Reclaiming Metro Viaduct Buffers: A GIS-Based Nature-Based Solutions Framework for Chennai

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Abstract:

Introduction: *Elevated metro corridors in urban areas improve transportation but create underutilized ground-level spaces known as Metro Viaduct Buffers (MVBs). These neglected areas pose challenges such as heat accumulation, pollution, and poor connectivity. This study investigates how these spaces can be repurposed through Nature-Based Solutions (NBS) and GIS-based analysis to improve urban resilience and environmental quality.* ***Methods:*** *Chennai, a rapidly urbanizing Indian city, was selected as the study area. GIS tools were used to identify and categorize MVBs based on land surface temperature, pollution levels, land use context, and physical conditions. Data from Land sat imagery, DEMs, and urban planning maps were analyzed using Arc GIS. Each site was assessed to determine the feasibility of applying NBS interventions.* ***Results:*** *Findings show that MVBs are unevenly distributed across Chennai, with elevated environmental stress in high-density commercial and transit zones. Urban heat island (UHI) hotspots and pollution clusters were identified under viaducts, particularly in areas with low vegetation cover. Based on spatial and environmental data, tailored NBS strategies such as urban forests, bio swales, shaded pedestrian corridors, and vertical gardens were proposed for different site types.* ***Discussion:*** *The study presents a scalable GIS-NBS framework for redeveloping MVBs, enhancing microclimate regulation, air quality, and pedestrian accessibility. The framework provides clear design and policy guidelines for urban planners. The pilot case study demonstrates replicability across other Indian cities facing similar challenges.* ***Conclusion:*** *Transforming MVBs using data-driven, nature-integrated strategies offers a path toward inclusive, low-carbon urban development. The proposed approach supports climate resilience, ecological restoration, and improved public space quality in infrastructure-dominated urban contexts.*

Keywords: *Metro Viaduct Buffers, Nature-Based Solutions, GIS Mapping, Urban Heat Islands, Green Infrastructure, Chennai.*

Introduction:

The rapid expansion of urban transportation infrastructure has significantly altered the spatial dynamics of cities. Elevated metro corridors, while improving connectivity and reducing congestion, often leave behind neglected spaces beneath viaducts, known as Metro Viaduct Buffers (MVBs). Despite their strategic urban location, these spaces remain underutilized, fragmented, and environmentally degraded, often transforming into heat islands, pollution hotspots, and sites of encroachment. Their current condition not only affects the urban aesthetic and ecological balance but also restricts their potential as functional public spaces. This study explores the MVBs by integrating Nature-Based Solutions (NBS) with GIS-based spatial analysis to develop climate-resilient urban interventions. By assessing land surface temperature (LST), flood vulnerability, and air pollution levels, this research identifies high-impact sites for green infrastructure integration. Drawing from global best practices in transit infrastructure reuse, the study proposes a scalable urban resilience framework that reimagines metro viaduct spaces as shaded pedestrian corridors, urban forests, and water-sensitive landscapes, contributing to a greener, cooler, and more livable city. Urban perception is shaped by landmarks, edges, districts, nodes, and paths key elements defined by Lynch(Lynch, 2008)in his theory of The Image of the City. Metro viaducts, as dominant infrastructure, serve as major urban edges, while the voids beneath them function as disruptive gaps in the city's spatial continuity. When left unplanned, MVBs become negative landmarks, reinforcing urban decay. However, through strategic interventions, these voids can be redefined as positive urban identifiers, offering shaded pedestrian corridors, green transit hubs, and micro-parks. Successful MVB transformations contribute to urban identity, making them recognizable as eco-friendly, livable, and accessible urban spaces (Mehta, 2014).By leveraging Nature-Based Solutions and place-sensitive design, metro viaduct buffers can be reclaimed as functional urban corridors, enhancing mobility, biodiversity, and social engagement while mitigating the negative spatial and environmental impacts of transit infrastructure. By reviewing existing literature and global case studies on Infrastructure-Induced Void Spaces (IIVS) under metro viaducts, the key challenges associated with Metro Viaduct Buffers (MVBs) have been categorized into physical, environmental, social, economic, and policy-related factors(Carmona, 2004; Hashem et al., 2022; Lynch, 2008; Mehta, 2014).The objectives are,

- To spatially map and categorize Metro Viaduct Buffers (MVBs) using GIS, assessing their environmental conditions, surface characteristics, and potential for revitalization.
- To develop and propose practical Nature-Based Solutions (NBS), including urban forests, vertical gardens, shaded pedestrian pathways, and bioswales, to transform Metro Viaduct Buffers into comfortable, usable, and inviting public spaces..

Literature review:

Understanding Metro Viaduct Buffers (MVBs) and Infrastructure-Induced Void Spaces (IIVS):

A growing body of research explores Nature-Based Solutions (NBS) as a sustainable approach for transforming Metro Viaduct Buffers (MVBs) into climate-resilient, multifunctional urban spaces. NBS interventions include urban forests, bioswales, vertical gardens, and permeable pavements, all of which can effectively reduce urban heat, manage stormwater, and improve air quality (Silvestrini et al., 2021; Pauleit et al., 2021). These nature-integrated strategies provide long-term ecological and social benefits, making them a viable solution for enhancing metro buffer spaces and integrating them into urban planning frameworks.

One of the primary benefits of NBS is urban cooling and mitigation of the urban heat island (UHI) effect. The concrete-heavy nature of metro viaducts leads to excessive heat absorption during the day and limited heat dissipation at night, exacerbating local temperature levels. Integrating green corridors, shaded vegetation, and vertical gardens can lower temperatures and create comfortable microclimates, making these spaces more pedestrian-friendly and thermally efficient (Pauleit et al., 2021). Similarly, stormwater management and flood control are key considerations in MVB redevelopment. The impermeable surfaces beneath metro viaducts contribute to poor drainage and urban flooding, especially during monsoons. Implementing bioswales, rain gardens, and permeable pavements can enhance groundwater absorption and flood resilience, mitigating risks associated with water stagnation and surface runoff (Silvestrini et al., 2021).

Another significant challenge within MVBs is air pollution accumulation due to high vehicular emissions beneath metro viaducts. Congestion in these areas traps particulate matter and gaseous pollutants, reducing local air quality and negatively impacting pedestrian health. The introduction of vegetation barriers, phytoremediation strategies, and green walls can help filter pollutants, absorb carbon emissions, and improve air quality (Sehrawat & Shekhar, 2023). Additionally, biodiversity enhancement and ecological connectivity are critical aspects of MVB regeneration. Metro viaduct spaces typically lack greenery, leading to poor urban biodiversity and ecological disconnection. Integrating pollinator gardens, native plantings, and linear green corridors can restore biodiversity and create habitat networks, fostering urban ecological resilience (Bonilla Brenes et al., 2024).

Beyond environmental benefits, NBS interventions also contribute to social and recreational improvements. Metro viaduct spaces are often perceived as unsafe and unattractive, discouraging public use and social interaction. Well-designed pedestrian pathways, shaded seating areas, and community spaces can transform these spaces into active urban hubs, fostering a sense of place, safety, and social engagement (George, 2022). By incorporating NBS strategies into MVB redevelopment, these underutilized urban voids can be repurposed into cooler, greener, and more inclusive environments, improving overall urban livability and sustainability.

While Infrastructure-Induced Void Spaces (IIVS) including spaces beneath flyovers, elevated highways, and underutilized transit corridorshave been widely studied, Metro Viaduct Buffers (MVBs) remain largely underexplored in the context of adaptive reuse and Nature-Based Solutions (NBS). The majority of research on transit infrastructure voids has focused on flyover spaces (Pauleit et al., 2021), highway underpasses (Brokking et al., 2021), and elevated rail infrastructure in high-density cities (Sehrawat & Shekhar, 2023). However, there is limited academic discourse on the specific spatial, environmental, and socio-economic challenges associated with MVBsdespite their increasing prevalence in rapidly urbanizing cities like Chennai.Current urban planning frameworks primarily consider metro viaducts from a transit-oriented development (TOD) perspective, focusing on station areas rather than the continuous stretches between them (O'Donnell et al., 2021). This gap in urban policies and design strategies results in MVBs being left unplanned, leading to urban fragmentation, inefficient land use, and environmental degradation. Additionally, while NBS strategies for urban heat mitigation, air pollution reduction, and stormwater management have been applied to parks, green roofs, and roadside vegetation (Silvestrini et al., 2021), their potential application within MVBs remains unexplored. The lack of empirical studies analyzing the feasibility of NBS-driven MVB transformations contributes to the absence of standardized policies or design guidelines for integrating MVBs into Chennai's green infrastructure network (George, 2022).

Methodology

Context Selection: Chennai, one of India's rapidly growing metropolitan cities, faces significant urbanization pressures characterized by rising population density, traffic congestion, pollution, and limited availability of green open spaces. The Chennai Metro Rail network, designed to ease transportation challenges, has introduced extensive elevated metro corridors throughout the city. While these corridors have improved mobility, they have simultaneously created underutilized urban spaces at ground level, known as Metro Viaduct Buffers (MVBs). Typically, these MVB spaces are neglected in urban planning, transforming into fragmented, inaccessible, and environmentally degraded zones, exacerbating urban heat islands, air pollution, pedestrian barriers, and flood vulnerability. Given Chennai's tropical climate, characterized by high temperatures, monsoon-driven flooding, and increasing pollution due to traffic congestion, MVBs represent a significant but overlooked opportunity for enhancing the city's resilience through strategic urban interventions.

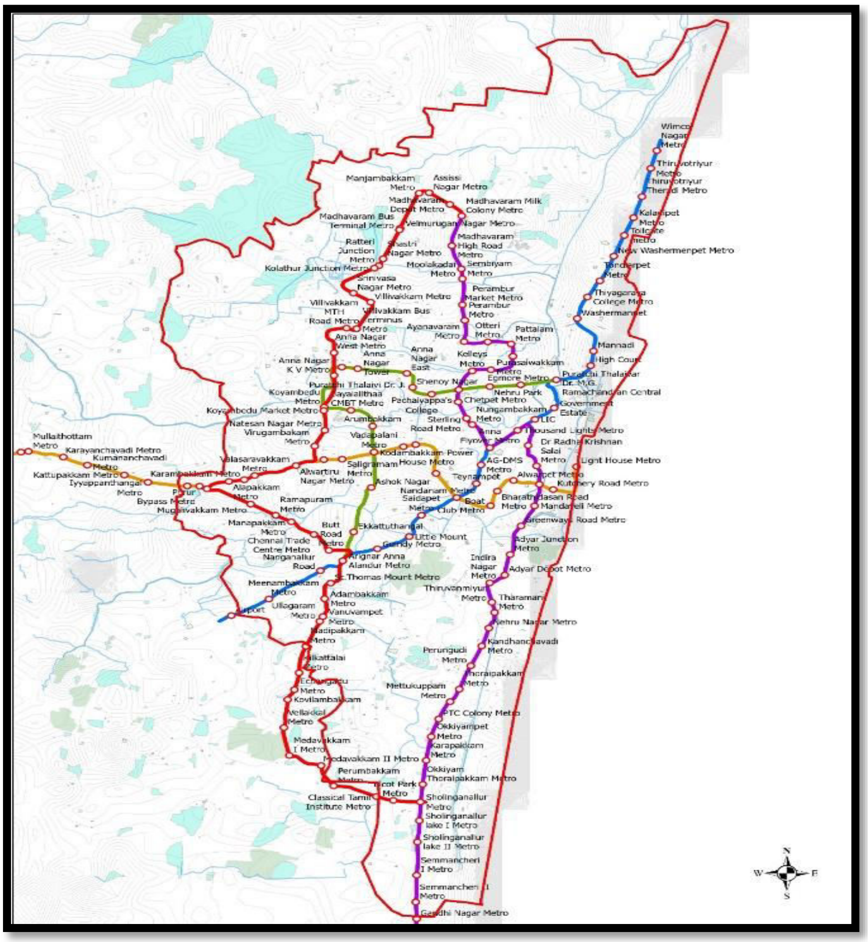

Figure 01: Illustrates the current Chennai Metro network, highlighting both the operational (existing) metro corridors and the proposed metro expansion under future
(**Source:** CMRL)

To achieve the first research objective to spatially map and categorize Metro Viaduct Buffers (MVBs) using GIS, assessing their environmental conditions, surface characteristics, and potential for revitalization the study employed a detailed GIS-based spatial analysis. This involved acquiring relevant spatial datasets such as satellite imagery (Landsat 8/9), Digital Elevation Models (DEM), metro alignment and station data from Chennai Metro Rail Limited (CMRL), and land-use information from Chennai's master planning authorities. Using ArcGIS software, these datasets were processed and analyzed to precisely map the locations and spatial extents of MVBs throughout Chennai. Each identified buffer space was then categorized based on their environmental conditions, current physical surface characteristics (paved, unpaved, vegetated), and the surrounding land use context (commercial, residential, industrial, transit-oriented). The GIS-based categorization helped in clearly identifying specific areas most suitable for redevelopment and interventions, thereby setting a solid, data-driven foundation for subsequent design strategies.

Secondly, based on the outcomes of the spatial analysis, the study proposed context-sensitive Nature-Based Solutions (NBS) to address identified environmental challenges and functional deficiencies. High heat-stress MVBs were recommended for urban forests, shaded corridors, and vertical gardens to mitigate the urban heat island effect. For pollution-prone spaces, vegetation-based interventions such as phytoremediation buffers, green walls, and roadside tree planting were proposed. Areas identified with pedestrian accessibility issues and fragmentation were targeted with pedestrian-friendly designs, green corridors, and community-focused spaces to enhance urban connectivity.

In summary, by contextualizing the urban challenges specific to Chennai and systematically applying GIS-based analysis coupled with landscape-driven NBS strategies, the methodology aims to establish an evidence-based framework for reclaiming Metro Viaduct Buffer spaces, contributing to enhanced urban sustainability and resilience.

Result and Discussion

The GIS-based spatial analysis of Metro Viaduct Buffers (MVBs) provides a comprehensive understanding of their distribution, environmental stressors, and potential for adaptive reuse. Figure 1 and 2 establish the spatial framework for MVB analysis by mapping the existing and proposed Chennai Metro network along with elevated metro corridors where MVBs exist. The Figure 2 focuses on only the elevated metro rail sections, eliminating underground routes where MVBs do not exist. It also marks metro station locations, which play a role in accessibility, urban integration, and land-use impact. Void spaces beneath elevated viaducts are scattered across the city's urban fabric, with some located in dense commercial zones while others are in residential or industrial areas.

The spatial distribution of MVBs suggests that some areas may require pedestrian integration strategies (e.g., shaded walkways, cycle paths), while others may need environmental interventions (e.g., urban forests, pollution mitigation).Proximity to metro stations affects land use, with MVBs near transit hubs often experiencing higher pollution exposure and pedestrian congestion, requiring air-filtering green buffers and cooling interventions.

The identification of these void spaces through GIS mapping provides crucial spatial context and enables precise prioritization of intervention sites for subsequent NBS implementation. These findings will guide targeted NBS strategies tailored specifically for enhancing the environmental quality, improving urban aesthetics, and promoting public usage within these metro viaduct buffers.

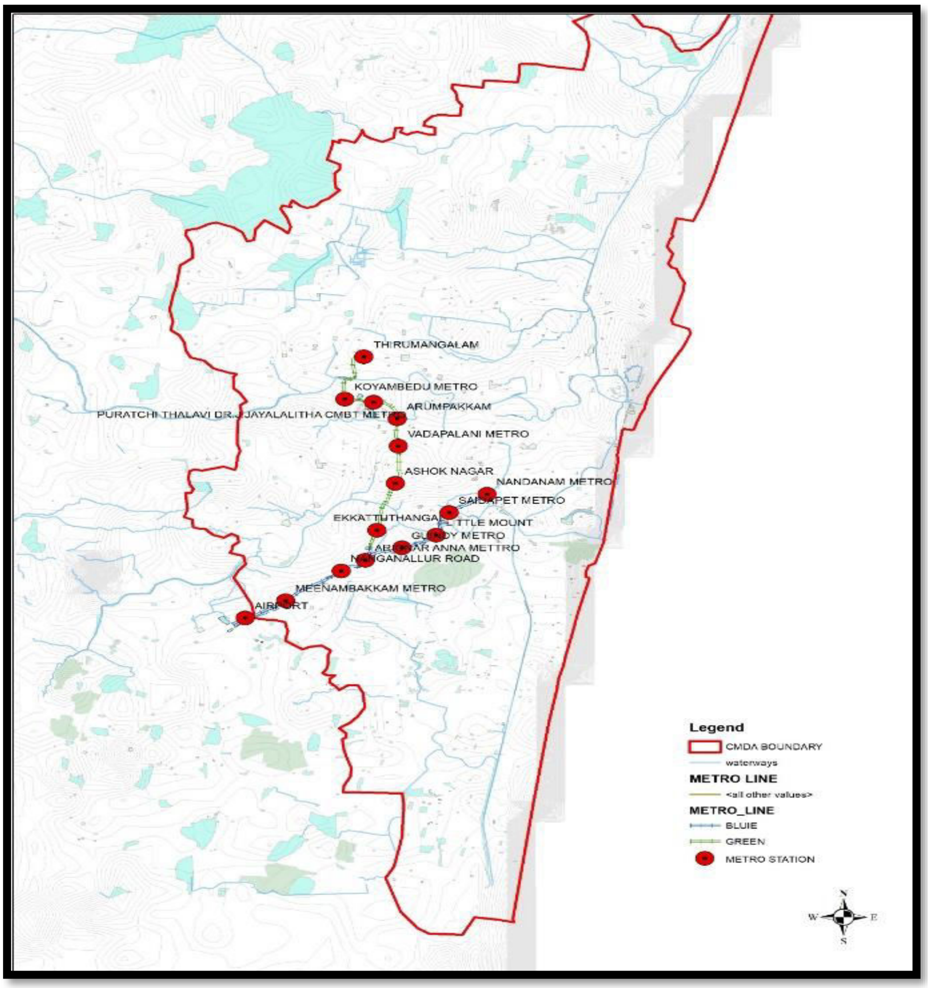

Figure 02: Presents the spatial distribution of the elevated metro corridors in Chennai, along with metro station locations
(**Source:** Author)

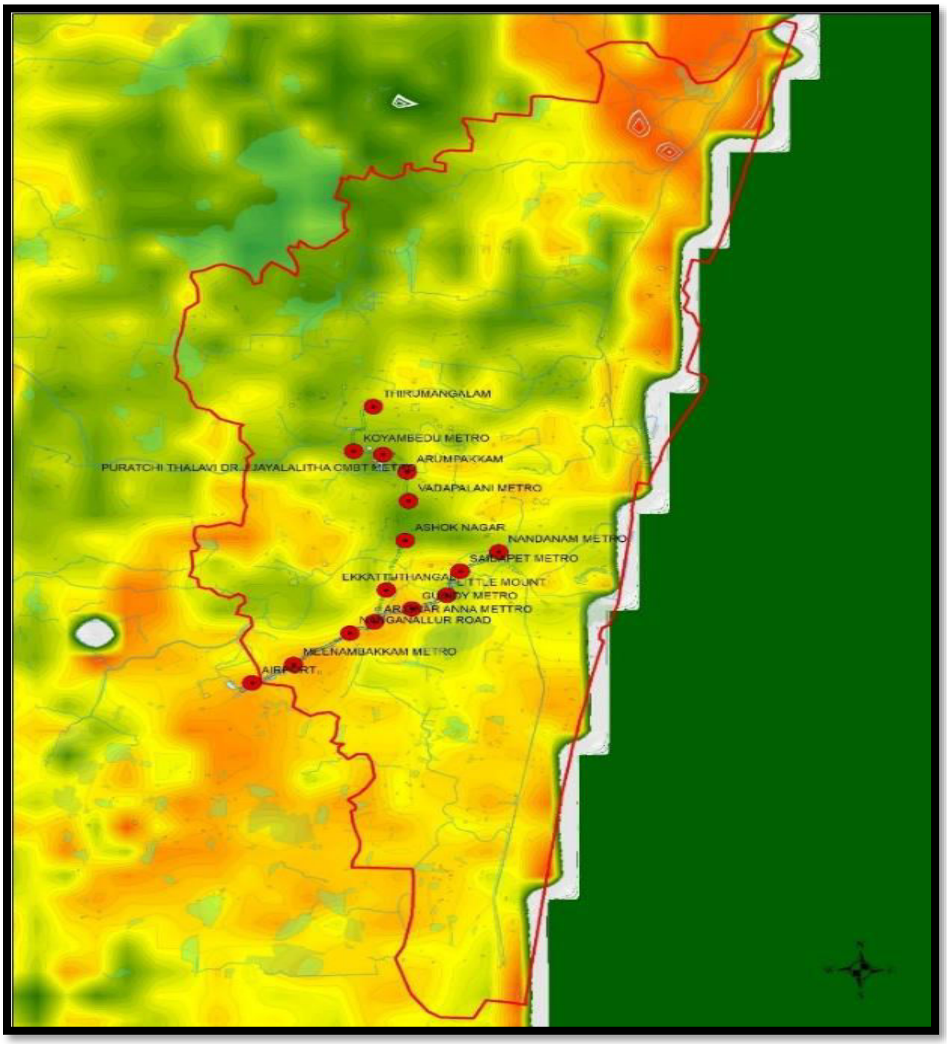

Figure 03: Illustrates the Land Surface Temperature (LST) variations across Chennai's metro viaduct buffers (MVBs), highlighting high-heat zones under elevated metro corridors
(**Source:** Author)

The Figure 03 highlights the heat retention characteristics of MVBs, demonstrating Urban Heat Island (UHI) intensity based on Landsat-derived Land Surface Temperature (LST) analysis. Several MVBs exhibit high surface temperatures, particularly those located in commercial and industrial zones with minimal vegetation cover. Moderate heat zones are found in MVBs with partial greenery or reflective surfaces. Lower temperature zones correspond to MVBs near parks, water bodies, or tree-lined streets, indicating the cooling effect of vegetation. Urban forests and shaded green corridors should be prioritized in high-heat MVBs to reduce surface temperatures and mitigate UHI effects. Cool pavements and vertical greening on metro pillars can be integrated to reduce heat absorption and enhance pedestrian comfort.

green areas, or less busy roads have noticeably lower pollution levels. To improve conditions in high-pollution MVB areas, planting trees like Neem, Banyan, or Peepal, and creating vertical gardens on metro pillars can help reduce pollution and make these spaces more pleasant and inviting. Adding greenery along pedestrian pathways can further enhance the comfort and usability of these urban areas..

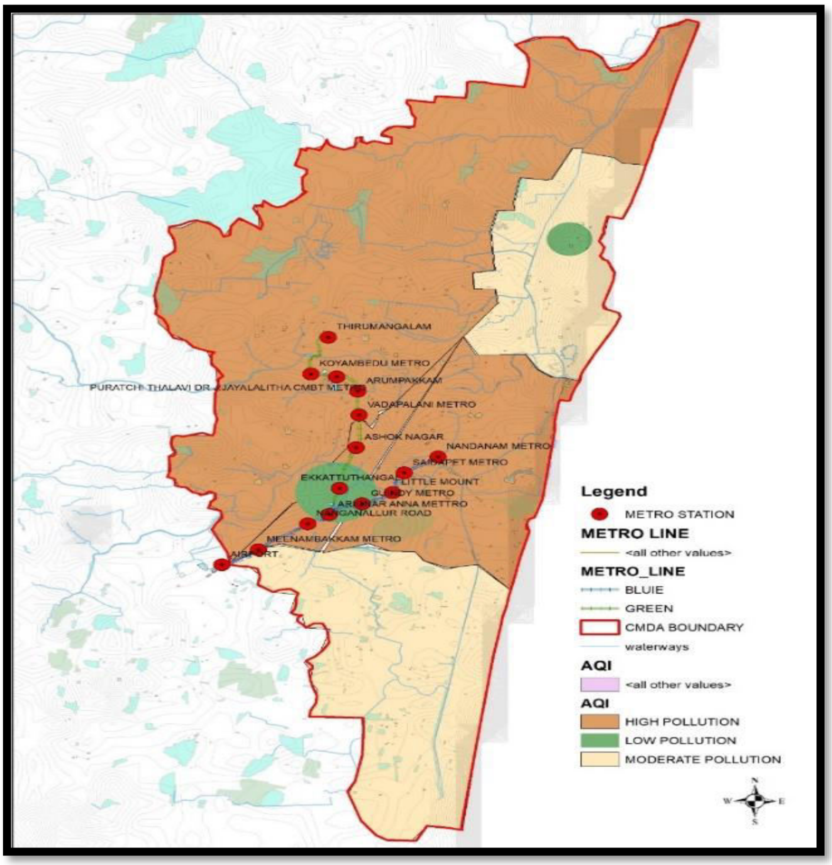

Figure 04: shows the Air Pollution Map variations across MVBs, revealing pollution hotspots near metro viaducts and transit corridors. (**Source:** Author)

Conclusion:

This research highlights the significant potential of Metro Viaduct Buffers (MVBs) as valuable but currently neglected urban spaces. Through detailed GIS-based analysis, key environmental and functional issues such as excessive heat, air pollution, flooding risks, and poor pedestrian accessibility were identified. By proposing tailored Nature-Based Solutions (NBS), including shaded pedestrian paths, urban forests, bioswales, and vertical greenery, these buffer spaces can be effectively transformed into sustainable and vibrant urban landscapes. The systematic three-phase implementation strategy recommended by this study not only addresses immediate

environmental challenges but also fosters long-term improvements in urban resilience and community well-being. By incorporating MVB redevelopment into broader urban planning policies, this research provides a replicable model for transforming infrastructure-induced urban voids into functional and sustainable public spaces, significantly enhancing urban livability and ecological health in rapidly urbanizing cities.
Future research directions could explore detailed economic assessments, long-term ecological monitoring, and evaluation of public acceptance and usability of redeveloped MVB spaces. Additionally, extending similar GIS and NBS methodologies to other infrastructure-induced voids, such as highway corridors or railway buffers, would further strengthen urban resilience strategies. Ultimately, this research advocates for transforming neglected urban spaces into vibrant public assets, contributing significantly to improved urban sustainability, ecological health, and community well-being.

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Reference:

1. *Fitzpatrick Ireland, J., & Comte, J. (2025). Renewable energy and urban sustainability: The intersection of green infrastructure. Renewable and Sustainable Energy Reviews, Article 114909.*
2. *Bonilla Brenes, R., & Oreamuno, R. (2024). Unplanned urban expansion in Latin America and its impact on hydrological processes. Frontiers in Sustainability, 6(1), 1425732.*
3. *Hassan, Z., & Lopez, F. G. (2024). Rapid urban population growth and its impact on ecosystems and infrastructure. In 3rd International Congress on Engineering and Life Science Proceedings Book (Vol. 18, p. 60578).*
4. *Muneerudeen, A. (2024). The transformation of urban public spaces through participatory approaches. Journal of Urban Studies, 22(1), 35684.*
5. *Krishnamoorthy, K., & Yassin, A. M. (2024). Leftover spaces and urban void formation in Kuala Lumpur. Planning Malaysia Journal, 22(32), 1517.*
6. *Sehrawat, S., & Shekhar, S. (2023). Integrating Blue-Green Infrastructure (BGI) in urban landscapes: Challenges and opportunities. Eco Cities, 4(1), 2409.*
7. *Pancewicz, A., & Suchy, N. (2023). Densification and green infrastructure strategies in European cities. Energies, 16(13), 5189.*
8. *Li, B., & Kazak, J. (2022). Green infrastructure planning for urban agglomeration: A land-based assessment. Land, 11(9), 1481.*
9. *George, J. (2022). Community governance and green urban infrastructure: A participatory approach. Urban Policy and Research, 40(3), 2093182.*

10. *Hwang, S., & Lee, S. J. (2020). Urban voids as challenges to the strategic utilization of cities. Urban Research & Practice, 13(2), 1634140.*
11. *Silvestrini, F., & Magini, R. (2021). Nature-based solutions in urban regeneration: The case of Rome's Portuense district. The Sustainable City XV, 15(2), 210021.*
12. *Pauleit, S., & Pribadi, D. O. (2021). The role of urban green and blue spaces in climate resilience. Frontiers in Sustainable Cities, 3(5), 735918.*
13. *O'Donnell, E., et al. (2021). Blue-Green infrastructure as a multifunctional solution for urban challenges. Water, 13(4), 05444.*
14. *Brokking, P., & Balfors, B. (2021). Urban planning and its role in developing nature-based solutions (NBS). Sustainability, 13(18), 10389.*
15. *Hamelin, C. (2016). The overlooked potential of urban voids in landscape planning and urban design. .*
16. *Rathi, K., & Kushwah, N. (2017). The role of public spaces in fostering sustainable urban environments. International Journal of Advance Research, Ideas and Innovations in Technology.*