When the Method Meets the Desert: How Environmental Models Fracture in Dust-Dominated Cities

Ronaldo Nassif[a*], Haoran Liu [b], Manni Bhatti [b]
[a] EnergyZone LLC, Al Qusais Ind. Third - Dubai
[b]UCL Department of Civil, Environmental and Geomatic Engineering, London, WC1E 6BT, UK
*This is the corresponding author

1. Introduction

Rapid urbanisation is transforming atmospheric and surface conditions at a pace that outstrips many cities' capacity to respond. Urban areas now generate a substantial share of global greenhouse gas emissions through changes in land use, transport, energy consumption, and industrial activity (4). One visible consequence is the urban heat island (UHI) effect, where built surfaces, sparse vegetation, and anthropogenic heat drive urban temperatures up to 5°C higher than surrounding rural zones (7, 11). This pattern is pronounced in Gulf cities such as Dubai, where minimum temperatures routinely exceed those of adjacent desert areas (5).

Evidence from the region underscores the moderating influence of vegetation even in harsh climates. Abulibdeh reports temperature differences of 1–6°C between urban and green areas, with cooling effects reaching 5°C in Abu Dhabi and 2°C in Dubai (2). These findings have fuelled the adoption of urban greening as a core component of climate-adaptation and liveability agendas. Beyond thermal regulation, greening is promoted for its potential to enhance comfort, support ecological functions, and deliver wider social benefits (16).

Yet even as greening and climate-adaptation initiatives accelerate, air pollution remains a persistent public-health challenge in rapidly expanding cities. Despite widespread adoption of emission-control policies aligned with World Health Organization (WHO) guidelines (10), more than 80% of urban residents worldwide continue to be exposed to concentrations of $PM_{2.5}$, PM_{10}, and ozone that exceed recommended thresholds (16). In the UAE, emissions from traffic, energy production, heavy industry, and petroleum-related activities compound these risks, with particulate matter linked to elevated rates of premature mortality (9, 19). These pressures are intensified by regional climatic conditions such as extreme heat, low humidity, and frequent dust events, which complicate mitigation efforts and shape exposure patterns in ways that differ markedly from temperate settings (14).

Urban green infrastructure—street trees, vegetation barriers, green roofs, and vertical greening—has therefore attracted significant attention as a potential co-benefit strategy within sustainability and adaptation agendas. Vegetation can improve air quality through pollutant deposition, particulate interception, and microclimate regulation, although the magnitude and reliability of these effects vary substantially across contexts (1, 3, 21). Beyond environmental performance, green spaces contribute to social, aesthetic, and recreational wellbeing, enhancing urban liveability and supporting physical and mental health (16). Yet the capacity of greening to reduce air pollution remains contested. Vegetation can also impede airflow, alter dispersion patterns, and in some cases exacerbate local pollutant concentrations depending on species traits, urban morphology, and climatic conditions (12, 15, 20).

Urban Green Spaces (UGSs) themselves are diverse and lack a universally accepted definition, typically encompassing parks, community gardens, meadows, woodlands, and increasingly rooftop and vertical greenery (6, 18). In fast-growing cities, these spaces are under pressure from densification and land-use change, which replace vegetated areas with impervious surfaces and intensify heat, pollution, and discomfort (8, 17). Dubai exemplifies this tension. While the city has invested heavily in green infrastructure—from large parks such as Mushrif Park to landscaped boulevards—its extreme climate and recurrent dust events limit the extent to which vegetation can meaningfully influence air quality (13). These conditions underscore the need for context-specific assessments rather than assumptions imported from temperate-city literature.

Despite substantial investment in greening, a critical question remains: are green spaces located where environmental need is greatest? In many cities, vegetation is unevenly distributed and often fails to coincide with areas experiencing the highest pollution burdens. This spatial mismatch raises concerns not only about environmental effectiveness but also about environmental justice.

1.1 When the Method Meets the City

The empirical study that accompanies this reflective paper set out to examine whether UGS distribution in Dubai aligns with pollution hotspots and to evaluate the extent to which greening contributes to air-quality outcomes. By integrating long-term monitoring data with GIS-based spatial analysis, the study provided a nuanced assessment of both the effectiveness and the equity implications of urban greening in an arid, rapidly developing metropolis.

Yet as the empirical analysis unfolded, a second story began to surface—one not about the city, but about the method itself. The spatial mismatch between greening and pollution was true, but the tools used to detect it proved unexpectedly fragile. Buffers behaved unpredictably; vegetation categories were too coarse to capture functional differences; particulate datasets were incomplete; and dust repeatedly overwhelmed the analytical signal. The more the method was pushed to explain the city, the more it exposed its own limitations.

This paper therefore shifts focus. Rather than revisiting the empirical results, it interrogates the methodological journey that produced them. It asks what it means when a method, widely used and theoretically sound in temperate-city research, begins to fracture in an arid, dust-dominated metropolis. It treats these fractures not as errors to be corrected, but as “beautiful failures”. These failures illuminate the structural realities of arid-city environments and the assumptions embedded in our analytical tools.

What follows is a reflective, method-centred narrative. It reconstructs what the method was designed to do, traces where and why it broke down, and draws out the broader lessons for environmental modelling in cities where dust, heat, and infrastructural unevenness shape both pollution and the data used to study it. In doing so, the paper argues for a more context-sensitive, humble, and adaptive approach to modelling environmental processes in arid megacities.

Author Note

Relationship Statement

This reflective paper accompanies and extends the empirical study (22) published as "Urban Green Space Distribution and Air Quality in Dubai: A Spatial Analysis of Environmental Mismatch" in Local Environment (2026). While the original article presents the full analytical results, this companion piece focuses on the methodological journey behind those findings. It examines how established modelling tools behaved when applied in a dust-dominated arid city and documents the limitations, contradictions, and "beautiful failures" that emerged. Together, the two papers offer both an empirical assessment of Dubai's green space–pollution dynamics and a methodological critique intended to support more context-sensitive environmental modelling in arid megacities.

2. What Was Intended: The Architecture of the Original Method

The empirical study began with a methodological design that was both defensible and aligned with established environmental-modelling practice. The approach drew on tools that are widely used: 500-metre buffers around monitoring stations to represent local greenness exposure (23); vegetation layers derived from OpenStreetMap (OSM) and processed through NextGIS; regression models linking greenspace area to NO_2, $PM_{2.5}$, and PM_{10}; and $PM_{2.5}/PM_{10}$ ratios as a proxy for distinguishing dust from anthropogenic particulates. These elements reflected methodological conventions that have shaped urban greening and air-quality research for more than a decade (24, 25).

The assumptions used in the design were equally conventional as they were grounded in a literature dominated by temperate-city case studies, where vegetation datasets are richer, pollution sources more stable, and meteorological conditions less extreme. It was assumed that vegetation would be spatially meaningful at a neighbourhood scale; that greenspace categories would be sufficiently detailed to capture functional ecological differences; pollution data would be temporally consistent across stations; and dust and anthropogenic particulates could be separated cleanly using established ratio-based heuristics.

However, the method carried the weight of Dubai's data landscape as $PM_{2.5}$ was missing for half the study period, and monitoring stations varied in coverage and completeness. Vegetation categories were coarse, unable to distinguish canopy density or species. Meteorological confounders—wind, humidity, dust storms—were only partially captured. These constraints were, acknowledged, and noted in the empirical paper. What was less visible, however, was how profoundly they would shape the behaviour of the method itself.

The design was therefore both reasonable and fragile. It was reasonable in its alignment with established practice, but fragile in its dependence on assumptions that would soon prove incompatible with the realities of an arid, dust-dominated metropolis.

3. Where the Method Broke Down: A Narrative of Contradictions

The analytical journey that followed was marked by a series of fractures—some predictable, others unexpected, and a few that resisted explanation altogether. These fractures form the core of this reflective account.

3.1 Unexpected or Null Findings

Green space showed inconsistent correlations with $PM_{2.5}$ and PM_{10}, even in areas where vegetation was abundant. A seemingly strong city-wide correlation between NO_2 and tree counts dissolved under scrutiny, revealed to be a temporal artefact rather than a vegetation effect. Stations adjacent to large parks, such as Mushrif Park, continued to exhibit high PM_{10} levels, contradicting expectations that vegetation would moderate particulate concentrations. Conversely, dense areas with little green space did not always show proportionally higher $PM_{2.5}$.

The results proved destabilising, revealing that the method was not simply missing expected patterns but was producing false positives — detecting patterns that were not actually present.

3.2 Structural Breakdowns

As the analysis progressed, deeper structural failures became apparent. The 500-metre buffer, intended to capture neighbourhood-scale environmental conditions, proved too coarse to reflect the microscale dynamics of pollution in a city shaped by wind exposure, traffic corridors, and discontinuous vegetation. The vegetation categories derived from OSM were too aggregated to capture functional greening, collapsing diverse ecological structures into broad labels that obscured meaningful variation.

Dust, meanwhile, overwhelmed the vegetation signal in particulate modelling. PM_{10} remained persistently high across the city, driven by natural dust rather than anthropogenic emissions. Temporal trends—regulatory changes, construction cycles, pandemic-related emission shifts—confounded spatial interpretation, making it difficult to disentangle vegetation effects from broader structural forces.

These breakdowns were not isolated errors. They were systemic, revealing a method struggling to operate in a context for which it had not been designed.

3.3 Irreconcilable Contradictions

The most revealing moments were those in which the method produced contradictions that no model could reconcile. The greenest stations sometimes had the highest PM_{10}. Stations with no green space occasionally recorded moderate pollutant levels. $PM_{2.5}/PM_{10}$ ratios behaved inconsistently across stations, undermining their use as a proxy for source differentiation.

These contradictions were not noise. They were signals—signals that the assumptions underpinning the method were misaligned with the environmental realities of Dubai. They pointed to a deeper mismatch between the analytical tools and the city they sought to explain.

4. Why the Method Failed: Structural Limits of Arid-City Modelling

The failures described above were not methodological accidents. They were structural consequences of applying temperate-city methods to an arid, dust-dominated environment.

4.1 Imported Assumptions That Did Not Hold

Methods developed in temperate cities assume that vegetation meaningfully alters pollutant dispersion, that greenspace datasets capture functional ecological structure, and that pollution sources are relatively stable and anthropogenic. In Dubai, these assumptions collapse. Vegetation is often ornamental rather than functional, designed for aesthetic or recreational purposes rather than ecological performance. Dust storms disrupt typical pollutant–vegetation relationships, introducing particulate loads that vegetation cannot meaningfully intercept. Pollution sources vary across time and space, shaped by construction cycles, industrial activity, and meteorological conditions.

4.2 What the Failures Reveal About Arid-City Modelling

The failures reveal structural truths about environmental modelling in arid cities. Dust overwhelms vegetation effects, making particulate modelling unstable. Greening initiatives are not always aligned with air-quality objectives, limiting their capacity to influence pollutant concentrations. Air-quality stations are not sited to capture exposure gradients, reducing the spatial sensitivity of monitoring networks. Data infrastructures are uneven and incomplete, constraining the resolution and reliability of analytical tools.

These truths are not unique to Dubai. They reflect broader challenges faced by arid megacities across the Gulf, North Africa, and Central Asia.

4.3 Implications for Future Research

Future research must therefore adopt more context-sensitive approaches. Species-level vegetation data are needed to capture functional ecological differences. Meteorological data must be integrated to account for wind patterns, dust events, and humidity. Multiscale spatial modelling is required to reflect the complex interplay between microscale and city-wide processes. Environmental monitoring must be better aligned with urban planning to ensure that data capture reflects exposure gradients and environmental need.

5. Lessons Learned: Towards a More Context-Sensitive Methodology

The methodological journey documented here offers several lessons for researchers working in arid megacities.

Lesson 1: Standard GIS buffer methods may be inappropriate in low-density, wind-exposed cities.
Buffers assume spatial coherence that may not exist in environments shaped by discontinuous vegetation and strong wind dynamics.

Lesson 2: Temporal trends can masquerade as spatial causality.
Long-term regulatory, economic, and meteorological shifts can produce correlations that appear spatial but are in fact temporal artefacts.

Lesson 3: Vegetation datasets in arid cities are too coarse for pollution modelling.
OSM-derived categories obscure functional differences that matter for pollutant deposition and dispersion.

Lesson 4: Dust overwhelms vegetation effects, destabilising particulate modelling.
In dust-dominated environments, vegetation plays a limited role in moderating PM_{10} and $PM_{2.5}$.

Lesson 5: Negative results are essential for improving environmental-modelling frameworks.
Failures reveal the limits of existing tools and point toward new methodological directions.

6. Contribution: The Value of Failure in Environmental Modelling

This paper argues that methodological reflection is not ancillary to empirical research but essential to building robust, context-sensitive modelling practices. Failure, when documented carefully, becomes a form of methodological knowledge. It reveals the assumptions embedded in analytical tools, exposes their limits, and highlights the need for new frameworks that reflect the environmental realities of arid cities.

This reflective paper complements the empirical study by explaining not only what was found, but why the method struggled to find it. It offers a narrative of methodological fragility that is as important as the empirical findings themselves.

7. Conclusion: Rethinking Methodological Assumptions in Arid Cities

The spatial mismatch between greening and pollution in Dubai is real, but the tools used to detect it were fragile. The failures documented here are not errors to be hidden but insights to be shared. They show that environmental modelling in arid cities requires new assumptions, new data infrastructures, and new methodological humility. By embracing failure as a source of knowledge, researchers can develop more robust, context-sensitive approaches to environmental analysis in desert environments.

1. Abhijith KV, Kumar P, Gallagher J, McNabola A, Baldauf R, Pilla F, et al. Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments – A review. *Atmos Environ*. 2017;162:71–86.
2. Abulibdeh A. Analysis of urban heat island characteristics and mitigation strategies for eight arid and semi-arid Gulf Region Cities. *Environ Earth Sci*. 2021;80(7).
3. Akasha H, Ghaffarpasand O, Pope FD. Air pollution and economic growth in Dubai: a fast-growing Middle Eastern City. *Atmos Environ X*. 2024;21:100246.
4. Anderson V, Gough WA. Evaluating the potential of nature-based solutions to reduce ozone, nitrogen dioxide, and carbon dioxide through a multi-type green infrastructure study in Ontario, Canada. *City Environ Interact*. 2020;6:100043.
5. Ballard I, Mazzeno A. Green spaces in Dubai. ArcGIS StoryMaps; 2024. Accessed 2024 Jun 20.
6. De Haas W, Hassink J, Stuiver M. The role of urban green space in promoting inclusion: Experiences from the Netherlands. *Front Environ Sci*. 2021;9.
7. Elhacham E, Alpert P. Temperature patterns along an arid coastline experiencing extreme and rapid urbanization: Case study Dubai. *Sci Total Environ*. 2021;784:147168.
8. Fu J, Fu H, Zhu C, Sun Y, Cao H. Assessing the health risk impacts of urban green spaces on air pollution: Evidence from 31 China's provinces. *Ecol Indic*. 2024;159:111725.
9. Li Y, Gibson JM, Jat P, Puggioni G, Hasan M, West JJ, et al. Burden of disease attributed to anthropogenic air pollution in the United Arab Emirates. *Sci Total Environ*. 2010;408(23):5784–93.
10. Mandal M, Popek R, Przybysz A, Roy A, Das S, Sarkar A. Breathing fresh air in the city: Implementing avenue trees as a sustainable solution to reduce particulate pollution in urban agglomerations. *Plants*. 2023;12(7):1545.
11. McDonald AG, Bealey WJ, Fowler D, Dragosits U, Skiba U, Smith RI, et al. Quantifying the effect of urban tree planting on PM10 in two UK conurbations. *Atmos Environ*. 2007;41(38):8455–67.
12. Meskens D, Maas P, de Souza F, Molderez I. The effect of urban green spaces on air quality and respiratory diseases. 2023.
13. Nassar AK, Blackburn GA, Whyatt JD. What controls the magnitude of the daytime heat sink in a desert city? *Appl Geogr*. 2017;80:1–14.
14. Osipov S, Chowdhury S, Crowley JN, Tadic I, Drewnick F, Borrmann S, et al. Severe atmospheric pollution in the Middle East is attributable to anthropogenic sources. *Commun Earth Environ*. 2022;3(1).
15. Salmond JA, Tadaki M, Vardoulakis S, Arbuthnott K, Coutts A, Demuzere M, et al. Health and climate-related ecosystem services provided by street trees. *Environ Health*. 2016;15(S1).
16. Sicard P, Agathokleous E, Araminiene V, Carrari E, Hoshika Y, De Marco A, et al. Should we see urban trees as effective solutions to reduce increasing ozone levels in cities? *Environ Pollut*. 2018;243:163–76.
17. Száraz L. The impact of urban green spaces on climate and air quality in cities. *Geogr Locality Stud*. 2014;2:326–54.

18. World Health Organization. Urban green spaces and health. 2016. Accessed 2024 Jun 1.
19. Willis HH, MacDonald Gibson J, Shih RA, Geschwind S, Olmstead S, Hu J, et al. Prioritizing environmental health risks in the UAE. *Risk Anal*. 2010;30(12):1842–56.
20. Xing Y, Brimblecombe P. Trees and parks as “the lungs of cities.” *Urban For Urban Green*. 2020;48:126552.
21. Yin S, Shen Z, Zhou P, Zou X, Che S, Wang W. Quantifying air pollution attenuation within urban parks. *Environ Pollut*. 2011;159(8–9):2155–63.
22. Nassif, R., Liu, H., & Bhatti, M. (2026). Spatial misalignment between urban greening initiatives and air pollution hotspots in Dubai. *Local Environment*, 1–25. https://doi.org/10.1080/13549839.2026.2656610.
23. Mazumdar S, Knibbs LD, Browning MHEM, Huang WZ, Jalaludin B. Greenness Exposure Assessment Methods. Green Space and Human Health in China. 2024;5–26.
24. Idris, A.B., Hossain, M.M., Islam, M.A. *et al.* Green Infrastructure and Urban Air Quality: A Semi-Systematic Review of Multiscale Evidence, Methodologies, and Policy-Relevant Insights. *Water Air Soil Pollut* **236**, 993 (2025). https://doi.org/10.1007/s11270-025-08505-x.
25. Sun Y, Guan Y, Zhang B, Zhou Y, Du L, Zhu C. Air PM10,2.5 removal by urban green space under urban realistic stressors. *Atmosphere*. 2024;15(12):1443. doi:10.3390/atmos15121443.