IJEMD-BMCR, (3) 1 (2025) https://doi.org/ 10.54938/ijemdbmcr.2025.03.1.441

International Journal of Emerging Multidisciplinaries:
Biomedical and Clinical Research

Research Paper
Journal Homepage: www.ojs.ijemd.com
ISSN (print): 2957-8620 ISSN (online): 2960-0731

Spatial Modelling Of Air Quality And Pollution Propagation Around An Active Dumpsite In Abeokuta, Nigeria

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Abstract

The dumpsite represents a notable source of air pollutants because waste materials are openly burned there, resulting in the emission of harmful gases and particulate matter into the atmosphere. This study investigates the Air Quality Index (AQI) and spatial distribution of air pollution around the Saje dumpsite in Abeokuta, Nigeria. The concentrations of air pollutants of particulate matter ($PM_{2.5}$ and PM_{10}) and carbon monoxide (CO) were measured using portable handheld gas detectors at the dumpsite and adjoining residential area. The pollutant concentration obtained were used to calculate the AQI. Spatial distribution analysis was performed using inverse distance weighted interpolation method in an ArcGIS environment to map the distribution of the air quality around Saje dumpsite and its environment. The AQI at the dumpsite was categorized as unhealthy, highlighting a significant public health concern. In contrast, the surrounding residential areas showed comparatively lower pollution levels with AQI ranging from "good" to "moderate". The spatial distribution of the pollutants indicated a high concentration at the vicinity of the dumpsite and the concentrations fizzled out towards the residential areas. This study identified health risks, pollution hotspots and spatial air quality patterns near the dumpsite.

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Keywords: Dumpsite, Pollution, Air Quality Index, Spatial distribution, Inverse distance weighted

INTRODUCTION

Air pollution presents a growing environmental challenge in Nigeria, especially in urban regions where industrial activities, vehicle emissions, and waste disposal practices contribute to high pollutant levels in the air [1,2]. Improper solid waste management, including the open dumping of refuse in dumpsites, is a notable source of air pollution in these areas [3]. The rapid urbanization and population growth in Nigeria have led to an increase in solid waste generation, much of which is disposed of in poorly managed dumpsites [4]. Dumping waste in dumpsites is a common waste management practice in many developing nations [5]. During this process, waste burning and uncontrolled incineration are often used to reduce waste volume. It is estimated that approximately 41% of global waste is burned in dumpsites, with potentially higher rates in developing nations with lower incomes [6]. While most dumpsite burning occurs accidentally, some may be intentional to reduce waste volume. However, in less developed and developing nations, this practice is largely unregulated and can pose significant risks of toxic exposure.

In many dumpsites, waste undergoes rapid combustion, leading to the direct release of odors, particulate matter, greenhouse gases, and other gaseous pollutants into the atmosphere [7]. Additionally, the decomposition of organic waste in these dumpsites can result in the emission of various pollutants, including volatile organic compounds (VOCs), particulate matter (PM), and hazardous gases like methane (CH_4) and hydrogen sulfide (H_2S). These emissions can have a significant influence on local air quality, posing health risks to individuals. The presence of air pollution has detrimental effects on health and well-being of humans. Several studies have found significant associations between air quality and a range of health issues, including difficulty breathing, chest pain, throat irritation, asthma, nausea, bronchitis, and lung cancer [8,9]. Exposure to air pollution can also lead to serious health problems such as high blood pressure and cardiovascular issues [10]. Globally, air pollution is considered a significant cause of mortality, surpassing AIDS, malaria, and breast cancer combined [11]. Particulate matter (PM) in the air is particularly harmful to health [12], contributing to an estimated 3 to 7 million deaths annually, mainly through the exacerbation of cardiovascular and respiratory diseases [13].

The Air Quality Index (AQI) is a numeric system utilized to convey the air quality at a particular site, determined by the levels of air pollutants present [14]. It offers a standardized method for comprehending the possible health hazards linked to inhaling the air within that vicinity. Assessing the AQI around a dumpsite involves monitoring and measuring the concentration of key air pollutants at various locations within and around the dumpsite. These measurements are then used to calculate the AQI, which is typically categorized into different levels of health concern, ranging from "Good" to "Hazardous" [15]. The AQI not only provides information about the current air quality but also offers recommendations for sensitive groups and the general population based on the level of pollution [16].

The spatial distribution of air pollutants around dumpsites is of particular interest due to the potential health risks posed to nearby communities. Geographic Information Systems (GIS) have emerged as valuable tools for studying the spatial distribution of air pollution around dumpsites [17,18,19]. GIS allows for the integration of spatial data, such as air quality measurements, topography, land use, and meteorological factors, to create spatial models that can predict the dispersion of pollutants in the atmosphere [20,21]. By employing GIS-based spatial distribution modeling, researchers can assess the extent of air pollution around dumpsites, identify hotspots of pollution, and evaluate the potential exposure of nearby populations. The objective of this study is to assess the air quality and spatial pollution propagation around an active dumpsite in Abeokuta, Nigeria. Evaluating the air quality near an open dumpsite can aid in predicting the effects on greenhouse gas concentrations in the atmosphere, potentially influencing climate change. Furthermore, it can assess the impact on dumpsite workers, waste pickers, and nearby communities.

MATERIALS AND METHOD

Description of the Study Area

Abeokuta, the capital of Ogun State in southwest Nigeria, spans an area of approximately 879 km^2 and is located between latitude 7º 9' 39’’ N and 3º 20'54’’E. The city has undergone increased cosmopolitanism since it became the state capital in 1976 [22]. Positioned within Nigeria's rainforest zone, Abeokuta's proximity to Lagos, the country's commercial capital, main seaport, and industrial hub, has enhanced its accessibility. The city is located in a diverse basement composed of igneous and metamorphic rocks, which are covered by sedimentary layers. Its topography is characterized by rugged, rock-strewn relief, particularly in the northern, central, and southeastern parts. The city's drainage system is facilitated by the Ogun River and several small streams. Some of these streams originate from nearby rocky hills, while others serve as distributaries for the major rivers [23].

The study area is situated within Nigeria's humid tropical region, specifically between 7°10'30" and 7°12'0"N latitude and between 3°21'0" and 3°22'30"E longitude [24] as presented in Figure 1. The Saje dumpsite, which was established in 2006, was previously a quarry site operated by the Associated Granite Industry (AGI) Quarry [25]. This dumpsite, the only designated one for the Abeokuta metropolis, occupies an area of about 119,000 square meters [26]. Presently situated in a densely populated area of Abeokuta, the Saje dumpsite is surrounded by residential buildings. To the North, South, East and West of the dumpsite are the Olobi community, Oke-Aregba community, Elega housing estate and Labaiwa community respectively at the Saje area of Abeokuta. To the south of the dumpsite, there is a perennial stream that acts as a tributary to the Arakonga stream in Abeokuta [23].

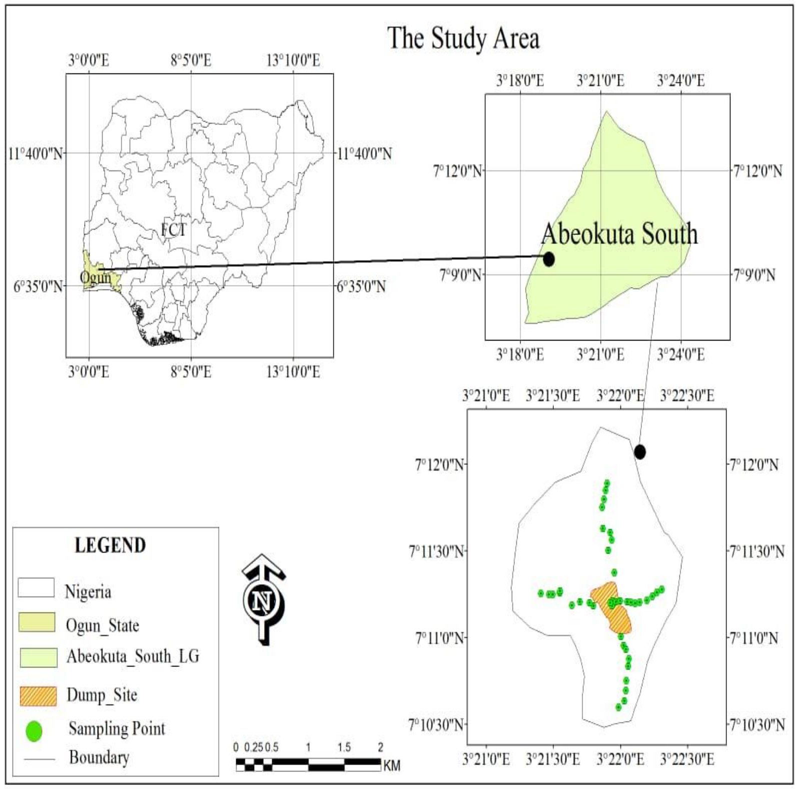

Figure 1: Study area map

Study Design and Data Collection

Sampling was carried out to monitor the air quality at the Saje dumpsite and adjoining residential areas along the four paths of propagation (towards the North, South, East and western transverse from the dumpsite). Air pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}) were measured using a professional air tester (AX-8060) and carbon monoxide was measured using a multifunctional gas detector (Pulitong version 4.6). Ten sampling points were obtained from the dumpsite to each path of propagation making a total of forty sampling points using global positioning system (GPS) and each samplings coordinate were obtained and recorded as shown in Table 1. The distance of each sampling point from the dumpsite (which serve as the reference point) were obtained and recorded appropriately using Google Earth Pro. The sampling was carried out from February to April and May to July, 2023 for dry and wet season sampling respectively at 21 days sampling interval.

Table 1: Sampling locations

	Northern Transverse (NT)				Southern Transverse (ST)		
S/N	Latitude	Longitude	Distance (m)		Latitude	Longitude	Distance (m)
1	7.18687	3.36567	0		7.18641	3.36566	0
2	7.18958	3.36593	367		7.18345	3.36673	402
3	7.19173	3.36515	662		7.18259	3.36707	449
4	7.19274	3.36559	756		7.18221	3.36733	564
5	7.19345	3.36539	855		7.18132	3.36772	670
6	7.19384	3.35447	918		7.18061	3.36763	718
7	7.19589	3.36442	1090		7.17919	3.36742	853
8	7.19662	3.36463	1140		7.17827	3.36735	947
9	7.19748	3.36481	1270		7.17727	3.36714	1052
10	7.19818	3.36503	1315		7.17666	3.36646	1120
	Western Transverse (WT)				Eastern Transverse (ET)		
	Latitude	Longitude	Distance (m)		Latitude	Longitude	Distance (m)
1	7.18667	3.36541	0		7.18679	3.36612	0
2	7.18641	3.36331	277		7.18687	3.36662	75
3	7.18664	3.36284	353		7.18678	3.36749	125
4	7.18677	3.36163	420		7.18673	3.36796	189
5	7.18647	3.36062	559		7.18665	3.36849	268
6	7.18766	3.35909	648		7.18672	3.36908	396
7	7.18781	3.35825	783		7.18693	3.36995	428
8	7.18752	3.35825	866		7.1873	3.37064	506

9	7.18751	3.3578	917		7.18768	3.37122	610
10	7.18761	3.35678	1040		7.18798	3.37182	780

Determination of Air Quality Index (AQI)

The Equation (1) was utilized to determine the air quality index [16]. The pollutant concentrations were used to determine the two breakpoints and the corresponding AQI for each breakpoint. The data were then used to determine the AQI index of the pollutants and values obtained was rounded up to the nearest integer.

$$I_p = \left(\frac{\mathrm{IHi} - \mathrm{IHo}}{BPHi - BPLo}\right) * (\mathrm{Cp} - \mathrm{BPLo}) + \mathrm{IHo} \quad (1)$$

Where;

Ip = the index for pollutant p

Cp = the rounded concentration of pollutant p

BPHi = the breakpoint which is greater than or equal to Cp

BPLo = the breakpoint less than or equal to Cp

IHi = the AQI value corresponding to BPHi

ILo = the AQI value corresponding to BPLo

Pollutant Mapping

The levels of concentration at each specific location were visualized using ArcGIS software version 10.7.1. This software facilitated the integration of spatial data on air pollutants collected from various sampling points situated within the Saje dumpsite and the surrounding areas in Abeokuta. These data were utilized as input variables, and the software analyzed graphical representation, generating curves or contours reflecting the levels of air pollutants. The interpolation method employed for creating a spatial model of air pollutants was inverse distance weighted (IDW).

RESULTS AND DISCUSSION

Air quality index (AQI) for the study area

The study focused on three primary air pollutants; $PM_{2.5}$, PM_{10}, and CO whose concentration levels fell within the standard categories of the Air Quality Index (AQI) rating. The AQI concentration of $PM_{2.5}$ at the dumpsite ranged between 180 – 320 and 161 – 187 μg/m^3 for dry and wet seasons, respectively. This indicated that the AQI categories span from very unhealthy (associated with breathing discomfort, suffocation, airway irritation, etc) to hazardous conditions that can significantly worsen heart and lung diseases, leading to premature mortality in individuals with such conditions. Moreover, there are serious risks of respiratory effects for the general population, and health warnings may be issued for emergency conditions [16]. At the residential areas, the $PM_{2.5}$ AQI concentration ranges from 54 – 123 and 42 – 119 $\mu g/m^3$ for dry and wet seasons, respectively. The AQI categories ranged from moderate to unhealthy for sensitive groups. In moderate AQI category, some people may experience discomfort and for sensitive groups such as young and old people and in most cases, asthmatic patients may experience breathing difficulties.

The concentration of PM_{10} at the dumpsite, as measured by the AQI during the dry and wet seasons, varies between 89 – 179 and 64 – 92 $\mu g/m^3$, respectively. The AQI categories falls within the range of good to unhealthy for sensitive groups, indicating no significant health risks, though there could be potential discomfort for individuals in the unhealthy category. In residential areas, AQI concentrations for PM_{10} range from 21 – 71 in the dry season and 11 – 45 $\mu g/m^3$ in the wet season. Most locations in the residential areas show air quality ranging from good to moderate, which does not pose a health threat to individuals exposed to these pollutants. The CO AQI categories for all sampling points during the dry (0 – 9 ppm) and wet (0 – 28 ppm) seasons are categorized as good and do not pose a health risk. However, at the dumpsite (14 – 169 ppm in the dry season and 6 – 76 ppm in the wet season), the air quality index is unhealthy, which could cause breathing difficulties for sensitive groups like asthmatic patients, and the elderly and young.

Spatial Distribution of the Air Quality Index

Particulate Matter ($PM_{2.5}$) for Dry Season

The concentration of $PM_{2.5}$ pollutants during the dry season as shown in Figure 2 shows a high concentration at the dumpsite and also at the residential locations near the dumpsite towards the western transverse (the Labaiwa community). This shows that, the concentration of $PM_{2.5}$ propagates towards the western and southwestern transverse in the study area. There is also a moderate concentration of the pollutant towards the northern transverse and a very low concentration propagation at the eastern transverse. Those living at the western and southern transverse are at risk of health related issues which is related with $PM_{2.5}$. Breathing difficulty, discomfort and airway irritation will be very common in this area. At the eastern transverse, there is no significant health threat which is related to $PM_{2.5}$ during the dry season. Suffocation might be experience with those on the dumpsite due to high concentrations of the pollutants if proper safety gadgets are not used.

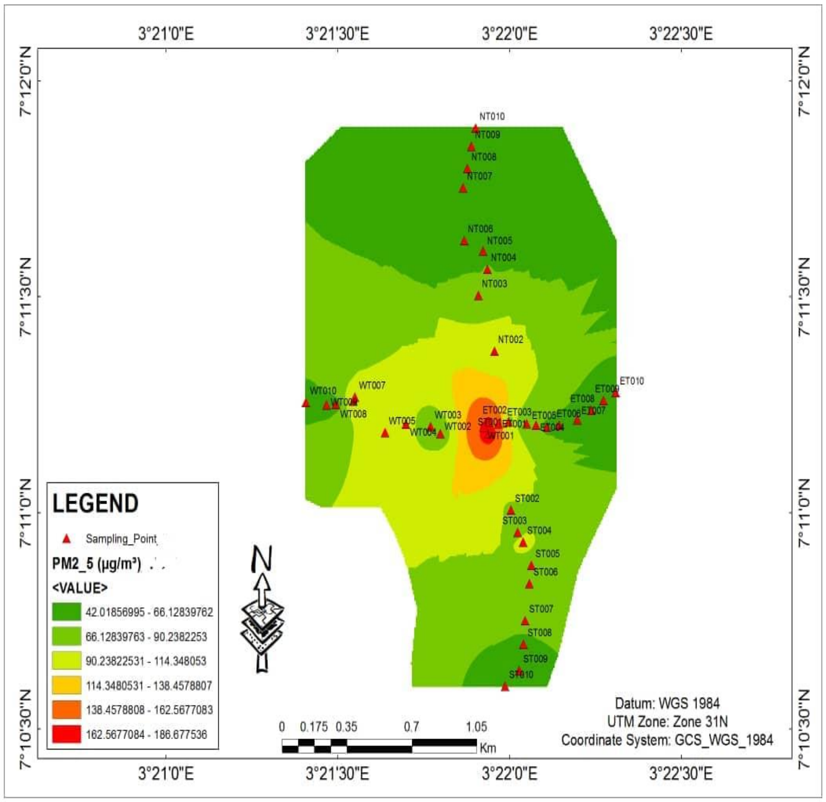

Figure 2: Spatial distribution of $PM_{2.5}$ during the dry season

Particulate Matter ($PM_{2.5}$) for Wet Season

High concentration of $PM_{2.5}$ can be observed at the dumpsite and also at some locations in the western transverse during the wet season as shown in Figure 3. These locations are very near the dumpsite towards the Labaiwa community. There is a dispersion of $PM_{2.5}$ concentrations towards the eastern transverse of the Elega housing estate area. Majority of the locations at the Olobi community and Oke-Aregba area which is at the northern and Southern transverse respectively have a very low concentrations of $PM_{2.5}$ which have a little or no effects of health implication related to the $PM_{2.5}$. Discomfort and breathing difficulty might be experience at the eastern, some part of the western and southern transverses in which $PM_{2.5}$ propagate during the wet season. The people on the dumpsite need to be using safety gadgets regularly in order to prevent suffocation which is related to high concentration of these pollutants.

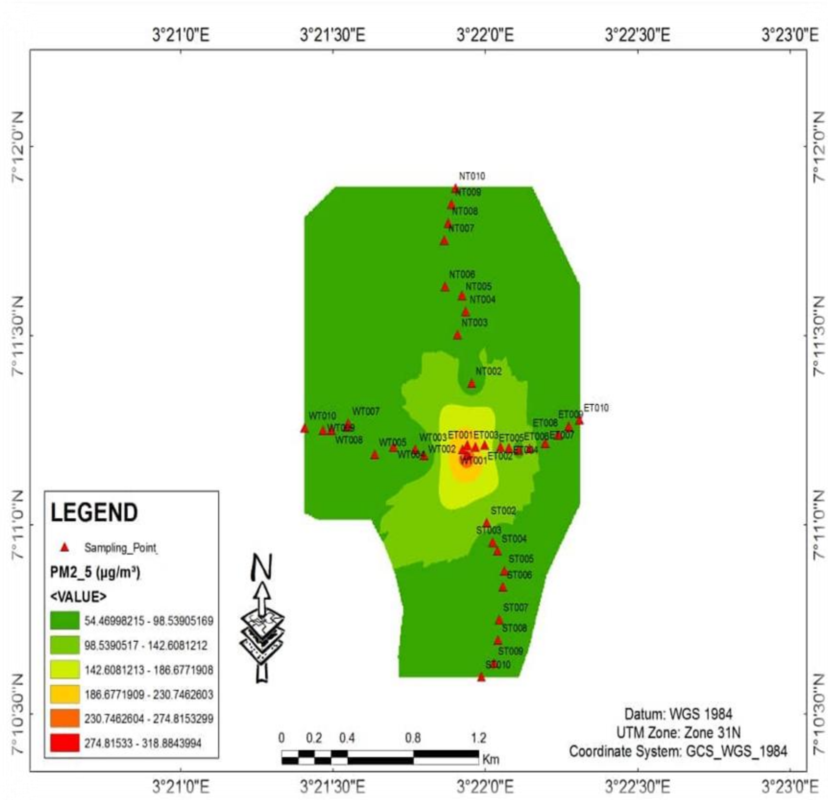

Figure 3: Spatial distribution of $PM_{2.5}$ during the wet season

Particulate Matter (PM_{10}) for Dry Season

As shown in Figure 4, high concentration of PM_{10} can be observed at the dumpsite which dispersed majorly towards the western and southern transverse within the study area. The people living in this areas are at high risks of health issues such as breathing difficulty, airway irritation and suffocation in case of very high concentration of the pollutants. Those at the northern transverse might also experience slight irritation and odor from the dumpsite.

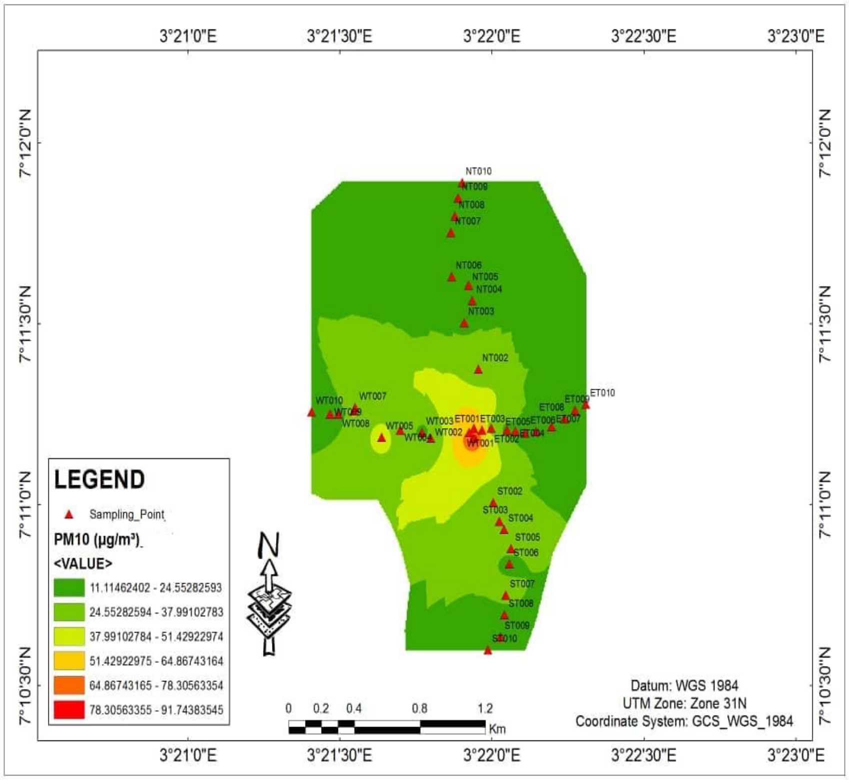

Figure 4: Spatial distribution of PM_{10} during the dry season

Particulate Matter (PM_{10}) for Wet Season

During the wet season sampling as shown in Figure 5, the dispersion of PM_{10} from the dumpsite are through the southwestern direction. The locations within the dumpsite show a high concentration. Those living at the northern, southern and eastern transverse might have a slight breathing difficulty, airway irritation and other health issues related to PM_{10}. Most of the locations in the western transverse had a low concentration of PM_{10} with corresponding low health issues related to PM_{10} during the wet season.

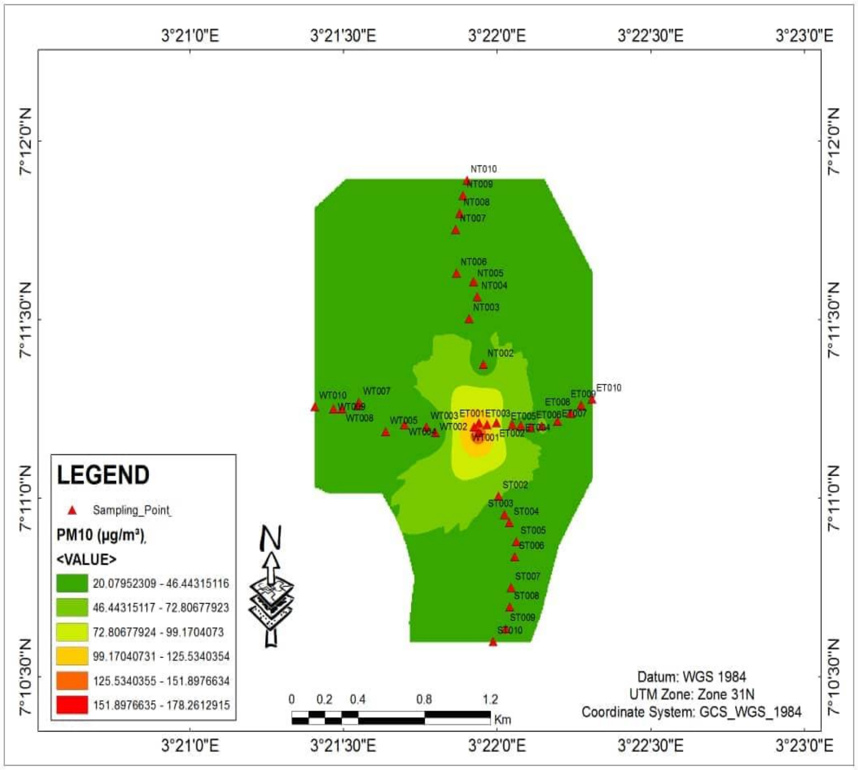

Figure 5: Spatial distribution of PM_{10} during the wet season

Carbon dioxide (CO) for Dry and Wet Season

The concentration of CO at all the sampling locations for both dry and wet seasons are relatively low except at the dumpsite which has a slightly higher concentration than the other locations. It was observed that, there were burning activities at the dumpsite which cause a higher concentration at the dumpsite than the other locations which might have filtered off during propagation. There is a low or no health issue related to CO effects on the human population within the study area. Figures 6 and 7 showed the spatial distribution of carbon dioxide (CO) for dry and wet seasons respectively.

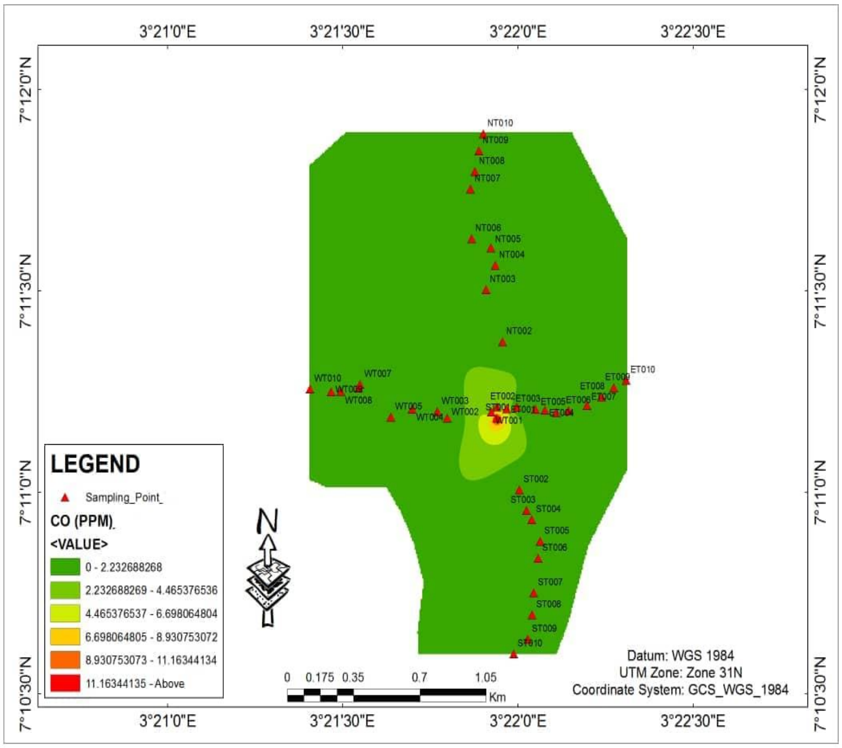

Figure 6: Spatial distribution of CO during the dry season

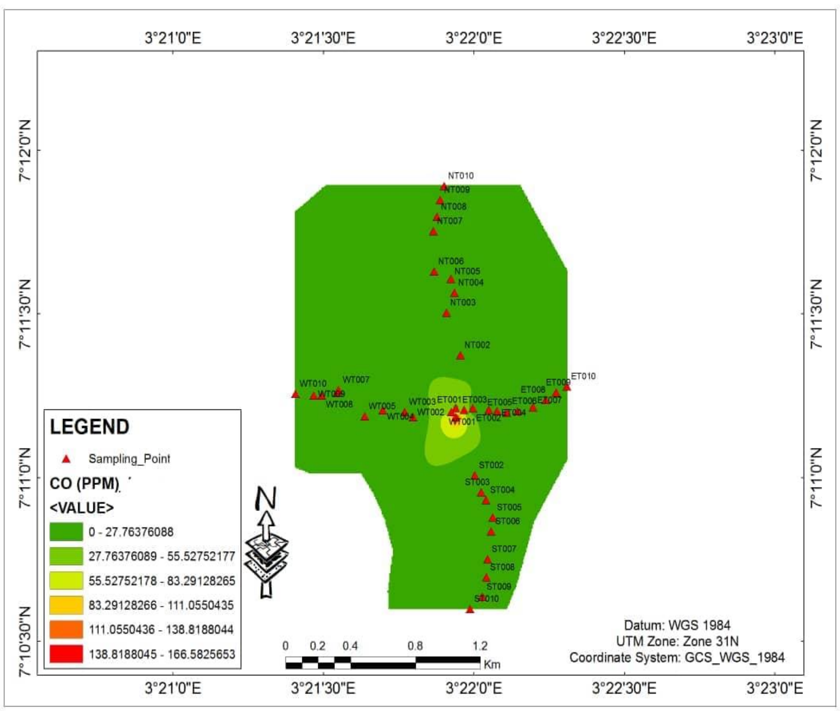

Figure 7: Spatial distribution of CO during the wet season

CONCLUSION

The air quality index (AQI) rating and its corresponding health related effects categories for particulate matter ($PM_{2.5}$ and PM_{10}) and carbon monoxide (CO) were determined to know the impacts of these pollutants on the human population. The particulate matte ($PM_{2.5}$) during the dry and wet season sampling have a moderate AQI category in most of the locations in the residential area and are unhealthy to sensitive groups. The AQI rating of $PM_{2.5}$ at the dumpsite is high and the health effect is hazardous to the people who are exposed to the particulate matters ($PM_{2.5}$). The PM_{10} and CO AQI categories for both dry and wet seasons shows a good rating with little or no health effects to those who are exposed to these pollutants except at the dumpsite where the AQI rating is high and are unhealthy for sensitive groups. The spatial distribution models shows higher air quality concentration at the dumpsite than the residential area. The distribution towards the residential area is highly visible during the dry seasons compared to the wet season. Continuous monitoring of the air quality near an operational dumpsite should be a top priority to prevent harmful air pollution and ensure the safety of residents.

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