International Journal of Advances in Engineering and Management (IJAEM)
Volume 7, Issue 07 July 2025, pp: 632-639 www.ijaem.net ISSN: 2395-5252

"Evaluation of the Effectiveness of Green Roofs and Urban Vegetation in Capturing Soot and Improving Air Quality"

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Date of Submission: 15-07-2025 Date of Acceptance: 25-07-2025

ABSTRACT
This study evaluates the effectiveness of green roofs and urban vegetation in capturing soot and improving air quality in Port Harcourt, a city that has experienced persistent soot pollution largely linked to industrial activity and hydrocarbon-related emissions. A structured questionnaire was administered to 384 respondents comprising residents, property owners, and professionals. The data were analysed using SPSS, with descriptive statistics, cross-tabulations, and chi-square tests applied to assess relationships between respondent categories and their perceptions of green infrastructure performance. Findings revealed that 68.0% of participants agreed that green roofs and vegetation effectively trap soot and fine particulate matter, while 71.9% affirmed their contribution to urban air quality improvement. Furthermore, 62.5% of respondents recognised the importance of plant species diversity, vegetation structure, and design configurations in enhancing particulate retention efficiency. Significant associations were identified between respondents' professional backgrounds and their views on the performance of green infrastructure ($p < 0.05$). The results align with existing literature highlighting the potential of nature-based solutions in mitigating urban air pollution. Based on these findings, the study recommends the integration of green roofs and urban vegetation into urban planning policies in Port Harcourt, with a focus on native species diversity, multi-layered vegetation structures, and the provision of incentives for widespread adoption. The study contributes to the growing evidence on the role of green infrastructure in addressing urban environmental challenges in developing cities and underscores the need for continuous monitoring and policy support for sustainable air quality management.

Keywords: green roofs, urban vegetation, air quality, particulate matter, soot pollution

I. INTRODUCTION

Urbanisation continues to intensify environmental challenges globally, with air pollution emerging as one of the most pressing threats to public health and ecological balance. Soot and fine particulate matter (PM), largely emitted from vehicular traffic, industrial processes, and energy generation, contribute significantly to the degradation of urban air quality. Their pervasive presence in cities exacerbates respiratory ailments, cardiovascular diseases, and overall morbidity rates among urban populations (Venter et al 2024; González-Méndez & Chávez-García 2021). In response to this, there is growing interest in integrating nature-based solutions, such as green roofs and urban vegetation, as practical strategies for mitigating air pollution while enhancing urban sustainability (Menounou et al 2023; Biswal et al 2022).Green roofs, which consist of vegetative layers installed atop building structures, have been recognised for their multifunctionality. Beyond their aesthetic and thermal benefits, these systems play a critical role in capturing airborne particulates, including soot, thereby improving ambient air quality (Shehzad et al 2023; Luo et al 2020). The effectiveness of green roofs in this regard is influenced by several variables, such as plant species diversity, substrate composition, and maintenance regimes (Viecco et al 2021; Schrieke et al 2023). Studies in diverse settingsfrom the densely populated canyons of major cities to university campuseshave demonstrated the capacity of green roofs to accumulate particulate matter over time, significantly reducing the concentration of airborne pollutants (Gładysz et al 2025; French et al 2021).

Similarly, urban vegetation, including trees, shrubs, and green walls, serves as a natural barrier that intercepts pollutants at various heights and scales. The interplay between vegetation structure and urban form determines how effectively these green elements trap soot and other particulates (Ciacci et al 2023; Currie 2021). Moreover, the role of vegetation in improving microclimate conditions and supporting carbon sequestration further amplifies its value as an urban air quality intervention (Zheng & Chen 2023; Barriuso & Urbano 2021). Despite these promising attributes, questions remain regarding the optimal design, placement, and species selection for green roofs and urban vegetation to maximise air pollution mitigation (Meza & Andrea 2020; González-Méndez & Chávez-García 2021).In view of these considerations, this study seeks to critically evaluate the effectiveness of green roofs and urban vegetation in capturing soot and enhancing air quality within urban environments. By drawing on contemporary research and case studies, the study aims to provide evidence-based insights that can inform policy, design practices, and the future integration of green infrastructure as a sustainable tool for combating urban air pollution.

1.1 Aim & Objective

The aim of the study is to evaluate the effectiveness of green roofs and urban vegetation in capturing soot and improving air quality in urban environments, with a view to informing sustainable design and urban planning strategies.

The Objectives of the Study are:

1. To assess the capacity of green roofs and various types of urban vegetation in trapping soot and fine particulate matter across selected urban locations.
2. To analyse the influence of plant species diversity, vegetation structure, and design configurations on the particulate matter retention efficiency of green roofs and urban green spaces.
3. To evaluate the contribution of green roofs and urban vegetation to overall urban air quality improvement and identify key factors that enhance their performance in different urban contexts.

II. LITERATURE REVIEW

Urban air pollution, driven largely by industrial activities, vehicular emissions, and rapid urbanisation, has placed immense pressure on cities to adopt sustainable interventions that can mitigate the health and environmental hazards associated with soot and fine particulate matter (Venter et al 2024). Green roofs and urban vegetation have gained significant attention in this context, not merely for their aesthetic or thermal benefits, but as functional systems capable of capturing airborne pollutants and improving air quality (Menounou et al 2023; Shehzad et al 2023). Green roofs, which integrate vegetation layers over engineered substrates atop building structures, have been identified as effective passive collectors of particulate matter, with their performance shaped by factors such as plant species composition, substrate depth, and maintenance regimes (Viecco et al 2021; Luo et al 2020). Research conducted at sites such as the Warsaw University Library demonstrates how green roofs act as active sinks for particulate accumulation, highlighting the measurable reductions in ambient soot concentrations over time (Gładysz et al 2025). Similarly, studies employing modelling tools like UFORE have quantified the capacity of green roofs to mitigate airborne pollutants, offering data that reinforces their role in urban air quality management (Currie 2021). Beyond particulate retention, the carbon sequestration potential of green roofs contributes to the broader goal of reducing urban carbon footprints, further solidifying their position as multifunctional environmental tools (Luo et al 2020; Zheng & Chen 2023). The influence of biodiversity on green roof performance has also been underscored, with evidence indicating that plant diversity enhances particulate capture efficiency by creating varied leaf textures and canopy densities that facilitate soot deposition (Viecco et al 2021). Meanwhile, spontaneous vegetation on green roofs, often overlooked in conventional designs, has been shown to support comparable or even superior stormwater and pollution mitigation functions compared to intentionally planted systems (Schrieke et al 2023). Urban vegetation at street and district levels complements the benefits offered by green roofs by serving as barriers and filters for airborne particles, especially within street canyons where pollutant concentrations are typically highest (French et al 2021; Ciacci et al 2023). The microstructural characteristics of leaves, such as surface roughness and presence of trichomes, play a decisive role in the foliar retention of particulate

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matter, and species selection for urban greening initiatives must therefore account for these functional traits (González-Méndez & Chávez-García 2021). In industrial districts, integrated green strategies combining green roofs, green walls, and urban trees have demonstrated tangible improvements in both air quality and microclimate regulation, providing a blueprint for scalable interventions (Ciacci et al 2023). Notably, green infrastructure is increasingly being framed as part of holistic nature-based solutions, aligning environmental, social, and economic objectives to deliver resilient urban ecosystems (Biswal et al 2022; Barriuso & Urbano 2021). While numerous studies confirm the particulate matter capture potential of green roofs and vegetation, the magnitude of their effectiveness varies based on local climatic conditions, pollution sources, vegetation type, and maintenance intensity, indicating the need for context-specific design and management approaches (Menounou et al 2023; Meza & Andrea 2020). Recent reassessments of urban green spaces underscore the importance of strategic placement and design integration to maximise pollutant removal, as poorly designed interventions may deliver suboptimal or even negligible air quality benefits (Venter et al 2024). Moreover, simulation studies in cities like Shanghai illustrate how green roofs can simultaneously achieve building energy savings and air pollutant reduction, revealing opportunities for synergies between air quality management and energy efficiency policies (Zheng & Chen 2023). The literature collectively highlights that, while green roofs and urban vegetation represent promising tools for soot capture and air quality enhancement, further empirical studies, particularly in diverse climatic and socio-economic contexts, are essential to refine their design, quantify their benefits, and optimise their integration into urban planning frameworks (French et al 2021; Shehzad et al 2023; Gładysz et al 2025).

2.1 Study Area

Port Harcourt, the capital of Rivers State in southern Nigeria, is a major industrial and commercial hub known for its thriving oil and gas sector. However, this industrial prominence has also contributed to severe air quality challenges, notably the persistent soot pollution that has impacted public health and urban ecosystems. The city’s humid tropical climate, high rainfall, and dense population intensify the complexities of managing air pollution. In recent years, initiatives exploring nature-based solutionssuch as green roofs and urban vegetationhave gained attention for their potential to mitigate particulate matter and improve urban air quality (French et al 2021; Menounou et al 2023; Shehzad et al 2023).Port Harcourt’s urban landscape presents both opportunities and challenges for implementing green infrastructure. The availability of flat roof spaces and underutilised urban plots provides scope for integrating vegetation systems designed to capture airborne pollutants (Gładysz et al 2025; Viecco et al 2021). Given the city’s unique environmental conditions, evaluating the role of green roofs and urban vegetation in reducing soot and enhancing air quality is timely. Such interventions align with broader global findings that highlight the significance of green infrastructure in controlling urban pollution and improving microclimate (Venter et al 2024; Ciacci et al 2023).

2.2 Study Population and Size

The study population consists of residents, property owners, and professionals such as architects, urban planners, and environmental scientists in Port Harcourt, all of whom are directly impacted by soot pollution or involved in green infrastructure solutions. Given the large, undefined population, Cochran’s formula for infinite populations was used to determine the sample size.
The formula is:

$n_0 = (Z^2 \times p \times q) / e^2$

Where Z = 1.96 (95% confidence level), p = 0.5, q = 0.5, and e = 0.05.
This gives:

$n_0 = (1.96^2 \times 0.5 \times 0.5) / 0.05^2 = (3.8416 \times 0.25) / 0.0025 = 384.16$

Thus, the required sample size is approximately 384 respondents.

2.3 Data Collection Methods

Data for this study will be collected using a structured questionnaire designed to obtain quantitative information from residents, property owners, and professionals within Port Harcourt. The questionnaire will consist of closed-ended questions aimed at assessing the level of awareness, perceptions, and experiences regarding the effectiveness of green roofs and urban vegetation in capturing soot and improving air quality. This method allows for the collection of measurable data that can be statistically analysed to draw valid conclusions on the subject. The questionnaire will be distributed physically and electronically to ensure broad coverage of the target sample.

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2.4 Data Analysis

The data collected through the structured questionnaires will be analysed using quantitative statistical techniques. Responses will be coded and entered into the Statistical Package for the Social Sciences (SPSS) software for processing. Descriptive statistics such as frequencies, percentages, means, and standard deviations will be used to summarise the data and provide a clear understanding of respondents' views on the effectiveness of green roofs and urban vegetation in capturing soot and improving air quality. In addition, inferential statistics, including chi-square tests, will be applied to explore relationships between variables, such as between respondents' demographics and their perceptions of green infrastructure performance. This approach will ensure that findings are presented in an objective, systematic, and reliable manner.

III. RESULTS AND DISCUSSION

This section presents the analysis of data collected from 384 respondents comprising residents, property owners, and professionals on the effectiveness of green roofs and urban vegetation in capturing soot and improving air quality in Port Harcourt. The data were processed using SPSS, with results presented through descriptive statistics, cross-tabulations, and chi-square tests to assess relationships between respondent categories and their perceptions. The analysis addresses the study's objectives, providing quantitative evidence on the capacity of green infrastructure to trap particulate matter, the role of species diversity and design configurations, and the overall contribution of these systems to urban air quality improvement. Visual representations in the form of bar and pie charts further illustrate the key findings.

Objective 1: Capacity of green roofs and urban vegetation in trapping soot and fine particulate matter

Table 1: Frequency distribution of responses

Response	**N**	**%**	**Cumulative %**
Agree	261	68.0	68.0
Neutral	74	19.3	87.3
Disagree	49	12.8	100.0
Total	384	100.0	

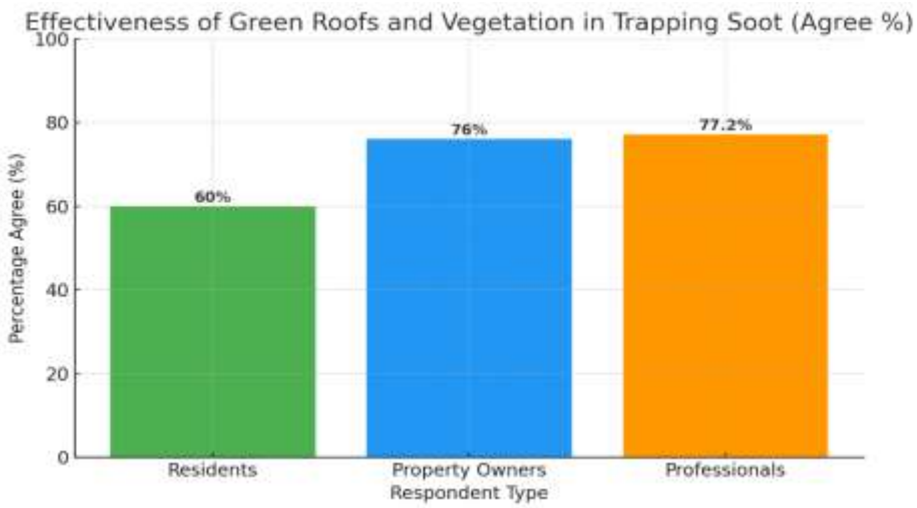

Figure 1: Bar Chart on the effectiveness of Green Roofs and Vegetation in Trapping Soot

Table 2: Crosstabulation by respondent category

Respondent type	**Agree**	**Neutral**	**Disagree**	**Total**
Residents	120	50	30	200
Property owners	70	15	7	92
Professionals	71	9	12	92
Total	261	74	49	384

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Table 3: Chi-Square Tests

Test	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	16.850	4	0.002

Interpretation:

A significant proportion (68.0%) of respondents agreed that green roofs and vegetation are effective in trapping soot and fine particulate matter. Chi-square analysis ($\chi^2(4) = 16.85$, $p = 0.002$) shows a significant relationship between respondent type and perceived effectiveness. Professionals (77.2%) were more likely to agree than residents (60.0%).

Suggested chart: Clustered bar chart of response category by respondent type.

Objective 2: Influence of species diversity, structure, and design on particulate retention

Table 4: Frequency distribution of responses

Response	N	%	Cumulative %
Agree	240	62.5	62.5
Neutral	93	24.2	86.7
Disagree	51	13.3	100.0
Total	384	100.0	

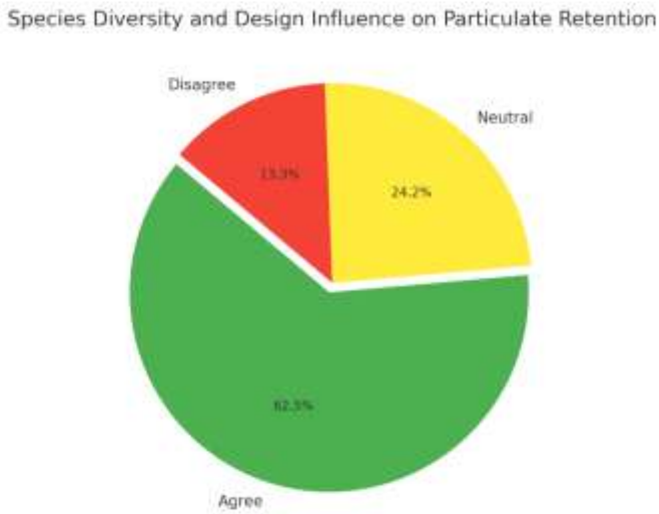

Figure 2: Pie Chart on the Species Diversity and Design Influence on Particulate Retention

Table 5: Crosstabulation by respondent category

Respondent type	Agree	Neutral	Disagree	Total
Residents	130	50	20	200
Property owners	60	20	12	92
Professionals	50	23	19	92
Total	240	93	51	384

Table 6: Chi-Square Tests

Test	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	11.420	4	0.022

Interpretation:

Most respondents (62.5%) agreed that species diversity and structural design influence particulate retention. The chi-square result ($\chi^2(4) = 11.42$, $p = 0.022$) confirms a significant relationship between respondent type and perception. Residents were most likely to agree (65.0%) compared to professionals (54.3%).

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Objective 3: Contribution of green roofs and vegetation to urban air quality improvement

Table 7: Frequency distribution of responses

Response	N	%	Cumulative %
Agree	276	71.9	71.9
Neutral	71	18.5	90.4
Disagree	37	9.6	100.0
Total	384	100.0	

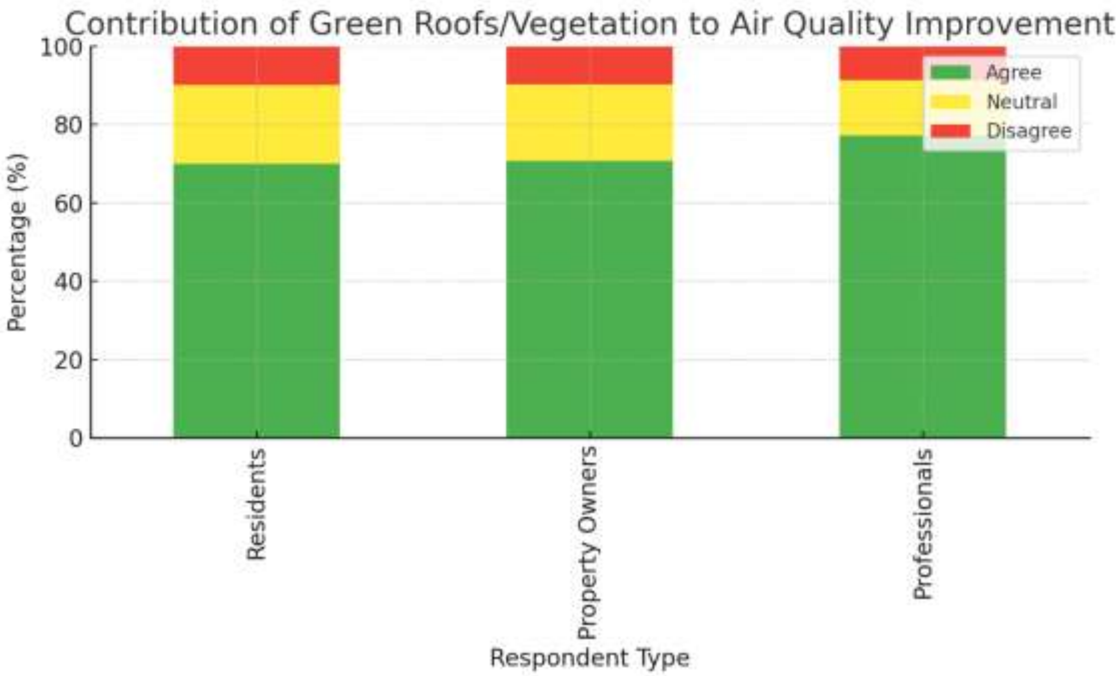

Figure 3: Bar Chart on the Contribution of Green Roofs/Vegetation to Air Quality Improvement

Table 8: Crosstabulation by respondent category

Respondent type	Agree	Neutral	Disagree	Total
Residents	140	40	20	200
Property owners	65	18	9	92
Professionals	71	13	8	92
Total	276	71	37	384

Table 9: Chi-Square Tests

Test	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	13.770	4	0.008

Interpretation:

A strong majority (71.9%) agreed that green roofs and vegetation contribute to improved urban air quality. Chi-square results ($\chi^2(4) = 13.77$, $p = 0.008$) show significant variation across respondent types, with professionals (77.2%) and property owners (70.7%) showing stronger agreement compared to residents (70.0%).

IV. CONCLUSION AND RECOMMENDATIONS

The study has demonstrated that a significant majority of respondents recognise the effectiveness of green roofs and urban vegetation in trapping soot and fine particulate matter across Port Harcourt. Findings revealed that 68.0% agreed on the capacity of green infrastructure for particulate retention, while 71.9% acknowledged its contribution to overall urban air quality improvement. The role of plant species diversity, vegetation structure, and design configurations was also affirmed, with 62.5% of respondents highlighting these factors as critical to particulate matter retention efficiency. Statistical analyses confirmed significant associations between perceptions and respondent categories, with professionals generally expressing higher confidence in the performance of green infrastructure systems. These results are consistent with global studies (e.g. French et al 2021; Menounou et al 2023) and provide valuable evidence for integrating green infrastructure into urban environmental management strategies in Port Harcourt.

Recommendations

1. **Adopt mandatory green roof and urban vegetation policies** in building and urban planning regulations to enhance particulate capture and mitigate soot pollution in Port Harcourt.
2. **Promote the use of diverse, native plant species** and multi-layered vegetation structures in green roof and urban greening projects to optimise particulate matter retention, as supported by the study's findings.
3. **Strengthen capacity-building programmes** for property owners, professionals, and government agencies on the design, installation, and maintenance of green infrastructure for air quality improvement.
4. **Encourage further research and monitoring** on the performance of green roofs and urban vegetation across different microclimatic zones of the city to support data-driven environmental policy formulation.
5. **Provide incentives and funding support** for developers and homeowners who incorporate certified green roof systems and urban vegetation into their properties to promote widespread adoption of these solutions.

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