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Bioaerosol Capture by Vehicle Air Filters and its Implications for Forensic Applications Along the Ado-Ikere-Iju-Itaogbolu-Akure Road, Southwestern Nigeria

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ABSTRACT

Pollen grains and spores are valuable indicators of vegetation composition and environmental conditions and have important applications in forensic investigations. This study evaluated the potential of vehicle air filters as passive collectors of airborne biological particles and assessed their forensic significance along the Ado-Ikere-Iju-Itaogbolu-Akure Road in southwestern Nigeria. A vegetation survey and palynological analysis were conducted to compare roadside floristic composition with the spectrum of airborne particles captured in vehicle air filters. The vegetation assessment recorded 858 individuals belonging to 54 species, 47 genera, and 29 families in the study region. Herbs constituted the largest proportion of individuals (388), followed by grasses (117), trees (132), shrubs (79), climbers (75), creepers (31), ferns (7), and lianas (2) species. The dominant plant species were *Chromolaena odorata, Tithonia diversifolia, and Panicum maximum*. Palynological analysis revealed 49 pollen types belonging to 33 families, 80 fungal and fern spores, 17 insect remains, 9 zooplankton, and 6 diatom frustules in the samples. Dominant palynomorphs included *Hagenia abyssinica, Chromolaena odorata, Cannabis sativa, Curvularia, Glomus, and Peronospora*. Rainfall, relative humidity, and wind speed significantly influenced the distribution of airborne pollen and spores in this study area. A strong correspondence was observed between the roadside vegetation and atmospheric pollen assemblages. Vehicle air filters effectively capture pollen and spores that reflect the surrounding vegetation and environmental conditions along travel routes. These pollen markers can serve as valuable forensic tools for linking vehicles and other objects to specific geographical locations, thereby supporting criminal investigations and geographic source attribution in forensic palynology.

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INTRODUCTION

Bioaerosols are microscopic biological particles suspended in the atmosphere, including pollen grains and fungal spores, which are readily transported by wind and atmospheric circulation (Ghosh *et al.* 2022). These particles originate from both natural ecosystems and anthropogenic activities and can be dispersed over long distances via atmospheric processes (Hamann *et al.,* 2025). Because their distribution often reflects the surrounding vegetation and environmental conditions, bioaerosols can serve as location-specific markers. Their high abundance, persistence in the atmosphere (Kazadzis *et al.*, 2025), and ability to adhere to surfaces make them valuable indicators for tracing environmental exposure and linking objects, individuals, or vehicles to particular geographic locations (Walter *et al.*, 2023; Orijemie & Israel, 2019). Among bioaerosols, pollen grains and fungal spores are particularly significant because they are produced in large quantities and can remain airborne for extended periods (Walter *et al*., 2025). Their composition and morphology often reflect regional vegetation patterns and climatic conditions, making them useful indicators of forensic environmental reconstruction ((Nyayapathi *et al.,* 2025; Ravindra *et al.*, 2022).

Although airborne pollen is traditionally monitored using fixed-volumetric samplers, vehicle air filters provide an effective passive alternative (Tummon *et al.,* 2024). As vehicles travel through different landscapes, their air filters accumulate pollen, spores, dust, and soot from the surrounding environment, forming a cumulative record of the biological particles encountered along the travel routes (Trzyna *et al.,* 2023). These trapped palynomorphs often reflect local vegetation, seasonal flowering patterns and prevailing environmental conditions (Milne *et al.*, 2024; Hamann *et al.*, 2025; Walter *et al*., 2025). Consequently, the analysis of bioaerosols captured in vehicle air filters can reveal their spatial distribution and relationships with meteorological factors, such as rainfall, temperature, humidity, and wind speed (Yu *et al.,* 2025), providing valuable information for environmental monitoring, air quality assessment, and the reconstruction of movement patterns relevant to forensic investigations, particularly in areas lacking conventional aerobiological monitoring networks.

Previous studies in Nigeria have demonstrated the growing potential of pollen and spore evidence in forensic applications (Walter *et al*., 2019; Adekanmbi *et al*., 2022), particularly for linking vehicles to locations and reconstructing their travel histories (Orijemie & Israel, 2019; Walter *et al.,* 2023). However, limited information exists on pollen assemblages captured from vehicle air filters along the Ado–Ikere–Iju–Itaogbolu–Akure road in Southwestern Nigeria, a major transportation route that passes through diverse ecological landscapes. Therefore, this study investigated the palynomorphs trapped in vehicle air filters along this corridor to establish local pollen signatures that can support forensic investigations and improve the reconstruction of vehicle movement patterns.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted along the Ado–Ikere–Iju–Itaogbolu–Akure road, an important intercity transport corridor in Southwestern Nigeria that connects Ekiti State with Ondo State and facilitates the movement of people, agricultural produce, and commercial goods between these regions. The road links major urban centers such as Ado-Ekiti, Ikere-Ekiti, and Akure, while also passing through smaller settlements, including Iju and Itaogbolu. This route experiences substantial vehicular traffic owing to its role in regional trade, commuting and interstate transportation.

Geographically, the study area lies approximately between latitudes 07.52°N and 07.25°N and longitudes 05.20°E and 05.30°E (Figure 1). The region falls within Nigeria's tropical rainforest belt, which is characterized by a warm and humid climate with distinct wet and dry seasons. The surrounding landscape is composed of a mixture of secondary forests, cocoa and food crop plantations, fallow lands, and expanding urban settlements, reflecting both natural vegetation and areas modified by human activities.

Sampling points along the road were mapped using ArcGIS 10.3.1 (Figure 1). The area experiences a humid tropical climate with two principal rainy periods (April–July and September–November) and relatively dry periods between December and March and August. The mean annual rainfall ranges between 1,200 and 2,000 mm, with monthly rainfall varying considerably depending on the seasonal patterns (Salami *et al.,* 2025). Daytime temperatures generally range from 24–34 °C, whereas nighttime temperatures typically fall between 20 and 24 °C (Ikuemonisan *et al.,* 2025). The relative humidity remains high for most of the year, commonly exceeding 70–80% particularly during the rainy season (Agan, 2026).

Atmospheric circulation in this region is strongly influenced by the seasonal migration of the Intertropical Convergence Zone (Ogunbode *et al.,* 2025). During the wet season, moist southwest monsoon winds from the Atlantic Ocean dominate, bringing heavy rainfall, whereas dry northeast trade winds (Harmattan) prevail between November and February, often accompanied by reduced humidity and increased atmospheric dust. These climatic and environmental conditions influence vegetation dynamics and the dispersal of airborne pollen and spores in this study area.

Vegetation Study

The vegetation survey for this study was conducted between May and June 2021 along the Ado–Ikere–Iju–Itaogbolu–Akure road corridor in Southwestern Nigeria. A systematic line transect method was adopted to document the vegetation types occurring approximately 20 m from the roadside along selected sections of the road. Transects were established at representative points along the study area to capture plant species diversity in the surrounding landscape. All living trees with a girth at breast height (GBH) of 1.3 m above ground level were recorded and measured at the midpoint of the transect. Plant taxa encountered during the survey were identified and classified in the field using diagnostic morphological characteristics described in standard floras, manuals, and botanical monographs (Akobundu and Agyakwa 1998). Species identification was further verified by comparing the collected specimens with authenticated samples deposited at the University of Lagos Herbarium, Department of Botany, University of Lagos, Nigeria, Nigeria.

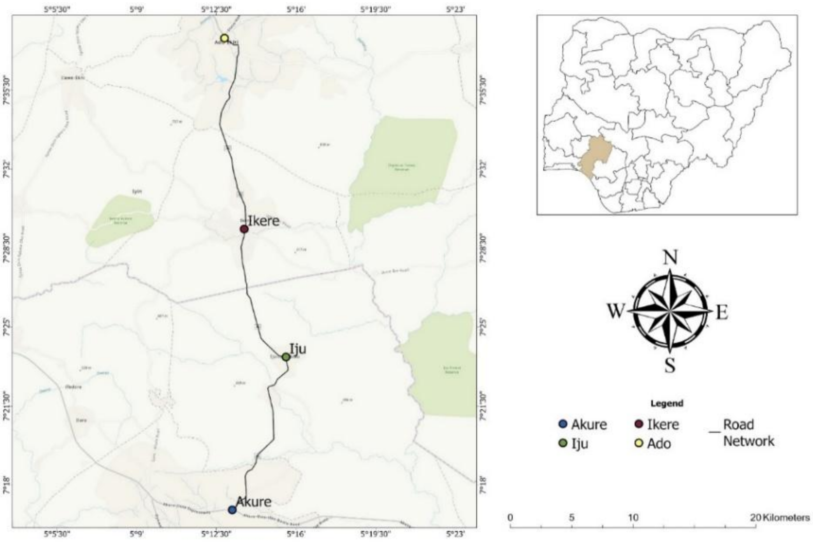

Figure 1: The Study Route Along the Ado-Ikere-Iju-Itaogbolu-Akure Road

Species nomenclature and authorship were confirmed using the International Plant Names Index (IPNI, 2025) to ensure taxonomic accuracy and data consistency. The recorded vegetation was categorized into five tropical life-form classes: climbers, herbs, grasses, shrubs, and trees, following the classification scheme of Müller-Dombois (1972). The conservation status of each identified species was assessed using the International Union for Conservation of Nature (IUCN) Red List Categories, including Not Evaluated (NE), Data Deficient (DD), Least Concern (LC), Near Threatened (NT), vulnerable (VU), endangered (EN), Critically Endangered (CR), Extinct in the Wild (EW), and extinct (EX) (IUCN, 2025). This assessment provides an understanding of the ecological significance and conservation priorities of the plant species recorded in the study area.

Descriptive Statistics and Diversity Indices

Data obtained from the vegetation survey along the Ado-Ikere-Iju-Itaogbolu-Akure road were analyzed to evaluate the composition and diversity of the plant species in the study area. Basic descriptive statistics were used to summarize the distribution, abundance, and frequency of the recorded taxa across the sampling locations. Biodiversity indices were calculated to assess species richness, dominance patterns, and vegetation diversity in roadside ecosystems. All statistical analyses were performed using Paleontological Statistics software (PAST v4.13c) (Hammer & Harper, 2024). A significance level of 0.05 was adopted for the analyses, corresponding to a 95% confidence level for interpreting statistical outputs.

Basal Area (BA)
The basal area represents the cross-sectional area of a tree trunk measured at breast height (1.3 m above ground level) and is widely used to evaluate the structural dominance and size distribution of trees within the study area. It was calculated using the following formula:

$$BA = \frac{\pi D^2}{4} \quad (1)$$

Where:
BA = Basal area (m²); D = Diameter at breast height (cm); π = pi (3.142). The total BA for each plot was obtained by adding all the trees BA in the plot (Ige *et al*., 2025).

Relative Density (RD)
Relative density describes the proportion of individuals of a particular species to the total number of individuals of all species recorded within the study area. It was computed using:

$$RD = \frac{n_i}{N} x\,100 \quad (2)$$

where RD (%) is the relative species density, n_i is the number of individuals of species *i*, and *N* is the total number of all individual trees of all species in the entire community (Ige *et al*., 2025). This index helps identify species that are numerically dominant in the vegetation assemblage.

Relative Dominance (RD*o*)
Relative dominance measures the degree to which a species contributes to the total basal area of the vegetation community, thereby reflecting its ecological influence in terms of size and spatial occupation. It was computed using:

$$RD_o = \frac{\sum Ba_i \; x\,100}{\sum Ba_n} \quad (3)$$

where Ba_i is basal area of all trees belonging to a particular species *i* and Ba_n is basal area of all trees in a plot (Ige *et al*., 2025). Higher values indicate species that occupy a larger space and exert stronger structural dominance within the community.

Family Importance Value
The Family Importance Value was calculated to determine the overall contribution of each plant family to the vegetation community (Ige *et al*., 2025). It was computed using:

$$FVI = \frac{(\mathrm{RD} + \mathrm{RDo})}{2} \quad (4)$$

Importance Value Index (IVI)
The Importance Value Index (IVI) was used to evaluate the overall ecological significance of individual tree species within the plant community (Ige *et al*., 2025). It was computed using:

$$IVI = \frac{(\mathrm{RD}\ x\ \mathrm{RDo})}{2} \quad (5)$$

Sampling Technique
Vehicles operating along the Ado-Ikere-Iju-Itaogbolu-Akure road in Southwestern Nigeria were randomly selected for this study. These vehicles regularly travel between major urban centers in Ekiti and Ondo States, enabling them to accumulate airborne particulates from diverse vegetation zones and settlement areas along the road.
At the start of the study, new engine air filters were installed in all selected 15 vehicles. Sampling was conducted monthly from January 2020 to December 2022 at the study site. During each sampling event, approximately 5 g of dust and soot was gently collected from the pleated surfaces of the filters under sterile laboratory conditions, allowing repeated sampling without affecting the filter performance. To maintain efficiency, the filters were replaced annually. Although the vehicles mainly operated along the Ado-Ikere-Iju-Itaogbolu-Akure route, occasional short deviations occurred for refueling or maintenance in the nearby towns. All vehicles used standardized Toyota Genuine Parts engine air filters (17801-0C020) and dry-type pleated paper filters with high particulate retention efficiency (approximately 99.5% for particles ≥5 µm). A detailed exposure log was maintained for each vehicle, recording the filter installation and removal dates, duration of use, and distance traveled.

Laboratory Processing
Approximately 5 g of dust and soot collected from vehicle air filters was processed using standard palynological techniques. Samples were first wet-sieved through 250 µm and 5 µm meshes to remove coarse debris and ultrafine particles. Heavy liquid separation using zinc chloride (specific gravity 2.0 g/cm³) and centrifugation at 3,500 rpm for 10 min were applied to isolate organic palynomorphs from mineral particles. Chemical treatments were performed sequentially, including 10% hydrochloric acid (HCl) to dissolve carbonates and 40% hydrofluoric acid (HF) to remove siliceous materials. The residues were then subjected to acetolysis using acetic anhydride and concentrated sulfuric acid (9:1) at 70°C to remove excess organic matter and enhance pollen wall visibility. After thorough rinsing, the final residues were preserved in glycerol. Microscope slides were prepared with glycerin jelly, sealed with paraffin wax, and examined using an Olympus CH-20i light microscope at ×400 magnification. Pollen and spores were identified using published pollen atlases and reference collections from the University of Lagos. Meteorological data from the Nigerian Meteorological Agency (NiMet) were obtained to assess the influence of climatic factors on airborne pollen deposition.

Statistical Analysis
Pollen and spore data were organized and visualized using Tilia 2.6.1 software to generate pollen diagrams and seasonal pollen calendars (Grimm, 2020). The relationship between atmospheric variables and palynomorph abundance was examined using Pearson's correlation analysis at a significance level of $p < 0.05$. Pollen and spore counts were grouped by month across the three study years (2020–2022), and the results were expressed as mean monthly values for the entire period. The values reported in this study represent the raw cumulative counts of pollen and spores recovered from all processed samples.

RESULTS AND DISCUSSION
Results
On the Ado-Ikere-Iju-Itaogbolu-Akure road, 858 individuals from 54 species, 47 genera, and 29 families were recorded (Tables 1 and 2). Of these, 21 species, comprising 132

individuals, were recorded as trees, eight species, with 79 individuals, as shrubs, 13 species, with 388 individuals, as herbs, three species, with 117 individuals, as grasses, seven species, with 75 individuals, as climbers, and one species each for creepers, ferns, and lianas, with 31, 7, and 2 individuals, respectively. The Asteraceae family was the most prevalent, with 234 individuals and four species, representing 27.27% of the total count, followed by Fabaceae with 146 individuals and 11 species, representing 17.01%; Poaceae with 117 individuals and three species, representing 13.63%; Amaranthaceae with 75 individuals and two species, representing 8.74%; and Euphorbiaceae with 60 individuals and one species, representing 6.99% (Table 2).

Table 1: Structural Analysis of Woody Species Along Ado-Ikere-Iju-Itaogbolu-Akure Road

No.	Name	Family	Habitat	F	DBH	BaHa-1	RD	RDo	IVI	FIV	FP	IUCN
1.	*Spondias mombin* L.	Anacardiaceae	Tree	12	254.4	5.08	5.61	6.81	19.09	6.21	April-June	LC
2.	*Rauvolfia vomitoria* Afzel.	Apocynaceae	Shrub	3	8.7	0.00	1.40	0.01	0.00	0.70	Dec.-Jan, June-Aug.	LC
3.	*Elaeis guineensis* Jacq.	Arecaceae	Tree	3	63.6	0.32	1.40	0.42	0.30	0.91	Jan-Dec.	LC
4.	*Ceiba pentandra* (L.) Gaertn.	Bombacaceae	Tree	1	21.2	0.03	0.47	0.05	0.01	0.26	Dec.-Feb.	LC
5.	*Combretum platyterum* (Welw.) Hutch. & Dalziel	Combretaceae	Shrub	1	2.9	0.00	0.47	0.00	0.00	0.23	Sept-Nov	LC
6.	*Combretum racemosum* P. Beauv.	Combretaceae	Shrub	4	11.6	0.01	1.87	0.01	0.01	0.94	Dec.-May	LC
7.	*Byrsocarpus coccineus* Schum. & Thonn.	Connaraceae	Shrub	3	8.7	0.00	1.40	0.01	0.00	0.70	Sept.-Nov.	NE
8.	*Cnestis ferruginea* DC.	Connaraceae	Shrub	2	5.8	0.00	0.93	0.00	0.00	0.47	Jan.-March	LC
9.	*Alchornea cordifolia* (Schum. & Thonn.) Müll. Arg.	Euphorbiaceae	Shrub	44	110	0.95	20.56	1.27	13.09	10.92	Oct.-Dec.	LC
10.	*Flueggea virosa* (Roxb. ex willd.) Voigt	Euphorbiaceae	Shrub	14	35	0.10	6.54	0.13	0.42	3.33	Oct.-Jan.	LC
11.	*Margaritaria discoidea* (Baill.) G.l. Webster	Euphorbiaceae	Tree	2	42.4	0.14	0.93	0.19	0.09	0.56	Oct.-Feb.	LC
12.	*Albizia adianthifolia* (Schum.) W. F. Wight	Fabaceae	Tree	1	24.3	0.05	0.47	0.06	0.01	0.26	Jan.-April	LC
13.	*Albizia zygia* (DC.) J. F. Macbr.	Fabaceae	Tree	7	148.4	1.73	3.27	2.32	3.79	2.79	Jan.-March Aug-Sept.	LC
14.	*Dialium guineense* Willd.	Fabaceae	Tree	13	275.6	5.97	6.07	7.99	24.27	7.03	Dec.-March	LC
15.	*Gliricidia sepium* (Jacq.) Walp.	Fabaceae	Tree	35	742	43.25	16.35	57.93	473.70	37.11	Nov.-March	LC
16.	*Millettia thonningii* (Schum. &	Fabaceae	Tree	9	190.8	2.86	4.20	3.83	8.05	4.02	Nov.-March	LC

No.	Name	Family	Habitat	F	DBH	BaHa-1	RD	RDo	IVI	FIV	FP	IUCN
	Thonn.) Baker											
17.	*Senna occidentalis* (L.)	Fabaceae	Shrub	11	27.5	0.06	5.14	0.08	0.20	2.61	March -June	LC
18.	*Senna siamea* (Lam.) H.S. Irwin & Barneby	Fabaceae	Tree	14	296.8	6.92	6.54	9.27	30.32	7.90	Aug.-May	LC
19.	*Anthocleista vogelii* Planch.	Loganiaceae	Tree	1	27.9	0.06	0.47	0.08	0.02	0.27	March -May	LC
20.	*Trichillia tessannii* Harms.	Meliaceae	Tree	1	12.4	0.01	0.467	0.02	0.00	0.24	April-Sept.	LC
21.	*Ficus exasperata* Vahl	Moraceae	Tree	5	106	0.88	2.34	1.18	1.38	1.76	Oct. - May	LC
22.	*Ficus sur* forssk.	Moraceae	Tree	3	63.6	0.32	1.40	0.42	0.30	0.91	April-Sept.	LC
23.	*Pycnanthus angolensis* (Welw.) Warb.	Myristicaceae	Tree	1	37.2	0.11	0.47	0.14	0.03	0.31	Oct.-May	LC
24.	*Allophylus africanus* P. Beauv.	Sapindaceae	Tree	4	84.8	0.56	1.87	0.76	0.71	1.31	Dec.-March	LC
25.	*Blighia unijugata* Baker (L.) Jacquin	Sapindaceae	Tree	1	22.5	0.04	0.47	0.05	0.01	0.26	Sept.-Oct.	LC
26.	*Lecaniodiscus cupanioides* Planch. ex Benth.	Sapindaceae	Tree	11	233.2	4.27	5.14	5.72	14.70	5.43	Jan.-March	LC
27.	*Malacantha alnifolia* (Baker) Pierre	Sapotaceae	Tree	1	13.8	0.01	0.47	0.02	0.00	0.24	March -June	VU
28.	*Sterculia tragacantha* Lindl.	Sterculiaceae	Tree	5	106	0.88	2.34	1.18	1.38	1.76	Aug.-Sept.	LC
29.	*Celtis zenkeri* Engl.	Ulmaceae	Tree	2	17.3	0.02	0.93	0.03	0.01	0.48	Feb.-April	LC

Table 2: Structural Analysis of Non-Woody Species Along Ado-Ikere-Iju-Itaogbolu-Akure Road

No.	Name	Family	Habitat	F	RD	FP	IUCN
1.	*Asystasia gangetica* (L.) T. Anders.	Acanthaceae	Herb	4	0.62	Nov-April	LC
2.	*Alternanthera brasiliensis* Voss	Amaranthaceae	Herb	51	7.92	Mar-May	LC
3.	*Cyathula prostrata* (L.) Blume	Amaranthaceae	Herb	24	3.73	Jan-Mar.	LC
4.	*Culcasia scandens* P. Beauv.	Araceae	Climber	21	3.26	Aug-Nov	LC
5.	*Aspilia africana* (Pers.) C.d. Adams	Asteraceae	Herb	30	4.66	Sept-Feb	LC
6.	*Chromolaena odorata* (L.) R. M. King & h. Rob.	Asteraceae	Herb	92	14.28	Dec-Mar.	LC
7.	*Tithonia diversifolia* (Hemsl) A. Gray	Asteraceae	Herb	79	12.27	Oct.-Dec.	LC
8.	*Tridax procumbens* L.	Asteraceae	Herb	33	5.12	Jan.-Dec.	LC
9.	*Palisota ambiqua* (P. Beauv.) Kunth.	Commelinaceae	Herb	1	0.15	Sept.-Jan.	LC
10.	*Merremia aegyptia* (L.) Urban	Convolvulaceae	Climber	9	1.40	Dec.-Feb.	LC
11.	*Tetracera podotricha* Gilg	Dilleniaceae	Liana	2	0.31	June-Oct	LC
12.	*Dioscorea preussii* Pax	Dioscoreaceae	Climber	1	0.15	------------	LC
13.	*Calopogonium mucunoides* Desv.	Fabaceae	Climber	13	2.02	Dec-Mar.	LC
14.	*Cassia mimosoides* L.	Fabaceae	Herb	2	0.31	Dec.-Apr.	LC

No.	Name	Family	Habitat	F	RD	FP	IUCN
15.	*Centrosema pubescens* Benth.	Fabaceae	Climber	10	1.55	Sept.-Feb.	LC
16.	*Desmodium adscendens* (SW.) Dc.	Fabaceae	Creeper	31	4.81	Sept.-Oct.	LC
17.	*Platostoma africanum* P. Beauv.	Lamiaceae	Herb	28	4.35	July-Oct.	LC
18.	*Sida acuta* Burm. F.	Malvaceae	Herb	13	2.02	Nov-April	LC
19.	*Bambusa vulgaris* Schrad. ex Wendel.	Poaceae	Grass	16	2.48	-----------	LC
20.	*Imperata cylindrica* (L.) P. Beauv.	Poaceae	Grass	12	1.86	Mar.-May	NE
21.	*Panicum maximum* Jacq.	Poaceae	Grass	89	13.82	Jan.-Dec.	LC
22.	*Borreria ocymoides* (Burm. F.) DC.	Rubiaceae	Herb	17	2.64	Jan.-Aug.	NE
23.	*Spermacoce ocymoides* Burm. F.	Rubiaceae	Herb	38	5.90	Sept.-Jan.	LC
24.	*Cardiospermum halicacabum* L.	Sapindaceae	Climber	10	1.55	July-Aug.	LC
25.	*Paullinia pinnata* L.	Sapindaceae	Climber	11	1.71	Dec.-Jan.	NE
26.	*Cyclosorus afer* (H. Christ.)	Thelypteridaceae	Fern	7	1.09	July-Jan.	CE

The highest non-arboreal plant species with the largest individuals and relative densities were *Chromolaena odorata* (L.) R. M. King & H. Rob. (92, 14.28), *Tithonia diversifolia* (Hemsl.) A. Gray (79, 12.27), *Panicum maximum* Jacq. (89, 13.82), *Alternanthera brasiliensis* Voss (51, 7.92), and *Spermacoce ocymoides* Burm. f. (38, 5.90) (Figure 2). *Alchornea cordifolia* (Schum. & Thonn.) Müll. Arg. had the highest number of individuals, relative density, relative dominance, important value index, and family important value of all tree species, followed by *Gliricidia sepium* (Jacq.) Walp. (35, 16.35, 57.93, 473.70, 37.11), *Flueggea virosa* (Roxb. ex willd.) Voigt (14, 6.54, 0.13, 0.42, 3.33), *Senna siamea* (Lam.) H.S. Irwin & Barneby (14, 6.54, 9.27, 30.32, 7.90), and *Dialium guineense* Willd. (13, 6.07, 7.99, 24.27, 7.03 (Figure 3).

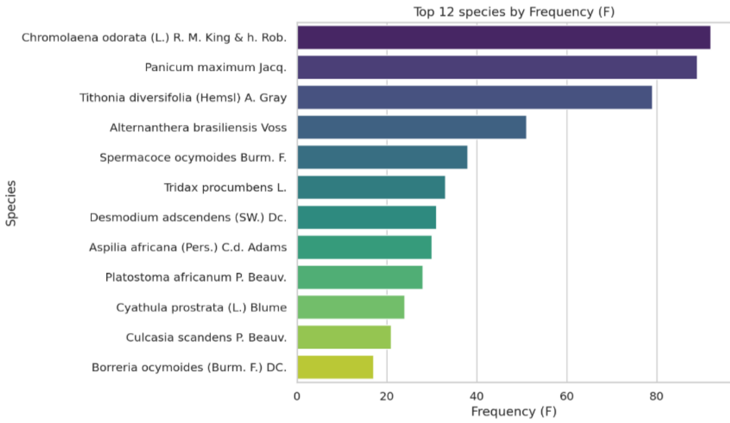

Figure 2: Distribution Frequency of Predominant Non-Woody Plant Species

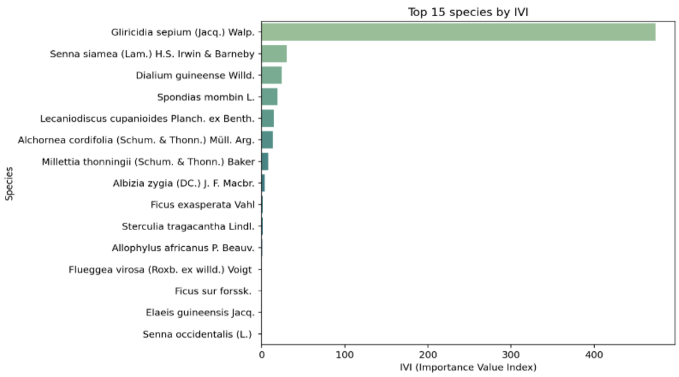

Figure 3: Distribution Frequency of Dominant Woody Plant Species Based on Importance Value Index

A total of 49 atmospheric pollen types belonging to 33 families, 80 fungal and fern spores, 17 insect parts, 9 zooplankton, and 6 diatom frustules were recorded on Ado-Ikere-Iju-Itaogbolu-Akure Road. The highest pollen count was recorded in December 73 (13.5%), January 65 (12%), October 54 (10%), June 44 (8.2%), May 42 (7.8%), and March 43 (8.0%), while the lowest was recorded in April 28 (5.2%), August 30 (5.6%), October 38 (7.0%), July 40 (7.4%), and February, September 41 (7.6%) (Figures 4a and 4b).

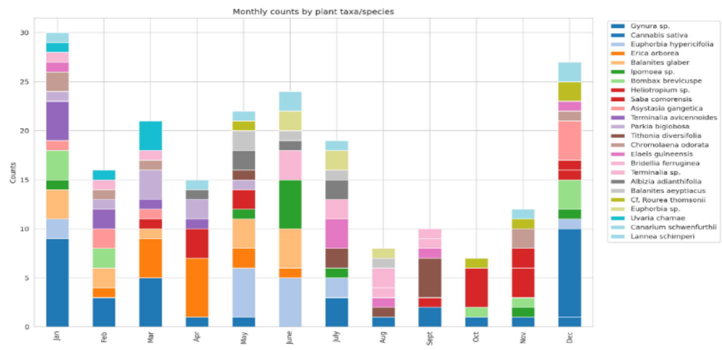

Figure 4a: Monthly Variation in the Counts of Recovered Pollen Grains

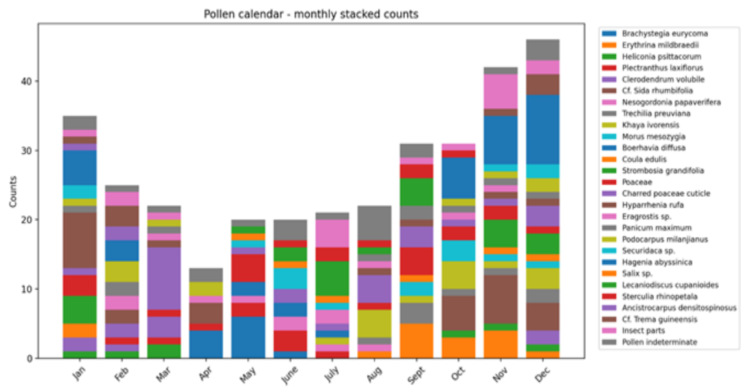

Figure 4b: Monthly Variation in the Counts of Recovered Pollen Grains

Months with lowest spore counts were November 0 (0%), March and October 1 (1.2%), April, August, and December 4 (5.0%), while the highest spore counts were found in January 22 (27.5%), May, June, and July 10 (12.5%), September 9 (11.2%), and February 5 (6.2%). *Hagenia abyssinica* (5.7%), *Chromolaena odorata* (3.7%), *Cannabis sativa* (3.1%), *Glomus* sp. (11.2%), *Curvularia* sp. (12.5%), *Dryopteris* sp. (7.5%), *Meliola* sp. (6.2%), *Peronospora* sp. (7.5%), Zooplankton (11.2%), and Diatom frustule (7.5%) were the dominant palynomorph types (Table 5).

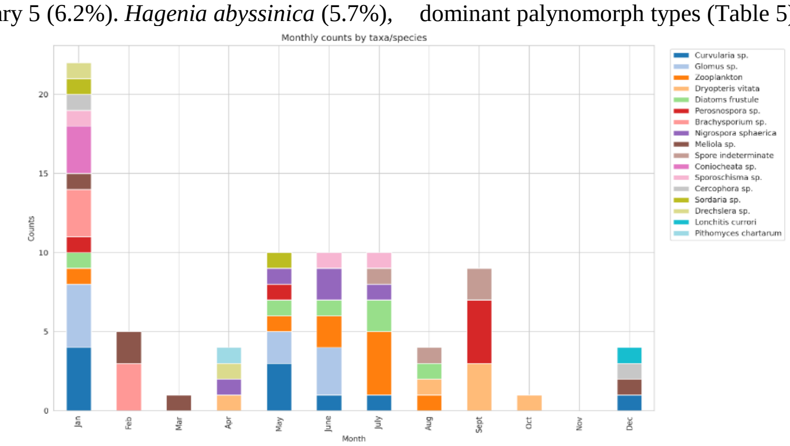

Figure 5: Monthly Variation in the Counts of Recovered Fungal and Fern Spores

Pearson's correlation analysis revealed varying degrees of association among spore count, pollen count, and the measured meteorological parameters (temperature, relative humidity, rainfall, and wind speed) at AIIAR (Figure 6). Spore count showed a moderate positive correlation with pollen count (r = 0.31).

However, spore concentration showed negative correlations with temperature (r = –0.12), relative humidity (r = –0.28), and rainfall (r = –0.43), indicating that increases in these meteorological variables were generally associated with reductions in airborne spore abundance. The relationship between spore count and wind speed was negligible (r = –0.041). Pollen count demonstrated moderate negative correlations with temperature (r = –0.31) and relative humidity (r = –0.44), and a strong negative correlation with wind speed (r = –0.63). A weak positive correlation was observed between pollen count and rainfall (r = 0.12).

Figure 6: Heat Map of Pearson Correlation Between Total Monthly Palynomorph Counts and Meteorological Data (−1 to +1).

A comparative assessment of the floristic composition and the atmospheric pollen spectrum (Table 3) along the Ado–Ikere–Iju–Itaogbolu–Akure Road reveals both concordance and disparity between standing vegetation and airborne pollen representation. The vegetation survey indicates that the woody flora is dominated by Fabaceae, Euphorbiaceae, Sapindaceae, Moraceae, and Poaceae, while the non-woody layer is largely composed of Asteraceae, Poaceae, Amaranthaceae, and Fabaceae species. The atmospheric pollen assemblage is quantitatively dominated by Poaceae (3.7%), charred Poaceae cuticles (5.2%), and *Hagenia abyssinica* (Rosaceae) (5.7%), followed by *Gynura* sp. (Asteraceae) (3.7%), *Hyparrhenia rufa* (3.3%), *Cannabis sativa* (3.1%), *Sida rhumbifolia* (3.0%), *Euphorbia hypericifolia* (2.8%), *Erica arborea* (2.6%), *Erythrina mildbraedii* (2.6%), *Khaya ivorensis* (2.6%), and *Lecaniodiscus cupanioides* (2.4%). A strong vegetation–pollen agreement was observed for Poaceae, which was well represented in both ground flora and atmospheric pollen rain (3.7%), in addition to the high proportion of charred Poaceae cuticles (5.2%). This overrepresentation is consistent with the high pollen productivity and effective wind dispersal of grasses, making Poaceae a key forensic indicator of open vegetation and disturbed roadside habitats.

Similarly, members of Asteraceae, such as *Chromolaena odorata* and *Tithonia diversifolia*, which are abundant in non-woody vegetation, are reflected in the pollen record. Euphorbiaceae also showed correspondence, with *Alchornea cordifolia* and other taxa present in the vegetation, and *Euphorbia hypericifolia* contributed 2.8% of the pollen assemblage. However, several dominant woody taxa recorded in the vegetation show comparatively low pollen percentages in the atmospheric record (generally ≤1–2%). This under-representation may be attributed to entomophily, heavier pollen grains, or localized distribution patterns that limit their wide dispersal.

Certain taxa with relatively low field abundance displayed moderate to high pollen percentages. *Hagenia abyssinica* accounts for 5.7% of the pollen spectrum despite not being a dominant roadside species. This suggests either long-distance transport or higher pollen productivity, a phenomenon of particular relevance in forensic palynology, where extra-local inputs may influence the evidential interpretation.

Table 3: Atmospheric Pollen Count of Ado-Ikere-Iju-Itaogbolu-Akure Road

Plant taxa/Family	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	%
Acanthaceae														
Asystasia gangetica	1	2	1	0	0	0	0	0	0	0	0	4	8	1.5
Anacardiaceae														
Lannea schimperi	1	0	0	0	0	0	0	0	0	0	1	2	4	0.7
Annonaceae														
Uvaria chamae	1	1	3	0	0	0	0	0	0	0	0	0	5	0.9
Apocynaceae														
Saba comorensis	0	0	1	3	2	0	0	0	0	0	2	1	9	1.7
Arecaceae														
Elaeis guineensis	1	0	0	0	0	0	3	1	1	0	0	1	7	1.3
Asteraceae														
Tithonia diversifolia	0	0	0	0	1	0	2	1	4	0	0	0	8	1.5
Gynura sp.	9	3	5	1	1	0	0	0	0	0	0	1	20	3.7
Chromolaena odorata	2	1	1	0	0	0	0	0	0	0	2	1	7	1.3
Balanitaceae														
Balanites glaber	3	2	1	0	3	4	0	0	0	0	0	0	13	2.4

Plant taxa/Family	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	%
Balanites aeyptiacus	0	0	0	0	2	1	1	1	0	0	0	0	5	0.9
Bombacaceae														
Bombax brevicuspe	3	2	0	0	0	0	0	0	0	1	1	3	10	1.8
Boraginaceae														
Heliotropium sp.	0	0	0	0	0	0	0	0	1	4	3	1	9	1.7
Burseraceae														
Canarium schwenfurthii	0	0	0	1	1	2	1	0	0	0	0	0	5	0.9
Cannabaceae														
Cannabis sativa	0	0	0	0	0	0	3	1	2	1	1	9	17	3.1
Combretaceae														
Terminalia avicennoides	4	2	1	1	0	0	0	0	0	0	0	0	8	1.5
Terminalia sp.	1	1	1	0	0	0	0	2	1	0	0	0	6	1.1
Connaraceae														
Cf. *Rourea thomsonii*	0	0	0	0	1	0	0	0	0	1	1	2	5	0.9
Convolvulaceae														
Ipomoea sp.	1	0	0	0	1	5	1	0	0	0	1	1	10	1.8
Ericaceae														
Erica arborea	0	1	4	6	2	1	0	0	0	0	0	0	14	2.6
Euphorbiaceae														
Euphorbia sp.	0	0	0	0	0	2	2	1	0	0	0	0	5	0.9
Euphorbia hypericifolia	2	0	0	0	5	5	2	0	0	0	0	1	15	2.8
Bridellia ferruginea	0	0	0	0	0	3	2	1	1	0	0	0	7	1.3
Fabaceae														
Albizia adianthifolia	0	0	0	1	2	1	2	0	0	0	0	0	6	1.1
Parkia biglobosa	1	1	3	2	1	0	0	0	0	0	0	0	8	1.5
Brachystegia eurycoma	0	0	0	3	6	1	0	0	0	0	0	0	10	1.8
Erythrina mildbraedii	0	0	0	0	0	0	0	1	5	3	4	1	14	2.6
Heliconiaceae														
Heliconia psittacorum	1	1	2	0	0	0	0	0	0	1	1	1	7	1.3
Lamiaceae														
Plectranthus laxiflorus	0	0	1	0	2	3	1	0	0	0	0	0	7	1.3
Clerodendrum volubile	2	1	3	0	0	0	0	0	0	0	0	2	8	1.5
Malvaceae														
Cf. *Sida rhumbifolia*	0	0	0	0	0	0	0	0	0	5	7	4	16	3.0
Nesogordonia papaverifera	0	0	0	0	1	2	1	1	0	0	0	0	5	0.9
Meliaceae														
Trechilia preuviana	0	0	0	0	0	0	0	1	3	1	1	2	8	1.5
Khaya ivorensis	0	0	0	0	0	0	1	4	1	4	1	3	14	2.6
Moraceae														
Morus mesozygia	0	0	0	0	0	0	0	0	2	3	1	1	7	1.3
Nyctaginaceae														
Boerhavia diffusa	0	0	0	1	2	2	1	0	0	0	0	0	6	1.1

Plant taxa/Family	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	%
Olacaceae														
Coula edulis	2	0	0	0	0	0	0	0	1	0	1	1	5	0.9
Strombosia grandifolia	4	0	0	0	0	0	0	0	0	0	4	3	11	2.0
Poaceae														
Poaceae	3	1	1	1	4	0	0	1	4	2	2	1	20	3.7
Charred poaceae cuticle	1	2	9	0	1	2	1	4	3	1	1	3	28	5.2
Hyparrhenia rufa	8	2	1	3	0	0	0	1	1	0	1	1	18	3.3
Eragrostis sp.	0	2	1	1	0	0	2	1	0	1	1	0	9	1.7
Panicum maximum	1	2	1	0	0	0	0	1	2	1	1	1	10	1.8
Podocarpaceae														
Podocarpus milanjianus	1	3	1	2	0	0	0	0	0	1	1	2	11	2.0
Polygalaceae														
Securidaca sp.	2	0	0	0	1	3	1	0	0	0	1	2	10	1.8
Rosaceae														
Hagenia abyssinica	5	3	0	0	0	0	0	0	0	6	7	10	31	5.7
Salicaceae														
Salix sp.	0	0	0	0	1	1	1	0	0	0	0	0	3	0.5
Lecaniodiscus cupanioides	0	0	0	0	1	2	5	1	4	0	0	0	13	2.4
Sterculiaceae														
Sterculia rhinopetala	0	0	0	0	0	1	2	1	2	1	0	0	7	1.3
Tiliaceae														
Ancistrocarpus densitospinosus	1	2	0	0	0	0	0	0	0	0	0	0	3	0.5
Ulmaceae														
Cf. *Trema guineensis*	1	3	0	0	0	0	0	0	0	0	1	3	8	1.5
Insects parts	1	2	1	0	0	0	4	0	1	1	5	2	17	3.1
Pollen indeterminate	2	1	1	2	1	3	1	5	2	0	1	3	22	4.1
Total	65	41	43	28	42	44	40	30	41	38	54	73	539	
%	12	7.6	8.0	5.2	7.8	8.2	7.4	5.6	7.6	7.0	10	13.5		

Table 4: Atmospheric Spore Count of Ado-Ikere-Iju-Itaogbolu-Akure Road

Plant taxa/Family	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total	%
Glomeraceae														
Glomus sp.	4	0	0	0	2	3	0	0	0	0	0	0	9	11.2
Sordariaceae														
Sordaria sp.	1	0	0	0	1	0	0	0	0	0	0	0	2	2.5
Trichosphaeriaceae														
Brachysporium sp.	3	3	0	0	0	0	0	0	0	0	0	0	6	7.5
Pleosporaceae														
Curvularia sp.	4	0	0	0	3	1	1	0	0	0	0	1	10	12.5
Pithomyces chartarum	0	0	0	1	0	0	0	0	0	0	0	0	1	1.2
Drechslera sp.	1	0	0	1	0	0	0	0	0	0	0	0	2	2.5
Coniochaetaceae														
Coniocheata sp.	3	0	0	0	0	0	0	0	0	0	0	0	3	3.7
Lasiosphaeriaceae														
Cercophora sp.	1	0	0	0	0	0	0	0	0	0	0	1	2	2.5

Perosnospora sp.	1	0	0	0	1	0	0	0	4	0	0	0	6	7.5
Apiosporaceae														
Nigrospora sphaerica	0	0	0	1	1	2	1	0	0	0	0	0	5	6.2
Dryopteridaceae														
Dryopteris vitata	0	0	0	1	0	0	0	1	3	1	0	0	6	7.5
Meliolaceae														
Meliola sp.	1	2	1	0	0	0	0	0	0	0	0	1	5	6.2
Lonchitidaceae														
Lonchitis currori	0	0	0	0	0	0	0	0	0	0	0	1	1	1.2
Chaetosphaeriaceae														
Sporoschisma sp.	1	0	0	0	0	1	1	0	0	0	0	0	3	3.7
Zooplankton	1	0	0	0	1	2	4	1	0	0	0	0	9	11.2
Diatom's frustule	1	0	0	0	1	1	2	1	0	0	0	0	6	7.5
Spore indeterminate	0	0	0	0	0	0	1	1	2	0	0	0	4	5.0
Total	22	5	1	4	10	10	10	4	9	1	0	4	80	
%	27.5	6.2	1.2	5.0	12.5	12.5	12.5	5.0	11.2	1.2	0	5.0		

Discussion

The vegetation along the Ado–Ikere–Iju–Itaogbolu–Akure Road (AIIIAR) is characterized by relatively low woody species diversity, with non-arboreal taxa showing the highest relative density. This structural pattern likely reflects canopy openings and anthropogenic disturbances, which create favorable microhabitats for herbs and grasses. Recent vegetation ecology studies in West African secondary forests have similarly reported increased herbaceous dominance in fragmented landscapes (Adeleye *et al.,* 2021; Kassa *et al.,* 2026). The dominance of Fabaceae along this route aligns with contemporary floristic assessments, showing that Fabaceae remains one of the most species-rich and ecologically adaptable families in tropical African ecosystems (Siddiqui, 2025).

The palynological assemblage from the Ado–Ikere–Iju–Itaogbolu–Akure road showed clear seasonal and taxonomic patterns that can serve as reliable forensic markers. Variations in pollen diversity, abundance, and seasonal occurrence create a distinctive "pollen signature" for this transport corridor in southwestern Nigeria. Some taxa, particularly *Gynura* sp., were dominant and widely distributed, reflecting the strong influence of roadside weeds and the presence of disturbed vegetation. While such taxa form the baseline pollen spectrum owing to their resilience and high pollen production, their seasonal peaks enhance their forensic value. The recovered assemblage of pollen and spore types reflects a complex vegetation mosaic of grasslands, secondary forest patches, cultivated land, and disturbed roadside habitats. This ecological diversity strengthens the forensic potential of the pollen record by providing seasonal and spatial environmental signatures (Walter *et al.,* 2025).

Members of the Poaceae and Asteraceae families dominated the assemblage and served as regional background signals. Poaceae pollen, *Hyparrhenia rufa, Panicum maximum,* and *Eragrostis* sp. reflect extensive grassland cover and roadside savannas. The significant recovery of charred Poaceae cuticles, especially during March, indicates dry season burning, a common land management practice that increases airborne grass fragments. High abundances of disturbance-adapted Asteraceae, such as *Gynura* sp., *Chromolaena odorata,* and *Tithonia diversifolia,* are consistent with roadside and disturbed habitats along the road (Meng *et al*., 2022). The presence and distribution of these families formed a recognizable baseline profile for the study area, enhancing regional forensic discrimination.

Several taxa display clear seasonality, which increases their forensic value by providing a temporal context for the collected samples. Dry season indicators such as Erica arborea, *Bombax brevicuspe, Parkia biglobosa, Terminalia avicennoides,* and *Podocarpus milanjianus* are predominantly recorded between January and April. The pronounced dry-season peak of *Hagenia abyssinica* further reinforces this pattern and provides a distinct phenological marker. Such seasonal peaks align with known flowering phenologies in West African climates, making these taxa useful temporal markers for inferring seasonal aspects of forensic evidence (Dagnachew *et al*., 2022). Wet season taxa also enhance the temporal resolution. *Euphorbia hypericifolia, Ipomoea* sp., *Brachystegia eurycoma,* and *Lecaniodiscus cupanioides* peaked during the rainy months (April-September), representing mid-year vegetation dynamics. The concentration of *Brachystegia eurycoma* in April-May is particularly useful as a phenological marker for the early rainy season. These distinct wet season signatures are consistent with rain-mediated pollen release and dispersal patterns described in recent aerobiological studies (Waudby *et al*., 2022; Santos-Malengue *et al.,* 2023).

Late rainy season and Harmattan indicators include *Khaya ivorensis, Erythrina mildbraedii*, Cf. *Sida rhombifolia* and *Trechilia preuviana,* with strong representation from September to December. The extended seasonal presence of *Cannabis sativa* from July to December serves as a particularly diagnostic taxon because of its distinctive pollen morphology and association with disturbed or semi-cultivated sites. Recent forensic palynology research highlights the value of distinctive, low-richness taxa, such as *Cannabis*, in differentiating local sources and improving match probabilities in trace evidence (Walter *et al.,* 2023; Rull *et al.,* 2024).

The recovery of forest-affiliated taxa, such as *Strombosia grandifolia, Coula edulis, Nesogordonia papaverifera,* and *Canarium schweinfurthii,* alongside savanna grasses and disturbance weeds, confirms the forest-savanna transitional nature of the road. This mixed ecological indicator set creates a distinct regional fingerprint that enhances geographic specificity, which is crucial in forensic assignments in which locality must be inferred from trace palynomorphs (Lopez, 2025). The monthly distribution of pollen showed the highest counts in December, January, and November, indicating enhanced pollen transport during dry and Harmattan conditions. These patterns are consistent with decreased washout by rainfall and increased atmospheric dispersal, as described in aerobiological studies (Suffert, 2025). Such meteorological influences are a key consideration in forensic interpretations, where timing and environmental conditions influence the deposition and preservation of pollen on evidentiary materials.

Insect fragments and indeterminate pollen reflect additional biotic contributions and physical degradation processes in pollen rain. Although indeterminate pollen cannot be taxonomically resolved, its presence is accounted for in forensic assessment models that incorporate uncertainty and fragmentary evidence (Bhoyar and Srivastava, 2025). The distinct combination of abundant Poaceae and Asteraceae taxa, seasonally restricted woodland and wet season indicators, diagnostic species such as *Cannabis sativa,* and ecological transition forest taxa creates a unique palynological fingerprint for the Ado–Ikere–Iju–Itaogbolu–Akure road area. This combined temporal spatial signature enhances the forensic capacity to link trace samples, such as vehicle air filters, clothing fibers, or soil residues, to this specific route and to infer the associated seasons of contact.

The results reveal the important influence of meteorological factors on bioaerosol dynamics along AIIIAR. Significant correlations between rainfall, wind speed, and total palynomorph counts demonstrate that atmospheric conditions strongly regulate the distribution of airborne pollen and spores. Rainfall plays a dual role by triggering plant phenology (Dhawan *et al*., 2025), while also removing particles from the atmosphere through washout processes, whereas wind speed influences dispersal distance and atmospheric mixing (Beggs, 2025). Comparable positive associations between pollen and spore abundances have been reported in recent urban aerobiology studies, where synchrony between flowering and fungal sporulation seasons drives co-variations (Ajikah *et al.,* 2023; Sharmi *et al.,* 2026). In tropical regions, transitions between rainy and dry seasons often produce peak variability in airborne pollen and spores due to combined effects of flowering cycles and changing atmospheric circulation.

Pearson's correlation analysis indicates that pollen and spore concentrations respond similarly to seasonal and vegetation-driven factors, as shown by the moderate positive relationship between their abundances. However, spore counts showed negative correlations with rainfall, relative humidity, and temperature, suggesting that wet conditions promote deposition and reduce airborne spore concentrations. This pattern is consistent with studies reporting that rainfall and high humidity suppress spore suspension through wet deposition (Suffert, 2025; Ajikah *et al*., 2023). Pollen counts also showed moderate negative relationships with temperature, relative humidity, and particularly wind speed. Dry conditions promote anther dehiscence and pollen release (Mehmood *et al*., 2025), while stronger winds may dilute near-surface pollen concentrations through vertical mixing (Bani Khalifi *et al*., 2025). Similar climatic link has been reported for rain-dominated ecosystems in southern Nigeria and other humid tropics (Onuminya *et al*., 2025).

The vegetation–pollen relationship along the Ado–Ikere–Iju–Itaogbolu–Akure road reveals clear differential representation between plant abundance and atmospheric pollen rain. Poaceae dominate the assemblage due to high pollen productivity and efficient wind dispersal (Wu *et al.,* 2025), while abundant charred cuticles indicate recurrent burning and anthropogenic disturbance (do Rosario Nogueira *et al.,* 2025). Moderate representation of Asteraceae and Euphorbiaceae reflects the local herbaceous and shrub vegetation, consistent with documented pollen productivity and tropical pollen rain patterns (Onuminya *et al.,* 2025). Dominant entomophilous Fabaceae trees are under-represented due to limited wind dispersal (Siddiqui, 2025). The relatively high occurrence of *Hagenia abyssinica* likely reflects long-distance atmospheric transport (Savina *et al.,* 2025), a factor critical in forensic environmental interpretation (Patel *et al.,* 2025; Küçük & Celenk, 2025). The pollen assemblage reflects productivity, dispersal efficiency, disturbance regimes, and atmospheric transport dynamics, providing a reliable environmental fingerprint for forensic matching in disturbed tropical landscapes.

Distinctive pollen assemblages can help reconstruct vehicle travel routes and destinations by providing location-specific pollen fingerprints (Laurence & Bryant, 2019; Orijemie & Israel, 2019). Since pollen composition reflects vegetation patterns and seasonal weather conditions, it offers time-sensitive evidence that can link vehicles to crime scenes and help challenge false alibis (Adekanmbi *et al.,* 2021). Integrating palynological data with GIS-based spatial analysis further improves environmental matching and vehicle tracking in investigations such as kidnapping, smuggling, human trafficking, and hit-and-run cases, thereby strengthening the accuracy and reliability of forensic investigations.

CONCLUSION

The study demonstrates that vehicle air filters effectively trap airborne pollen and spores from local plants. Temperature, humidity, rainfall, and wind influence the distribution of these bioaerosols along roadsides. Pollen and spores are primarily dispersed by nearby vegetation, with patterns shaped by plant type, flowering season, and local climate. Rainfall and humidity strongly affect pollen washout, while wind facilitates dispersal. The findings show the dynamic interaction between vegetation, meteorology, and human activity, providing a useful ecological baseline for environmental monitoring, public health forecasting, and forensic applications in tropical roadside environments.

DECLARATIONS

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