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Design of a Municipal Solid Waste Collection System in Situations with a Lack of Resources: Nikki (Benin), a Case in Africa

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Abstract: Waste collection is one of the most important public services in a town. However, waste collection has not been effectively implemented in some places due to the lack of economic and management resources. The waste is placed in inappropriate sites with the consequent risks of pollution and unhealthy conditions for the inhabitants. Therefore, establishing a municipal solid waste collection plan can be complicated. The methodologies and techniques that work in countries with medium and high income levels cannot be extrapolated to others with low income level because the boundary conditions are widely different. The aim of this paper is to design a municipal solid waste collection system adapted to this type of situation where not much money can be invested and where data are limited. In these cases, municipalities need to use their existing resources effectively. This paper offers a methodology for these cases as well as a case study. The first step was to gather information about the type and amount of waste generated and the characteristics of the town. The second step was to propose the location of the bins and, finally, the waste collection routes. With all these data, the technical and human resources were set. The methodology used was validated in a real case, the town of Nikki (Benin) in Africa. The collection of three waste fractions was designed with the actual resources of the city in order to offer a realistic implementation. Similar situations can be found around the world, and this case study can be used as an example to improve the waste management practices in some places with low resources.

Keywords: solid waste; collection; lack resources; low-income countries; fractions

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1. Introduction

The collection of the municipal solid waste (MSW) is still a challenge in some countries. While in developed countries, this is a regular public service, in developing countries with low income, this is not a common practice. In these places, regulations are often limited; available resources are scarce and other inefficient ways for final waste disposal are often used.

Authors like those of [1] have extracted from surveys that, for example, in Emburu (Kenya), 37% of the households discarded their solid waste in open places, 32% burnt it, and 24% recycled it. Only 8% households reused the solid waste. In Liberia, burning or burying the waste were common disposal practices, and few households separated or recycled waste [2]. In Asella (Ethiopia), the majority of the residents practiced improper solid waste management. The lack of adequate data about solid waste management and the limitations to collecting the waste could have contributed to the improper solid waste disposal [3]. The most popular ways to eliminate waste in Africa involve using open dump sites. In fact, according to [4], only Kampala (Uganda) has an engineered disposal site. The ongoing disposal of MSW in poorly engineered “dump sites” on the outskirts of Al-Bayda (Libya) is unsustainable and will not meet the demands of the growing population and increasing urbanization [5]. In this case, the authors also detected the lack of resources and services that significantly affected the disposal of waste: an inadequate number of waste collection containers, making the distance to these containers excessive for many households, thus leading to an increased likelihood of dumping solid waste in open areas and roadsides. The result of these practices proved that the existence of open dumps contributed to the increase in air pollution measured around the dump sites. They showed that around the dump sites, the oxygen levels within the vicinity were below the comfortable level of 19.5%. CO levels ranged between 2 and 9 ppm, with the maximum value of 9 ppm when refuse containing plastics was burning [6].

Households with easy access to legal alternatives, such as centralized drop-off containers or curbside waste collection, are less likely to dispose of their waste in an illegal manner [7]. Obviously, if citizens do not have any options to dispose of their waste near their homes, they are, in part, excluded from the waste collection process. The consequences of these practices are the pollution of the soil, water, and air and the loss of health-related quality of life, as well as the emergence of vectors (insects, rats, birds, etc.) that can transmit diseases.

However, trying to design a waste collection plan is difficult in these cases due to the lack of basic information and resources. In low-to middle-income countries, advanced assessments are difficult to introduce due to the lack of technical knowledge, financial support, and a recycling sector [8]. The inclusion of this sector, in this case, allowed a reduction of the expenses, an increase in the recycling rate, and a reduction of the distances travelled. Anyway, the governance factors are key. Basic information for starting the process of designing the waste collection system is not available on many occasions. For example, a gap in the management of MSW for the city of Kitwe (Zambia) was identified [9]. There was not a correct and detailed database for waste generation, collection, treatment, and disposal. Other authors started their work by trying to identify waste generation and composition. In Bahir Dar City (Ethiopia), 196 households were selected to collect data, and their results showed that the mean weight of waste generated by sample households was 0.22 kg per inhabitant and day [10]. In Ghana, reliable national data on waste generation and composition showed that effective planning for waste management was also absent. For this reason, they recruited selected households in each region to obtain data on the rate of waste generation, physical composition of waste, sorting and separation efficiency, and waste per capita [11]. In this work, they determined that waste generation in Ghana was 0.47 kg per inhabitant/day. They also found that the highest waste fraction, in weight, was organic material (61%), followed by plastics (14%), inert material (5%), miscellaneous material (5%), paper (5%), metals (3%), glass (3%), leather and rubber (1%), and textiles (1%). As in Ghana, in the rest of Africa, the plastic fraction is usually the major waste fraction, and paper is the second one. Their collection and treatment could save energy in the case of Nigeria [12]. A total of 1046.43 GWh of energy could be saved per year by recycling the recyclable waste materials rather than producing new products from virgin materials. Therefore, it is interesting to take the collection of the plastic fraction into account separately from the other waste fractions.

Once waste generation is defined, other items should be considered, such as the distribution of the population, the location of the bins, the layout of the city, the frequency of the waste collection, and the transport used. In this respect, some authors proposed improvements for the city of Aksum (Ethiopia) [13]. They focused on three service attributes (frequency of waste collection, waste disposal mechanism, and mode of transport used to transport waste), along with a monetary attribute (monthly charges of households for the service rendered). Additionally, morphological features, such as the uneven quality of urban road networks or the density of settlements, undoubtedly affect the waste collection by garbage trucks in different parts of Bafoussam (Cameroon) [14]. They also pointed out the importance of considering workers and their everyday practices, as well as incentives and accountabilities, for the design of sustainable solid waste management.

The aim of this work is to present a detailed methodology to allow towns with scarce resources to implement a municipal solid waste collection system. Additionally, we present a case study to show how to apply the methodology to a town where waste is currently not properly collected. Other challenges to deal with are the great gap in the information needed, such as waste generation and composition, the population distribution, the layout of the city, and the means that can be used to transport the waste. Once all these drawbacks are solved, the main fractions to be collected are defined and collection routes for each fraction are designed with the aid of geographical information systems (GISs). The locations of the bins and the collection routes are defined by taking into account the vehicles available in the city to try to minimize the cost of waste collection. All of the steps were focused on Nikki (Benin), an African city where the waste generated in the households is not collected, with consequent sanitary and environmental problems. The final goal, in any case, is to improve the quality of life of the citizens as well as the environment. This work offers a methodology that can be used in similar situations where a great effort is needed to achieve proper and efficient municipal waste management. The novelty of this methodology is that it emphasizes two basic features: It is simple and easy to implement, as it considers the basic elements for designing a sustainable waste collection system. Moreover, it does not require a great amount of hardly accessible data. Finally, it takes into account that the implementation of the collection system must be real, and therefore, the economic investment must be as low as possible. For this reason, the technical devices selected are cheap, simple to maintain, and accessible in the study zone.

2. Methodology

Some of the reasons for not having implemented a municipal solid waste collection system can be the low available budget and the lack of basic data, such as the waste generation or distribution of the inhabitants in the town, as well as the lack of environmental legislation or qualified staff. The aim of this section is to define a methodology for organizing the waste collection system and applying it afterwards to a case study. Figure 1 shows all the stages proposed in this methodology. In a context where the resources are scarce, the waste collection plan must start identifying the real needs of the town, as well as its constraints.

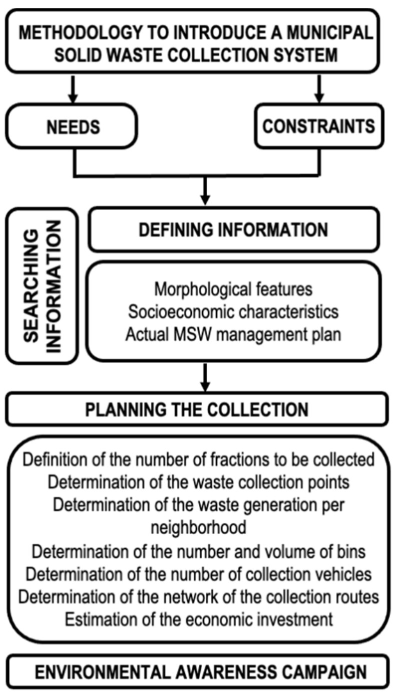

Figure 1. Methodology for introducing a municipal solid waste (MSW) collection system.

Regarding the needs, different scenarios can appear. There are towns without a waste collection plan, towns where the waste is not collected separately, or towns with a formal and informal collection. Therefore, the final aim can vary depending on these factors. The requirements of the town must be also taken into account, as they will define the scope of the project. First of all, the actual waste collection system should be analyzed if this service is being supplied. It is also essential to determine the actual human resources, technical restrictions, and economical constraints.

Depending on these, the final decisions can vary. Once the needs and the constraints are identified, the following step is to search for information about the morphological features, the socioeconomic characteristics, and the actual MSW management plan. All of these items are clues for starting to design a collection plan.

The socioeconomic characteristics are those referring to the population (size, per capita income, economic activities, etc.). They are needed to estimate the amount of waste generated, its composition, and the changes over the year. The morphological features refer to the spatial distribution of the population, the economic activities, the types of households and their distribution, the road infrastructure, etc. They are needed to know the spatial distribution of the waste and to design the collection routes in the studied zone. Finally, it is also important to gather information about the existing MSW plan to take maximum advantage of its technical equipment, human resources, and infrastructures.

In the collection planning stage, depending on the final possibilities of waste recovery, the manager must decide on the number of waste fractions to be collected. Each fraction will need a collection system.

At this stage, the possible collection points (CPs) can be located and the waste generation in the neighborhoods can be calculated. Subsequently, the number and volume of the bins where the citizens will throw the waste can be determined, as well as the number and type of collection vehicles. Finally, the final investment for implementing the collection plan can be estimated.

To successfully implement the new system, an awareness campaign must be designed to achieve the participation of a great percentage of citizens. Citizens must be informed about the characteristics of the designed system and why it was adopted. It is also essential to highlight the importance of their participation to achieve good results. In the example proposed for Nikki, all of the aspects and variables considered in the methodology are fully described.

3. Description of the Case Study: The Case of Nikki

3.1. Definition of the Socioeconomic Characteristics

In this case study, the data needed are about Nikki. Nikki is a town located in Benin (West Africa) between Nigeria and Togo, in the Borgou department, and has 61,565 inhabitants. The main activities in the zone are agriculture and farming. The climate in Benin is hot and humid. Benin has two rainy and two dry seasons. The main dry season ranges from December to April, and the shorter, cooler dry season ranges from late July to early September. Nikki is divided into seven neighborhoods: Bukasua, Kpawlou, Danri, Maró, Gha-Maró, Gourú, and Totorú.

3.2. Morphological Features

Nikki has a peculiarity in the distribution of the houses. The town has several avenues and secondary streets connected to these main streets. The entrances to the courtyards are through the secondary streets, and the houses are located around the courtyards. The secondary streets are not paved, and a collection vehicle could not access the courtyards through them. Additionally, in the rainy season, the secondary streets are in bad condition.

As there is not official information about the number of houses in the town, this was found with the aid of a free tool, Open Street Maps©. This tool showed that Nikki has 6996 houses and 1752 courtyards. The average number of houses per courtyard was four, and the average number of people per house (8.8 inhabitants per house) was calculated from the number of inhabitants and the number of houses. At this point, it is also essential to use a georeferenced map of the town. As this actually does not exist, it was drawn using ArcGIS tools. Therefore, 3418 lines representing the streets were traced and 6996 points related to the houses were marked.

According to Table 1, the neighborhood with the most houses is Maró (1637 houses), followed by Gha-Maró (1467 houses) and Bukasua (1202 houses). The rest of the neighborhoods have less than 1000 houses. The information related to the houses and the number of inhabitants was saved in a map. Therefore, the map in Figure 2 shows the linear population density in the town. This information allows the waste managers to start organizing the collection.

Table 1. Distance between the houses and their nearest courtyard.

Distance (m)	Number of Houses	% of Houses	Number of Inhabitants	% of Inhabitants
		Bukasua		
0–50	1168	97.17	102,278.4	97.17
50–100	32	2.66	281.6	2.66
100–150	2	0.17	17.6	0.17
		Danri		
0–50	509	98.64	4479.2	98.64
50–100	6	1.16	52.8	1.16
100–150	1	0.19	8.8	0.19
		Gha-Maró		
0–50	1423	97.07	12,522.4	97.07
50–100	36	2.46	316.8	2.46
100–150	7	0.48	61.6	0.48
		Gourú		
0–50	856.6	98.73	7532.8	98.73
50–100	6	0.69	52.8	0.69
100–150	5	0.58	44	0.58
		Kpawlou		
0–50	884	95.98	7779.2	95.98
50–100	35	3.80	308	3.80
100–150	2	0.22	17.6	0.22
		Maró		
0–50	1618	98.84	14,238.4	98.84
50–100	17	1.04	149.6	1.04
100–150	2	0.12	17.60	0.12
		Totorú		
0–50	374	96.89	3291.2	96.89
50–100	12	3.11	195.6	3.11
100–150	0	0	0	0

3.3. Actual MSW Management Plan in the Town

Nowadays, as there is not a waste collection system, the waste is carried to certain points near the houses—for example, open spaces, access roads, water courses, or improvised dump sites. Once the waste is accumulated, it is usually burnt, generating pollution in the environment. The main causes of this lack of waste management are the low budget, the poor road conditions, and the lack of data, environmental legislation, and qualified staff. Furthermore, awareness about the need for waste collection is low among the population.

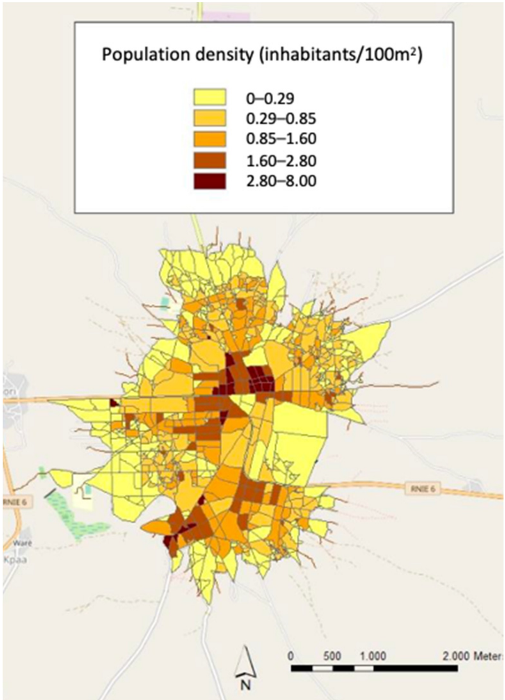

Figure 2. Population density in Nikki.

The following step is to determine the amount of waste generated. Nowadays, there are not data about waste composition. The proposed solution is to make a socioeconomic comparison with other towns in Borgou, such as Bémbéréké or Parakou. In these towns, there is more information about waste generation and composition, and they have similar characteristics to those of Nikki (climate, geographical location, etc.).

One of the main characteristics of this town is the climate, as there is a dry season and a wet season. According to [15], in the dry season, the average waste production is 0.99 $\pm$ 0.16 kg/inhabitant·day, while in the wet season, the average production of waste is 0.87 $\pm$ 0.19 kg/inhabitant·day. This author also analyzed the waste production and composition. The greatest fraction corresponds to debris (54.88%), followed by the organic fraction (37.71%) and, in the third place, the plastic fraction (3.21%).

3.4. Determination of the Waste Fraction Separation at the Origin

To decide the number of waste fractions to separately collect, several factors were taken into account, such as the environmental awareness, the waste composition, and the difficulty of recycling the collected fractions. Currently, in Nikki, there is only an informal collection of plastics, as they are the greatest fraction after the fine debris and the biowaste, and they can be recycled. There is a certain interest in recovering this fraction, as it allows one to obtain an economic advantage. This fraction is mainly composed of plastic bags. If the plastic fraction is collected separately, it is cleaner and its economic value increases. Agriculture is one of the main activities in the zone, and the land quality has been getting worse in recent years. For this reason, compost from the organic fraction could be used to enhance the quality of the land. Therefore, the waste manager can decide which fractions to collect separately. In the case of Nikki, attending to its above-mentioned characteristics, the fractions to collect separately should be plastic, biowaste, and a mixed fraction (with the rest of the wastes). In this zone, there is not a national or regional market for selling the rest of the waste fractions.

3.5. Organization of the Collection

Once the waste production is defined and the main fractions to be collected are known, the following step is to organize the collection system. Additionally, the main requirements for implementing the waste collection that were taken into account were:

- The initial investment budget and its maintenance must be low.
- The project must be economically, socially, and environmentally sustainable over time.
- The collection vehicles must be adapted to the state of the roads in the town.
- The collection bins must be located near the houses to achieve a good rate of participation of the citizens. The special characteristic of the houses' placement around courtyards makes them possible places to locate the bins.

To deal with the organization of the waste collection, the following stages should be taken into account:

- The waste collection points;
- The waste generation in each neighborhood;
- The number and volume of the bins;
- The number of vehicles depending on the collection frequency (CF) and routes;
- An economic analysis.

3.5.1. Waste Collection Points

Due to the special characteristics of the distribution of the houses around the courtyards and also due to the low waste collection awareness, two considerations regarding waste disposal and collection were defined. The first of them takes the daily waste disposal into account. To achieve a good rate of participation of the inhabitants, the bins where they dispose of their waste should be next to the houses, and as close as possible. The best place is, consequently, the courtyard that several houses share. The second consideration is related to the collection of waste by the collection staff. As the secondary streets are narrow, collection vehicles cannot access the courtyards. Moreover, the secondary streets are not always in good condition. For these reasons, the collection points where the vehicles will collect the waste should be located on the main streets.

As mentioned before, taking into account the special morphology of the town, a good place to locate the bins is in the courtyard of each group of houses. An analysis of the distance between a house and the nearest courtyard was performed for each neighborhood (Table 1). This analysis allowed us to know the number of inhabitants that would deposit their waste in each courtyard.

According to the data in Table 1, up to 95% of the inhabitants will have a bin in which to drop their waste at a distance of less than 50 m, and the maximum distance to travel from a house to a bin will be 150 m, which is considered a reasonable distance.

The collection vehicles will load the waste at the collection points (CPs), which must be located on the main streets, as the access to the courtyards is not possible. At these CPs, the staff of the waste collection system will load the waste onto trucks. First, 813 possible collection points were located every 150 m along the main streets of the town, near the courtyards and near the shops (Figure 3).

After analyzing the distance between the CPs and the courtyards, it was observed that some points were not needed, as they were too far from the courtyards. Therefore, only 700 possible collection points were finally considered. Table 2 shows the distances between the courtyards and the CPs.

The results in Table 2 show that with this initial distribution of the CPs, Gha-Maró, Maró, and Bukasua have most of their courtyards at a distance from a CP of less than 50 m. In Bukasua, Gha-Maró, Kpawlou, and Maró, more than 99% of the people can have a CP less than 100 m away. In Danri, Gourú, and Totorú, all of the citizens will have a CP less than 150 m away.

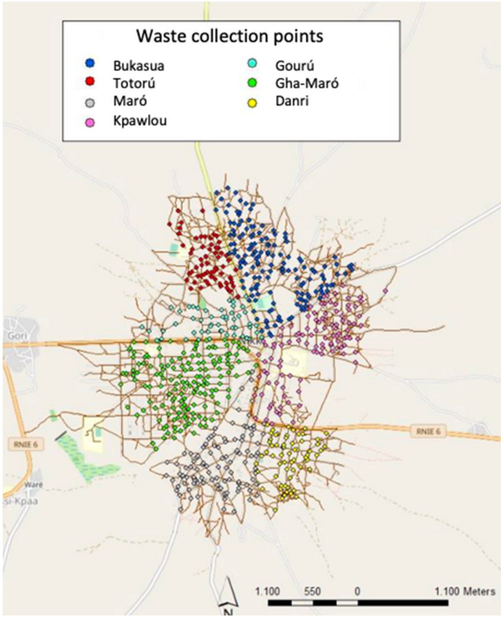

Figure 3. Waste collection points in Nikki.

Table 2. Number of courtyards depending on the distance from a collection point (CP).

Distance (m)	Bukasua	Danri	Gha-Maró	Gourú	Kpawlou	Maró	Totorú
0–50	216	93	260	140	156	251	73
50–100	84	36	105	77	71	155	24
100–150	1	0	2	0	1	4	0

3.5.2. Waste Generation in Each Neighborhood

According to [15], every citizen produces 341 kg year^{-1} of household waste. They produce more waste in the months of December, January, and March. According to these data, it can be said that the waste generation is 0.94 ± 0.10 kg/inhab·day. To calculate the waste generation, we selected the greater value for reasons of safety.

Knowing the waste generation per capita and the number of inhabitants per courtyard, the generation per courtyard and the collection frequency (CF) can be calculated for each waste fraction. Five CFs were analyzed: daily collection (CF = 7), collecting the waste three times a week (CF = 3), collecting the waste twice a week (CF = 2), collecting the waste once a week (CF = 1), and collecting the waste once every two weeks (CF = 0.5). CF = 7 and CF = 0.5 were, finally, not selected. Taking into account that waste is not currently collected, daily collection would not be a realistic value, as the inhabitants do not have the habit of disposing of waste separately in bins. Furthermore, CF = 0.5 would lead to accumulation of too much garbage in the courtyards. If the waste remains in the courtyards for several days, it can attract insects and rodents. Additionally, as the climate in Nikki is a warm climate, this option was discarded.

The most realistic options for Nikki are the options with a CF of up to once a week. Table 3 shows the results of the daily generation per courtyard (DGC) of the mixed waste fraction, the plastic fraction, and the biowaste fraction, taking three CFs into account. The values in Table 3 correspond to the weight of the waste. CF = 3 represents collection three times per week on alternate days—for example, Monday, Wednesday, and Friday. Therefore, CF = 3 collects the accumulated waste in a maximum of three days. Meanwhile, CF = 2 implies the collection of the accumulated waste on a maximum of two days; consequently, two days of the week should be fixed for collecting the waste. It is important to always fix the same days of the week for collecting the waste, as the inhabitants will transport it from the courtyards to the nearest CP on the nearest main street. It is also important to separate the days equidistantly in order to prevent the problem of overflowing rubbish.

Table 3. Generation of the waste.

	Inhabitants/Courtyard	DGC (kg/day per Courtyard)	kg/day per Courtyard	kg/day per Courtyard	kg/day per Courtyard
			CF = 3	CF = 2	CF = 1
Mixed waste fraction generation					
Min.	8.8	7.32	21.95	29.27	51.23
Max.	96.8	80.50	241.50	322.0	563.50
Average	35.14	29.22	87.67	116	204.56
St. Dev.	12.43	10.34	31.02	72.38	72.38
Plastic waste fraction generation					
Min.	8.8	0.42	1.26	1.68	2.93
Max.	96.8	4.61	13.83	18.43	32.26
Average	35.14	1.67	5.02	6.69	11.71
St. Dev.	12.43	0.59	1.78	2.37	4.14
Biowaste fraction generation					
Min.	8.8	3.28	9.83	13.11	22.94
Max.	96.8	36.05	108.16	144.21	252.37
Average	35.14	13.09	39.26	52.35	91.61
St. Dev.	12.43	4.3	13.89	18.52	32.42

3.5.3. Number and Volume of the Bins

In this section, the volume and number of bins needed for each waste fraction are analyzed. To achieve this aim, the characteristics and the resources of the zone, such as the types of collection vehicles or the types of bins available, must be taken into account. In the case of the collection vehicles, the most appropriate vehicles are motorized tricycles. The advantage of these vehicles is that, as they are small, they can access all types of streets. The main disadvantage of these vehicles is that they have no lifting devices; for this reason, the weight of the waste to be loaded into the vehicle must be fixed. In this sense, a weight of 25 kg was fixed to avoid injuries to the waste collection workers. Taking this information into account, as well as the results in Table 4, it is clear that the mixed waste fraction needs an average of two bins if CF = 3, two bins if CF = 2, or three bins if CF = 1. Therefore, considering all the courtyards in the city, the number of bins for the mixed fraction needed in Nikki is 2343 bins if the waste is collected three times a week, 2962 bins if the waste is collected twice a week, and 4808 bins if the waste is collected only once a week. Regarding the plastic fraction, the number of bins needed is one bin per courtyard for all CFs. Consequently, the number of bins for the plastic fraction is 1752 bins. Finally, the results in Table 4 show that to collect the biowaste fraction, 1752 bins are needed to collect the waste three times a week, 1776 bins are needed to collect the waste twice a week, and 2349 bins are needed if the waste is collected only once a week.

Table 4. Number of bins per courtyard depending on the collection frequency (CF).

	CF = 3				CF = 2				CF = 1			
	Average	Min	Max	Total	Average	Min	Max	Total	Average	Min	Max	Total
Mixed waste fraction	2	1	3	2343	2	1	4	2962	3	1	6	4808
Plastic fraction	1	1	1	1752	1	1	1	1752	1	1	1	1752
Organic fraction	1	1	2	1752	1	1	2	1776	2	1	3	2349

To calculate the volume of the bin, the waste density must be taken into account. In Nikki, there are two seasons: the dry and the wet season. The waste density in the wet season was used in this case, as it represents the worst scenario. In this season, the mixed waste fraction has a density of 1021.55 kg/m^3, the density of the plastic fraction is 105.79 kg/m^3, and the density of the biowaste is 339.53 kg/m^3. These values were calculated from the waste data provided by [15]. Therefore, by fixing the maximum weight of waste per bin as 25 kg to take collection workers' health into account, the volumes of the bins needed are 24.49 L, 235.85 L, and 62.66 L for each type of waste, respectively.

3.5.4. Number of Vehicles Depending on the CF and Routes

To find the number of vehicles and to calculate the routes around the city, the ArcGIS software was used. As mentioned before, all the streets, courtyards, houses, and collection points were drawn to start the calculations. This is an essential task in order to finally implement the routes for waste collection. The final disposal in the case of Nikki is a disposal point located next to the city, but outside it. It must be a controlled site. Moreover, to calculate the routes, three speeds of the vehicle were chosen depending on the state of the street. In Nikki, not all of the streets are paved; for this reason, and especially in the rainy season, the state of the streets is not good. Therefore, slow speeds were chosen for the streets in bad condition and higher speeds for streets in better condition (20 km/h, 30 km/h, or 50 km/h). The proposed vehicle for collecting the waste was a motorized tricycle with a cabin, as it is able to collect any of the fractions and is a cheap vehicle that can be acquired and maintained in the zone. The capacity of this vehicle is 2.25 m^3. This information is essential for calculating the number of trips from the CP to the final depot point. The number of vehicles depends on the CF. The maximum number of vehicles needed for the organic fraction is 13; for the plastic fraction, it is 12 vehicles; for the mixed fraction, it is 15 vehicles with CF = 3. When CF = 2, the organic and plastic fractions need nine vehicles per fraction, and the mixed fraction needs 13. Finally, with CF = 1, the organic and plastic fractions need five vehicles per fraction and the mixed fraction needs 13 vehicles.

To calculate the routes, the town was divided into six sectors, with one sector per neighborhood. In this sense, each sector represents a neighborhood, except for sector 5, which comprises the neighborhoods of Totorú and Danri. Consequently, Bukasua is in sector 1, Gha-Maró is in sector 2, Kpawlou is in sector 3, Gourú is in sector 4, Totorú and Danri are in sector 5, and Maró is in sector 6. Finally, the collection routes for each type of waste (mixed, plastic, and organic waste) in each sector, as well as the number of collection vehicles needed, were calculated. The number of routes per neighborhood was between 9 and 11. Figure 4 shows an example of two routes defined in sector 2 to collect the mixed fraction considering CF = 3.

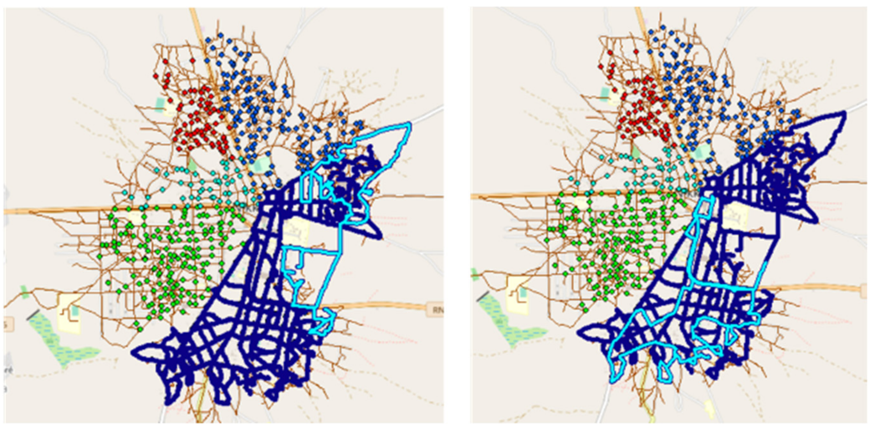

Figure 4. Examples of routes in sector 2.

4. Conclusions

Waste management is an essential task for assuring the hygiene and health conditions of a town. Nowadays, developed countries have sufficient means and tools to maintain these good conditions, such as updated waste generation data and even real-time waste generation data, qualified staff, and modern fleets of collection vehicles equipped with the latest technological advances or tools, such as geographical information systems. However, unfortunately, in some places, waste disposal services have not yet been implemented due to the lack of budget, official data, means, and even social awareness, which are translated into a disordered disposal of waste.

Therefore, implementing a new waste management plan in a town with scarce resources is a challenging task, which is more complicated than in other towns that would have greater chances of success. In these cases, the town's limitations must be taken into account and must be always placed in the forefront.

This paper offers a methodology for these situations and shows its application to a real case study. Moreover, in each step of the methodology, decisions must be made in order to go on. The decisions must always be adapted to the resources of the town. In this study, decisions were adopted by considering the situation of Nikki. Therefore, for this specific case and taking all the parameters related to municipal waste collection into account, the fractions into which the waste should be separated are plastics, organic matter, and a reject fraction consisting of the remaining materials. Two types of collections points were defined. The first type of collection point was located in the courtyards, next to the households, and, consequently, next to the inhabitants. This decision was made due to the particular distribution of the households around the town and due to the fact that the bins should be as near to the inhabitants as possible to achieve a good rate of participation of the people. The second type of collection point was located in the main streets of the town, next to the courtyards, as the collection vehicles could not enter some secondary streets to access the courtyards.

Another aspect of the collection program was the determination of an adequate collection frequency and the number of bins needed by considering the amount of waste generated per fraction and the average density. As a result, from the point of view of collection frequency, three possible scenarios were proposed: collecting the waste once, twice, or three times per week. For each scenario and for each type of waste fraction, the number of bins needed was calculated. The number of bins also depended on their capacity.

The collection vehicles available in this zone are motorized tricycles. As these vehicles cannot load the waste automatically, collection workers have to load it into the vehicle themselves. For this reason, the bins should not have an excessive weight in order to protect the health of the workers. This fact limits the volume of the bins. Depending on the CF, the number of vehicles will vary between 23 and 40.

Otherwise, to calculate the collection routes, the town was divided into six sectors, considering each neighborhood as a sector. Finally, the collection routes, as well as the number of vehicles needed for each waste fraction in each sector, were calculated.

All of this work contributes to solving the problem of waste disposal in a singular zone where urgent solutions are needed to move towards sustainable development.

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