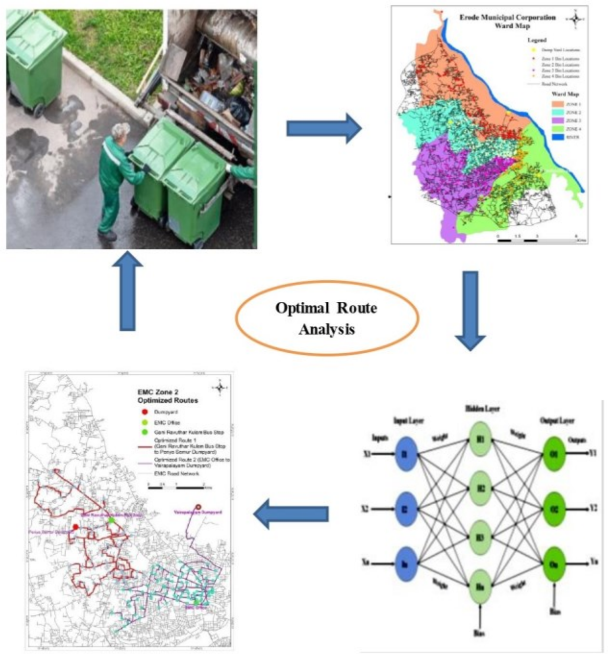
Global NEST Journal, Vol 26, No 9, 06187

Neural-network-driven approach in optimization of municipal solid waste collection integrated with geo-spatial techniques

Vishnuvardhan K[1]*, Rajkumar R[2] , Navin Ganesh V[2] and Sakthiprasanth K[2]
[1]Department of Civil Engineering, Kongu Engineering College, Perundurai, Erode, India
[2]Department of Civil Engineering, PSG Institute of Technology and Applied Research, Coimbatore, India
Received: 21/05/2024, Accepted: 19/09/2024, Available online: 08/10/2024
*to whom all correspondence should be addressed: e-mail: vishnukaruna@gmail.com
https://doi.org/10.30955/gnj.06187

Graphical abstract



ABSTRACT

Municipal solid waste (MSW) management is the most important as well as difficult tasking the present context of rapid urbanization. In this study, a comparison has been done using Geographical information system(GIS) and artificial neural network(ANN) to determine optimum route and time for the collection of solid waste during each single trip by each type of collection vehicle; this will reduce the cost involved in collection phase of Municipal Solid Waste (MSW). The area selected for the study was Erode city which is located in north west of Tamil Nadu, India. The optimum route analysis have been carried out using both GIS and ANN tools. Multiple structures of ANN have been analyzed by modifying the hidden layers. Based on the results, the optimized structure of the network was found. The suggested model is validated by the high value of the coefficient of regression, minimum value of mean square error. Based on these performance parameters, it is found that the ANN model gives optimum results. Implementing these optimum routes will leads to a cost-effective solid waste management system.

Keywords: Erode City; Remote sensing & GIS; Network analyses; Bin locations; ANN; dump sites.

1. Introduction

Urbanization is the major cause for generation of urban solid waste, which has immense impact in socio-economic and environment [Abeliotis *et al.* 2009]. Municipal Solid Waste (MSW) management is the most difficult tasks as it involves generation, collection and storage, transport, treatment and waste disposal [Boskovic and Jovicic 2015].Most of the cities in Asia have been facing severe problems in managing solid waste, as the annual waste generation increases with rise in population as well as require more land for disposal of waste [Chalkias and Lasaridi 2009]. In Indian cities, MSW are being made in an unscientific haphazard method of dumping i.e. dumping of waste on the outer reaches of cities, which leads to overflowing landfills, which are not possible to reclaim. It also causes severe environmental implications in terms of groundwater pollution and global warming [De Oliveira Simonetto and Borenstein 2007]. MSW management needs huge expenditure and it is a main problem to municipal corporations. The prospective for service optimization of quality and costs of waste collection and transport can only be attained using advanced decision support tools as well as through model the various components of an integrated waste management system [Ghose *et al.* 2009; Gupta *et al.* 1998; Idris *et al.* 2004; Kanchanabhan 2010].

Solid Waste Collection is the second major essential part of the Solid Waste Management. The fundamental elements of collection involves not only gathering the waste and recycled material, also the transportation of these materials after collection, the distance between the dump ward site and the collection point. In urban settings, it is difficult to collect and segregate the waste because of different generation of wastes collected from different sections like residential area, industrial facilities, hospitals, commercial areas, streets, parks and even vacant places.

Therefore, in this case, the type of waste, the needed equipment, and associated labor required along with the time and the routes, is important to be looked [Karadimas and Loumos 2009].Efficient execution, management and monitoring of primary performance indicators will guarantee noteworthy decrease in operational cost and raise revenue [Leao *et al.* 2001].

Geographical Information System (GIS) is commonly used for the solid waste route optimization policies, as it is capable tool for these studies as it has the capacity to store, retrieve, analyze, and visualize a large amount of spatial data [Karadimas and Loumos 2009; Malakahmad *et al.* 2014]. GIS helps in identifying suitable site for waste disposal and plays a vital role in decision making for solid waste management [Sanjeevi and Shahabudeen 2015].Application of GIS in optimization of MSW collection system includes planning of bins, vehicles and optimal routing which reduces the cost as well as impact on the environment [Sulemana *et al.* 2019].

A number of studies were conducted using GIS for optimization of routing for MSW collection. Sulemana *et al.* 2018 proposed an effective route for garbage truck from collection point to sanitary landfill in Kluang district Johor using ArcGIS network analyst. Identifying the optimized location and appropriate number of storage bins by p-median constraint model on GIS platform was conducted [Tavares *et al.* 2008].Identifying the optimum scenario for waste collection to reduce the collection time, distance travelled, man-effort, and consequently financial and environmental costs were carried out in the municipality of Nikea [Gupta *et al.* 1998], a similar kind of study was conducted in Ipoh city, Malaysia [Karadimas and Loumos 2009], and optimum municipal solid waste collection using GIS and vehicle tracking for Pallavaram municipality [Zainun *et al.* 2016]. A study on effect of optimal routing on travel distance, travel time, and fuel consumption of waste collection trucks were carried out in three different regions viz. Kumasi Metropolitan Assembly (KMA) of the Ashanti Region, Sunyani Municipal Assembly (SMA) of the Brong Ahafo Region, and Bolgatanga Municipal Assembly (BMA) of the Upper East Region, in Ghana [Leao *et al.* 2001]. A study on optimization of MSW collection routes for minimum fuel consumption using 3D GIS modeling was carried out in Cape Verde region [Kanchanabhan *et al.* 2010].

The aim of the present study is to propose an optimized route to collect the waste in the Erode City Municipal Corporation using AHP, ANN and GIS technique, and also useful for enhancing the existing system to minimize the collection time, distance travelled, fuel consumption, and environmental impacts.

2. Materials and methods

2.1. Study Area

Erode Town was divided from the composite Coimbatore District since the year 1979 and it is the headquarters of Erode District. The Erode town was constituted as a Municipality in the year 1871 and promoted as Corporation during the year2008.The Erode Corporation covers an area of about 109.52 Sq.Km. and consists of Surampatti, Peelamedu, Sarkar Chinna Agraharam revenue villages. The Town has been divided into 60 Electoral wards and 15 sanitary divisions. According to census 2011, the population of the Corporation was 0.49 million and population as on 2015 was 0.53 million. The Corporation is divided into four zones and Vendipalayam and Vairapalayam are the two disposal sites is shown in **Figure 1.** The percentage of sources includes residential, commercial, and Silt/Inert are 55%, 27%, and 18% respectively, in which, Green waste (49.85%), food waste (10.15%), paper waste (12.00%), plastic waste (9.99%), Rags, leather, metals, (1.00%), and inert materials (18.00%). The quantity of waste generation is 250 MT/day which covers Bio degradable waste (128 MT/day), Non-Bio degradable waste (55 MT/day), Bio Methonisation potential waste (22 MT/per day), and Silt/Inert (45 MT/day).Per capita waste generation per day is 500 grams/person/day.

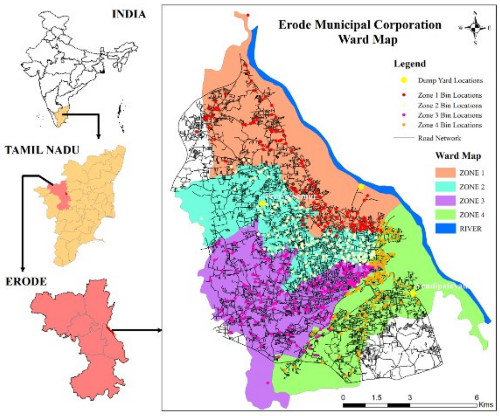


Figure 1. Study area map show different zones in Erode Municipal Corporation (EMC) along with Road/Street and Bin Locations

2.2. Data and Methodology

The proposed GIS model for optimization of route to collect waste requires existing bin locations, current route plan of collection and locations of disposal sites. Generation of GIS spatial database is requisite to efficiently build a MSW system but it includes collection of various data through fieldwork. There are 557 bin locations were collected through extensive field work using FOIF Differential Global Positioning System(DGPS with static post processing accuracy of H:±2.5mm+0.5×10 ·D;V:±5.0mm+0.5×10 ·D)in all four zones of the study region. These surveyed bin locations were imported to GIS platform. The locations of dump sites were identified through Erode Corporation portal and their coordinates were marked in the Google Earth and imported to the GIS environment. A network data which includes major roads and street is essential for network analysis in GIS software. Moreover, the quality of network data will decides the output of your analysis. The road/Street network was digitized in QGIS 3.14 software using open street map. The data related to routes, route plan, vehicle number, type of vehicle, start point, end point, total Kilometers travelled, maximum and average speed of the vehicle were collected from Erode City Municipal Corporation – Vehicle Tracking System (VTS).

The vehicles are enabled with GPS and tracking are made with a common control room. The network analyst extension in GIS is a highly powerful tool facilitates us to carryout spatial analysis of network data. Hence, in the present study the network analyses tool in GIS were used to analyze the optimum route. The detailed methodology is illustrated in the **Figure 2**.

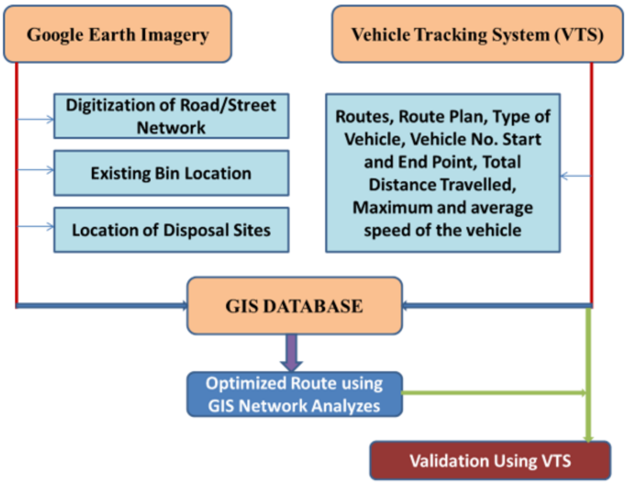


Figure 2. Detailed Methodology adopted in the present study

2.3. ANN model formulation:

Optimal route was predicted by using an artificial neural network (ANN). Group Method of Data Handling (GMDH) Neuro Shell 2 software was utilized to perform the ANN-based route analysis. The fundamental idea is to design a feed forward network based on a quadratic node transfer function, with coefficients determined using a regression technique. The individual time required to complete each of the six activities listed in **Table 1** (T1, T2, T3, T4, T5, T6).The model's inputs were random normalized values for T1, T2, T3, T4, T5, and T6. Equation 1 shows the input values of the ANN model. The output is the optimal collection time (T).

$$T= (W_{T1} \text{ X } T_1^{'}) + (W_{T2} \text{ X } T_2^{'}) + (W_{T3} \text{ X } T_3^{'}) +(W_{T4} \text{ X } T_4^{'}) +(W_{T5} \text{ X } T_5^{'}) +(W_{T6} \text{ X } T_6^{'}) \quad (1)$$

Where,T1’ - Normalized value of T1; T2’ - Normalized value of T2; T3’ - Normalized value of T3; T4’ - Normalized value of T4; T5’- Normalized value of T5; T6’ - Normalized value of T6; W_{T1}- Weight of T1; W_{T2}- Weight of T2; W_{T3} - Weight of T3; W_{T4} - Weight of T4; W_{T5} - Weight of T5; W_{T6} -Weight of T6

Table 1. Detail of the events involved in collection activities

Activity	Symbol
Travelling time from garage to first collecting point	T1
Total time needed to load and unload the collecting bins	T2
Total traveling time between the two containers	T3
Time spent travelling from collecting point to disposal facility to unload collected solid waste	T4
Time consumed in disposal site	T5
Time spent in travelling from disposal point to garage	T6

Artificial neural networks are capable of anticipating and making decisions, and they can be used to identify license plates, recognize speech, and recognize faces. The model is a forward propagation artificial neural network with at least three layers of structure: input, hidden, and output.

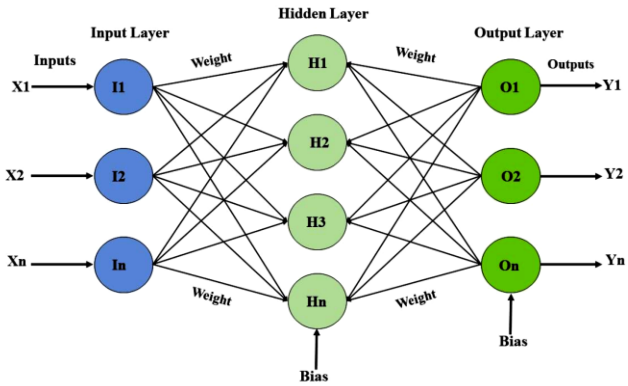


Figure 3. Structure of ANN Optimal routing Model network

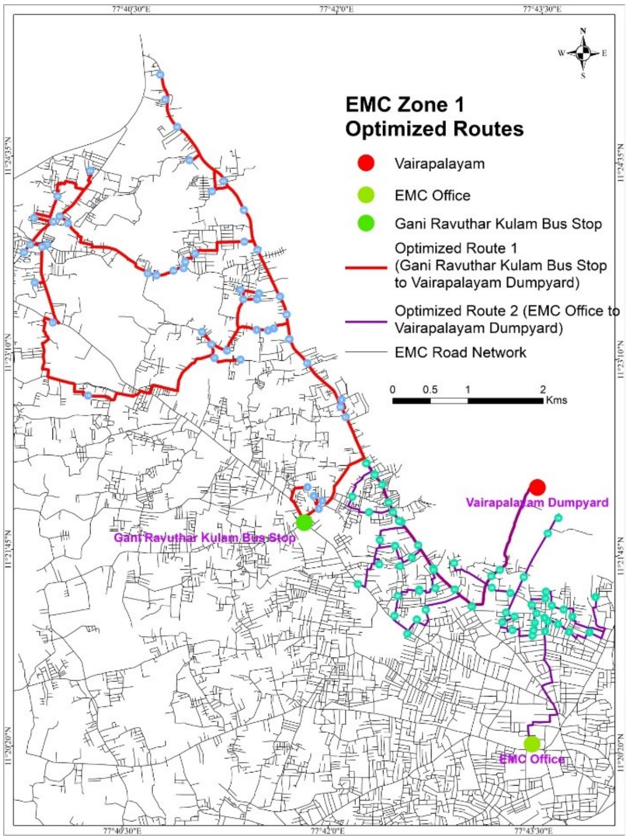


Figure 4. Optimized Route of EMC Zone 1

3. Results and Discussion

3.1. 3.0 GIS Model

The network dataset of the study region were divided into different administrative zones in the present study region. In terms of bin locations Zone 1, 2, 3, 4 consist of 114, 146, 168, and 129 bins respectively in the study region. Further, the bin locations in each zone were divided into different number of groups viz. 2 (Zone 1), 2 (Zone 2), 3 (Zone 3), 2 (Zone 4) based on the total number of bin locations and direction of travel from start point. The determination of start point is very important in optimization of route, hence critical examination were done before choosing the start point. In the present study, two start points were selected viz. Erode Municipal Corporation (EMC) office and Gani Ravuthar Kulam bus stop according to the number of bin locations to be covered and distance from the dump yard site.

Through GIS based network analyses the optimization of selected routes from start point to dump yard in each zone were determined. The GIS-outputs with route map of zone 1, 2, 3, 4 is illustrated in the Figures 3, 4, 5, 6 respectively. The start and end point, number of bin locations covered, and the total distance needs to be travelled to collect the waste is given in the **Table 1.** Based on the study, the total distance needs to be covered in Zone 1 is 60.55 Kms by two routes, Zone 2 is 147.02 Kms by two routes, Zone 3 is 206.27 Kms by three routes, Zone 4 is 102.57 Kms by two routes (**Figure 7**).

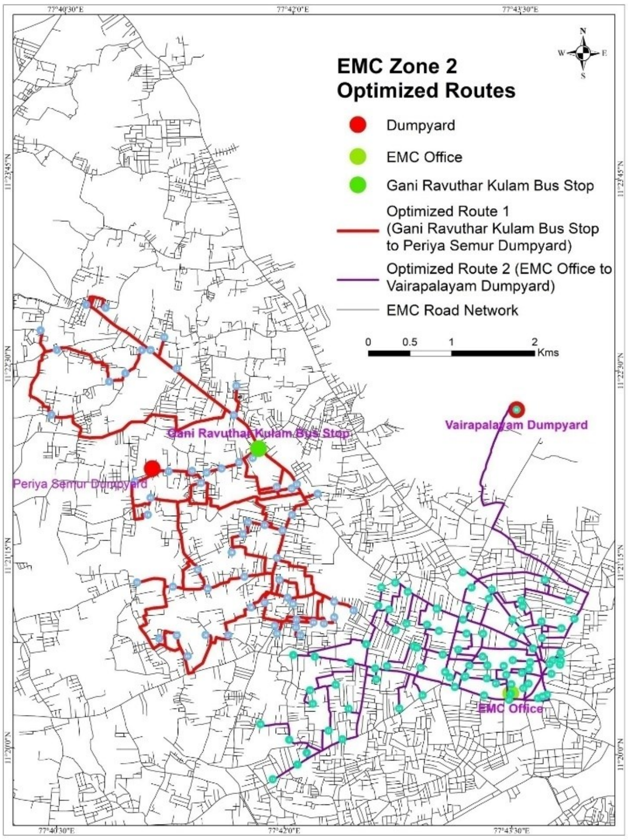


Figure 5. Optimized Route of EMC Zone 2

3.2. ANN Model

The results were simulated using the artificial neural network time series tool. The optimal ANN time series model was found by adjusting the number of hidden layer neurons. During this iteration procedure, numerous ANN topologies were discovered. The minimal value of Mean Square Error (MSE) and the maximum value of R are utilized as performance indicators to evaluate the optimum network configuration.

The optimum route analysis of the study region was carried out for four zone and the results reveal that, in north zone the length of the from disposal siteEllapalayam to RKV Nagar, Ayyankadu, BA Agrahram are 6.8 Km, 5.15 Km, 5.47 Km, Chithode to salangapalayam, Suriyampalayam to Jambai and Krishnampalayam to T.Kavundampalayam are 14.75 Km, 13.10 Km and 10.89 Km respectively. In west zone, Ellapalaym to Narripalam, Soolai, Sampath Nagar, Nethaji Market are 3.30 Km, 4.68 Km, 6.23 Km and 8.70 Km respectively and Erode Municipal Park to T. Kavundampalayam is 12.12 Km..In South zone, LIC Nagar to Ellapalayam is 5.31 Km, Sakthi Nagar to Pungampadi is 8.59 Km, Arasunagar to Pungampadi is 12.76 Km, Kaikolar Thottam to T. Kavundampalayam is 14.74 Km, Thanthai Periyar Memorial to T. Kavundampalayam is 12.95 Km. Cheran Nagar to Avalpoondurai is 11.50 Km, Nadarmedu to T. Kavundampalayam is 14.04 Km, Tiruneelakandar to T. Kavundampalayam is 13.82 Km, Telephone Nagar to Avalpoondurai is 9.27 Km and Rangampalayam to Pungampadi is 9.8Km are optimum route in the west zone of the study region (**Figures 8 and 9**) (**Tables 2 to 5**).

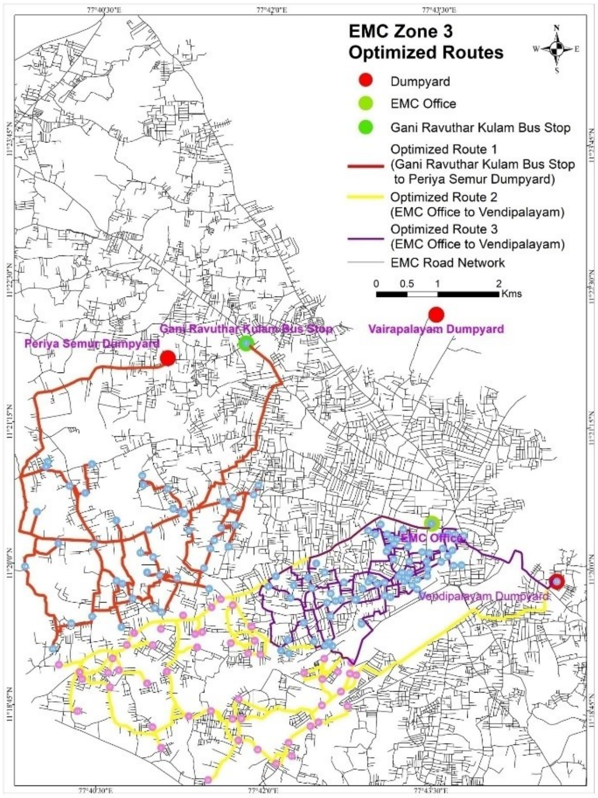


Figure 6. Optimized Route of EMC Zone 3

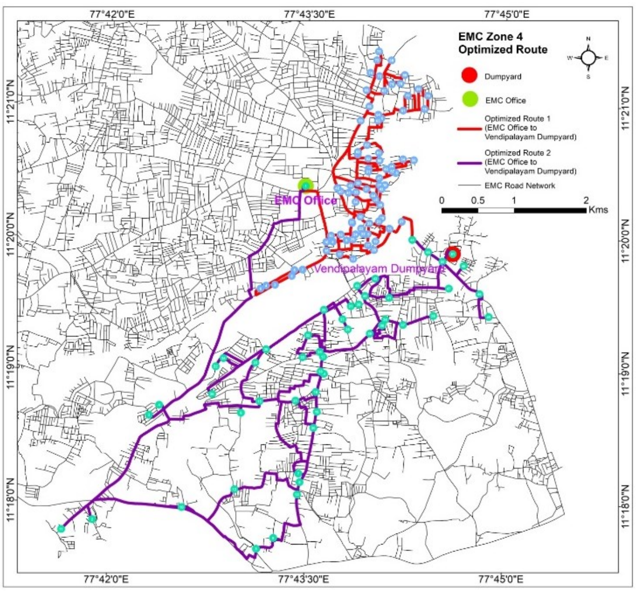


Figure 7. Optimized Route of EMC Zone 4

Table 2. Calculated Optimum length of the disposal point from the site in North zone

S No	Dustbin Point	Disposal Point	Length (km)	Zone Code
N1	RKV Nagar	Ellapalayam	6.80	Zone I
N2	Ayyankadu	Ellapalayam	5.15	Zone I
N3	B A Agrahram	Ellapalayam	5.47	Zone I
N4	Chithode	Salangapalayam	14.75	Zone I
N5	Suriyampalayam	Jambai	13.10	Zone I
N6	Krishnampalayam	T. Kavundampalayam	10.89	Zone I

Table 3. Calculated Optimum length of the disposal point from the site in South zone

S No	Dustbin Point	Disposal Point	Length (km)	Zone Code
S1	Narripalam	Ellapalayam	3.30	Zone II
S2	Soolai	Ellapalayam	4.68	Zone II
S3	Sampath Nagar	Ellapalayam	6.23	Zone II
S4	Nethaji Market	Ellapalayam	8.70	Zone II
S5	Erode Municipal Park	T. Kavundampalayam	12.12	Zone II

Table 4. Calculated Optimum length of the disposal point from the site in East zone

S No	Dustbin Point	Disposal Point	Length (km)	Zone Code
E1	LIC Nagar	Ellapalayam	5.31	Zone III
E2	Sakthi Nagar	Pungampadi	8.59	Zone III
E3	Arasunagar	Pungampadi	12.76	Zone III
E4	Kaikolar Thottam	T. Kavundampalayam	14.74	Zone III
E5	ThanthaiPeriyar Memorial	T. Kavundampalayam	12.95	Zone III

Table 5. Calculated Optimum length of the disposal point from the site in West zone

S No	Dustbin Point	Disposal Point	Length (km)	Zone Code
W1	Cheran Nagar	Pungampadi	11.50	Zone IV
W2	Nadarmedu	T. Kavundampalayam	14.04	Zone IV
W3	Tiruneelakandar	T. Kavundampalayam	13.82	Zone IV
W4	Telephone Nagar	Avalpoondurai	9.27	Zone IV
W5	Rangampalayam	Pungampadi	9.88	Zone IV

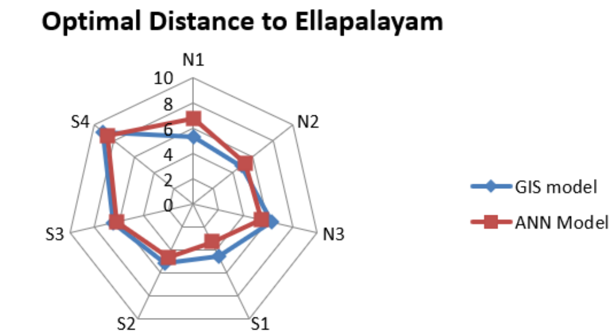


Figure 8. Optimized distance to Ellapalayam disposal yard

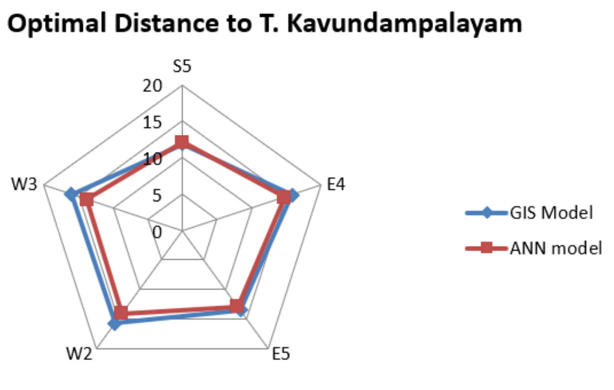


Figure 9. Optimized distance to T.Kavundapalayam disposal yard

4. Conclusion

In the present study, the application of Geographical Information Systems(GIS) and Artificial neural network(ANN) based tools helps us to bring an efficient model to management of waste collection systems in urban region. The study builds a MSW model with limited dataset with a help of GIS and ANN model. Because the current model employed the collection path currently employed by the municipality, this suggested time may be directly integrated in their system. The number of bin locations and its spatial distribution is very important in enhancing the waste collection systems to reduce the more cost. The developed database will be highly useful for the administrators to plan for new bin locations wherever inadequate bins and removal of closely located bins. The study will also be useful to rethink existing routes, fuel costs, and number of vehicles required in each zone. The optimal route suggested in this study will reduce the operational cost of collection. In future, site suitability analysis can be perfomed for T.Kavundapalayam disposal yard

References

Abeliotis K., Karaiskou K., Togia A., and Lasaridi K. (2009), Decision support systems in solid waste management, *Global NEST Journal*, **11**(2), 117-126.

Bimastyaji Surya Ramadan (2024), Optimization of municipal solid waste collection sites by an integrated spatial analysis approach in Semarang City, *Journal of Material Cycles and Waste Management,* **26**:1231–1242.

Boskovic G., Jovicic N. (2015), Fast methodology to design the optimal collection point locations and number of waste bins: A case study, *Waste Management & Research*, **33(12)**, 1094-1102.

Chalkias C., Lasaridi K. (2009), A GIS based model for the optimization of municipal solid waste collection: the case study of Nikea, Athens, Greece. *Wseas Transactions on Environment and Development*, **10(5)**,640-650.

De Oliveira Simonetto E., Borenstein D. (2007), A decision support system for the operational planning of solid waste collection. *Waste Management*, **27(10)**, 1286-1297.

Dipti Singh (2018), Prediction of municipal solid waste generation for optimum planning and management with artificial neural network case study: Faridabad City in Haryana State (India), Int J Syst Assur Eng Manag, **9(1):**91–97.

Dipti Singh, Ajay Satija (2018), Prediction of municipal solid waste generation for optimum planning and management with artificial neural network—case study: Faridabad City in Haryana State (India), *Int J Syst Assur Eng Manag*, **9(1)**, 91–97.

Ghose M.K., Dikshit A.K., Sharma S.K. (2006), A GIS based transportation model for solid waste disposal., A case study on Asansol municipality. *Waste Management*, **26(11)**, 1287-1293.

Gupta S., Mohan K., Prasad R., Gupta S., and Kansa A. (1998), Solid waste management in India: Options and opportunities. *Resources, Conservation and Recycling*, **24**, 137–154.

Idris A., Inane B., Hassan M.N. (2004), Overview of waste disposal and landfills/dumps in Asian countries. *Journal of Material Cycles and Waste Management*, **6**, 104–110.

Kanchanabhan T.E., Mohaideen J.A., Srinivasan S., Sundaram V.L.K. (2010), Optimum municipal solid waste collection using geographical information system (GIS) and vehicle tracking for Pallavapuram municipality, *Waste Management & Research*, **29(3)**, 323-339.

Karadimas N.V., Loumos V.G. (2009), GIS-based modeling for the estimation of municipal solid waste generation and collection. *Waste Management & Research*, **26**, 337–346.

Leao S., Bishop I., Evans D. (2001), Assessing the demand of solid waste disposal in urban region by urban dynamics modeling in a GIS environment. *Resources, Conservation and Recycling*, **33(4)**, 289-313.

Malakahmad A., Md Bakri P., Md Mokhtar M.R., Khalil N. (2014), Solid waste collection routes optimization via GIS techniques in Ipoh city, *Malasia.Procedia engineering*, **77**, 20-27.

Rajkumar R., Elangovan K. (2020), Impact of urbanisation on formation of urban heat island in Tirupur region using geospatial technique. *Indian Journal of Geo-Marine Sciences,* **49(6),** 1593-1598.

Sanjeevi V., Shahabudeen P. (2015), Development of performance indicators for municipal solid waste management (PIMS): a review. *Waste Management and Research*, **33(12)**, 1052-1065.

Sulemana A., Donkor E.A., Forkuo E.K., Oduro-Kwarteng S. (2018), Optimal routing of solid waste collection trucks: A Review of methods. *Journal of Engineering*, **1**, 12.

Sulemana A., Donkor E.A., Forkuo E.K., Oduro-Kwarteng S. (2019), Effect of optimal routing on travel distance, travel time and fuel consumption of waste collection trucks. *Management of Environmental Quality*, **30(4**), 803-832.

Tavares G., Zsigraiova Z., Semiao V., Carvalho M. (2008), A case study of fuel saving through optimization of MSW transportation routes. *Management of Environmental Quality*, **19(4)**, 444-454.

Vijay R., Gautam A., Kalamdhad A., Gupta A. Devotta S. (2008), GIS-based locational analysis of collection bins in municipal solid waste management systems. *Journal of Environmental Engineering and Science*, **7**, 39-43.

Yuan Huang, Cheng‑Tien Tsao (2024), Neural‑network‑driven method for optimal path planning via high‑accuracy region prediction, *Artificial Life and Robotics,* **29:**12–21.

Zainun N.Y., Samsu K.N.S.K., Md Rohani M. (2016), Proposing an effective route for transporting solid waste using GIS approach. *IOP Conf. Series: Materials Science and Engineering*, **160**, 012050.