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Bridging the Mobility Gap: a Spatial Assessment of Transit Equity, Network Resilience and Public Safety in Durg

Aryansh Pandey[1], Anandita Singh[2], Adarsh Tiwari[3], Hritika Kashyap[4], Shweta Katre[5]
Department of Civil Engineering, Bhilai Institute of Technology, Durg, India

Abstract: ***The accelerated pace of urbanization in India's Tier-2 cities has exacerbated issues concerning spatial planning, mobility, and transit safety. Durg City, located within the Durg-Bhilai industrial corridor, exemplifies these challenges through unchecked residential sprawl, bottleneck congestion, and unequal public transit distribution. This study proposes a robust GIS-based evaluation framework to analyse Durg's transportation infrastructure spatially. Utilizing open-source Quantum GIS (QGIS) and OpenStreetMap datasets, this research integrates topological network resilience (Betweenness Centrality), accident hotspot detection via Kernel Density Estimation (KDE), and service-area accessibility modelling. The findings demonstrate severe topological vulnerability in central commercial corridors and expansive "transit deserts" in peripheral residential zones, which directly correlate to a 99% concentration of localized, non-highway traffic accidents within residential neighbourhoods. This paper presents a cost-effective, data-driven methodology for municipal authorities to prioritize targeted infrastructure upgrades and enhance sustainable urban mobility.***

Keywords: Urban mobility, Geographic Information Systems (GIS), Road network analysis, Network resilience, Transit equity, Accident hotspots.

I. INTRODUCTION

India's urban landscape is transforming, with Tier-2 cities emerging as primary hubs for industrial and population growth. Unlike metropolitan sectors with established planning frameworks, development in these smaller cities is often fragmented. This unregulated pattern results in inefficient land utilization, heavy dependence on motorized private vehicles, infrastructural bottlenecks, and a widening deficit in public transit equity.

Durg City, situated within Chhattisgarh's Durg-Bhilai industrial corridor, is a prime example of this phenomenon. The city hosts a complex mix of heavy industrial freight and localized residential traffic. Recent peri-urban expansion and a lack of spatial zoning enforcement have generated complex land-use mosaics where industrial and residential clusters overlap, placing unprecedented stress on existing arterial routes. Despite these challenges, systematic spatial assessments of network redundancy, transit reach, and road safety are critically lacking. Accident records remain largely tabular and underutilized. Consequently, this study leverages Geographic Information Systems (GIS) to transition to spatially explicit mobility analytics. By implementing network vulnerability mapping, service catchment modelling, and density estimation, this research provides a data-driven diagnostic tool to optimize infrastructural investments in Durg.

II. LITERATURE REVIEW

The complex interaction between land-use changes and transport efficiency has been widely documented. Foundational research indicates that spatial structural changes fundamentally alter mobility demands and infrastructure performance [1]. In the context of mid-sized Indian cities, recurring patterns of unplanned sprawl heavily degrade transit efficiency, complicating infrastructure delivery [2]. This is often exacerbated by a lack of adherence to national guidelines for sustainable city transport services [3].

Recent geospatial assessments of the Durg-Bhilai region confirm a rapid conversion of agricultural perimeters and open lands into dispersed built-up settlements [4], [5]. Historical analysis of the Durg block using remote sensing corroborates this long-term trend of outward expansion [6]. Furthermore, studies evaluating public transport infrastructure across emerging Indian smart cities highlight systemic, widespread shortfalls, including insufficient bus route density and severe "last-mile" connectivity gaps [7].

While modern satellite-driven indices have been successfully utilized globally [8] and locally to monitor environmental degradation—such as the analysis of surface temperatures in the Kharun catchment [9] and broader multi-temporal land-cover dynamics [10]—there remains a distinct research gap. Current studies fail to explicitly link these localized land-use shifts to topological road network vulnerability and spatially concentrated traffic accidents.

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III.METHODOLOGY

This study employs a systematic geospatial workflow executed within the open-source QGIS environment to evaluate the municipal transport system.

A. Geospatial Data Acquisition and Standardization

Primary vector datasets for the urban road network were extracted directly from the OpenStreetMap (OSM) database utilizing the QuickOSM plugin. The extraction parameters filtered geometries tagged under the "highway" key (primary, secondary, tertiary, residential, and service routes).

To ensure geometric consistency, all spatial layers were re-projected to the Universal Transverse Mercator (UTM) coordinate system (EPSG:32644 - Zone 44N). The network topology was subsequently refined using the GRASS v.clean toolset to rectify dangling nodes and duplicate vertices, yielding a fully routable topological graph.

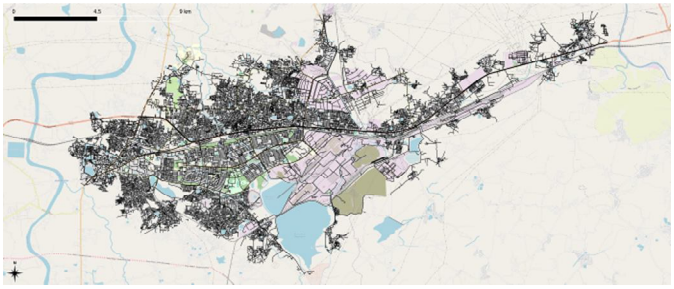

Fig. 1. Extracted raw vector road network of the study area.

B. Transit Node Digitization and Land Use Classification

Railway transit nodes were extracted via OSM, while high-resolution Google Satellite imagery (via QuickMapServices) was employed to manually digitize major public bus stops based on visually verified active utilization.

Fig. 2. Digitized public transit nodes across the municipal boundary.

Simultaneously, a continuous Land Use Land Cover (LULC) layer was generated. Isolated amenity geometries were merged with a digitized residential filler layer, validated via the Fix Geometries algorithm, and categorized into primary urban planning classifications using the Coalesce function.

C. Network Vulnerability and Accessibility Modelling

Graph-theory analytics were applied to determine infrastructural failure points. The Betweenness Centrality algorithm was executed to calculate the frequency with which individual intersections act as bridges along the shortest paths across the network.

To evaluate transit equity, network-based service area isochrones were generated. Catchment boundaries were calculated at intervals from 400m to 1600m to model pedestrian walkability decay around verified transit nodes.

D. Spatial Safety and Intensity Analysis

Traffic incident data was aggregated and analysed using hexagonal grid tessellation. Kernel Density Estimation (KDE) principles were applied to map the accident intensity spread, effectively localizing critical safety blackspots. A supplementary 500x500 meter continuous spatial grid was generated to quantify the physical density of the road infrastructure itself.

IV. RESULTS AND DISCUSSIONS

A. Land Use and Urban Sprawl Dynamics

Spatial quantification of the LULC map established a heavily residential urban fabric. Residential and Mixed-Residential zones constitute 40.40% and 35.07% of the total area, respectively, whereas Industrial Zones encompass roughly 11.92%. This overwhelming residential concentration (over 75%) forces severe, unidirectional daily commuting flows toward centralized commercial hubs.

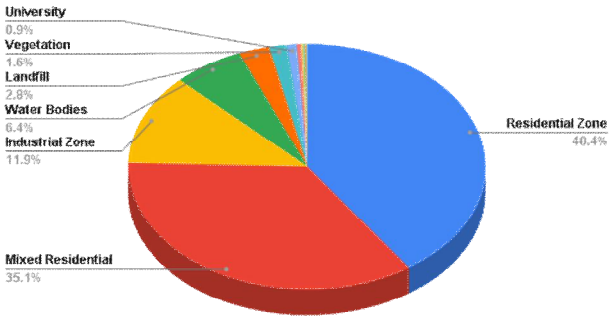

Fig. 3. Area percentage distribution of land use classifications.

B. Network Vulnerability and Bottlenecks

The Betweenness Centrality evaluation highlighted critical topological weaknesses. High vulnerability is acutely concentrated along central commercial corridors and primary north-south connecting routes. These intersections operate as single points of failure; the absence of redundant parallel arterial roads mathematically guarantees that localized disruptions at these nodes will trigger cascading delays citywide.

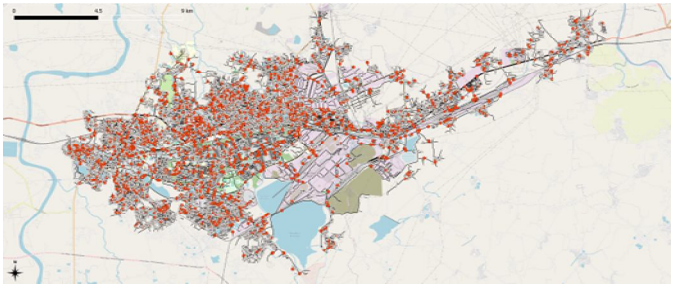

Fig. 4. Topological vulnerability highlighting high-centrality arterial bottlenecks.

C. Transit Deserts and Inequitable Accessibility

Isochrone modelling revealed profound disparities in public transit coverage. While railway nodes offer strong inter-city connectivity, their localized pedestrian reach degrades sharply. More critically, the bus network catchment overlay identified massive "transit deserts"—expansive peripheral residential zones situated entirely beyond the 1600m viable walking limit. This forces peripheral reliance on private motorized vehicles, cyclically driving central congestion.

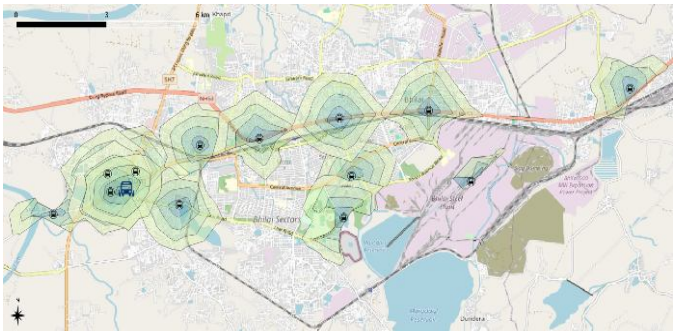

Fig. 5. Public transit accessibility mapping revealing unserved residential sectors.

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D. Accident Hotspots and Safety Distribution

The hexagonal density analysis identified two distinct localized safety hazards. First, severe, high-intensity blackspots are predominantly clustered along the National Highway (NH) corridor, driven by the volatile friction between high-speed regional transit and local crossing traffic.

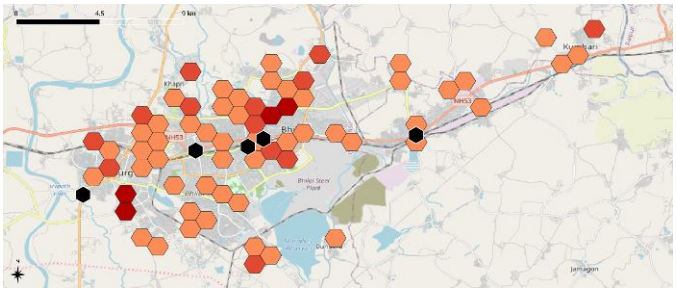

Fig. 6. Hexagonal accident intensity heatmap and localized blackspots.

Second, a spatial correlation overlay demonstrated that an overwhelming 99% of localized, non-highway traffic incidents are tightly clustered inside designated Residential and Mixed Residential Zones. This points to a severe lack of neighbourhood traffic-calming infrastructure and mismanaged localized traffic density.

E. Infrastructure Intensity

Grid density analytics corroborated the vulnerability findings. Road infrastructure is densely packed within the historical and commercial cores but remains highly fragmented across the sprawling residential peripheries, proving that outward housing expansion has vastly outpaced structural road development.

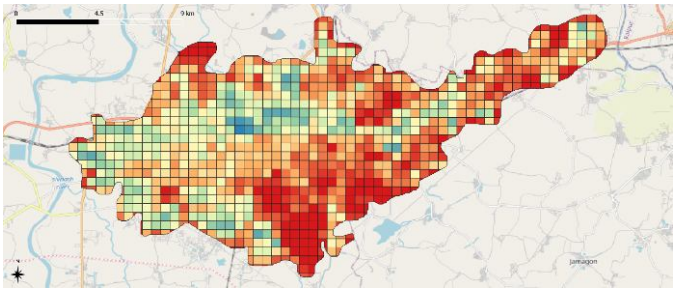

Fig. 7. Grid density analysis illustrating the spatial concentration of physical road infrastructure across the urban sprawl.

V. CONCLUSIONS

This study successfully implemented a comprehensive GIS framework to diagnose urban mobility challenges in Durg City. The findings definitively show that the city's transport issues are driven by disjointed land-use planning. Peripheral residential sprawl has outpaced transit infrastructure, creating vast transit deserts and severe central network bottlenecks. Furthermore, the spatial clustering of accidents reveals critical safety deficits along both regional highways and internal residential networks.

To mitigate these challenges, municipal authorities must prioritize targeted interventions: establishing new transit routes within identified peripheral deserts, investing in parallel arterial ring roads to reduce topological vulnerability, and aggressively implementing localized traffic-calming measures within residential zones. This spatial methodology provides a cost-effective, replicable blueprint for sustainable urban transport planning in resource-constrained Tier-2 cities.

VI. ACKNOWLEDGMENT

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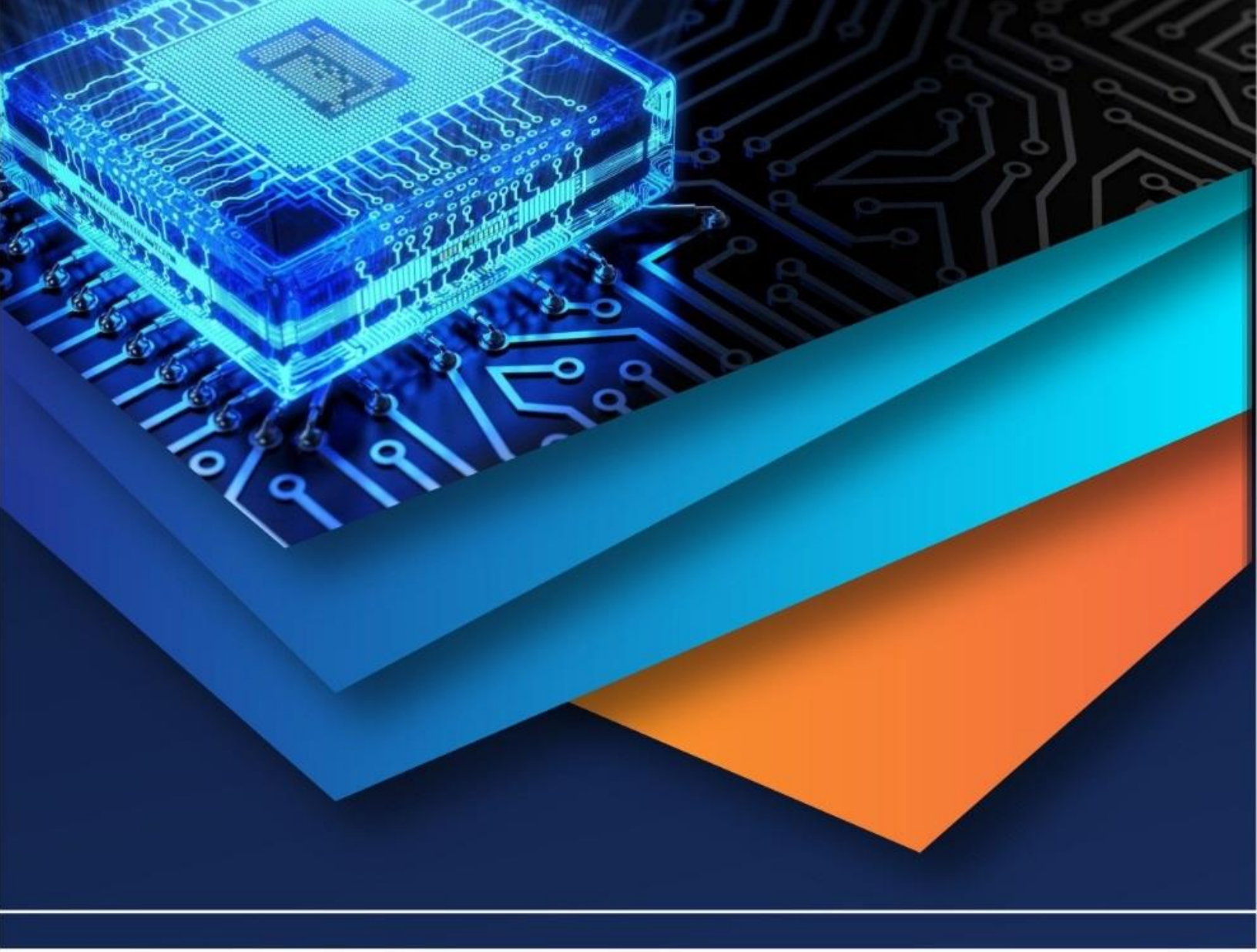

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