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Article · January 2023

DOI: 10.37256/epr.3120231758

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New Approaches in Solid Waste Recycling and Management in Erbil City

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Received: 27 July 2022; **Revised:** 13 October 2022; **Accepted:** 3 November 2022

Abstract: Solid waste management (SWM) is an integral part of an environmental management system. This study focused on the production of urban solid waste, the amount of each part of solid waste, and the revenue from recyclable materials in Erbil City, Iraq's Kurdistan Region. The results show that the average generation rate of municipal solid waste (MSW) was around 1.338 kg/capita/day. Also, MSW usually contained combustibles (60%), non-combustibles (5%), and recyclable materials (35%). The average weight percentages of MSW components were: organic material (35%), plastic (27%), paper and corrugated cardboard (14%), metals (2%), glass (3%), yard trimmings and wood products (3%), and other types (16%). The study observed that large quantities of food waste were produced from a common source. Additionally, the expected income from the recyclable solid waste in the City of Erbil for plastic, metal, cartons, and papers was 175 $/ton, 235 $/ton, and 135 $/ton, respectively.

Keywords: antimicrobial resistance, bioaerosols, indicator bacteria, municipal wastes

1. Introduction

The increase in urban pollution and solid waste output is the main issue in both developed and developing countries. Their outcomes have negatively influenced the environment, resilience, and socioeconomic conditions. Several principles and international guidelines regulate the reduction, recycling, processing, and final disposal of solid waste [1, 2]. Lowering the quantity of trash created is the best method to reduce the environmental effects. Waste should be recycled. The recovery of reusable materials like paper, glass, plastic, metals, and building and demolition waste is referred to as recycling. Consequently, recycling is the most effective way to solve the problem since it minimises the amount of garbage disposed in a landfill [3]. Furthermore, recycling does provide the opportunity to keep dumping costs and trash delivery expenses under control while allowing the expansion of landfill sites [4].

Solid waste management (SWM) is the complete process of disposing solid wastes, which are solid materials collected from different sources and discarded. This management aids in reducing environmental and human health risks. This ultimately protects both the environment and public health [5]. SWM is often defined as the collection, transfer, recycling, treatment, and removal of waste [6]. These wastes have major environmental consequences, which may be seen in the environmental loads and resources required to produce food as well as emissions related to any food waste.

In Iraq and Kurdistan, municipal solid waste (MSW) is a severe hassle in city areas. In Iraq, huge quantities

DOI: https://doi.org/10.37256/epr.3120231758

of waste due to population growth, human consumption, and limitless financial openness have created complicated pollution problems [7]. Other issues include a lack of imaginative and prescient mechanisms to deal with massive amounts of waste, as well as the inability to seek out appropriate measures to assist in non-public areas' MSW [8].

Many kinds of research on SWM and recycling have been conducted in Iraq. Some research on SWM has been undertaken in Iraq's Kurdistan Region, mostly in Erbil. Aziz et al. [9] researched the handling of recyclable solid waste items to estimate the economic activity attributable to recycling. It is necessary to associate recyclable materials and recycling flows with the physical processes involved in transforming recyclable materials into useful products. It has been observed that the city is still lacking in terms of efficient waste treatment technology, sufficient funds, and public awareness. Moreover, Jalal and Shekha [10] investigated converting household solid waste into compost and reusing it as soil fertiliser by using four procedures for compost production: aerobic, anaerobic, pit, and vermicomposting, in order to know which method is more convenient. Additionally, Shekha [11] determined Erbil's MSW quality and amounts, converted it into compost, and reused it as soil fertiliser.

Aziz et al. [12] showed the amount and types of residential solid trash collected from several Erbil neighbourhoods, as well as the viability of recycling these wastes. Rashid et al. [13] studied solid waste control inside the Sulaimanyah governorate, which is a case that was observed at Chamchamal (the Dwbra valley open dump). This study outlined this waste dump as a point source pollution and emphasised the solutions for the endangered area and its surrounding area. Also, Alkaradaghi et al. [14] clarified the status of MSW management across the Sulaimaniyah governorate and presented a comprehensive overview and the implications of poor SWM in the study area. The results revealed that the daily per capita waste generation in the Sulaimanyah governorate is 1.32 kg by 2040, a cumulative amount of solid waste of about 10,445,829 tons.

Additionally, Hamza [7] examined MSW's content and quantity and classified recyclable waste items to limit waste disposal in the Pshdar region, which is a portion of Sulaimanyah province. Another study was conducted on the properties and structure of Mosul's solid waste [15]. Yasir et al. [16] conducted a study to assess waste management in the southern governorates of Iraq. In Kerbala, a detailed analysis was conducted using waste-aware standard displays for effective and coordinated SWM to evaluate the city's SWM system performance [17].

Iraq, one of the Middle East's international locations, has faced extreme hassles with SWM. Most towns in Iraq are absent of an operational approach to solid waste management and remedy, which has besieged the roads of Iraq with trash. In most parts of Iraq, solid waste collection and remediation agents are required, which has littered the roads of Iraq with rubbish. Although the MSW collection framework is accessible in several towns, but the user support is scarce. In landfill sites, the preparation for solid waste transfer is done with an obsolete system, such as an open dumping system, rather than a modern system that works and creates a sanitary landfill [7]. The objectives for conducting the present research in Erbil City were to: 1) evaluate the current situation of the MSW; 2) study the components and quantity of the MSW; and 3) study new approaches for recyclable solids.

2. Materials and methods

2.1 *Study area*

Erbil Governorate is located in the north of Iraq and covers an area of 14,873.68 km^2. It is the capital of the Kurdistan Region. Geographically, Erbil is elevated by about 414 m above sea level. Erbil City is located between 36° 11' 28.0068" N latitude and 44° 0' 33.0012" E longitude. It has around 1.5 million inhabitants, while Erbil Governorate has around 2.2 million inhabitants as of 2020. From the information obtained from the Erbil directorate of region service and environment, the MSW collected from Erbil City and transported to Kani Qirzhala landfill ought to be more than 2,000 tons/day. Kani Qirzhala landfill is positioned at the left of the Erbil-Mosul road, which is one of the important roads in Erbil City, Iraq. The landfill was initially opened in 2001 and is likewise located 15 km from the centre of Erbil [9, 18].

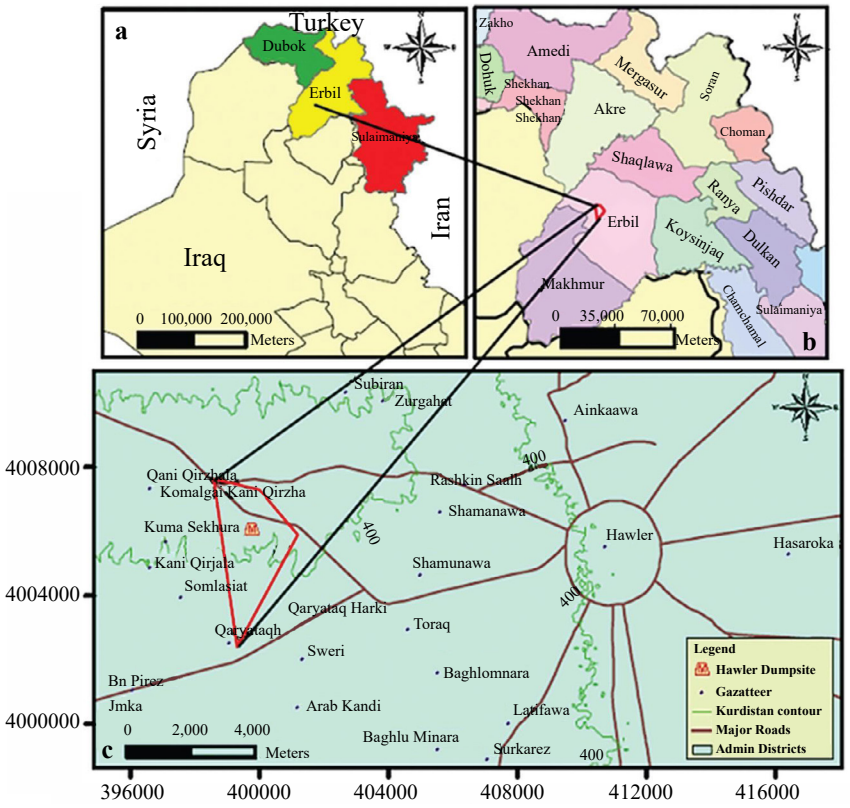

Figure 1. Satellite image of Erbil landfill [19]

2.2 *Data collection and analysis*

In this research, both quantitative and qualitative methods were applied for data collection. Erbil City's Directorate of Municipal Services and Environmental Protection and recyclable material locations were visited in order to collect quantitative data. Visiting was done on 21 November 2021, 1 December 2021, and 16 December 2021. A part of the MSW quantity and component data was obtained from the Directorate of Municipality Services and Environmental Protection. On the other hand, information on quantity, purchasing price, and recycling approaches was obtained from the owners of recyclable material locations, as shown in Figure 2. Recyclable materials in Erbil City are located on the Erbil-Bnaslawa old road, the Erbil-Makhmour road near the 120 m street interchange, and on the right side of the Erbil-Gwer main road (behind the Erbil landfill site).

Qualitative data collection was carried out via direct interviewing with the Director of Municipality Services and Environmental Protection in Erbil City and the owners of the recyclable material locations.

Figure 2. Recyclable materials in Erbil City

MSW or urban solid waste usually consists of rubbish, demolition and construction wastes, street sweepings, garden wastes, abandoned vehicles and equipment, and treatment plant residues.

Data collection on MSW characteristics was carried out by the Director of Municipality Services and Environmental Protection in Erbil City three times in 2020: the first data was collected from 1 January 2020 to 31 March 2020, the second data was collected from 1 April 2020 to 30 May 2020, and the last data was collected from 1 July 2020 to 30 September 2020. These data were then retrieved by the authors. The solid waste technology and its contents can be distinguished based on seasonal and socioeconomic rates. Erbil City is divided into six zones; collecting solid wastes in each zone is the responsibility of a municipal administration, there are waste collection companies in each municipality, such as Zone 1 (Municipality 1-Glass Stuttgart company), Zone 2 (Municipality 2-Qadar company), Zone 3 (Municipality 3-Baghi Prgul company), Zone 4 (Municipality 4-Artush company), Zone 5 (Municipality 5-Zug company), Zone 6 (Municipality 6-Nrkh company) and Municipality of Mala Omer collected the wastes by Hot Clean company. Also, the average daily MSW collection for all companies is more than 2,000 tons.

The solid wastes were additionally separated into several sub-fractions, for instance, food waste, yard waste, paper, cardboard, plastic, metal, textile, and glass. They were also evaluated by their weight plus the percentage composition and generation rate as labelled by Odonkor et al. [20].

The percentage composition of each of the solid waste components in each zone and at different times were calculated using Equation 1:

$$\text{Percentage composition of waste fraction} = \frac{\text{Weight of separated waste (kg)}}{\text{The total of mixed waste sampled (kg)}} \times 100 \quad (1)$$

The generation rate (kg/capita.day) is determined according to the combined or total waste accumulated in a day, and the separated fractions were calculated using Equation 2, which was also tested by Aziz et al. [12]:

$$\text{Generation rate} = \frac{\text{Weight of solid waste (kg)}}{\text{Population (capita)} \times \text{duration (day)}} \times 100 \quad (2)$$

The purpose of determining the generation rate is to get facts that can be used to determine the total quantity of waste substances to be managed.

3. Results and discussion

3.1 *MSW composition and quantification*

After collecting and analysing the solid waste in all the zones over three different periods, it has been discovered that the amount and composition of waste vary by area. These quantities are a result of generation services, distinctive buyer styles, resident composition, per capita waste generation, and social and financial status, which are impacted by financial variables.

All MSW samples were weighed during three different periods, and the average of all wastes created at each time was 2,216, 1,704, and 2,105 tons/day, respectively. The average solid waste additives and amounts for each zone are shown in Tables 1 to 3.

Table 1. MSW characteristics in Erbil City from 1 January 2020 to 31 March 2020

Project information		Amount and rate		Garbage and debris						
Working border	Company	Amount of MSW (ton/day)	%	Food (ton/day)	Paper and corrugated cardboard (ton/day)	Plastic (ton/day)	Metal (ton/day)	Glass (ton/day)	Yard trimmings and wood products (ton/day)	Other types (ton/day)
Municipality 1	Glass Stuttgart	198.08	8.94%	68.5	36.01	51.03	3.43	6.89	5.15	27.08
Municipality 2	Qadar	351.14	15.85%	121.42	63.84	90.45	6.07	12.22	9.13	48
Municipality 3	Baghi Prgul	270.13	12.19%	93.41	49.11	69.59	4.67	9.40	7.02	36.93
Municipality 4	Artush	609.56	27.51%	210.79	110.82	157.02	10.55	21.21	15.85	83.33
Municipality 5	Zug	295.48	13.33%	102.18	53.72	76.12	5.11	10.28	7.68	40.39
Municipality 6	Nrkh	452.28	20.41%	156.4	82.22	116.51	7.82	15.74	11.76	61.83
Municipality of Mala Omer	Hot Clean	39.33	1.77%	13.6	7.15	10.13	0.68	1.37	1.02	5.38
Total (ton)		2216		766.29	402.87	570.84	38.34	77.12	57.62	302.93
Total (%)			100	34.58	18.18	25.76	1.73	3.48	2.60	13.67

Table 2. MSW characteristics in Erbil City from 1 April 2020 to 30 June 2020

Project information		Amount and rate		Garbage and debris						
Working border	Company	Amount of MSW (ton/day)	%	Food (ton/day)	Paper and corrugated cardboard (ton/day)	Plastic (ton/day)	Metal (ton/day)	Glass (ton/day)	Yard trimmings and wood products (ton/day)	Other types (ton/day)
Municipality 1	Glass Stuttgart	103.37	6.07%	39	12.04	1.55	3.41	6.89	3.92	17.48
Municipality 2	Qadar	294.31	17.27%	111.04	73.93	4.41	9.71	12.22	11.15	49.77
Municipality 3	Baghi Prgul	206.32	12.11%	77.84	51.83	3.09	6.81	9.40	7.82	34.89
Municipality 4	Artush	500.34	29.36%	188.78	125.69	7.51	16.51	21.21	18.96	84.61
Municipality 5	Zug	203.94	11.97%	76.95	51.23	3.06	6.73	10.28	7.73	34.49
Municipality 6	Nrkh	382.01	22.42%	144.13	95.96	5.73	12.61	15.74	14.48	64.60
Municipality of Mala Omer	Hot Clean	13.71	0.8%	5.17	3.44	0.21	0.45	1.37	0.52	2.32
Total (ton)		1704		642.92	198.52	428.04	25.56	56.23	64.58	288.15
Total (%)			100	37.73	11.65	25.12	1.5	3.3	3.79	16.91

Table 3. MSW characteristics in Erbil City from 1 July 2020 to 30 September 2020

Project information		Amount and rate		Garbage and debris						
Working border	Company	Amount of MSW (ton/day)	%	Food (ton/day)	Paper and corrugated cardboard (ton/day)	Plastic (ton/day)	Metal (ton/day)	Glass (ton/day)	Yard trimmings and wood products (ton/day)	Other types (ton/day)
Municipality 1	Glass Stuttgart	183.21	8.7%	61.3	20.01	58.15	6.25	4.69	3.08	30.01
Municipality 2	Qadar	337.35	16.03%	112.37	36.84	107.07	11.50	8.64	5.67	55.26
Municipality 3	Baghi Prgul	250.09	11.88%	83.3	27.31	79.38	8.53	6.4	4.2	40.96
Municipality 4	Artush	599.74	28.49%	199.77	65.49	190.36	20.45	15.35	10.08	98.24
Municipality 5	Zug	276.84	13.15%	92.22	30.23	87.87	9.44	7.09	4.65	45.35
Municipality 6	Nrkh	430.19	20.44%	143.3	46.98	136.54	14.67	11.01	7.23	70.47
Municipality of Mala Omer	Hot Clean	27.58	1.31%	9.19	3.01	8.75	0.94	0.71	0.46	4.52
Total (ton)		2105		701.18	229.87	668.13	71.78	53.89	35.36	344.8
Total (%)			100	33.31	10.92	31.74	3.41	2.56	1.68	16.38

This study evaluates several components of solid waste, especially organic materials (fruit and vegetal shells, food waste), recyclable materials (paper and corrugated cardboard, plastic, metal, glass, etc.), yard trimmings and wood products. As shown in Tables 1 to 3, the largest composition is organics, which consists of decayed and biodegradable resources at 34.58%, 37.73%, and 33.31%, respectively, at three different data collection points These quantities show a slight variation between them; the cause for this fluctuation is related to food and different organic matter adversely affected as a result of excessive temperature or some other effect, as observed through plastic waste elements with the quantities of about 25.76%, 25.12%, and 31.74%, respectively. Moreover, paper and corrugated cardboard account for approximately 18.18%, 11.65%, and 10.92% of recyclable materials, respectively. Conversely, metal accounts for the least amount of waste, which is about 1.73%, 1.5%, and 3.41%, respectively. Meanwhile, the amount of glass is 3.48%, 3.3%, and 2.56%; additionally, the quantity of yard trimmings and wood products is about 2.6%, 3.79%, and 1.68%

individually. They are allowing the amount of plastic in recyclable material to be categorised as more than paper, metal, glass, etc. To compare this data with another previous study in Erbil City conducted by Aziz et al. [9], the average proportion of decomposable materials such as plastic, corrugated and paper, glass, aluminium, and ferrous metal were 34.87%, 13.39%, 1.84%, 0.5%, and 1.74%, respectively. Hence, it is discovered that organic waste is around 28%; these data have shown that plastic had a large amount in that year. However, Shekha [11] showed that the waste from households in Erbil was mainly organic, a large portion of which was food scraps (79%), afterward papers (5%), and yard trimmings and wood products (3%); whereas the inorganic composition was denoted by plastic and nylon; glass and porcelain; and metals (5%, 4%, and 3%, respectively). Similar results were obtained by Aziz et al. [12]. The weight ratios of food, plastic, paper, metal, glass, and cloth as constituents of solid household waste were 79.34%, 6.28%, 5.9%, 3.6%, 3.42%, and 1.45%, individually. The percentage of the total amount of MSW is subject to certain aspects, such as the season, lifestyle, geographic condition, demographic profile, and local legislative impact [21]. Figure 3 shows the average weight percentages of MSW in Erbil City and the Erbil landfill area for the year 2020 at three different times.

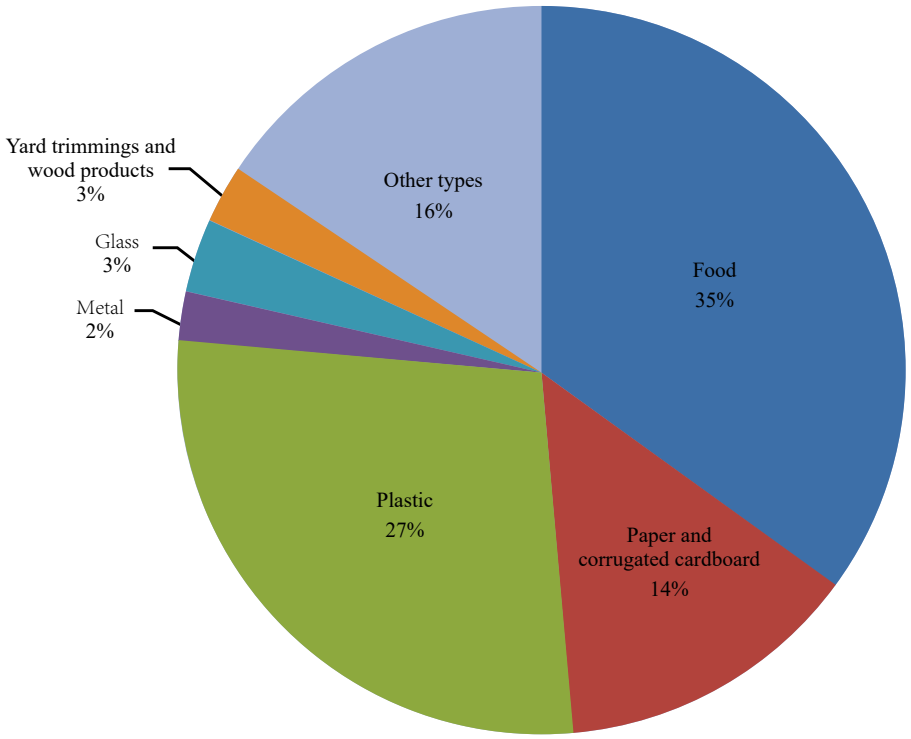

Figure 3. Average weight percentages of MSW components in Erbil City

Food waste, which accounts for the majority of MSW in this study, indicates the most significant amount of recyclable waste and depicts the most elevated portion of household waste. Anaerobic composting is a process commonly done in nature. Anaerobic composting is oxygen-free composting. In this procedure, organic matter is broken down by various types of anaerobic microorganisms [22]. There are also highly critical materials from which products can be remanufactured to create benefits; these materials include paper and cardboard, glass, metals, wood, and wastes from construction work, as recycling is one of the fundamental methods in economic exercises [5]. Additionally, waste-to-energy processes have the benefits of source operation and the minimization of landfill dumping [23].

The MSW generation rate for the data collection periods in 2020 is given in Table 4. The total waste generation in Erbil City for the year 2020 at three different times was 2.61 kg/capita/day, 1.89 kg/capita/day, and 2.39 kg/capita/day, respectively, for the population of Erbil City, which was approximately 860,000 in that year. It can be seen that the generation rate for the second time, which was from 1 April 2020 to 30 June 2020 of the collected data, decreased to 1.89 kg/capita/day and then the generation rate increased again. In this study, the average generation rate was about

2.30 kg/capita/day, which is higher than estimated by published works [10-12], which were about 0.654 kg/capita/day, 0.420 kg/capita/day, and 0.632 kg/capita/day, respectively. Additionally, it is greater than the reported data by Aziz et al. [9], which was about 1.27 kg/capita/day. The MSW generation rate for Municipality 4 was higher than in other areas; this may be due to the giant Langa Market, which is located in this part. On the other hand, the lower generation was recorded in the Erbil central business district due to the collection of recyclable waste separately. The MSW generation rate in Erbil City has increased as a result of lifestyle changes and increased per capita income.

Table 4. MSW generation rate in Erbil City in 2020

Working border	Company	Amount of MSW (1 January 2020 to 31 March 2022) (ton/day)	Amount of MSW (1 April 2020 to 30 June 2022) (ton/day)	Amount of MSW (1 July 2020 to 30 September 2022) (ton/day)	Generation rate (1 January 2020 to 31 March 2022) (kg/capita/day)	Generation rate (1 April 2020 to 30 June 2022) (kg/capita/day)	Generation rate (1 July 2020 to 30 September 2022) (kg/capita/day)
Municipality 1	Glass Stuttgart	198.08	103.37	183.21	1.40	0.73	1.30
Municipality 2	Qadar	351.14	294.31	337.35	2.49	2.09	2.39
Municipality 3	Baghi Prgul	270.13	206.32	250.09	1.92	1.46	1.77
Municipality 4	Artush	609.56	500.34	599.74	4.32	3.55	4.25
Municipality 5	Zug	295.48	203.94	276.84	2.10	1.45	1.96
Municipality 6	Nrkh	452.28	382.01	430.19	3.21	2.71	3.05
Municipality of Mala Omer	Hot Clean	39.33	13.71	27.58	2.809	0.98	1.97
Average		316.57	243.43	300.71	2.61	1.85	2.39

3.2 *Solid waste management status*

SWM is related to the control of the generation, capacity, collection, exchange, transport, preparation, and transfer of solid wastes. It is a method that is in accord with the most excellent standards of open health, financial matters, designing, preservation, aesthetics, and different natural contemplations [24].

The solid waste administration problems began with the preliminary present-day human lifestyles. However, it has become one of the most prevalent problems in the world due to population growth, financial growth, financial development, and the industrial revolution [25]. The flow chart in Figure 4 shows the interrelationships between the useful components in SWM.

The cost of MSW includes budgets for collection, transportation, transfer stations, administration, and treatment. The presidency of Erbil Municipality, private companies, and independent persons participate in the collection and transportation of the MSW. Meanwhile, only the government contributes to the administration, supervision and treatment at the landfill site. Consequently, defining budgets for collection, transportation, transfer stations, administration, and treatment.

More than 2,000 tons of waste are produced daily in Erbil City. On average, every individual in the country produces about 1.338 kg of waste every day in the city and rural areas.

The collection of solid waste in most districts of the Erbil Governorate is mostly conducted by private companies. The municipalities are the specialists capable of observing the collection and exchange of solid waste from major urban cities, including streets and private, industrial, and commercial ranges, to the final disposal area.

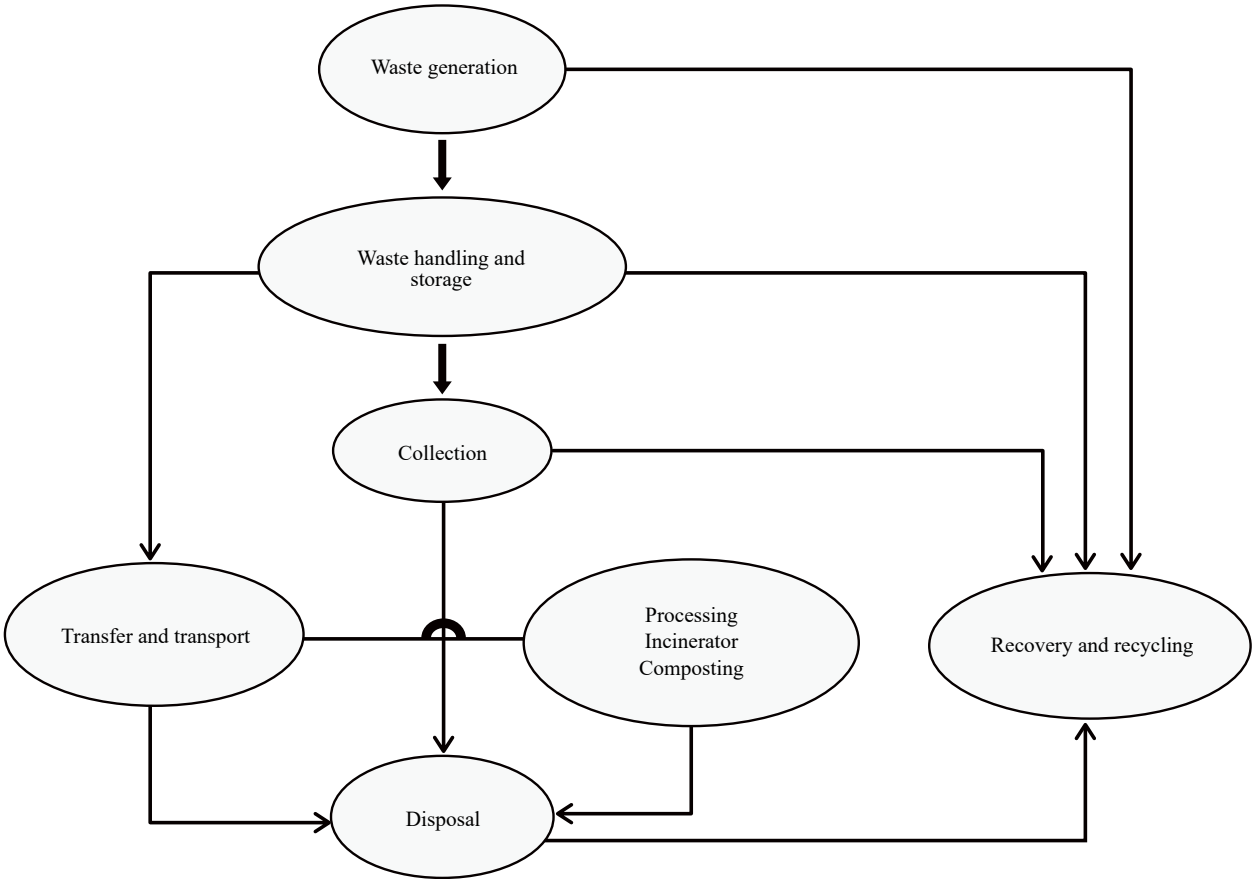

Figure 4. Schematic diagram of SWM

Al-Mohammed et al. [26] stated that Iraq requests stations for sorting and transporting waste and stations for recycling plastic, paper, and metals. To date, most commonly, MSW is collected and disposed of in landfills and dumpsites. There is no proper design, planning, handling, or treatment of MSW in Iraq. Hence, a lack of appropriate MSW management in Iraq is still occurring to this day [26]. Attempts to collect recycling materials can be seen on the ground, but there is still no applicable plan for the separation, transportation, treatment, and recycling of recyclable materials such as cartons, papers, metals, glass, plastics, batteries, tyres, etc.

3.3 *New approach for recycling solid waste in Erbil City*

The process of recovering and reusing materials from waste is known as recycling. Recycling of solid waste refers to the reuse of products that can be reused by recovering resources such as steel, copper, plastic, paper, and glass. Recycling and recovery are just one phase of an integrated approach to waste management. This includes reducing the amount of waste generated, composting, incinerating, and landfilling.

Additionally, in order to reduce the proportion of substances disposed of as waste, the waste change scheme has provided great benefits to a range of groups by offering savings in the disposal and raw material prices and costs, thereby enhancing the company's public image.

The rate of recycling resources from waste has increased dramatically in recent years in Erbil City. Waste recycling in growing countries depends mostly on the informal restoration of materials with the aid of scavengers or waste pickers.

In Erbil City, the researchers investigated the important role of recycling. Aziz et al. [12] showed that the average weight ratio of recyclable materials (i.e., plastic, paper, metal, and glass) was 19.2% and that the average daily generation rate of recyclable materials is 87.99 tons (320.03 tons/year). Also, Shekha [11] presented that the huge

section of the refuse produced by the humans beneath the study can be recycled or is perhaps recyclable (13.79% can be recycled, 85.87% is possibly recyclable, and 0.34% can't be recycled). In addition, Aziz et al. [9] studied that the quantity of everyday generation of MSW in Erbil City was once observed to be around 1.27 kg/capita/day. The percentage ratios of recyclable materials, such as plastic, paper and corrugated cardboard, glass, aluminium, and ferrous metals, were 34.87%, 13.39%, 1.84%, 0.5%, and 1.74%, respectively, and the expected profits from the recyclable materials were 334,488.85 $/day. Furthermore, food or organic waste, which was also found to be the most important part generated from solid waste, can be used in composting. Jalal and Shekha [10] confirmed that the research was largely directed at performing several techniques for changing MSW into compost and soil fertilisers, and the fee of compost quality index was stretched from 54.73 to 321.12. The compost quality grade for all kinds of composts falls below the tremendously suitable category. Previously, all components of MSW were mixed and disposed of at the Erbil landfill site. Consequently, the amount of disposed MSW was huge and impacted the environment. Currently, papers and cartons, plastic materials, metals, and tyres are collected by people and private companies, and the processes are regarded as a new approach for recycling solid waste in Erbil City. As a result, organic and other wastes are lessened, leading to a decrease in MSW at the landfill. Collected recycled materials are later used as raw materials, which serve as a source of income for numerous people and companies. Collected papers and cartons are used as rollers for producing new products in Erbil City, while plastics are ground and become granular. The plastics are later used as raw materials for new plastic materials. Iron was collected and sent to the steel factories to produce new steel bars. The Directorates of Municipality, private companies, and people have a great role in the management of MSW in the city.

3.3.1 *Plastic materials*

According to the Directorate of Service and Environment Protection in Erbil City, the average daily collection of MSW for Erbil City ranged from 1,704 tons to 2,216 tons. The number of plastics ranged from 428.04 tons/day to 668.13 tons/day (Tables 1 to 3). The price is 175 $/ton and the source of plastic is Erbil City. There are many workers who collect plastic from different parts of Erbil City and transfer it to different factories. They will clean it and make it granular, which will be reused in different types of plastic materials such as containers of crops, nylon, and so on.

3.3.2 *Metals*

The predicted ratio of metals in the total MSW of Erbil City is 2%, which is about 44.2 tons/day (Tables 1 to 3). Collected metals include iron, brass, aluminium, and copper. The price is 235 $/ton, and the sources of metals are mostly from Erbil City and sometimes from other governorates, such as Duhok City. The workers will collect the metals, segregate them from each other, and transfer them to different steel factories. The steel factories in Erbil City will reuse the metals after separating, cleaning, washing, and melting them.

3.3.3 *Cartons and papers*

The predicted ratio of cartons and papers in the total MSW of Erbil City is 14%, which is about 271.6 tons/day (Tables 1 to 3). The price is 135 $/ton, and the source of the cartons and papers is from Erbil City. The workers will collect it and reuse it in local factories, and sometimes they will export it to Iran and Turkey factories as well.

3.3.4 *Tyres*

There is no exact prediction of tyre amount in Erbil City; they would collect it in one place on the left side of Makhmour Road. Some drivers reuse scrap tyres as second-hand tyres for their vehicles. The tyres could also be used as an alternative fuel for heat production in cement and steel factories.

3.4 *Combustible and non-combustible materials*

MSW burning can decrease the capacity of the waste and improve energy. The batch-fed burners made in the 1930s and 1940s reduced the volume of waste materials but were significant supporters of air contamination issues [27]. The largest of these incinerators have been closed down or transformed into more current designs. The innovative

incinerators utilise inventive tools to deliver vapour more productively and decrease air poisons to a better degree.

As presented in Figure 5, the average weight ratios for combustible materials (i.e., plastic, paper, corrugated cardboard, wood, and other types), non-combustible materials (i.e., metal and glass), and recyclable materials were 60%, 5%, and 35%, respectively.

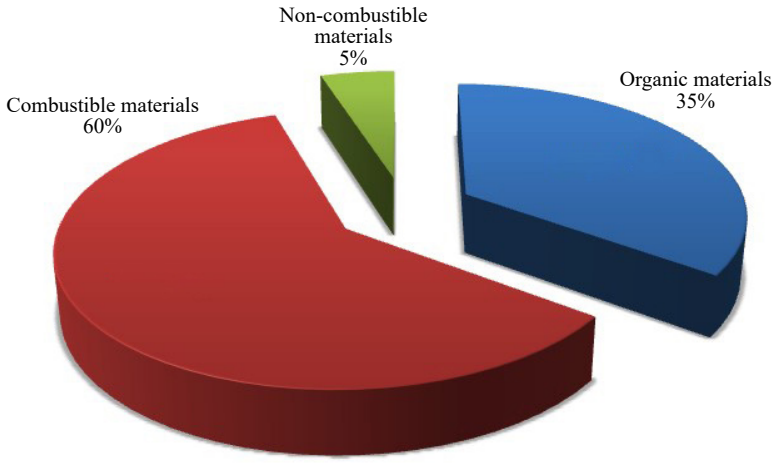

Figure 5. Schematic diagram of SWM

4. Conclusion

Over the last few years, the administration of solid waste, which consists of decreasing, recovering, and dumping waste, has grown to be more and more fundamental due to the fact that the amount of MSW produced on a daily basis is rapidly increasing due to growing populations and variations in the way of life.

This investigation focused on the MSW of Erbil in the Kurdistan Region of Iraq; the outcomes indicate that the average generation rate of MSW was around 2.30 kg/capita/day. Also, MSW usually contained combustible (60%), non-combustible (5%), and recyclable materials (35%). The average weight ratios of domestic solid waste components were: organic materials (35%), plastics (27%), paper and corrugated cardboard (14%), metals (2%), glass (3%), yard trimmings and wood products (3%), and other types (16%). The study observed that large quantities of food waste are produced from ordinary sources. Additionally, the expected revenue from recyclable solid wastes in Erbil City for plastic, metal, cartons, and papers was 175 $/ton, 235 $/ton, and 135 $/ton, respectively.

Finally, the specialist participating in the private segment ought to have a satisfactory plan to progress solid waste administration preparation and be capable of providing satisfactory solutions for decreasing the amount of waste that goes to landfills. Besides, both public and non-public sections should also increase public attention towards the waste administration system by using protective workspaces and boards, which will allow the community to support the management solid waste.

Acknowledgement

The authors would like to thank Dr. Farman Khalil (Director of Municipality Services and Environmental Protection in Erbil City) for supporting the work and providing information for this research.

Conflict of interest

The authors declare that there is no conflict of interest.

References

[1] Ferronato N, Bezzi M, Zortea M, Torretta V, Ragazzi M. An interdisciplinary approach for introducing sustainable integrated solid waste management system in developing countries: The case of La Paz (Bolivia). *Procedia Environmental Science Engineering and Management*. 2016; 3(2): 71-81. https://iris.unitn.it/handle/11572/208735

[2] Carlos-Alberola M, Gallardo Izquierdo A, Colomer-Mendoza FJ, Barreda-Albert E. Design of a municipal solid waste collection system in situations with a lack of resources: Nikki (Benin), a case in Africa. *Sustainability*. 2021; 13(4): 1785. https://doi.org/10.3390/su13041785

[3] Connett P, Sheehan B. *A citizen's agenda for zero waste*. Grass Roots Recycling Network; 2001. https://archive.grrn.org/zerowaste/community/activist/citizens_agenda_2_read.pdf [Accessed 14th December 2022].

[4] Bolaane B. Constraints to promoting people centred approaches in recycling. *Habitat International*. 2006; 30(4): 731-740. https://doi.org/10.1016/j.habitatint.2005.10.002

[5] Tulebayeva N, Yergobek D, Pestunova G, Mottaeva A, Sapakova Z. Green economy: Waste management and recycling methods. In: *The 1st International Conference on Business Technology for a Sustainable Environmental System (BTSES-2020), 19-20 March 2020, Almaty, Kazakhstan*. Les Ulis, France: EDP Sciences; 2020. p.1-9. https://doi.org/10.1051/e3sconf/202015901012

[6] McElhatton A, Pizzuto A. Waste and its rational management. In: McElhatton A, do Amaral Sobral PJ. (eds.) *Novel technologies in food science*. New York: Springer; 2012. p.3-19. https://doi.org/10.1007/978-1-4419-7880-6_1

[7] Hamza A. Municipal solid waste quantity, ingredients, and site disposal problems in Pshdar District in Sulaimanyah: Iraqi Kurdistan Region, Iraq. *Kufa Journal of Engineering*. 2020; 11(4): 1-8. https://journal.uokufa.edu.iq/index.php/kje/article/view/419

[8] Musahinib JM. Waste recycling in Iraq, wasted resources and lost opportunity. *Journal of Administration and Economics*. 2020; 2020(123): 76-88. https://www.iasj.net/iasj/article/182382

[9] Aziz SQ, Ismail SO, Omar IA. Recyclable solid waste materials management in Erbil City-Iraq. *International Journal of Engineering Inventions*. 2019; 8(1): 57-62. https://www.ijeijournal.com/papers/Vol8-Issue1/G08015762.pdf

[10] Jalal SY, Shekha YA. Compost quality assessment for the household solid wastes of Erbil city. *Zanco Journal of Pure and Applied Sciences*. 2019; 31(6): 143-149. https://www.researchgate.net/publication/337951935_Compost_quality_assessment_for_the_household_solid_wastes_of_Erbil_city

[11] Shekha YA. Household solid waste content in Erbil City, Iraqi Kurdistan Region, Iraq. *Zanco Journal*. 2011; 23(3): 1-8. https://www.academia.edu/54675647/Household_Solid_Waste_Content_in_Erbil_City_Iraqi_Kurdistan_Region_Iraq

[12] Aziz SQ, Aziz HA, Bashir MJ, Yusof MS. Appraisal of domestic solid waste generation, components, and the feasibility of recycling in Erbil, Iraq. *Waste Management & Research*: *The Journal for a Sustainable Circular Economy*. 2011; 29(8): 880-887. https://doi.org/10.1177/0734242X10387462

[13] Rashid CR, Tahir JJ, Mustafa OM. Solid waste management: A case study in Chamchamal (Debra Valley open dump), Sulaimani, Kurdistan Region. In: Kareem Sangawi AW, Saeed SR, Rachid SK. (eds.) *Proceedings of the 2nd International Conference of Natural Science (ICNS 2017), 5-6 July 2017 College of Basic Education, Charmo University, Chamchamal, Sulaimani, Kurdistan-Iraq*. Sulaimani, Kurdistan-Iraq: ICNS2017; 2017. p.210-219. http://dx.doi.org/10.31530/17025

[14] Alkaradaghi K, Ali SS, Al-Ansari N, Ali T, Laue J. Quantitative estimation of municipal solid waste in Sulaimaniyah Governorate, Iraq. In: Ksibi M, Ghorbal A, Chakraborty S, Chamine HI, Barbieri M, Guerriero G, et al. (eds.) *Proceedings of 2nd Euro-Mediterranean Conference for Environmental Integration (EMCEI-2): Recent Advances in Environmental Science from the Euro-Mediterranean and Surrounding Regions, 10-13 October 2019, Sousse, Tunisia*. New York: Springer; 2021. p.265-270. https://doi.org/10.1007/978-3-030-51210-1_44

[15] Al-Rawi SM, Al-Tayyar TA. Solid waste composition and characteristics of Mosul City/Iraq. *Science Journal of University of Zakho*. 2013; 1(2): 496-507. https://www.researchgate.net/publication/340256113_Solid_Waste_Composition_and_Characteristics_of_Mosul_CityIRAQ

[16] Yasir RA, Hussein TE, Khalaf HA, Selman MD, Hadi FK, Semir AH. Survey on solid waste management in the southern Governorates of Iraq. *Marsh Bulletin*. 2012; 7(1): 69-101. https://www.iasj.net/iasj/article/65995

[17] Abdulredha M, Khaddar RAL, Jordan D, Hashim K. The development of a waste management system in Kerbala during major pilgrimage events: Determination of solid waste composition. *Procedia Engineering*. 2017; 196: 779-784. https://doi.org/10.1016/j.proeng.2017.08.007

[18] Aziz SQ, Maulood YI. Contamination valuation of soil and groundwater source at anaerobic municipal solid waste landfill site. *Environmental Monitoring and Assessment*. 2015; 187: 1-11. https://doi.org/10.1007/s10661-015-

4971-y
[19] Gardi SQ. Environmental impact assessment of Erbil dumpsite area-West of Erbil City-Iraqi Kurdistan Region. *Journal of Tethys*. 2017; 5(3): 194-217. https://jtethys.journals.pnu.ac.ir/article_4570.html
[20] Odonkor ST, Frimpong K, Kurantin N. An assessment of house-hold solid waste management in a large Ghanaian district. *Heliyon*. 2020; 6(1): 1-7. https://doi.org/10.1016/j.heliyon.2019.e03040
[21] Sfeir H, Reinhart DR, McCauley-Bell PR. An evaluation of municipal solid waste composition bias sources. *Journal of the Air & Waste Management Association*. 1999; 49(9): 1096-1102. https://doi.org/10.1080/10473289.1999.10463903
[22] Yang B, Ma Y, Xiong Z. Effects of different composting strategies on methane, nitrous oxide, and carbon dioxide emissions and nutrient loss during small-scale anaerobic composting. *Environmental Science and Pollution Research*. 2019; 26: 446-455. https://doi.org/10.1007/s11356-018-3646-y
[23] Arafat HA, Jijakli K, Ahsan A. Environmental performance and energy recovery potential of five municipal solid waste treatment processes. *Journal of Cleaner Production*. 2015; 105: 233-240. https://doi.org/10.1016/j.jclepro.2013.11.071
[24] Pleşea DA, Vişan S. Good practices regarding solid waste management and recycling. *International Journal of Scientific & Engineering Research*. 2010; 5(5): 956. https://www.ijser.org/paper/Good-Practices-Regarding-Solid-Waste-Management-and-Recycling.html
[25] Castillo AL, Otoma S. Status of solid waste management in the Philippines. In: *Proceedings of the 24th Annual Conference of Japan Society of Material Cycles and Waste Management 2013*. Japan: Japan Society of Material Cycles and Waste Management; 2013. p.677-678. https://doi.org/10.14912/jsmcwm.24.0_677
[26] Al-Mohammed MA, Ulutagay G, Alabdraba WMS. The reality of solid waste management in Iraq and ways of development. *Tikrit Journal of Engineering Sciences*. 2021: 28(3): 1-20. https://doi.org/10.25130/tjes.28.3.01
[27] Singh GK, Gupta K, Chaudhary S. Solid waste management: Its sources, collection, transportation and recycling. *International Journal of Environmental Science and Development*. 2014; 5(4): 347-351. https://doi.org/10.7763/IJESD.2014.V5.507