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# PRELIMINARY ASSESSMENT OF PARTICULATE MATTER ($PM_{2.5}$ AND $PM_{10}$) POLLUTION AND AIR QUALITY OF GEO-REFERENCED OUTDOOR LOCATIONS IN A TERTIARY INSTITUTIONAL PREMISES LOCATED IN BENIN CITY, MID-WESTERN NIGERIA

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**Abstract**
*Particulate matter ($PM_{2.5}$ and $PM_{10}$) concentrations for twenty (20) geo referenced locations within the University of Benin Ekehuan Campus located in Benin city were obtained with the aid of a PM meter. The sampling points were visited once weekly for four weeks in the month of February 2024. The respective PM data sets were subjected to one-way analysis of variance test using relevant statistical software. Spatial PM maps were developed for the study area using the inverse distance weighting (IDW) interpolation procedure. Weekly $PM_{2.5}$ mean values for week 1 ranged from 61 ± 3 to 107 µg/m$^3$ ± 2.6. Weekly $PM_{10}$ mean values for week 1 ranged from 91 ± 1 to 134 µg/m$^3$ ± 2.5. Weekly AQI derived from $PM_{2.5}$ mean values ranged from 155 to 187 for Week 1 and 155 to 186 for week 4 respectively. For the respective $PM_{2.5}$ and $PM_{10}$ data sets, the observed differences were significant at P >0.05. Comparatively, the observed $PM_{10}$ levels were generally higher than the $PM_{2.5}$ concentrations in majority of the visited areas. With respect to $PM_{2.5}$ derived AQI data, the air quality of the study area was classified unhealthy for the residents and institutional workers respectively. It is suggested that studies focusing on the drafting and implementation of likely intervention measures targeting a reduction in the PM levels especially at the respective sources within the campus should be undertaken.*

**Key Words**: Air *quality, Air quality index, Ekehuan campus, Spatial map, Particulate matter*

## Introduction

Ambient particulate matter refers to a mixture of solid and liquid particles found in the atmosphere. The composition of these particles varies based on location and time (Adams *et al.,* 2015). Such variations are influenced by different sources of pollutants, which are typically categorized as either natural or anthropogenic. Natural sources include phenomena like wind and wildfires, whereas anthropogenic sources consist of emissions from vehicles and power generation facilities (Chen *et al*., 2017; Mukherjee and Agrawal, 2017). Interactions among airborne particulate matter result in the formation of secondary particles, which contribute to the total concentration of particulate matter in the atmosphere. The levels of particulate matter in a given area are influenced by various factors, such as seasonal changes, weather conditions, geographical features, and the emission of gaseous pollutants (Munjal *et al*., 2022). There are two main categories of particulate matter linked to environmental and health issues - $PM_{2.5}$ and $PM_{10}$. $PM_{2.5}$ covers particulates with diameters below 2.5 µm, while $PM_{10}$ are those with a diameter of 10 µm (Barzeghar *et al.,* 2020).

Particulate matter is a well-recognized element of smog. Due to its small size and large surface area, these particles can easily move and act as carriers for various harmful substances that can bypass filtration by nasal hairs, allowing them to enter the respiratory system. Once in the respiratory tract, particulate matter is known to gather and harm multiple body parts through gas exchange in the lungs (Thompson, 2018). In the lungs, the accumulation of particulate matter activates inflammatory cells, which leads to the release of mediators and the stimulation of alveolar receptors. This cascade of events is known to cause an imbalance of the autonomic nervous system as well as the neuroendocrine pathway (Bandyopadhyay, 2016). Increased levels of particulate matter (PM) are linked to cardiovascular issues, including chronic obstructive pulmonary disease (COPD), asthma, and lung cancer. Children, the elderly, and those with pre-existing health conditions are particularly vulnerable to the effects of PM (Bevan *et al*., 2021). Due to these negative health impacts, it has become essential to monitor airborne PM pollution, employing various methods for this purpose (Mukherjee and Agrawal, 2017).

Mapping the spatial distribution of particulate matter (PM) concentrations can aid in the identification of pollution hotspots, understand the sources of PM, and assess exposure levels and associated health risks. Additionally, mapping PM levels is valuable for informing urban planning decisions and evaluating the effectiveness of pollution control measures (Brown and Kytta, 2018). This preliminary study focused on analyzing the spatial distribution of $PM_{2.5}$ and $PM_{10}$ at the Ekehuan Campus of the University of Benin in Benin City, Nigeria.

***Study Area***

The University of Benin was founded in 1970. The University of Benin currently operates two campuses, the Ekehuan campus and Ugbowo campus which is the study area for this study. The Ekehuan campus lies at latitude 6°20’14” N, longitude 4°36’41” E. The campus is home to various departments including the Departments of Mass Communication, Fine and Applied Arts, Theatre arts, the Institute of Education and the Institute of Public Administration and Extension services. It also hosts the sachet water factory of the University, a student health centre, a mosque, a radio broadcasting studio and the optometry teaching clinic. A map of the study area is shown in Fig. 1.

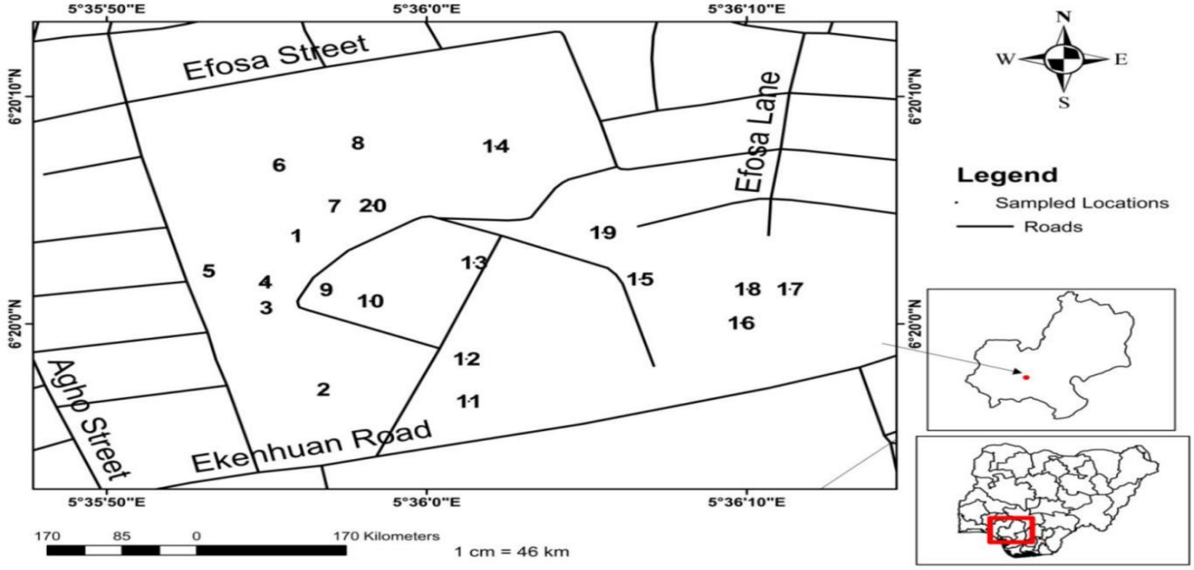


Fig. 1: Location map of Ekehuan campus

## Materials and Methods

### *Data Collection*

Outdoor sampling points were selected with the aid of ARCGIS 10.8 to generate random sampling locations within the Ekehuan campus. These points were visited once weekly for a period of 4 weeks in February 2024 and the respective $PM_{2.5}$ and $PM_{10}$ values were collected using a PM meter (Smart sensor model AS8700A). The PM values at each sampling point was collected in triplicates and the mean value was derived from the respective triplicate value sets

### *Air Quality Index (AQI) Determination*

The AQI values for $PM_{2.5}$ and $PM_{10}$ were calculated using the online AQI calculator hosted on the AirNow.gov official website. The AQI values obtained were rated based on the ratings in Table 1 below.

Table 1: AQI level ratings

| AQI | Health concern level | Air pollution level |
|---|---|---|
| 0 - 50 | Good | Level 1 |
| 51- 100 | Moderate | Level 2 |
| 101 - 150 | Unhealthy for sensitive groups | Level 3 |
| 151 - 200 | Unhealthy | Level 4 |
| 201 -300 | Very Unhealthy | Level 5 |
| 300 and above | Hazardous | Level 6 |

### *Spatial PM Mapping of Study Area*

To ascertain the spatial patterns of PM concentrations within the Ekehuan campus, an application of the inverse distance weighting (IDW) interpolation technique in ArcGIS 10.8 was used. The IDW technique can serve the purpose of predicting values at locations where measurements were not taken, relying on the information from neighbouring sampled locations (Li *et al.,* 2014). This technique operates under the assumption that the impact of PM concentrations at a specific site is primarily determined by its proximity to surrounding locations, as opposed to distant ones. Essentially, the closer a sample point is to the target location, the more significant its influence becomes in determining the estimated value of PM concentration at that particular site.

The PM concentrations data recorded from the study area were imported into the ArcGIS software environment where it was analysed by projecting to a convenient coordinate reference system and more in-depth analysis performed. The data was subjected to Kriging analysis using the using the arc toolbox, clipped to the study area and symbology was used to present the data in a presentable and colourful manner using appropriate colour ramps. After analysis, the maps were completed and exported in appropriate formats.

***Data analysis***

Each set of the mean $PM_{2.5}$ and $PM_{10}$ values were subjected to one-way ANOVA test using SPSS version 21. The tests were conducted at 95% probability level.

**RESULTS**

***Mean PM concentrations***

The weekly concentrations of $PM_{2.5}$ and $PM_{10}$ recorded from the study area are presented in Table 3. Weekly $PM_{2.5}$ mean values ranged as follows: Week 1 - 61µg/m$^3$ ± 3 (Location 11) to 107µg/m$^3$ ± 2.6(Location 17); Week 2 – 60 µg/m$^3$ ± 1.2 (Location 11) to 92 µg/m$^3$ ± 1 (Location 17); Week 3 – 60 µg/m$^3$ ± 1 (Location 11) to 102 µg/m$^3$ ± 0.6 (Location 1) and Week 4 – 61 µg/m$^3$ ± 1.5 (Location 11) to 106 µg/m$^3$ ± 1.5 (Location 1). Weekly $PM_{10}$ mean values ranged as follows: Week 1 - 91µg/m$^3$ ± 1 (Location 20) to 134µg/m$^3$ ± 2.5 (Location 17); Week 2 - 94µg/m$^3$ ± 0.6 (Location 15) to 126µg/m$^3$ ± 1 (Location 19); Week 3 - 99µg/m$^3$ ± 1 (Location 10) to 134µg/m$^3$ ± 1.5 (Location 1) and Week 4 - 98µg/m$^3$ ± 1 (Location 13) to 139µg/m$^3$ ± 1.5 (Location 1).

For the $PM_{2.5}$ data set, the observed differences were significant at $p > 0.05$. The grouped mean $PM_{2.5}$ values which caused the difference included; locations 20, 15,14, 13, 7, 10, 8, 6, 18, 12, 19, 5, 16, 2, 9, 3, 4, 1 and 17 respectively. For the $PM_{10}$ data set, the observed differences were significant at $p > 0.05$. The grouped mean $PM_{10}$ values which were responsible for the difference included; locations 13, 15, 14, 11, 12, 9,10, 18, 2, 16, 3 and 17 respectively.

Table 3: $PM_{2.5}$ and $PM_{10}$ concentrations for the respective outdoor locations visited in February, 2024

| Sampled locations | Mean value µg/m³ ± Std. deviation | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $PM_{2.5}$ | | | | $PM_{10}$ | | | |
| | Week 1 | Week 2 | Week 3 | Week 4 | Week 1 | Week 2 | Week 3 | Week 4 |
| **Location 1** | 104 ± 0.6 | 75 ± 1.5 | 102 ± 0.6 | 106 ± 1.5 | 131 ± 1 | 96 ± 1.5 | 134 ± 0.6 | 139 ± 1.5 |
| **Location 2** | 96 ± 1 | 72 ± 1 | 91 ± 1 | 93 ± 2 | 117 ± 1.2 | 94 ± 1 | 115 ± 1.2 | 114 ± 0.6 |
| **Location 3** | 99 ± 1.5 | 74 ± 1.5 | 96 ± 2 | 97 ± 1.5 | 125 ± 2.1 | 95 ± 1.2 | 118 ± 1.5 | 114 ± 1.1 |
| **Location 4** | 101 ± 2.1 | 74 ± 1.5 | 98 ± 1 | 99 ± 2 | 124 ± 1 | 96 ± 1.5 | 124 ± 1 | 119 ± 1.2 |
| **Location 5** | 85 ± 2.1 | 90 ± 1 | 85 ± 1 | 81 ± 1.5 | 110 ± 1 | 115 ± 1 | 119 ± 0.6 | 120 ± 1 |
| **Location 6** | 81 ± 1 | 96 ± 1.5 | 80 ± 1.5 | 77 ± 1.5 | 103 ± 1.5 | 124 ± 1 | 128 ± 0.6 | 129 ± 1.5 |
| **Location 7** | 75 ± 2.1 | 89 ± 1.5 | 74 ± 1 | 73 ± 1.5 | 97 ± 1.5 | 115 ± 1.5 | 123 ± 1 | 126 ± 1 |
| **Location 8** | 85 ± 2.1 | 83 ± 1 | 76 ± 1.5 | 83 ± 1.5 | 130 ± 1.5 | 107 ± 1 | 107 ± 1 | 110 ± 1.5 |
| **Location 9** | 100 ± 2.1 | 83 ± 1.2 | 82 ± 1.2 | 97 ± 1.5 | 96 ± 1 | 109 ± 1.5 | 107 ± 1.5 | 109 ± 1 |
| **Location 10** | 82 ± 2.1 | 81 ± 1.5 | 81 ± 1 | 81 ± 2.5 | 104 ± 0.6 | 101 ± 1 | 99 ± 1 | 129 ± 1 |
| **Location 11** | 61 ± 3 | 60 ± 1.2 | 60 ± 1 | 61 ± 1.5 | 102 ± 2 | 95 ± 1.5 | 105 ± 1.2 | 106 ± 1.5 |
| **Location 12** | 86 ± 2.1 | 75 ± 1 | 87 ± 1.2 | 87 ± 0.6 | 113 ± 1.5 | 96 ± 1 | 102 ± 1.5 | 102 ± 1.2 |
| **Location 13** | 76 ± 1.7 | 76 ± 0.6 | 77 ± 1 | 74 ± 1 | 101 ± 1.5 | 96 ± 1.5 | 102 ± 1.5 | 98 ± 1 |
| **Location 14** | 73 ± 1.5 | 74 ± 1 | 75 ± 1 | 72 ± 1.2 | 96 ± 2.1 | 98 ± 1.5 | 98 ± 1.5 | 108 ± 0.6 |
| **Location 15** | 73 ± 1.5 | 76 ± 1.2 | 72 ± 1 | 72 ± 1.5 | 94 ± 1 | 94 ± 0.6 | 106 ± 1 | 105 ± 0.6 |
| **Location 16** | 88 ± 1 | 81 ± 1 | 90 ± 0.6 | 90 ± 1.5 | 109 ± 0.6 | 103 ± 1.5 | 104 ± 1.5 | 126 ± 1.2 |
| **Location 17** | 107 ± 2.6 | 92 ± 1 | 101 ± 1.5 | 101 ± 1 | 134 ± 2.5 | 99 ± 1.5 | 110 ± 1 | 114 ± 1 |
| **Location 18** | 83 ± 2 | 86 ± 1.5 | 83 ± 1 | 82 ± 1.5 | 107 ± 1.5 | 107 ± 1.2 | 109 ± 1 | 110 ± 1.5 |
| **Location 19** | 84 ± 1.5 | 99 ± 1.5 | 78 ± 1.5 | 79 ± 0.6 | 107 ± 1.2 | 126 ± 1 | 131 ± 1 | 132 ± 1 |
| **Location 20** | 71 ± 1.5 | 77 ± 1 | 69 ± 1 | 70 ± 1.5 | 91 ± 1 | 98 ± 1.5 | 100 ± 0.6 | 102 ± 1 |

**KEY**: Location 1 - Football field; Location 2 - Lawn tennis; Location 3 - Optometry teaching clinic; Location 4 - Institute of Public Administration; Location 5 - Department of Fine Art; Location 6 - Institute of Education; Location 7 - Ceramic studio; Location 8 - Mass Communication Broadcasting Studio; Location 9 - Department of Mass Communication; Location 10 - NASU Centre; Location 11 - Health Centre; Location 12 - Pure water factory; Location 13 - Mosque; Location 14 - Library Annex; Location 15 - Sub-Library; Location 16 - Senior Staff Club; Location 17 - Nelson Mandela Hostel; Location 18 - NAFAS Secretariat; Location 19 - Department of Education; Location 20 - Lecture theatre.

***Spatial PM maps of the study area***

The PM maps of the study area are shown in Figures 3 to 6 ($PM_{2.5}$) and 7 to 10 ($PM_{10}$). It was observed that at week 1, the western sections of the campus had elevated $PM_{2.5}$ levels and this section had a greater concentration of sampled sites (Fig. 3). However, for week 2, there was a decline in the areal size of the mapped section having elevated $PM_{2.5}$ levels (Fig. 4). The decline was reversed at week 3 as observed in the coloured areal sections of the western and northwestern area of the spatial map (Fig. 5). The spatial map created for the visited sampling sites in the last week of February revealed lowered $PM_{2.5}$ values across the mapped study area.

A greater section of the spatially mapped study area had lower $PM_{10}$ values as presented in Fig. 7. The trend was also observed in the map shown in Fig.8. However, for maps created for week 3 and 4 respectively, greater areal sized sections within the respective maps had elevated $PM_{10}$ levels (Fig. 9 and 10).

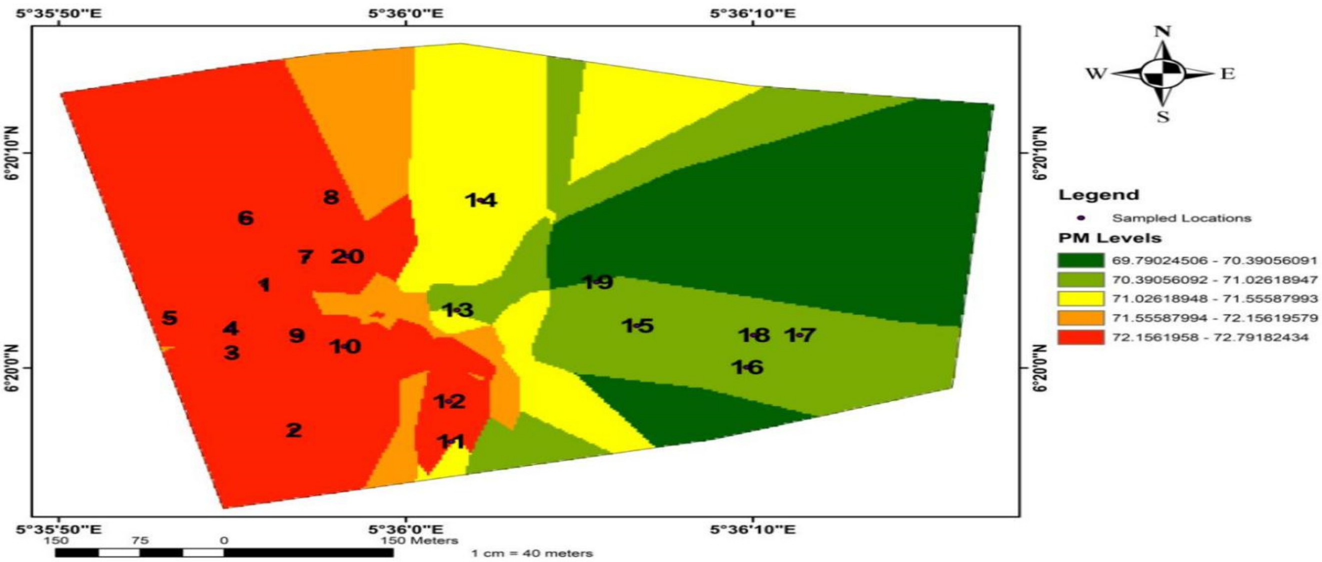


Fig. 3: PM$_{2.5}$ map for Week 1

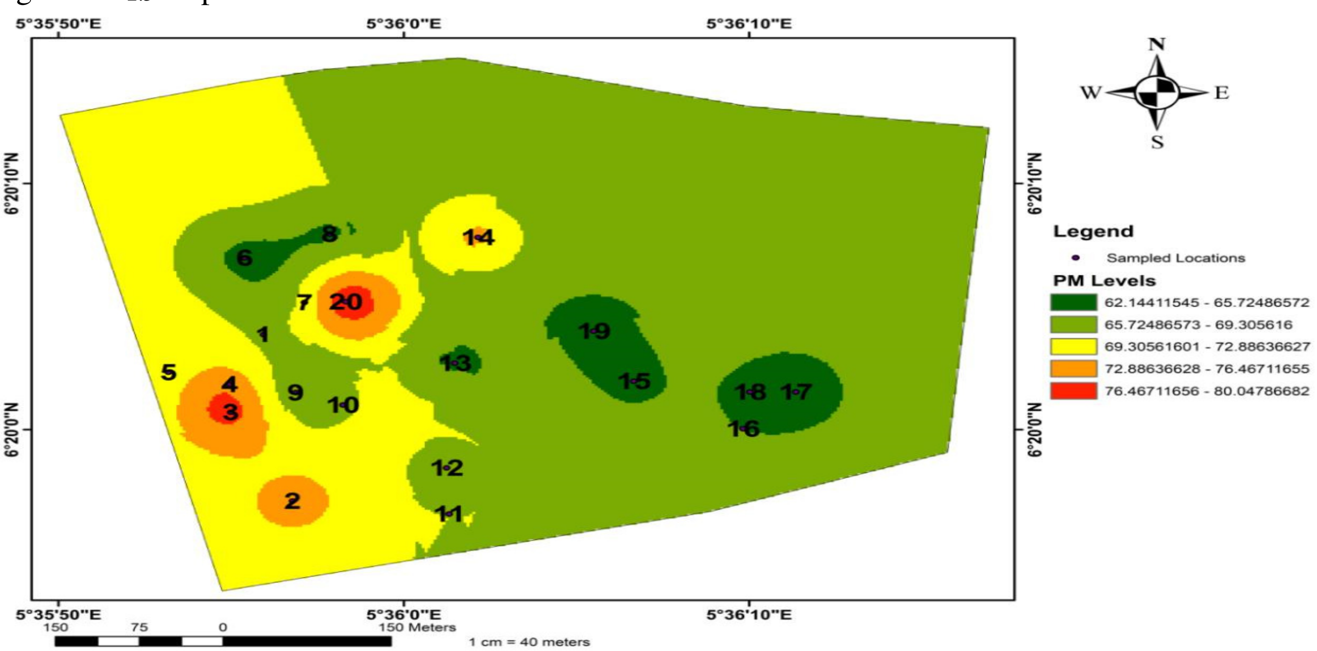


Fig. 4: PM$_{2.5}$ map for Week 2

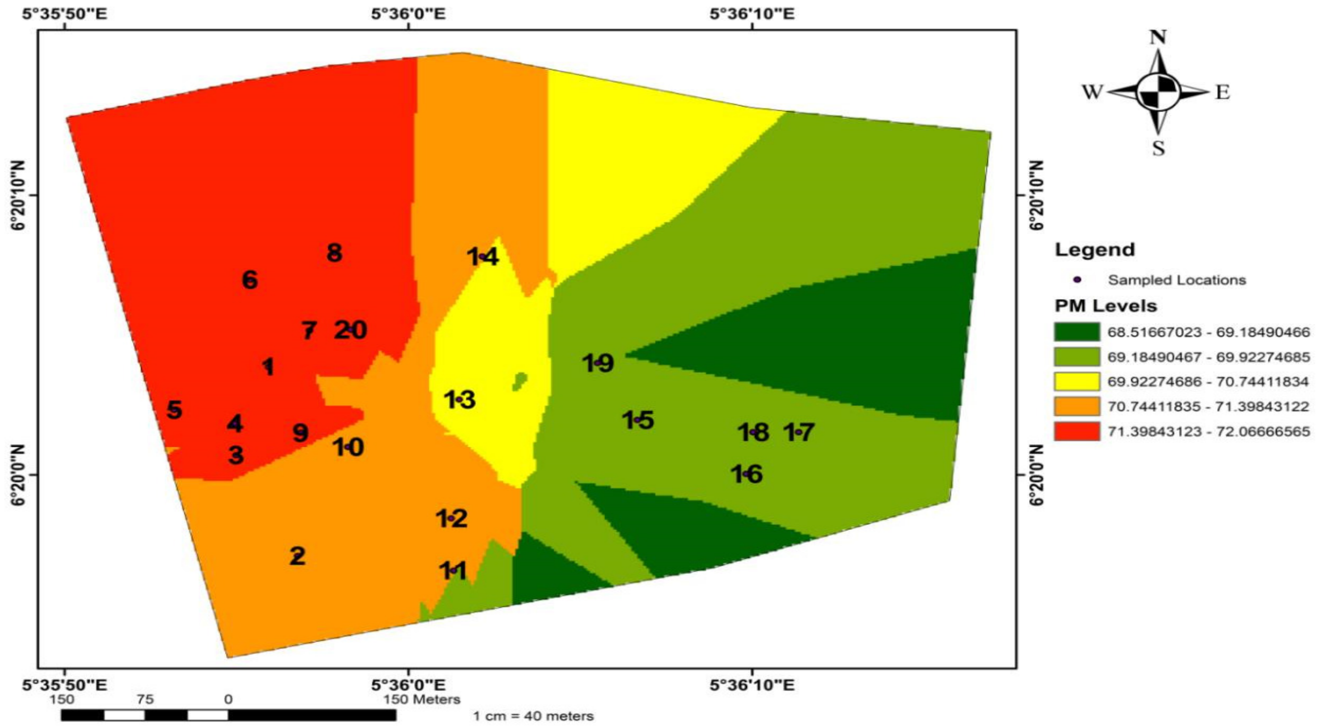


Fig. 5: $PM_{2.5}$ map for Week 3

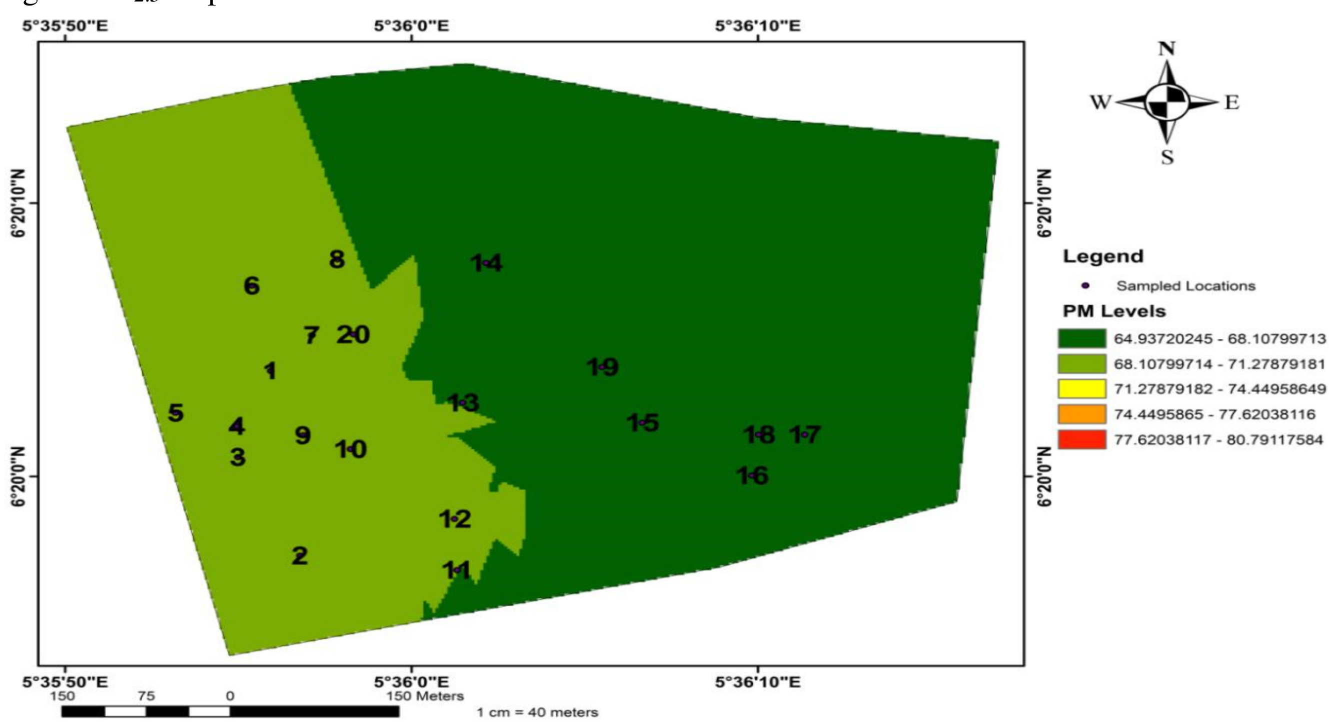


Fig. 6: $PM_{2.5}$ map for Week 4

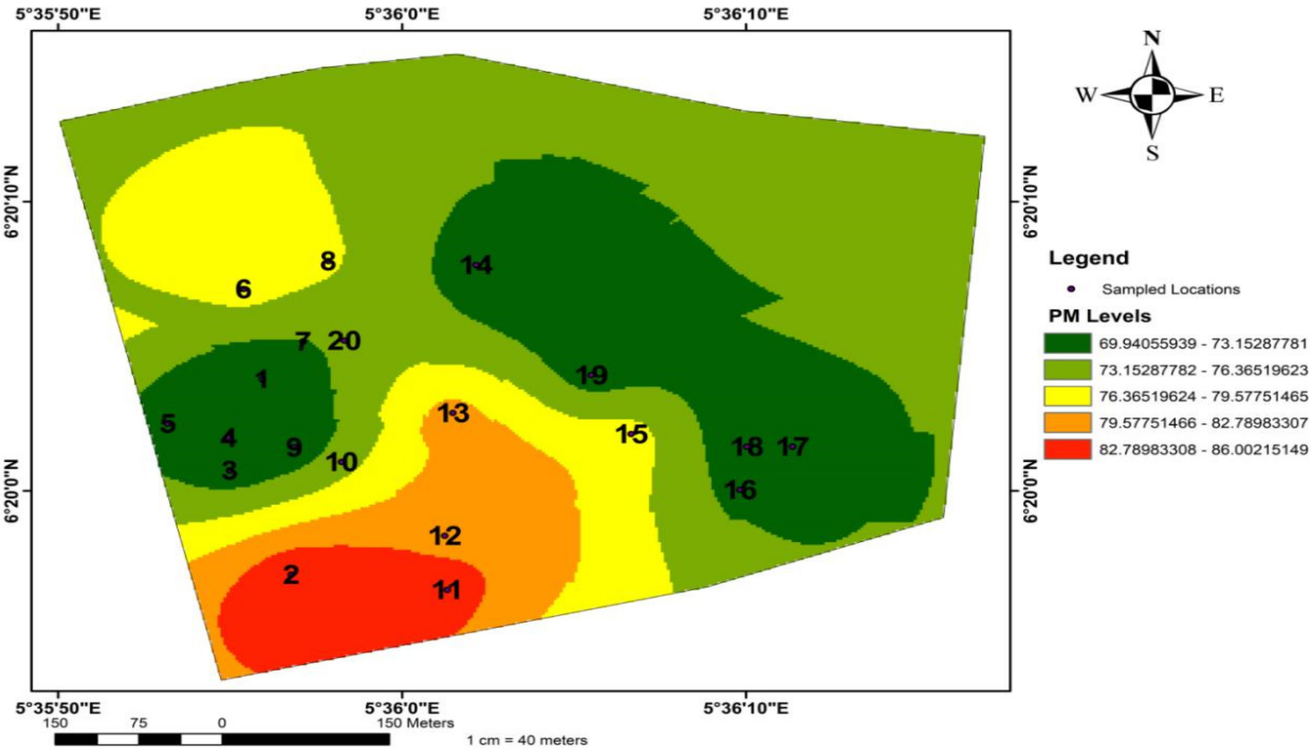


Fig. 7: $PM_{10}$ map for Week 1

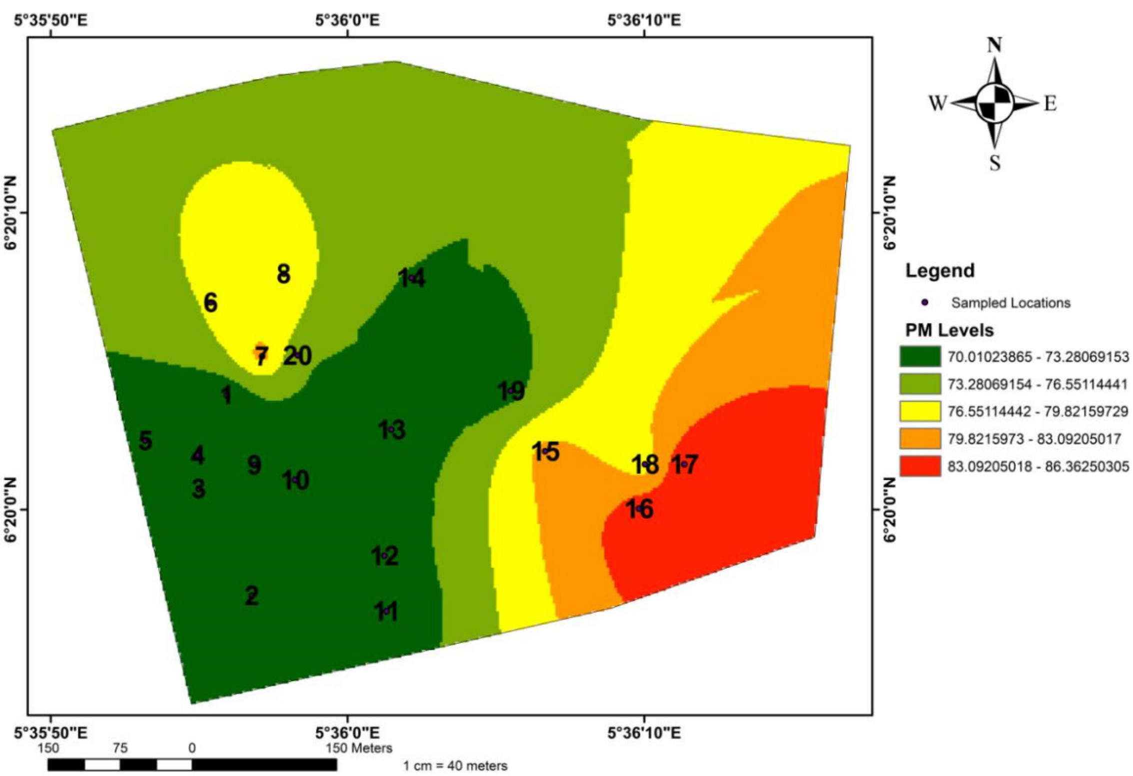


Fig. 8: $PM_{10}$ map for Week 2

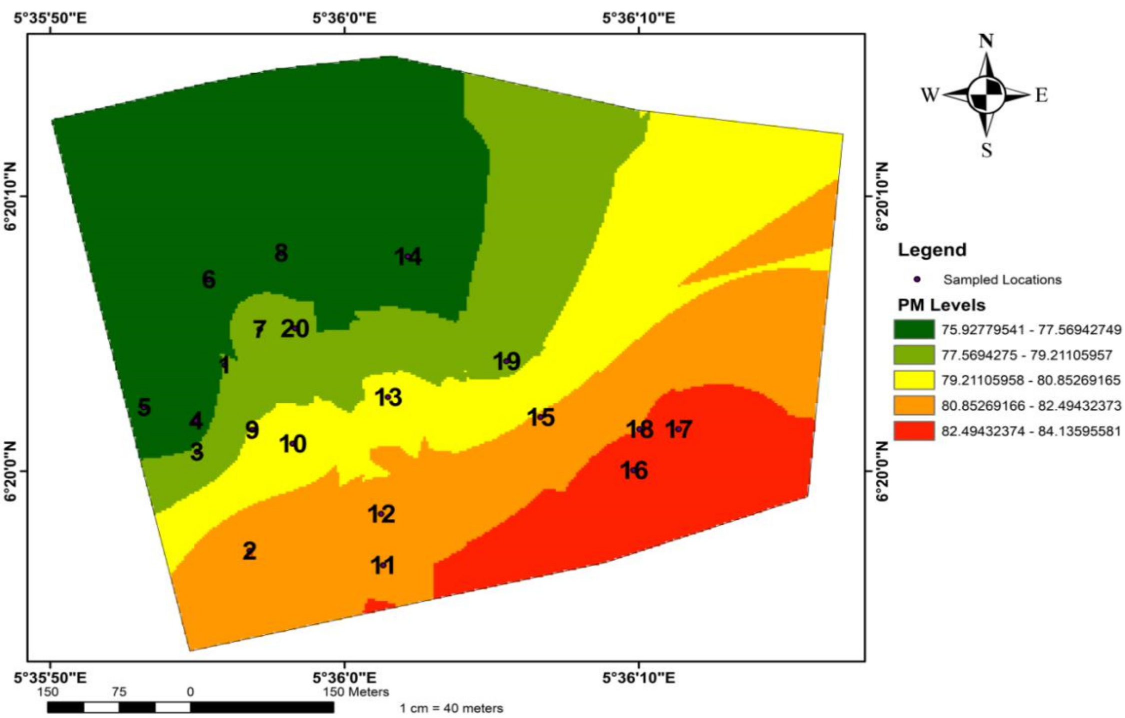


Fig. 9: $PM_{10}$ map for Week 3

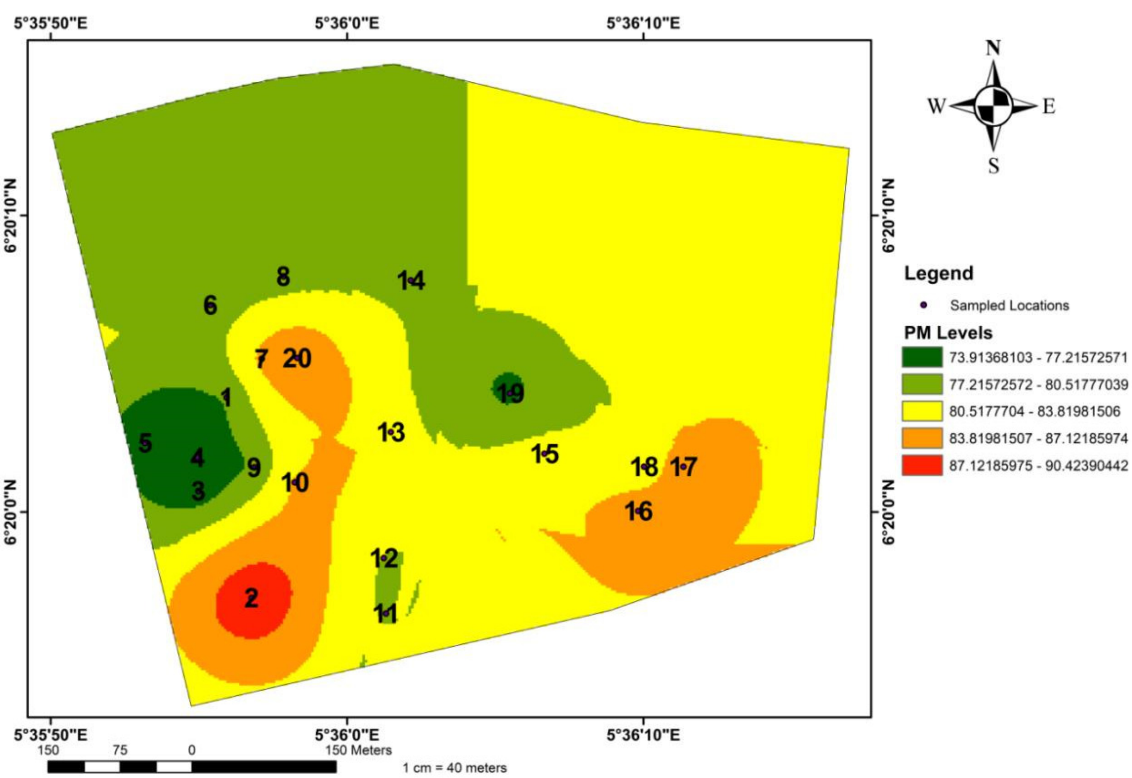


Fig. 10: $PM_{10}$ map for Week 4

***AQI Values***

Thee AQI values for particulate matter calculated in this study is presented in Table 4. The results showed that weekly AQI derived from $PM_{2.5}$ mean values ranged from 155 to 187 for Week 1, 157 to 179 for week 2, 154 to 184 for week 3, and 155 to 186 for week 4 respectively (Table 4). Weekly AQI derived from $PM_{10}$ values ranged from 71 to 91 for week 1, 70 to 86 for week 2, 70 to 90 for week 3, and 72 to 93 for week 4 respectively.

Table 4: AQI values for the study area

| Sampled locations | $PM_{2.5}$ | | | | $PM_{10}$ | | | |
|---|---|---|---|---|---|---|---|---|
| | Week 1 | Week 2 | Week 3 | Week 4 | Week 1 | Week 2 | Week 3 | Week 4 |
| **Location 1** | 185 | 165 | 184 | 186 | 89 | 71 | 90 | 93 |
| **Location 2** | 179 | 163 | 176 | 177 | 82 | 70 | 81 | 80 |
| **Location 3** | 181 | 164 | 179 | 180 | 86 | 71 | 82 | 80 |
| **Location 4** | 183 | 164 | 181 | 181 | 86 | 71 | 85 | 83 |
| **Location 5** | 172 | 175 | 172 | 169 | 78 | 81 | 83 | 83 |
| **Location 6** | 169 | 179 | 168 | 166 | 75 | 85 | 87 | 88 |
| **Location 7** | 165 | 174 | 164 | 163 | 72 | 81 | 85 | 86 |
| **Location 8** | 172 | 170 | 165 | 170 | 88 | 77 | 77 | 78 |
| **Location 9** | 182 | 170 | 169 | 180 | 71 | 78 | 77 | 78 |
| **Location 10** | 170 | 169 | 169 | 169 | 75 | 74 | 73 | 88 |
| **Location 11** | 155 | 154 | 154 | 155 | 74 | 71 | 76 | 76 |
| **Location 12** | 173 | 165 | 173 | 173 | 80 | 71 | 74 | 74 |
| **Location 13** | 165 | 165 | 166 | 164 | 74 | 71 | 74 | 72 |
| **Location 14** | 163 | 164 | 165 | 163 | 71 | 72 | 72 | 77 |
| **Location 15** | 163 | 165 | 163 | 163 | 70 | 70 | 76 | 76 |
| **Location 16** | 174 | 169 | 175 | 175 | 78 | 75 | 75 | 86 |
| **Location 17** | 187 | 177 | 183 | 183 | 90 | 73 | 78 | 80 |
| **Location 18** | 170 | 172 | 170 | 170 | 77 | 77 | 78 | 78 |
| **Location 19** | 171 | 181 | 167 | 167 | 77 | 86 | 89 | 89 |
| **Location 20** | 162 | 166 | 161 | 161 | 91 | 72 | 73 | 74 |

**KEY**: Location 1 - Football field; Location 2 - Lawn tennis; Location 3 - Optometry teaching clinic; Location 4 - Institute of Public Administration; Location 5 - Department of Fine Art; Location 6 - Institute of Education; Location 7 - Ceramic studio; Location 8 - Mass Communication Broadcasting Studio; Location 9 - Department of Mass Communication; Location 10 - NASU Centre; Location 11 - Health Centre; Location 12 - Pure water factory; Location 13 - Mosque; Location 14 - Library Annex; Location 15 - Sub-Library; Location 16 - Senior Staff Club; Location 17 - Nelson Mandela Hostel; Location 18 - NAFAS Secretariat; Location 19 - Department of Education; Location 20 - Lecture theatre.

## Discussion

Expectedly, differing mean $PM_{2.5}$ and $PM_{10}$ values were detected and spatially mapped across the visited sampling locations within the study area. Comparatively, the observed $PM_{10}$ levels were generally higher than the $PM_{2.5}$ concentrations in majority of the visited areas as indicated in Table 3 as well as Figures 3 to 10. The dominance of suspended $PM_{10}$ particles in the respective outdoor locations might be indicative of the widespread distribution of suspended naturally sourced particulate matter in the study area. However, it has been documented that several anthropogenic activities such as vehicular traffic and industrial emissions are also sources of $PM_{10}$ (Wang *et al.*, 2024). Possible sources of suspended particulate matter in the study area include transportation and associated emissions, erosion by wind as well as sports activities (Jubaer *et al.,* 2022). The World Health Organisation (2021) has recommended a limit of 25 and 45 µg/m$^3$ for $PM_{2.5}$ and $PM_{10}$ respectively with respect to ambient air. These standard values were exceeded in all the visited locations. Previous studies which focused on PM pollution within parts of Benin city have recorded PM values that vary widely. Eghomwanre *et al.* (2022) recorded maximum $PM_{2.5}$ and $PM_{10}$ concentrations of 85.9 µg/m$^3$ and 104.5 µg/m$^3$, respectively in Benin City. Ojeaga and Okoro (2023) reported $PM_{2.5}$ concentrations around a dumpsite in Benin City to range from 36.20 µg/m$^3$ to 393.82 µg/m$^3$. However, the results of this study were lower than those recorded by Balogun and Orimoogunje (2015) where $PM_{2.5}$ and $PM_{10}$ concentrations were 2810.39 µg/m$^3$ and 665.84 µg/m$^3$. The detection of elevated concentrations of particulate matter especially $PM_{10}$ in the study area can be regarded as a likely public health threat. A variety of adverse health effects have been attributed to the presence of particulate matter of these sizes in the atmosphere including cardiovascular disorders, lung infections and worsening of conditions such as asthma and chronic obstructive pulmonary disorders (Edlund *et al.*, 2022)

The observed AQI values for $PM_{2.5}$ were between the range of 150 - 200 which is rated as "Unhealthy". AQI values in this category are a health threat for individuals who are dealing with heart disease or respiratory problems. Other demographic groups vulnerable to this group of suspended PM include both the children and the elderly (Tibuakuu *et al.,* 2018). Common health impacts associated with exposure include worsening of lung/heart disease as well as premature deaths in individuals, while overall respiratory health burden may be increased for the general population (de Bont *et al.*, 2022). The AQI values derived from the respective $PM_{10}$ mean values were within the range of 50 - 100 which is rated as "Moderate". This category of AQI values indicates a moderate health risk due to exposure with individuals having respiratory conditions being at the most risk (Mukherjee and Agrawal, 2017). The range of AQI values presented in this study was similar to values earlier reported by Eghomwanre *et al.* (2022). However, the range of AQI data presented in this study was at variance with values reported by Lala *et al.* (2023) which documented ranges (65.13 - 927.07 and 73.51 - 256.65) respectively for AQI derived from $PM_{2.5}$ and $PM_{10}$. The values prove that adverse health impacts may be experienced in the study area due to exposure to particulate matter and indicate that protective measures are needed.

## Conclusion

Varying levels of mean $PM_{2.5}$ and $PM_{10}$ concentrations were detected in 20 outdoor location within the Ekehuan Campus of the University of Benin, Benin city. Spatial maps of these PM distributions within the campus were also created. AQI data directly derived from the respective PM concentrations was also generated. The study findings revealed that for the month of February 2024, elevated levels of PM especially $PM_{10}$ were detected in the sampled outdoor air corridors. However, with respect to $PM_{2.5}$ derived AQI data, the air quality of the study area was classified unhealthy for the residents and institutional workers respectively.

## Recommendations

It is recommended that further follow up studies pertaining to determining the magnitude of PM pollution in other months especially during the wet season should be conducted. It is also suggested that studies focusing on the drafting and implementation of likely intervention measures targeting a reduction in the PM levels especially at the respective sources within the campus should be undertaken. This recommendation is relevant given the likely health impact of continued exposure of vulnerable demographic groups residing or transiting through the campus to the poor and unhealthy outdoor air within the study area.

## References

Adams, K., Greenbaum, D.S., Shaikh, R., van Erp, A.M. and Russell, A.G. (2015). Particulate matter components, sources, and health: Systematic approaches to testing effects. *Journal of the Air and Waste Management Association*, 65(5): 544–558. https://doi.org/10.1080/10962247.2014.1001884.

Balogun, V.S. and Orimoogunje, O.O.I. (2015). An assessment of seasonal variation of air pollution in Benin City, Southern Nigeria. *Atmospheric and Climate Sciences*, 5(3): 209 - 218. DOI: 10.4236/acs.2015.53015.

Bandyopadhyay, A. (2016). Neurological disorders from ambient (urban) air pollution emphasizing UFPM and $PM_{2.5}$. *Current Pollution Report,* 2: 203-211, https://doi.org/10.1007/s40726-016-0039-z

Barzeghar, V., Sarbakhsh, P., Hassanvand, M.S., Faridi, S. and Gholampour, A. (2020). Long-term trend of ambient air $PM_{10}$, $PM_{2.5}$, and $O_3$ and their health effects in Tabriz city, Iran, during 2006–2017. *Sustainable Cities and Society*, 54: 101988. DOI: 10.1016/j.scs.2019.101988.

Bevan, G.H., Freedman, D.A., Lee, E.K., Rajagopalan, S. and Al-Kindi, S.G. (2021). Association between ambient air pollution and county-level cardiovascular mortality in the United States by social deprivation index. *American Heart Journal*, 235: 125-131. DOI: 10.1016/j.ahj.2021.02.005.

Brown, G. and Kyttä, M. (2018). Key issues and priorities in participatory mapping: Toward integration or increased specialization? *Applied Geography*, 95: 1-8. DOI: 10.1016/j.apgeog.2018.04.002

Chen, J., Li, C., Ristovski, Z., Milic, A., Gu, Y., Islam, M. S., Wang, S., Hao, J., Zhang, H., He, C., Guo, H., Fu, H., Miljevic, B., Morawska, L., Thai, P., Lam, F., Pereira, G., Ding, A., Huang, X. and Dumka, U.C. (2017). A review of biomass burning: Emissions and impacts on air quality, health and climate in China. *Science of Total Environment*, 579: 1000-1034. DOI: 10.1016/j.scitotenv.2016.11.025

de Bont, J., Jaganathan, S., Dahlquist, M., Persson, Å., Stafoggia, M. and Ljungman P. (2022). Ambient air pollution and cardiovascular diseases: An umbrella review of systematic reviews and meta-analyses. *Journal of Internal Medicine* 291(6): 779-800. doi: 10.1111/joim.13467.

Edlund, K., Sallsten, G., Molnar, P., Andersson, E., Ögren, M., Segersson, D., Fagman, E., Fagerberg, B., Barregard, L. and Bergström, G. (2022). Long-term exposure to air pollution, coronary artery calcification, and carotid artery plaques in the population-based Swedish SCAPIS Gothenburg cohort.

*Environmental Research*, *214*, 113 - 126. DOI: 10.1016/j.envres.2022.113926. DOI: 10.1016/j.envres.2022.113926

Eghomwanre, A.F., Oguntoke, O., Taiwo, A.M. and Ukpebor, E.E. (2022). Air pollutant concentrations and health risk assessment around residential areas in Benin City, Nigeria. *Journal of Materials and Environmental Science*, 13(9): 1081 - 1100.

Jubaer, A., Khorshed Ali, M., Mahmud Tanvir Hassan, S. and Zahirul-Talukder, M. (2022). Urban air pollution caused of particulate matter and lead in the city of Chittagong-Bangladesh. *American Journal of Environmental Science and Engineering* 6: 7 – 13. DOI: 10.11648/j.ajese.20220601.12.

Lala, M.A., Onwunzo, C.S., Adesina, O.A. and Sonibare, J.A. (2023). Particulate matters pollution in selected areas of Nigeria: Spatial analysis and risk assessment. *Case Studies in Chemical and Environmental Engineering*, 7: 100288. DOI: 10.1016/j.cscee.2022.100288.

Li, L., Losser, T., Yorke, C. and Piltner, R. (2014). Fast inverse distance weighting-based spatiotemporal interpolation: A web-based application of interpolating daily fine particulate matter $PM_{2.5}$ in the contiguous US using parallel programming and kd tree. *International Journal of Environmental Research and Public Health*, 11(9): 9101-9141. DOI: 10.3390/ijerph110909101.

Mukherjee, A. and Agrawal, M. (2017). World air particulate matter: sources, distribution and health effects. *Environmental Chemistry Letters*, 15: 283–309. DOI: 10.1007/s10311-017-0611-9.

Munjal, A., Sharma, S., Nema, A.K. and Kota, S.H. (2022). Factors affecting particulate matter levels near highway toll plazas in India. *Transportation Research Part D: Transport and Environment*, 110: 103403. DOI: 10.1016/j.trd.2022.103403.

Ojeaga, K. and Okoro, A. (2023). Assessment of $PM_{2.5}$ in Oluku Dumpsites and Selected Residential Areas, Ovia Northeast Local Government, Benin City, Edo State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 27(9): 1945 - 1950. DOI: 10.4314/jasem.v27i9.7.

Thompson, J.E. (2018). Airborne particulate matter: human exposure and health effects. *Journal of Occupational and Environmental Medicine*, 60(5): 392-423. DOI: 10.1097/JOM.0000000000001277.

Tibuakuu, M., Michos, E.D., Navas-Acien, A. and Jones, M.R. (2018). Air pollution and cardiovascular disease: a focus on vulnerable populations worldwide. *Current Epidemiology Reports,* 5: 370 - 378. DOI: 10.1007/s40471-018-0166-8.

Wang, Y., Koutrakis, P. and Michanikou, A. (2024). Indoor residential and outdoor sources of $PM_{2.5}$ and $PM_{10}$ in Nicosia, Cyprus. *Air Quality and Atmospheric Health* 175: 485-499, http://doi.org/10.1007/511869-023-01460-8.

World Health Organisation (2021). WHO global air quality guidelines. Particulate matter ($PM_{2.5}$ and $PM_{10}$), ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide. Geneva: World Health Organization; 2021. Licence: CC BY-NC-SA 3.0 IGO.