Environ Res Tec, Vol. 7, Issue. 1, pp. 3–12, March 2024

Environmental Research and Technology
https://ert.yildiz.edu.tr - https://dergipark.org.tr/tr/pub/ert
DOI: https://doi.org/10.35208/ert.1244707

Environmental Research & Technology

Research Article

A comparative study on the selection of the most suitable route for the collection and transportation of municipal solid waste

Abdullah İzzeddin KARABULUT[1], Benan YAZICI KARABULUT[2], Perihan DERİN[1], Mehmet İrfan YEŞİLNACAR[*2], Hale PAMUKÇU[3]

[1]Graduate School of Natural and Applied Sciences, Remote Sensing and Geographic Information Systems, Harran University, Şanlıurfa, Türkiye
[2]Department of Environmental Engineering, Harran University, Şanlıurfa, Türkiye
[3]Graduate School of Natural and Applied Sciences, Harran University, Şanlıurfa, Türkiye

ARTICLE INFO

Article history
Received: 30 January 2023
Revised: 21 September 2023
Accepted: 10 October 2023

Key words:
Landfill siting; Municipal solid waste management; Route optimization; GIS

ABSTRACT

Worldwide, approximately US$410 billion is spent annually on the management of four billion tons of domestic solid waste (MSW). The transportation cost alone accounts for more than 50% of the total expenditure on solid waste management. This cost constitutes approximately 85% of the collection and transportation cost. 54.4% of environmental protection expenditures cover waste services. The population of the Barış neighborhood in the Kayapınar district of Diyarbakır, which is the subject of this study, is 23 581 according to the 2020 TUIK data. The average amount of waste produced per person in a month is 7.6 kg/person. In the results of these statistics, it has been seen that the investment costs in the transportation of wastes are increasing day by day. In this study, the performance of ant colony and genetic algorithms, which are among the artificial intelligence techniques, and route optimization using GIS (geographic information system) software were tried to be achieved to solve the GSP (traveling salesman problem), which is included in the route planning problems. The results of the study showed that savings were achieved with an improvement of 15.1576% in GIS, 29.8104% in GA (Genetic algorithm) and 40.5171% in ACS (Ant Colony System) compared to real life. As a result of the application, it has been observed that the ant colony algorithm is superior to the Genetic algorithm and GIS, as it draws a shorter route in terms of distance and obtains a better result in terms of improvement rate.

Cite this article as: Karabulut Aİ, Yazıcı Karabulut B, Derin P, Yeşilnacar Mİ, Pamukçu H. A comparative study on the selection of the most suitable route for the collection and transportation of municipal solid waste. Environ Res Tec 2024;7(1)3–12.

INTRODUCTION

Solid waste is one of the important causes of the environmental crisis, which negatively affects human health all over the world and is rapidly approaching a disaster level that will directly threaten human life. As with all other environmental problems, the increase in solid waste production, which goes in parallel with the increasing population and increasing consumption, has become a focus of great concern. Additionally, problem of global warming has become a major problem that the international community must face in this century. The IPCC's (Intergovernmental Panel on Climate Change) report stated that development based largely on fossil fuel energies will increase global

***Corresponding author.**
*E-mail address: mirfan@harran.edu.tr

average temperatures by about 4.5 °C in the 21st century. Therefore, good management of these processes is of great importance in terms of cost, environment and time. Otherwise, significant problems arise in terms of excessive fuel consumption, waste of time, depreciation expense, environment and public health [1]. In this study, optimization methods in the literature are examined in order to develop an optimal route plan for solid waste collection and transportation. Waste management has become an important issue in many developing countries as it poses significant risks to the environment and public health. Municipal solid waste generation has been increasing steadily over the last decade. In 2016, it was reported that 2.01 billion tons of municipal solid waste was generated worldwide. This figure is expected to increase to 3.4 billion tons by 2050 [2]. Even a small improvement in waste collection will result in significant cost savings, as MSW collection and handling often make up the bulk of waste management budgets [3]. The amount of waste often generated in urban areas is not known exactly. Optimizing the collection and transport of MSW contributes significantly to waste management system design [4]. In general, different sources of waste are unevenly distributed in urban areas. This situation increases waste collection and transportation costs [4]. Therefore, managers and decision makers are interested in dealing with the lowest possible cost [5].

Therefore, there is a need for an optimization system that will consider the diversity of the waste generated and take into account the costs [5]. Recently, many models have been proposed to optimize collection and transport over the entire garbage truck network. Geographic Information System (GIS) is used in some of these proposed models. GIS is a suitable tool for such studies as it can store, retrieve, analyze and apply large amounts of data, and visualize response time and output [6]. Various algorithms have been investigated for optimization problems in waste management. The reason for this diversity is that the vast majority of routing algorithms involve the use of heuristics. Heuristic algorithms are temporary, trial and error methods that do not guarantee finding the optimum solution but are designed to find near-optimal solutions in a fraction of the time required by optimal methods [7].

Optimal routing in solid waste collection includes planning and defining routes for the passage of trucks during the collection process. Failure to apply scientific or technological interventions in the selection of the optimal route causes the take distance of waste collection trucks to prolong the distance and increase the collection cost [8]. Studies in the literature have explored the solid waste collection problem in terms of optimization using mathematical programming and GIS-based approaches to achieve resource conservation and environmental protection [9]. The objective of vehicle routing is to minimize time, cost, and distance, given some relevant parameters [10, 11]. A metaheuristic approach methodology using the Ant Colony Optimization (ACO) algorithm was employed to find optimal routes with the minimum total distance [12]. The ACO algorithm is expected to provide faster computation times for solving this problem, while ensuring that the resulting routes have the minimum total distance. Studies in routing of solid waste collection trucks therefore consider the importance of path constraints [13]. There are many studies that are similar to the subject of the study and conducted in previous years. In a study conducted ACS (Ant Colony System) was used in order to solve the road problem in the collection and transportation of wastes and to save time, and it was seen that efficient results were obtained [14]. In another study conducted it was demonstrated that high efficiency was obtained from this method by working with the Ant Colony System, which is recommended for the collection of household waste with minimal cost expenditure [15]. Conducted an optimization study using ArcGIS application in Chennai, one of the major metropolitan cities in southeast India [16]. After developing a spatial database for the whole of Chennai with 200 nodes, 13 solid waste transfer stations were identified through optimization studies using ArcGIS. This optimization process has reduced the distance traveled by 9.93%. Yetiş [17] used the Geographical Information System to calculate the groundwater salinity in the Şanlıurfa Balıklıgöl Basin and created the areal distribution maps of the study region. As a result of the study, it was observed that the sampling point was found more easily and most importantly, time was saved with the spatial mapping of GIS.

In their study, presented a hybrid algorithm consisting of a combination of GIS and genetic algorithm to reduce route length, travel time and fuel consumption [18]. Proposed a mathematical model for solving the municipal waste collection problem in order to reduce the total cost and emissions of waste collection and transportation route. They argued that the proposed model is effective in adjusting the waste collection process over time and reducing the emissions of environmental pollutants [19].

In their study, aims to improve the effectiveness of Intervention Units for Social Events (IUES) by providing decision support for efficient re-deployment to district stations. Criticality values from Erzurum province experience are used to develop a mathematical model. Optimal solutions are presented, achieving a 22% improvement in event coverage rate with three unit deployments. Expert evaluations find the results reasonable [20]. In their study, The study aims to determine the most cost-effective, safe, and uninterrupted route for hazardous materials transportation, considering the increasing industrialization. It involves face-to-face meetings with managers of a company transporting hazardous materials between Gaziantep and Erzurum provinces, using the SMAA-2 method to manage risks involved in hazardous materials transportation. This approach ensures safety and uninterrupted operations [21]. In their study, investigates the strategic-level ammunition distribution network design problem (ADNDP) for military units, focusing on determining depot locations and service assignments. The

Figure 1. Location map of study area.

methodology uses multi-objective mathematical modeling, Analytic Hierarchy Process (AHP), TOPSIS, and GIS to minimize transportation costs and risk scores. The study has applied the methodology to design and evaluate a real ammunition distribution network, using the weighted-sum method to find non-dominated solutions and discussing tradeoffs with experts. The paper presents the proposed methodology, findings, and insights [22]. In their study, focuses on the Anti-Tank Guided Missiles (ATGMs) selection problem, a strategic decision problem. The methodology uses simulation data from hundreds of scenarios to determine the best anti-tank weapon system for combat scenarios with high uncertainty. The methodology consists of four phases and 15 steps, using Fuzzy Shannon's Entropy and Fuzzy CoCoSo with Bonferroni methods. The methodology combines technical data from weapon systems and JCATS simulation tool, providing more precise criteria for combat environments. The sensitivity analysis confirms the methodology's stability, robustness, and practicality [23].

In this study, the existing solid waste collection route belonging to the Barış neighborhood of the Kayapınar district of Diyarbakır province was excavated and examined. In order to minimize the costs, Genetic Algorithm and Ant Colony method and Network Analysis method were also used to calculate the route optimization. The problem covered in the study was calculated using the Python programming language with Genetic Algorithm and Ant Colony optimization methods. In addition, a suitable route was created by using Network Analysis, which is one of the GIS analyzes. All the results obtained were compared with the existing solid waste collection route of the municipality. In this study, it is seen that significant environmental and economic gains can be achieved with different algorithms used in the route optimization process.

MATERIALS AND METHODS

Kayapınar district, which is one of the four central districts in Diyarbakır province, was chosen for route optimization. The population of Diyarbakır has increased compared to the previous year and is 1,783,431 people according to 2020 TUIK data. The area of the province is 15,168 km^2 and there are 118 people per km^2 in the province. Kayapınar, one of the central districts, has a surface area of 438 km^2 and is the most populous district in the province with a population of 400,905 people according to TUIK 2020 data [24]. Barış neighborhood, which is the study area, covers an area of 303.85 hectares (Fig. 1).

Barış neighborhood is a settlement where people with different socioeconomic characteristics live together, showing an example of both regular and unplanned urbanization. There are various structures within the boundaries of the neighborhood: community health center, various schools, mosque, TEIAŞ, playgrounds, health centers. In the neighborhood, wastes are collected in metal solid waste containers of 600–800 liters, located in front of apartments, parks and schools.

Solid waste is collected by 27 solid waste collection vehicles, 11 in the morning and 16 in the evening, across the Kayapınar district. While the capacity of 1 solid waste truck is approximately 5.5 to 6 tons, 162 tons of waste is collected daily in the district. An average of 16 tons of waste is collected in a week, this amount is 23 tons on Monday, 12/13 tons on Sunday and 16 tons on the remaining days. Approximately 64 tons of waste is collected monthly [25]. In Barış neighborhood, solid waste is collected by a vehicle between 06:00 and 12:00 in the morning. A fruit and vegetable market are set up in the neighborhood 2 days a week, and the vehicle collects about 8.25/9 tons of waste in 1.5 trips, collecting half an extra solid waste on those days. The wastes

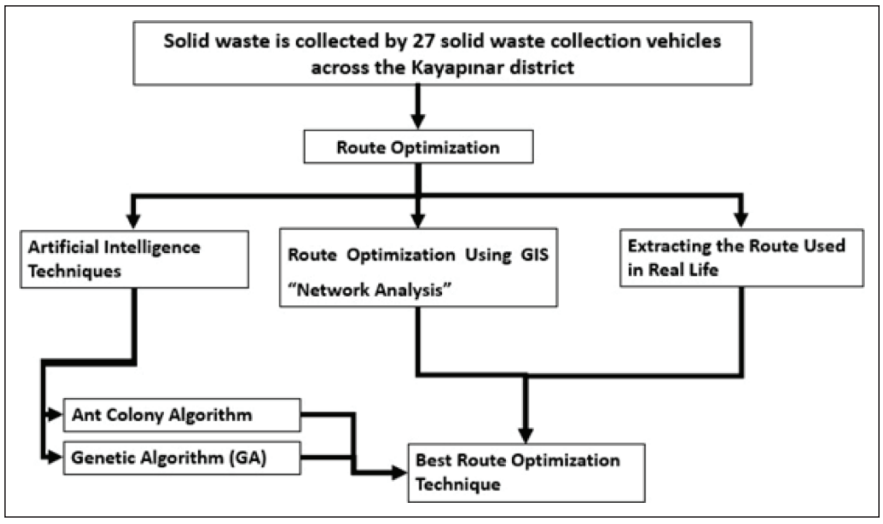

Figure 2. The block diagram of the procedure.

accumulated in the solid waste containers are collected daily by rear-loading, hydraulic compression vehicles belonging to Kayapınar Municipality.

Data Collection

Various field trips were conducted initially to determine the route of the study area and the locations of waste containers along this route. In addition, discussions were held with municipal vehicle operators to gain insight into the technical and logistical aspects. The route map of the study area was obtained from the Department of Public Works. To monitor the garbage trucks and determine the working area, the Mobilize tracking system device was utilized. By examining the routes taken by the tracking device, the coordinate data of solid waste container points were identified, and the locations of these container points were transferred to Google Earth Pro. The transferred container point data in KMZ format was then imported into Esri ArcGIS software. The block diagram of the procedure is given in Figure 2.

Barış neighborhood has a population of 23,581 according to 2020 TUIK data. The average amount of waste produced per person in a month is 7.6 kg/person [24]. The maximum slope of the elevation profile of Barış neighborhood, which is one of the neighborhoods where the population with different socioeconomic characteristics is densely populated, is 14.1% and has an average slope of 2%. According to the Highways Geometric Standards, the topographic structure of Barış neighborhood is inclined. The coordinate data of the solid waste container points were determined by checking the routes that the tracking device passed, and the locations of these container points were transferred to Google Earth Pro.

In this study, mainly the Genetic Algorithm method is used for the solution of the route optimization problem, and calculations are also made with the Ant Colony method. Using the Python programming language, Genetic Algorithm and Ant Colony optimization methods were used to calculate the shortest distances between the solid waste container points and the result was also obtained using GIS. By comparing the results obtained, the method that gives the most appropriate route has been adopted [26].

For the GIS solution, ArcMap module, which operates based on the Dijkstra algorithm and the method of finding the shortest path, was used and the studies were carried out with the network analyst tool of this module. Creating a single or multimodal network dataset with the network analysis tool, determining the best route using a network dataset, creating a model for route analysis, transporting several orders with a fleet of vehicles, performing network analysis using traffic data, allocating the most appropriate location, etc. analysis can be done [27].

Genetic Algorithm (GA)

Genetic algorithms (GA)s can be defined as a method in which the evolutionary event is coded in the computer environment to find answers to some problems that are difficult to solve with traditional methods and an attempt is made to search for optimal or near-optimal results by using this evolutionary process. In this context, the genetic algorithm is a metaheuristic search method based on the encoding of parameters that searches randomly and tries to find a solution [28].

Instead of a single result for the problem tried to be solved in the genetic algorithm, a set of results is created in which the most appropriate result will be evaluated. The result obtained because of the calculations made in the genetic algorithm creates the possibility of being selected, but it cannot guarantee being selected. The selection to be made is random like the initial population created at the beginning, and the fitness value of the solutions shows the determination of the solution candidates [29].

GA is a heuristic screening method developed by being inspired by the change processes in nature. It is a robust and flexible approach in general and can be used to solve many problems that have both discrete and continuous character. The general solution methods group, which includes

genetic algorithms, is called evolutionary algorithms, and essentially evolutionary algorithms are a sub-branch of artificial intelligence. On a theoretical basis, it can be said that the origin of evolutionary algorithms dates to the 1950s. In particular, Turing's work titled "The Calculator and Intelligence" contains many concepts that form the basis of evolutionary algorithms [30].

Ant Colony Algorithm

In the calculation of the ant colony algorithm, it is aimed to find the shortest path inspired by the pheromone secreted by the ants along the route to find food and then return to their nests [31]. In history, Dorigo applied the algorithms created by the behavior of ants, namely the pheromone ratios they secreted, to the traveling salesman problem for the first time and obtained positive results. The positive result obtained from the algorithm has also set an example for future generations and has been used in many route problems [32].

In environmental modeling, there has been increased interest in the design of optimization models and meta-heuristic algorithms to shorten the travel routes of solid waste collection vehicles [33]. The Ant Colony Optimization (ACO) algorithm was inspired by the observation of swarm colonies and especially ants [7]. Amal [33] proposes a new Spatial Geographic Information System (GIS) based Genetic Algorithm to optimize the solid waste collection route. The algorithm proposed as SGA is a modified version of the original Dijkstra algorithm in GIS to generate optimal solutions for vehicles.

The basic logic in the ant colony algorithm is the behavior of ants while searching for food. This behavior was also measured by the pheromone they left in parallel with the probability of finding food on the route they passed. First of all, ants head towards the points where the food is found randomly. Since they secrete the smell, they call pheromone while passing there, other ants that pass through the same route head there, depending on the rate of finding food. In other words, the pheromone left by the ants passing through the route shows parallelism with the ratio of the food available at that point. The basic relationship between these pheromone traces and ants enables the ants to return to their nests where they left while searching for food. This characteristic feature in real ants has been used in artificial ant colonies to solve integrated optimization problems [34].

The first thing to do when starting the calculations with the ant colony algorithm is to determine how many ants will be used. Afterwards, each ant is randomly placed on a point, and thus, all available points are visited one by one, and the ants complete the tour. The representation of these process steps in mathematical language is given in equation 1 [34].

$$P_{i,j}^{\ell} = \frac{\left[\tau_{ij}\right]^{\alpha}\left[\eta_{ij}\right]^{\beta}}{\sum_{l \in N_i^{\ell}}\left[\tau_{il}\right]^{\alpha}\left[\eta_{il}\right]^{\beta}} \quad \text{, if} \quad J \in N_i^{l} \qquad (1)$$

Here;

P_{ij}^{ℓ}: Probability of the ant going from point i to point j

τ_{ij} : Pheromone value in the middle of i and j points

η_{ij}: Heuristic value between points i and j

α: Pheromone criterion

β : Intuitive criterion

N: Dots part

Network Analysis tool in GIS

It covers the processes of transferring all kinds of data belonging to the earth to the computer environment by establishing relations with the space and storing these data by means of special programs used, classification, comparison with each other, analysis, updating and visualization as maps, graphics, and tables as desired. As such, GIS is not just transferring and storing various data to the computer environment. The most important feature that distinguishes GIS from other database systems is that it stores all data depending on the place they belong to on earth and allows a wide variety of spatial associations, that is, various analyzes between them [35].

GIS, which started to develop in Türkiye recently, especially after the 1990s, has now been widely used in many different sectors. When we look briefly in which areas GIS is used, in socioeconomic areas, health, local government, transportation planning, service and city management applications. In defense; target area identification, tactical support, mobile command modelling, smart data integration, in business life; market sharing analysis, insurance, fleet management, target marketing, positioning of sales areas, infrastructure; network management, service provision, communication, emergency response, environmental management; It is seen that it is used effectively in site selections, EIA studies, pollution controls, disaster management and resource management.

GIS technology has been widely adopted in waste management, particularly in the planning process, due to its ability to effectively digitize spatial feature data, including the objects and their attributes with geographic accuracy. By incorporating spatial feature data, GIS technology enables efficient management and analysis of waste-related information. This includes mapping waste collection points, tracking routes, optimizing collection schedules, analyzing waste generation patterns, and identifying suitable locations for waste facilities. The extensive use of GIS technology in waste management has significantly improved the planning process, allowing for better decision-making and enhanced operational efficiency in the industry. GIS technology has gained widespread use in waste management, particularly in the planning process, due to its ability to effectively digitize spatial feature data, including the object and its attributes with geographic accuracy. By incorporating spatial feature data, GIS technology enables comprehensive utilization in waste management, particularly in the planning phase [36]. In this context, ArcGIS, with its network analysis extension, allows users to dynamically model realistic network conditions, including turn restrictions, speed limits, and traffic

conditions. Network analysis in ArcGIS not only examines the closest facility within a digitized connected line network but also provides the ability to model specific network attributes based on inputs such as traversal distance, travel time and cost, barriers, vehicle restrictions, and more [37].

Municipalities have limited budgets for basic sanitation services, which is why technological strategies and trained human resources are necessary for improved municipal solid waste management. From a technical perspective, GIS provide a powerful tool to model and optimize service routes where a better scenario can be proposed. GIS offers up-to-date services in terms of modeling and optimizing service routes for improved municipal solid waste management [38]. In addition to the ability to store verbal information of spatial data in an integrated way in the database, GIS also has the feature of querying and processing these data with the help of programming languages and visualizing the analysis results. For this reason, it provides visualization and more appropriate analysis of classical database operations such as data storage, querying and statistical analysis.

RESULTS AND DISCUSSION

Performing Route Optimization with Genetic Algorithm

There are 105 solid waste container points belonging to Barış neighborhood. The coordinates of these container points were obtained from the Google Earth Pro application and a dataset was created with this information. The created coordinate information was transferred to the working environment using the "Pandas" library. The data set was obtained by labeling the coordinate information of 105 solid waste containers. The distance information obtained by calculating the Euclidean distance between the tagged coordinates was used in the genetic algorithm. The formula used to calculate the distance is as follows:

$$d = \sqrt{[(x_2-x_1)^2+(y_2-y_1)^2]} \quad (2)$$

Using the distances obtained by the formula, the following steps were used to determine the best route between the container points.

1. Creation of the starting route; At this stage, a random route was created between 105 coordinates.
2. Calculation of the total length of the created route: Calculation of the distance between the points of the route created with the Euclidean distance shared in the formula.
3. Performing crossover between points: Creating a new route by performing crossover between selected points.
4. Mutation: Applying a mutation between the new route created according to the mutation probability.
5. Continuing the cycle by returning to the second step for the specified number of steps.

For population formation, which is one of the stages of the genetic algorithm, the data entry of 105 containers was written in accordance with the python programming language. When it comes to the final stage in the calculation of the Genetic Algorithm, routes were created according to the number of generations and distance calculations were made with this route. The distance after the 1000th population was 18910.63 meters (18.9106 km) (Figure 3, Table 1). The results obtained in Table 1 are shown in meters.

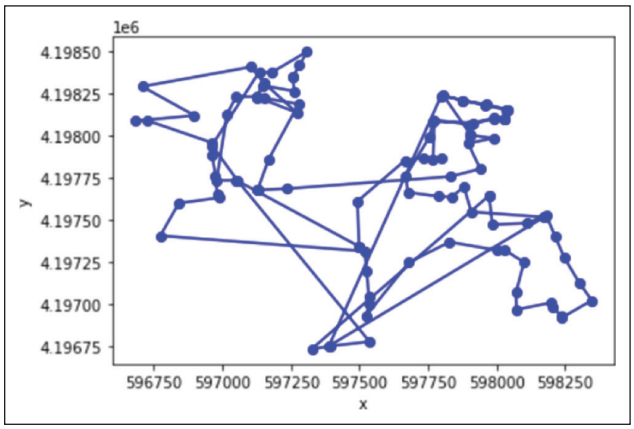

Figure 3. 1000. The population-generated route.

Table 1. The best distance values obtained according to the number of generations

Population	Distance (m)
1. Population	75965.44
100. Population	59833.45
1000. Population	18910.63

Performing Route Optimization with Ant Colony

There are some parameters that need to be determined when calculating the Ant Colony Algorithm. What these parameters are can be explained step by step as follows:

- Number of Steps: Indicates how many steps the optimization process will take.
- Number of Ants: It refers to the total number of ants in the colony.
- Alpha Value: Indicates the importance of the pheromone value between points.
- Beta Value: Indicates the importance value of the distance between the points.
- Pheromone Evaporation Value: Indicates the pheromone evaporation rate between points after each step.

In accordance with the parameters mentioned above, the values of the CCA calculated in the 'python' computer programming language are given in Table 2.

As shown in Table 2 above, ant colony algorithm parameters were determined. The following steps were taken in line with these determined parameters and optimization was carried out with the data set used in section 2.

Step 1: Ants are randomly placed on the dots.

Step 2: Each ant creates a route according to the determined alpha and beta values.

Step 3: The created route values are calculated.

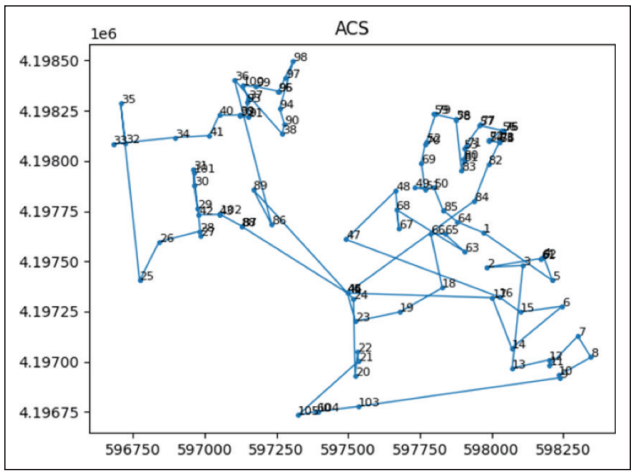

Figure 4. Ant colony algorithm optimization map.

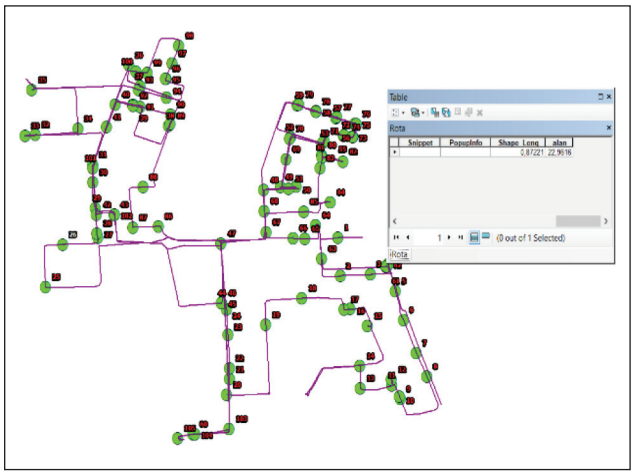

Figure 5. Network analysis optimization map.

Table 2. Ant colony algorithm parameter values

Parameter	Value
Number of steps	1000
Number of ants	150
Alpha ratio	1.0
Beta rate	3.0
Pheromone evaporation rate	1.0

Step 4: The pheromone ratio in the route that the ants pass according to the direction they form is increased.

Step 5: The amount of pheromone on the route is reduced according to the pheromone evaporation rate.

Step 6: It is repeated by returning to Step 2 as many as the number of steps.

Optimization was achieved in 1000 iterations by following the specified steps, and the route obtained is shown in Figure 4. The total distance obtained according to the CCW optimization result shown in Figure 4 is 16026.21 m (16.0262 km).

Solution of Route Optimization with GIS

It is solved with the route feature of the ArcMap network analysis tool of Esri ArcGIS application. As a result of these solutions, the results of the solution of 11 problem sets are shown in Figure 5. The distance obtained for this ranking is 22.9616 km. Each result in the table; It shows the most suitable route between the vehicle starting from the first point, stopping at other destination points, and returning to the starting point again.

Extracting the Route Used in Real Life

Mobilize tracking device is placed in solid waste collection vehicles to determine the route used for the collection of household waste in Barış neighborhood. Thanks to the tracking device, the data of the application can be obtained when the solid waste collection vehicle enters and exits the neighborhood. By analyzing the data obtained at the end of the day,

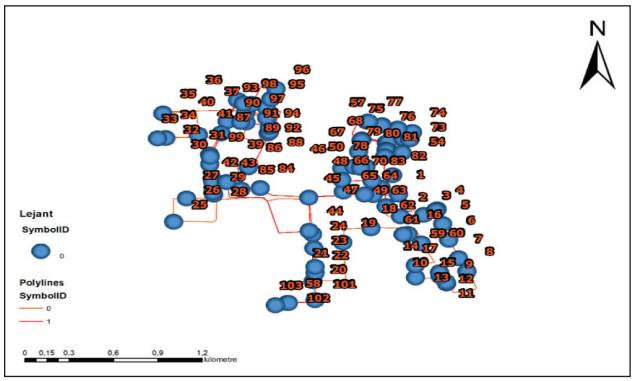

Figure 6. Route ranking used in real life.

105 container points were determined on the route of Barış neighborhood. The distances between 105 container points on this route have been calculated as 22.8488 km (Fig. 6).

CONCLUSIONS

The waste collection plays a crucial part in the waste management system because of the high cost of transportation. As a result, waste management activities are becoming more and more important. Decision-makers are now required to make educated choices due to rising costs of solid waste management, which account for a considerable share of total expenses for local administrations.

This study addresses the waste collection and transportation problem, which constitutes a significant portion of the costs of solid waste management systems. In particular, genetic algorithm, ant colony algorithm and traveling salesman problem optimization are used to generate feasible solutions to the waste collection problem involving 103 points distributed in Barış neighborhood of Kayapınar district of Diyarbakır. The results obtained with the studies carried out in this direction were compared with the real-life data.

Using real-life data for a small area and evaluating the studies on it can provide convenience. However, as the working area grows, optimization studies are carried out with the emergence of constraints such as time, traffic density, number of

vehicles and increase in the number of employees. In the study conducted for this purpose, it has been seen that GIS, GA and CCA give more advantageous results than real life data.

As a result of the study, it was seen that savings were achieved with 15.1576% improvement in GIS, 29.8104% improvement in GA (Genetic algorithm) and 40.5171% improvement in ACS (Ant Colony System) against real life data. As a result of the application, it was seen that the ant colony algorithm is superior to the Genetic algorithm and GIS because it draws a shorter route in terms of distance and achieves a better result in terms of improvement rate.

Within the scope of this study, it has been tried to optimize the route used in the collection and transportation of solid wastes with GIS, Ant Colony Algorithm and Genetic Algorithm. The results obtained with the studies carried out in this direction were compared with the real-life data.

Using real-life data for a small area and evaluating the studies on it can provide convenience. However, as the working area grows, optimization studies are carried out with the emergence of constraints such as time, traffic density, number of vehicles and increase in the number of employees. In the study conducted for this purpose, it has been seen that GIS, GA and CCA give more advantageous results than real life data.

In the process of determining the optimum route used by local governments in the collection and transportation of domestic solid waste; It has been seen by experimental studies that the use of heuristic methods has a significant share in terms of economic and environmental gains. Optimization and comparison of the traveling salesman problem with the genetic algorithm and the ant colony algorithm were used to calculate the route optimization in the collection and transportation of solid wastes. With the calculations made, it was seen that the ant colony gave a better improvement result than the genetic algorithm. A GIS solution was implemented using the network analysis tool of the ArcMap module of the Esri ArcGIS application. In large-scale study areas, GIS gives more advantageous results than real data. Likewise, it has been seen that the result obtained from ArcGIS for the study area is more advantageous than the real data Likewise, in the neighborhood, which is the subject of the thesis, it was seen that the result obtained from ArcGIS was more advantageous than the real data. It has been determined by calculations that the efficiency obtained from algorithms used outside of GIS is much more advantageous. In the calculations made under four headings for Barış neighborhood, the most advantageous ratio was obtained with the Ant Colony Algorithm, with a distance of 16.0262 km and an improvement of 40.517%.

In this study, calculations were performed on certain criteria with different algorithms. More extensive studies can be carried out by adding criteria such as time and cost to the algorithms. As a result, in the determination of the optimum route used by local governments in the collection and transportation of domestic solid waste; It has been seen by experimental studies that the use of heuristic methods has a significant share in terms of economic and environmental gains.

In the next study plan, the problem will be done to cover the whole district and the whole province. While solving these problems, other real life constraints such as vehicle breakdown and traffic congestion will be added, and optimization solutions will be produced.

Acknowledgements
This study was financially supported by Harran University Scientific Projects Research Coordinator (HUBAP) under grant no 20150.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

REFERENCES

[1] A. İ., Karabulut, B., Yazici-Karabulut, P. Derin, M. İ., Yesilnacar, and M. A., Çullu, "Landfill siting for municipal solid waste using remote sensing and geographic information system integrated analytic hierarchy process and simple additive weighting methods from the point of view of a fast-growing metropolitan area in GAP area of Turkey," Environmental Science and Pollution Research, 29, 4044–4061, 2022. [CrossRef]

[2] S., Varjani, H., Shahbeig, K., Popat, Z., Patel, S., Vyas, A. V., Shah, and M., Tabatabaei, "Sustainable management of municipal solid waste through waste-to-energy technologies," Bioresource Technology, Vol. 355, Article 127247, 2022. [CrossRef]

[3] W., Xue, K., Cao, and W. Li, "Municipal solid waste collection optimization in Singapore," Applied Geography, Vol. 62, pp. 182–190, 2015. [CrossRef]

[4] K., Nguyen-Trong, A., Nguyen-Thi-Ngoc, D., Nguyen-Ngoc, and V., Dinh-Thi-Hai, "Optimization of municipal solid waste transportation by integrating GIS analysis, equation-based, and agent-based model," Waste Management, Vol. 59, pp. 14–22, 2017. [CrossRef]

[5] E., Babaee Tirkolaee, I., Mahdavi, M. M., Seyyed Esfahani, and G. W., Weber, "A hybrid augmented ant colony optimization for the multi-trip capacitated arc routing problem under fuzzy demands for urban solid waste management," Waste Management and Research, Vol. 38(2), pp. 156–172, 2020. [CrossRef]

[6] A., Malakahmad, P. M., Bakri, M. R. M., Mokhtar, and N., Khalil, "Solid waste collection routes op-

timization via GIS techniques in Ipoh city, Malaysia," Procedia Engineering, Vol. 77, pp. 20–27, 2014. [CrossRef]

[7] N. V., Karadimas, M., Kolokathi, G., Defteraiou, and V., Loumos, "Ant colony system vs ArcGIS network analyst: The case of municipal solid waste collection," In 5th WSEAS international conference on environment, ecosystems and development (pp. 128-34), 2007. [CrossRef]

[8] G., Tavares, Z., Zsigraiova, V., Semiao, and M. G., Carvalho, "Optimisation of MSW collection routes for minimum fuel consumption using 3DGISmodelling," Waste Management, 29(3), 1176–1185, 2009. [CrossRef]

[9] A., Sulemana, E. A., Donkor, E. K., Forkuo and S., Oduro-Kwarteng, "Optimal routing of solid waste collection trucks: A review of methods," Journal of Engineering, Vol. 2018, Article 4586376, 2018. [CrossRef]

[10] A. V., Bhambulkar and I. P., Khedikar, "Municipal solid waste (MSW) collection route for laxmi nagar by geographical information system," International Journal of Advanced Engineering Technology, Vol. 2(4), pp. 48–53, 2011. [CrossRef]

[11] C. A., Arribas, C. A., Blazquez, and A., Lamas, "Urban solid waste collection system using mathematical modelling and tools of geographic information systems," Waste Management & Research, Vol. 28(4), pp. 355–363, 2010. [CrossRef]

[12] D. H., Dayanara, N. I., Arvitrida, and N., Siswanto, "Vehicle routing problem with split service, time window and intermediate facility for municipal solid waste collection in surabaya city with ant colony optimization algorithm," In IOP Conference Series: Materials Science and Engineering, Vol. 598(1), Article 012020. IOP Publishing, 2019. [CrossRef]

[13] P., Keenan, "Modelling vehicle routing in GIS," Operational Research, Vol. 8(3), pp. 201–218, 2008. [CrossRef]

[14] J., Liu, and Y., He, "A Clustering-Based Multiple ant colony system for the waste collection vehicle routing problems," Fifth International Symposium on Computational Intelligence and Design, 28-29 October, Hangzhou, China, pp.182–185, 2012. [CrossRef]

[15] M., Reed, A., Yiannakou, and R., Evering, "An ant colony algorithm for the multi-compartment vehicle routing problem," Applied Soft Computing, 15, pp. 169–176, 2014. [CrossRef]

[16] V., Sanjevi, and P., Shahabudeen, "Optimal routing for efficient municipal solid waste transportation by using arc gis application in chennai, India," Department of Industrial Engineering, College of Engineering, Anna University, India. Sage Journals, Vol. 34(1), pp. 11–21, 2016. [CrossRef]

[17] R. A., Yetiş, "Şanlıurfa Balıklı göl havzasında yer altı suyu tuzluluğunun coğrafi bilgi sistemi kullanılarak değerlendirilmesi," Uluslararası Su ve Çevre Kongresi, Mart, Bursa, pp. 1, 2018.

[18] L., Amal, L. H., Son, and H., Chabchoub, "SGA: spatial GIS-based genetic algorithm for route optimization of municipal solid waste collection," Environmental Science and Pollution Research, Vol. 25, pp. 27569–27582, 2018. [CrossRef]

[19] J., Valizadeh, P., Mozafari, and A., Hafezalkotob, "Municipal waste management and electrical energy generation from solid waste: a mathematical programming approach," Journal of Modelling in Management, Vol. 17(1), pp. 309–340, 2022. [CrossRef]

[20] O., Demirdöğen, H., Erdal, and E., Acar, "An integrated model proposal for increasing the effectiveness of security service production: A multi-criteria maximal covering model," International Journal of Recent Scientific Research, Vol. 6(6), pp. 4881–4890, 2015.

[21] H., Erdal, "Tehlikeli madde taşımacılığı güzergâh seçimi problemi için stokastik bir risk analizi", Anemon Muş Alparslan Üniversitesi Sosyal Bilimler Dergisi, Vol. 6(6), pp. 935–943, 2018. [Turkish]

[22] İ., Akgün, and H., Erdal, "Solving an ammunition distribution network design problem using multi-objective mathematical modeling, combined AHP-TOPSIS, and GIS," Computers & Industrial Engineering, Vol. 129, pp. 512–528, 2019. [CrossRef]

[23] H., Erdal, K., Kurtay, H., Dagistanli, and A., Altuntas, "Evaluation of anti-tank guided missiles: An integrated fuzzy entropy and fuzzy cocoso multi criteria methodology using technical and simulation data" Applied Soft Computing, Vol. 137(C), Article 110145, 2023. [CrossRef]

[24] TÜİK, "Turkish Statistical Institute, "https://www.tuik.gov.tr/. Accessed on Feb 16, 2021.

[25] Anonymous, "Çevresel göstergeler," https://cevreselgostergeler.csb.gov.tr/atik-duzenli-depolama-tesis-sayisi-belediye-sayisi-hizmet-verilen-nufus-i-85750 Accessed on Feb 16, 2021.

[26] H., Pamukçu, "Optimization of solid waste collection route: The example of Kayapinar (Diyarbakir) county," Harran University Graduate School of Natural and Applied Sciences, [Unpublished Master Thesis], 2022.

[27] O., Rızvanoğlu, S., Kaya, and M., Ulukavak, "Optimization of municipal solid waste collection and transportation routes, through linear programming and geographic information system: a case study from Şanlıurfa, Turkey," Environmental Monitoring and Assessment, Vol. 192, Article 9, 2020. [CrossRef]

[28] Ç., Elmas, "Yapay Zeka Uygulamaları," Seçkin Yayıncılık, 2007. [Turkish]

[29] B., Özkan, "Design and implementation of an optimization library with visual software development environment for the solution of dynamic traveling salesman problem," Ege University, Institute of Science and Technology, [Unpublished Master Thesis], İzmir, 2008.

[30] Y., Pehlivanoğlu, "Optimizasyon: temel kavramlar ve yöntemler," Ankara, 2017.

[31] M., Demircioğlu, "A heuristic approach to vehicle routing problem and an application," Çukurova University, Institute of Social Sciences, [Doctorial Thesis], Adana, pp. 175, 2009,

[32] M., Dorigo, and G., Di Caro, "Ant colony optimization: a new meta-heuristic," In Proceedings of the 1999 congress on evolutionary computation-CEC99 (Cat. No. 99TH8406) (Vol. 2, pp. 1470-1477). IEEE, 1999.

[33] L., Amal, L. H., Son and H., Chabchoub, "SGA: spatial GIS-based genetic algorithm for route optimization of municipal solid waste collection," Environmental Science and Pollution Research, Vol. 25, pp. 27569–27582, 2018. [CrossRef]

[34] S., Serin, "Planning of highway routine pavement maintenance work using ant colony approaches," Süleyman Demirel University, Institute of Science and Technology, [Unpublished Master Thesis], pp. 89, 2009.

[35] A., Demirci, and M., "Karakuyu, Afet yönetiminde coğrafi bilgi teknolojilerinin rolü," Doğu Coğrafya Dergisi, Vol. 9(12), pp. 67–100, 2004.

[36] H., Cheniti, M., Cheniti, and K., Brahamia, "Use of GIS and Moran's I to support residential solid waste recycling in the city of Annaba, Algeria," Environmental Science and Pollution Research, Vol. 28, pp. 34027–34041, 2021. [CrossRef]

[37] D., Das, A. K., Ojha, H., Kramsapi, P. P., Baruah, and M. K., Dutta, "Road network analysis of Guwahati city using GIS". SN Applied Sciences, Vol. 1, pp. 1–11, 2019. [CrossRef]

[38] V., Del Carmen-Niño, R., Herrera-Navarrete, A. L., Juárez-López, M. L., Sampedro-Rosas, and M., Reyes-Umaña, "Municipal solid waste collection: challenges, strategies and perspectives in the optimization of a municipal route in a southern mexican town". Sustainability, Vol. 15(2), Article 1083, 2023. [CrossRef]