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AN ENGINEERED SYSTEM FOR SOLID WASTE COLLECTION IN SAMARU, ZARIA, NIGERIA

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ABSTRACT

Solid waste includes all materials that are firm and stable in shape including semisolid materials that are no longer considered of sufficient value to be retained in a given setting. Solid waste generation rates and patterns within the study area were mapped out through GPS, Google route software, AutoCAD, ArcGIS, GPS, Route optimization software, measuring tape, Marker, Containers of equal volume, Record book, Calculator, and Stopwatch. Eleven sacks were used to collect solid waste from eleven different households daily within three months of the wet and dry seasons of the year. The highest average volume of solid waste generated per household per week in Samaru was in the dry season =0.25 m^3. The dry season witnesses a substantial volume of 0.206 m^3 for garbage organic materials, constituting 66.45% of the total composition. In the wet season, this volume remains significant at 0.104 m^3, accounting for 61.18% of the total composition. The highest percentage of organic materials (garbage) during both seasons suggests a need for improved organic waste management. The minimum allowable capacity of the solid waste collection containers for the designed system is 10 m^3 considering a minimum of two containers per city block.

Keywords: Engineered system, Solid waste collection, Collection route, Samaru Zaria

INTRODUCTION

Solid waste includes all materials that are firm and stable in shape including semisolid materials that are no longer considered of sufficient value to be retained in a given setting (Howard 1985). According to the United States Environmental Protection Agency (EPA), (2021). Solid waste refers to any discarded, abandoned, or unwanted material in a solid state, excluding hazardous waste and liquid or gaseous waste. It encompasses various types of non-liquid waste generated by residential, commercial, industrial, and institutional activities.

Irrespective of the level of civilization of man, no matter his occupation or social status, he generates solid waste. However, the rate of generation and the method of generation varies. Our daily activities generate waste which requires to be properly managed to protect human health and the environment while enhancing aesthetics. This is predominantly evident in urban settlements, which generate large quantities of solid, liquid, and gaseous waste due to the high human population. The impacts of poor solid waste management within urban settlements, particularly cities and big municipalities can be disastrous. As such, there is a need for proper knowledge to enhance efficient waste management (World Health Organization 2020).

The quantity and general composition of solid waste materials that are generated are of critical importance in the design and operation of solid waste collection system. There are unofficial dumpsites within the Samaru area because of the absence of a solid waste collection system, examples include; dumpsite at Lemu LEA Primary School Samaru, Hayin Dogo dumpsite, and dumpsites along Rafi Pensioner quarters. Studies conducted by the World Bank concluded that waste generation in communities tends to increase with the economic level of countries or cities (World of Refuse, 1988-89). Hence the amount of domestic refuse collected varies widely, depending on the standard of living and eating habits.

Study Area

Samaru is part of the Zaria urban setting. It lies within latitudes 11º06N and 11º12N of the equator and longitudes 7º39E and 7º45E of the Greenwich meridian. Three major dumpsites are identified within the Samaru area of Sabon Gari local government for this study. The dumpsite located within Lemu LEA Primary School Samaru lies on latitude 11º10'12" N and longitude 7º 39'0" E. That of Hayin Dogo lies on latitude 11º 9' 54" and longitude 7º 39' 17". Dumpsites along Rafi, pensioner quarters lie on latitude 11º 9' 38" and longitude 7º 39' 44". Samaru is located at the central high plain of Northern Nigeria at a height of about 670 meters above sea level. It is about 13km from Zaria city along Sokoto road, 8km to Shika, and 7km from Bassawa. Samaru is found in the Sabon Gari Local government area and it is bounded to the North and North East by Bassawa military cantonment, to the South by Ahmadu Bello University (ABU) main campus, and to the West by the Division of Agricultural Collages (Figure 1). Samaru is one of the suburbs of Zaria which is made up of distinct loosely coordinated units (Mortimore, 1970).

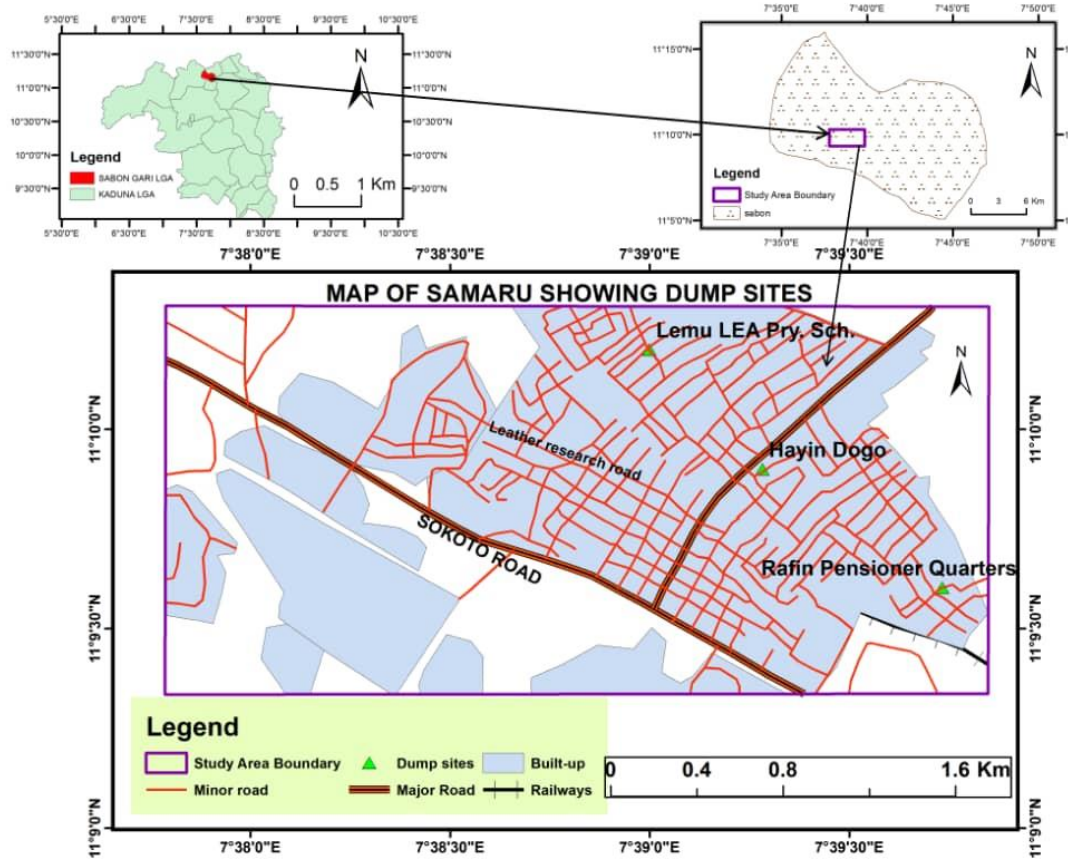

Figure 1: Location map of the study area

MATERIALS AND METHODS

The materials and software used in this research for the design of an engineered system for solid waste collection include; AutoCAD, ARCGIS, GPS, Route optimization software, measuring tape, Marker, Containers of equal volume, Record book, Calculator, and Stop watch.

Solid waste generation rates and patterns within the study area.

To determine the solid waste generation rates and patterns in the study area; The spatial features of land use within Samaru were mapped out through the use of GPS, Google route software, AutoCAD, and a thorough reconnaissance survey of the study area. This map was further divided into four sections labelled A, B, C, and D. The inter street hauled distances and the number of households per each city block were counted by the researcher and represented on the map in sections A, B, C, & D

Volume of solid waste estimation

Eleven sacks of equal capacities 0.4m³ each were used to collect solid waste from eleven different households daily within three months of wet and dry seasons of the year. The readings were taken in the evening periods of every day and recorded for each week of the month. These sacks were randomly distributed using an order of 3, 3, 3, 2 in sections A, B, C, & D of the map respectively. The eleven households used as test samples were served with one sack each labelled A_1, A_2, A_3, B_1, B_2, B_3, C_1, C_2, C_3, D_1, and D_2 and placed in the backyards of the households of 16, 9, 6, 7, 14, 10, 5, 8, 12, 6 & 11 people respectively. Daily observations to determine the volume of solid waste generated by each household per day were successfully carried out considering the wet and dry seasons of the year.

The measuring tape was used to measure the daily increase in the height of solid waste in the sacks. The observed values were recorded in the record book and volume (V) = $\frac{\pi d^2}{4}h$ were calculated. The average volume of solid waste generated per household in the dry season (i.e. vol. of S.W. gen/household/week) D =

$$\frac{A_{1D}+A_{2D}+A_{3D}+B_{1D}+B_{2D}+B_{3D}+C_{1D}+C_{2D}+C_{3D}+D_{1D}+D_{2D}}{11}$$

Concerning the computations of solid waste generated per each sample of household per week, a conclusion on an average volume of solid waste generated per household per week in Samaru during the wet season (i.e. vol. of S.W. gen/household/week)W

$$= \frac{A_{1w} + A_{2w} + A_{3w} + B_{1w} + B_{2w} + B_{3w} + C_{1w} + C_{2w} + C_{3w} + D_{1w} + D_{2w}}{11}$$

Equipment and Labour requirement

To determine the equipment and labour requirement; the following parameters were considered and used for computations according to (Howard 1985)

i. Time per trip ($Tscs$) = ($Pscs + s + a + bx$)… (1)

ii. Pickup time per trip $(P_{scs}) = C_t uc + (n_p - 1)(dbc)$ (2)

iii. Number of trips per day $(N_d) = \frac{(1-W)H-(t_1+t_2)}{P_{scs}+s+a+bx}$ (3)

iv. Length of workday $(H) = \frac{(t_1+t_2)+N_d(P_{scs}+s+a+bx)}{(1-W)}$ (4)

Collection route

To lay out the collection route; the volume of solid waste generated per section per week was first determined. This volume was divided by the vehicle's carrying capacity to obtain the number of trips per section in a day/week. The collection route/trip was optimized using Google route optimization software.

RESULTS AND DISCUSSION

Figure 2 shows the road network map of the study area. This map has been further divided into four sections labeled A, B, C, & D.

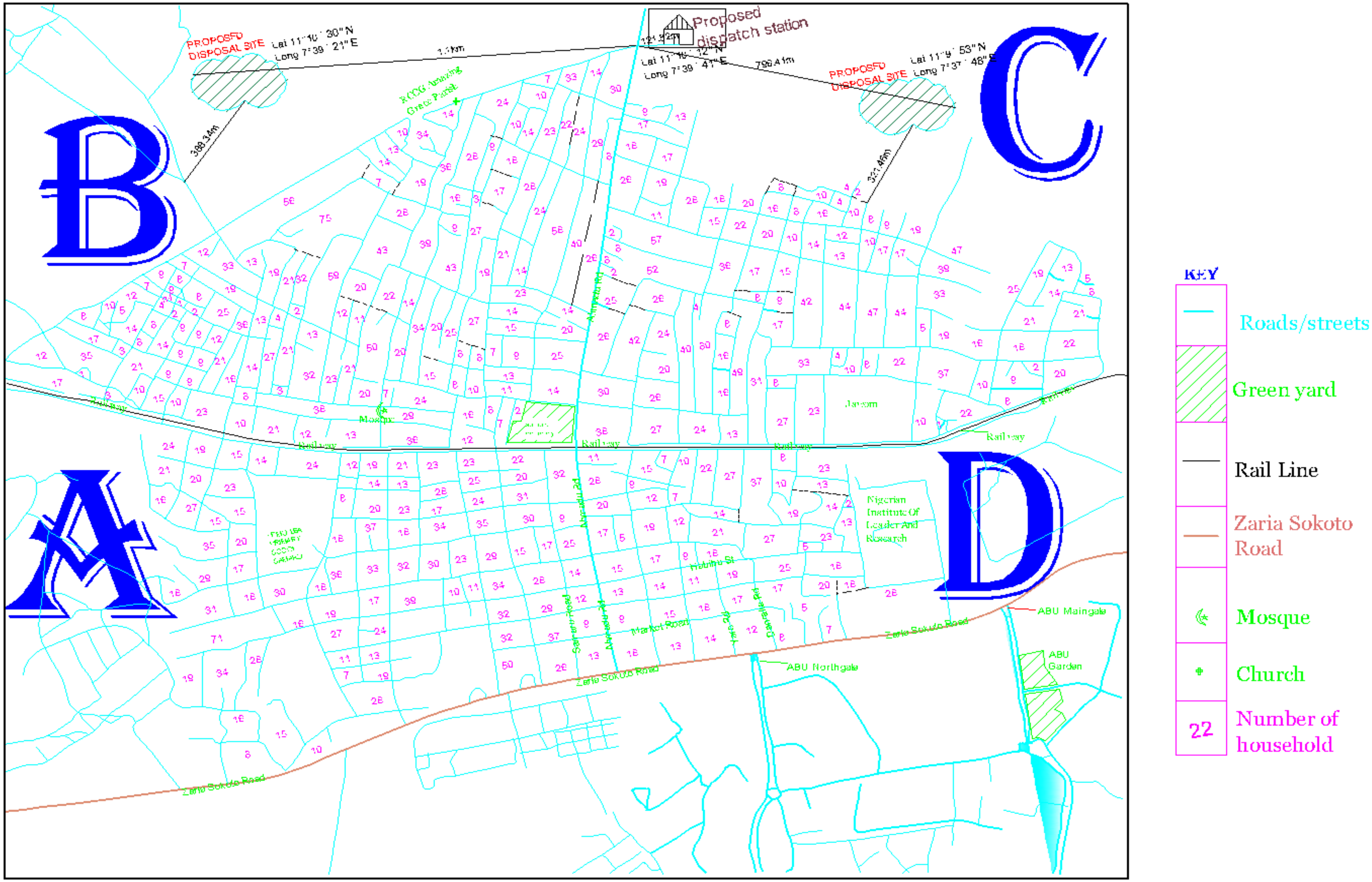

Figure 2: Road Network Map of Samaru

The average volume of solid waste generated/household/week was determined for both dry and wet seasons of the year as shown in Table 1. The highest average volume of solid waste generated per household per week in Samaru was in the dry season $= 0.25\, m^3$ (Table 1). The World Bank suggests that 0.2 to 0.5 m^3 per capita per year is typical for low-income countries. Therefore, the average value of 0.25 m^3 per week falls within this range, World Bank (2019).The wet season generates slightly less waste (0.13 m^3). This reduction could be due to factors like reduced outdoor activities or changes in consumption patterns. Similarly, for the Waste Generation Rate per Capita, which represents the individual waste generation rate, during the dry season, a value of 0.029 m^3 is recorded. In comparing it to global standards, the United States Environmental Protection Agency (EPA), (2021) estimates an average of 4.4 pounds (approximately 0.02 m^3) per person per day. The provided value of 0.029 m^3 per week aligns with this estimate. The wet season's waste generation rate per capita of 0.015 m^3 is even lower. This could be due to reduced outdoor activities or other factors.

Table 1: The average volume of solid waste generated by households in Samaru

Households	Number of people	The volume of solid waste generated per household per week		Waste generation rate per capita per week	
		Dry Season (m^3)	Wet Season (m^3)	Dry season (m^3)	Wet season (m^3)
A_1	16	0.31	0.19	0.019	0.012
A_2	9	0.36	0.14	0.040	0.016
A_3	6	0.29	0.15	0.048	0.025
B_1	7	0.25	0.13	0.036	0.019
B_2	14	0.22	0.12	0.016	0.009
B_3	10	0.23	0.12	0.023	0.012
C_1	5	0.23	0.10	0.046	0.020
C_2	8	0.20	0.10	0.025	0.013
C_3	12	0.26	0.11	0.021	0.009
D_1	6	0.17	0.11	0.028	0.018
D_2	11	0.24	0.10	0.023	0.009
Average		0.25	0.13	0.029	0.015

The kinds of solid waste generated in Samaru and their compositions are shown in Table 2.

The dry season witnesses a substantial volume of 0.206 m^3 for garbage organic materials, constituting 66.45% of the total composition. In the wet season, this volume remains significant at 0.104 m^3, accounting for 61.18% of the total composition. The higher percentage of organic materials (garbage) during both seasons suggests a need for improved organic waste management. Composting and recycling organic waste can reduce landfill usage and methane emissions (Derhab & Elkhwesky, 2023). During the dry season, the volume of plastic, polythene, and rubber is 0.072 m^3, making up 23.23% of the total composition. In the wet season, this volume decreases to 0.024 m^3, representing 14.12% of the total composition. Similarly, during the dry season, the volume of paper/cardboard is 0.007 m^3, constituting 2.26% of the total composition. In the wet season, the volume increases to 0.021 m^3, accounting for 12.35% of the total composition. This shows that plastic and paper/cardboard constitute a substantial portion of the waste. These materials are often recyclable, it is therefore recommended that a strengthening of recycling programs be encouraged for plastics and paper/cardboard. Encourage proper disposal and recycling practices. (González-Sánchez et *al.,* 2023)

Table 2: Composition of solid waste in Samaru (Dry and Wet season)

Composition	Volume (m^3) (Dry season)		Volume (m^3) (Wet season)	
	Average	% Composition	Average	% Composition
Paper/cardboard	0.007	2.26	0.021	12.35
Glass	0.006	1.93	0.007	4.12
Metal, Cans, and Tins	0.019	6.13	0.014	8.24
Plastic, Polythene & Rubber	0.072	23.23	0.024	14.12
Garbage organic materials	0.206	66.45	0.104	61.18
Total	0.31	100	0.17	100

Table 3 provides information about the highest number of households or city blocks (labeled as Sections A, B, C, and D) and the corresponding volume of solid waste generated per week (measured in cubic meters, m^3). Section A has a relatively high number of households or city blocks (71), but the volume of solid waste generated is moderate (18 m^3). Section B has the highest number of households or city blocks among all sections. However, the increase in waste volume (from Section A) is minimal. Section D has the fewest households or city blocks, resulting in the lowest waste volume. The relationship between the number of households/city blocks and waste volume is not strictly linear. Factors such as waste disposal practices, population density, and waste composition influence the results (Deus *et al.*, 2022). This helps to know the minimum size of containers to be assigned per city block of the sections.

Table 3: Volume of solid waste generated by a city block with the highest number of households in each section

SECTION	HIGHEST NUMBER OF HOUSEHOLD/CITY-BLOCK	VOLUME OF SOLID WASTE GENERATED/WEEK (m^3)
A	71	18
B	75	19
C	60	15
D	37	10

The minimum sizes of containers to be selected for solid waste collection per city blocks of sections A, B, C, & D are $18m^3$, $19m^3$, $15m^3$, and $10m^3$ respectively.
The total number of households in sections A, B, C & D are shown in Table 4 including the volume of solid waste generated by each section per week and the required vehicle capacity to collect the waste per day per week. It also shows the number of trips to be made per week and the number of households expected by the vehicle to collect solid waste before being filled up.

Table 4: Estimation of the number of households covered per trip

PARAMETER	SECTION A	SECTION B	SECTION C	SECTION D
Household/section	1985	2544	1974	428
Volume (m^3/week)	99.25	127.2	98.7	41.4
Vehicle capacity (m^3)	30	30	30	25
Trips/week	4	5	4	2
Household/trip	497	509	494	414

The Collection Route

The selected containers are placed for each city block considering the volume of solid waste generated per periodic time of collection. A minimum of two containers are placed on the opposite sides of each city block using a stand-up right-hand drive collection for easy collection as shown in Figures 3-6.

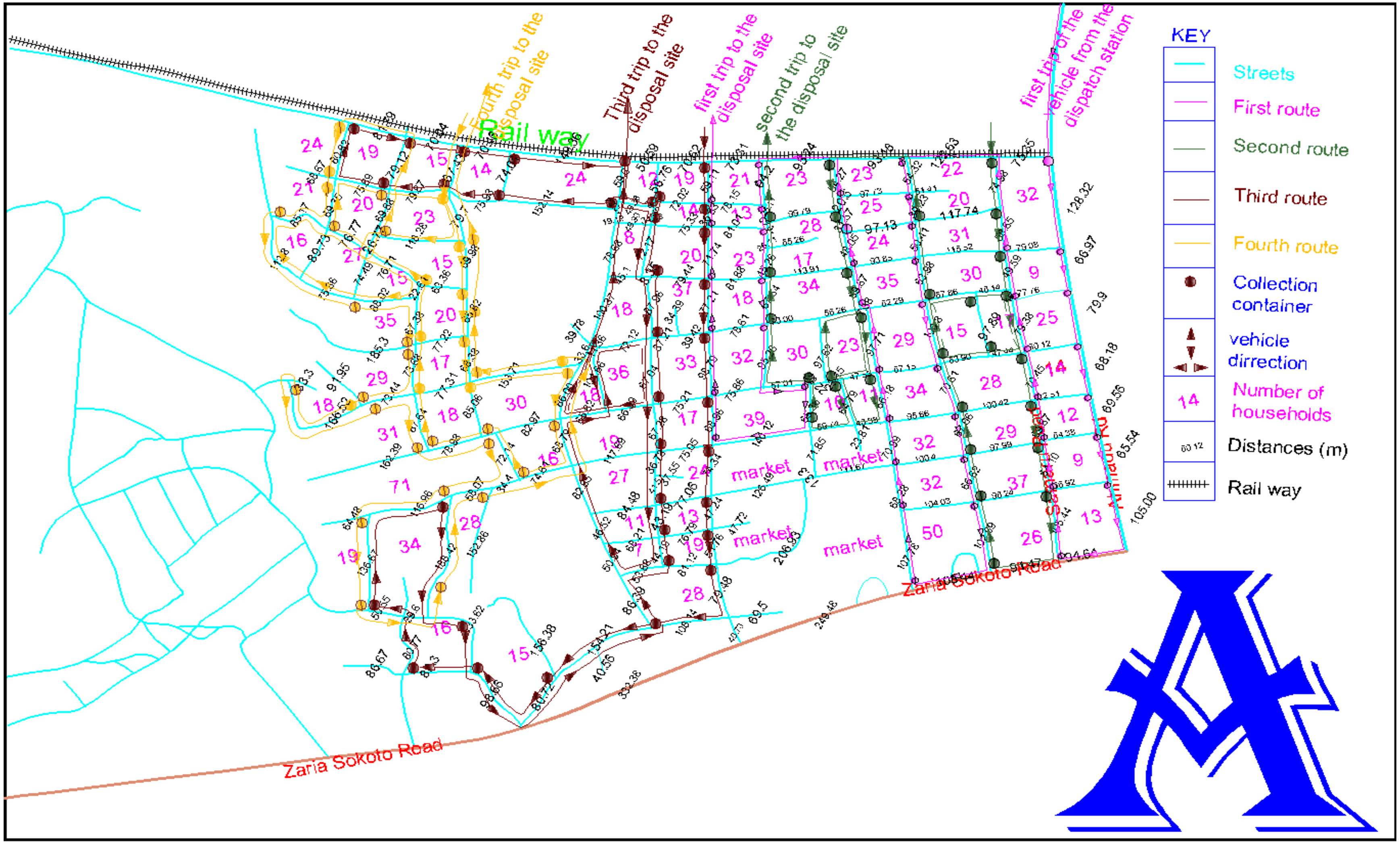

Figure 3: Section A of the road network map of Samaru showing the collection route per trip

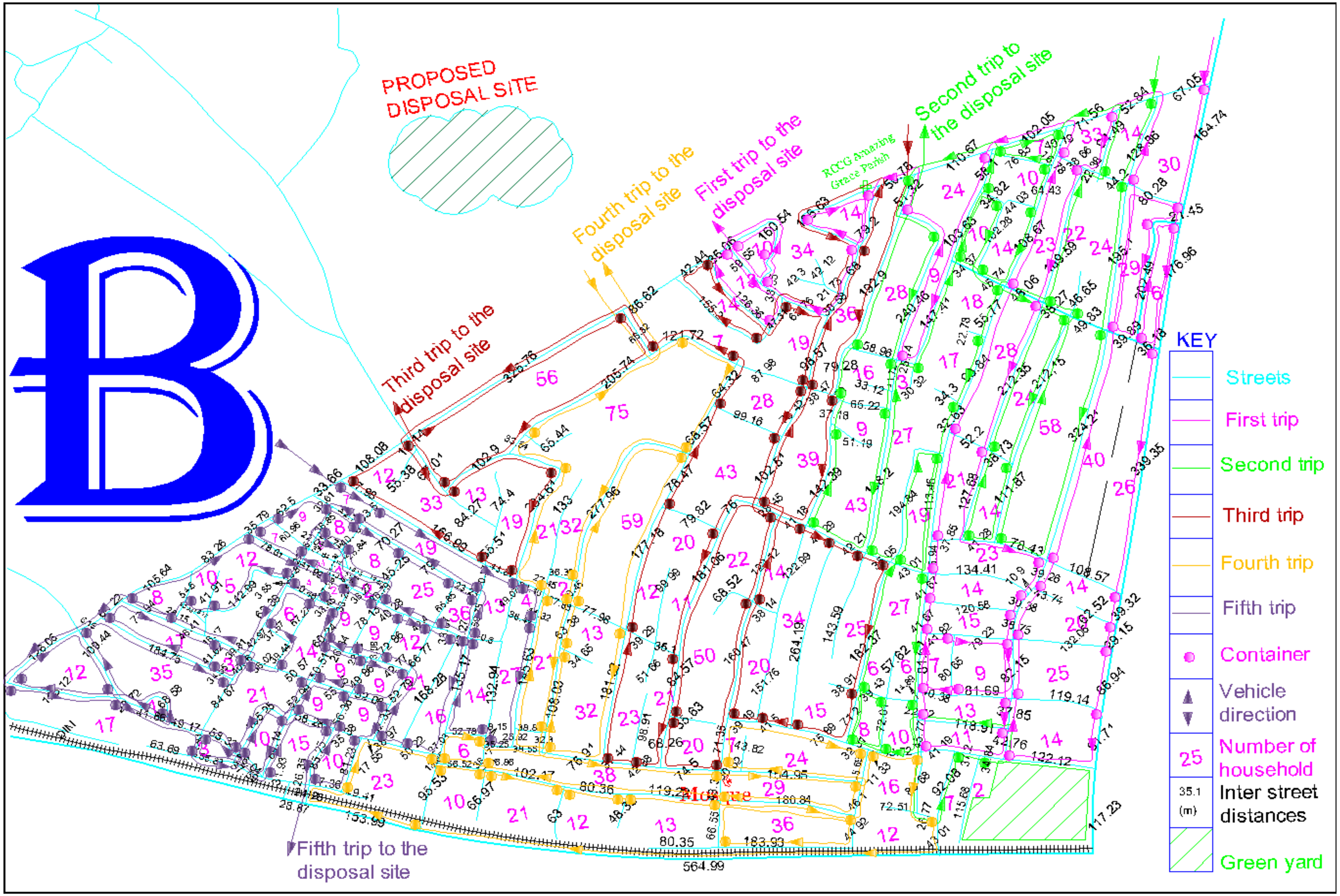

Figure 4: Section B of the road network map of Samaru showing the collection route per trip

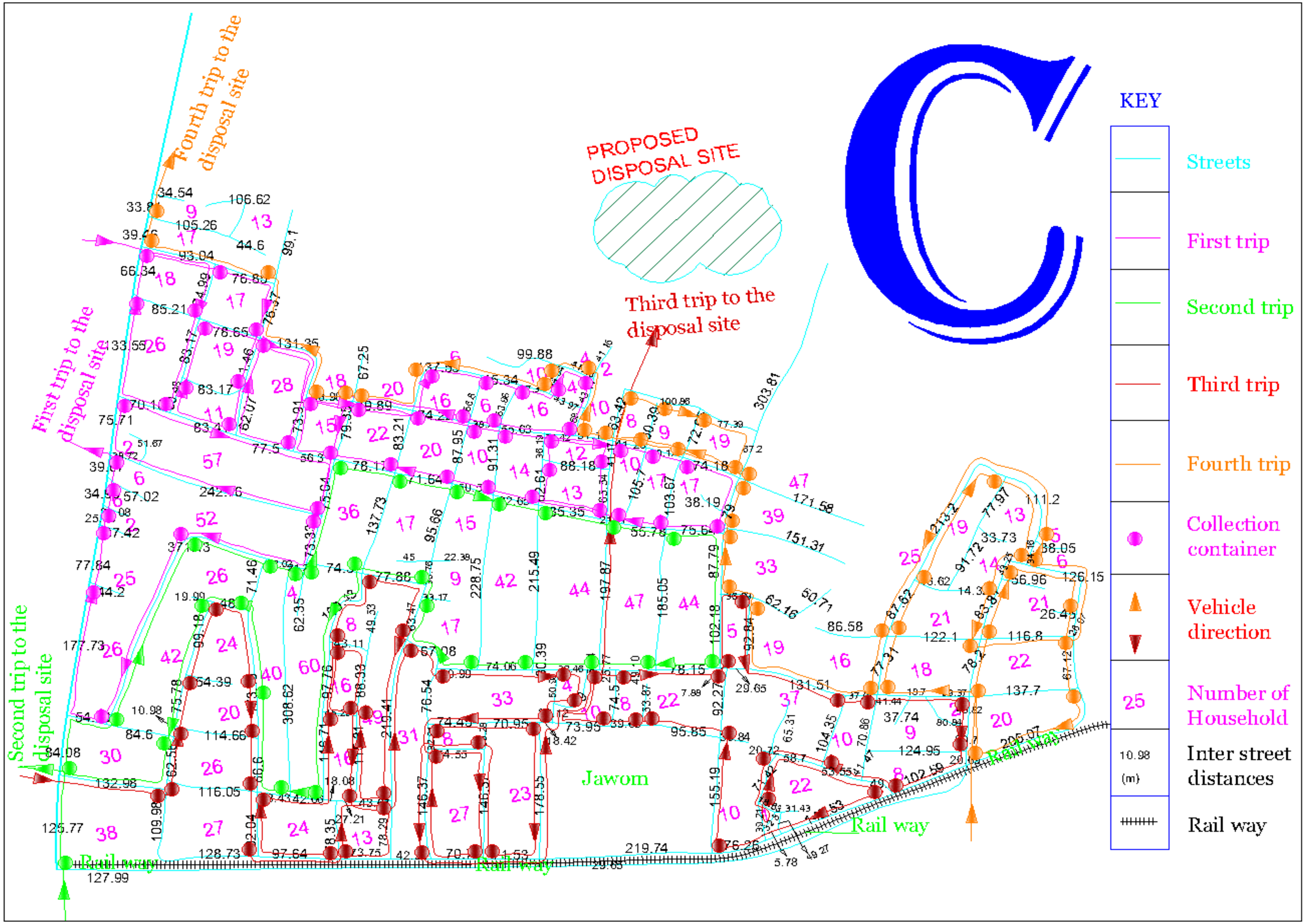

Figure 5: Section C of the road network map of Samaru showing the collection route per trip

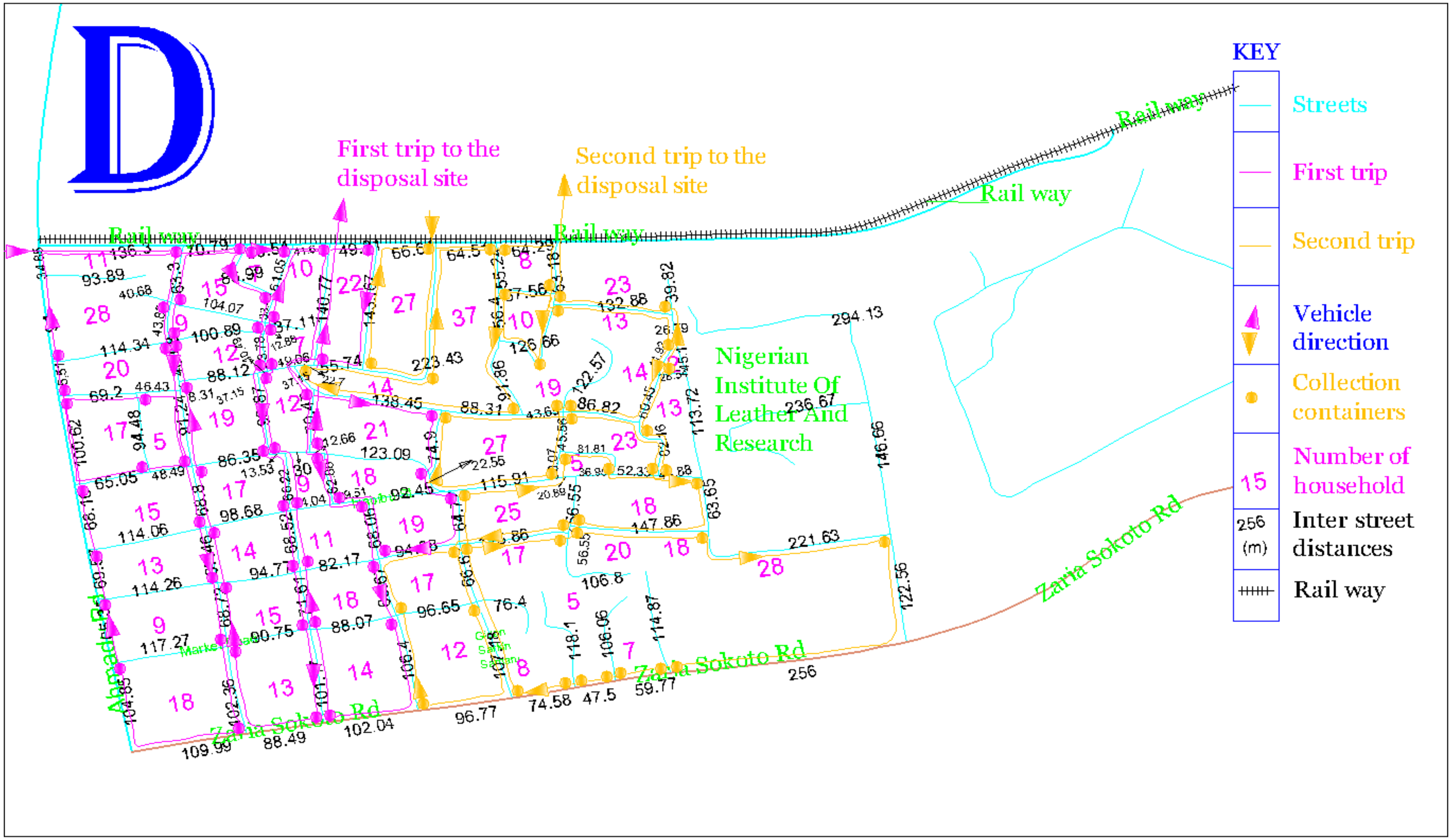

Figure 6: Section D of the road network map of Samaru showing the collection route per trip

Drivers with unutilized time of 2.6 hours and above after completing their original assigned trip will be paid for overtime to go for another trip the same day for the following reasons:

i. To reduce the number of vehicles operating/day/week
ii. To ensure that all the solid waste generated per week is collected in a day per week
iii. To prevent excessive cost of operation.

The computations help to reduce the number of solid waste collection vehicles from fifteen vehicles to four vehicles as shown in Table 5

Table 5: Number of solid waste collection vehicles operating per day per week

Vehicle Capacity(m^3)	Route/vehicle/day	Collection days/week	Number of vehicles operating per day	
			30m^3	**25m^3**
30	1st trip route in section A	Monday	2	-
30	2nd trip route in section A			
	2nd trip route in section C			
30	3rd trip route in section A	Tuesday	1	1
25	4th trip route in section A			
30	1st trip route in section B	Wednesday	2	-
	4th trip route in section C			
30	2nd trip route in section B			
	4th trip route in section B			
30	3rd trip route in section B	Thursday	1	1
	2nd trip route in section C			
25	5th trip route in section B			
25	1st trip route in section C	Friday		2
	2nd trip route in section D			
25	1st trip route in section D			
Required number of vehicles for operation			**2**	**2**

CONCLUSION

The amount of solid waste generation was determined alongside the volume of waste collection containers. The collection routes with the required number of waste collection vehicles were also determined. The following conclusions were drawn from the studies;

The rate of solid waste generation in Samaru varies considering the wet and dry seasons of the year producing a result of 0.13m^3/household/week and 0.25m^3/household/week respectively. Average of 0.19m^3/household/week.

The minimum allowable capacity of solid waste collection containers for the designed system is 10m^3 considering a minimum of two containers per city block. However, a minimum of 9m^3, 9.5m^3, 7.5m^3, and 5m^3 is allowed for sections A, B, C, and D respectively considering a minimum of two containers per city block.

Concerning the collection routes laid out and the computations, four (4) solid waste collection vehicles will be adequate for the collection of 15 trips of solid wastes per day per week. The capacity of two of the vehicles will be 30m^3 each while the other two will be 25m^3 each.

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