5.2 and 10.6ug/m^3 respectively which was considerably the healthiest among all locations sampled and this is corroborated by a study done at Ngwogo Nike of Enugu State, where a rural settlement recorded the lowest level of pollutants concentration among the nine sampled areas. Maitera, *et al* (2018) also reported that Jimeta Market is the most CO polluted spot of all the ten locations sampled in Yola. Figures 2 and 3 show the spatial variation of concentration of pollutants across the sampled locations in Yola Metropolis. The map shows pollution spread for CO, $PM_{2.5}$, PM_{10}, H_2S and SO_2. It is important to note that the By-pass market has the highest measurements for both $PM_{2.5}$ and PM_{10} and this is due to the observed emission from continuous grinding of corn and other related food material together with intense burning of iron material within the market areas. $PM_{2.5}$ was averagely as high as 95.3ug/m^3 which according to US EPA (2018) is unhealthy for sensitive groups. At ByPass Market, $PM_{2.5}$ was averagely as high as 199.9ug/m^3 and according to US EPA (2018), children, older adults, asthmatic patients and other sensitive groups of persons should avoid prolonged exertion. According to Okudo *et al* (2022), Ogbete Layout which was a commercial area sampled at Enugu state recorded the highest level of Particulate Matter among other land uses because of high vehicular movement and market presence in the area. Eighty units' quarters, a quiet residential area with very low emission activities, recorded the lowest value of $PM_{2.5}$ and PM_{10} at 4.7 and 9.2ug/m^3 respectively. With CO between 9.5 to 12.4ppm, the results obtained at the locations were attributed to high movement of vehicles at the commercial and transportation land-use types while at the Abattoir, it is attributed to the intense burning at the early hours of the day.

The study undertaken by Lagos Metropolitan Transport Management Authority (LAMATA) on air quality between 2003 and 2007 showed that vehicles promote approximately 43% of ambient air pollution making them the highest point source contributors of carbon. Lagos transport sector for instance, contributes more than 50% of total greenhouse gas in Nigeria (Maduekwe *et al*, 2020). According to the US Environmental Protection Agency Office of Air Quality Planning and Standards (2018), the air is unhealthy for sensitive groups (e.g people with heart disease). According to US EPA Standard, sensitive people should consider reducing prolonged or high exertion at areas with $PM_{2.5}$ between 12.1 and 35.4ug/m^3. PM_{10} at the highest at the commercial centres (59ug/m^3) followed by Abattoir (53.3ug/m^3) and according to US EPA standards (2018), prolonged exposure should be avoided by sensitive people when the value of PM_{10} is between 55-154 ug/m^3. The high SO_2 and H_2S at abattoir were partly because ruminant animals produce large amounts of H_2S during digestion due to the breakdown of sulfur-containing feed. As a result, the air in and around the abattoir tends to contain higher levels of H_2S (Singh *et al*, 2020).

By comparing Maitera *et al* (2017) in his investigation on H_2S and SO_2 concentration in Jimeta, the highest overall result of the H_2S obtained at abattoir (0.1741ppm) is higher than the results he obtained at all locations he sampled while SO_2 obtained in this research is still around the range of the values he obtained in Jimeta. Although, he did not take samples at Abattoir, but this shows H_2S at Abattoir is significantly higher than every location he sampled in his research with the highest value of H_2S he obtained being around a location called Hayin Gada (0.057ppm). Hayin Gada is a bridge with farming activities happening under it which also has a lot of waste material around it. Maitera *et al* (2017) noted that the high value of H_2S at Hayin Gada could be due to the breaking down of bacteria, organic matter, human and animal waste which was the source of bad odor at the site. He also noted that the delayed food stuff, waste and refuse generated could be responsible for high emission of H_2S in these locations and this corroborates why Abattoir emits high value of H_2S as a lot of animal wastes are dumped at this site. Finally, Agricultural area marks the least polluted area, marking the land-use type with the least emissions.

The values are at the lowest in the afternoon at 9.39 and 19.06ug/m^3 respectively. The highest value in the evening was due to a lot of commercial activities at its peak, especially in places like Yola market, Jimeta main market and Jambutu, where there were a lot of suya joints, cooking joints and others apart from high vehicle movement around the same time. The same period also represented the time when some people return home from work. According to the US EPA (2018), sensitive people should avoid prolonged exposure between 12.1-35.4 ug/m^3 for $PM_{2.5}$ while the same group should avoid prolonged exposure between 55-154 ug/m^3 for PM_{10}. Wet seasons recorded lower PM values due to cleaning up from the rain (Ngele & Owu, 2014) while high values during the dry season could be influenced by transport of windblown suspended dust (Enotoriuwa *et al,* 2016). Wet season PM values were significantly less than PM values for dry season and this can be attributed to atmospheric clean up through wash out and rain out (Ramson *et al,* 2016). This is also corroborated with the research carried out by Adebayo *et al* (2022), they discovered that Particulate matters are higher on dry season than wet seasons on Ibadan-Ilorin Highway of Nigeria. According to Okudo *et al* (2022), the concentrations are higher during the dry season; this may be because of increase in the atmospheric temperature which makes the particulates dry, lighter and more mobile (Masih, *et al 2012,* Moreno, *et al* 2006). Okudo *et al* (2022) also noted that the concentrations are higher during the dry season because temperatures make pollutants dry and more mobile.

Conclusion

A lot of Nigerians are ignorant of the volume of polluted air they inhale daily, especially in the cities. The variance between city air and that of rural areas is widening up. In developing countries, the history of air pollution problems has typically been that of high levels of smoke coming from vehicular emissions, internal combustion engines, and industries. According to IQAir (2022), once pollutants move into the circulatory system, they can cause inflammation, damage blood vessels, and increase arterial calcification. The sources of air pollution identified in the study also exposed the common channels of environmental pollution and its effects on the people of Yola Metropolis. These sources were majorly commercial, transportation centres and Abattoir which activities cut around emissions from vehicles and burning activities of various sorts. CO was compounded by daily movements of tricycles, cars and trucks while the burning activities in the evening by roadside food sellers makes the pollutants also spike at this time. Persons at the agricultural sites like Rumde were safer and enjoyed a much healthier environment since there was very little or no movement of vehicles. The locations of Yola Metropolis have been appraised based on the world standard of air quality. It should also be noted that the major pollutants that constitute the atmosphere of Yola Metropolis were CO, $PM_{2.5}$ and PM_{10}. It should also be noted that the emission from some diesel engine machines in the market constitute spots of air pollutant source. This was clearly observed in By-pass Market. The mill grinders are also congested at a spot which makes this spot a major source of pollutant. Unfortunately, people are not educated on the implications of their actions to the environment.

Recommendation

Based on the findings of the study, the following recommendations are made.

i. The people in the study area should be educated so that they will be aware of the implication of their various activities on air quality.
ii. There is a need for instruments to be installed especially at the highly polluted locations identified in this work to monitor the concentration swings and quickly warn sensitive people to avoid locations when concentrations are high.
iii. It is also important to begin to switch to cleaner energies for vehicles and other machines being used in urban areas of Nigeria like Yola Metropolis.

iv. There is a need to enforce policies by relevant agencies to curb air pollution in the metropolis.
v. Sensitive groups of people should be advised to go out during periods when the air is cleanest. According to this study, the safest time to go out is in the afternoon when pollution has reduced due to lower vehicular movements

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