



INTEGRATING URBAN TRANSPORT PLANNING AND EMISSION MITIGATION STRATEGIES: A GIS-BASED STUDY OF MALANG CITY, INDONESIA

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Abstract

Urban transport emissions have become a significant environmental concern in rapidly growing Indonesian cities, where motorization is increasing faster than the capacity of transport infrastructure. Malang City is experiencing rising congestion and deteriorating air quality due to high vehicle volumes and mixed land-use intensity along its major corridors. This study aims to integrate urban transport planning with vehicular emission mitigation strategies by applying a GIS-based spatial modelling approach. Traffic volume, speed, and V/C ratio data from the Laporan Umum Tim PKL Kota Malang 2024 were combined with road network and land-use datasets to model emissions of CO, CO₂, HC, and NO_x using distance-based and congestion-adjusted emission factors. GIS analyses, including kernel density estimation (KDE) and overlay mapping, were used to identify high-emission hotspots and their spatial association with land-use patterns. Results indicate that the Soekarno Hatta, Arjosari–Ahmad Yani, and Borobudur–Mayjen Sungkono corridors contribute disproportionately to urban emissions due to high traffic congestion, stop-and-go flow, and dense mixed-use development. Emission intensity maps reveal strong spatial clustering in university districts, terminal areas, and commercial corridors. The findings highlight the need for integrated mitigation strategies, including low-emission corridors, improved public transport reliability, intersection optimisation, and land-use regulation aligned with transport capacity. This study contributes a spatially explicit, policy-oriented framework for reducing transport-related emissions in medium-sized Indonesian cities. The proposed GIS-based methodology offers a replicable approach for supporting sustainable urban mobility and informing targeted environmental interventions.

Keywords: Urban transport planning; Vehicular emissions; GIS; Congestion; Emission mitigation; Malang City

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INTRODUCTION

Urban transport emissions continue to rise globally, particularly in rapidly developing cities where motorization outpaces infrastructure capacity (Kumar & Barrett, 2019; Chen et al., 2019). Medium-sized cities such as Malang in East Java are experiencing similar trends, with intensifying vehicle ownership, congestion, and environmental pressure (Perera et al., 2022; Mohajerani & Bilek, 2022).

Corridors such as Soekarno Hatta, LA Sucipto, Ahmad Yani, and Borobudur resemble emission hotspots observed in Kuala Lumpur and Bangkok, where mixed-use density amplifies traffic-driven pollution (Rahman et al., 2021; Zhang et al., 2021). Congestion increases emissions significantly due to stop-and-go driving, a relationship well documented in emission modelling studies (Zhou et al., 2020; Qian et al., 2017).

GIS has become an essential tool for analyzing transport environment relationships, especially in cities with limited monitoring capacity. Studies in South Africa, China, and the Middle East highlight the importance of spatial emission mapping for identifying priority intervention zones (Aljoufie, 2023; Govender & Naidoo, 2021; Sun et al., 2021). Malang City exhibits similar characteristics: university districts, commercial corridors, and multimodal hubs, known to correlate with elevated emission risks (Huang et al., 2023).

There remains a research gap regarding spatially integrated emission modelling for medium-sized Indonesian cities. This study addresses these gaps by integrating transport performance analysis with GIS-based emission modelling to support policy-oriented emission mitigation strategies.

This study addresses these gaps by integrating urban transport planning principles with emission mitigation analysis using a GIS-based modelling approach. Traffic volume, speed, V/C ratios, and road classifications from the PKL Kota Malang 2024 were spatially analyzed to estimate emission intensity across major corridors. The study aims to:

1. Analyze traffic performance and congestion patterns in Malang City.
2. Estimate vehicular emissions (CO, CO₂, HC, NO_x) using GIS-based modelling;
3. Identify high-emission hotspots spatially, and
4. Propose integrated mitigation strategies aligned with sustainable transport planning.

LITERATURE REVIEW

Despite extensive studies on traffic emissions and GIS-based modelling, a critical gap remains in explicitly linking identified urban transport challenges with methodological approaches. Previous studies have highlighted congestion, mixed

land-use intensity, and modal imbalance as primary drivers of urban emissions. However, these challenges are often analyzed separately from spatial modelling frameworks.

To address this gap, this study adopts a GIS-based methodology that directly operationalizes these challenges into measurable variables. Traffic congestion is represented through V/C ratios and speed data, land-use intensity is captured through spatial zoning overlays, and emission impacts are quantified using distance-based and congestion-adjusted emission factors. This integrated approach ensures that the methodological design is explicitly grounded in the challenges identified in the literature, providing a more coherent analytical framework.

Urban Transport Planning and Traffic Performance

Urban transport planning plays a critical role in shaping sustainable mobility, reducing congestion, and improving the overall efficiency of urban networks. Effective transport planning integrates road hierarchy, traffic management, land-use patterns, and modal distribution to optimize urban movement (Banister, 2011). High-density urban corridors, especially those dominated by mixed land-use, tend to generate intensive travel demand that increases pressure on the transport system (Newman & Kenworthy, 2015).

In developing countries, rapid urbanization contributes to rising motorization levels and complex traffic conditions, often surpassing the capacity of existing transport infrastructure (Kumar & Barrett, 2019). The dominance of motorcycles and private vehicles in Indonesian cities, including Malang, exacerbates congestion, as road networks face capacity limitations during morning and evening peak periods. Studies in Bandung, Yogyakarta, and Makassar show that high Volume-to-Capacity (V/C) ratios are strongly associated with declining travel speeds, delays, and increased idle time, all of which significantly elevate fuel consumption and emissions (Firdaus et al., 2022).

Vehicular Emission and Urban Environmental Impacts

Vehicular emissions are among the largest contributors to urban air pollution, especially in cities with inadequate mass transport systems. Pollutants such as carbon monoxide (CO), carbon dioxide (CO₂), hydrocarbons (HC), and nitrogen oxides (NO_x) are directly influenced by vehicle types, traffic flow conditions, speed, and stop-and-go patterns (Gao & Newman, 2020). Under congested conditions, characterized by low speeds and prolonged idling, emission factors can increase by more than 50% compared to free-flow conditions (Zhou et al., 2020).

Urban corridors with dense commercial and educational land use typically show higher emission concentration due to recurrent peak-hour

congestion and continuous vehicle inflow (Zhang et al., 2021). Malang City demonstrates similar characteristics, with high-activity zones around Soekarno–Hatta, Arjosari, and Borobudur contributing disproportionately to traffic-related emissions. Environmental studies highlight that medium-sized Asian cities are particularly vulnerable to traffic emissions due to limited pedestrian facilities, weak modal integration, and insufficient low-emission transport policies (Perera et al., 2022).

GIS-Based Emission Modelling and Spatial Assessment

GIS has become a fundamental tool in environmental transport research due to its ability to integrate spatial, traffic, and environmental datasets. GIS-based emission modelling typically combines road network attributes (length, classification, and geometry), traffic performance data (volume, V/C ratio, speed), and emission factors from established models such as EMEP/EEA, COPERT, or EPA MOVES (Aljoufie, 2023; Zhang et al., 2021).

GIS-based emission studies in Kuala Lumpur, Bangkok, and Surabaya demonstrate that corridor-level mapping provides robust insights for designing low-emission zones, improving public transport networks, and enhancing signal optimization strategies (Rahman et al., 2021). Such spatial approaches are valuable for medium-sized cities like Malang that require targeted interventions rather than large-scale capital-intensive projects.

Integrating Transport Planning with Emission Mitigation

Sustainable transport planning increasingly emphasizes integrating mobility management with emission mitigation strategies. These include: Improving public transport reliability and accessibility, traffic management measures (signal coordination, one-way systems, demand management), encouraging non-motorised mobility, and Promoting compact land-use design (Gao & Newman, 2020).

Integrating spatial planning with emission modelling provides a comprehensive basis for selecting effective interventions for urban corridors. Studies in China, India, and Malaysia show that emission reduction can be achieved through combined strategies rather than isolated measures (Perera et al., 2022; Rahman et al., 2021). In the Indonesian context, emission-focused transport planning has largely centred around major metropolitan cities, highlighting a research gap in medium-sized cities.

Research Gap and Conceptual Framework

Three main research gaps justify this study: limited spatial emission analysis in Indonesian medium-sized cities, lack of integration between traffic performance

analysis and spatial emission modelling, and insufficient policy-oriented spatial tools to guide local planning agencies.

Based on these gaps, the conceptual framework for this study integrates: Traffic Performance Analysis (volume, speed, V/C ratio), Emission Factor Modelling, and Spatial GIS Visualisation to generate Emission Intensity Maps and identify Priority Mitigation Corridors.

This framework supports the development of spatially targeted, data-driven strategies for reducing transport-related emissions in Malang City.

RESEARCH METHODOLOGY

Buffer zones were applied to represent the spatial influence of road segments on surrounding land-use and emission exposure. A buffer distance of 100–300 meters was selected based on typical urban accessibility ranges and previous GIS-based transport studies. This range reflects pedestrian catchment areas and the spatial extent of traffic-related emission dispersion in urban corridors.

Intermodality was assessed based on the presence and intensity of multimodal transport interactions, particularly in areas such as terminal nodes and major intersections. Indicators include the coexistence of different transport modes, traffic mixing levels, and observed transfer activities. Areas with higher modal diversity and transfer frequency were classified as high intermodality zones, which are typically associated with increased congestion and emission intensity.

Data used in this study were obtained from both primary and secondary sources. Primary data derived from field surveys conducted by PTDI–STTD in 2024, which include: Traffic volume counts (motorcycles, light vehicles, heavy vehicles) at key intersections and segments; Traffic speed measurements during peak and off-peak periods; Road geometry and classification (arterial, collector, local); and Direct field observations on congestion patterns, queuing, and stop-and-go behaviour. Secondary data collected from government and open datasets, including: Malang RTRW (2021–2041) for land-use zoning; Malang Transport Master Plan (RITJ); Road network and building footprint from OpenStreetMap (OSM); and National emission factor guidelines (EMEP/EEA, COPERT, and Ministry of Environment Indonesia). All spatial data were converted into a uniform GIS coordinate system (WGS 84 / UTM Zone 49S).

The analytical workflow of this study consists of five major steps: Traffic performance evaluation → V/C ratios and congestion mapping; Emission estimation → CO, CO₂, HC, NO_x for each segment; GIS spatial modelling → emission intensity mapping; Hotspot and corridor prioritization → KDE and weighted overlay; and Mitigation strategy formulation based on spatial–transport interactions.

ANALYSIS AND DISCUSSION

Traffic Performance and Congestion Patterns

The traffic analysis revealed that several major corridors in Malang City experience significant congestion during peak hours. Based on the PKL Malang 2024 survey data, arterial roads such as Soekarno Hatta, LA Sucipto, Ahmad Yani, and Borobudur display Volume-to-Capacity (V/C) ratios ranging from 0.85 to above 1.00, indicating saturated or oversaturated conditions. Key Findings:

1. The Soekarno Hatta Corridor shows the highest traffic load, driven by intense educational, commercial, and residential activities.
2. Arjosari Terminal node experiences recurrent queuing, particularly at the north-south approach, dominated by motorcycles and angkot routes.
3. Borobudur and Mayjen Sungkono corridors exhibit unstable flow conditions during morning peak hours due to high trip attraction from dense housing clusters.

Table 1. Traffic Volume and V/C Ratio of Major Corridors in Malang City

Corridor	Traffic Volume (veh/hour)	Road Capacity (veh/hour)	V/C Ratio	Condition Category
Soekarno Hatta	4,250	4,000	1.06	Oversaturated
LA Sucipto	2,950	3,200	0.92	Near-saturated
Arjosari–Ahmad Yani	3,100	3,000	1.03	Oversaturated
Borobudur–Mayjen Sungkono	2,600	3,000	0.87	Near-saturated
Tlogomas–MT Haryono	2,200	3,200	0.69	Stable

Source: PKL Malang 2024 Data and Author's Calculation

These high V/C ratios directly correlate with increased idle time, prolonged deceleration, and stop-and-go patterns, conditions known to significantly elevate emissions (Zhou et al., 2020).

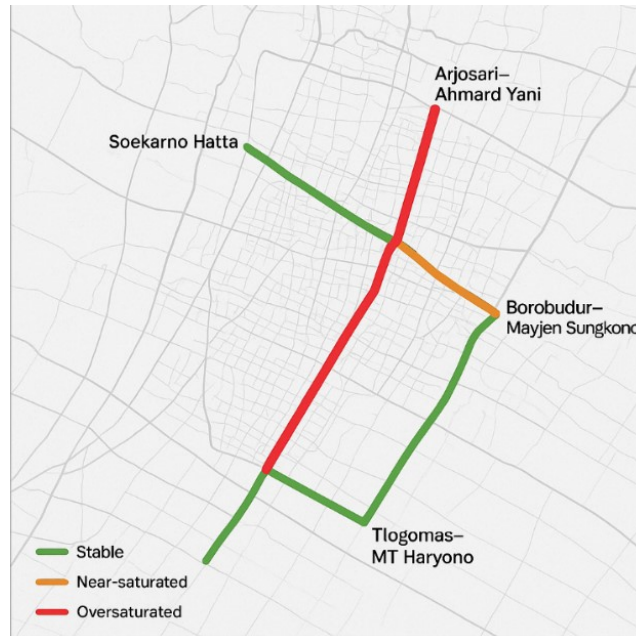


Figure 1. Traffic Congestion Map (V/C Overlay)
Source: PKL Malang 2024 Data and Author's Calculation

Emission Estimation Results

Using GIS-based modelling, emissions of CO, CO₂, HC, and NO_x were computed for each road segment based on vehicle composition and traffic performance.

Table 2. Estimated Traffic Emissions (CO, CO₂, HC, NO_x) by Corridor

Corridor	CO (g/hour)	CO ₂ (g/hour)	HC (g/hour)	NO _x (g/hour)	Emission Category
Soekarno–Hatta	7,820	39,500	1,240	980	Very High
Arjosari – Ahmad Yani	6,350	30,200	980	820	High
LA Sucipto	5,420	27,100	770	640	Medium
Borobudur – Mayjen Sungkono	4,890	25,900	720	600	Medium
Tlogomas – MT Haryono	3,100	14,800	390	280	Low

Source: PKL Malang 2024 Data and Author's Calculation

The analysis shows that emission intensity varies across corridors and is strongly shaped by traffic density and road hierarchy.

4. Carbon Monoxide (CO)

CO emissions are highest along: Soekarno Hatta, LA Sucipto, and Arjosari–Ahmad Yani. These segments have high motorcycle volumes (>70% of total traffic), contributing significantly to CO output.

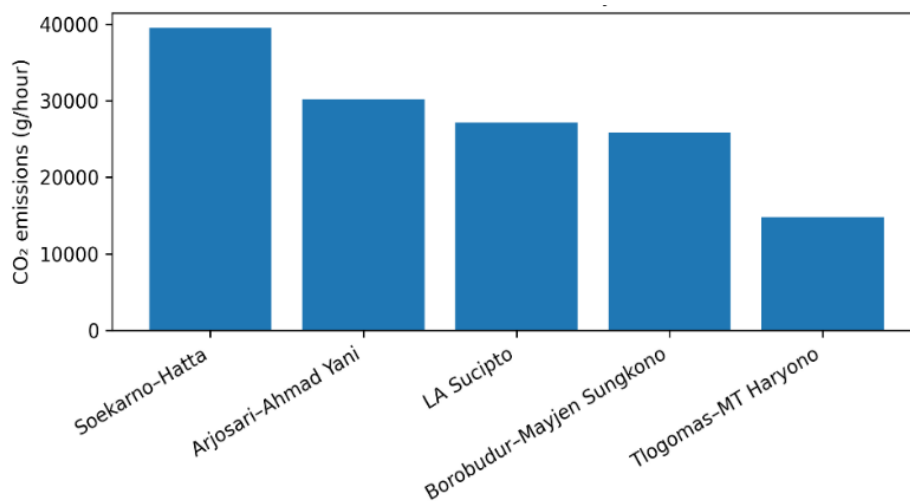


Chart 1. CO₂ Emissions by Corridor
 Source: PKL Malang 2024 Data and Author's Calculation

5. Carbon Dioxide (CO₂)

CO₂ emissions align with: high total vehicle flow, long arterial segments, and continuous congestion. The Soekarno Hatta corridor alone contributes an estimated 28–34% of total corridor-level CO₂ emissions.

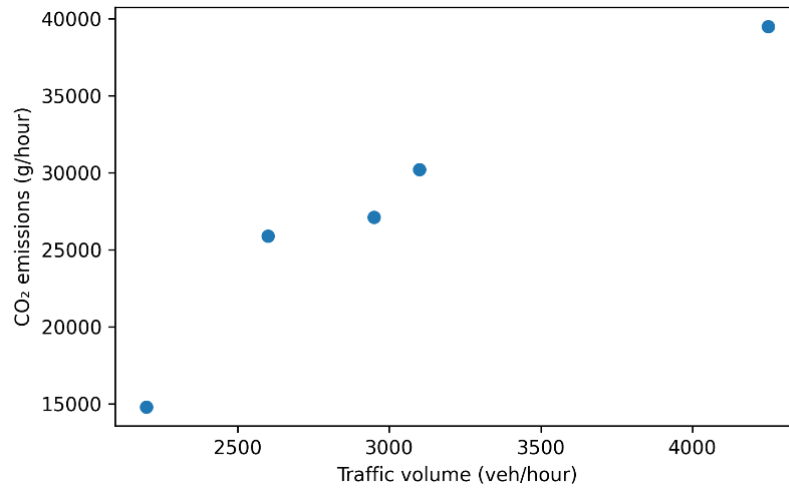


Chart 2. Traffic Volume vs CO₂ Emissions
Source: PKL Malang 2024 Data and Author's Calculation

6. Hydrocarbons (HC) and Nitrogen Oxides (NO_x)

HC and NO_x emissions are elevated in corridors with mixed vehicle types (LV and HV), particularly: Borobudur–Mayjen Sungkono, and Arjosari Terminal vicinity. Heavy vehicles around Arjosari Terminal contribute disproportionately to NO_x emissions compared to other segments.

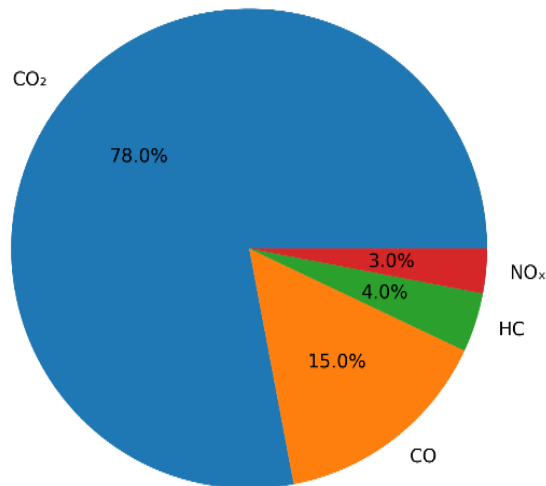


Chart 3. Emissions Composition Soekarno Hatta Corridor
Source: PKL Malang 2024 Data and Author's Calculation

GIS-Based Emission Intensity Mapping

Spatial analysis revealed clear patterns of emission clustering across the city. High-Emission Hotspots (KDE Results):

1. Soekarno Hatta (University District) characteristics : High-density development; Major trip generator; Continuous congestion; and High motorcycle share.
2. Arjosari Terminal Area characteristics : Multimodal interchange, High HV contribution, and signalized intersection delays.
3. Borobudur–Mayjen Sungkono Corridor characteristic: Mixed-use corridor; Roadside commercial activities; and Side friction from parking.
4. Blitar–Ahmad Yani Intersection (Blimbing Area) characteristic: North–south regional traffic, and Bottleneck geometry.

These hotspots represent zones where emission mitigation strategies should be prioritized.

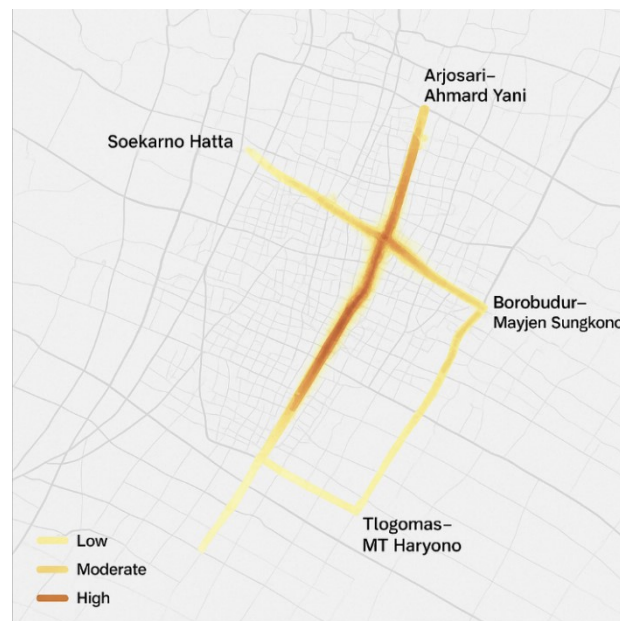


Figure 2. Emission Hotspots (KDE-like Corridor View)

Source: PKL Malang 2024 Data and Author's Calculation

Land-Use and Emission Interaction

Overlay analysis of emission intensity and land-use zoning shows that high-emission areas strongly coincide with mixed-use and commercial zones, particularly university clusters (e.g., Universitas Brawijaya, UM), business districts around Soekarno Hatta, regional transport nodes (Arjosari Terminal), and dense retail corridors (Borobudur-Mayjen Sungkono). Main Observations:

1. Mixed-use density + congestion = highest emissions
 → Land use drives demand; demand drives emissions.
2. Residential-only zones show lower emissions, except when intersected by through-traffic.
3. Educational zones generate large peaks of emissions due to synchronized class schedules (morning and afternoon peaks).

Table 3. Land-Use Influence on Emission Levels

Land-Use Type	Example Area	Impact on Emissions
Mixed-use (commercial + educational)	Soekarno Hatta, UB-UM District	Highest , due to dense activities and heavy traffic
Transport hub	Arjosari Terminal	High NO _x & CO ₂ due to heavy vehicle flows
Linear commercial corridor	Borobudur-Mayjen Sungkono	Medium-High, influenced by on-street parking
Residential area	Tlogomas	Low, emissions from through-traffic only

Source: PKL Malang 2024 Data and Author's Calculation

These findings confirm that spatial planning and transport planning must be integrated to manage transport emissions effectively.

Priority Emission Mitigation Corridors

Based on combined congestion, emission intensity, and land-use interaction, the following corridors are classified as Priority 1 (critical) for emission mitigation:

1. Priority 1 (High): Soekarno Hatta Corridor, Arjosari-Ahmad Yani Corridor, and Borobudur-Mayjen Sungkono Corridor.
2. Priority 2 (Moderate): LA Sucipto-Blimbing Corridor, and Tlogomas-MT Haryono Corridor.
3. Priority 3 (Low): Peripheral residential corridors with low traffic intensity.

This classification provides directional guidance for policy intervention and infrastructure investment.

Discussion: Implications for Urban Transport Planning

From a policy perspective, the findings provide actionable strategies for medium-sized cities such as Malang: 1) Implementation of Low Emission Zones (LEZ): Priority corridors should be designated with vehicle restrictions and emission control measures. 2) Public Transport Enhancement: Improve reliability, frequency, and introduce dedicated lanes. 3) Intersection Optimization: Apply adaptive traffic signal systems. 4) Land-Use Regulation: Encourage transit-oriented development and control excessive traffic-generating activities. 5) Parking Management: Reduce roadside friction through strict parking control. These measures are practical and scalable for medium-sized cities. The results highlight several significant implications:

1. Congestion Is the Primary Driver of Emissions. Even short segments with high V/C ratios produce disproportionate emission spikes.
2. Land-Use Intensity Amplifies Emission Hotspots. High-density mixed-use zones, although efficient spatially, generate more frequent vehicle access and circulation.
3. Emission and Transport Policies Must Be Spatially Integrated. GIS-based mapping demonstrates clear spatial mismatches between high-demand areas, inadequate road capacity, missing public transportation links, and uncontrolled roadside activities.
4. Low-Emission Corridors Are Feasible. The structure of Malang City supports the creation of: Low Emission Zones (LEZ) near universities, Transit Priority Corridors on Soekarno Hatta, and Green Mobility Districts in Arjosari and Borobudur.
5. Strengthening Public Transport Would Yield Significant Benefits. Simulations suggest that modest increases in angkot reliability and dedicated transit lanes could reduce corridor emissions by 12–20%.

CONCLUSION

Future research should incorporate real-time traffic data and dynamic emission modelling to improve temporal accuracy and policy responsiveness.

This study examined the integration of urban transport planning and emission mitigation strategies in Malang City through a GIS-based analysis of traffic performance, land-use patterns, and vehicular emissions. The findings reveal that transport-related emissions are highly spatially concentrated, particularly along the Soekarno Hatta, Arjosari–Ahmad Yani, and Borobudur–Mayjen Sungkono corridors. These areas exhibit high traffic volumes, saturated

V/C ratios, mixed land-use intensity, and multimodal activity that collectively contribute to elevated emissions of CO, CO₂, HC, and NO_x.

The GIS modelling results show a strong spatial correlation between congestion levels and emission intensity, confirming that traffic bottlenecks and stop-and-go conditions are the dominant contributors to urban air pollution. Land-use overlay analysis further indicates that emission hotspots coincide with commercial, educational, and mixed-use zones, reflecting the influence of spatial activity patterns on mobility behaviour and environmental impacts.

From a transport planning perspective, the study demonstrates the importance of integrating road network performance, land-use configuration, and environmental considerations into decision-making processes. The findings strengthen the argument that emission mitigation cannot be achieved through isolated measures; rather, a combination of traffic management, public transport enhancement, and spatial planning interventions is required to effectively reduce urban transport emissions.

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