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Associations between Indoor Bioaerosol Concentrations and the Prevalence of Childhood Asthma in Benin City, Southern Nigeria

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Abstract: As a growing public health concern, childhood asthma lacks direct research linking it to specific airborne bacteria and fungi in this region. This study investigated the association between indoor bioaerosol concentrations and the prevalence of childhood asthma in Benin City, Nigeria. We conducted a case–control study in which indoor bioaerosol samples (total bacterial count and total fungal count) and meteorological data were collected while retrospective asthma case records were obtained from local hospitals. The results revealed that males and children aged 0-4 years accounted for the highest percentage of asthma cases, a finding that is consistent with global trends. The study revealed a distinct seasonal pattern, with asthma cases and bioaerosol concentrations significantly higher during the wet season. All the sampling sites exceeded the established guidelines for indoor bioaerosol concentrations. Critically, TBC was significantly positively correlated with asthma in both the wet ($r = 0.341$) and dry ($r = 0.409$) seasons. In the dry season, both TFC and relative humidity were significantly positively correlated with asthma incidence. Regression analysis confirmed that bioaerosols are reliable predictors of asthma, with the dry season model explaining 16.9% ($R^2 = 0.169$) of the variation. Indoor bioaerosols, particularly bacteria, are major triggers of childhood asthma in Benin City. We recommend that public health interventions focus on improving indoor air quality and ventilation to reduce exposure to these airborne microbial agents.

1. Introduction

Asthma is a prevalent and chronic respiratory disease characterized by symptoms such as wheezing, coughing, and airway obstruction (Braman, 2006). It has become a significant global public health issue, with childhood asthma detection rates reaching 10% (Lambrecht and Hammad, 2015). In recent decades, the worldwide prevalence, morbidity, and economic burden of this condition have steadily increased (Caffrey *et al.*, 2020). The exact causes of asthma are not fully understood, but its progression is known to be linked to a combination of factors, including reduced lung function, allergic disorders, and bacterial and viral infections (Toskala and Kennedy, 2015; Deng *et al.*, 2016; Alizadeh *et al.*, 2017). Furthermore, asthma is strongly associated with compromised lung activity, which can originate in the prenatal stage and continue through childhood and adulthood. This can also accelerate the development of chronic obstructive pulmonary disease (McGeachie, 2017). Asthma development is influenced by complex interactions between genes and environmental factors that can manifest even before preschool age (Papi, *et al.*, 2017; von Mutius and Smits, 2020). Bioaerosols are a diverse class of airborne particles that contain or are derived from living organisms (Hayoun, *et al.*, 2024). They can be composed of whole microorganisms, such as bacteria, viruses, and fungi, as well as their organic components, including endotoxins, metabolites, and toxins. A significant portion of atmospheric aerosols originate from these biological sources (Smets *et al.,* 2016). The characteristics of bioaerosols, including their size and composition, are highly variable and are determined by their source and environmental conditions. Their size typically ranges from 20 nanometers to over 100 micrometers, which allows them to remain suspended in the air for varying durations and to be inhaled deep into the respiratory system. Exposure to environmental bioaerosols has become a major public health issue, particularly in enclosed microenvironments where people spend a significant amount of time. Airborne bacteria, in particular, are a key determinant of poor indoor air quality. High concentrations of these bacteria can pose serious health risks and serve as causative agents for various infectious diseases, including asthma and allergies (Yang *et al.,* 2019; Passi *et al.,* 2021). The sources of indoor bioaerosols are numerous and varied. They can originate from building materials, microbial contamination on interior surfaces such as walls and ceilings, and the resuspension of dust from floors and furnishings (Xie et al., 2020). Other common sources include houseplants, flower vases, pet bedding, and clothing. Additionally, bioaerosols can infiltrate indoor spaces from outdoor environments (Nazaroff, 2016; Jabeen *et al.*, 2023). Human activities also play crucial roles in the generation and dispersal of airborne bacteria indoors.

Activities such as sweeping, walking, and even simple movements can stir up dust and re-suspend microbial particles. The movement of people can also introduce microorganisms into indoor air from their clothes and bodies (van Doremalen et al., 2020). Childhood asthma is a growing public health concern in Nigeria, particularly in urban areas such as Benin City, particularly due to urbanization and related environmental factors. This condition is believed to be underdiagnosed and undertreated in many parts of the country. Eghomwanre and Oguntoke (2022a) reported a morbidity rate of 5.6% for clinical asthma (a formal diagnosis) and 11.8% for recurrent wheezing (a symptom of multiple episodes of wheezing). The study also identified several risk factors, including family history, the number of occupants in a household, and the use of kerosene, but it did not directly establish a link between asthma and specific bioaerosols. However, other studies have shown a connection between indoor air pollution and respiratory illnesses in Nigerian children, with sources such as household solid fuel use being a major contributor to air pollution-related pneumonia deaths (Passi et al., 2021).

The link between indoor air quality and respiratory health has been established in numerous studies (Mustapha et al., 2011; Adaji, 2020; Eghomwanre et al., 2022; Eghomwanre et al., 2024). A variety of biological pollutants, including bacteria, molds, and fungi, release allergens and microbial products such as endotoxins, which can trigger or exacerbate asthma symptoms. While studies in Benin City have identified the presence of airborne bacteria (Ologbosere et al., 2022; Eghomwanre et al., 2023; Eghomwanre et al., 2022b) and the prevalence of childhood asthma, there is a gap in research that directly links the two. The available data suggest that a combination of environmental factors, including gaseous pollutants, particulate matter, and other biological agents, contributes to this problem. Further research is needed to investigate the specific composition of indoor airborne bacterial communities in residential settings in Benin City and their direct associations with childhood asthma. Understanding this link is crucial for developing targeted interventions, such as improving ventilation, reducing exposure to indoor pollutants, and implementing public health campaigns to reduce the burden of asthma on children in the region. Therefore, the purpose of this study was to investigate the association between the prevalence of childhood asthma and airborne bioaerosol concentrations in the homes of school-age children in Benin City, Nigeria.

2. Methodology

2.1 Study Area

Benin City is geographically located in the tropical region of Nigeria, with coordinates situated between latitudes 6°20′N and 6°58′N and longitudes 5°35′E and 5°41′E. The city covers an area of approximately 113 km^2. Its climate is characterized by a distinct wet season (March-October) and a dry season (November-February). This tropical climate, with high humidity and rainfall, can influence the growth and dispersal of microorganisms, making it a relevant factor for the study of airborne bacteria. The city has a substantial and rapidly growing population, estimated at 1,973,000 people in 2024. The study focused on households in the city's outskirts, which are part of five local government areas: Egor, Uhunmwonde, Ovia, Oredo, Ikpoba – Okha, and Ovia North East. These areas are predominantly informal settlements and are densely populated, largely due to frequent migration from other parts of the country. This high population density and the nature of the settlements are important considerations for understanding public health issues. The housing in the study area of Benin is primarily composed of detached flat houses, which typically have three to five rooms, each measuring approximately 12 by 12 feet. The average room has approximately three occupants. The buildings are constructed with cemented and tiled walls and floors. However, many roofs have leakages, and some buildings are situated in flood-prone areas, which could contribute to indoor dampness and microbial growth. Owing to their low socioeconomic status, most households in these areas rely on solid fuels for cooking and heating, a practice known to contribute significantly to indoor air pollution.

2.2 Selection of sampling sites

The study employed a systematic approach to sample collection. First, a map of Benin City was divided into a grid of 1.5 × 1.5 km cells using ArcMap 10.1 software (**Figure 1**). All locations within each cell were then identified and documented. From the total of 181 cells, a random selection of 45 cells (25%) was chosen for sampling (Eghomwanre and Oguntoke, 2022a). Within each of these selected cells, five households were chosen, creating a total of 225 sampling points for bioaerosol sampling air and assessment across the five local government areas (Ikpoba Okha, Ovia North East, Egor, Uhunmwonde, Oredo) in the city.

2.3 Study design and data sources

The study design was structured around three primary data collection components to gather comprehensive information from the selected households. The local microclimatic conditions of the selected households were measured to determine how environmental factors might influence the concentration and dispersal of indoor bioaerosols and, in turn, affect the respiratory health of the children. Direct measurement of airborne bacteria and fungi within the selected homes was performed to determine the concentrations of bioaerosols in the living environments of the children. The researchers obtained past medical records on childhood asthma from two major hospitals where the residents of the selected households received medical care. This provided crucial health outcome data and was used to determine the associations between the measured bioaerosol exposures and documented cases of childhood asthma in the study area.

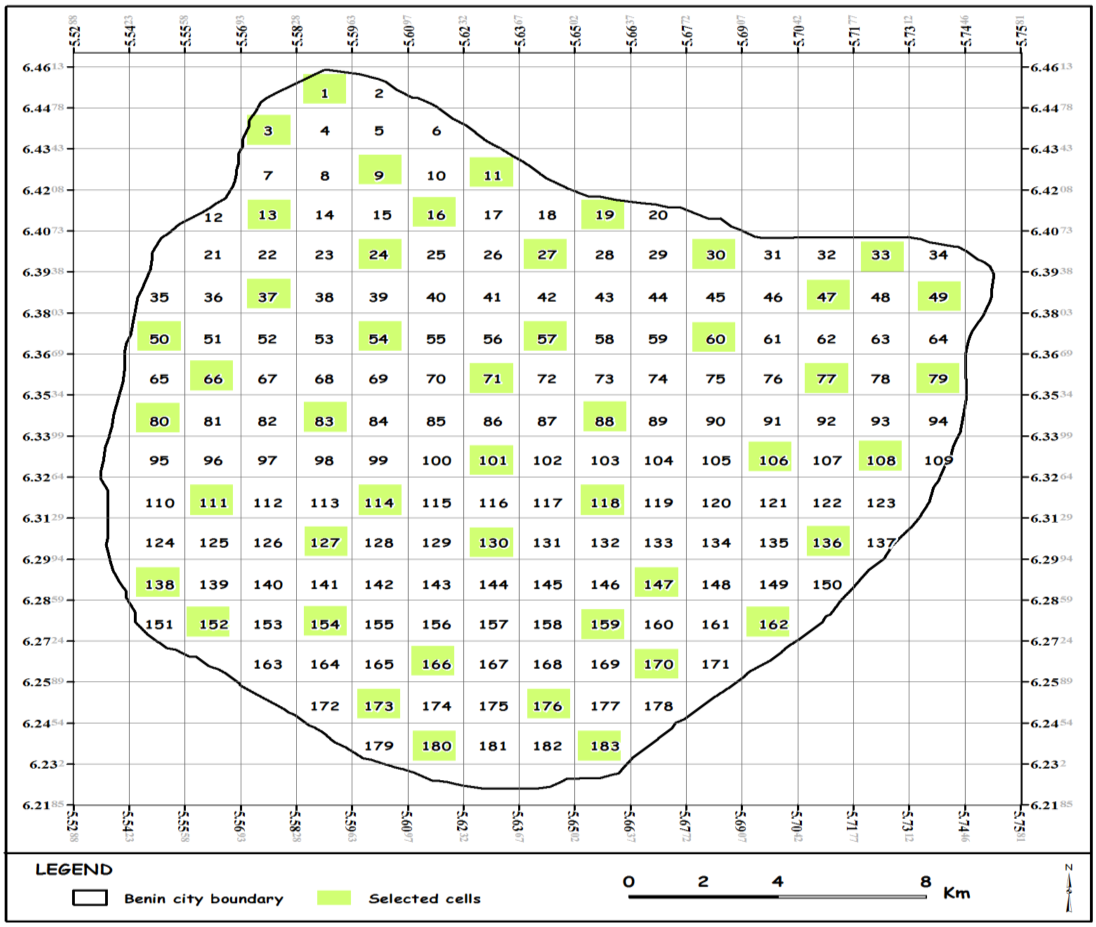

Figure 1. Grided map of Benin City showing the selected sampling locations.

2.4 Sampling duration and frequency

The study was conducted over a 12-month period, from November 2023 October 2024. To ensure data accuracy and account for seasonal variations, air samples and meteorological parameters were collected monthly and in triplicate at each sampling location.

2.5 Hospital data collection

Retrospective medical information on recorded cases of asthma in children was obtained from Stella Obasanjo Women and Children Clinic and Central Hospital, Benin. The data spanned a period of 10 years, from 2008-2017. Demographic information, including the number of cases, sex, and age, was collected to provide context for the patient population.

2.6 Collection of meteorological parameters

Meteorological data, specifically temperature and relative humidity data, were measured at each sampling site. A Lutron 4-in-1 environmental tester (LM-8000) was used to take monthly measurements in triplicate concurrently with bioaerosol sampling.

2.7 Airborne microbial sampling

Air samples were collected exclusively from the living room of each of the selected households. This location was chosen because it represents the most frequently used communal space for family members, including children. This ensures that the bioaerosol concentrations collected are representative of the environment to which the children are most exposed within their homes. The samples were also collected from the outdoor environment to provide a baseline for comparison. This study utilized the passive method of airborne microbial sampling, which quantifies the bioaerosols that settle on surfaces. This method was chosen for its accessibility, cost-effectiveness, and non-intrusive nature. Sampling was conducted monthly between 9:00 a.m. and 1:00 p.m. indoors (in a living room). Sterile 90 mm Petri dishes containing nutrient agar (NA) for bacteria and potato dextrose agar (PDA) for fungi were used. These plates were treated with Griseofulvin and chloramphenicol to inhibit unwanted microbial growth. The plates were positioned at a height of 2 m, at least 1 m away from the walls, doors, and windows, and left for 30 min to collect samples. After collection, the plates were immediately transported to a laboratory and incubated as follows: bacterial plates at 37°C for 48 hours and fungal plates at 25°C for 7 days. After incubation of the exposed cultured agar plates, discrete airborne bacterial and fungal colonies were calculated and converted to CFU/m³ using a standard empirical formula by Awad and Mawla (2012):

$CFU/m^3 = \frac{A(1000)}{PXtX0.2}$ A = Number of colonies on the Petri dish (cfu), P = Surface area of the Petri dish (cm^2), t = Time of exposure (minutes), 1000 = combined conversion factor (m^3 to cm^3/min to sec) and 0.2 = sedimentation rate factor (cm/sec (centimeters per second)

2.8 Ethical considerations

The study was conducted in full compliance with ethical principles, and the research protocol was granted approval by the Ethics Committee of the Edo State Hospital Management Board, Benin City. Before any data were collected, the research team obtained written informed consent from the parents or legal guardians of all the participating children. The consent form clearly outlined the study's purpose, procedures, potential risks, and benefits and explicitly stated that participation was voluntary and that households could withdraw at any time without penalty. To ensure strict confidentiality, all personal and medical data were de-identified by assigning a unique identification number to each respondent. Access to the data was limited to the research team.

2.9 Statistical analysis

Data was analyzed using SPSS 20.0. Descriptive and inferential analyses, including mean, Analysis of Variance (ANOVA), paired t-tests were used to compare differences in asthma cases across years, age groups and gender. Correlation, and regression analysis were employed to examine the relationships between meteorological parameters, bioaerosol concentrations, and childhood asthma cases. A value of $p<0.05$ was considered to indicate statistical significance. We subjected the data to a multicollinearity test using the Variance Inflation Factor (VIF) and also performed the Hosmer–Lemeshow (HL) test to check the model's goodness-of-fit. The model was found to be a good fit for the dataset, with VIF values for the independent variables ranging from 1.71 to 4.33. The Hosmer-Lemeshow goodness-of-fit test yielded a non-significant result ($p=0.06$). Since this p-value is greater than the standard alpha level of ($p>0.05$). To ensure the reliability and validity of our findings do this, we ran a sensitivity analysis, which involved repeatedly running the analysis without any extreme data points (outliers). This confirmed that our results were not disproportionately influenced by a few data points

3. Results

3.1 Recorded cases of asthma

During the ten-year period from 2008 - 2017, a total of 4126 asthma-related cases were recorded in the study area. These cases were not evenly distributed between genders. The data revealed that (2,293) 55.56% of all cases were males. Conversely, females accounted for (1,833) 44.44% of the total asthma cases (Table 1). The results revealed a noticeable trend in asthma case percentages over the decade, with the gap between male and female cases narrowing significantly. In 2008, males accounted for 62.72% of the cases. This percentage generally decreased over the years, reaching a low value of 51.69% in 2017. The decline was not entirely steady, with slight increases observed in 2011 and 2015. (Table 1). Conversely, the percentage of asthma cases in females generally tended to increase, with 37.28% in 2008, and the percentage of females increased to 48.31% by 2017. The proportion of cases in females gradually increased, approaching parity with males towards the end of the period. The differences in asthma cases between males and females were statistically significant, with males having a higher number of cases (Table 1). These findings indicate that sex is a factor influencing the prevalence of asthma in the study area, with males being more affected than females.

Table 1. Mean number of asthma cases by sex (2008 -2017, *N* = 4126)

Outcome by Sex (%)	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	p value
Male	62.72	59.69	54.51	54.61	58.13	54.19	52.64	55.64	51.83	51.69	0.001[a]
Female	37.28	40.31	45.49	45.39	41.87	45.81	47.36	44.36	48.17	48.31	

[a]=paired t – test

Table 2 reveals that children in the 0–4 years age group accounted for the highest number of cases of asthma, with an average of 2,415 (58.53%) of all cases over the ten-year period. The 5–9 year age group represented an average of 1,048 (25.40%) asthma cases. The lowest percentage of cases were between the ages of 10 to 17 years, with an average of 663 (16.08%) cases recorded. The differences in asthma cases across the age groups were statistically significant ($p<0.001$), with the 0–4 years age group having the highest (58.53%) percentage of asthma cases over the ten-year period. These results indicate that the 0–4 years age group was most affected by asthma, accounting for well over half of the total cases.

Table 2. Mean number of asthma cases by age (2008 - 2017, *N* = 4126)

Outcome by Age (%)	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	p value
0-4yrs	60.09	59.30	58.84	61.78	54.88	59.30	56.10	57.67	59.16	58.13	0.001*
5-9yrs	24.56	24.42	23.83	21.16	25.61	23.93	29.07	27.36	27.96	26.09	
10-17yrs	15.35	16.28	17.33	17.06	19.51	16.77	14.83	14.97	12.88	15.78	

statistically significant at $p< 0.05$

The results also revealed a distinct seasonal pattern in the occurrence of asthma (Table 3). During the wet season (May-October), a total of 53.36% of all recorded asthma cases were observed. The months of May (11.82%), April (11.26%), and June (10.73%) had the highest percentages of cases during the entire year. In the dry season (November to April), 46.63% of the asthma cases were recorded. The percentages were generally lower during this period, with the lowest rates in November (6.25%), October (6.49%), and January (6.64%). These findings suggest a clear link between season and the prevalence of asthma, with the wet season experiencing a greater proportion of cases.

Table 3. Monthly variations in asthma cases (*N* = 4126)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
% of occurrence	6.64	7.29	7.49	11.26	11.82	10.73	7.63	6.98	9.71	6.49	6.25	7.70

3.2 Variations in meteorological variables across the sampling sites

The results revealed that the dry season was consistently warmer than the wet season was (Table 4). Across all the sites, the average temperature was highest in the dry season, with Egor and Oredo showing the most notable increases. The highest average temperature was recorded in Oredo at 34.08°C during the dry season. Conversely, the wet season had a slightly lower average temperature across the board. Conversely, the wet season consistently had a relatively high relative humidity. The average Rh for all the sites was greater during the wet season, with Egor and Ovia north east having the highest average values of 74.47% and 68.78%, respectively. In the dry season, the relative humidity was notably lower, with Uhunmwonde and Oredo having the lowest average Rh values, at 51.90% and 54.60%, respectively. Temperature: Egor had the highest average temperature in the dry season (32.60°C), whereas Oredo had the highest average temperature in the wet season (30.86°C). Overall, the Uhunmwonde and Oredo sites experienced the most significant temperature increase during the dry season. Uhunmwonde and Oredo had the lowest minimum relative humidity readings during the dry season, at 17.10% and 16.70%, respectively. This wide range between the minimum and maximum Rh values indicates significant day–to-day fluctuations in humidity during the dry season, which can be observed at the Uhunmwonde (17.10% to 70.60%) and Egor (22.30% to 79.20%) sites.

Table 4. Indoor meteorological variables by season

Sampling sites	Wet season						Dry season					
	Temp (°C)			Rh (%)			Temp (°C)			Rh (%)		
	X	Min	Max	X	Min	Max	X	Min	Max	X	Min	Max
Ikpoba Okha	31.67	28.50	36.10	68.83	53.40	79.93	31.53	29.70	33.50	72.22	64.70	82.60
Ovia north east	31.64	27.70	35.63	68.78	55.00	81.77	30.22	29.10	31.70	77.09	66.90	87.70
Egor	30.06	2.40	33.60	74.47	37.00	83.00	32.60	30.60	34.40	66.86	22.30	79.20
Uhunmwonde	30.68	27.90	33.10	73.71	68.67	83.50	33.49	33.10	34.50	51.90	17.10	70.60
Oredo	30.86	27.10	34.90	70.58	57.00	79.10	34.08	32.80	35.30	54.60	16.70	70.70

Temp=Temperature, Rh= Relative humidity, X = Mean, Min= Minimum, Max=Maximum

3.3 Concentrations of Indoor Bioaerosols

The descriptive statistics for the bioaerosol counts across the sampling locations are presented in Table 5. The highest average counts for both TBC (945.38 CFU/m³) and TFC (699.72 CFU/m³) were recorded at the Ovia north east sampling site during the wet season. The lowest average TBC was found in Egor during the dry season (443.62 CFU/m³), whereas the lowest average TFC was in Oredo during the dry season (392.65 CFU/m³). The Oredo site also consistently had the lowest average TBC and TFC values during the wet season, at 552.08 CFU/m³ and 322.92 CFU/m³, respectively. The wide range between minimum and maximum values represented during the wet season TBC for Ikpoba Okha, ranging from 462.96 to 1981.48 CFU/m³, indicates a high degree of variability within each site and season ($p<0.005$). The indoor bioaerosol concentrations at all the sampling sites were above the guidelines set by the American Industrial Hygiene Association (AIHA), which recommends limits of less than 250 CFU/m³ for total fungi and less than 500 CFU/m³ for total bacteria.

Table 5. Mean seasonal indoor bioaerosol concentrations

Sampling sites	Wet season						Dry season					
	TBC (CFU/m³)			TFC (CFU/m³)			TBC (CFU/m³)			TFC (CFU/m³)		
	X	Min	Max	*X*	Min	Max	*X*	Min	Max	*X*	Min	Max
Ikpoba Okha	874.15	462.96	1981.48	585.03	92.59	1055.56	674.43	296.30	1333.33	558.74	259.26	1074.07
Ovia north east	945.38	481.48	1888.89	699.72	407.41	1074.07	531.88	240.74	1240.74	496.72	240.74	1074.07
Egor	751.03	407.41	1129.63	571.60	259.26	1018.52	443.62	166.67	796.30	409.47	259.26	685.19
Uhunmwonde	713.37	425.93	1611.11	558.78	203.70	981.48	568.44	314.82	851.85	466.99	296.30	592.59
Oredo	552.08	314.82	777.78	322.92	92.59	592.59	454.57	222.22	740.74	392.65	222.22	592.59

TBC=Total bacteria count, TFC=Total fungi count, *X* = Mean, Min= Minimum, Max=Maximum

Table 6 shows clear seasonal variation in both total bacterial count (TBC) (t = 14.19, p=0.001) and total fungal count (TFC) (t = 5.39, p=0.001), with higher levels generally recorded during the wet season. Both the TBC and TFC averages were significantly higher in the wet season than in the dry season. The overall average TBC for the wet season was 767.20 CFU/m³, whereas the average for the dry season was 534.59 CFU/m³. Similarly, the average TFC for the wet season was 547.61 CFU/m³, whereas it was 464.91 CFU/m³ for the dry season.

Table 6. Seasonal variations in bioaerosol concentrations

Variable	Mean	Std. Deviation	Std. Error Mean	t	df	Sig. (2-tailed)
^{W}TBC - ^{D}TBC	245.55	301.71	17.30	14.19	303	0.001
^{W}TFC - ^{D}TFC	77.05	250.85	14.39	5.36	303	0.001

W and D = wet and dry seasons

3.4 Associations between meteorological variables and bioaerosol counts

Table 7 shows the relationships between the meteorological variables and bioaerosol counts using the Pearson correlation coefficient (r). The results revealed a significant negative correlation (r = −0.220) between temperature and total fungal count (TFC). This means that as temperatures increase, the total fungal count tends to decrease. There was a significant positive correlation (r = 0.188) between relative humidity and the TFC. This suggests that as humidity increases, so does the fungal count. The correlations for total bacterial count (TBC) were not significant in the wet season, indicating that there was no strong relationship with either temperature or relative humidity during this period. There was a significant negative correlation (r = −0.155) between temperature and TBC. This finding indicates that as temperatures increase, bacterial counts tend to decrease. There is a significant negative correlation (r = -0.246) between relative humidity (RH) and total bacterial count (TBC). This is a crucial finding, showing that as relative humidity decreases, the bacterial count tends to increase, and conversely, as relative humidity increases, the bacterial count tends to decrease.

Table 7. Correlations between meteorological parameters and bioaerosol concentrations

variables	***Wet season***		***Dry season***	
	TEMP	RH	TEMP	RH
THBC	-0.065	0.013	-0.155**	-0.246**
THFC	-0.220**	0.188**	0.180**	0.245**

**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level

3.5 Correlation between environmental factors and asthma cases

Table 8 shows the associations among the bioaerosol counts, meteorological variables and asthma cases. There was a moderate, highly significant positive correlation (r=0.341) between TBC and asthma cases. This finding indicates that as the concentration of airborne bacteria increases, the number of asthma cases also tends to increase. The correlations between asthma incidence and temperature, relative humidity, and total fungal count (TFC) were not statistically significant. These findings suggest that in the wet season, factors other than temperature and humidity, such as the bacterial load in the air, have a more direct effect on asthma incidence. Similar to the wet season, there was a strong, highly significant positive correlation (r=0.409) between TBC and asthma. Unlike in the wet season, there was a significant positive correlation (r=0.322) between the TFC and asthma cases. This means that an increase in airborne fungi is also significantly linked to an increase in asthma incidence. A particularly notable finding was the highly significant positive correlation (r=0.417) between relative humidity and asthma. This suggests that even though the dry season is generally less humid, days with higher humidity are strongly associated with more asthma cases.

Table 8. Association between asthma cases and meteorological and bioaerosol levels

variables	TEMP	RH	TBC	TFC
Asthma (Wet season)	-0.033	-0.239	0.341^{**}	0.198
Asthma (Dry season)	-0.122	0.417^{**}	0.409^{**}	0.322^{*}

**Correlation is significant at the 0.01 level; *Correlation is significant at the 0.05 level

3.6 Influence of indoor bioaerosols on asthma cases

Table 9 presents the two separate regression models for predicting asthma cases in the wet and dry seasons. During the wet season, Model 1 shows that both the total bacterial count (THBC) and total fungal count (THFC) positively influence asthma cases, with THBC having a stronger predictive value. This model explained 11.8% of the variation in asthma cases (R^2 = 0.118). The model is statistically significant (p = 0.028). During the dry season, Model 2 shows that THBC has a positive influence on asthma cases, whereas THFC has a negative influence. This model, which incorporates only two variables, is the best predictor of all models tested, explaining a statistically significant portion of the variation in asthma prevalence (R^2 = 0.169). The model is statistically significant (p = 0.05), indicating a reliable predictive relationship between the limited bioaerosol variables and asthma prevalence in the dry season. While 16.9% is a substantial amount of the total variation explained by just the included bioaerosol factors (TBC and TFC), it should be noted that a large portion of the overall variation remains unexplained, likely due to the omission of critical unmeasured factors such as Socio-Economic Status and genetics.

Table 9. Influence of bioaerosol concentrations on asthma patients

variable	**Regression Model 1 for Indoor (Wet season)**	***R***	**R^2**	***R^2* (%)**	**Std. error of the est.**	**Sig. F**
Asthma	$Y_{Asthma} = 22.463 + 0.021X_{THBC} + 0.003_{THFC}$	0.343	0.118	11.8	18.698	0.028
	Regression Model 2 for Indoor (Dry season)					
Asthma	$Y_{Asthma} = 11.476 + 0.030X_{THBC} -0.007_{THFC}$	0.411	0.161	16.9	12.865	0.050

$R^{2=}$ coefficient of determination

4. Discussion

The results revealed a clear sex disparity in asthma cases, with males accounting for a higher percentage of cases overall but with a notable trend toward near-parity over the ten-year period. While the exact reasons are complex, they are thought to involve a combination of biological, hormonal, and environmental factors. Fuseini and Newcomb (2017) reported that boys tend to have smaller airways relative to their lung size than girls do, making them more susceptible to wheezing and asthma symptoms in early childhood. The male predominance in the cases of asthma reported in this study is in line with the findings of studies from Africa and other tropical regions (Mwang et al., 2025; Borrelli, 2025; Mulugeta et al., 2022). However, the consistent upwards trend in female cases and the downwards trend in male cases that almost reached parity by 2017 in this study is a particularly notable finding that requires further investigation. While post-puberty reversal is a global phenomenon, the observation of this trend within an all-age population over a single decade suggests that local factors may be at play. Globally, asthma incidence is typically higher in boys before puberty, with a male-to-female ratio of approximately 2:1. However, after puberty, this trend reverses, and asthma becomes more prevalent and often more severe in females. This is largely attributed to hormonal changes that influence lung function, airway inflammation, and immune responses (Papi, 2018). The overall male predominance in this study suggests that these childhood trends may be a dominant factor in the study area's population. This study therefore highlights the need for targeted interventions. Healthcare professionals and public health programs can utilise this information to develop gender-specific screening and management protocols. For instance, focusing on early detection and prevention of asthma in young males could be particularly effective (Venkatesan, 2023). The findings of this study indicate that children in the 0–4year age group have the highest number of asthma cases, which is a significant public health result. This finding is in tandem with reports of studies in Africa and other developing regions that have consistently reported a high prevalence of childhood asthma, often with the highest rates observed in preschool-aged children (Mwang et al., 2025; Dharmage et al., 2019; Eghomwanre et al., 2022). These findings indicate that a majority of the asthma burden in the study population lies within the youngest demographic. From a public health perspective, this highlights the urgent need for a stronger focus on the early diagnosis and management of asthma in the study area.

The study revealed a clear seasonal pattern in asthma cases, with a higher prevalence during the wet season. This finding has important implications for public health strategies and aligns with trends observed in other tropical and subtropical climates (D'Amato et al., 2020). These findings suggest that the environmental conditions specific to this period are key drivers of asthma incidence in the study area and that healthcare providers can anticipate a higher volume of asthma cases during the wet season and allocate resources accordingly. The findings of a wet season peak in asthma patients are consistent with patterns observed in many other tropical regions, but they differ from those reported in temperate climates. This is often linked to the "September asthma epidemic," which is driven by children returning to school and being exposed to a surge of viral infections, as well as a new wave of allergens (Eghomwanre et al., 2022). However, in tropical climates, the primary seasonal driver is often related to rainfall and humidity. These findings align with other studies conducted in African countries with distinct wet and dry seasons, which have often reported an increase in respiratory illnesses, including asthma, during the rainy period (Adeloye et al., 2013; Mwang et al., 2025; Abbas et al., 2021). The relatively high humidity and dampness during the wet season create an ideal environment for the growth of molds and dust mites, which are major indoor allergens and significant asthma triggers (Bush et al., 2019). The high concentrations above the guidelines set by the American Industrial Hygiene Association (AIHA) could be linked to specific local conditions that lead to poor air exchange or increased human activity (Enebeli et al., 2018). The TBC and TFC values reported in this study are comparable to those reported in other Nigerian cities, validating the findings as representative of the region (Akande et al., 2023; Jabeen et al., 2023; Eghomwanre et al., 2022a; Eghomwanre et al., 2024). The results confirm that the study area, like many other areas with similar climates, faces a significant challenge with respect to indoor air quality. Globally, indoor environments often have higher bioaerosol concentrations than outdoor environments do. The specific levels vary based on the building type, occupancy, and climate. Goh et al. (2000) reported high indoor fungal counts, particularly during wet seasons, due to the high humidity that facilitates mould growth. This study revealed that bioaerosol concentrations are not uniform and vary considerably by location, season, and even within the same site. The wide range of variations in bioaerosol counts in this study indicates that indoor bioaerosol concentrations can fluctuate dramatically, potentially due to human activities (such as sweeping or cooking), air circulation, or sudden changes in humidity. This means that individuals can experience periods of extremely high exposure, which may be enough to trigger a severe asthma attack or an allergic reaction, even if the average count over time seems moderate. This study revealed that the wet season, with its high humidity, is a prime environment for fungal growth, as evidenced by the positive correlation between the RH and TFC. These findings suggest that damp conditions facilitate the proliferation of airborne bacteria, which become the dominant trigger for asthma symptoms, overshadowing the influence of the meteorological factors themselves (Mudarri and Fisk, 2018). The dry season presents a more complex picture. While the overall humidity was lower, the data revealed a highly significant positive correlation between RH and asthma cases. This finding indicates that on days with relatively low humidity during the dry season, asthma cases spike. This is likely because the increased moisture allows both bacteria and fungi to thrive and become airborne, a hypothesis supported by the significant positive correlations between RH and both TBC and TFC. This finding is consistent with reports of other studies conducted in the region (D'Amato et al., 2020; Wemedo and Beke, 2020). This study revealed a clear and dynamic relationship between meteorological variables and bioaerosol counts, which varied significantly between the wet and dry seasons. These findings imply that relative humidity is a crucial factor for microbial growth, but its influence on bacteria and fungi differs seasonally. The findings establish a direct link between climatic conditions and the air quality of indoor environments. The positive correlation between relative humidity and fungal concentration is a universal finding, particularly for indoor environments in tropical and subtropical regions. Several studies have confirmed that dampness and moisture, often a result of high humidity and poor ventilation, are consistently associated with increased fungal spore counts (Zang et al., 2014; Mendell et al., 2011; Wemedo and Beke, 2020). The study revealed a clear and compelling link between bioaerosol counts and asthma cases, with the specific triggers varying by season. These findings confirm that airborne bacteria are a significant factor annually, whereas fungi and humidity play a more crucial role in the dry season. The significant positive correlation between TBC and asthma cases in both the wet and dry seasons implies that, regardless of the time of year, as the concentration of airborne bacteria increases, so does the prevalence of asthma. This makes airborne bacteria a consistent and powerful predictor of asthma in the study area. The lack of a significant correlation between asthma and the meteorological variables (temperature and RH) could suggest that in the wet season, the bioaerosol load itself, particularly from bacteria, is the dominant factor. While much of the research has focused on fungi, a growing body of evidence, especially in tropical climates, highlights the equal importance of bacteria as respiratory triggers. The study's emphasis on TBC aligns with this emerging research. These results are consistent with findings from other studies conducted in similar climates (Gu et al., 2024; D'Amato et al., 2020; Wemedo and Beke, 2020). This study confirmed that the concentration of airborne microbes is a significant factor in explaining asthma cases. The dry season model, which explained 16.9% of the variation in asthma cases, was the strongest predictor, suggesting that during the dry season, the relationship between airborne microbes and asthma is more pronounced and predictable. The most consistent finding is the positive influence of the total bacterial count (TBC) in both seasonal models. These findings indicate that an increase in airborne bacteria is a key driver of asthma cases in the study area, regardless of the season. This highlights the importance of considering bacterial load in indoor air quality assessments, a factor that is sometimes overshadowed by fungal research. Globally, regression models have been used to link environmental triggers to asthma (Hughes et al., 2022). Hughe et al. (2022) reported similar results, where bioaerosol counts, particularly fungal spores, explained a significant portion of asthma-related hospital visits. However, the specific predictive power of TBC in both seasons is a notable finding that distinguishes this study, as much of the existing research has focused predominantly on the role of fungi. While strong correlations between bioaerosols and asthma have been established, these relationships are likely influenced by a triad of complex interacting factors. Socioeconomic status (SES) is a critical confounder that can significantly shape the results. Households in the study area, often informal settlements, have a low socioeconomic status. This can indirectly influence asthma incidence through several pathways, such as substandard housing and a lack of access to health care and lifestyle choices (Passi et al., 2021; Eghomwanre et al., 2024). While this study focused on environmental triggers, hereditary factors are a fundamental component of asthma etiology. Asthma has a strong genetic component, and a family history of asthma or atopy (the genetic tendency to develop allergic diseases) significantly increases a child's risk (Papi et al., 2018, Eghomwanre and Oguntoke, 2022a).

5. Conclusion

This study revealed a clear and significant association between indoor bioaerosol concentrations, seasonal variations, and the prevalence of childhood asthma in Benin City, Nigeria. These findings confirm that while a complex interplay of sex, age, and climatic factors influences asthma, the burden of the disease is most pronounced in young children and is closely linked to the air quality of their homes. The results of this study are consistent with global and regional trends, yet they also provide unique insights, particularly regarding the consistent and strong role of airborne bacteria as key asthma triggers. The statistically significant predictive models highlight that bioaerosol concentrations are not merely correlated but are reliable predictors of asthma incidence, reinforcing the need for targeted environmental health strategies.

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