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Towards Sustainable Waste Management: A Study of Household Solid Waste Generation in Koya City

Anwer Hazim Dawood [1,*], Salah Farhan A. Sharif [2]

[1] Department of Geotechnical Engineering, Faculty of Engineering, Koya University, Koya, 44023, Iraq

[2] Medical Instrumentation Department, College of Engineering Technology, Al-Kitab University, Kirkuk, 36001, Iraq

*Corresponding Author: Anwer Hazim Dawood, E-mail: anwer.hazim@koyauniversity.org

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Abstract

Solid waste management (SWM) is an increasing challenge in Koya and its surrounding areas, driven by population growth and changing consumption patterns. This study assesses the current state of household solid waste (SW) generation and composition in the Koya District. A field survey was conducted across selected neighborhoods in Koya City to estimate household waste generation rates and analyze waste composition. The findings were compared with Koya Municipality records and showed strong consistency. The results indicate an average household waste generation rate of 1.035 kg/person/day in Koya City, with lower and higher rates observed in the Ashti (0.73 kg/person/day) and Shoresh (1.21 kg/person/day) districts, respectively. Composition analysis revealed that daily household waste is approximately 121 tons, predominantly composed of decomposable organic materials and paper, plastics, metals, glass, textiles, and dust. All household solid waste is disposed of in landfills without any reduction, reuse, or recycling practices. These findings highlight the urgent need for integrated SWM strategies in Koya to minimize environmental impacts and promote sustainable waste management.

1. Introduction

The term "SW" refers to urban waste, which encompasses seven categories: household waste, commercial waste, institutional waste, street waste, construction and demolition waste, sanitation waste, and industrial waste [1]. Solid urban waste often refers to (SW) in municipalities or other government bodies, originating from homes, streets and public areas, stores, offices, and hospitals. SW consists of discarded materials with low liquid content that may pose environmental hazards. It includes municipal, industrial, and commercial waste from agricultural operations and animal husbandry. Demolition waste and associated SW represent one of the growing problems facing the municipality of Koya and its related aspects [2]. This problem is exacerbated dramatically due to the increase in population, rapid urban development, and the failure to follow appropriate SWM methods [2].

In First Nations communities, the focus has been on controlling costs and goods, not the environment,

with the main issues being population growth, urban development, and industrialization faced by developing countries in Africa, Asia, and South America, all of which point to further increases in waste due to population growth [3].

The fundamental goal of the programs for SWM is to reduce environmental contamination. In developing countries, per-capita waste generation rates are lower than in higher-income countries, but the capacity of developing countries for waste management, recycling, reuse, and disposal is limited by the local authorities responsible [4].

While SWM challenges are common in developing regions, understanding the specific context of Koya District remains limited due to a lack of comprehensive studies. Therefore, reviewing existing research on solid waste generation, management, and challenges in nearby regions and comparable contexts is essential to frame the current study.

This study aims to evaluate household solid waste generation in Koya District, focusing on quantifying the volume and analyzing the composition of domestic waste. This assessment is crucial for safeguarding human health, protecting the environment, and conserving natural resources. The following section reviews existing literature on solid waste management practices and challenges in similar contexts.

2. Literature Review

A few SW studies conducted in the cities neighborhood of Koya, Aziz and Mustafa [5] in 2018 conducted a study on Evaluations of Municipal Solid Waste from Erbil City, evaluating the economic and energy potential of solid waste in Erbil City, focusing on landfill management and energy recovery. Key findings include:

The daily waste disposal at the Erbil Landfill Site (ELS) is around 2,000 tons/day, with 34% plastic, 27% food waste, 14% paper, and 6% wood, due to poor landfill management, methane emissions, and leachate pollution are significant environmental concerns [5]. In 2020, Hamza conducted a Solid Waste Components study in Ranya City, east of Koya. This study focuses on the seasonal variations in the Ranya District's solid waste generation and composition. The average total solid waste generation was 286.9 tons/day, with a per capita waste generation of 1.108 kg/day [6]. Also, Alkaradaghi and his colleagues conducted a study in 2016, Quantitative Estimation of Municipal Solid Waste in Sulaimaniyah City; this research provides a detailed analysis of solid waste generation trends in Sulaimaniyah Governorate and predicts future waste quantities up to 2040. Key points include the daily per capita waste generation in 2016 being 1.12 kg, which is expected to rise to 1.32 kg by 2040 [7].

In 2021, Al-Mohammed, Ulutagay, and Alabdraba studied SW Management in Iraq [8]. This study investigates the current state of SWM in Iraq and explores potential development strategies. Data were collected through interviews and questionnaires from 326 participants between February and March 2021.

The study employed qualitative and quantitative methods, analyzed using IBM SPSS v23, to provide

comprehensive insights. Key findings highlight weaknesses in municipal waste management, including the lack of structured collection schedules, inadequate sorting at the source (64% of respondents), and insufficient coordination between municipalities and the public.

Additionally, 39% of participants acknowledged the absence of sanitary landfills, while 33% emphasized the lack of effective policies and regulations. However, 49% of respondents were willing to sort waste if provided with appropriate containers, and 53% agreed to pay for waste collection services. The study recommends establishing sorting and recycling stations for plastic, paper, and metals and environmentally compliant sanitary landfills. It also emphasizes the need for stronger municipal involvement, greater private sector participation, and community awareness programs through educational initiatives in schools and universities. These measures can enhance Iraq's SWM system and promote sustainable waste management practices [8].

Internationally, the total SW quantity created in urban India is estimated in the Planning Commission report (No.5) to be 62 million tons annually (TPY) (0.573 million metric tons per day, MMT per day), with an estimated 165 million tons per year in the urban center by 2031, and 436 million tons by 2050 [9-11].

Table 1. Change in sources of municipal SW [11]

Year	Bio-degradable million ton	Paper million ton	Plastics million ton	Metal million ton	Glass million ton	Rags million ton	Inert million ton	Others million ton
1996	42.21	3.63	0.6	0.49	0.6	0	45.13	0
2005	47.43	8.13	9.22	0.5	1.01	4.49	25.16	4.02
2011	42.51	9.63	10.11	0.63	0.96	0	17	0

SWM is a management system that reduces or eliminates the adverse impact on the environment & human health generated by different types of waste. Each municipality tries to provide its inhabitants with an SWM facility. In the United States of America, for example, a few decades earlier, watertight garbage cans were first introduced, and sturdier vehicles were used to collect and transport waste. Slowly, the changes occurred globally, and in today's scenario, many different processes are involved in effectively managing waste from municipal areas. Among all the mentioned waste management steps, the SW collection (SWC) process deals with different challenging issues [12]. In this process, vehicles normally start with human resources from their sources (say from office complexes or collection centers).

During the collection period from various areas or regions, vehicles keep their engines operating even when waste bins are loaded, resulting in enormous fuel consumption and higher emissions. Every month, a large portion of the total budget allotted for SWM by the state or central government is used for the SWC process, and these budgets mostly go to fuel consumption [2]. Waste collections are conducted without perceiving or analyzing demand, and the drivers are normally responsible for constructing travel routes for waste collection. Therefore, various research [9, 13, 14] have shown that diverse advanced technologies, including information management, time, risk, and environment, lead to a better economy and environment.

This work mainly focuses on the overall municipal SWM system with the help of recent advanced technologies. As this waste comes under the umbrella of SW, the overall management techniques for handling this waste are considered formally. It is harder to collect because most people live in spontaneous settlements, which are often illegal and outside governmental control. Most of them are poor and are not subject to law. It should be remembered that deteriorating health conditions affect the inhabitants of low-income communities and the general population. According to Ndum, Busch, and Voigt [3], most waste generated worldwide (57 to 85%) has been disposed of primarily in sites, including open dumping and sanitary landfill sites.

Methods of disposing of SW differ dramatically depending on waste forms and local circumstances. Thus, waste management systems should consider the fundamental objectives, thoroughly consider local circumstances and causes, appreciate the full spectrum of available technology solutions, and know the traditional know-how and systems built by residents [15]. Municipal waste disposal is among developing countries' most severe and contentious urban problems. Local governments are facing it. Despite emerging technologies, production decisions, and consumer strata, per capita waste generation continues to increase the population's income level and city volume effect, see Table 2.

Table 2. SW quantities generation according to income and city volume kg/Capita/day [16]

	Low-income country kg/Capita/day	**Middle-income country kg/Capita/day**	**High-income country kg/Capita/day**
Mixed urban waste in a large city	0.5-.75	0.55-1.1	0.75-2.2
Mixed urban waste in small to medium city	0.35-0.65	0.45-0.75	0.65-1.5
Residential waste only	0.25-0.45	0.35-0.65	0.55-1.0

Also, the SW quantity depends on general consumer habits and a country's level of technical development. It is a popular sense that waste in the wrong location is nothing other than useful material, and, in the world, no material is useful [16].

Waste management has become an urgent problem for industrial societies due to economic development and lifestyle, which has led to the generation of vast amounts of waste. The solutions to the issue do not end with waste management technologies like landfill site selection and incineration [17]. People should shift their attitude towards waste as waste forms. It has led people to understand that the alternative is to use waste instead of destruction as a resource. Public sensitivity and waste attitudes will impact the population's Willingness to engage in proper waste management activities.

This study aims to evaluate household SW Generation in Koya District, focusing on the initial phases: quantifying and estimating the volume of domestic waste generated and analysing its composition. This contributes to safeguarding human health, protecting the environment, and conserving natural resources.

According to the literature, the lack of comprehensive SW characterization studies in Koya is the research gap.

3. Materials and Methods

To conduct the research, the following methodology is employed:

Data collection is carried out for the population using SW components, including food (organic material), paper, metallic waste, plastic, glass, cloth, and dust. Additionally, Koya City is divided into three zones to estimate solid waste generation effectively.

3.1. Study Area

Koya district has an important geographical location, as it is located between three governorates, Sulay-maniyah, Kirkuk, and Erbil, and it is bordered on the east and south by the Lower Zab River that separates it from the Kirkuk and Sulaymaniyah governorates and the north-east by Mount Heibat Sultan, and embraced from the west by Mount Bawaji. Koya district was divided into six municipalities: Koya, Taq Taq, Segrdakan, Shorash, Shorash, Ashti, And Saktan. The location of municipalities is shown in Figure 1.

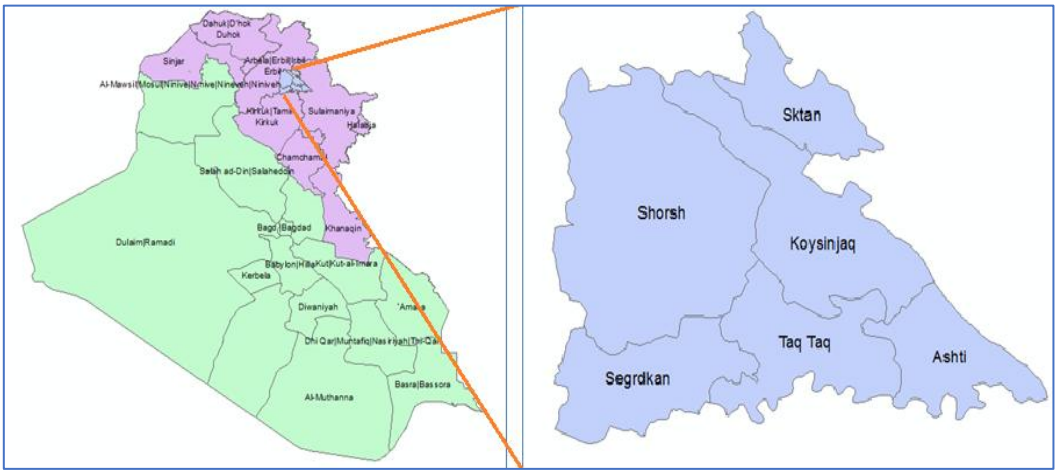

Figure 1. Location of the study area: Koya district

3.2. Population Estimation

The population of Koya is a key element in the assessment of the quantities of SW generated. One method for estimating the total amount of SW generated is to rely on published data for countries with similar socioeconomic indicators and obtain the amount of waste per capita per day. This number, multiplied by the studied population, can provide the total amount of the generated waste. According to the Koya district's municipality of Koya, a census indicated the district's total population was 119640 in 2019, see Figure 2 [2].

This research adopted this data for the SW generation rate study to help evaluate waste management.

3.3 Waste Generation Rate by Adopted Population of Koya District

According to the Kurdistan Regional Government [2], a summary of SW generation and collection service in the Koya district during the period Jan 01 to Jul 01, 2019, is shown in Table 3, and Figure 3 shows the daily SW generation of the Koya district (Kg/capita).

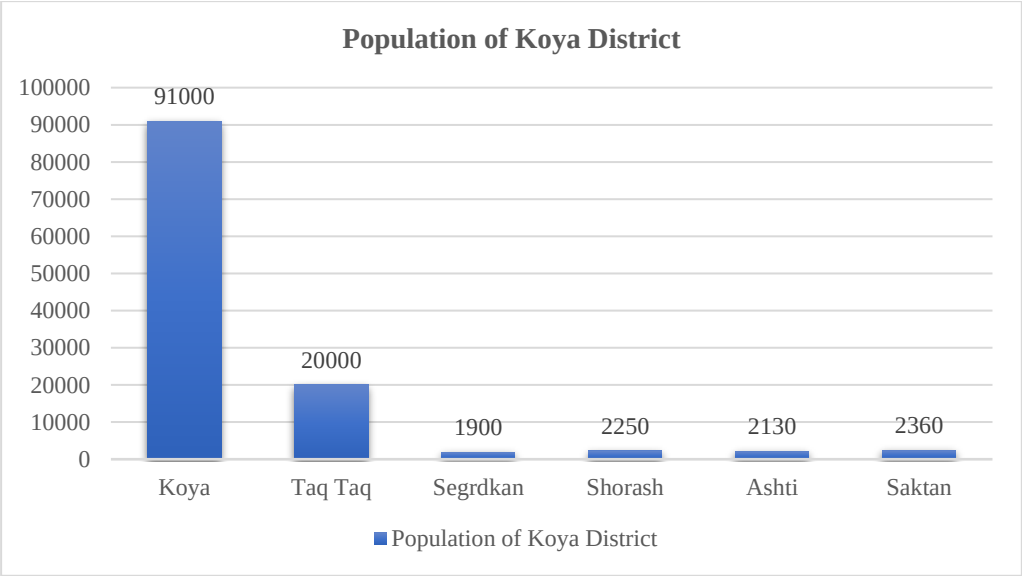

Figure 2. Population of Koya district [2]

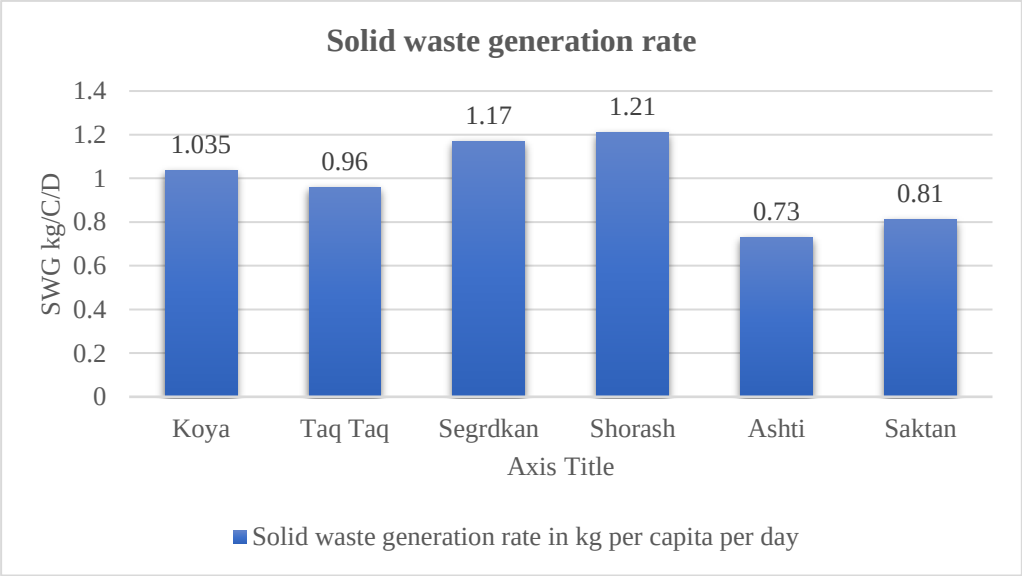

Figure 3. Daily SW generation of Koya district Kg per capita [2]

Table 3. Summary SW generation and collection service in Koya district from Jan 01 to Jul 01, 2019 [2]

No.	Municipality	Company	Population	Daily SWG Kg/C/D	Daily Waste Generation Kg	AnnuallSWG Ton /Y
1	Koya	Papa Group	91000	1.035	94148	34364
2	Taq Taq	Papa Group	20000	0.96	19143	6987.2
3	Segrdqan	Papa Group	1900	1.17	2223	811.395
4	Shorash	Papa Group	2250	1.21	2723	993.895
5	Ashti	Papa Group	2130	0.73	1549	565.385
6	Saktan	Papa Group	2360	0.81	1914	698.61
	Total		119640	Mean =0.986	121700	44420.5

So, the data on the SW generation rate indicate that the average SW generation is 0.986 kg per capita per day, and the total is about 44420.5 tons per year, which is dumped as garbage into landfills without any

treatment, as shown in Figure 4.

Figure 4. Landfill site in Koya City

4. Results and Discussions

Selecting neighborhoods and families for data collection was carefully justified to improve transparency. Three specific neighbourhoods, Haibat Sultan, Azadi, and Iskan, were chosen to measure actual solid waste generation by households. These areas were selected based on the following criteria:

- Population density: these neighborhoods represent different densities, allowing for a more comprehensive understanding of waste generation patterns.
- Variety of household types: the selected areas include a mix of residential structures, such as apartments and standalone houses, which can influence waste composition.
- Socioeconomic factors: the study considers variations in income levels and consumption patterns, ensuring a more representative analysis of waste generation in Koya City.

To accurately assess the SW generated by households, families consisting of five members were chosen from each neighbourhood. The data collection spanned seven non-consecutive days. This approach ensures variability in waste generation and accounts for daily and seasonal fluctuations in waste production.

The methodology involves:

1. **Selection of Households**: Families with five members were chosen to standardize the data and to make comparisons between neighbourhoods easier.
2. **Duration**: Waste generation was monitored for seven non-consecutive days to get a comprehensive view of daily waste patterns while avoiding bias that may come from specific days (such as weekends or holidays).
3. **Data Collection**: Each household was given bags to segregate their SW, which was collected and weighed daily. Types of waste such as organic, recyclable, and non-recyclable materials were recorded better to understand the composition of waste in the city.

Tables 4, 5, and 6 show the selected areas' SW generation data.

Table 4. SW component measured in Haibat Sultan, Koya (by the researchers)

No.	Date	SW Component (Kg/D)						Total Weight	Weight /Capita
		Food	Paper	Metallic	Plastic	Glass	Cloth & Dust		
1	24/12/23	2.72	0.32	0.26	0.56	0.00	0.46	4.32	0.86
2	26/12/23	3.54	0.26	0.29	0.45	0.00	0.35	4.88	0.98
3	28/12/23	3.04	0.34	0.30	0.35	0.62	0.56	5.22	1.04
4	1/1/24	3.52	0.30	0.35	0.46	0.00	0.18	4.82	0.96
5	3/1/24	3.36	0.29	0.27	0.43	0.91	0.88	6.14	1.23
6	6/1/24	3.04	0.38	0.34	0.54	0.53	0.80	5.63	1.13
7	10/1/24	1.76	0.42	0.43	0.53	0.00	1.28	4.42	0.88
Summation								35.42	7.08

The average SW generation for Haibat-Sultan is 7.08/7 = 1.01 kg per capita per day.

Table 5. SW component measured in Azadi, Koya (by the researchers)

No.	Date	SW component (kg/d)						Total weight	Weight /capita
		Food	Paper	Metallic	Plastic	Glass	Cloth & Dust		
1	24/12/23	2.88	0.18	0.24	0.24	0.80	0.32	4.66	0.93
2	26/12/23	3.04	0.24	0.30	0.35	0.32	0.19	4.45	0.89
3	28/12/23	2.88	0.27	0.32	0.40	0.00	0.24	4.11	0.82
4	1/1/24	3.36	0.22	0.21	0.34	0.16	0.27	4.56	0.91
5	3/1/24	3.52	0.26	0.24	0.35	0.00	0.37	4.74	0.95
6	6/1/24	3.68	0.32	0.18	0.50	0.18	0.35	5.20	1.04
7	10/1/24	2.72	0.26	0.26	0.45	0.16	0.00	3.84	0.77
Summation								31.55	6.31

The average SW generation for Azadi is 6.31/7 = 0.9 kg per capita per day.

Table 6. SW component measured by the researcher in Iskan, Koya

No.	Date	SW component (kg/d)						Total weight	Weight /capita
		Food	Paper	Metallic	Plastic	Glass	Cloth & Dust		
1	24/12/23	2.40	0.16	0.19	0.53	0.00	0.46	3.74	0.75
2	26/12/23	3.52	0.26	0.18	0.38	0.00	0.35	4.69	0.94
3	28/12/23	2.80	0.34	0.22	0.29	0.50	0.56	4.70	0.94
4	1/1/24	4.00	0.18	0.19	0.46	0.00	0.18	5.01	1.00
5	3/1/24	3.04	0.29	0.19	0.43	0.88	0.88	5.71	1.14
6	6/1/24	2.80	0.38	0.24	0.54	0.34	0.80	5.10	1.02
7	10/1/24	2.24	0.42	0.43	0.53	0.00	0.00	3.62	0.72
Summation								32.58	6.52

The average SW generation for ISKAN is 6.52/7 = 0.93 kg per capita per day.

Figure 5 illustrates the average SW generation for Koya zones.

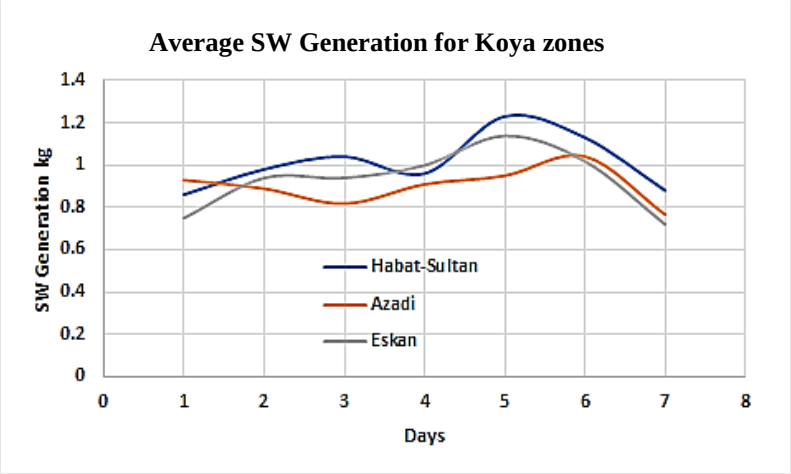

Figure 5. Average SW Generation in Koya City zones

The average SW generation for Koya is (1.1+0.9+0.93)/3= 0.95 kg/capita/d. That means the average near the no evaluated by Koya municipality is 0.986 kg/Capita/day.

Low-income countries, with the smallest proportion of urban populations, have the lowest waste generation rates, ranging from 0.1 to 0.5 kg per capita per day [14].

For neighboring countries with similar socioeconomic indicators, those with a GNP below $400 generate less than 0.5 kg of daily waste per capita [14]. The per capita rate of urban waste generation also rises from 0.5 to 1.1 kg/day as GNP rises to the middle-income level. The most high-income countries, typically more than 1.1 kg per person daily, show the highest urban waste generation rates.

Table 7 shows the difference between the developed and developing countries regarding these items by comparing the SW generation between the high-income and low-income centuries. Data from nearby and other countries are presented in the subsequent sections [13].

Table 7. Typical waste generation rates from several countries kg/capita/day [13]

Category	Bangladesh (1999) kg/C/D	Pakistan (2001)	Indonesia (2001)	Thailand (2003)	United States (2002)
Amount of waste Generated	0.5	0.6 – 0.8	0.8 – 1.0	1.6	3.26

Table 8. Typical waste generation rates from some cities around Koya kg/capita/day [5, 7]

Category	Erbil 2018	Sulaymaniyah 2016	Ranya 2020
Amount of waste Generated	1.0	1.12	1.108

The lowest percentage of urban populations and the lowest waste production rate are in countries with low-income populations, ranging from 0.1 to 0.5kg per day per capita [13].

The rate of urban waste production also rises per capita as GNP grows from 0.5 to 1.1 kg a day to medium-sized revenue. High-income countries generate the highest rates of city waste, generating more than 1.1 kg per person per day.

The estimated value of 0.986 kg/capita/d and 0.95 kg/capita/d for waste generation in Koya is reasonable compared to similar cities, as shown in Table 8, particularly in regions with comparable socioeconomic conditions. However, the fact that low waste generation rates are reported could be attributed to incomplete or inconsistent waste collection in certain areas. As waste collection services expand and become more efficient, these reported rates will likely increase, providing a more accurate reflection of the true waste generation levels.

Socioeconomic factors play a crucial role in influencing individual waste generation rates, with the percentage of poverty in each district having a direct impact. Poorer areas tend to generate less waste due to lower consumption levels, while wealthier districts produce more waste, often linked to packaging and consumer goods. This variance highlights the need for more localized waste management strategies that cater to different districts' specific needs and conditions.

One of the main challenges in waste management across many parts of the world is the lack of reliable, comparable data. Poor data quality can lead to inaccurate waste generation estimates, affecting decision-making processes related to waste management infrastructure and services. In the case of Koya, improving data collection and reporting mechanisms is crucial for developing a comprehensive waste management plan that can adapt to future changes in population growth, income levels, and other external factors.

5. Conclusions

The findings of this study underscore the urgent need for an effective solid waste management (SWM) system in the Koya District, where rising waste generation rates—estimated at 0.986 kg/capita/day—pose serious environmental and urban development challenges. Without immediate action, continued population growth and economic expansion will further strain the district’s waste management capacity, leading to increased environmental degradation and public health risks.

The proposed solid waste treatment plant construction represents a critical and forward-looking solution. By integrating the principles of reduce, reuse, recycle, and recover (4Rs) and generating energy from waste, this project addresses the growing waste burden and transforms waste into a valuable resource. It aligns with global movements toward circular economies and sustainable urban development.

Moreover, this initiative has the potential to generate significant economic benefits for Koya by creating jobs in the waste management and energy sectors while fostering environmental stewardship. If successfully implemented, the project could serve as a pioneering model for other cities in the region facing similar challenges.

Sustainable waste management is no longer an option but necessary for Koya’s future. This study provides a foundation for informed decision-making and highlights the importance of continued research,

investment, and policy support to ensure the district's success and long-term impact of waste management initiatives.

Declaration of Competing Interest: The authors declare they have no known competing interests.

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