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Research Article

Solid Waste Handling Scenarios, Management and Economic Study in Erbil City

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Abstract: Solid waste management has become an important issue for developing countries. Solid waste management is also a weighty problem in Erbil City, Kurdistan Region, Iraq. To date, weak points have been observed in Erbil City, particularly in the handling and transportation of municipal solid waste. Consequently, this issue affects the environment, human health, management, finances, and aesthetics of the city. This research focused on handling scenarios, management, and an economic study of solid waste in New Zanco Village, Erbil City. Data on the quantity and generation rate (GR) of solid waste and current routes for solid waste collection were collected directly. Additionally, truck volume, handling options, and economic subjects were studied. Untimorous software was applied to find the optimum routes for solid waste collection in the studied area. Results revealed that the average GR for 48 samples was 1.114 kg/capita/day. The minimum and maximum values were 0.24 kg/capita/day and 3.28 kg/capita/day, respectively. The optimized capacity for the trucks was 7 m^3. The number of pick-up locations per truck was 92. From the current waste collection route, waste is collected in eight cycles each week and the total weekly travel length equals 321.12 km. Based on the results obtained from OptimoRoute software, waste is collected in seven cycles and the total weekly travel length equals 294.03 km. The waste collection will reduce the 27.09 km of travel length in each week, which equals a reduction of 8.43% of the total distance. The operation cost will be reduced by 8.43% per week. Additionally, the total yearly travel length will be reduced by 1,300.32 km and the total yearly cost will be reduced by about $2,730.67.

***Keywords*:** economy, Erbil City, generation rate, management, solid waste, treatment

1. Introduction

Solid waste collection and management are crucial aspects of maintaining a clean and healthy environment. Proper solid waste management involves the collection, transportation, and disposal of waste in a way that is environmentally friendly and safe for public health. Inadequate solid waste management and population growth are causing problems and creating many health and environmental issues [1]. The annual production of solid waste has increased significantly due to population growth, urbanization, and economic development [2]. In Iraq, most municipal solid waste (MSW) is landfilled, and waste treatment facilities such as composting and waste incineration are rarely used. Traditional waste disposal methods are associated with problems such as air pollution, groundwater contamination, soil contamination, and the release of harmful gases, which endanger the infrastructure of communities [3]. The quantity and composition of MSW differ from one country to another, from one region to another, from one neighborhood to another, and even from

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one community to another [4]. Developed countries generate more than developing countries because of their higher waste per capita and also because of their higher consumption rates [5]. One of the most critical issues in environmental and natural resource protection is waste management. Vučijak et al. [6] investigated the dependability of multi-criteria decision methodologies for selecting the best MSW management (MSWM) scenario among six solution alternatives, achieving optimal results for a city in Bosnia-Herzegovina. Rizwan et al. [7] created a Mixed Integer Nonlinear Programming (MINLP) model for optimizing the MSW path from generation points to valuable product production. The well-known waste treatment technologies that generate bioethanol and electricity are economically analyzed in this model. Ayvaz-Cavdaroglu et al. [8] analyzed the MSWM of Istanbul by applying the techniques of mathematical programming methodology. The results of the study emphasized the importance of material recovery and incineration facilities to improve profitability and minimize environmental side effects.

MSWM is related to the collection, transportation, and treatment of MSW. Erbil City, Kurdistan Region, Iraq has been developed in the last two decades. The population, projects, and industrial and commercial areas increased in the city. Of course, the generation rate (GR) of MSW changed as well. All types of waste are mixed, and there is no separation of waste at the source. MSW in Erbil City is collected and transported by the private sector using compactor trucks. The drivers of compactor trucks and the crew are responsible for the selection of routes and paths for the MSW collection in different areas. Traditional and random methods for MSW collection in Erbil City lead to a waste of time, fuel, human energy, and money. Therefore, scientific study for route selection for MSW collection is essential in Erbil City and other cities in the Kurdistan Region. Consequently, the objectives of this research were to: (1) study the quantity of the generated waste directly in front of the houses; (2) examine solid waste handling scenarios and management; and (3) test an economic study for waste collection and transportation in Erbil City. In the extant literature, there are no documented works and research on direct measuring of GR for different families, providing various scenarios for MSW pick-up, presenting the optimal route for MSW collection, and presenting an economical study in Erbil City or in Kurdistan Region, Iraq.

2. Materials and methods

2.1 *Study area*

New Zanco Village is located on the left side of the Erbil-Kirkuk main road in Erbil City. New Zanco Village is approximately 7 km from Erbil City Center (Figure 1). The geographical coordinates are 36° 08’ 27” N and 44° 01’ 49” E. It has a total of 1,000 houses and a population of about 5,000 inhabitants, assuming a 5-person resident in each house. It consisted of four zones, namely, A, B, C, and D.

Figure 1. Satellite image for New Zanco Village in Erbil City

2.2 *Data collection and analysis*

A compactor truck collected waste produced by homes in New Zanco Village (Figure 2). Solid waste is collected via private companies in cooperation with the Directorate of Municipality of Erbil City. The crew size for each vehicle comprises a driver and two workers. A normal plan decided by the company for solid waste collection without any previous scientific study. Six days per week, solid waste is collected in this village. For each house, the produced waste will be collected two (sometimes three) times a week. All wastes are mixed without any prior separation. Currently, scavengers collect discarded cartons, plastic, and metals in front of houses. Later, they transport these recyclable materials to some private locations in Erbil City. Normally, the produced wastes comprise organic or food waste, garden trimmings, glasses, clothes, plastic, paper, cartons, metals, plastic bags, etc.

Data was collected at New Zanco Village through cooperation with the Directorate of Municipality for Services and Environment in Erbil City. Three houses were selected in each zone (i.e., A, B, C, and D). Consequently, the total number of houses was 12. Four different samples from each house were gathered. 48 samples were collected. To find the quantity of the produced solid waste, trash cans were weighed before and after unloading the waste on the compactor truck (Figure 2). Additionally, the number of people in the house and the time between the previous and current solid waste collections were reported. GR was found for the selected houses using Equation 1 [9-11]:

$$\mathrm{GR} = \frac{\text{Weight of collected solid waste (g)}}{\text{Population} \times \text{Duration (day)}} \tag{1}$$

For further study and checking the GR of the solid waste, extra samples were collected in groups C and Rasty Q.

Figure 2. Solid waste collection at New Zanco Village (August 2021)

2.3 *Paths for solid waste collection*

Normal paths for solid waste collection in the New Zanco Village were registered. Additionally, new paths for solid waste collection were examined. Proposed routes were based on collection time, fuel consumption, delay, and distance. OptimoRoute software was applied for finding optimum routes for solid waste collection in the studied area. This software will design a new route based on the average waste per house and the maximum capacity of the truck [12]. The average waste per house can be calculated by knowing GR and the average number of persons per house, as well as the capacity of the truck can be determined using the following equation [13]:

$$V_T = \frac{V_p}{r \times t_p}\left[\frac{H}{N_d} - \frac{2 \times X}{S} - 2 \times t_d - t_u - \frac{B}{N_d}\right] \tag{2}$$

where V_T is the volume of solid waste carried per trip by truck at a mean density (the density that results after the waste has been compacted in the truck; m^3), V_p is the volume of solid waste per pickup location or stop (m^3/stop), r is the compaction ratio (ratio of the density after compaction to that before compaction), t_p is the mean time per collection stop plus the time in the meantime to reach the next stop (hours), H is the length of the working day (hours), N_d is the number of trips to the disposal site per day, X is the one-way distance to a disposal site (km), S is the average haul speed to and from the disposal site (km/hours), t_d is the one-way delay time (hours/trip), t_u is the unloading time at the disposal site (hours/trip), and B is the off-route time per day (hours). The t_p value can be estimated from the empirical equation [13].

$$t'_p = 0.72 + 0.18 \times C_n + 0.014\ (pRH) \tag{3}$$

where t'_p is the mean time per collection stop plus the time in the meantime to reach the next stop (min/stop), C_n is the mean number of containers at each pickup location, and pRH is the number of rear-of-house pickup locations (%). To convert t'_p to t_p, it must be divided by 60 (min/hour).

2.4 *SW collection routes*

In the present research, both practical and software aspects of MSW collection at New Zanco Village were studied. Direct MSW collection routes were applied through normal daily truck routes. Meanwhile, OptimaRoute software was applied to find the optimum routes for the MSW collection. OptimoRoute is a routing optimization software developed in 2012 in the United States and utilized by numerous organizations from various business areas around the world [12].

3. Results and discussions

3.1 *Solid waste GR*

The collected solid waste in the assigned houses in the New Zanco Village is shown in Table 1. The average GR for 48 samples was 1.114 kg/capita/day. The minimum and maximum values were 0.24 kg/capita/day and 3.28 kg/capita/day, respectively. On the other hand, GR in another house in New Zanco Village was 1.002 kg/capita/day (Table 2). It can be noticed that the results are close to each other. Additionally, GR in a house at Rasty Q, which is located outside of the study area, was 0.714 kg/capita/day (Table 3). Lifestyle, income, awareness, and social factors are affecting the GR of MSW [14]. Aziz [9] stated that the GR for 72 domestic solid waste samples was 0.654 kg/capita/day. In addition, Aziz et al. [15] found that the quantity of daily MSW generation in Erbil City was around 1.27 kg/capita for the population of 1,118,187 in 2016. It can be noticed that GR in Erbil City has increased in the last decade. Ojeda-Benítez et al. [16] studied the GR of three categories of families (nuclear, extended, and monoparental). They reported that the per capita daily waste generation of the nuclear family was 1.10 kg, the extended family produced 0.782 kg, and the monoparental family produced 1.35 kg. The GR range of 0.685 kg/capita/day for Cork City to 2.548 kg/capita/day for Denmark was published by Kiely [17]. Commonly, the results of the current work agree with the published works [16, 17]. Aziz [10] studied domestic solid waste GR during 140 continuous days in Erbil City; the author stated that GR for 140 samples was 0.915 kg/capita/day. Additionally, he examined variations in GR during each day of the week. Aziz [10] also reported that domestic solid waste from 2007 to 2021 increased by 147.55%.

Table 1. Solid waste data collection for New Zanco Village

No	House no.	Date	Weight of waste plus container (kg)	Weight of container (kg)	Weight of waste (kg)	Duration (days)	No. of people	GR (kg/ capita/day)	Notes
1	C	02 August 2021	18.9	7.1	11.8	2	5	1.18	C-192
2	C	02 August 2021	25.75	3.8	21.95	2	4	2.74	C-190
3	C	02 August 2021	16.5	7.35	9.15	2	3	1.53	C-194
4	D	02 August 2021	12.3	7.5	4.8	2	4	0.6	D-305
5	D	02 August 2021	14.85	7.15	7.7	2	3	1.28	D-301
6	D	02 August 2021	20.9	7.9	13	2	5	1.3	D-280
7	A1	03 August 2021	40.85	8.65	32.2	2	7	2.3	A-17
8	A2	03 August 2021	12.2	8.5	3.7	2	7	0.26	A-15
9	A3	03 August 2021	17.6	5.3	12.3	2	6	1.03	A-9
10	B1	03 August 2021	11.95	2.6	9.35	2	4	1.17	B-249
11	B2	03 August 2021	25.65	7.85	17.8	2	5	1.78	B-174
12	B3	03 August 2021	10.25	5.2	5.05	2	5	0.51	B-255
13	C1	04 August 2021	12.35	7.35	5	2	3	0.83	C-194
14	C2	04 August 2021	10.5	7.1	3.4	2	5	0.34	C-192
15	C3	04 August 2021	10.9	3.8	7.1	2	4	0.89	C-190
16	D1	04 August 2021	15.5	7.85	7.65	2	5	0.77	D-280
17	D2	04 August 2021	8.6	7.15	1.45	2	3	0.24	D-301
18	D3	04 August 2021	13	7.5	5.5	2	4	0.69	D-305
19	A1	05 August 2021	25.1	8.8	16.3	2	7	1.16	A-17
20	A2	05 August 2021	12.8	8.4	4.4	2	7	0.31	A-15
21	A3	05 August 2021	14.9	5.3	9.6	2	6	0.8	A-9
22	B1	05 August 2021	22.65	2.4	20.25	2	4	2.53	B-249
23	B2	05 August 2021	12.75	7.85	4.9	2	5	0.49	B-174
24	B3	05 August 2021	17.65	5.5	12.15	2	5	1.22	B-255
25	C	07 August 2021	14.95	6.45	8.5	2	5	0.85	C-192
26	C	07 August 2021	18.3	3.5	14.8	2	4	1.85	C-190
27	C	07 August 2021	26.6	6.9	19.7	2	3	3.28	C-194
28	D	07 August 2021	17.2	7.5	9.7	2	4	1.21	D-305
29	D	07 August 2021	17.4	5.9	11.5	2	3	1.92	D-301
30	D	07 August 2021	17.15	7.8	9.35	2	5	0.94	D-280
31	A1	08 August 2021	22.9	8.7	14.2	2	7	1.01	A-17
32	A2	08 August 2021	25.4	8.85	16.55	2	7	1.18	A-15
33	A3	08 August 2021	23.15	5.35	17.8	2	6	1.48	A-9
34	B1	08 August 2021	14.15	2.6	11.55	2	4	1.44	B-249
35	B2	08 August 2021	13.85	7.95	5.9	2	5	0.59	B-174
36	B3	08 August 2021	12.85	5.45	7.4	2	5	0.74	B-255
37	C1	09 August 2021	20.7	6.85	13.85	2	3	2.31	C-194
38	C2	09 August 2021	11.5	6.35	5.15	2	5	0.52	C-192

Table 1. *Continued*

No	House no.	Date	Weight of waste plus container (kg)	Weight of container (kg)	Weight of waste (kg)	Duration (days)	No. of people	GR (kg/ capita/day)	Notes
39	C3	09 August 2021	9.1	3.5	5.6	2	4	0.7	C-190
40	D1	09 August 2021	10.4	7.8	2.6	2	5	0.26	D-280
41	D2	09 August 2021	7.55	5.95	1.6	2	3	0.27	D-301
42	D3	09 August 2021	15.9	7.65	8.25	2	4	1.03	D-305
43	A1	10 August 2021	33.75	8.6	25.15	2	7	1.8	A-17
44	A2	10 August 2021	15.6	8.55	7.05	2	7	0.5	A-15
45	A3	10 August 2021	18.9	5.4	13.5	2	6	1.13	A-9
46	B1	10 August 2021	12.8	2.6	10.2	2	4	1.28	B-249
47	B2	10 August 2021	14.15	7.85	6.3	2	5	0.63	B-174
48	B3	10 August 2021	10.25	5.5	4.75	2	5	0.48	B-255

Table 2. Extra solid waste collection data at New Zanco Village

No.	Location	Date	No. of people	Duration (day)	Mass (kg)	GR (kg/capita/day)
1	New Zanco Village	28 June 2021	2	1	1.610	0.805
2	New Zanco Village	29 June 2021	2	1	1.430	0.715
3	New Zanco Village	30 June 2021	2	1	2.005	1.003
4	New Zanco Village	01 July 2021	2	1	3.370	1.685
5	New Zanco Village	02 July 2021	2	1	1.600	0.800
6	New Zanco Village	03 July 2021	2	1	3.600	1.800
7	New Zanco Village	04 July 2021	2	1	4.20	0.210

Table 3. Further solid waste collection data in Rasty Q

No.	Location	Date	No. of people	Duration (day)	Mass (kg)	GR (kg/capita/day)
1	Rasty Q	06 November 2021	5	1	2.860	0.572
2	Rasty Q	07 November 2021	5	1	3.950	0.790
3	Rasty Q	08 November 2021	5	1	3.800	0.760
4	Rasty Q	09 November 2021	5	1	2.700	0.540
5	Rasty Q	10 November 2021	5	1	4.300	0.860
6	Rasty Q	11 November 2021	5	1	1.850	0.370
7	Rasty Q	12 November 2021	5	1	5.550	1.110

3.2 *Determination of MSW truck capacity*

Truck capacity is one of the factors in the solid waste collection. Other parameters are crew size, labor, and capital costs. The following calculation illustrates the estimated volume of solid waste that a truck must be able to carry.

To calculate the volume of the truck, data collection shows that each stop typically has four cans, and about 10% of the stops are backyard pickups.

$$t_p = \frac{t'p}{60} = \frac{158 \text{ min}}{60} = 0.0263 \text{ hours}$$

$$t'_p = 0.72 + 0.18(4) + 0.014(10) = 1.58 \text{ min/stop}$$

From the collected data, the volume of four solid waste cans can be calculated using Equation 4:

$$V_p(\text{m}^3) \text{ for four cans} = \frac{\text{Weight (kg)}}{\text{Desity}\left(\frac{\text{kg}}{\text{m}^3}\right)} \tag{4}$$

As data collection shows that the GR is 1.114 kg/capita/day, and the density is 175.72 kg/m^3 [9], the volume of four solid waste cans is:

$$V_p(\text{m}^3) \text{ for four cans} = \frac{5\frac{\text{people}}{\text{family}} \times (1.114 \text{ kg/capita/day}) \times 4 \text{ cans}}{175.72\left(\frac{\text{kg}}{\text{m}^3}\right)} = 0.1268 \text{ m}^3$$

These values were then applied to Equation 2: r = 2 [18], H = 8 hours, N_d = 2 (from interview), X = 26 km (from data collection), S = 70 km/hours (from data collection, Table 4), t_d = 15 min (from interview), t_u = 6 min [13], and B = 30 min (from interview).

$$V_T = \frac{0.1268}{2 \times 0.0236}\left[\frac{8}{2} - \frac{2 \times 26}{70} - 2 \times \left(\frac{15}{60}\right) - \frac{6}{60} - \frac{0.5}{2}\right] = 2.6864\left[2.4071\right] = 6.4665 \text{ m}^3$$

It is suggested to use trucks with a capacity of 7 m^3 for the collection of solid waste at the New Zanco Village Area. Currently, solid waste is collected using compactor trucks with a capacity of 8 m^3. The yielded truck capacity value of 7 m^3 is very close to the existing capacity of the truck.

The number of pickup locations that a certain crew can handle is calculated by dividing the available time after the haul by the average pickup time. The number of pickup locations per load (N_p) can be calculated using Equation 5:

$$N_p = \frac{\left[\frac{H}{N_d} - \frac{2 \times X}{S} - 2 \times t_d - t_u - \frac{B}{N_d}\right]}{t_p} \tag{5}$$

$$N_p = \frac{\left[\frac{8}{2} - \frac{2 \times 26}{70} - 2 \times \left(\frac{15}{60}\right) - \frac{6}{60} - \frac{0.5}{2}\right]}{0.0263} = \frac{2.4071}{0.0263} = 91.52$$

Hence, in this study, the value of N_p is 92.

3.3 *Solid waste collection scenario and management*

Solid waste management includes collecting, treating, and disposing of solid materials. This study focused on waste collection, and the current waste collection system was investigated, then new waste collection methods were proposed.

The existing collection strategy and its frequency are shown in Table 4. The current collection system in the New

Zanco Village is door-to-door collection. The waste produced by each house will be collected three times per week using an 8-m³ truck. The average pick-up period is 27.17 seconds per house, and on average, on each trip, 2887.27 kg of waste have been collected. The collected data clearly showed that the current waste collection frequency was not well organized and the collection was not uniform because on Saturday and Sunday, the waste was collected by two cycles per day, while on Monday, Tuesday, Wednesday, and Thursday, the waste was collected by one cycle per day. Each week, waste is collected in eight cycles and the total weekly travel length equals 321.12 km. The current waste collection route is shown in Figure 3.

Based on the results obtained in the current situation, the researchers tried to propose a new route and a new collection scenario. The proposed route was determined by using OptimoRoute.

The results from Table 4 were entered in OptimoRoute to calculate the shortest path. The input data includes GR = 0.74 kg/capita/day (from data collection, Table 4); average waste per house = 3.7 kg/day (5 people/family × 0.74 kg/capita/day); average waste collection period per house = 27.17 sec; and vehicle capacity = 3,720 kg.

Table 4. Data from field observation of the New Zanco Village door-to-door collection system

Cycle no.	Date	Zone	Route length (km)	No. of house	Collection start (hours: min)	Collection end (hours: min)	Collection period (hours: min)	Collection period (sec/ house)	Weight of waste (kg)	kg/ house. cycle	Duration between cycles (days)	kg/ house. day	GR (kg/ capita/ day)
1	Monday, Aug 2, 2021	D	39.76	352	09:10	11:22	02:12	21.68	2,160	6.14	2	3.07	0.64
2	Monday, Aug 2, 2021	C	39.76	234	12:43	14:32	01:49	22.92	1,840	7.86	2	3.93	0.81
3	Tuesday, Aug 3, 2021	A & B	39.93	406	07:43	10:32	02:49	22.08	3,240	7.98	2	3.99	0.83
4	Wednesday, Aug 4, 2021	C & D	43.11	586	07:23	11:51	04:28	14.01	3,800	6.48	2	3.24	0.67
5	Thursday, Aug 5, 2021	A & B	39.93	406	07:22	10:40	03:18	28.2	3,140	7.73	2	3.87	0.8
6	Saturday, Aug 7, 2021	D	39.76	352	07:25	12:15	04:50	46.02	4,140	11.76	3	3.92	0.81
7	Saturday, Aug 7, 2021	C	39.76	234	13:10	14:57	01:47	22.62	1,920	8.21	3	2.74	0.57
8	Sunday, Aug 8, 2021	B	37.76	268	07:35	09:55	02:20	29.55	2,880	10.75	3	3.58	0.74
9	Sunday, Aug 8, 2021	A	37.76	138	11:28	13:05	01:37	35.74	1,380	10	3	3.33	0.69
10	Monday, Aug 9, 2021	C & D	43.11	586	07:26	11:45	04:19	25.74	4,080	6.96	2	3.48	0.72
11	Tuesday, Aug 10, 2021	A & B	39.93	406	07:44	11:26	03:42	30.33	3,180	7.83	2	3.92	0.81
	Average							27.17	2,887.27			3.55	0.74

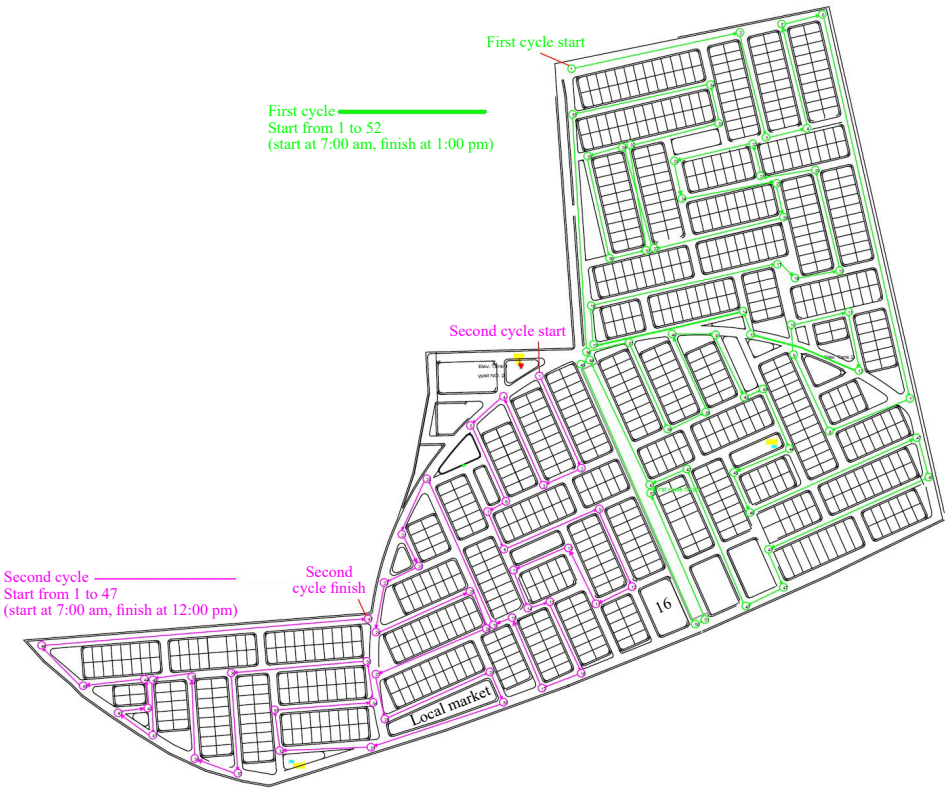

Figure 3. Current waste collection route

The new waste collection schedule was calculated by OptimoRoute and the results are demonstrated in Table 5. Every Saturday, Monday, and Wednesday, waste in New Zanco Village can be collected in two cycles per day and the length of the first cycle will be 40.5 km, as shown in Figures 4 and 5. Meanwhile, the second cycle will be 42.01 km, as shown in Figures 5 and 6. Every Thursday, the waste in New Zanco Village can be collected in one cycle and the length will be 46.5 km. The total weekly travel length will be 294.03 km; this result indicates that the proposed waste collection will reduce the 27.09 km travel length each week.

Table 5. Proposed waste collection schedule

Collection no.	Day	Cycle no.	Route length (km)	No. of house	Collection start (hours: min)	Collection end (hours: min)	Collection period (hours: min)	Weight of waste (kg)
1	Saturday	1	40.5	496	8:00	11:50	3:50	3,720
2	Saturday	2	42.01	496	13:00	16:52	3:52	3,720
3	Monday	1	40.5	496	8:00	11:50	3:50	3,720
4	Monday	2	42.01	496	13:00	16:52	3:52	3,720
5	Wednesday	1	40.5	496	8:00	11:50	3:50	3,720
6	Wednesday	2	42.01	496	13:00	16:52	3:52	3,720
7	Thursday	1	46.5	992	8:00	15:36	7:36	3,720

Figure 4. Proposed waste collection (Cycle 1)

Figure 5. Proposed waste collection to depot (Cycles 1 and 2)

Figure 6. Proposed waste collection (Cycle 2)

3.4 *Economic study*

The sum of all expenses involved in running a single vehicle is normally known as the vehicle operating cost. Vehicle operating costs are classified into three categories: standing costs, running costs, and overhead costs. Standing and running costs are two variables used to calculate transportation costs. Standing cost is calculated and stable, while running cost is divided into five categories, namely tire, fuel, maintenance, labor, and total variable cost [19]. From the current waste collection route, each week, waste is collected in eight cycles and the total weekly travel length equals 321.12 km. Based on the results obtained from OptimoRoute, each week, waste is collected in seven cycles and the total weekly travel length equals 294.03 km. The waste collection will reduce 27.09 km of travel length each week, which equals a reduction of 8.43% of the total distance, which means that the operating cost will reduce by 8.43% per week. As well, the total yearly travel length will be reduced by 1,300.32 km and the total yearly cost will be reduced by about $2,730.67 per year which is determined based on the data obtained during the interview, in which the average operation cost equals $2.1 per km, as shown in Table 6.

Table 6. Costs per kilometer for the garbage truck

Description	Cost rate ($/km)
Depreciation rate	0.59
Repair, maintenance, and tires	0.28
Fuel consumption	0.56
Costs such as drivers and workers	0.67
Total	2.1

4. Conclusion

This study aimed to investigate the current status of solid waste management and improve it by using the most modern software. Firstly, the GR was determined, which is equal to 1.114 kg/capita/day. GR increased when compared with previous works. It suggested using trucks with a capacity of 7 m^3 for the collection of solid waste at the New Zanco Village Area. The number of pick-up locations per truck was 92. From the current waste collection route, each week, waste is collected in eight cycles and the total weekly travel length equals 321.12 km. The OptimoRoute program for best solid waste collection resulted in saving one cycle of solid waste collection per week, 27.09 km of distance per week, and a reduction of operational cost by 8.43%. Additionally, optimizing solid waste collection routes led to savings of $2,730.67 per year. Consequently, optimizing solid waste collection routes is essential for all sectors of the city.

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Conflict of interest

There is no conflict of interest in this study.

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