An International Journal of Optimization and Control: Theories & Applications
ISSN: 2146-0957 eISSN: 2146-5703
Vol.9, No.2, pp.197-207 (2019)
https://doi.org/10.11121/ijocta.01.2019.00714

RESEARCH ARTICLE

Optimization of medical waste routing problem: The case of TRB1 region in Turkey

Suleyman Mete [a*], Faruk Serin [b]

[a] *Department of Industrial Engineering, Munzur University, Turkey*
[b] *Department of Computer Engineering, Munzur University, Turkey*
suleymanmete@munzur.edu.tr, fserin@munzur.edu.tr

ARTICLE INFO

Article history:
Received: 24 September 2018
Accepted: 13 April 2019
Available Online: 29 April 2019

Keywords:
Medical waste
GIS
Routing
Case study

AMS Classification 2010:
90-08, 90B06, 90C10

ABSTRACT

A fundamental problem concerning medical waste disposal is the evaluation of the real and potential risks arising from waste with the focus on the risk of infection. Therefore, the optimization of medical waste routing from collection to disposal center can minimize the risk of infection. The routing of medical waste considers significant to determine potential routes and select the route with minimum distance. The management of the medical waste is important decision for environmental sustainability and includes the collection, transportation and disposal of these materials. In this paper, a geographic information system (GIS) solution approach is proposed to determine the best location of disposal center. Proposed approach is applied to medical waste transportation between 167 health institutions (collection centers) and predetermined 5 disposal centers through TRB1 region in Turkey, which consist of Malatya, Elazığ, Bingöl and Tunceli provinces. The results of case study are examined and suggestions for future research are provided.

1. Introduction

Medicine is one of the important sectors showing development throughout the world during recent decades. Thus, the industrial and technological advances in the medicine sector have created a large medical waste in the developed world. There are four types of waste generated by health institutions. They can be classified as municipal wastes, medical wastes, hazardous and radioactive wastes. The sub-groups of medical waste can be listed as infection wastes (used surgical operating clothes, infectious organ pieces, blood and blood products etc.), pathological wastes (organs, tissues, placenta etc.) and sharp objects (syringes, needles, blades, broken glass etc.). Besides, there are four interchangeable terms for entitled medical waste which are medical waste, hospital waste, infectious medical waste and regulated medical waste. The collection, transportation and disposal of the medical waste are serious processes that need to be considered [1].

Generated medical waste is increased day by day due to the increase in the number of health institutions and populations. Classification and appropriate segregation of medical waste are important processes for its transportation and disposal [2]. The medical waste materials have remarkable risks and to produce negative effect on human health and the environment during storage, handling, usage and transporting processes due to their naturel conditions. Awareness of environmental problems and living healthy have raised in modern societies in recent years. Therefore, plan and practices on transportation of medical waste should be applied to reduce the risks in addition to legal constraints. The selection of disposal center for the logistic operation of medical waste has a great importance due to potential negative effect of the medical waste over human health.

The locations of disposal center for medical waste have a significant impact on the feasible routing decisions and the total transportation risk and distance. It is important to consider the locations of medical waste disposal center and the routing plans simultaneously. Routing of vehicles that carry medical waste effects the costs, economic evaluation or environmental security and community issues. Therefore, alternative routes should be identified for these vehicles to choose the

*Corresponding author

route with minimum distance.

This study aims to present a solution for the routing problem of medical waste in TRB1 region of Turkey. The data is obtained using QGIS 3.0 Girona software and OpenStreetMap for four provinces as Malatya, Elazığ, Bingöl, and Tunceli. In the paper, QGIS 3.0 is employed as the GIS platform to support the analysis of routing problem. GIS-based solution approach is also applied for the determine the best location of disposal center. 167 collection centers of medical waste and predetermined 5 disposal centers are examined in the paper. The softwares used to solve the problem as travelling salesperson are QGIS 3.0, OpenStreetMap, PostgreSQL database, PostGIS, pgRouting, pgr_TSP routing function.

The rest of the paper is outlined as follows: in next section, we provide an overview and a summary of the related studies. In section 3, proposed approach to solve the problem are detailed. The case study is outlined and related data are given in section 4. Results of the case study are analyzed and discussed in section 5. Finally, evaluations are provided in the conclusion section.

2. Related studies

There are extensive literature related to routing problem. The problem is solved with different techniques such as mathematical modeling, meta-heuristics and geographic information system–based methods [3]. In this part literature is divided as three sub-section. Firstly, literature for the location-routing are analyzed then literature of hazardous material routing and medical waste collection are examined respectively.

A location-routing problem can be described as given a set of potential depots and a set of customers with known demand, define the optimal locations of the depots with vehicle routes from chosen depots to the customers simultaneously while minimizing the total system costs [4]. Exact solution and heuristic/ metaheuristic methods are developed for location-routing problem in the literature. The first exact solution approach for the general location-routing problem is proposed by Laporte and Nobert [5]. Later, Laporte et al. [6], Ghiani and Laporte [7], Averbakh and Berman [8], Labbe et al. [9], Alumur and Kara [10], Ponboon et al. [11] and Farham et al. [12] also propose exact methods to solve the problem with optimal manner. Heuristic and meta-heuristic approaches are also proposed to solve the problem since the complexity of the location-routing problem is NP-Hard nature [13]. Exact methods ensure important insights into problems, but they can tackle for small/medium instances due to the complexity of the problem [14]. Therefore, many researchers focus on the heuristic and metaheuristic approach to solve the problem such as simulated annealing algorithm [15], ant colony optimization [16], tabu search [17-18], hybrid heuristic algorithm approach [19] and memetic algorithm [20]. The reader is referred to the comprehensive surveys by Nagy and Salhi [14] for models and issues, models and methods of the location-routing problems, and they also develop a classification scheme for the location-routing studies.

There are extensive literature related to hazardous material routing problem. Different solution approaches are developed for hazardous material routing problem. Erkut and Verter [21] develop different risk models formulation to solve hazardous material shipment problem between a given origin-destination pair. Leonelli et al. [22] propose mathematical formulation to select the best route of the transportation of a hazardous substance. Androutsopoulos and Zografos [23] present model to solve the bicriterion routing and scheduling problem for hazardous material distribution. The concept of chaos theory based on dynamic risk definition and damage severity network is used by Mahmoudabadi and Seyedhosseini [24] to determine best route for transportation of hazardous material. On the other hand, meta-heuristics approaches are proposed to solve hazardous material routing problem. Zografos and Androutsopoulos [25] propose a heuristic algorithm integrated with GIS based decision support system to solve hazardous material distribution network. Huang et al. [26] integrate genetic algorithm with GIS based system to evaluate the risk of hazardous material transportation. Pamučar et al. [27] propose a new approach, which is based on adaptive neuro fuzzy inference system, artificial bee colony algorithm and Dijkstra's algorithm, for cost and risk assessment of hazardous material transportation on a network of city roads. Özceylan et al. [3] present a solution approach based on GIS for solving hazardous material routing with a case study. Hazardous waste has been investigated with consideration population and environmental impact by Yılmaz et al. [28]. The reader is referred to the comprehensive survey by Erkut et al. [29] for a recent coverage of the state of the art on models and solution algorithms.

We investigate the related problems in detail since our focus area is to solve problems of transportation and collection of medical waste. There are studied related medical waste routing and collection in the literature. Shih and Chang [30] use a computer program for the gathered of infectious medical waste. They propose a mathematical model and a two-phase periodic vehicle routing problem for scheduling and routing the gathered of medical waste. The proposed approach is also applied to 348 hospitals in the Tainan City/ Taiwan. Mourao and Almeida [31] define a capacitated arc routing problem to minimize total cost of a refuse collection in Lisbon. Therefore, two lower bounding method and a three-phase heuristic approach are developed for solving the problem. Alagöz and Kocasoy [2] use special software programs, which are called MapInfo and Roadnet, to solve the scheduling and route optimization for transportation health-care waste collection in Istanbul. Marinkovic et al. [32] introduce a combine approach based on a hierarchical structure from generation medical waste point to disposal center. The aim of proposed integrated approach points out probable solution for the management medical waste in Croatia. Abdulla et al. [33] investigate the medical waste management system, which is used in health institutions in northern Jordan. Therefore, they analyze a comprehensive inspection survey for all hospital located in the area, and they propose results of main findings of the study. Birpınar et al. [1] examine the present status of medical waste management in the light of the Medical Waste Control Regulation in Istanbul. Windfeld and Brooks [34] investigate medical waste management related studies including the common sources, governing legislation and handling and disposal methods. Alshraideh and Qdais [35] pay attention to stochastic medical waste collection problem in Jordan and proposed a route scheduling model for minimizing the total transportation cost and reduces emissions. Mmereki et al. [36] introduce an overview of the current generated waste from health institutions in Botswana. Hence, they analyze storage, collection, treatment and disposal system for the case in Botswana.

Scope of this study is to answer as follows questions: (i) how to route the produced medical waste from collection center to disposal center, (ii) which of the presented solutions are reasonable according to total distance. Therefore, a GIS-based solution approach is developed to solve routing of medical waste problem. The approach is applied to case study of TRB1 region in Turkey, which include Malatya, Elazığ, Bingöl and Tunceli provinces. Data related collection and disposal center are provided from QGIS 3.0 and OpenStreetMap.

3. The methodology

The mathematical model for routing is used in this paper to determine the best location for disposal center and routing. The model used in this study is proposed by Baldacci et al. [37]. The problem can be defined as capacitated vehicle routing problem. The mathematical model formulation is given as follows:

$$min \sum_{i,j\in E} d_{ij} X_{ij} \tag{1}$$

$$\sum_{i,j\in t(h)} X_{ij} = 2, \qquad \forall h \in V, \tag{2}$$

$$\sum_{i,j\in t(S)} X_{ij} \geq 2k(S), \qquad \forall S \in s, \tag{3}$$

$$\sum_{j\in V} X_{0j} = 2r, \tag{4}$$

$$X_{ij} \in \{0,1\}, \ \forall\, i,j \in E \setminus (0,j : j \in V) \tag{5}$$

$$X_{0j} \in 0,1,2, \quad \forall\, 0,j, \quad j \in V, \tag{6}$$

$S = \{S : S \subseteq V, |S| \geq 2\}$, and $q(S) = \sum_{i\in S} q_i$ be the total produced of medical waste $S \in s$ and $k(S)$ minimum number of sub-routes that is equal to minimum number of vehicles with Q capacity for multi-vehicle routing problem, and r is the number of sub-route. Further, let $t(S) = \{\{i,j\} \in E : i \in S,\ j \notin S \ or\ i \notin S,\ j \in S\}$. $X_{i,j}$: a binary variable equal to 1 if and only if edge$(i;j)$ is chosen in the solution for all $\{i,j\} \in E \setminus \{\{0,j\} : j \in V\}$ and value $\{0,1,2,$ for all $\{0,j\}, j \in V$ with $X_{i,j} = 1$ when edge is traversed and $X_{0,j} = 2$ when a route $(0,j,0)$ in the solution.

The objective function (1) is to minimize total transportation distance between collection center and disposal center. Constraint (2) is degree restriction and it specifies the degree of each collection center. Constraint (3) are determined capacity restriction. Constraint (4) represent that a truck must leave and back to disposal center. Constraint (5 and 6) are integrality restriction.

The usage of GIS-based solution method for the medical waste routing problem presents several advantages. GIS offers database properties that can handle data qualification, and it allows the addition of relevant layers for using spatial analysis [38;40;41]. In this paper, a GIS-based routing problem for transporting medical waste between 167 collection centers and five different possible location for disposal centers is considered. Spatial data of collection and disposal centers were gathered on OpenStreetMap and stored to PostgreSQL database via QGIS 3.0 software. QGIS known as Quantum GIS is an open source and free software used for Geographic Information Systems. The gathered data were used as input for PostGIS an extension of PostgreSQL database. The results were obtained by using pgRouting, which is an extension of PostGIS for routing operation. A routing function of pgRouting, pgr_TSP, were used to solve the problem as travelling salesperson problem. Finally the route results were shown on the OpenStreetMap via QGIS.

4. The case study of TRB1 region in Turkey

In this paper, 167 collection centers and 5 predetermined disposal centers that are located in TRB1 region in Turkey are considered (see Figure 1). The following locations are selected as candidates for disposal center: (i) the four locations are predetermined in Malatya, Elazığ, Bingöl and Tunceli provinces respectively, (ii) one location is also predetermined between Elazığ, Bingöl and Tunceli provinces. In other words, we face a problem with 5 possible locations for disposal center, where we can choose only one of them.

Figure 1. Study area: TRB1 region of Turkey

Health institutions consist of state hospitals, special hospitals, health centers and university hospitals. The locations of health institutions (red nodes) and disposal centers (green nodes) are given in Figure 2. In addition, related data including coordinates, number of population and district for each locations of collection center are given in Table A1 as appendix.

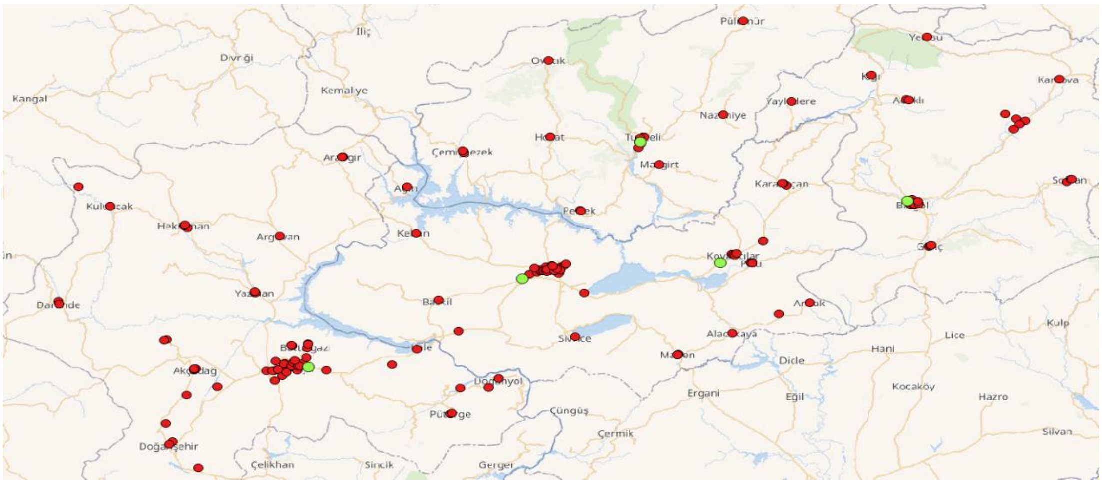

Figure 2. The locations of 167 collection centers (red nodes) and 5 disposal centers (green nodes)

Table1: Weekly produced medical waste according to the population of each collection center

Center	Medical Waste Produced (Kg)	Center	Medical Waste Produced (Kg)	Center	Medical Waste Produced (Kg)	Center	Medical Waste Produced (Kg)	Center	Medical Waste Produced (Kg)
1	120.462	35	99.116	69	45.938	103	183.490	137	63.261
2	120.462	36	99.116	70	45.938	104	183.490	138	98.164
3	120.462	37	79.829	71	45.938	105	183.490	139	98.164
4	120.462	38	79.829	72	45.938	106	183.490	140	142.760
5	120.462	39	98.999	73	45.938	107	183.490	141	1192.829
6	120.462	40	54.870	74	45.938	108	183.490	142	1192.829
7	72.953	41	37.448	75	27.225	109	183.490	143	1192.829
8	72.953	42	257.764	76	27.225	110	183.490	144	1192.829
9	136.758	43	257.764	77	27.225	111	183.490	145	1192.829
10	152.102	44	257.764	78	27.225	112	183.490	146	247.741
11	56.055	45	257.764	79	27.225	113	183.490	147	247.741
12	115.956	46	257.764	80	31.967	114	183.490	148	187.608
13	106.594	47	257.764	81	31.967	115	183.490	149	187.608
14	106.594	48	257.764	82	31.967	116	183.490	150	187.608
15	59.532	49	257.764	83	21.552	117	183.490	151	187.608
16	340.797	50	257.764	84	21.552	118	183.490	152	25.774
17	340.797	51	257.764	85	21.552	119	183.490	153	25.774
18	340.797	52	257.764	86	25.217	120	183.490	154	25.774
19	340.797	53	257.764	87	25.217	121	183.490	155	108.342
20	340.797	54	257.764	88	21.278	122	183.490	156	108.342
21	340.797	55	257.764	89	21.278	123	183.490	157	108.342
22	340.797	56	257.764	90	12.084	124	183.490	158	49.840
23	340.797	57	257.764	91	12.084	125	183.490	159	49.840
24	340.797	58	257.764	92	12.084	126	183.490	160	70.001
25	217.616	59	257.764	93	26.858	127	183.490	161	70.001
26	217.616	60	257.764	94	21.576	128	183.490	162	93.173
27	217.616	61	257.764	95	21.562	129	183.490	163	93.173
28	214.489	62	257.764	96	8.782	130	63.261	164	93.173
29	214.489	63	257.764	97	32.701	131	63.261	165	82.412
30	214.489	64	257.764	98	32.701	132	63.261	166	82.412
31	99.116	65	257.764	99	32.701	133	63.261	167	82.412
32	99.116	66	257.764	100	32.701	134	63.261		
33	99.116	67	257.764	101	32.701	135	63.261		
34	99.116	68	257.764	102	32.701	136	63.261		

The medical waste per person in Turkey is computed using the following formula: (Total generated medical waste for a year / total population). Hence, the annual produced medical waste per person is 8,1024,000 / 79,510,000=1.01 kg/person for the year 2016 according to Turkish Statistical Institute [39]. Total population of the TRB1 regions is approximately 1,726,199 people. Weekly produced medical waste according to the population of each health institutions (collection center) is given in Table 1. These values are calculated according to the population of each collection center. In other words, the generated medical waste in weekly for each collection center can be computed: (The total population of city x 1.01 / the number of collection center) / 52 week. For example, Tunceli province has six collection centers which are 1, 2, 3, 4, 5, 6, and each of them are produced approximately 120.462 kg/week medical waste with a population of 6,202 people (see Table 1).

Transportation cost of the medical waste is more than other waste since medical waste is shipped with special equipment and trucks. Therefore, distances between collection and disposal centers are used as a measure of cost. Thus, the cost of distance has a significant role to determine routing and disposal center. There is one type of truck that is used in this study to collect medical waste from collection center to disposal center, and it has 3,000 kg capacity. On a weekly basis, truck starts its trip from the disposal center, collects medical waste from the 167 collection centers, then drives back to the disposal center. When the truck reaches its capacity during trips, it back to disposal center to unload the medical waste, and then continues the trip. This trip is scheduled for every week.

In the study, single depot and single vehicle are considered for the problem. Euclidean distances between the identified collection points and the alternative locations were obtained by using QGIS 3.0 Girona software and OpenStreetMap, and the distances are calculated in meters. All runs are taken on a server with 2.4 GHz Intel® Core™ processor and 8 GB RAM, and the computation time required to solve the problem is less than 1 CPU second. Results for the routing problem of medical waste are analyzed in next section.

5. Results and Discussions

In this section, results of the five alternatives are analyzed, and the best of one is selected. A GIS-based solution approach is proposed to search feasible routes for shipping medical waste from 167 collection centers to one of the five alternative location (disposal centers). The objective is to minimize total distance which consist of total trip distance including loading and unloading distance. By this way, total risk of medical waste during shipping can be minimized.

Five different location areas are predefined for disposal center. These location areas are in Tunceli, Bingöl, Elazığ and Malatya provinces. Besides, one of the them is located between Tunceli, Bingöl and Elazığ provinces. Thus, we can determine the best location for disposal center among 5 different alternatives locations. Routes of these alternatives location for feasible routes between collection and disposal center are given in Figure 3. For example, if the disposal center locates in Tunceli province, total trip takes 6,558,215 meters and the truck will have to go through the disposal center 12 times during trip (see Figure 3a). Total trip takes 5,082,553 meters if disposal center locates in Malatya province (see Table 2). The results show that the opening of a disposal center in Malatya province seems to be a reasonable decision.

Total travel distance includes the distance from disposal center to first collection center, between sequential collection centers, and from last collection (where truck is full, or collections are finished) center to disposal center. Therefore, unloading number and amount of medical waste generated according to population is significant indicator to select location of disposal center. Thus, disposal center located in Malatya province is logical according to total population, amount of medical waste generated and distance.

Results of the feasible routes for location of disposal center in Malatya province are shown in Figure 4. There are 12 sub-routes (truck unloading number) for this solution.

Table 2. Total travel distance and truck unloading number according to disposal center

Location area	**Total travel distance (m)**	**Unloading number**
Tunceli	6,558,215	12
Bingöl	8,308,406	13
T-B-E*	6,126,680	13
Elazığ	5,237,900	13
Malatya	5,082,553	12

*Location area is between Tunceli, Bingöl and Elazığ provinces

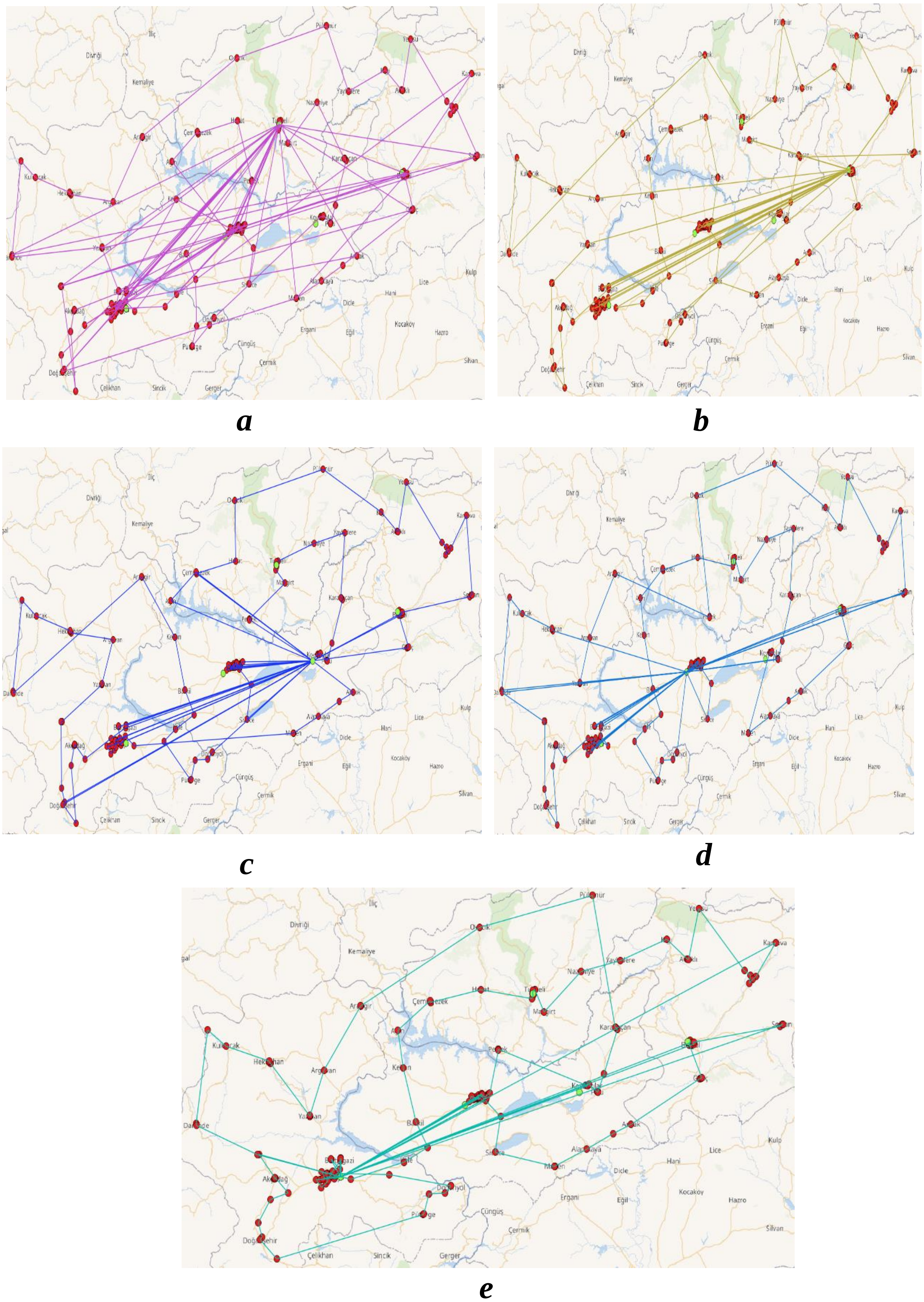

Figure 3. Feasible routes between collection and disposal center a) the disposal center located in Tunceli, b) the disposal center located in Bingöl, c) the disposal center located between Tunceli, Bingöl and Elazığ provinces, d) the disposal center located in Elazığ, e) the disposal center located in Malatya

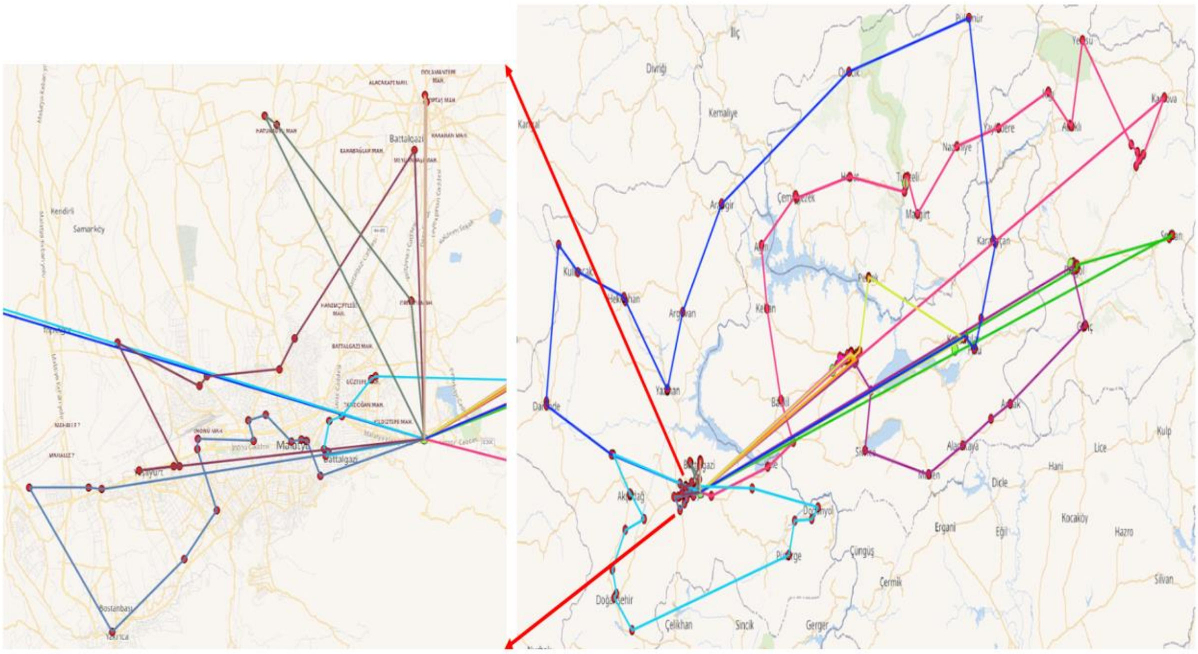

Figure 4. Disposal center located in Malatya province

Each of the sub-routes is painted with different colour (see Figure 5b). The route starts the disposal center and then collect medical waste from the first collection center and continue collecting waste from the other collection center until the route is terminated by truck capacity (see Figure 5a). When it reaches capacity, truck backs to disposal center to unload medical waste. For example, detail of a sub-route shown in Figure 5a, truck starts from disposal center located in Malatya then gather medical waste until it reaches its capacity after visit 25 collection center. Then, the truck returns back to disposal center with load of 2884.37 kg in order to unload waste (the sub-route 8 is given in Table 3).

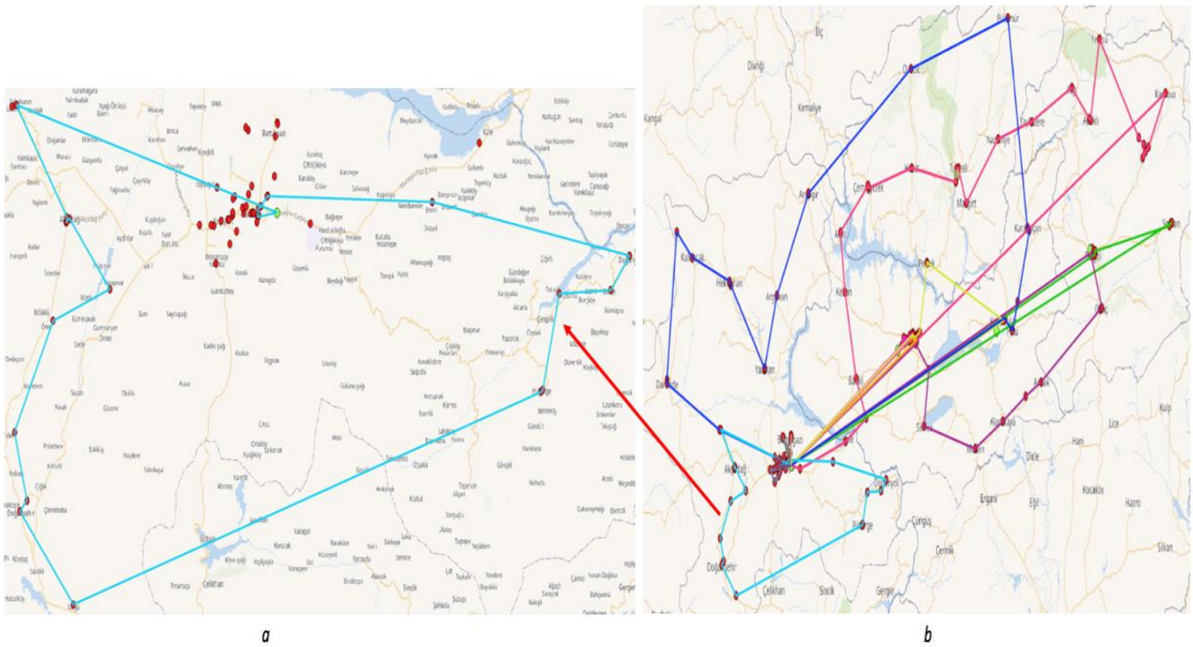

Figure 5. The best solution among 5 alternatives. a) Detail of one sub-route b) starting and finishing point for all sub-routes with different colour

All sub-routes of the best solution among the alternatives are given in Table 3. If the disposal center is opened in Malatya, the best solution is achieved according to total distance or total transportation cost. For example, if truck visits collection center 143 and 141 in the sub-route 11, it fills capacity with 2385.658

kg and returns to the disposal center. That is, these two health institutions are produced many waste, and they are in Malatya city center.

In this study, the weekly collection of medical waste from health institutions in TRB1 region of Turkey to the final disposal center are examined, and the best feasible (the most efficient) route among the alternatives is selected as disposal center with perspective of efficiency. Using the selected disposal center reduces risks to human health, cost arising from transportation and provides economic advantages

Table 3. Results of the best solution among all alternatives (disposal center in Malatya)

Sub-route	Trips	Waste (kg)
1	115-159-89-88-95-96-8-7-9-6-5-1-4-2-3-10-11-41-39-37-38-40-31-32-35-34-33-36	2801.644
2	30-29-28-24-17-16-23-22-21	2688.249
3	19-18-20-27-26-25-86-87-94-91-90-92-93-74-68	2948.947
4	70-69-50-49-48-47-44-46-43-65-64	2835.404
5	66-67-45-63-60-61-62-58-59-42-54	2835.404
6	72-73-53-52-51-71-55-56-57-14-13-75-76-77	2991.353
7	78-83-85-84-79-80-81-82-15-12-138-139-140-167-166-165-155-157-160-161-146-147-137	2992.009
8	136-133-130-132-131-134-135-151-148-149-150-162-163-164-154-152-153-158-113-114-127-126-110-111-112	2884.37
9	123-109-108-107-106-124-105-104-102-101-120-118-97-116-117-98	2935.84
10	119-99-100-122-121-103-125-128-142	2660.749
11	143-141	2385.658
12	145-144-129	2569.148

6. Conclusion

The medical waste routing is important problem among all logistic transportation. Therefore, nearly all societies have regulation and law for transportation waste to protect people and environment. Medical wastes are needed special regulations to transport them. Thus, the scope of this study is to answer as follows questions: (i) how to route the produced medical waste from collection center to disposal center, (ii) which of the presented solutions are reasonable according to total cost.

The TRB1 region of Turkey is the focus for this study. A GIS-based solution approach is applied the case study, which consist of Malatya, Elazığ, Bingöl, and Tunceli provinces, to determine the best location of disposal center and routing. The results show that the opening of a disposal center located in Malatya province seems to be a reasonable decision. The opening of disposal center near to Malatya province would be appropriate decision for planners or decision-makers due to number of collection center and generated amount of medical waste in Malatya.

Some of the limitations of this study is given as follows: we are focusing only TRB1 region of Turkey that makes the study a bit narrow scoped. The other region of Turkey can be considered for future research and different scenario can be analyzed. The values used in study are not real produced medical waste, these are taken based on the total population for each health institutions. Hence, the exact amount of medical waste generated per year can be determined from each health institution, and accordingly the real values can provide more rational decisions for future research. Lastly, we have used Euclidean distance between collection and disposal center, but in real life applications these distances must be real distances or rectilinear.

In this study, the problem is considered as single depot and single vehicle. However, the problem can be considered as multi-depot and single vehicle, single depot and multi-vehicle, or multi-depot and multi-vehicle in future works.

References

[1] Birpınar, M. E., Bilgili, M. S., & Erdoğan, T. (2009). Medical waste management in Turkey: A case study of Istanbul. Waste Management, 29(1), 445-448.

[2] Alagöz, A. Z., & Kocasoy, G. (2008). Improvement and modification of the routing system for the health-care waste collection and transportation in Istanbul. Waste Management, 28(8), 1461-1471.

[3] Özceylan, E., Erbaş, M., Çetinkaya, C., & Kabak, M. (2017). A GIS-based risk reduction approach for the hazardous materials routing problem in Gaziantep. Human and Ecological Risk Assessment: An International Journal, 23(6), 1437-1453.

[4] Wu, T. H., Low, C., & Bai, J. W. (2002). Heuristic solutions to multi-depot location-routing problems. Computers & Operations Research, 29(10), 1393-1415.

[5] Laporte, G., Nobert, Y., (1981). An exact algorithm for minimizing routing and operating costs in depot location. European Journal of Operational Research 6, 224–226.

[6] Laporte G, Nobert Y, Desrochers M (1985) Optimal routing under capacity and distance restrictions. Oper Res 33:1058–1073

[7] Ghiani, G., Laporte, G., (1999). Eulerian location problems. Networks 34, 291–302.

[8] Averbakh, I., Berman, O., (2002). Minmax p-traveling salesmen location problems on a tree. Annals of Operations Research, 110, 55–62.

[9] Labbé, M., Laporte, G., Martin, I. R., & González, J. J. S. (2005). Locating median cycles in networks. European Journal of Operational Research, 160(2), 457-470.

[10] Alumur, S., & Kara, B. Y. (2007). A new model for the hazardous waste location-routing problem. Computers & Operations Research, 34(5), 1406-1423.

[11] Ponboon, S., Qureshi, A. G., & Taniguchi, E. (2016). Branch-and-price algorithm for the location-routing problem with time windows. Transportation Research Part E: Logistics and Transportation Review, 86, 1-19.

[12] Farham, M. S., Süral, H., & Iyigun, C. (2018). A column generation approach for the location-routing problem with time windows. Computers & Operations Research, 90, 249-263.

[13] Perl, Jossef, and Mark S. Daskin (1985). A warehouse location-routing problem. Transportation Research Part B: Methodological,19(5): 381-396.

[14] Nagy, G., & Salhi, S. (2007). Location-routing: Issues, models and methods. European journal of operational research, 177(2), 649-672.

[15] Vincent, F. Y., Lin, S. W., Lee, W., & Ting, C. J. (2010). A simulated annealing heuristic for the capacitated location routing problem. Computers & Industrial Engineering, 58(2), 288-299.

[16] Ting, C. J., & Chen, C. H. (2013). A multiple ant colony optimization algorithm for the capacitated location routing problem. International Journal of Production Economics, 141(1), 34-44.

[17] Albareda-Sambola, M., Díaz, J. A., & Fernández, E. (2005). A compact model and tight bounds for a combined location-routing problem. Computers & Operations Research, 32(3), 407-428.

[18] Caballero, R., González, M., Guerrero, F. M., Molina, J., & Paralera, C. (2007). Solving a multiobjective location routing problem with a metaheuristic based on tabu search. Application to a real case in Andalusia. European Journal of Operational Research, 177(3), 1751-1763.

[19] Marinakis, Y., & Marinaki, M. (2008). A bilevel genetic algorithm for a real-life location routing problem. International Journal of Logistics: Research and Applications, 11(1), 49-65.

[20] Asgari, N., Rajabi, M., Jamshidi, M., Khatami, M., & Farahani, R. Z. (2017). A memetic algorithm for a multi-objective obnoxious waste location-routing problem: a case study. Annals of Operations Research, 250(2), 279-308.

[21] Erkut, E., & Verter, V. (1998). Modeling of transport risk for hazardous materials. Operations research, 46(5), 625-642.

[22] Leonelli, P., Bonvicini, S., & Spadoni, G. (2000). Hazardous materials transportation: a risk-analysis-based routing methodology. Journal of Hazardous Materials, 71(1-3), 283-300.

[23] Androutsopoulos, K. N., & Zografos, K. G. (2010). Solving the bicriterion routing and scheduling problem for hazardous materials distribution. Transportation Research Part C: Emerging Technologies, 18(5), 713-726.

[24] Mahmoudabadi, A., & Seyedhosseini, S. M. (2014). Solving Hazmat Routing Problem in chaotic damage severity network under emergency environment. Transport policy, 36, 34-45.

[25] Zografos, K. G., & Androutsopoulos, K. N. (2004). A heuristic algorithm for solving hazardous materials distribution problems. European Journal of Operational Research, 152(2), 507-519

[26] Huang, B., Cheu, R. L., & Liew, Y. S. (2004). GIS and genetic algorithms for HAZMAT route planning with security considerations. International Journal of Geographical Information Science, 18(8), 769-787.

[27] Pamučar, D., Ljubojević, S., Kostadinović, D., & Đorović, B. (2016). Cost and risk aggregation in multi-objective route planning for hazardous materials transportation—A neuro-fuzzy and artificial bee colony approach. Expert Systems with Applications, 65, 1-15.

[28] Yilmaz, O., Kara, B. Y., & Yetis, U. (2017). Hazardous waste management system design under population and environmental impact considerations. Journal of environmental management, 203, 720-731.

[29] Erkut, E., Tjandra, S. A., & Verter, V. (2007). Hazardous materials transportation. Handbooks in operations research and management science, 14, 539-621.

[30] Shih, L. H., & Chang, H. C. (2001). A routing and scheduling system for infectious waste collection. Environmental Modeling & Assessment, 6(4), 261-269.

[31] Mourao, M. C., & Almeida, M. T. (2000). Lower-bounding and heuristic methods for a refuse collection vehicle routing problem1. European Journal of operational research, 121(2), 420-434.

[32] Marinković, N., Vitale, K., Holcer, N. J., Džakula, A., & Pavić, T. (2008). Management of hazardous medical waste in Croatia. Waste management, 28(6), 1049-1056.

[33] Abdulla, F., Qdais, H. A., & Rabi, A. (2008). Site investigation on medical waste management practices in northern Jordan. Waste management, 28(2), 450-458.

[34] Windfeld, E. S., & Brooks, M. S. L. (2015). Medical waste management–A review. Journal of environmental management, 163, 98-108.

[35] Alshraideh, H., & Qdais, H. A. (2017). Stochastic modeling and optimization of medical waste collection in Northern Jordan. Journal of Material Cycles and Waste Management, 19(2), 743-753.

[36] Mmereki, D., Baldwin, A., Li, B., & Liu, M. (2017). Healthcare waste management in Botswana: storage, collection, treatment and disposal system. Journal of Material Cycles and Waste Management, 19(1), 351-365.

[37] Baldacci, R., Mingozzi, A., & Roberti, R. (2012). Recent exact algorithms for solving the vehicle routing problem under capacity and time window constraints. European Journal of Operational Research, 218(1), 1-6.

[38] Huang, B. (2006). GIS-based route planning for hazardous material transportation. Journal of Environmental Informatics, 8(1).

[39] TUIK (2016). Turkish Statistical Institute URL http://www.tuik.gov.tr/PreHaberBultenleri.do?id=24871 (accessed 08.03.2018)

[40] Koç, Ç., Erbaş, M., & Ozceylan, E. (2018). A rich vehicle routing problem arising in the replenishment of automated teller machines. An International Journal of Optimization and Control: Theories & Applications (IJOCTA), 8(2), 276-287.

[41] Özceylan, E., Uslu, A., Erbaş, M., Çetinkaya, C., & İşleyen, S. K. (2017). Optimizing the location-allocation problem of pharmacy warehouses: A case study in Gaziantep. An International Journal of Optimization and Control: Theories & Applications (IJOCTA), 7(1), 117-129.

***Suleyman Mete**, Ph.D., is an assistant professor employed at Industrial Engineering Department, Faculty of Engineering, Munzur University in Turkey. He received his Ph.D. from Gaziantep University Industrial Engineering in 2017. His research interests include optimization, assembly line balancing, disassembly line balancing, mathematical modelling, heuristics and supply chain network design.*

***Faruk Serin** Ph.D. is an assistant professor employed at Computer Engineering Department, Faculty of Engineering, Munzur University in Turkey. He received his Ph.D. from Inonu University Computer Engineering in 2017. His research interests include optimization, graph theory, medical image processing, software development and intelligent transportation.*

Appendix

Table A1. Details of each collection center (health institutions)

No	Coordinates of each collection center	Population	District	No	Coordinates of each collection center	Population	District
1	39.092656, 39.534555	6202	Tunceli	86	38.563042, 40.133517	7285	Arıcak
2	39.107586, 39.548470	6202	Tunceli	87	38.526074, 40.024725	7285	Arıcak
3	39.108177, 39.549838	6202	Tunceli	88	38.572833, 38.825329	6147	Baskil
4	39.105014, 39.537221	6202	Tunceli	89	38.469615, 38.897301	6147	Baskil
5	39.085395, 39.537456	6202	Tunceli	90	38.391986, 39.668712	3491	Maden
6	39.071738, 39.531108	6202	Tunceli	91	38.393291, 39.669636	3491	Maden
7	39.056797, 38.915608	3756	Çemişgezek	92	38.391711, 39.667650	3491	Maden
8	39.063197, 38.910971	3756	Çemişgezek	93	38.449708, 39.306255	7759	Sivrice
9	39.107788, 39.219301	7041	Hozat	94	38.461784, 39.862198	6233	Alacakaya
10	39.017486, 39.604064	7831	Mazgirt	95	38.791417, 38.747895	6229	Keban
11	39.181128, 39.828766	2886	Nazımiye	96	38.944260, 38.715064	2537	Ağın
12	39.358613, 39.213172	5970	Ovacık	97	38.306264, 38.249966	9447	Malatya
13	38.868046, 39.325471	5488	Pertek	98	38.338283, 38.246168	9447	Malatya
14	38.864925, 39.326670	5488	Pertek	99	38.343494, 38.272933	9447	Malatya
15	39.486677, 39.899012	3065	Pülümür	100	38.343520, 38.275126	9447	Malatya
16	38.893839, 40.512630	17546	Bingöl	101	38.347269, 38.281832	9447	Malatya
17	38.896886, 40.508926	17546	Bingöl	102	38.349641, 38.282068	9447	Malatya
18	38.903743, 40.493254	17546	Bingöl	103	38.363603, 38.285414	9447	Malatya
19	38.894091, 40.493612	17546	Bingöl	104	38.349209, 38.303028	9447	Malatya
20	38.884586, 40.488033	17546	Bingöl	105	38.353717, 38.300896	9447	Malatya
21	38.884425, 40.499017	17546	Bingöl	106	38.348958, 38.317117	9447	Malatya
22	38.885775, 40.503229	17546	Bingöl	107	38.349523, 38.320828	9447	Malatya
23	38.888507, 40.516567	17546	Bingöl	108	38.349181, 38.322555	9447	Malatya
24	38.896382, 40.515534	17546	Bingöl	109	38.349161, 38.322899	9447	Malatya
25	38.748457, 40.552280	11204	Genç	110	38.347355, 38.329214	9447	Malatya
26	38.750893, 40.559666	11204	Genç	111	38.346763, 38.330915	9447	Malatya
27	38.752232, 40.562885	11204	Genç	112	38.345762, 38.329923	9447	Malatya
28	38.960349, 41.039450	11043	Solhan	113	38.363641, 38.348608	9447	Malatya
29	38.968884, 41.054195	11043	Solhan	114	38.363067, 38.346979	9447	Malatya
30	38.968853, 41.057233	11043	Solhan	115	38.339852, 38.429746	9447	Malatya
31	39.184484, 40.822721	5103	Karlıova	116	38.338702, 38.218910	9447	Malatya
32	39.166470, 40.859766	5103	Karlıova	117	38.338702, 38.241226	9447	Malatya
33	39.160725, 40.892433	5103	Karlıova	118	38.322543, 38.276932	9447	Malatya
34	39.148974, 40.872563	5103	Karlıova	119	38.342497, 38.260033	9447	Malatya
35	39.133302, 40.851683	5103	Karlıova	120	38.333575, 38.289083	9447	Malatya
36	39.297461, 41.012747	5103	Karlıova	121	38.361435, 38.282608	9447	Malatya
37	39.231998, 40.474007	4110	Adaklı	122	38.371177, 38.251983	9447	Malatya

38	39.228551, 40.482647	4110	Adaklı	123	38.341261, 38.327933	9447	Malatya
39	39.311165, 40.350023	5097	Kığı	124	38.354986, 38.307458	9447	Malatya
40	39.434421, 40.545510	2825	Yedisu	125	38.365277, 38.312533	9447	Malatya
41	39.225182, 40.068196	1928	Yayladere	126	38.353613, 38.331258	9447	Malatya
42	38.665451, 39.176808	13271	Elazığ	127	38.354711, 38.335983	9447	Malatya
43	38.668440, 39.215796	13271	Elazığ	128	38.372137, 38.318308	9447	Malatya
44	38.675805, 39.218482	13271	Elazığ	129	38.380643, 38.361883	9447	Malatya
45	38.681706, 39.205488	13271	Elazığ	130	38.341398, 37.964915	3257	Akçadağ
46	38.675665, 39.218072	13271	Elazığ	131	38.344551, 37.971046	3257	Akçadağ
47	38.675526, 39.222176	13271	Elazığ	132	38.341889, 37.965867	3257	Akçadağ
48	38.675710, 39.224222	13271	Elazığ	133	38.345567, 37.966340	3257	Akçadağ
49	38.676096, 39.226041	13271	Elazığ	134	38.284262, 38.047939	3257	Akçadağ
50	38.676552, 39.226463	13271	Elazığ	135	38.257135, 37.939866	3257	Akçadağ
51	38.680583, 39.230025	13271	Elazığ	136	38.441390, 37.869899	3257	Akçadağ
52	38.682097, 39.226022	13271	Elazığ	137	38.439853, 37.860979	3257	Akçadağ
53	38.683806, 39.227159	13271	Elazığ	138	39.042819, 38.489391	5054	Arapgir
54	38.687404, 39.226380	13271	Elazığ	139	39.043341, 38.487801	5054	Arapgir
55	38.681304, 39.256234	13271	Elazığ	140	38.782882, 38.265986	7350	Arguvan
56	38.686995, 39.268710	13271	Elazığ	141	38.426661, 38.366989	61413	Battalgazi
57	38.690172, 39.274589	13271	Elazığ	142	38.414407, 38.363186	61413	Battalgazi
58	38.656429, 39.147293	13271	Elazığ	143	38.425235, 38.367706	61413	Battalgazi
59	38.663050, 39.171864	13271	Elazığ	144	38.420140, 38.311554	61413	Battalgazi
60	38.668174, 39.184377	13271	Elazığ	145	38.422173, 38.307073	61413	Battalgazi
61	38.672751, 39.181227	13271	Elazığ	146	38.567572, 37.488809	12755	Darende
62	38.677054, 39.162677	13271	Elazığ	147	38.558679, 37.490319	12755	Darende
63	38.667702, 39.196292	13271	Elazığ	148	38.103632, 37.889787	9659	Doğanşehir
64	38.668448, 39.204698	13271	Elazığ	149	38.094143, 37.876737	9659	Doğanşehir
65	38.666832, 39.209029	13271	Elazığ	150	38.014520, 37.978566	9659	Doğanşehir
66	38.672330, 39.208134	13271	Elazığ	151	38.162058, 37.866300	9659	Doğanşehir
67	38.672774, 39.208180	13271	Elazığ	152	38.312752, 39.038298	1327	Doğanyol
68	38.659779, 39.248515	13271	Elazığ	153	38.312919, 39.037713	1327	Doğanyol
69	38.669269, 39.234170	13271	Elazığ	154	38.283361, 39.002510	1327	Doğanyol
70	38.669867, 39.254512	13271	Elâzığ	155	38.809920, 37.940828	5578	Hekimhan
71	38.675446, 39.243989	13271	Elazığ	156	38.816863, 37.930921	5578	Hekimhan
72	38.684490, 39.227117	13271	Elazığ	157	38.819480, 37.932717	5578	Hekimhan
73	38.684306, 39.226773	13271	Elazığ	158	38.358658, 38.662539	2566	Kale
74	38.594938, 39.339688	13271	Elazığ	159	38.409407, 38.751558	2566	Kale
75	38.722280, 39.857082	7865	Kovancılar	160	38.879655, 37.670062	3604	Kuluncak
76	38.721591, 39.864926	7865	Kovancılar	161	38.945336, 37.558323	3604	Kuluncak
77	38.719497, 39.870589	7865	Kovancılar	162	38.196186, 38.869032	4797	Pütürge
78	38.726224, 39.877146	7865	Kovancılar	163	38.198197, 38.872848	4797	Pütürge
79	38.767172, 39.968681	7865	Kovancılar	164	38.280418, 38.904296	4797	Pütürge
80	38.948427, 40.050371	9235	Karakoçan	165	38.594554, 38.179979	4243	Yazıhan
81	38.955583, 40.040303	9235	Karakoçan	166	38.595805, 38.180568	4243	Yazıhan
82	38.955853, 40.036226	9235	Karakoçan	167	38.598539, 38.180332	4243	Yazıhan
83	38.695150, 39.926747	6226	Palu				
84	38.695564, 39.931961	6226	Palu				
85	38.693875, 39.930698	6226	Palu				