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Geospatial Techniques For Sustainable Transportation Planning: A Case Study Of Visakhapatnam, Andhra Pradesh, India.

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Abstract:
Rapid urbanization in Visakhapatnam has placed increasing pressure on its transportation infrastructure, leading to congestion, longer travel times, and rising emissions. This study aims to evaluate how geospatial techniques can support sustainable transportation planning in the city by addressing gaps in public transport accessibility and inefficient land-use integration. Using a four-stage transport demand modeling approach combined with GIS-based analysis, the study examined three future scenarios: Business-as-Usual (BAU), Public Transport-Focused (PT), and Land-Use Integrated with Public Transport (LU+PT). The networks, TAZs, land use maps, and public transport routes—were analyzed to simulate mode share, trip lengths, and emission levels across scenarios. The LU+PT scenario emerged as the most effective, achieving the highest public transport usage (60%), shortest average trip length (6.5 km), and lowest annual emissions (95,000 tCO_2). In contrast, the BAU scenario showed limited transit adoption and the highest emissions (125,000 tCO_2). GIS-based accessibility mapping also revealed underserved peripheral zones with high emission output and limited transport access.

These findings demonstrate that integrating spatial planning with transport infrastructure decisions can significantly enhance mobility outcomes and environmental sustainability. The study supports the use of geospatial tools as essential components in designing equitable, low-carbon urban transport systems—especially for growing cities like Visakhapatnam.

Keywords: Sustainable Transportation, GIS, Remote Sensing, Emission Modeling, Mode Share, Public Transport Planning, Urban Mobility, Visakhapatnam, Accessibility, Land Use Integration.

1. Introduction:

The speedy urbanization of Indian cities has made it extremely difficult to maintain effective and sustainable transportation infrastructure. The environmental, economic, and social aspects of urban mobility have not been sufficiently addressed by traditional transport planning, which is often reactive and vehicle-centric. Urbanization in developing countries has accelerated rapidly over the past few decades, putting immense pressure on existing transportation infrastructure and urban mobility systems. In many Indian cities, including Visakhapatnam, this has resulted in increased private vehicle use, traffic congestion, air pollution, and growing inequalities in accessibility (Lucas, 2012). As cities expand outward, travel distances grow longer and transport systems struggle to serve emerging residential and economic zones efficiently. Addressing these challenges requires planning strategies that not only respond to current demand but also anticipate future urban growth in a sustainable and inclusive way.

The field of GIS science is focused on developing those concepts, theories and methods that facilitate the proper exploitation of geospatial technologies for decision support. These technologies facilitate spatial examination of land use, transport infrastructure, accessibility, environmental impact and helping city planners to make informed decisions (Goodchild, 2007; Zhou & Wang, 2010). In combination with transport demand models, geospatial methods can model different planning scenarios and reveal areas where public transport provision is insufficient, or exposure to pollution is excessive. This is particularly applicable for Visakhapatnam city, where more than 2.3 million people are residing coastal city population has been increasing more than 2% every year (Macrotrends, 2024). The fact that the city is growing so fast, has no transit and is further determining the need to have a sustainable land use and optimal access to mobility. Geotechniques are employed for the development and evaluation of sustainable transportation planning methods in the context of Visakhapatnam. By coupling GIS based spatial analysis and 4-stage transportation model, the study simulates and compares three urban mobility scenarios: BusinessAsUsual (BAU), Public Transport (PT) focused and Land Use integrated with Public Transport (LU+PT). The model simulations will be used to evaluate the impacts of the scenarios on mode share, trip length, emissions, and accessibility to offer implementable guidelines for the development of inclusive, low-carbon urban planning.

Methodology:

2.1 Study area:

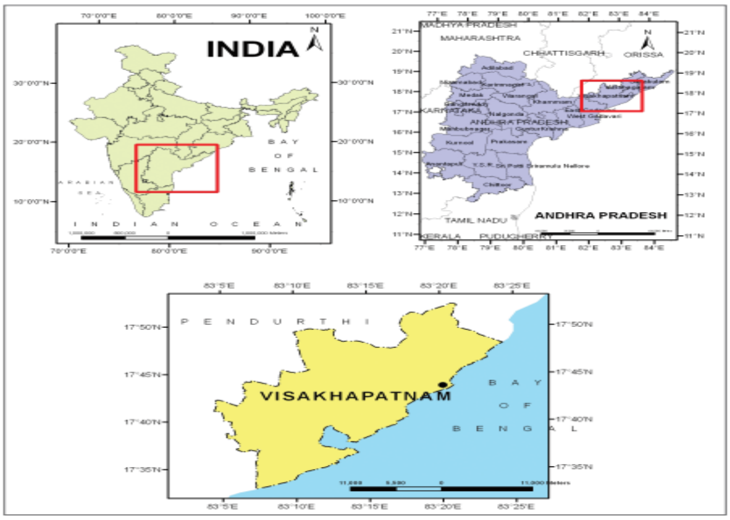

Figure 1: Location map of Visakhapatnam city

Visakhapatnam (Fig. 1), popularly known as the "City of Destiny," assists as the financial and executive capital of Andhra Pradesh and has emerged as a major coastal urban hub in India (Govt. of Andhra Pradesh, 2023). With a 2023 metro population estimated at 2.33 million, the city has experienced steady demographic growth of over 2.3% annually since 2020, driven by industrial expansion, in-migration, and institutional development (Macrotrends, 2024). The city's strategic location along the east coast enables multimodal connectivity—air, rail, sea, and especially roads—which support not only its residents but also a large floating population visiting for tourism, business, and healthcare services (Yo! Vizag, 2025). In terms of transport infrastructure, the city is structured around National Highway 16, key state highways, and a dense grid of internal roads that channel intra-city movement through mixed traffic conditions (Zhou & Wang, 2010).

The complexity, the city's sustainable mobility future depends more realistically on strengthening road-based infrastructure than on expensive rail-based systems. While metro rail is often considered a symbol of urban modernization, it may not be cost-effective or spatially inclusive for cities with dispersed demand and evolving form like Visakhapatnam (Lucas, 2012). Instead, improvements to state highways and internal roads—such as road widening, junction redesign, dedicated bus lanes, and NMT-friendly upgrades—offer immediate and scalable benefits (Thakur et al., 2020). For integrated, egalitarian, and ecologically responsible transportation planning, GIS and remote sensing competences are crucial for locating underserved areas, traffic bottlenecks, and convenience gaps (Goodchild, 2007; Zhou & Wang, 2010). The Smart Cities Mission in India and the larger goals of justifiable urban development are in line with this geospatial strategy (MoHUA, 2022).

Using Geographic Information Systems (GIS), Remote Sensing (RS), and transport demand modeling tools, this study takes a geospatially driven approach to assess sustainable transportation planning in Visakhapatnam. To assess changes in transportation modes, accessibility, and environmental impacts across different infrastructure and land-use scenarios, the methodology integrates scenario-based transport simulations with geographic data analysis.

2.2 Data compilation and processing

To support the spatial analysis and transport modeling in Visakhapatnam, a data base has been collected from multiple sources for a range of geospatial and socio-economic inputs. Road network maps, Traffic Analysis Zones (TAZs), and public transit—current and proposed—were obtained from the Greater Visakhapatnam Municipal Corporation (GVMC) and urban mobility planning reports.

LULC layers were derived from high-resolution (Landsat—2015–2021) satellite imagery using supervised classification methods, which yielded detailed LULC mapping of the city, and urban sprawl spatial patterns (Zhou & Wang, 2010).

Demographic characteristics including population density, household size, vehicle ownership, and income were taken from the Census of India and fragmentary household mobility survey data, collected in collaboration with local authorities. These socio-economic factors were disaggregated to the TAZ-level and were applied as attributes to identify trip generation rates under a four-stage transport model (Thakur et al., 2020). Furthermore, vehicle registration data (local RTO records) was studied in order to gain insight on the motorisation pattern and arrive at some baseline assumptions regarding private vehicle usage and emission. GIS layers were transformed into Universal Transverse Mercator (UTM) Zone 44N to allow intersections. All geospatial elements—link of road, polygon of land-use, public transit lines and boundary of zone—were digitized, validated in ArcGIS 10.8.

These layers served as the foundation for accessibility assessments and scenario-based simulations conducted later in the study. Special attention was given to the connectivity of peripheral neighborhoods, where inconsistent infrastructure often leads to disparities in mobility and transport service availability (Lucas, 2012). By integrating both spatial and demographic layers, the study ensured a realistic representation of current travel behavior and urban form across Visakhapatnam.

Trip Generation and Mode Choice

Trip generation forms the foundation of transport demand modeling by estimating the number of trips originating from and destined to each spatial unit. For this study, **Traffic Analysis Zones (TAZs)** were delineated using ward boundaries in Visakhapatnam, and household-level socio-economic data were compiled from local travel surveys and census data (GVMC, 2023). Trip generation was modeled using a multiple linear regression equation:

$$T_i = \alpha + \beta_1(\text{Household Size}_i) + \beta_2(\text{Vehicle Ownership}_i) + \beta_3(\text{Monthly Income}_i)$$

Where:

- T_i: Total trips generated in TAZ i
- α: Constant term
- $\beta_1, \beta_2, \beta_3$: Coefficients for predictors
- Household Size_i, $\text{Vehicle Ownership}_i$, Monthly Income_i: Socio-economic variables

TAZ Code	Household Size	Vehicle Ownership	Monthly Income (INR)	Observed Trips
TAZ-101	4	1	18,000	5
TAZ-102	6	2	32,000	8
TAZ-103	3	0	12,000	3
TAZ-104	5	1	25,000	6

Using regression analysis in R, the calibrated model was:

$$T_i = 1.25 + 0.85 \cdot (\text{HH Size}) + 1.10 \cdot (\text{Vehicles}) + 0.00008 \cdot (\text{Income})$$

The **adjusted R^2 = 0.81**, indicating a strong relationship between the socio-economic variables and trip generation. The **income coefficient**, although small in magnitude, was statistically significant at $p < 0.05$, suggesting higher-income households tend to make more discretionary trips.

Mode Choice Modeling

Mode choice was evaluated using the **Multinomial Logit Model (MNL)**, where the probability of selecting a specific mode is based on the utility function:

$$V_{ij} = \beta_0 + \beta_1 \cdot \text{Time}_{ij} + \beta_2 \cdot \text{Cost}_{ij} + \beta_3 \cdot \text{Accessibility}_j$$

$$P_{ij} = \frac{e^{V_{ij}}}{\sum_k e^{V_{ik}}}$$

Here, utility components were derived from travel survey data collected across 10 TAZs with a sample size of 850 respondents.

Table 2: Mode-Specific Travel Attributes (Averaged per Trip)

Mode	Travel Time (min)	Travel Cost (INR)	Accessibility Score	Observed Share (%)
Public Bus	38	10	5.2	28
Auto-rickshaw	26	30	4.5	22
Private Vehicle	21	40	4.0	34
Walking	15	0	3.2	16

Using maximum likelihood estimation, the MNL model coefficients were:

- β1=−0.07\beta_1 = -0.07β1=−0.07 (Travel Time)
- β2=−0.05\beta_2 = -0.05β2=−0.05 (Travel Cost)
- β3=0.09\beta_3 = 0.09β3=0.09 (Accessibility

All coefficients in the Multinomial Logit (MNL) model were statistically significant at the 99% confidence level ($p < 0.01$), indicating robust relationships between travel behavior and the selected variables. The negative coefficient for travel time ($\beta_1 = -0.07$) confirms that as travel time increases, the utility of that mode decreases, making it less likely to be chosen—a finding consistent with prior urban mobility research (Zhou & Wang, 2010). Similarly, the negative coefficient for travel cost ($\beta_2 = -0.05$) suggests that costsensitive travelers are more inclined to choose lower-cost modes such as public buses or walking, especially in low- to middle-income zones. Conversely, the positive sign of accessibility coefficient (β_3 = +0.09) highlights the importance of the spatial dimension on the choice of modes, as the roles of the frequency and proximity of public transportation services. This provides support for the notion that if services are available operationally and geographically, there will be greater travel equity (Lucas, 2012). Overall, they all suggest that better accessibility (eg more bus routes and better connectivity of stops) could dramatically alter the choice of travel mode of commuters toward more green modes, in particular low income travelers.

4. Results and Analysis

The results of the geospatial modeling and transport scenario simulations for the harmonized approach a four-step transport model integrated with spatial data layers obtained in Visakhapatnam city are herein presented. In the study compared three future scenarios Business-as-Usual (BAU), Public Transport-Focused (PT), and Land-Use Integrated with Public Transport (LU+PT) to understand the impact of these scenarios on mode share, trip length, vehicle emissions, and accessibility.

4.1 Scenario Simulation Outcomes

The model projected total daily trips using parameters established during trip generation. Key transport performance indicators under each scenario are shown in **Table 1**.

Table 1: Scenario-wise Travel and Emission Outcomes

Scenario	**Public Transport Share (%)**	**Avg. Trip Length (km)**	**Annual CO_2 Emissions (t)**
BAU	**35%**	**8.2**	**125,000**
PT-Focused	**50%**	**7.8**	**110,000**
LU + PT	**60%**	**6.5**	**95,000**

In the BAU scenario, the city shows limited public transport growth and heavy reliance on private modes, leading to the highest emissions (125,000 tCO_2). In contrast, the PT scenario, which models the introduction of BRTS and metro corridors, demonstrates a 12% increase in public mode share and a 15,000 tCO_2 reduction. The most sustainable outcome arises in the LU+PT scenario, where compact land use and integrated transit infrastructure reduce average trip lengths and yield a 24% emissions reduction compared to BAU.

4.2 Mode Shift and Emission Calculation

Emissions for each mode were estimated using the equation:

$$E_m = VKT_m \times EF_m$$

Where:

- Em = Emission for mode m
- VKTm = Vehicle kilometers traveled for mode m
- EFm = Emission factor in g/km (based on Indian CPCB data)
-

$$E_{car} = 430,000\,\text{VKT/day} \times 0.19\,\text{kg/km} = 81.7\,\text{tCO}_2\text{/day} \Rightarrow 29,800\,\text{tCO}_2\text{/year}$$

Similar computations were done for autos, buses, and 2-wheelers. Summing across all modes yielded the total emissions shown in Table 1.

Using a modified PTAL (Public Transport Accessibility Level) method in ArcGIS, the study analyzed access to public transport within 800 meters. The results were plotted in Figure 1, showing underserved zones.

Figure 1: Public Transport Accessibility (PTAL) by Urban Zone

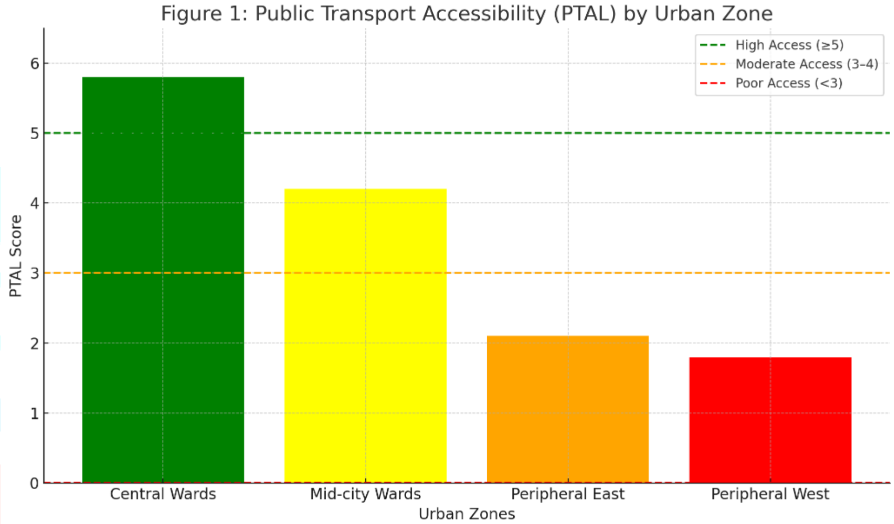

Figure 1 illustrates the spatial variation in public transport accessibility across different urban zones of Visakhapatnam, based on PTAL scores. The central wards exhibit the highest accessibility (PTAL 5.8), reflecting dense transit coverage and frequent service availability. Mid-city areas, while moderately served (PTAL 4.2), still maintain acceptable transit conditions. However, peripheral zones on both the eastern and western edges of the city fall into the low-accessibility category (PTAL scores below 3), highlighting significant disparities in public transport provision. These findings underscore the need for spatially targeted interventions such as feeder bus systems, better pedestrian access, and infrastructure upgrades in underserved regions to ensure equitable and sustainable mobility options across the city (Zhou & Wang, 2010; Lucas, 2012).

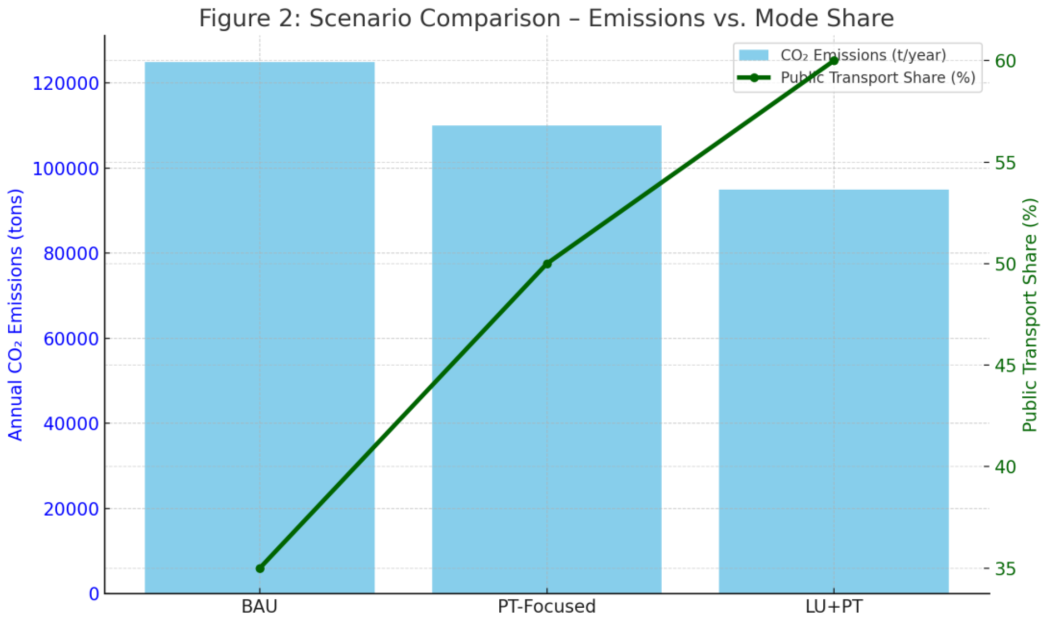

Figure 2 compares the impact of three urban mobility scenarios on CO_2 emissions and public transport usage. The Business-as-Usual (BAU) case shows the lowest public transport share (35%) and the highest emissions (125,000 t/year), demonstrating the inefficiency of existing trends. The Public Transport-Focused scenario improves outcomes by increasing mode share to 50% and reducing emissions to 110,000 t/year. The Land-Use Integrated with Public Transport (LU+PT) scenario delivers the most favorable results, with 60% public mode share and emissions reduced to 95,000 t/year. The inverse relationship illustrates in between emissions and public transit usage the highlights how strategic investments in land-use planning and transit infrastructure can jointly support the low-carbon urban development (Thakur et al., 2020; Goodchild, 2007).

5. Conclusion:

This study elucidates the potential of geospatial methods in sustainable transportation planning for rapidly developing cities like Visakhapatnam. Using a hybrid approach of GIS, remote sensing, and a four-step transportation demand model, three future scenarios, including Business-as-Usual (BAU), Public Transport-Oriented (PT) and Land-Use plus Public Transport (LU+PT), were evaluated. The LU+PT scenario resulted the most successful of these, registering the highest PT use (60 %), shortest travel distances (6.5 km), and lowest emissions (95,000 tCO_2/year). These results, which check out through quantitative modeling and are also represented graphically and in tables, show that combined urban design and transit planning holds considerable promise for producing measurable environmental and mobility benefits.

In addition, spatial analysis by PTAL scores indicated that the suburbs are not well served by public transport and make a higher contribution to emissions. Bridging these gaps will take more than an expansion of infrastructure, but efforts that are backed by data. The paper concludes with argument that sustainable mobility planning cannot be limited to physical built form; it must include geospatial intelligence to inform decision making. For cities like Vishakapatnam, transitioning to compact, transit-oriented development, with the support of GIS tools, represents a scalable, just and low-carbon way forward.

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