Metro Route Site Selection for Madurai City Using Remote Sensing and GIS

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Abstract. This study mainly deals with the selection of optimal locations for metro network and stations in Madurai city as a solution to meet the present and future transportation demands. Remote Sensing, Geographic Information System and AHP have been used for the purpose of extracting data, pre-processing, prioritizing and analyzing the data spatially. For the site selection process, criteria like population density, important locations that attracts traffic, busy intersections, existing road networks, land use – land cover and slope maps are considered. Each criteria map is ranked according to its suitability and weightage to each criteria is obtained by Analytical Hierarchical Process based on their relative importance to the selection process. Weighted overlay analysis is carried out using GIS by superimposing all the weighted criteria maps. As a result, four routes are selected as decision alternatives with four end stations (origin and destination stations) - two routes in south west to north east direction and two routes in east to west direction and intermediate stations are identified along the selected routes. Finally two routes (one in each direction) are proposed as optimal metro routes. The proposed metro lines can be extended to places that will be densely populated in future.

Keywords: Metro route selection; GIS; Madurai; Site selection; AHP; Spatial analysis.

1 Introduction

Increase in vehicular traffic in Madurai city results in traffic congestion, air pollution and increased the number of road accidents. This has led to a demand for an alternative mass transportation system which is more effective, fast and reliable than the existing road transportation facilities. Proposing a mass transit system is therefore necessary to meet the present transport demand and also to reduce the negative impacts of existing road transportation systems. Metro system is an electrically operated means of transport which operates on an exclusive right of way with protected at-grade crossing and has a capacity to carry more than 1500 passengers per train (Shafik Jendia and Mohammed Skaikm, 2016). A metro rail consists of minimum three number of coaches and depending upon the requirement it can be increased to eight. Metro systems are mostly operated in inner metropolitan areas of cities having high population density (Maher A. EI-Hallaq and Khalid D. EI- Yazory 2017). The primary goal of the site selection process is to find the optimal locations for metro network and stations that meet predefined selection criteria. Such a process involves manipulation of spatial data and requires fulfillment of multiple criteria to take critical and successful decisions. Geographic Information System (GIS) has been widely used in the field of transportation to take critical decisions in planning, modelling, transit service planning and accident analysis due its ability to manage, store, manipulate, analyze, retrieve and visualize

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the geographical information (Elangovan,2006, Andras Farkas, 2009). But GIS will not deal with multiple decision factors. For the purpose of handling multiple decision parameters, Multi Criteria Decision Making (MCDM) method has to be used (Srimathi et 2014, Rajkumar and Elangovan,2020). Hence this study employs both Geographic Information System to manage spatial and non-spatial data, to perform suitability analysis and MCDM System, usually the Analytical Hierarchical Process (AHP) for prioritizing the criteria based on their importance.

2 Study area

Madurai city is located in southern side of Tamil Nadu, spans between 78°2’43” and 78°11’8” E and 9°50’18” and 9°59’40” N. It is considered as the third largest city of the state and has got 25th position in India in terms of population. The city is located at an elevation of about 101 meters and the corporation boundary covers an area of 147.97 km². As per 2011 census the population of Madurai metropolitan region is 1.47 million and it is estimated that, the population exceeds 3 million in the year 2019. Madurai city boundary is divided into 100 wards and the ward map of the city is shown in Fig. 1.

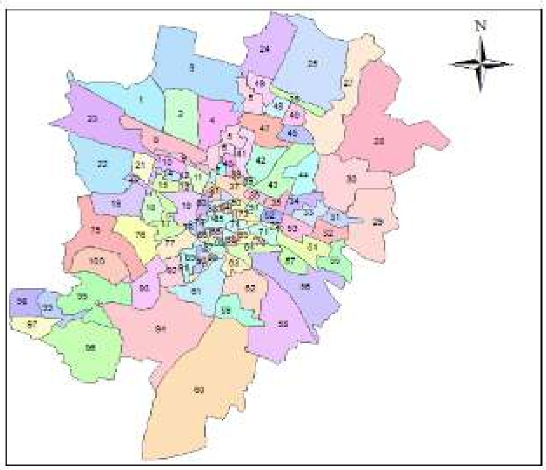
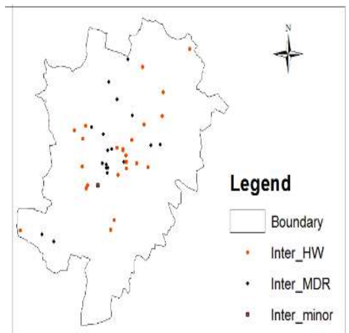


Fig. 1. Ward map of study area.

3 Methodology

The criteria required for the site selection process have been identified. Required data are collected from relevant sources and pre-processed in order to convert the data into GIS acceptable formats. Pre-processing involves digitizing the base map, adding attribute data, geo-referencing etc. Then each criteria map is ranked such that the area which is more suitable for the site selection will get the highest rank. Prioritization of criteria is done by Analytical Hierarchy Process (AHP), considering the relative importance of criteria for site selection. Final composite map which shows the optimal locations for metro network is obtained by

Weighted Overlay Analysis by overlapping all the weighted criteria maps. After finding the suitable locations for end stations, least cost paths (decision alternatives) connecting the end stations are obtained and the intermediate stations are distributed along the selected rail routes. From the decision alternatives, optimal routes are selected by calculating the effectiveness of each route based on the extent to which the stations located along a particular route is suitable for metro network.

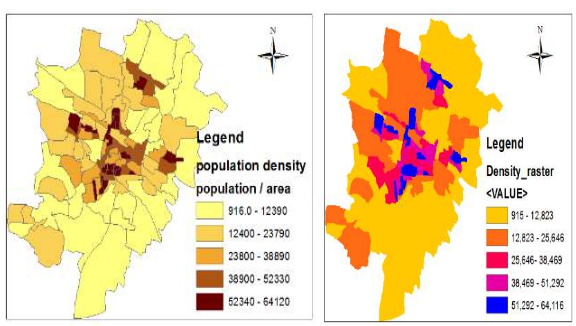


4 Data collection and pre-processing

Data required for the suitability analysis are picked out from the predefined criteria and collected from relevant sources. The data collected include the following – ward wise population, important places, existing road network, busy intersections, slope, and land-use/land-cover.

4.1. Population density

Ward wise population for the past three decades are collected from Madurai Corporation and projected for the year 2041 by appropriate forecasting methods based on the growth trend. The projected population is added to the digitized ward map as attribute data. Then the population density map is generated by normalizing the projected population of each ward by their corresponding area and the map is converted to raster format. The maps are shown in the Fig. 2.

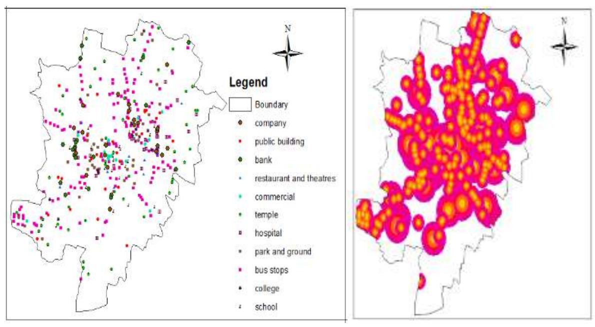


(a) **(b)**

Fig.2. (a) Population density map; **(b)** Density map in raster.

4.2. Important locations

Important locations which attract people from various places like bus stops, educational institutions, offices, hospitals etc.., are identified and digitized which is shown in Fig 3 a. The map which is in vector format is converted to raster so that the map can be ranked. Hence a buffer of 500m is created around bus stops and a buffer 1000m is created around all other location and is shown in Fig. 3 b.

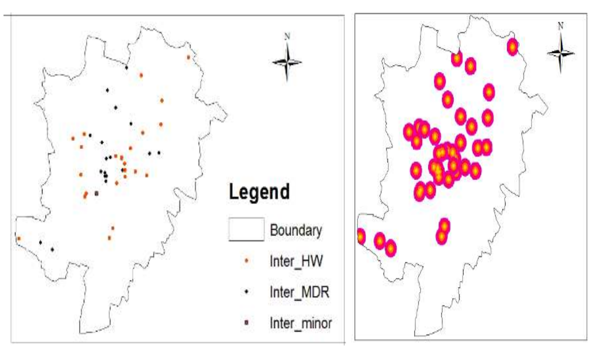


(a) **(b)**

Fig. 3. (a) Important locations; **(b)** Locations with buffer.

4.3. Intersections

Forty five major intersection have been identified based on the traffic count and its proximity to important places. The traffic details are obtained from Comprehensive Mobility Plan report of Madurai city. Around each intersection a buffer of 500m is created.

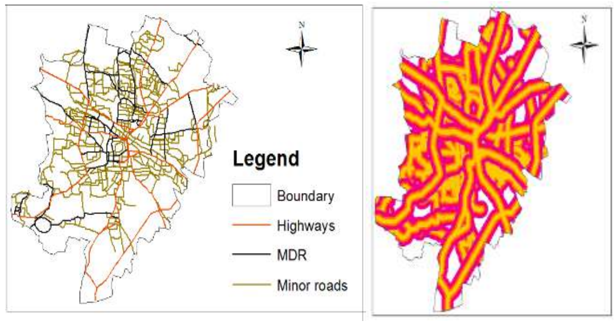


(a) **(b)**

Fig.4. (a) Intersections; **(b)** Intersections with buffer.

4.4. Road networks

All the existing road networks in Madurai city including highways, major district roads and other minor networks are digitized. A buffer of 500m is created on either sides of all the road networks to rank the map for spatial analysis. The digitized map and buffer zones are shown in Fig. 5.



(a) **(b)**

Fig. 5. (a) Road networks; **(b)** Road networks with buffer.

4.5. Slope

The slope map of the study area is derived from DEM data using slope spatial analyst tool available in GIS which is shown in Fig. 6. The DEM data is obtained from Advanced Space borne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM).

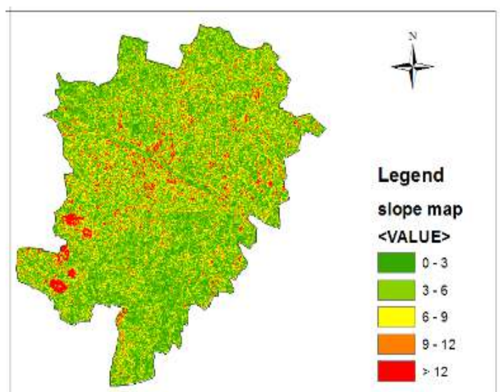


Fig. 6. Slope map.

4.6. Land use – Land cover

The land use - land cover map shown in Fig. 7 is derived from Landsat 8 satellite imageries. Supervised classification method is adopted in order to identify the surface features. Madurai city is found to have different surface features including agricultural area, urban settlement, fallow land and water bodies. From the Fig.7, it is observed that most of the areas in the city are occupied by human settlement.

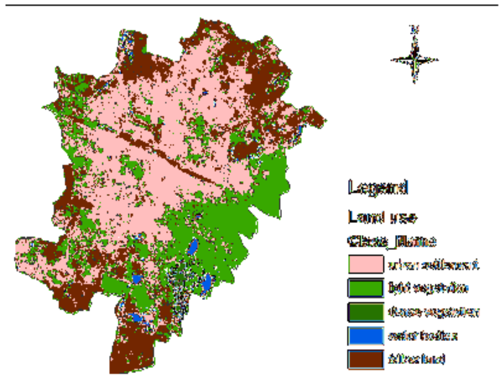


Fig. 7. Land use map.

5 Re-classification of criteria map

Each criteria map is reclassified according to its suitability. The scale adopted to reclassify the map is shown in Table 1.

Table 1: scale adopted for ranking the criteria

Rank	1	2	3	4	5
Suitability	Very low	Low	Moderate	High	Very high

1. Population density: The population density map is ranked in such a way that the areas having highest population density get the highest rank and areas with least density value get the lowest rank. The ranking adopted is shown in Table 2.

Table 2: Ranking of density map

Population density (per km^2)	Rank
915 - 12823	1
12823 - 25646	2
25646 - 38469	3
38369 - 50292	4
> 50292	5

2. Important locations: Here the ranking is based on the proximity of the buffer zone to important places. The area which is close to the locations will get highest rank and the rank will get decreased as the distance from the location increases as shown in Table 3.

Table 3: Ranking of locations

Distance (m)	Rank
>1000	1
750-1000	2
500-750	3
250-500	4
0-250	5

As each location will attract traffic in different proportion according to its importance, the weightage to each location is found by AHP and by performing weighted overlay analysis a composite map for locations is obtained. Similarly the composite map for intersections and road networks are obtained by adopting the same ranking as locations.

3. Slope map: Flat areas are more suitable for construction as it is more economical. Hence the area with least slope will get the highest rank and maximum slope will get the lowest rank. Table 4 shows the rank of the slope value.

Table 4: Ranking of slope values

Slope (degree)	Rank
>12	1
9-12	2
6-9	3
3-6	4
0-3	5

4. The ranking adopted for Land use classification is shown in the Table 5.

Table 5: Ranking of land use

Land use	Rank
Water bodies	1
Urban settlement	2
Dense vegetation	3
Light vegetation	4
Bare ground	5

Weighted evaluation criteria

To create a final composite map, each criteria is prioritized by considering its importance to the suitability analysis. The weightage to all the predefined criteria are calculated by Analytical Hierarchy Process (Saaty's method). Initially a pairwise comparison matrix is generated by making appropriate judgments and after obtaining the weightage to criteria, a consistency check is carried out to check the accuracy of the judgments made. The sum of all the weightage values must be equal to 100. The composite suitability score of all the raster cells are calculated to obtain the final suitability map which merges all the ranked criteria maps by weighted overlay analysis using GIS.

Table 6: criteria weightage

Criteria	Weight (%)
Population density	34
Important places	30
Intersections	15
Road networks	10
slope	6
Land use-Land cover	5
Total	100

From the spatial analysis carried out in GIS, the final suitability map obtained is shown in the Fig. 8 the area shown in red color (rank 4) is the most suitable area and the area in dark green color (rank 1) is the least suitable area for metro network.

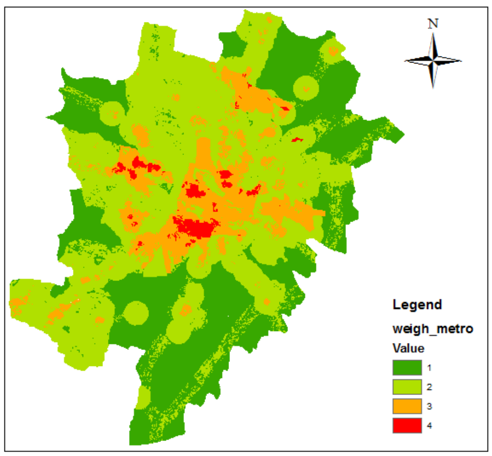


Fig. 8. Final composite map.

Selection of optimal metro routes

Initially the end stations for the metro network are fixed such that the proposed metro route will cover all the interlaying suitable locations. Then by using least cost path tool, the metro network is drawn between the origin and destination stations. Intermediate metro stations are distributed along the selected metro lines (decision alternatives). Four routes are fixed as decision alternatives as shown in Fig. 9. Route 1 and 2 have same origin and destination. Similarly the origin and destination stations for Route 3 and 4 are same. So one route in each direction should be chosen. The impedance value of each route is calculated. The route with minimum impedance value is fixed as optimal route. The impedance value calculations for decision alternatives are shown in the Table 7.

Mean Spatial Utility:

$\text{MSU}_i = \sum_{j=1}^{N} \text{U}_j / \text{N}, \quad i = 1, 2, ...\text{M}$

Impedance:

$\Omega_i = (5 - \text{MSU}_i)*\text{L}_i , \qquad i = 1, 2,...\text{M}$

Optimal value: $\Omega^* = \min \{\Omega_i\}$

L*i* – length of *i*th route
U*j* – suitability index of the pixel underlying the *j*th metro station along *i*th route
M – No. of alternative routes
N – No. of selected stations along the *i*th route

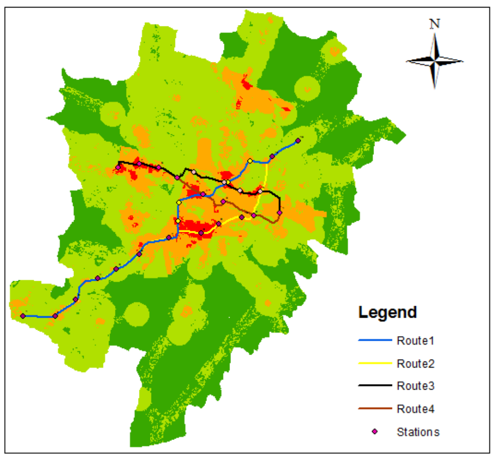


Fig. 9. Decision alternatives.

Table 7: Impedance values

Direction	SW - NE		E-W	
Route	Route 1	Route 2	Route 3	Route 4
No. of stations	14	13	9	8
Length (km)	14.816	14.791	8.069	7.8
MSU	3.357	2.975	3.966	3.462
Ω_i	24.343	29.952	8.343	11.996
Ω^*	24.343		8.343	
Optimal route	Route 1		Route 3	

From the four alternative routes, Route 1 and Route 3 which has the minimum impedance value compared to Route 2 and Route 4 respectively are fixed as best optimal metro networks. The proposed optimal metro lines are shown in the Fig. 10 and the list of metro stations are shown in the Table 8.

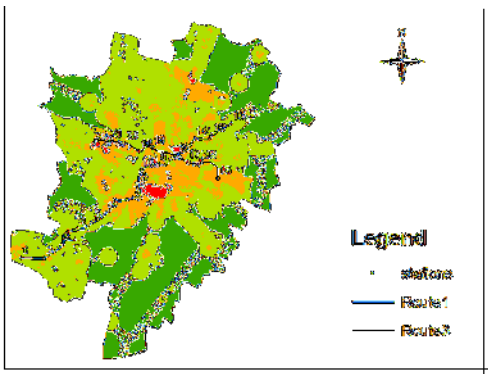


Fig. 10. Optimal metro routes.

Table 8: List of metro stations

Route	Station no.	Station name	Distance between stations (km)
Route 1	1	Thirunagar	1.279
	2	Tiruparankunram	1.089
	3	Thyagaraja college	1.384
	4	Pasumalai	0.879
	5	Pykara	1.074
	6	Palanganatham	1.481
	7	Madura College	0.940
	8	Periyar	0.783
	9	Madurai Junction	1.220
	10	Simmakkal	1.243
	11	Gorippalayam	1.216
	12	Outpost	1.023
	13	K K Nagar	1.205
	14	Matuthavani	
Route 3	15	Anna Nagar	1.523
	16	Anna Bus Stand	0.849
	17	Medical College	0.716
	11	Gorippalayam	1.293
	18	Sellur	0.890
	19	Arapalayam cross road	0.853

	20	Arapalayam	0.861
	21	Guru Theater	1.084
	22	Bethaniyapuram	
Total length			22.885

6 Conclusion

Six parameters have been identified to select the best locations for metro network - population density, existing road networks, important locations, busy intersections, land-use, and slope. All the ranked criteria maps are prioritized by Analytical Hierarchy Process. By using weighted overlay analysis in GIS, four routes were selected as decision alternatives. And the best optimal network is selected by measuring the effectiveness of the selected metro lines. Impedance value of each route is calculated and the routes having minimum impedance are fixed as the optimal routes. Finally two metro lines (Route 1 and Route 3) have been selected as best optimal routes. Route 1 - covers a length of 14.816 Km and passes through 14 metro stations. Route 3 - covers a length of 8.343 Km and passes through 9 metro stations. The total length of the proposed metro network is 22.885 km and consists of 22 metro stations (1 common junction) including four end stations. The total approximate cost required for the construction of the metro network is 2980 crores. The proposed routes can be further extended to reach places that will be densely populated in future.

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