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Original Research Paper

Correlation of Fine Particulates and Meteorological Parameters in Indoor Public Schools Environment within Benin City, Edo State, Nigeria

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Abstract

This study focused on the correlation of fine particulates and meteorological parameters in indoor public-school environments, in Benin City, Edo State, Nigeria. Thirty public schools (17 primary and 13 secondary) were selected for the study. The $PM_{2.5}$ samples were taken 1.5 – 2.0 meters within the human breathing zone. The sampling was done using an Apex 21 S Casella regular pump with a conical inhalable sampling (CIS) head for eight hours at a flow rate of 3.5 L per minute (LPM). The 37-diameter quartz filters were processed in a muffle furnace for four hours at 450 – 500 °C before sampling and weighing afterward. The results obtained showed variations in the meteorological parameters with a range of temperature from 28.52 – 29.82 °C. The relative humidity ranged from 84.22 – 427.78 %; pressure was 1006.70 - 5052.87 mmHg; wind speed was 4.13 – 1660.88 Km/h and dew point was 24.7 – 3293.56 %. The correlation coefficient showed a positive relationship exists in meteorological parameters between primary and secondary schools' sources of enrichment. The $PM_{2.5}$ mass concentration had the range of 135 – 785.31 µg/m³ which were above the stationary limits of 25 µg/m³ and 35 µg/m³ stipulated by the National Ambient Air Quality Standards and World Health Organization, respectively. These call for greater attention to alleviate all negative outcomes of environmental health issues.

Keywords: Fine particulate, Meteorological, Indoor Public Schools, $PM_{2.5}$ mass concentration

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1. Introduction

Most of the anthropogenic activities occur in the indoor environment, which is characterized by serious alteration of the chemical composition of air quality. It is estimated that people spend more of their daily time indoors; hence, the tendency to be exposed to indoor air contaminants is considerably high compared with outdoor air pollutants (Hassan et al., 2021). Considerations for students' health and well-being frequently center on diet, exercise, and emotional support (Son et al., 2020). However, the air students breathe in their classrooms is an important factor that is rarely taken into account. As such, the quality of air in classrooms has become a major concern for parents and educators in recent years. Given that children spend a large amount of their active hours in school, it is critical to make sure the air they breathe is pure and unpolluted. The health, academic performance, and general well-being of students can all suffer from poor indoor air quality (Holden et al., 2023). Several studies have shown that classroom air contains many of these toxic contaminants (Ologbosere et al., 2023). Prominent among these pollutants is fine particulate matter. Fine particulate matter ($PM_{2.5}$) is the term used to describe microscopic particles less than 2.5 micrometers in diameter that are suspended in the atmosphere for longer durations. Due to their tiny size, these particles can readily pass through the respiratory system and deeply into the lungs. Fine particulates at or below 12 ug/m^3 are considered healthy with no little risk from exposure but if the level of exposure goes to or above 35 ug/m^3 during 24 hours, the air is considered unhealthy and has the tendency to cause health issues for people that are exposed to it. High levels of $PM_{2.5}$ exposure above 50 ug/m^3 can lead to several health challenges, including cardiovascular disease, respiratory disorders, cognitive decline, and even premature mortality. Children, the elderly, and people with breathing and heart problems may be particularly vulnerable to $PM_{2.5}$ exposure (Lam et al, 2023). In any environment, the weather condition at the time has a great influence on the quality of the air, especially when it comes to human activity. Therefore, meteorological factors such as air temperature, relative humidity, wind direction, speed, and pressure as well as ultraviolet and solar radiation have an immense impact on how quickly $PM_{2.5}$ diffuses, dilutes, and accumulates in an indoor environment (Okuo et al., 2018). Wind speed and direction play a crucial role in pollutant dispersion. Higher wind speeds can help dilute contaminants and disperse them over a larger area, reducing their concentrations (Li et al., 2024). Strong wind may also transport contaminants from nearby industrial or traffic sources into school environments (Irei & Chan, 2024). Wind direction is significant in determining the potential source of pollutants and their impact on air quality. Similarly, high humidity levels can contribute to the growth of mold and mildew, which can further worsen air quality and cause respiratory symptoms (Gubb et al., 2018). On the other hand, low humidity levels can increase the dispersal of particulate matter (PM) and dust, leading to higher concentrations of airborne particles (Tang & Pfrang, 2023). Benin City is a region that has seen a significant increase in industrial activity and urbanization as high activity in transportation and industrial sector is expected to increase fine particulates concentrations. A study in the ecosystem as reported by Ologbosere et al. (2023) highlight physicochemical qualities of indoor air in selected public primary schools in Benin City, Edo State, however, there is a lack of comprehensive research on the relationship between fine particulates and meteorological parameters such as temperature, relative humidity, pressure, wind speed and dew point in an indoor public-school environment within Benin City, Edo State. Furthermore, existing studies delimited its scope to public primary schools only. Therefore, this research aims to fill the identified gaps by incorporating public secondary schools and under studied parameters such as pressure, wind speed and dew point. By doing so, it seeks to provide a hoslistic data on the correlation of fine particulates and meteorological parameters in indoor public schools in Benin City, Edo State, Nigeria.

2. Materials and Method

2.1 Study Area

Benin City, the capital of Edo State, lies between latitude 6°23′55″ N to 6°27′39″ N and longitude 5°36′18″ E to 5°44′30″ E. It has a tropical climate, characterized by two distinct seasons, the wet and the dry. In this study, the selected public secondary and primary schools were chosen from the five Local Government Areas of Benin City. They are Egor, Ikpoba-Okha, Oredo, Ovia Northeast, and Uhunmwonde Local Government Areas respectively, and delineated, as shown in in **Figure 1**. The list of schools is presented in **Table 1**.

2.2 Sampling Strategy for $PM_{2.5}$

A total of 306 public schools were enumerated in the study area comprising of 230 public primary and 76 secondary schools. However, 30 public schools (17 primary and 13 secondary) were selected as sampling sites and the distribution is as shown in Fig. 1 and Table 1. The selection was based on the similarities in human activities around the study area as well as the clustered nature of the schools.

The sampling period was between March 2023 to August 2023 and a total of 90 fine air particulates ($PM_{2.5}$) samples were collected. Triplicate samples were collected. Meteorological Parameters namely: temperature, relative humidity, pressure, wind speed and dew point were also measured and recorded during samplings.
The $PM_{2.5}$ samples were taken 1.5–2.0 meters above the ground and placed onto 37 mm-diameter quartz filters. The collection was done using Combining an Apex2IS Casella regular pump with a conical inhalable sampling (CIS) head for eight hours at a flow rate of 3.5 L per minute (LPM).
For every field sampling, the pump was pre- and post-calibrated to meet the recommended flow rate of ± 10% for every sampling interval. The 37 mm-diameter quartz filters were processed in a muffle furnace for 4 hours at

450–500 °C prior to sample time. To remove the effect of humidity, the polyurethane foam (PUF) and quartz filter that were placed within the cassette were equilibrated in a desiccator for 48 hours (Onaiwu & Okuo, 2022).

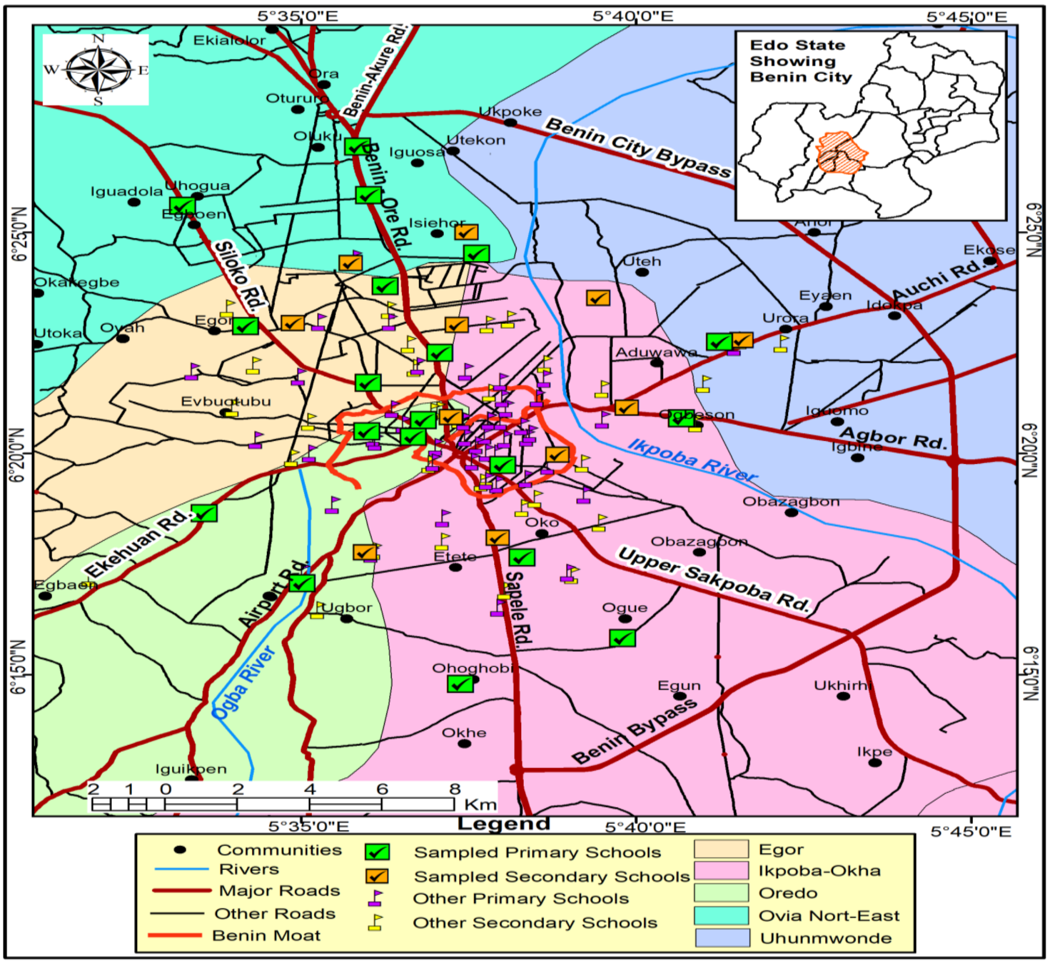

Figure 1. Map of the sampling sites (public schools in Benin City).

2.3 Meteorological Parameter Collections

For each sampling location, an automatic weather monitoring system (a professional weather station) was mounted 2.5–3.0 meters above ground level and meteorological data namely: indoor temperature, relative humidity (RH), pressure, wind speed (WS), and dew point were recorded (Onaiwu & Okuo, 2022). The weather station was situated close to the $PM_{2.5}$ sampler. It was designed to gather data and store it in memory at 5-minute intervals using the Weather Smart app. The recorded readings were downloaded to a computer.

3. Results and Discussion

The meteorological data obtained from the thirty (30) public schools (17 primary and 13 secondary) are shown in **Table 2** and **Figures 2 and 3**. The monthly average temperature, relative humidity, pressure, wind speed, dew point, and $PM_{2.5}$ mass Conc., ($\mu g/m^3$) as well as the correlation coefficient analysis during the wet season for the month of March to August 2023 were discussed in the results.

3.1 Meteorological Parameter

The average means of the meteorological sampling are as shown in **Table 2** above. There were variations in temperature in all the schools with a range of 228.52 – 29.82 ^{o}C. The temperature variations could be a result of prevailing weather conditions in the area (Onaiwu & Okuo, 2022) and solar radiation (Okieimen et al., 2015). The relative humidity showed the highest percentage in Ikpoba Okha L.G.A primary school with a percentage of

427.78 % while the lowest percentage was observed in Uhunmwonde L.G.A secondary school with 84.22 %. Other meteorological parameters were measured, and they fell within the following ranges: pressure 5052 – 1006.70 mmHg, wind speed; 4.13 – 1660.88 Km/h. The correlation coefficient for the meteorological parameters is shown in **Figures 2** and **3**. The results revealed a positive correlation (r = 1.00) existing between the primary and secondary schools, which indicates the likelihood of having the same sources of enrichment.

Table 1. List of schools with their respective coordinates

S/N	School Name	Address	Latitudes	Longitudes	L.G.A	Level	Ownership
1	Iyoba Girls Secondary School	Edo Technical School Road	6.381640	5.621975	Egor	Secondary	Government
2	Uwelu Secondary School	Akongbowa/ Osa-Osagie, Uwelu Road	6.382369	5.581137	Egor	Secondary	Government
3	Army Day Secondary School	Isiehor, Along Benin Oluku Road	6.404933	5.595598	Ovia North East	Secondary	Government
4	Ekosodin Secondary School	Ekosodin	6.416573	5.624364	Ovia North East	Secondary	Government
5	Itohan Girls Grammer School	Benin-Sapele Road	6.301520	5.632109	Ikpoba-Okha	Secondary	Government
6	Ute Secondary School	Ekiuwa Road, Upper Mission Extension	6.391861	5.657090	Ikpoba-Okha	Secondary	Government
7	Western Boys High School	Benin Agbor Road, Ikpoba Hill	6.350439	5.664203	Ikpoba-Okha	Secondary	Government
8	Edo College	Murtala Muhammed Way	6.332762	5.646968	Oredo	Secondary	Government
9	Emotan College	Wire Road	6.346977	5.620496	Oredo	Secondary	Government
10	Oba Ewuare Secondary School	Gapiona Road, Oko Central, GRA	6.296612	5.601655	Oredo	Secondary	Government
11	Eyaen Secondary School	Along Old Benin Ehor Road	6.375973	5.692716	Uhunwode	Secondary	Government
12	Edaiken Primary School	Uselu - Lagos Road, Uselu	6.371105	5.617839	Egor	Primary	Government
13	Egor Primary School	Egor	6.381161	5.569497	Egor	Primary	Government
14	Aruosa Primary School	Upper Siluko Road, Iguedayi	6.426556	5.553862	Egor	Primary	Government
15	Ivbioba Primary School	Ugbighoko Quarters	6.310701	5.559218	Egor	Primary	Government

Table 1 Cont'd

16	Oba Ewuare II Primary School	Ugbowo	6.396294	5.604231	Egor	Primary	Government
17	Ogida Primary School	Ogida	6.359899	5.599972	Egor	Primary	Government
18	Erosoyen Primary School	Ogbeson	6.346435	5.677908	Ikpoba Okha	Primary	Government
19	Etete Primary School	Erediauwa Street	6.294126	5.638269	Ikpoba Okha	Primary	Government
20	Evbabogun Primary School	Evbabogun Road	6.263677	5.663334	Ikpoba Okha	Primary	Government
21	Obe Primary School	Obe	6.246394	5.622975	Ikpoba Okha	Primary	Government
22	Ezomo Primary School	2nd Cemetery Road	6.341546	5.599672	Oredo	Primary	Government
23	Ighiwiyisi Primary School	Ogba	6.284418	5.583615	Oredo	Primary	Government
24	Ivbiore primary school	Oghenosa Street	6.345836	5.613716	Oredo	Primary	Government
25	Uvbi Primary School Girls	First East Circular Road	6.328931	5.633469	Oredo	Primary	Government
26	Uyiosa Primary School	West Circular Road	6.339531	5.611229	Oredo	Primary	Government
27	Owina Primary School	Uselu - Lagos Road, Idunmwowina	6.430530	5.600172	Ovia North East	Primary	Government
28	Eresoyen Primary School	Uselu - Lagos Road, Oluku	6.448819	5.597389	Ovia North East	Primary	Government
29	Ekosodin Primary School	Ekosodin	6.408537	5.626923	Ovia North East	Primary	Government
30	Eyaen Primary School	Benin Auchi Road	6.373424	5.691255	Uhunmwode	Primary	Government

3.2 $PM_{2.5}$ Mass Concentration

The average means mass concentration and correlation coefficient obtained from the representative sampling locations, for the wet season during the month of March to August 2023, in primary and secondary schools in Benin City, Edo State, Nigeria, are shown in **Table 1** and **Figures 2** and **3**.

The results showed the highest mass concentration of 785.31 μg/m^3 in Oredo primary schools and the lowest (135 μg/m^3) in Uhunmwonde L.G.A primary schools, which were above the limits of 25 μg/m^3 and 35 μg/m^3 stipulated by the World Health Organization (WHO, 2021) and the National Ambient and Air Quality Standards (USEPA, 2024). Urban areas have higher concentrations of vehicles, industrial facilities, and residential heating systems, all of which release combustion byproducts such as particulate matter into the air. These anthropogenic activities may account for the higher mass concentration in Oredo primary schools compared to Uhunmwonde L.G.A primary schools. In addition, urban regions usually have less vegetation compared to rural areas, which reduces the natural filtration and adsorption of pollutants from the air accounting for high mass concentration level.

Table 2. Summary of the meteorological parameters in public Primary and Secondary schools in Benin City Edo State Nigeria

L.G.A /Location	Temp (°C).	Relative humidity (%)	Pressure (mm/Hg)	Wind speed (Km/h)	Dew point (%)
Uwunwonde Secondary Sch	28.52±1.92	84.22±4.66	1006.70±2.09	4.13±0.50	24.84±1.32
Uwunwonde Primary Sch	28.95±1.92	85.51±4.65	1008.56±214	4.98±0.47	24.72±1.10
Egor Secondary Sch	29.79±3.68	166.92±9.74	201.43±2.60	8.57±1.47	50.38±1.96
Egor Primary Sch	29.82±11.69	314.14±21.37	1090.09±273.94	1660.88±305.86	3293.56±610.07
Ikpoba Okha Secondary Sch	29.15±5.93	255.70±14.27	3023.92±5.78	14.10±1.60	74.36±3.50
Ikpoba Okha Primary Sch	28.97±10.40	427.78±25.44	5052.87±5.26	34.17±6.30	139.73±2.56
Oredo Secondary Sch	29.66±4.30	253.90±14.78	3028.28±3.51	17.91±4.24	79.55±1.44
Oredo Primary Sch	29.33±10.40	427.77±25.44	5052.87±5.26	34.17±6.30	139.73±2.56
Ovia N.E Secondary Sch	29.82±12.66	165.39±8.61	1010.29±1.78	7.37±1.15	49.89±1.92
Ovia N.E Primary Sch	28.85±7.99	251.82±13.83	3025.96±4.13	13.47±3.32	51.09±2.12

Table 3. Summary of the $PM_{2.5}$ mass concentration (μg/m³) in public Primary and Secondary schools in Benin City Edo State Nigeria

S/N	Category	Egor L.G.A	Ikpoba Ohka L.G.A	Oredo L.G.A	Ovia North East L.G.A	Uwunwonde L.G.A
1	Secondary Schoool	404.54±63.49	702.16±112.49	576.60±157.58	403.43±107.45	168.68±61.88
2	Primary School	6558.36±1218.18	785.31±324.66	785.31±324.66	476.18±182.71	135.58±60.73

Figures 2 and **3** show the high presence of mass concentrations of $PM_{2.5}$ in the study areas; this may be a potential source of short-term health effects such as coughing, asthma, difficulty in breathing, and eventual death. The elevated levels of $PM_{2.5}$ indoors can be caused by a variety of anthropogenic activities occurring in the environment, including traffic emissions, industrial activities, and wildfires as reported/supported by Yao et al., 2023. This is particularly true if classrooms are situated close to busy roads or industrial areas, road dust resuspension, as well as wear and tear of vehicle parts can raise indoor $PM_{2.5}$ levels (Xu et al., 2023). Furthermore, older buildings or those with poor filtration systems may be particularly susceptible. Poor building ventilation and air exchange rates can also cause $PM_{2.5}$ to accumulate indoors (Hayashi, 2022).

The decrease in $PM_{2.5}$ in some areas may be ascribed to natural cleansing processes such as sedimentation and precipitation runoff. Suspended particles in the air gradually fall to ground or onto surfaces due to the force of gravity. In this process, the concentration of $PM_{2.5}$ in the air will be reduced. Similarly, the resuspension of particulates in the air is reduced through these liquid processes, typically associated with cleaning or the presence of water in the indoor environment (Nihar et al., 2023). Furthermore, the correlation coefficient of $PM_{2.5}$ in the primary and secondary schools showed a strong positive correlation (r = 1.00). The $PM_{2.5}$ correlation with the meteorological parameters showed that there is a positive correlation relationship between temperature (r = 0.97)

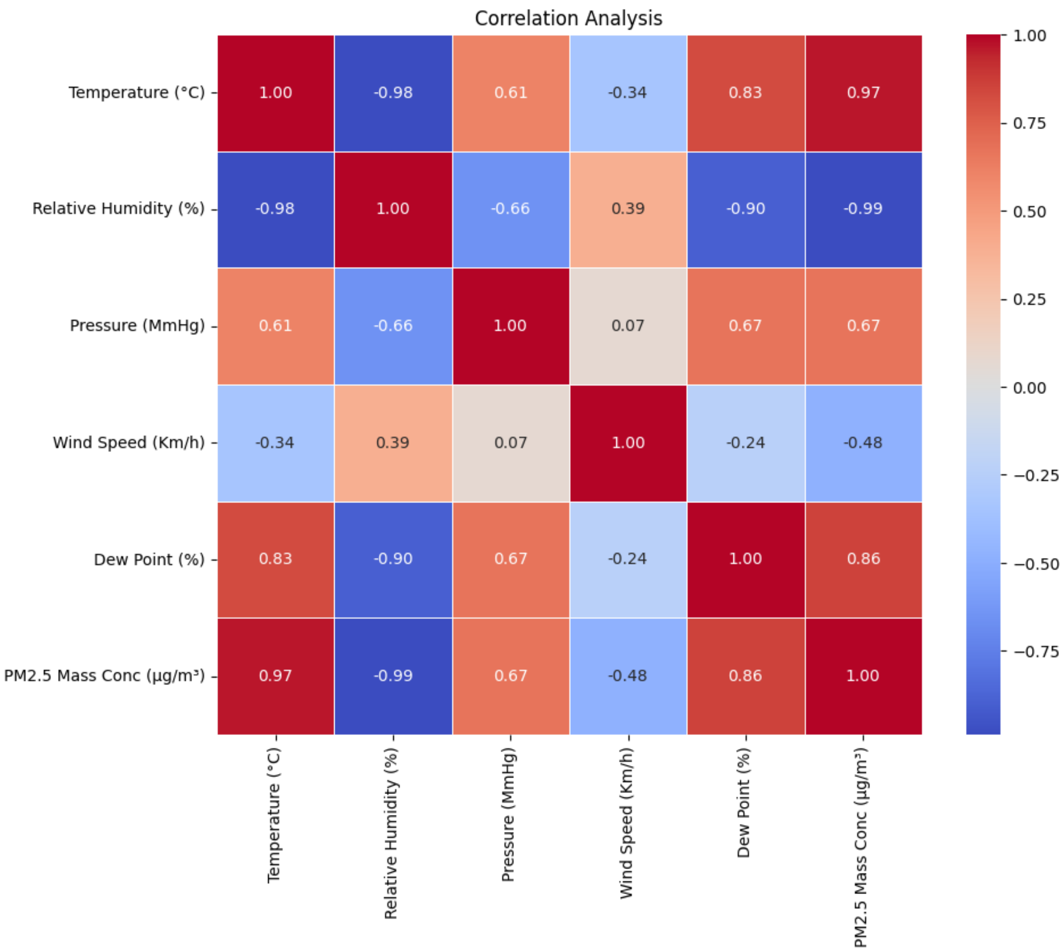

Figure 2. Correlation coefficient analysis in Oredo L.G.A primary school.

and dew points (r = 0.86) in Oredo Primary School, with a negative correlation (r = 0.99) between relative humidity. This can lead to discomfort, as the air might feel sticky and warm. As a result of this, it could also promote the growth of mold and mildew in classrooms, which can affect the indoor air quality leading to adverse health effects on school children (Silversand et al., 2023).

In Ohunmwonde L.G.A primary schools $PM_{2.5}$ had a positive correlation (r = 0.97) with temperature and a strong negative correlation with relative humidity which is by a similar study by Oniawu & Okuo, (2022). Guntu et al. (2023) state that while reduced humidity might be healthier and more comfortable, it can also result in dry air, which can contribute to health problems including dry skin, respiratory irritation, and a higher risk of static electricity.

4. Conclusion

The average mean of $PM_{2.5}$ mass concentration in the study areas exceeded the WHO and NAAQS daily averages in the wet season which is potentially harmful to sensitive groups' health including the school children. The meteorological survey also revealed a very strong correlation (r = 1.00) between secondary and primary school. Hence, there is a need for the best environmental practices by individuals and organizations to curb this menace, as such energy conservation, green energy, and effective emission controls measures could be implemented, as these will help reduce indoor air pollution and improve air quality thereby enhancing a cleaner environment and healthy living.

Declaration of Competing Interests: We hereby declare that there is no conflict of interest.

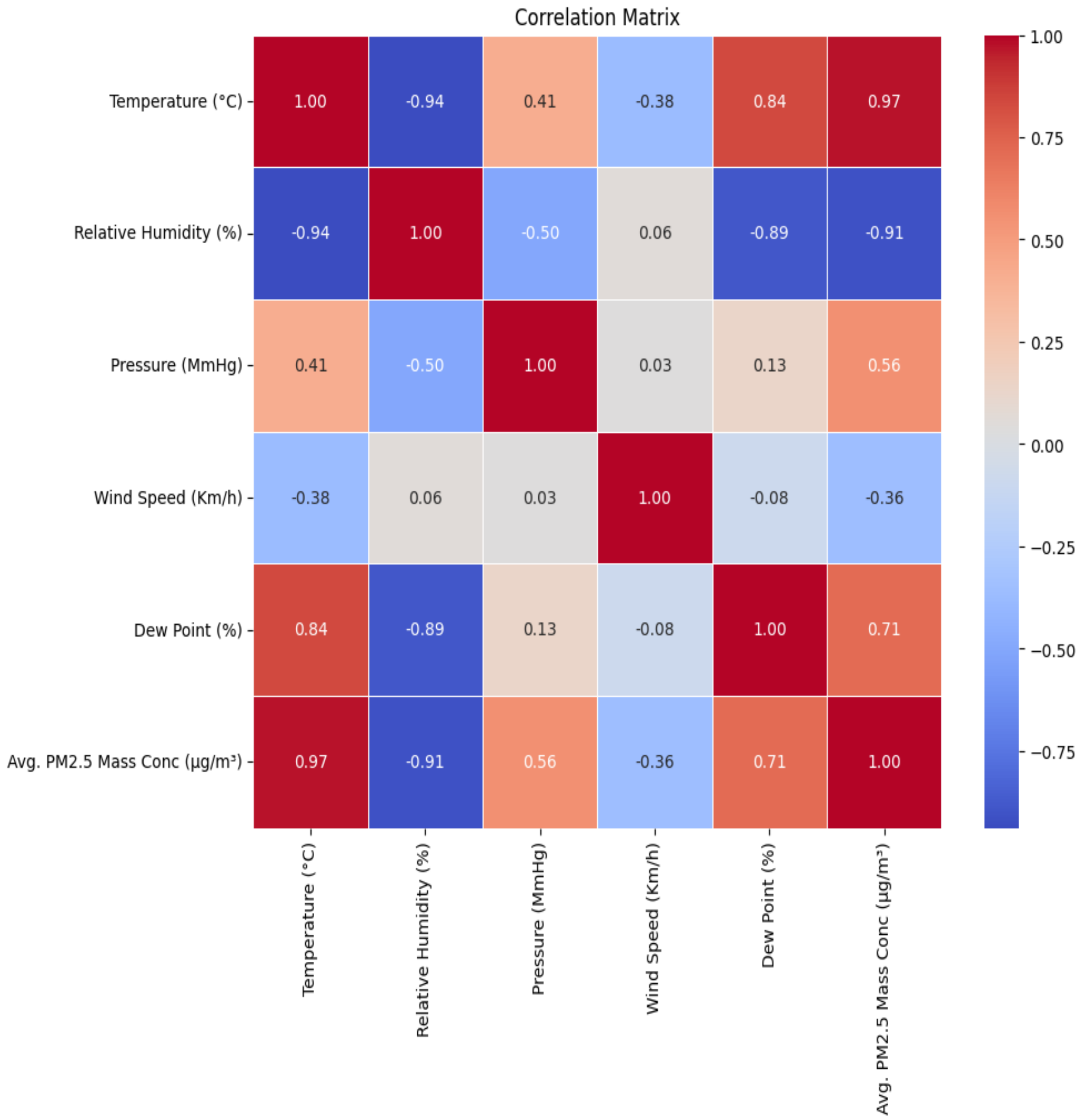

Figure 3. Correlation coefficient analysis in Uhumnwonde L.G.A primary school

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