AN AHP-GIS BASED APPROACH FOR OPTIMAL METRO ROUTE PLANNING IN TIRUCHIRAPALLI CITY, TAMILNADU

SUVISH S

M.TECH.,Student,Department of Remote Sensing,Bharathidasan University,Trichy-23

ABSTRACT

This study focuses on identifying optimal locations for a metro network in Tiruchirapalli city to address current and future transportation needs. Utilizing Remote Sensing, Geographic Information System (GIS), and Analytical Hierarchical Process (AHP), the research extracts, preprocesses, prioritizes, and spatially analyzes data. Criteria such as population density, key traffic hubs, intersections, existing road networks, land use, Groundwater level,and slope maps are evaluated for site selection. Each criterion is ranked based on its relevance and weighted using AHP. GIS-based weighted overlay analysis integrates these criteria maps to identify potential routes. Five routes, spanning southwest to northeast and east to west directions, with respective origin and destination stations, are proposed. Finally, two optimal metro routes (one in each direction) are recommended, with the potential for future extensions to accommodate growing population centers.

Keywords: Metro network optimization,Geographic Information System (GIS),Analytical Hierarchical Process (AHP),Site selection criteria

1. INTRODUCTION:

Urbanization and population growth pose significant challenges to transportation systems in cities worldwide. Tiruchirapalli, a bustling city in state of Tamil Nadu, India, is no exception. With its rapid expansion and increasing traffic congestion, there is an urgent need for efficient and sustainable transportation solutions to meet the demands of its residents and ensure the city's continued development.

In response to these challenges, this study explores the feasibility of introducing a metro network in Tiruchirapalli city. Metro systems have proven to be effective in alleviating congestion, reducing pollution, and enhancing connectivity in many urban centers globally [1]. By leveraging advanced technologies such as Remote Sensing, Geographic Information System (GIS), and Analytical Hierarchical Process (AHP), this research aims to identify optimal locations for metro routes.

The selection of suitable sites for metro infrastructure involves a multifaceted approach. Factors such as population density, traffic flow patterns, existing infrastructure, and land use must be carefully considered to ensure the network's effectiveness and accessibility [2]. Through a systematic analysis of these criteria, this study seeks to propose viable routes and station placements that cater to both current and future transportation needs in Tiruchirapalli.

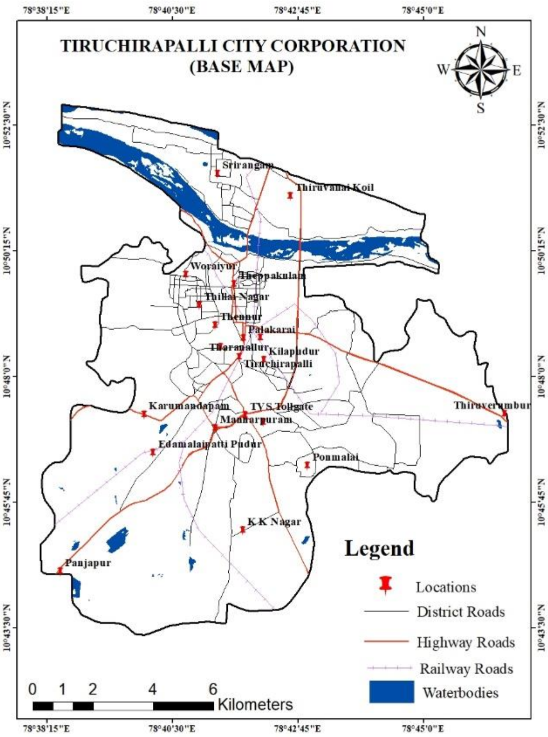
Furthermore, the implementation of a metro system in Tiruchirapalli has the potential to catalyze urban development and improve the quality of life for its residents. By providing fast, reliable, and environmentally-friendly transportation options, the metro can spur economic growth, enhance mobility, and reduce dependence on private vehicles [3].

Moreover, the expansion of the metro network to areas projected for future population growth will ensure its long-term sustainability and relevance in the evolving urban landscape.

In summary, this study endeavors to contribute to the discourse on urban transportation planning in Tiruchirapalli by offering data-driven insights into the feasibility and benefits of introducing a metro network. By harnessing the power of technology and strategic decision-making processes, the aim is to propose a sustainable and inclusive solution that addresses the city's pressing transportation challenges and fosters its continued growth and prosperity.

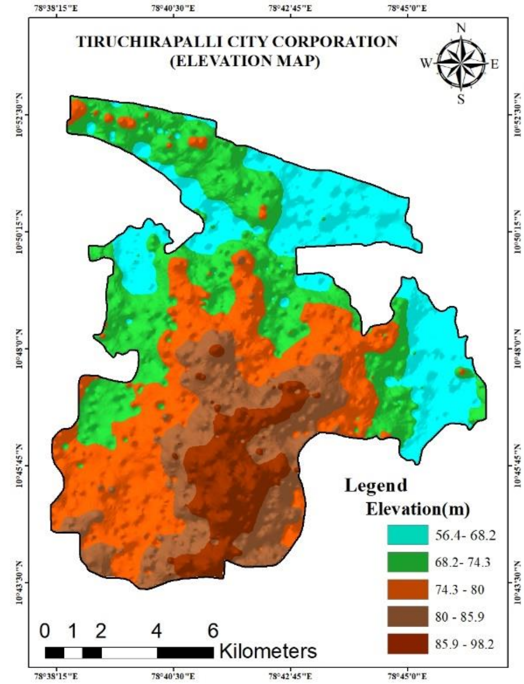
2. STUDY AREA-TIRUCHIRAPALLI CITY

The Tiruchirappalli Metro Route Selection Study reveals key insights about the area. Covering 65 wards and spanning 157.92 square kilometers, it lies between latitudes 10°40′N and 10°56′N, and longitudes 78°36′E and 78°47′E. Positioned in central Tamil Nadu, it hosts numerous heritage sites. The Cauvery River flows through, bringing fertile soil. Rainfall peaks from October to December due to northeast monsoons, with a cold, humid climate from December to February. Average rainfall is 840.00 mm, with hottest months from April to June. Temperatures average 27°C annually, with maxima and minima recorded at 43°C and 13.9°C. The study area comprises four soil types: loamy, gravelly loamy, cracking clay, and deep clay soil. In 2011, Tiruchirappalli had a population of 847,387, projected to grow 1.39% to 2.16% from 2019 to 2030. To avoid the challenges in transportation activities for better convenience and also to avoid traffic congestion over city.



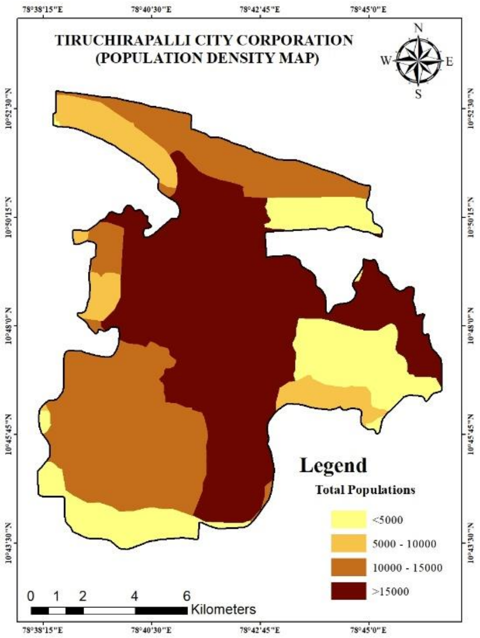
3. ELEVATION MAP

The elevation map derived from the Google earth reveals the varying elevation gradients within Trichy City. Different gradients of elevation were identified in certain regions, indicating potential challenges for urban development and infrastructure planning.



4. POPULATION DENSITY

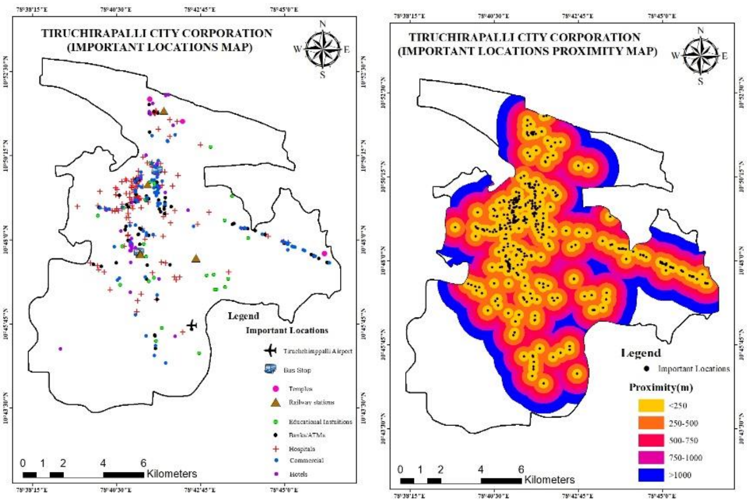
Map Population density serves as a pivotal indicator for the Metro Route Selection Study. Leveraging data extracted from the 2011 census handbook of India, population statistics for Tiruchirapalli city were extracted. Using the point density tool within ArcGIS 10.8.1, a population density map was generated.



This map delineates population density into four distinct classes, spanning from areas of low density to those of high density. Through a comprehensive analysis of these density gradients, an urban suitability map can be devised, facilitating urban planning and development endeavors aimed at accommodating the city's burgeoning population while ensuring optimal resource allocation and infrastructure development.

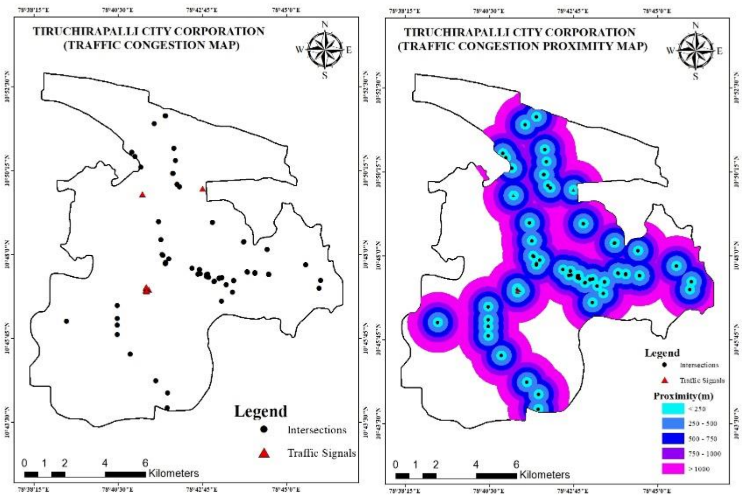
5. **IMPORTANT LOCATIONS / IMPORTANT LOCATIONS PROXIMITY MAP**

   Key locations were identified and mapped using ArcGIS 10.8.1, including airports, bus stops, railway stations, schools, hospitals, stores, hotels, banks, and religious sites. A buffer zone analysis categorized distances into thresholds (less than 250m, 250-500m, 500-750m, 750-1000m, and over 1000m), offering insights into spatial relationships and accessibility patterns. The areas within 250m of bus stops might see heavier foot traffic. This analysis aids urban planners and policymakers in optimizing infrastructure development and resource allocation, enhancing livability and accessibility. It informs strategic decision-making in urban management and development.



6. **TRAFFIC CONGESTION / TRAFFIC CONGESTION PROXIMITY MAP**

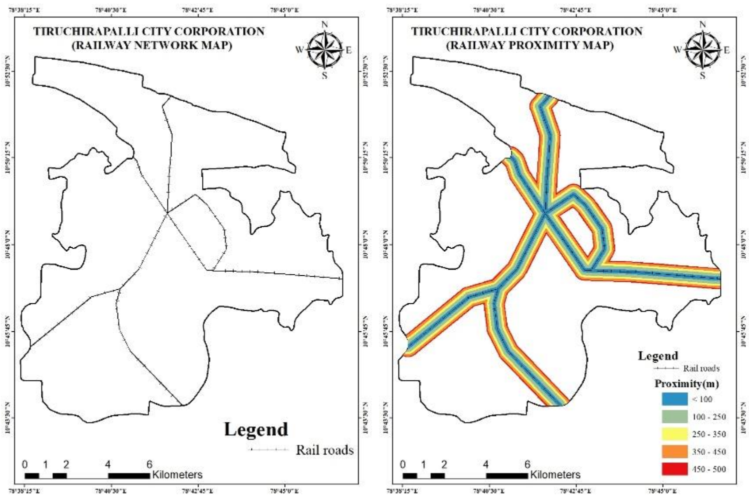
   Traffic congestion areas were pinpointed and mapped using advanced GIS software such as ArcGIS 10.8.1, encompassing major road intersections, and traffic signals. Utilizing buffer zone analysis, distances were segmented into specific thresholds (less than 250m, 250-500m, 500-750m, 750-1000m, and over 1000m), revealing spatial relationships and congestion patterns. The areas within 250 meters of major intersections might experience severe congestion during peak hours. This analysis empowers transportation planners and policymakers to optimize road infrastructure, implement traffic management strategies, and allocate resources effectively. Ultimately, it facilitates informed decision-making to alleviate traffic congestion, enhance commuter



experiences, and improve overall urban mobility.

7. **RAILWAY NETWORK / RAILWAY NETWORK PROXIMITY MAP**

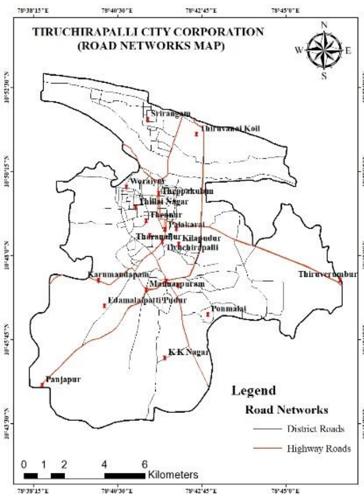
   The rail roads and its networks were spatially mapped using a vector layer i,e., polyline. Employing buffer zone analysis, distances were segmented into specific thresholds (less than 100m, 100-250m, 250-350m, 350-450m, and 450-500m), providing nuanced insights into spatial relationships and accessibility dynamics.

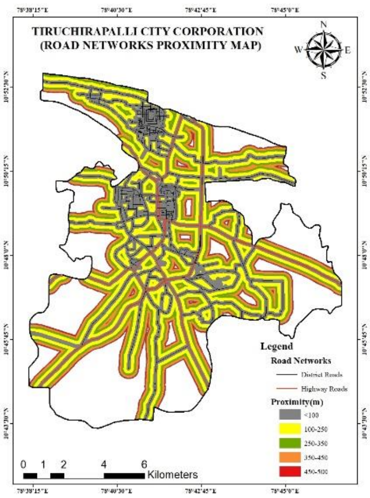


The proximity within 250m of railway stations may exhibit heightened commuter activity. This spatial scrutiny equips urban planners and policymakers with crucial data to streamline infrastructure growth, optimize resource allocation, and elevate the overall functionality and accessibility of rail networks. It serves as a cornerstone for informed decision-making in urban planning and development endeavors.

8. ROAD NETWORKS/ ROAD NETWORKS PROXIMITY MAP

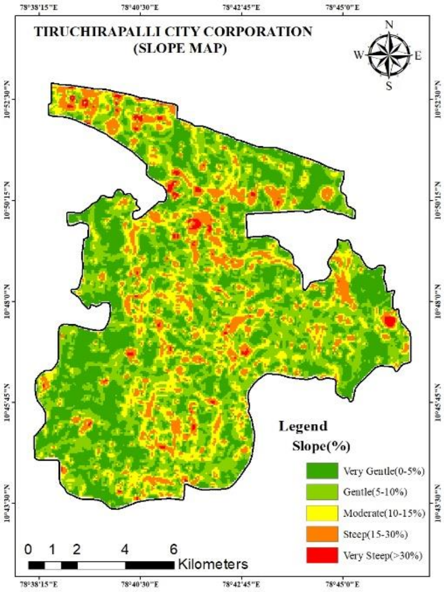
Road networks were analyzed and mapped using ArcGIS 10.8.1, identifying highways, and major roads over the city. Additionally, a proximity map was generated to assess the relationship between road networks and surrounding amenities, such as schools, hospitals, commercial areas, and residential neighborhoods. Buffer zones were established at varying distances (less than 100m, 100-250m, 250-350m, 350-450m, and 450-500m) to understand the influence of road infrastructure on nearby areas. This analysis provides valuable insights for urban planners and policymakers, aiding in strategic decision-making to optimize transportation networks, enhance accessibility, and improve urban development and livability.





9. SLOPE MAP

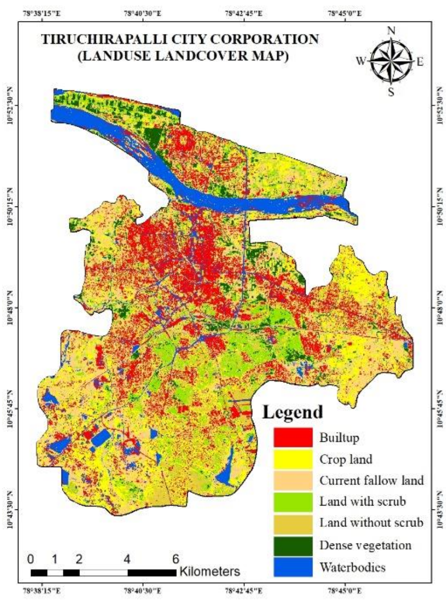
Slope is an important factor for the urban infrastructure developmental activity.The slope map of the study area was prepared based on Google Earth(0.5m) resolution data using the spatial analysis tool in ArcGIS 10.8.1 Slope grid is identified as "the maximum rate of change in value from each cell to its neighbours" (Burrough, 1986). Based on the slope, the study area can be divided into five slope classes. The areas having 0–5% slope fall into the 'very good' category because of the nearly flat terrain. The areas with 5-10% slope are considered as 'good' because of slightly undulating topography. The areas having a slope of 10-15% are considered to be 'moderate slope', 15-30% are steep slopes, and hence are categorized as 'poor' and the areas having a slope >30% are considered as 'very



poor' due to higher steep slope ,and also not suitable for urban development.

10. LAND USE/LAND COVER MAP

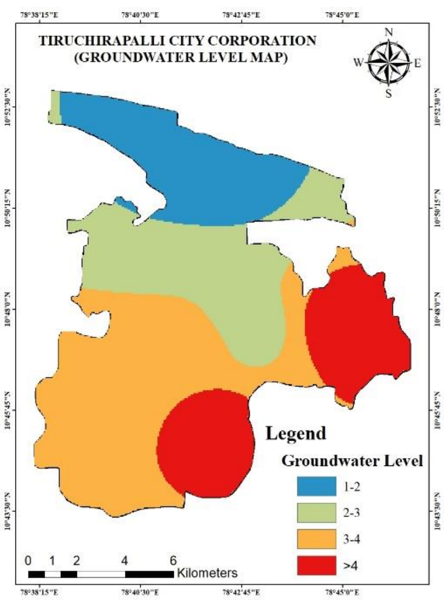
Land use/land cover map is derived by using Sentinel-2A multi-spectral imagery. Supervised classification method based on level 2 – NRSC classification is adopted to distinguish the land use patterns over the city such as builtup, crop land, current fallow land, land with scrub, land



without scrub, dense vegetation, and waterbodies. It is also key parameters to be consider for urban development to maintain a sustainable environment.

11. GROUNDWATER LEVEL MAP

For metro route selection study, understanding groundwater levels is vital as it influences the feasibility of route planning. Peripheral and newly developed areas often lack access to municipal water, relying instead on groundwater sources. Utilizing data from CGWB and employing the inverse distance weighted interpolation technique in ArcGIS 10.8.1. This map was segmented into five depth-based zones: high (< 2 m), moderate (2–3 m), low (3–4 m), very low (4–5 m), and severely low (> 5 m).Here, the higher rank of prioritization were assigned to low groundwater level zones.



12. RESULT AND DISCUSSION

Analytical hierarchy process is a decision-making tool designed for different multi criteria decision making problems. This method was developed by professor Thomas. L. Saaty (1970).The AHP method breaks down the complex multi-criteria decision problem into a hierarchy based on a pair-wise comparison of the importance of different criteria (Saaty 2005).

The first step in an AHP technique is to break down the decision problem into a hierarchy that identifies the parameter/criteria for the goal of the study. The identified criteria are compared against each other in a pairwise comparison matrix (Pij) which isa measure to express the relative preference among the factors. A scale for comparison (Saaty, 1977; Saaty and Vargas, 1991) consisting of values ranging from 1 to 9 which describe the intensity of importance were assigned for the parameters which expressesthe relative importance of one criterion over the other.

The columns of the pairwise comparison matrix are summed up to calculate the scale weights (SW).

Level of Preference Weight for AHP - Saaty and Vargas (1991)	
Intensity of importance	**Definition**
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance
Reciprocals	Reciprocals for inverse comparison

Next, to create a normalized pairwise matrix, each element of the matrix is divided byits respective scale weights following which the row average is calculated to find the Geometric mean (GM).

The Pair Wise comparison matrix obtained by the decision maker should satisfy Saaty'sconsistency condition that is, CR = CI / RI (< 0.1)…..... (1) Where, CI – Consistency index, RI – Random inconsistency.

In order to check for the consistency, a matrix is developed by multiplication ofpairwise comparison matrix and the geometric mean (Pij*GM). The sum of each row is found and divided by its respective geometric mean. The average of these sum valuesgives us the λmax which is used to calculate the

Consistency index (CI) CI = λmax - n/n-1 ………(2)

Where, λmax - highest eigen value of matrix Pij, n – No. of parameters.

The random inconsistency values as given by Saaty and vargas in 1991 is

The CR is calculated by the equation (1) which according to Saaty's consistency ratio condition should be less than 0.1. If not, the decision maker must revise his/her decision so that the consistency ratio is in an acceptable range (<10%). Then, the matrix is acceptable.

No. of Parameters	RI Values
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.54
13	1.56
14	1.57
15	1.59

13. EVALUATION OF MULTI-CRITERIA FOR OPTIMAL METRO ROUTE SELECTION

The integration of the AHP and the geospatial technique was carried out to find the optimal route selection for metro train transportation over the Tiruchirapalli city. The considered parameters such as population density, important locations, traffic congestion, railway proximity, road network

Pair-wise Comparison Matrix

Parameters	Population	Important	Traffic	Railway	Road	LULC	Slope	GW Level
Population	1	1	2	2	3	3	4	5
Important location	1	1	1	1	2	3	4	5
Traffic	0.50	1	1	1	2	2	3	4
Railway	0.50	1	1	1	2	2	3	4
Road	0.33	0.50	0.50	0.50	1	2	3	4
Slope	0.33	0.33	0.50	0.50	0.50	1	1	4
LULC	0.25	0.25	0.33	0.33	0.33	0.33	1	2
GW Level	0.20	0.20	0.25	0.25	0.25	0.25	0.50	1
	4.12	5.28	6.58	6.58	11.08	13.58	19.50	29.00

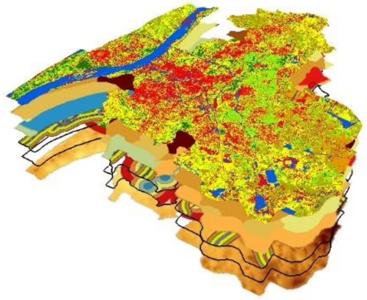
Normalized Pair-wise Comparison Matrix

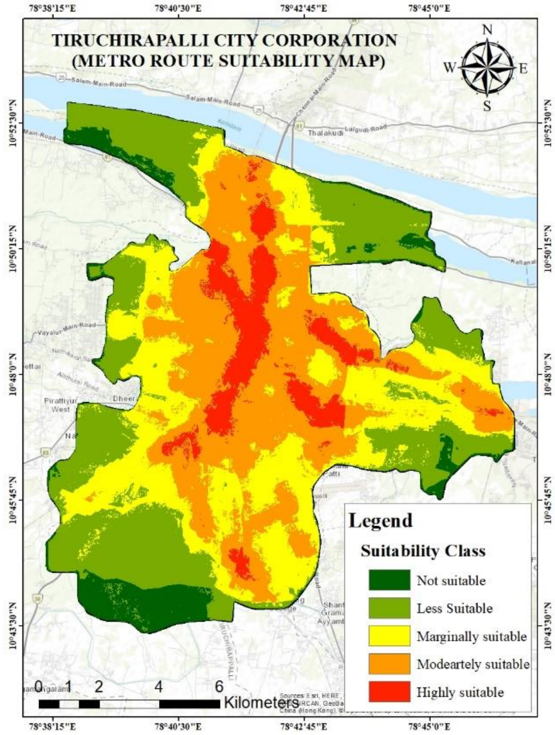
Parameters	Population	Important	Traffic	Railway	Road	LULC	Slope	GW Level	Sum	Criteria Weights	Criteria weight (%
Population	0.24	0.19	0.30	0.30	0.27	0.22	0.21	0.17	1.91	0.24	24
Important location	0.24	0.19	0.15	0.15	0.18	0.22	0.21	0.17	1.51	0.19	19
Traffic	0.12	0.19	0.15	0.15	0.18	0.15	0.15	0.14	1.23	0.15	15
Railway	0.12	0.19	0.15	0.15	0.18	0.15	0.15	0.14	1.23	0.15	15
Road	0.08	0.09	0.08	0.08	0.09	0.15	0.15	0.14	0.86	0.11	11
Slope	0.08	0.06	0.08	0.08	0.05	0.07	0.05	0.14	0.60	0.08	8
LULC	0.06	0.05	0.05	0.05	0.03	0.02	0.05	0.07	0.38	0.05	5
GW Level	0.05	0.04	0.04	0.04	0.02	0.02	0.03	0.03	0.26	0.03	3

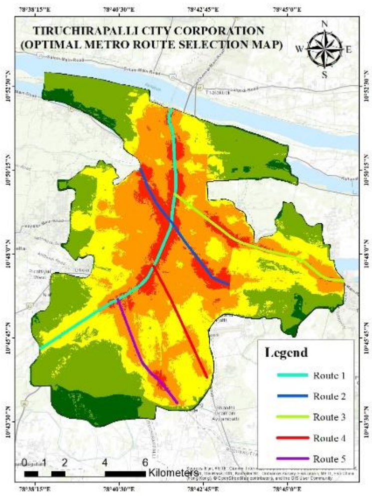
Consistency Ratio

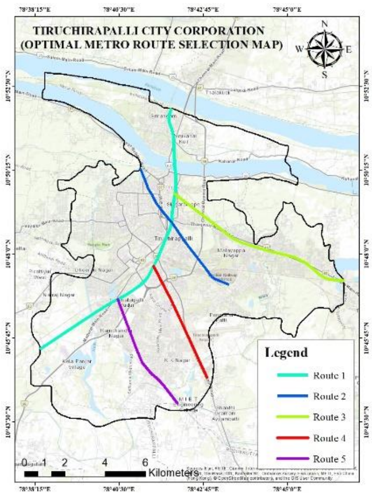
Parameters	Population	Important	Traffic	Railway	Road	LULC	Slope	GW Level	Weighted	Criteria Weight	WSV/CW
Population	0.24	0.19	0.31	0.31	0.32	0.23	0.19	0.16	1.95	0.24	8.17
Important location	0.24	0.19	0.15	0.15	0.21	0.23	0.19	0.16	1.53	0.19	8.10
Traffic	0.12	0.19	0.15	0.15	0.21	0.15	0.14	0.13	1.26	0.15	8.16
Railway	0.12	0.19	0.15	0.15	0.21	0.15	0.14	0.13	1.26	0.15	8.16
Road	0.08	0.09	0.08	0.08	0.11	0.15	0.14	0.13	0.86	0.11	8.05
Slope	0.08	0.06	0.08	0.08	0.05	0.08	0.05	0.13	0.61	0.08	8.02
LULC	0.06	0.05	0.05	0.05	0.04	0.03	0.05	0.07	0.38	0.05	8.01
GW Level	0.05	0.04	0.04	0.04	0.03	0.02	0.02	0.03	0.27	0.03	8.06
										L.Max	**8.09**

proximity, slope, Lulc, and Groundwater level were









Routes	Distance(km)	From - To
Route 1	15.04	Panjapur - Srirangam
Route 2	7.36	Woraiyur - Ponmalaipatti
Route 3	9.45	Singarathope - Thiruverumbur
Route 4	6.08	Tiruchirapalli Railway Jn - Airport
Route 5	5.98	Edamalaipatti pudur - MIET college

integrated under the ArcGIS 10.8.1 environment. The final output were categorized into five different classes i,e., not suitable, less suitable, marginally suitable, moderately suitable, and highly suitable.

14. CONCLUSION

GIS-based study conducted for selecting metro routes in Tiruchirapalli city has provided invaluable insights into optimizing transportation infrastructure. Through careful analysis of various factors such as population density, traffic flow, existing road networks, and potential growth areas, optimal metro routes have been identified. The integration of GIS technology has facilitated data-driven decision-making, ensuring efficiency and accuracy in route selection. The proposed metro routes aim to enhance connectivity, reduce congestion, and promote sustainable urban development in Trichy city. Furthermore, the study underscores the importance of leveraging advanced spatial analysis tools like GIS for strategic infrastructure planning in rapidly evolving urban environments. By implementing the recommended metro routes, Trichy can anticipate significant improvements in transportation accessibility and overall quality of life for its residents, while positioning itself for continued growth and development in the years to come.

15. REFERENCES

[1] International Association of Public Transport (UITP). (2019). "Metro systems worldwide: Statistical data". Retrieved from https://www.uitp.org/publications/metro-systems-worldwide-statistical-data.

[2] Akbari, M., Goli, A., & Goli, A. (2019). "Urban rail transit system site selection using a GIS-based spatial multi-criteria decision-making approach." Sustainability, 11(3), 621.

[3] Martínez, L. M., López, L., & Sánchez, R. (2018). "Assessment of the economic impact of urban rail transit projects in developing countries." Case Studies on Transport Policy, 6(4), 664-670.

[4] Liu, C., & Wu, J. (2018). Site selection of subway station entrances/exits: A review. Transport Reviews, 38(5), 585-605.

[5] Wang, H., Yang, L., & Shan, B. (2019). A GIS-based multi-criteria evaluation for metro station site selection: A case study in Nanjing, China. Sustainability, 11(5), 1320.

[6] Karami, M., Zare, S., & Zamani, M. (2018). Site selection of urban metro stations using a combined approach of GIS and multi-criteria decision making methods. Case Studies on Transport Policy, 6(4), 567-575.

[7] Zhang, W., Wang, Y., Zhu, X., & Cui, C. (2020). Optimization model for urban metro network based on fuzzy analytic hierarchy process. Journal of Advanced Transportation, 2020, 8852925.

[8] Ahmad, S., Rahman, M. S., & Ahsan, M. N. (2021). Site selection for metro stations using fuzzy analytic hierarchy process. Journal of Transportation Engineering, Part A: Systems, 147(3), 04021019.

[9] Li, J., Chen, H., Yang, W., & Yang, S. (2019). Urban metro network expansion planning using a hybrid model of GIS and multi-objective optimization: A case study in Shenzhen, China. Sustainability, 11(23), 6665.

[10] Ramezani, M., & Yaghoubi, J. (2018). An integrated GIS and multi-criteria decision-making approach for the selection of urban metro station locations: A case study from Tehran, Iran. Journal of Traffic and Transportation Engineering (English Edition), 5(5), 472-481.

[11] Núñez-Carballosa, A., Salazar-Ordóñez, M., & Páez, A. (2020). Using GIS and multi-criteria decision analysis to select optimal locations for new metro stations. Transportmetrica A: Transport Science, 16(1), 115-137.

[12] Bai, L., Meng, L., & Zhang, F. (2018). Urban metro network design optimization under passenger flow distribution. Journal of Advanced Transportation, 2018, 4916356.

[13] Lu, L., Zeng, Q., & Liu, X. (2019). Optimization of metro network based on complex network theory: A case study of Shenzhen, China. PloS one, 14(1), e0210242.

CR	0.02