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ORIGINAL ARTICLE

Comparative Feasibility Analysis of Mass Transit Options for Mangaluru-Udupi-Manipal Corridor

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Abstract

Objectives: Evaluate the techno-economic viability of a proposed ₹20,000 crore Heavy Metro system vis-a-vis alternate transit modalities (e.g., the inland waterway-based Water Metro) for the linear Mangaluru-Udupi-Manipal (MUM) urban corridor**. Method:** Using a mixed-methods methodology, demographic projections were conducted for the 2026 and 2031 horizon years against established benchmarks of the National Commission on Population. Existing railway infrastructure capacity has been audited through the lens of Scott's Formula for mixed traffic single line sections. A comparative Capital Expenditure Framework has been developed to assess Heavy Metro against MetroLite, Bus Rapid Transit (BRT) and Water Metro alternatives. **Findings:** Spatial demographic analysis reveals that the projected aggregate population of 1.02 million by 2026 satisfies only 51% of the statutory population threshold requirement for a Heavy Metro system, which, according to current trajectories, will not be reached until 2059. An operational assessment of the single-track Konkan Railway section indicates that it currently accommodates 72 daily trains despite a theoretical safe capacity of 33.6 trains, i.e., a 214% utilisation rate. If the proposed suburban rail paths are included, such figures become implausible at 363%. In terms of financial investment, deployment of a closed system BRT along NH66 demands 14.4% of the Heavy Metro capital outlay. However, the recently initiated Mangaluru Water Metro Project (MWMP) achieves very specific node connectivity objectives at just 3.1% of the heavy rail capital outlay benchmark**. Novelty:** This research presents an integrated techno-economical evaluation matrix specifically adapted for linear coastal conurbations of the Global South, as one of the first studies of its kind. This study systematically derives corridor-specific overcapacity metrics and juxtaposes them against recent literature on transit-oriented development, multi-system integration and emissions, to challenge the universality of deploying capital-intensive Heavy Metro systems as panaceas in mid-sized Indian cities.

Keywords: Linear Urban Corridor; Suburban Rail; Metro Viability; BRT; Water Metro

1 Introduction

Across the Global South, there are unprecedented rates of urban densification in Intermediate or Tier-2 cities. This urban growth spurt has been accompanied by an explosion in private vehicle ownership, which is resulting in chronic traffic congestion and deteriorating air quality [1]. In order to address these mobility issues, municipal planners across India have adopted capital-intensive Mass Rapid Transit Systems (MRTS). These systems, however, are often ill-suited for implementation in mid-sized urban areas.

The current 'Metro-first' policy continues to rely on central government grants rather than attracting substantial investments from private sector stakeholders through Public-Private Partnership models, a challenge highlighted in previous studies [2], resulting in the indiscriminate rollout of Heavy Metro rail solutions and causing acute financial distress in some of our cities as actual ridership numbers fail to reach projection figures stated in initial planning documentation.

The task of improving mobility in intermediate cities becomes more difficult due to significant regional inequalities and the complicated urban-rural continuum characteristic of much of developing India [3]. In general, conventional approaches to policy formulation prefer generalized methods, which overlook the complexity of local development and its spatial components [4]. Thus, the application of typical mega-projects that require enormous capital investments without localized evaluations may hide a number of specifics in terms of intraregional diversity and aggravate geographical inconsistencies [3], [4].

The case study focuses on the Mangaluru-Udupi-Manipal (MUM) Corridor, which represents a unique form of urban agglomeration situated along the south-western coast of Karnataka. Instead of the traditional 360-degree radial expansion witnessed in larger metropolitical centres such as Delhi or Bengaluru, the MUM Corridor is constrained within a linear topography bounded on one side by the Arabian Sea and another by the mighty Western Ghats (Figure 1).

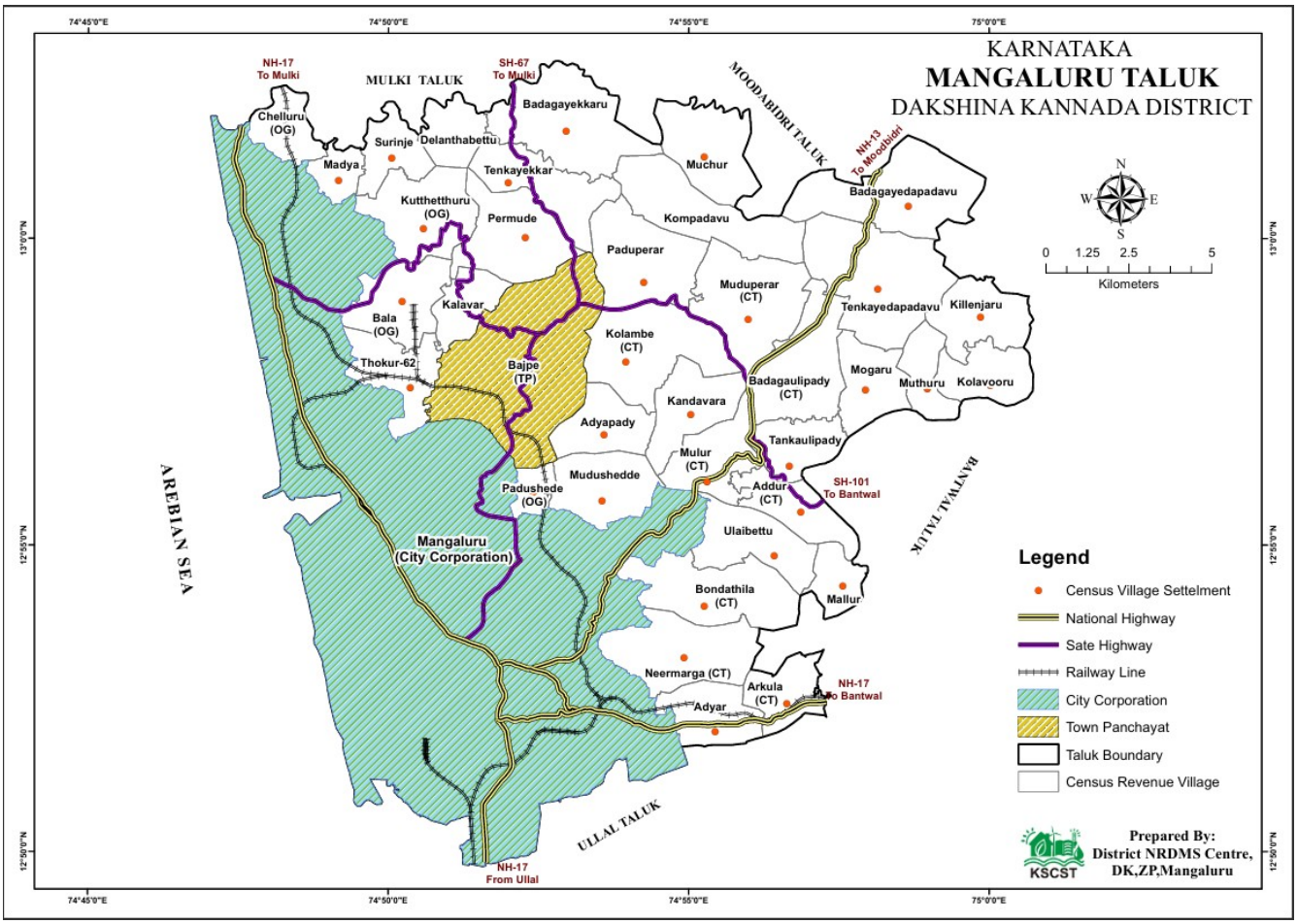


Fig 1. Mangaluru Taluka Map showing linear corridor geography between the Arabian Sea and the Western Ghats.

This linear funnelling results in an intense concentration of transit demand, residential densities, and commercial activity along a single longitudinal axis. Such geographical constraints render the region structurally incapable of sustaining the bidirectional, high volume passenger movements required for Heavy Metro systems to achieve farebox recovery.

The study seeks to provide critical insights into the techno economic viability of the deployment of a 64-kilometre-long dedicated Heavy Metro Line amidst a complex terrain. This paper analyses the scenario based on the guidelines provided by the National Metro Rail Policy 2017 [5] while also comparing the potential of Heavy Rail against intermediate transport modes such as Suburban Rail, BRT, MetroLite and the nascent inland waterways network.

2 Methodology

A structured mixed-methods approach was adopted to ensure analytical rigor and full reproducibility, synthesizing quantitative demographic forecasting, mathematical line capacity auditing and comparative financial modeling.

2.1 Dataset Availability and Explicit Sample Definition

The spatial sampling was limited to the continuous coastal urban strip, including the Mangalore corporation area, Udupi city, and the Manipal special educational area. The primary base population data were obtained from the Census of India 2011 [6]. The population for the target years 2026 and 2031 has been projected using demographic projections and mortality assumptions provided by the National Commission on Population in its Technical Group on Population Projections (2011-2036) available through the Ministry of Health and Family Welfare [7].

For the infrastructure data such as the length of block sections and average number of trains passing per day, we used the annual performance reports of the Konkan Railway Corporation Limited (KRCL) for the fiscal year of 2023-24 [8]. In addition, data regarding the capital expenditure benchmarking of the metro systems, namely, Metro, MetroLite, and Metro Neo, were acquired from the policy specifications of the Ministry of Housing and Urban Affairs (MoHUA) [9]. Finally, the operational details of the Mangaluru Water Metro Project were obtained from the reports of the Karnataka Maritime Board and the actual data from the Kochi Water Metro project [10].

2.2 Validation Against Benchmark Methods

To assess the practicality of overlaying a new suburban rail service onto existing rail tracks, a thorough mathematical line capacity investigation was undertaken. This was done specifically for the significant bottleneck location, which is the single-track railway connecting Thokur with Udupi. The results were further corroborated using Scott's formula, which is known to be the leading formula by the Research Design and Standards Organization (RDSO) of Indian Railways. The main advantage of Scott's formula is that it takes into consideration operational friction and speed differential peculiar to Indian mixed-traffic single-line sections [11].

$$C = 1440/(T + t) \times E$$

Where C is the line capacity (number of trains in a day); 1440 is the number of hours in a day; T is the slowest trains running time in the given track (in this case is projected to be 25 minutes for the railway section between Thokur and Udupi); t is the standard signalling operation time (5 minutes); E is the efficiency factor (which is 0.7 for mixed railway traffic in single lines). A sensitivity analysis has been conducted with a conservative estimate for the post-double capacity at 2C = 67.2 trains per day, assuming simultaneous upgrades in track geometry and signalling infrastructure.

The comparative CAPEX analysis has been done based on key comparisons for km throughout the MUM corridor. The total length of 64 km has been used to calculate the cost estimates for each transit mode to directly compare them with that of heavy metro costing ₹200 billion. The per km costs were also computed as ratios to the heavy metro mid-point benchmark rate of ₹286 crore per km.

2.3 Detailed Sensitivity Analysis

The study also included a detailed sensitivity analysis to assess future investment in infrastructure improvements. This phase consisted of three situational tests. In particular, the baseline EMF and absolute (A) signalization was established with E=0.7. Scenario B predicted the aggressive scenario with an increased level of efficiency (E=0.9), which simulates an upgrade to automatic block (AB) signalization. Scenario C represents a double tracked section allowing the assessment of the elasticity of corridor capacity.

3 Results and Discussion

3.1 Demographic Trajectories and Threshold Realities

The local population density has a significant impact on the financial success of any mass transit project. Based on the spatial extrapolation, it is estimated that by the year 2026, there will be around 1.02 million people living along the 64 km length of the corridor (Table 1).

However, to obtain funding for the Heavy Metro system, the National Metro Rail Policy requires the population of a certain area to be 2.0 million or more[5]. Currently, the MUM corridor meets only 51% of this requirement; moreover, the projected gradual increase in the local population at a rate of 2.05% ensures that the necessary number of people will be reached no earlier than 2059. This means that the Heavy Metro system commissioned today will finish its 30-year design life in conditions of loss-making operations.

Table 1. Population Estimates for the Mangaluru-Udupi-Manipal Corridor and Threshold Analysis

Urban Area	Est. Pop. (2026)	Est. Pop. (2031)	Classification	CAGR	% of 2.0M Threshold (2026)
Mangaluru City	795,000	955,000	Tier-2	2.05%	39.8%
Udupi City	185,000	212,000	Tier-3	Moderate	9.3%
Manipal	⊠40,000	⊠50,000	Special Zone	High	2.0%
Total Corridor	**1,020,000**	**1,217,000**	**Linear Conurbation**	**≈2.05% blended**	**51.0% → 49% below threshold**

3.2 Railway Capacity Diagnostics

A local group has suggested using the current infrastructure of the Konkan Railway system for the purpose of high-frequency commuter services (Figure 2). Nevertheless, the computations made with the help of Scott's formula about the Thokur-Udupi sector show that the prospects of such operations in practice are rather hopeless. According to the formula, the safe capacity used only for the movement of trains is about 33.6. However, the KRCL statistics state that there are 72 trains operating in this sector[8]. This means that this infrastructure operates at 214% of its capacity, which is more than double what it was designed to handle.

If it were attempted to provide slots for 50 suburban trains on this saturated line, then it would have been necessary to introduce 122 trains and achieve 363% utilization of the infrastructure. The calculations made proved that such a problem cannot be solved only with the simple upgrades in signalling technologies.

To illustrate the issue of operational stalemate in minute detail, let us analyze the headway calculation of the 122 scheduled daily trains. If we try to allocate 122 trains logically in a 24-hour cycle, we will arrive at about 11.8-minute average dispatch headway (1440 minutes/122 trains). However, application of standard engineering rules[11] leads to the conclusion that the Thokur-Udupi block can take not less than 30 minutes (25 min – running time, 5 minutes – signalling block time) to complete the processing of one train. The fact that the required dispatch headway of 11.8 minutes is many times lower than the block clearance time of 30 minutes makes it mathematically impossible to accumulate such a flow in one direction on a single track.

Even more, in the case of mixed traffic operational conditions, any minor disturbance, for instance, a 5-minute delay of a heavy goods train leaving Thokur, will result in domino-like cascading penalties down the chain. The blocked freight train will occupy the single-line block for 35 minutes instead of 30, which will lead to the waiting of the next suburban train at the signal. The delays cascade down the chain, leading to ever-building delays and gridlock[12].

Table 2. Konkan Railway Capacity Budget-Single Track vs. Track-Doubled Scenarios

Scenario	Theoretical Capacity (trains/day)	Actual/Projected Trains	Utilisation Rate	Operational Status
Current (single track, no suburban)	33.6	72 (55 pax + 17 frt)	214%	Critical - double theoretical capacity
Proposed (single track + 50 suburban paths)	33.6	122	363%	Impossible - arithmetically infeasible
Post-doubling (no suburban service)	67.2	72	107%	Marginally viable; maintenance feasible
Post-doubling + 50 suburban paths	67.2	122	182%	Still overcapacity; additional measures required

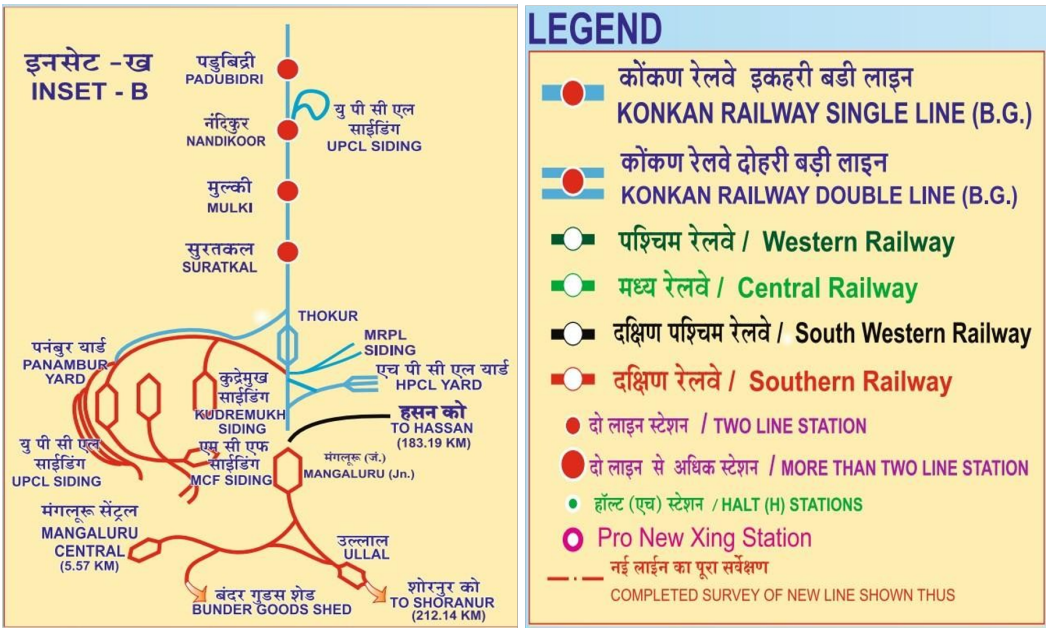


Fig 2. Konkan Railway Map illustrating the Mangaluru Railway Tangle and the critical Thokur-Udupi single-track section.

Thus, with the doubling of the tracks on the line, one will be able to achieve only 107% of the line use, which is enough to stabilize the operation of freight and express trains[8]. Nevertheless, in case 122 extra suburban trains are introduced in the double-tracked line, the line use commuter rail layer (Table 2).

3.3 Comparative Cost-Benefit Evaluation

Construction of a Heavy Metro along the corridor is too costly. Based on the MoHUA standards, the overall expenditure for the project is estimated at around ₹20,000 crores. On the contrary, intermediate modes offer high efficiencies in terms of capital. At ₹140-180 crores per kilometer, mid-point ₹160 crores/km, the MetroLite system would call for a total of ₹10,240 crores for the 64km long corridor, aligning well with its traffic demand[9].

Table 3. Comparative Cost and Capacity Analysis of Transit Modes (2024–25 Prices)

Transit Mode	CAPEX per km (₹Cr)	Total Cost, 64 km Corridor (₹Cr)	PHPDT Capacity	% of Heavy Metro CAPEX	Suitability for MUM
Heavy Metro	222–350 (286 mid)	20,000 (given)	> 15,000	100% (benchmark)	Low - fails demographic threshold; concession expires before 2.0M is reached
MetroLite (LRT)	140–180 (160 mid)	10,240 (saving ₹9,760 Cr)	10,000–15,000	56%	High - PHPDT-aligned; suitable for Udupi-Manipal node
BRT (closed system)	40–50 (45 mid)	2,880 (saving ₹17,120 Cr)	5,000–10,000	16%	Very High - leverages NH-66 median; integrates private bus fleet
Water Metro (MWMP)	9 (270 Cr / 30 km)	270 (30 km route)	Moderate	3.1%	Very High - serves industrial/port nodes; 74× cheaper than Heavy Metro

The approximate PHPDT of 10,000-15,000 would again relate to the traffic demand of the corridor. The BRT on NH-66 would amount to ₹40-50 crores/km, mid-point ₹45 crores/km, translating to ₹2,880 crores for the whole corridor, equivalent to 14.4 percent of the Heavy Metro cost and capital savings of ₹17,120 crores while providing PHPDT in the range of 5,000-10,000. For instance, a closed system BRT on the recently widened National Highway 66 (NH-66) requires only 14.4% of the initial capital cost for the Heavy Metro (Table 3, Figure 4).

The Mangaluru Water Metro Project (MWMP) comparison is indeed illuminating (Figure 5). The estimated total capital cost is ₹270 crore for the total distance of 30 km; thus, the MWMP indicates the per-kilometre cost of about ₹9 crore, which is only 3.1% of the Heavy Metro. Therefore, the Heavy Metro scheme would require around 74 times more capital than MWMP

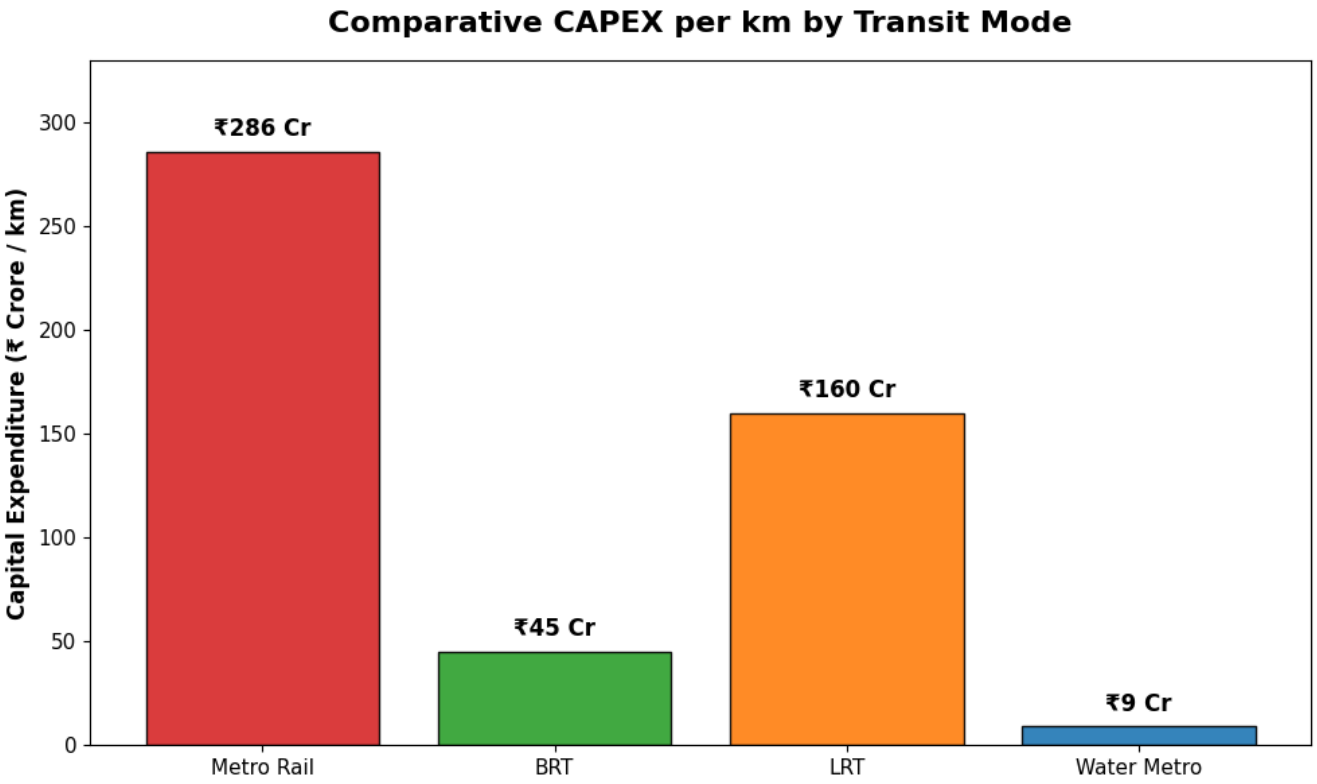


Fig 3. Comparative Capital Expenditure (CAPEX) per kilometre across transit modes.

for travelling the same distance but in a different geographical environment. When it comes to the cost-benefit analysis of both schemes, one could easily say that MWMP seems like a great solution for the connectivity of nearby regions.

3.4 Explicit Contrast with Prior Academic Literature

The findings reported here are in sharp contrast to conventional models of urban transit, which lend credence to the growing body of literature that casts doubt on the generally accepted notion that heavy rail systems can be implemented in second-tier cities. The author Kuriakose agrees with the demographic arguments made in this paper, warning that the introduction of heavy rail systems into cities that fall into the mid-size category will lead to the marginalization of the economically weaker sections of society[13].

In order to ensure effective servicing of the burden of massive debts, the operators are often compelled to introduce exclusionary price hikes with respect to fares. When crushing an investment project worth ₹20,000 crores on a city with a mere population of 1.02 million, one guarantees the emergence of such a dreadful inter-generational debt trap, which will definitely undermine the metro system's ability to carry out its main function of ensuring equal mobility.

With respect to geography, while Lin et al. argue that metro networks provide the opportunity for fast urbanization and land value enhancement, their econometric models are based on the assumption of a 360-degree catchment area[14]. Mehra and Vardhan assert that Transit-Oriented Development (TOD) should be developed with utmost consideration of local circumstances[15]. In the case of the MUM corridor, which is bordered on both sides by the Arabian Sea and the Western Ghats, the possibility of land value capture is limited. It is simply impossible to develop high-rise buildings over the sea, which is a blow to the financing that often helps realize mega-projects.

Moreover, the distinctive land-use transport dynamics found in the MUM corridor severely inhibit conventional radial Transit-Oriented Development (TOD). Due to the confinement of urban morphology between the Arabian Sea to the west and the Western Ghats to the east, land-use zoning occurs solely along the north-south corridor. Major employment centers, like Baikampady Industrial Area and New Mangalore Port Authority (NMPA), create one-way traffic flows that abruptly peak during certain times of the day. Because of the constraints in spatial distribution, flexible services from node to node should be



Fig 4. Operational view of the Hubballi-Dharwad BRTS, cited as a cost-effective corridor model.

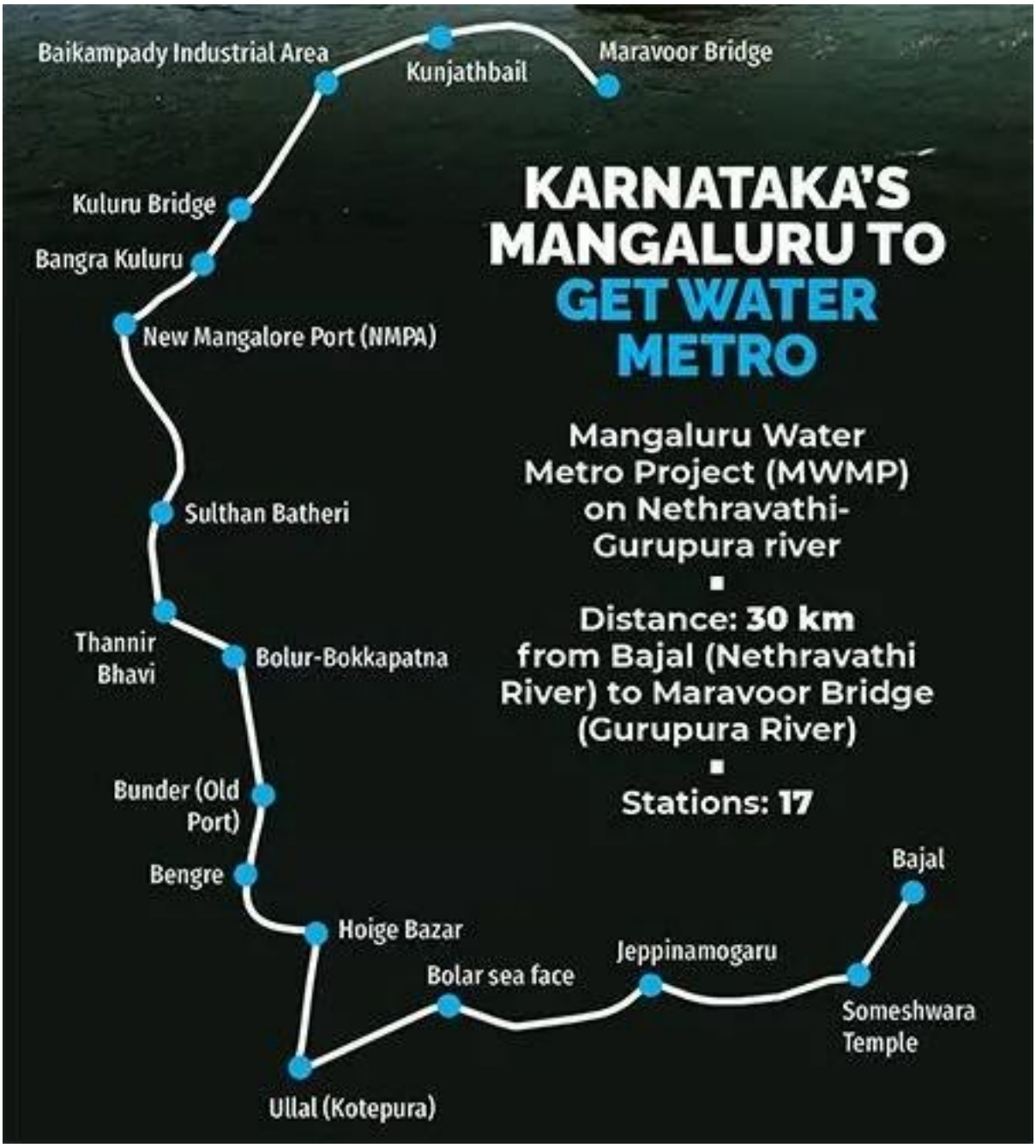


Fig 5. Proposed route map of the Mangaluru Water Metro Project (MWMP) across NW-74 and NW-43.

considered instead of costly methods such as the Heavy Metro. Unlike conventional metro systems that can be based on large catchment areas to sustain passenger flow and increase land values [14], the physical limitations imposed by the MUM corridor render adjacent real estate development almost impossible, thus jeopardizing the investment in heavy rail solutions.

In addition, determined bureaucratic obstacles to optimal scheduling are a real problem in this area. Lu et al. put forward complex mathematical models that allow planning a rail route in seamless operation mode [16]. But this algorithmic optimization is impossible without significant regulatory reform aimed at creating a metropolitan transportation authority, which would solve the complicated situation known as the "Mangaluru Railway Tangle." Adhering to the nation's logistics priorities creates even greater difficulties in terms of administration. Kumar et al. establish enduring obstacles to supply chain management in terms of rail transportation [12].

These obstacles confirm that the national freight transportation system will systematically maintain operational priority over local passenger services in terms of operation, even on saturated single-track routes. Another point to consider is rolling stock limitations; as indicated by Ishaq et al., reducing the amount of power consumed by suburban rail rolling stock is a very complicated task [17].

The ecological arithmetic also gives a clear advantage of waterway transport over infrastructure projects on land. Aryan et al. studied the first underground metro in Mumbai and found a counter-intuitive truth: the metro did not reduce GHG emissions at all at the start [1]. The metro used vast amounts of electricity from the power grid and attracted customers away from public buses, not from private cars, which pollute the environment a lot. A Heavy metro in Mangaluru would be subjected to the same problem of competing with the effective bus transportation service [18]. The Water Metro does not require land acquisition for land transport projects and runs hybrid-electric vessels instead, making it capable of carrying a large number of passengers without a significant amount of CO2 emissions from concrete elements.

The current literature emphasizes the importance of using structured, multi-criteria systems to address these planning gaps [3]. As the authors note, "by structuring the localized demographic issue and utilizing evidence-based rationale in the urban planning process, policy makers will be better positioned to enact fair and evidence-based policies" [4]. In line with this principle, the comparison matrix used in this study is designed to serve as a local support tool for decision-making processes. Figure 6 highlights the integration of an at-grade MetroLite (modern tram) system for high-density internal nodes



Fig 6. Exemplary integration of an at-grade MetroLite (modern tram) system for high-density internal nodes.

4 Conclusion

The research work accurately determines the feasibility of transit in the linear Mangaluru-Udupi-Manipal corridor. Present conditions due to demographics and infrastructure do not support the operational profitability of the Heavy Metro, which costs Rs. 20,000 crore. Reaching only 51% of the required population, the Heavy Metro would operate below the density threshold where the whole design lifecycle will be exhausted. At the same time, the functionality of the Konkan Railway's single-track section is already inhibited with 214% utilization. The sensitivity analysis indicates that track doubling is essential for stabilizing current operations of the transport means, but it will not be sufficient to host the entire suburban commuter network.

In order to solve the issue of mobility in the area, urban planners must shift to an integrated multimodal concept in transportation. The first step is to overlay a Bus Rapid Transit (BRT) system on the expanded NH-66. In addition to this, the state has to put maximum effort into the implementation of the Mangaluru Water Metro Project costing ₹270 crore. By using a low-emission fleet, MWMP allows for connecting the most highly populated industrial and port points of the location and avoids the negative impact of carbon footprints accompanying land rail lines.

This study has limitations that must be acknowledged. Due to the delay of the 2021 national census, the demographic data in this case are based on the estimates made during the 2011 census, resulting in compounded uncertainty. Moreover, while Scott's formula uses the recognized heuristics of the Research Designs and Standards Organisation (RDSO), further studies should be directed towards dynamic software modelling in order to account for every minute traffic disruption on the Konkan Railway.

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