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CHARACTERIZATION OF AIR POLLUTION BY PARTICULATE MATTERS EMITTED FROM CEMENT INDUSTRY LOCATED IN SAGAMU, NIGERIA

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Abstract

Air pollution in urban areas is a major concern to the general public and generally becoming a serious problem around the world. The effect of these pollutants on public health, animals and plants are devastating. This study examined environmental pollution caused by Lafarge Cement Plc, Sagamu at some terrestrial locations within the catchment area of the production. Particulate matters ($PM_{2.5}$ and PM_{10}) depositions were recorded for all the sampling locations. The Settling properties for particulate matters, optical properties and air quality index (AQI) for all referenced points were calculated from the measured data. The results show that the average AQI of Sagamu were found to be heavily polluted and therefore classified as hazardous for residence with AQI values of 186-699. The mass concentration of PM_{10} was highest at Abeokuta routes with a measurement of 349.2958μg/m^3 and ≤ 308.6125 μg/m^3 for other locations, this assertion was further corroborated by decreased visibility experienced at Abeokuta route.

Keywords: Air quality index, Optical properties, Particulates Matters deposition, Settling properties, Urban Air Pollution, Visibility

1.0 Introduction

Air pollution is the introduction of chemicals, particulate matter, or biological materials that cause harm or discomfort to humans or other living organisms, it also causes damage to the natural environment or built environment into the atmosphere. Air pollution is one of the environmental problems confronting growing cities and is currently the challenge faced by many developed and developing countries (Komolafe *et al*, 2014 and Fayomi et al., 2019). Various anthropogenic activities have either increased the content level of some of the natural pollutants or have added new pollutants to the air. Consequently, the air quality has deteriorated significantly and the atmosphere in general stands polluted considerably (Ahmad et al, 2014 and Abiye, 2013). The effects on human lives are enormous as it causes disease and can result in chronic illness. Apart from the health effects, air pollution contributes to our changing climatic conditions, which are potential sources of threats to local and international communities (Komolafe *et al*, 2014). Most

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citizens are aware of the need for air pollution control because of continual information from government, research sources and the press. The public, however, is not aware that accurate measurements are needed to bring about effective air-pollution control (Dewan, 2020). Measurements are important, first, to establish acceptable levels of contamination of the atmosphere taking into account meaningful data in the various location of study area. For this study, measurements were performed in different locales of Sagamu, Ogun state, Nigeria to determine the offending sources and degree of control required to put in place. On the basis of these measurements, control standards can be formulated and an enforcement mechanism set in motion, periodic sampling and measurements is required for use in proper legal proceedings against violators. This study has measured air pollutants using particulate matters as a case study, these major pollutants posed the greatest threat to human health and visibility of the area. The research went deeper in air quality analysis in which the Air Quality Index of the city had been found showing the environments status of Abeokuta, Ikorodu and Ijebu-ode.

2.0 Review of Literatures

Air Pollution sources can be classified either as from natural or man-made sources. Natural sources may be in terms of radiations or through earthquakes that releases those volcanic materials. Anthropogenic (man-made) sources may however be from those listed in the Table 1.

Table 1: Typical source emission standards (Federal Register, Dec. 23, 1971)

Source	***Pollutants (million tonnes)***					
	Particulates	**CO**	**SO_x**	**HC**	**NO_x**	**Total**
Transportation	1.4	69.1	0.9	7.8	9.1	88.3
Fuel combustion	1.4	2.1	19.0	0.2	10.6	33.3
Industrial processes	3.7	5.8	3.8	10.8	0.7	24.8
Solid waste disposal	0.4	2.2	0.0	0.6	0.1	3.3
Miscellaneous (forest fire, burnings, etc.)	0.9	6.2	0.0	2.4	0.2	9.7
Total	7.8	85.4	23.7	21.8	20.7	159.4

Particulate matter (PM) is a complex mixture of solids and liquids, including carbon, complex organic chemicals, sulphates, nitrates, mineral dust, and water suspended in the air. PM can be generated by industry, transport and agriculture, and due to their light weight, can also be carried on air currents from one country to another. The size of the particle is very important in determining their behaviour in the air, the distance and the height up to which they will be carried by air currents and the effect they will have on the organism inhaling them or on plants
which have to exchange gases through their stomata. Classification of PM may be done in terms of:

i. Total Suspended Particulates (TSP) are all the solid particles and liquid droplets in the air that are smaller than 30 micrometres in diameter.

ii. PM_{10} are the solid particles and liquid droplets in the air that are smaller than 10 micrometres in diameter. They can get into your lungs, but not into your bloodstream.

iii. $PM_{2.5}$ are the solid particles and liquid droplets in the air that are smaller than 2.5 micrometres in diameter. They can get into your lungs and bloodstream, and are the most harmful type of PM.

iv. Ultrafine PM are the solid particles and liquid droplets in the air that are smaller than 0.1 micrometres in diameter. They are even more harmful than $PM_{2.5}$ because they can enter cells and damage DNA.

It is worthy of note that many types of research are based on PM_{10}, $PM_{2.5}$, and sub-micron PM, while some are still based on total suspended particulates (TSP). Particulate pollution varies widely across countries in composition, distribution and sources. The assessment of PM concentrations and sources depend largely on the local sources within urban areas and long-range transport of the air pollutants (Emetere & Dania, 2019).

The PM sources in developing countries are much wider than those from developed (Industrial country). This is because of the increase and fast transition between rural and urban economies. Sources of PM in the urban and rural areas are different while in rural areas cooking with solid fuels is rampant so also biomass burning, but in the urban, it is fossil fuel. In the reviewed of Johnson *et al.* (2011), it was noted that major sources of pollution in urban places are heating and household cooking, using traditional fuels, animal husbandry, industrial processes particularly cement industry, burning of fossil fuels. In developing countries most especially Africa, Latin America and Asia, oil, biomass and coal are the main sources of pollution. Both in industrial and developing countries of the world, a major source of PM has been motor vehicles, this is due to the fuel (like diesel) used in powering them.

Consequently, in developing countries, due to economic hardship most vehicles used are old, they do not meet clean emission standards. As a result, they tend to be more polluting. According to literature reviewed, it was observed that the most contributors to PM include vehicles, industrial activity, household fuel, power sector, fugitive dust and unprocessed biomass fuel like wood, dung and crop residues (Alahmr *et al.*, 2012, Dallman *et al.*, 2014, Crilley *et al.*, 2014, Onabowale & Owoade, 2015, Fawole *et al.*, 2016, Owoade *et al.*, 2013, Owoade *et al.*, 2015, Orogade *et al.*, 2016 and Omole et al., 2016).

Particulate matters have been confirmed to have health implications on human. Onabowale & Owoade (2015) stated that about 28% of the sickness and death are caused by indoor air particulate in developing countries (Omole et al, 2016). This was corroborated by the results of the studies carried out by Kuehn (2014), where the study attributed more than 7 million deaths to the impact of PM (indoor and outdoor). In India, (Delhi) air pollution has been reported to cause 10,000 to 30,000 deaths every year (Gopalaswami, 2016). Acute and chronic problems are due to inhalation of PM_{10} and $PM_{2.5}$ (Ezeh *et al.*, 2012), and damage to respirative organs (Moses & Orok, 2015). Cases of respiratory diseases and even death have been reported in some Nigerian cities like Lagos, Ogun Port Harcourt, and Kano (Komolafe et al., 2014 and Etim et al., 2021). Podur & Wotton (2010) reported that the greatest effect on health is from $PM_{2.5.}$ This has resulted in hospitalization. Affected people (Old and Children) with asthma, cardiovascular and lung diseases are most vulnerable to fine PM. Duration of exposure has an effect on the sickness. According to the Economic Times Quoted by Gopalaswami (2016). It was noted that over 85% of the world's population lives in an area tagged by World Health Organization to be unsafe. The air pollution there is above the safe level. This showed that more than 5.5million people die prematurely due to the effect of pollution. Obioh *et al.* (2013) attributed the role of fine PM on poor visibility, corrosion, damage to vegetation and soiling. Apart from the damage done to materials, PM also disturbs the atmospheric chemistry and the radiation balance by scattering and absorbing solar radiation and also alter the formation of cloud droplets. The foregoing literature review show need to measure the air quality of our locales. This study evaluates the impact of cement production in a local community of Sagamu, Ogun State in South western Nigeria with a view to quantify the status of air within the neighbourhood. Information available to us shows Sagamu locales have not been previously explored for air pollution studies thus constituting a research gap to be explored.

3.0 Methodology

The Sagamu Cement plant, one of the leading cement manufacturing factories in Nigeria was chosen for this study. Cement production activities have been on for over four decades in this location. The factory utilizes wet and semi -wet production technology with the annual cement production varying between 254,000 and 479,000 metric tons (WAPC, 2000 & Dewan, 2020). It is located at Sagamu in Ogun State, South western Nigeria. The deposition of cement dust and other particulate matter over the catchment areas was very noticeable and of serious concern to the local community.

Sampling Sites

Various sites were considered suitable for sample collections based on their location upward and downward of the cement factory. Ijebu-ode, Abeokuta and Ikorodu routes were selected for air quality monitoring and air pollution studies.

Air Sampling

Samples of air in Ijebu-ode, Abeokuta and Ikorodu route were sampled for particulate matters deposition. Particulate matters and air quality monitoring were measured using Aeroqual S530 equipment at each of the 18 sampling locations with 6 locations on each route.

Determination of location

The Global Positioning system (GPS) was used to measure the coordinates of different locations of our study area. A stop-timer watch was used to measure the duration of time for our data collection**.**

Determination of the Settling properties

Settling characteristics are one of the most important properties of particulates matters, since settling is the major natural self-cleansing process for removal of particulate from the atmosphere. Application of stokes law is applied for calculating the settling operations involving particles in air streams.

Stoke's law is a mathematical model that was used to calculate the settling velocity of an airborne particulate.

Stoke's mathematical model is expressed in equation (1)

Settling velocity, V_t is expressed as:

$$V_t = \frac{g(\ell_p - \ell_a)\, dp^2}{18\mu} \quad \text{------------------------------------- (1)}$$

Where V_t = Settling velocity, m/s

g = Gravitational constant, m/s^2

ℓ_p = Density of the particle, kg/m^3

ℓ_a = Density of the air, kg/m^3

dp = diameter of the particle, m

μ = viscosity of air, kg/ms

Optical qualities

Particulate matters are primarily responsible for visibility reduction (Horvath, 1998). The mathematical relationship between visibility and particulate matter is given as

$$V = \frac{5.2\rho^r}{KM} \quad \text{--- (2)}$$

V = Visibility, Km

ρ = density of particle, kg/m^3

r = particle radius, μm

K= scattering area ratio (dimensionless)

M = mass concentration of particle, $\mu g/m^3$

According to Sinclair (1953),

Scattering area ratio, $K = \frac{S}{\pi r^2}$, -- (3)

Values for other determinant parameters are given below

K value for PM_{10} =2

K value for $PM_{2.5}$ = 4

Particle radius for $PM_{10} = 5 \times 10^{-6}$

Particle radius for $PM_{2.5} = 1.25 \times 10^{-6}$

ℓ_p PM_{10} = 0.00178 kg/m^3

ℓ_p $PM_{2.5}$ = 0.0015 kg/m

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Air Quality Index (AQI)

The Air quality Index is given in the section below

Calculation of AQI

An index for any given pollutant is its concentration expressed as a percentage of the relevant standard (Abulude, 2016).

$$\text{Index} = \frac{\text{pollutant concentration}}{\text{pollutant standard level}} \times 100 \quad \text{---------------------------------- (4)}$$

Pollutant Standard Level = 50 µg/m^3 24 hours of PM_{10} readings.

4.0 Result and Discussion

In this section, the results of the field studies and analyses therefrom are presented and thoroughly discussed.The first sub-section presents and explains the settling properties of particulate matters in three different locations around Sagamu axis, the second sub-section presents and explains the optical properties of the Sagamu locales caused by particulate matters in the three locations studied, and the third sub-section presents and explains the air quality index of the locales

Settling Properties

Particulate matter deposition constituted major atmospheric pollution issue in the cement plant and the auxiliary environment. This can be attributed to dust released during quarry activities,

dust re-mobilization from vehicular traffic. For this study, 6 points in various locations along Ijebu-ode route, Abeokuta route and Ikorodu route were used as data collection points to analyse the effect of pollutants from Lafarge cement plants on the immediate environment. The settling properties of the pollutants were calculated for $PM_{2.5}$ and $PM_{10.}$ Settling operations uses the application of stokes law in determining particles settling in air streams. The settling properties of particulate matters present in our study area is hereby calculated from field data. The surface properties of particulates including adsorption, absorption, chemisorption and adhesion are particularly important factors in the settling process of particulate matters

$PM_{2.5}$

The settling velocity for this study is calculated from equation (1). According to stokes, the viscosity of air depends mostly on the temperature, for this study, the temperature of the air is 30^o C as at the time of data collection.

$\ell_a = 1.164 kg/m^3$

ℓ_p $PM_{2.5} = 0.0015$ kg/m^3

$\mu = 1.872 \times 10^{-5}$ kg/ms

$g = 9.81 m/s^2$

$dp = 2.5 \times 10^{-6} m$

$$V_t = \frac{9.81(0.0015 - .1.164)(2.5 * 10^{-6})^2}{18 * (1.872 * 10^{-5})}$$

$V_t = 2.12 \times 10^{-7}$ nm/s

PM_{10}

$\ell_a = 1.164 kg/m^3$

ℓ_p $PM_{10} = 0.00178$ kg/m^3

$\mu = 1.872 \times 10^{-5}$ kg/ms

g = 9.81m/s^2

dp = 10 $\times 10^{-6}$m

$$V_t = \frac{9.81(0.00178 - .1.164)(10 * 10^{-6})^2}{18 * (1.872 * 10^{-5})}$$

$V_t = 3.38 \times 10^{-6}$ nm/s

Table 2: Approximate settling velocities for $PM_{2.5}$ and PM_{10}

Particle size, µm	Settling velocity
2.5	21.2nm/s
10	3.38nm/s

From the results, PM_{10} settles faster than $PM_{2.5}$ due to a faster settling speed and higher density, Particulate matter, especially the smaller particles (PM_{10} and $PM_{2.5}$), have the most harmful effects on human health than any other pollutant. WHO estimated that $PM_{2.5}$ contributes to 800,000 pre-mature deaths per year. Exposure to $PM_{2.5}$ for just a few hours or weeks, according to the findings, it can cause cardiovascular effects including atherosclerosis, heart failure, heart attack, stroke, arrhythmia, thrombosis, and death. Brief exposure is more dangerous for people with pre-existing cardiac artery disease, people with diabetes or obesity, and the elderly. Other health effects are lung diseases including asthma, chronic obstructive pulmonary disease, chronic bronchitis, reduced lung function, and lung cancer. The size of PM will determine where it will end up once you breathe it in. Larger particles may be trapped in your nose, while PM_{10} can reach your airways. Fine particles ($PM_{2.5}$) may reach the breathing sacs deep in your lungs, and ultrafine particles (less than 0.1 µm in diameter) may even cross into the blood stream (Etim et al., 2021).

Optical qualities

Reduction in visibility is one of the most obvious effects of air pollution and the scattering of light by particulate matter is primarily responsible for the reduction. Most people measure air pollution by visual observation. If a discharge stack at a cement plant emits black smoke, this is judged to be harmful pollution. The accumulation of smog around expressways on still days is evidenced by decreased visibility.

The mass concentration of particulates matter was measured from different sites and reported in Tables 3, 5 and 7, the visibilities for area of studies were calculated from equation (2) and reported in Table 4, 6 and 8.
For the three routes, 9 months were studied, results are reported in Tables 3, 5 and 7 and then plotted in Fig. 1.

Table 3: Mass concentration of Particulate matters in Ijebu-Ode route

Point	***$PM_{2.5}$ (μg/m³)***	***PM_{10} (μg/m³)***
1	24.64167	295.9375
2	34.95417	258.8333
3	21.89583	174.7958
4	24.97083	250.6208
5	22.99167	148.6625
6	24.04167	118.7208
7	22.14167	168.2542
8	18.20833	105.8625
9	21.19333	194.0067

Nine months data collection of $PM_{2.5}$ and PM_{10} on Ijebu-Ode route were analysed in Table 3.

Table 4: Visibility (KM) in Ijebu-Ode route

Points	$PM_{2.5}$ (KM)	PM_{10} (KM)
1	52.8455	8.7856
2	37.1960	10.0451
3	59.3743	14.8745
4	52.0604	10.3742
5	56.5414	17.4893
6	54.0720	21.9002
7	58.7120	15.4528
8	71.3972	24.5602
9	61.3401	13.4016

The results of Ijebu-Ode route visibilities using equation (2) were calculated and analysed in Table 4.

Table 5: Mass concentration of Particulate matter in Abeokuta route

Point	***$PM_{2.5}$ (μg/m³)***	***PM_{10} (μg/m³)***
1	49.01250	349.29580
2	31.80833	311.21250
3	20.80417	165.04170
4	21.38333	174.28750
5	22.68750	266.63330
6	27.36250	233.08330
7	18.26250	152.23750
8	27.22083	178.95420
9	28.73000	254.08000

Nine-months data collection of $PM_{2.5}$ and PM_{10} on Abeokuta route were analysed in Table 5.

Table 6: Visibility (KM) in Abeokuta route

Points	$PM_{2.5}$ (KM)	PM_{10} (KM)
1	26.5238	7.4435
2	40.8698	8.3544
3	62.4875	15.7536
4	60.7951	14.9178
5	57.3003	9.7512
6	47.5103	11.1548
7	47.7575	17.0786
8	45.2489	14.5289
9	61.3401	10.2330

The results of Abeokuta route visibilities using equation (2) were calculated and analysed in Table 6.

Table 7: Mass concentration of Particulate matter in Ikorodu route

Point	***$PM_{2.5}$ (μg/m³)***	***PM_{10} (μg/m³)***
1	61.75833	308.61250
2	32.27083	192.0375
3	27.85833	183.4875
4	27.83750	201.48750
5	36.75417	170.65420
6	16.11667	92.81667
7	33.85000	239.75670
8	34.84583	303.97920
9	14.60417	136.43330

Nine-months data collection of $PM_{2.5}$ and PM_{10} on Ikorodu route were analysed in Table 7.

Table 8: Visibility (KM) in Ikorodu route

Points	$PM_{2.5}$ (KM)	PM_{10} (KM)
1	21.0498	8.4248
2	40.2841	13.5390
3	46.6647	14.1699
4	46.6996	12.9040
5	35.3701	15.2355
6	80.6618	28.0122
7	38.4047	10.8443
8	37.3072	8.5532
9	89.0157	19.0569

The results of Ikorodu route visibilities using equation (2) were calculated and analysed in Table 8.

Decreased visibility interferes with safe operation of aircraft and automobiles. Airport operations are slowed down because of the need to maintain greater distance. At least 15 to 20 planes crash each year are attributed to poor visibility caused by particulate matters, as it can be seen in Figure 1 and Figure 2.

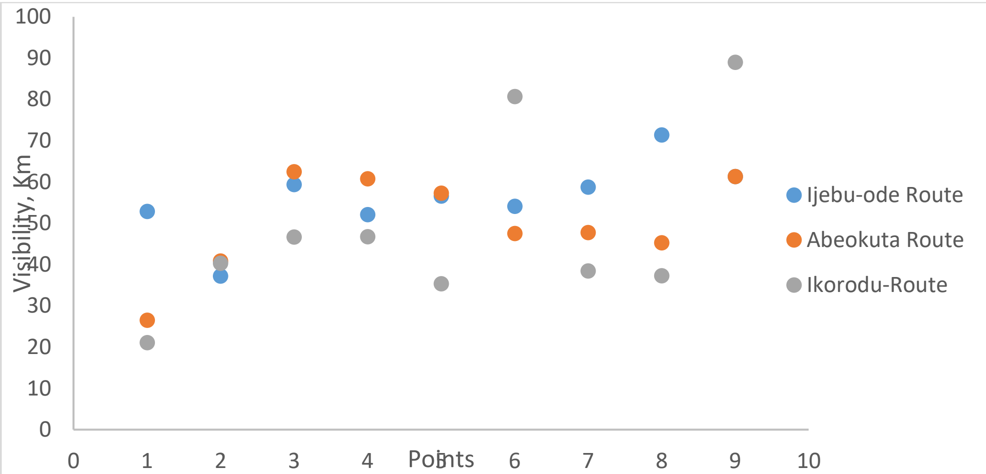

Figure 1: Visibility curve for $PM_{2.5}$ at various points along Ijebu-ode, Abeokuta and Ikorodu route

From Figure 1, decrease in visibility is experienced more at point 1 along Ikorodu route with $PM_{2.5}$ with a distance of 21.05km.

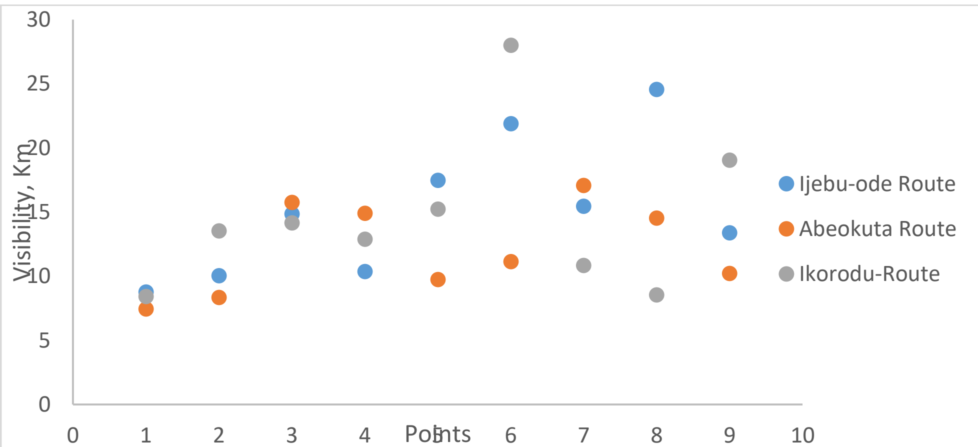

Figure 2: Visibility curve for PM_{10} at various points along Ijebu-ode, Abeokuta and Ikorodu route.

From Figure 2, PM_{10} interfere with visibility more at point 1 along Abeokuta route with a distance of 7.44km.

Air Quality Index

The Air Quality Index (AQI) is a pointer that determines the degree of pollution in an area or monitoring location by calculation. The pollutant determined were particulate matters 2.5 and 10. Each of these pollutants have an air quality standard which is used to calculate the overall AQI for the city (Air Now, 2016). AQI is used to assist someone in understanding what local air quality means to one's health. AQI is represented numbers 0 to ≥500 with 0 representing good air and ≥ 500 representing hazardous air. The AQI is broken down into six categories, each colour coded with the number scale.

- Good (green) is for numbers 0 through 50 and means satisfactory air quality
- Moderate (yellow) is 51-100 and is for acceptable air quality
- Unhealthy for Sensitive groups (tan) is 101-150 and means sensitive individuals with sensitive skin may be affected
- Unhealthy (red) is 151-200 and almost everyone may experience problems.
- Very unhealthy (pink) 210-300 is a health alert, where everyone may have health problems
- Hazardous (purple) over 300 numbers may contribute to emergency health problems
  and will affect most people (Air Now, 2016).

Air quality index (AQI) has been developed and implemented for Ijebu-ode, Abeokuta and Ikorodu routes. Data of two pollutants (PM2.5 and PM10) were collected from 18 locations from January to September 2020 and the AQI has been calculated using Equation 4 and reported in Tables 9, 10 and 11.

Table 9: Air Index for PM_{10} readings along Ijebu-ode route

Points	***Air Index***
1	592
2	518
3	350
4	501
5	297
6	237
7	337
8	212
9	388

From the investigations, Table 9 shows PM10 for Ijebu-ode route, 9 months were investigated for this study on this route, the results show AQI for these locations falls in the heavily polluted
category of AQI classifications with AQI value between 212-592.

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Table 10: Air Index for PM_{10} readings along Abeokuta route

Points	***Air Index***
1	699
2	622
3	330
4	348
5	532
6	466
7	304
8	358
9	508

Similarly, Table 10 shows PM10 for Abeokuta route, 9 sites were studied and taken as reference points for our measurements, results show AQI of the locations is hazardous and falls to the unhealthy categories of AQI value of 304 – 699.

Table 11: Air Index for PM_{10} readings along Ikorodu route

Points	***Air Index***
1	616
2	384
3	366
4	403
5	340
6	186
7	480
8	608
9	273

Furthermore, Table 11 shows results for Ikorodu route, 9 sites were also investigated along the route to classify the AQI of these locations. Results show AQI falls in heavily polluted categories with AQI values of 186 – 616.

5.0 Conclusion

With AQI readings ranging from 186 to 699 ppm, this study's findings can be generalized for the period of January through September 2020 and were determined to be classified as polluted, unhealthy, and dangerous. The finding that the AQI falls in the dangerous (purple) zone with over 300 may cause urgent health issues and may have an impact on the majority of the local residents. Therefore, it is worthy to note that, Air pollution in Sagamu and Environs may have harmful impacts on residence, patients and sensitive groups of people which may lead to unpleasant experience for the general public.

5.1 Recommendations

The followings are the recommendations made from findings in this study

For Visibility:

i. Reduce emissions from sources known to produce fine particulate matter, such as industrial processes, vehicles, and construction activities.

ii. Implement air quality monitoring and early warning systems to alert the public about deteriorating visibility conditions.
iii. Encourage the use of cleaner technologies and fuels in industries and transportation to minimize PM emissions.
iv. Implement vegetation and landscaping strategies, such as planting trees and creating green spaces, to help trap and filter particulate matter, improving local air quality and visibility.

For Settling Properties:

i. Promote dust control measures, like covering construction materials, maintaining unpaved roads, and using water for dust suppression in areas prone to dust storms.
ii. Encourage land use planning that minimizes the generation and resuspension of particulate matter near sensitive areas like residential communities.
iii. Use sedimentation ponds and other settling systems to remove particles from stormwater runoff.
iv. Regularly clean and maintain air filters and HVAC systems in buildings to prevent the accumulation of indoor PM and improve settling properties.

For Air Quality Index (AQI):

i. Develop and implement air quality standards and regulations to limit the concentration of various sizes of particulate matter (PM2.5 and PM10) in the air.
ii. Enhance monitoring networks to continuously assess air quality and provide real-time data for calculating the AQI.
iii. Educate the public about the health effects of PM exposure and provide guidance on actions to take during poor air quality days.
iv. Implement emission reduction strategies, such as vehicle emission standards, industrial emission controls, and renewable energy adoption, to lower PM concentrations.
v. Promote public transportation, carpooling, and active transportation modes to reduce vehicle emissions.
vi. Implement vehicle inspection and maintenance programs to ensure that vehicles on the road meet emission standards.

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