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*Corresponding author

Karzan A. Mohammed Hawrami
Karzan.mohammed
@spu.edu.iq

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An Evaluation of the Present State and Prospective Trends in Municipal Solid Waste Management within Halabja Province, Kurdistan Region, Iraq

Sami Khasraw Hamid¹, Karzan A. Mohammed Hawrami^{2*},
Shuokr Qarani Aziz ³, Baset B. Karim Baset⁴

1 Suzhou University of Science and Technology, School of Environmental Science and Engineering,

School of Environmental Science and Engineering, Suzhou University of Science and Technology, Suzhou 215009, PR China , Suzhou, Jiangsu, CN 215009

2 Halabja Technical institute, Sulaimani Polytechnic University, Sulaimani , Iraq

3 Department of Civil Engineering, College of Engineering, Salahaddin University- Erbil, Erbil, Kurdistan Region, Iraq .

4 Food science and quality control department, Halabja Technical College, Sulaimani Polytechnic University, Sulaimani, Iraq

ABSTRACT

Inadequate or harmful methods of handling solid waste pose threats to both the environment and public health. As the global population has grown, the production of waste has also increased significantly. Estimating future rates of municipal solid waste (MSW) generation might encourage analysis of gaps in the current waste management and more accurate planning techniques. The main objectives of this study were to assess current status of municipal solid waste management (MSWM): to plan future improvements, advise and promote sustainable waste management solutions, and to predict the quantity of MSW produced from 2025 to 2050 with population growth in Halabja province. The findings indicated that the mean solid waste generation reached 42 tons per day and 1.048 kg per capita per day in 2023. The generation rate (GR) from 2016 to 2023 has increased by 14.88%. The study predicted that the daily waste generation would arrive 306 tons/day and 1.0897 Kg/Capita/Day by 2050. In the Halabja city, an increase in MSW has caused environmental issues. As a result, the MSW disposal site had a significant negative impact on the surrounding areas, including air, water, and soil contamination. The situation of municipal solid waste management in the Halabja city was made clear in this article, and it also provided a thorough analysis and implications of the poor solid waste management in the research area.

1. Introduction

Solid waste management (SWM) poses a significant environmental challenge in urban areas due to population growth (Abubakar et al., 2022). This problem is especially prominent in developing nations. Factors such as population growth, gradual economic development, and improved living standards further accelerate solid waste production. Failure to properly handle waste on-site can result in various environmental issues. Therefore, every country must plan and execute waste management strategies encompassing generation, storage, collection, transportation, and disposal. This is crucial for environmental protection and the overall social and economic well-being (Abdel-Shafy & Mansour, 2018; Anuardo et al., 2022). However, the current waste management practices often fall short of recommended environmental ministry guidelines, resulting in visible gaps in waste management. The effectiveness of waste management techniques largely depends on accurate waste quantification, making waste forecasting and prediction a critical phase in the process (Ajim & Ahmad, 2019).

Solid waste management poses a considerable challenge for municipal authorities in urban areas of developing countries (Othman et al., 2023). An effective future strategy for holistic solid waste management must take into account the amount of solid waste generated (Othman et al., 2023). The Waste Management Strategy of the European Union incorporates the waste management hierarchy, a framework that has evolved over the last two decades (Othman et al., 2023). The preferred sequence for waste management efforts is outlined as follows: waste prevention, entailing waste generation reduction; recovery, encompassing recycling and reuse of waste; energy recovery via incineration; and ultimately, disposal (Othman et al., 2023). Efficient management and collection of solid waste are crucial for maintaining a hygienic and secure environment. Proper solid waste management encompasses the collection, transportation, and proper disposal of waste in a way that prioritizes environmental protection and promotes public health. The increase in population and insufficient solid waste

management techniques are factors that exacerbate a range of environmental and health issues.

Most MSW is landfilled in Iraq, and facilities for waste treatment like composting and trash incineration are only occasionally employed (Othman et al., 2023). In Kurdistan region (KR) of Iraq also, MSW is typically disposed in landfills and dumps in. The collection, transportation, and disposal of MSW are not properly planned for either (Hamza et al., 2022; Wali, 2020). Pollution of the environment results from disposing of MSW in landfills and dumps. Therefore, to prevent environmental degradation, it is crucial to build sanitary landfills. In KR, particularly in the Halabja province, solid wastes including household, hospital, and industrial wastes, are occasionally partially dumped in areas close to cities where people engage in various forms of agriculture, particularly crop production. The population size, way of life, level of income, management, and other factors have an effect on the amount, composition, and generation rate (GR) pace of household solid waste.

Numerous studies in the field of MSW have been done in various KR cities (Alkaradaghi et al., 2021; Aziz, 2023; Aziz & Maulood, 2015; Aziz & Mustafa, 2018; Hamza et al., 2022; Mohammed et al., 2018). However, based in our knowledge the future GR in Halabja province has not been studied to date.

There exist several challenges associated with Municipal Solid Waste Management (MSWM) in Halabja, including issues pertaining to waste collection, transportation, and disposal. The municipality is solely responsible for the collection of solid waste, which is subsequently disposed of without undergoing any treatment in close proximity to the Sirwan river located in the western part of the city, posing potential environmental pollution risks (Hamza et al., 2022). The adoption of strategies like recycling and reusing solid waste is greatly needed in this context.

In this locality, uncovered disposal areas are viewed as a notable ecological concern and could pose a substantial hazard to the adjacent water and soil. Alterations in the physical and chemical characteristics of water and soil have

occurred due to the discharge of contaminants from waste seepage at the disposal site. During the wet seasons, particularly in winter and spring, the seepage from the disposal site is transported by the river and seeps into the groundwater, which serves as the primary water source for agricultural operations of farmers. Various forms of gaseous contaminants may be emitted into the atmosphere as a result of waste incineration at the disposal site. The main aims of this investigation were to project forthcoming enhancements, estimate the quantity of municipal solid waste generated from 2023 to 2050 in connection with population growth, and to offer guidance on and advocate for sustainable waste management methodologies.

2. MATERIALS AND METHODS

2.1 Study area

The urban center of Halabja is situated in the northern region of Iraq, approximately 240 kilometers northeast of Baghdad. Positioned at a latitude of $35^{\circ}10'59.73''\text{N}$ and a longitude of $45^{\circ}58'59.05''\text{E}$, encompassing an area spanning about 1600 square kilometers. The elevation of the area stands at 721 meters above sea level. (Kasem et al., 2015). Geographically, it is situated on the southwest Sharazur plain, with the Hawraman Mountains to the north and Balambo Mountain and Darbandikhan Dam to the south. (Al-doski et al., 2013), as shown in Fig. 1. Halabja province comprises the central district (Halabja city), and three other districts, Sirwan, Xurmal, Biyare. The population of Halabja province is about 135384 at 2023 (Halabja Statistical Office, 2023). Halabja experiences a hot-summer Mediterranean climate characterized by intense summer heat and cool, wet winters. The location of the waste disposal site in Halabja is specifically positioned in the northern region of Halabja city, at a longitude of $45^{\circ}56'57.65''\text{E}$ and a latitude of $35^{\circ}12'28.08''\text{N}$ (Mohammed et al., 2018).

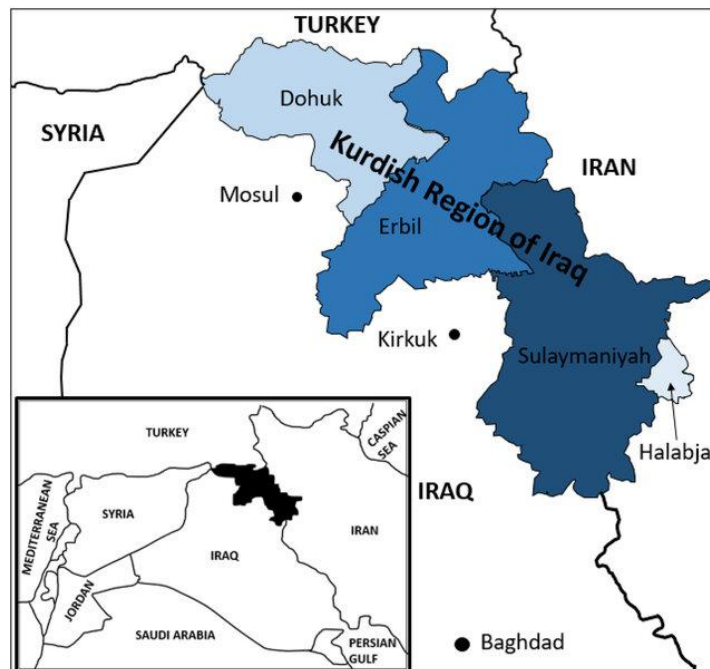


Fig. 1: Map of Kurdistan region of Iraq showing study location of Halabja province.

2.2 Data Collection

The information regarding MSWM for Halabja City was collected through relevant directories (General Directorate of Municipalities of Halabja, Halabja General Directorate of Health, Halabja Environmental Office and Halabja Statistical Office), site visits, and references. The following equation was used to determine the GR and MSW amount and percentage ratio of the MSW components:

$$\text{GR} = \frac{\text{Weight of collected solid waste (kg)}}{\text{Population} \times \text{Duration}}$$

[1]

$$\text{MSW amount (ton /day)} = \frac{\text{GR} \times \text{population}}{100}$$

[2]

$$\text{Percentage ratio of MSW component} = \frac{\text{Mass of the MSW componnet (kg)}}{\text{Total mass of MSW(kg)}} \times 100$$

[3]

2.3 Population Prediction Methods

The design population should be calculated while all the variables taking into account influencing the project area's future growth and development in the commercial, educational, social, and administrative spheres. Special factors that lead to an abrupt inflow of people or immigration should also be anticipated as much as feasible. A determination based on these elements would assist in choosing the most appropriate approach among the mathematical methods such as (Demographic method of population projection, Arithmetic increase method, Incremental increase method, Geometrical increase method, Decreasing rate of growth, Graphical method, Logistic method and Method of density)(Gokarna & Aryal, 2020; Raftery & Ševčíková, 2023; Vanella et al., 2020; Wilson et al., 2021).

The best way to determine the population prediction of Halabja province is geometrical increase method (Ahmed et al., 2023). This strategy provides a significantly better value and is mostly relevant to expanding towns and cities with a wide range of expansion options. According to this method, the rate of growth is assumed to be the percentage rise, and the future population increase is calculated using the average of the percentage increase.

$$P_t = P_o (1 + r)^n$$

[4]

Where:

P_t : expected future population number for the specific year.

P_o : present population for year 2023.

r : the annual rate of growth

n : number of years.

3.RESULTS AND DISCUSSIONS

3.1Municipal Waste management in Kurdistan Region

Municipal Waste management considers the entire waste management process, including waste production, storage, collection, transportation, processing, recovery, and final disposal (Ali & Mawlood, 2021). It is also intimately connected to economic, ecological, and social challenges. The local municipal authority's systematic approach to controlling waste is referred to as "management of

municipal solid waste" (Zaman & Lehmann, 2011) . Gas and leachate generation are inevitable consequences of practice of solid waste disposal in landfills. Aside from other issues including fires and explosions, vegetation damage, unpleasant odors, landfill settlement, ground water contamination, soil pollution, and global warming, the migration of gas and leachate beyond landfill boundaries poses major environmental risks. Both the chemical and geotechnical characteristics of the soil are significantly impacted by leachate from the solid waste landfill. Leachate has the ability to change the characteristics and behavior of soil (Pillai & Peter, 2014). MSW dumps located in unsuitable locations pose a major threat to the quality of the environment as a whole. These waste disposal sites have the potential to become substantial sources of chemical pollution and biological contamination of soil, groundwater, and surface waterways because they contain a high concentration of heavy metals and organic compounds that degrade slowly. Soil pollution is a challenging type of pollution to quantify and manage.

Soil pollution is a form of pollution difficult to measure and control. Uncontrolled disposal of trash from numerous human activities is one of the main sources of soil contamination (MIHĂILĂ et al., 2013).

Due to its inherent composition of diverse chemicals, materials, and products, solid waste is challenging to identify, describe, and categorize. This is further complicated by the significant variation in the content of different loads of garbage (Williams, 2005).

Due to the generation of leachate and its migration through waste, landfills are sources of pollution of the soil and groundwater. Groundwater resources can become contaminated by leachates and other pollutants from landfills and sediments if they are not properly managed (Akinola et al., 2021) Globally, there is a problem with groundwater contamination, frequently caused by the infiltration of pollutants from waste disposal areas. The pollution of groundwater resources has the potential to represent a significant concern to both local resource users and the

natural environment.

Globally, there is a problem with groundwater contamination, frequently caused by the infiltration of pollutants from waste disposal areas. The pollution of groundwater resources has the potential to represent a significant concern to both local resource users and the natural environment (Moeini & Paenafrakaty, 2008).

Due to alterations in consumption patterns and unregulated urbanization and industrialization, Solid Waste Management (SWM) currently poses as one of the most formidable challenges for contemporary society. Municipal Solid Waste (MSW) includes a variety of categories including household waste, commercial waste, street sweeping waste, institutional waste, construction

and demolition waste, and sanitation waste. (Moeini & Paenafrakaty, 2008). Furthermore, MSW is composed of materials that can be recycled (for example, paper, plastic, glass, metals), substances that pose a risk to health and the environment (such as paints, pesticides, used batteries, pharmaceuticals), organic matter that can naturally decompose (including fruit and vegetable peels, food scraps), and materials that have been contaminated (for instance, blood-soaked cotton, sanitary pads, disposable syringes). The oversight of MSWM in the Kurdistan region, covering the governorates of Halabja, Erbil, Sulaymaniyah, and Duhok (Moeini & Paenafrakaty, 2008), falls under the jurisdiction of the Ministry of Municipalities and Tourism (MOMT), as depicted in Fig. 2.

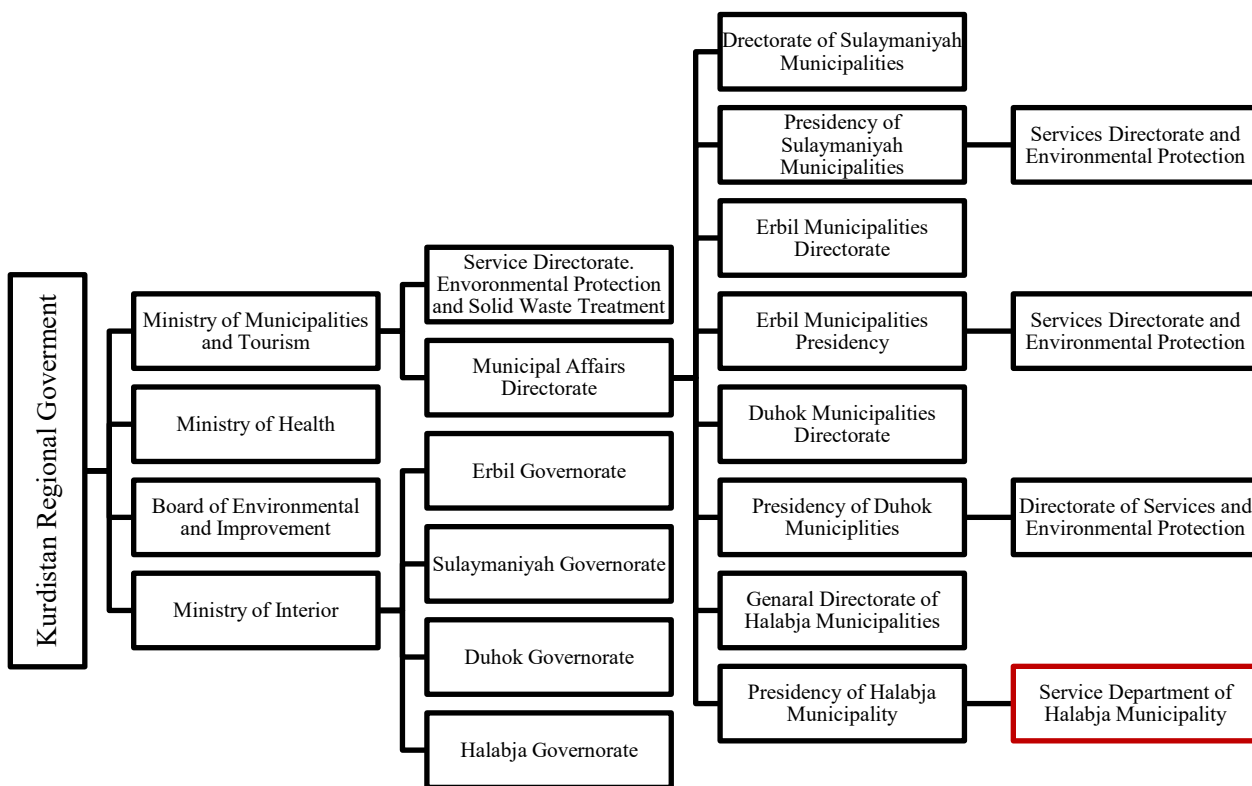


Fig 2. Kurdistan Regional Government Organization Structure Related to MSWM.

3.2 Municipal Waste Generation

The Fig. 3, illustrates the geographical location of the areas where municipal solid waste is disposed of in the Kurdistan Region. The unit generation rate is determined by dividing the amount of waste collected by the population that

is served by the waste collection service. Table 3 shows the average GR of the Kurdistan Region, which is 0.972 kg per capita per day and Table 4 displays the rate at waste production in several countries, including Iraq. Iraq's rate of waste generation surpasses both the worldwide average (0.75 kg/day/capita) and the regional

average of the Middle East and North Africa (0.81 kg/day/capita) (MCHMPW & MOMT, 2022). The amount of garbage that has to be handled is determined using the solid waste generation rate, which is also used as a design standard for final waste disposal facilities and a planning tool for other solid waste management procedures (Abdel-Shafy & Mansour, 2018).

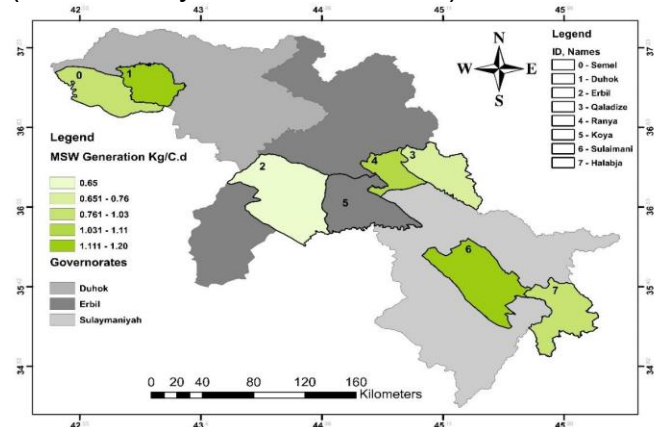


Fig 3. MSW disposal site locations and GR (Hamza et al., 2022).

Table 3: Daily waste generate on rate in Kurdistan Region. (Hamza et al., 2022).

City	Waste generation rate Kg/Capita/day
Erbil	0.65
Sulaymaniyah	1.20
Duhok	1.18
Halabja	1.00
Ranya	1.11
Semel	1.03
Qaladze	0.76

Table 4. The Waste Generation rate in some countries

Countries	Waste Generation kg/cap/day	Reference
China	0.73	(Zhu et al., 2021)
Iraq	1.36	(MCHMPW & MOMT, 2022)
Iran	0.74	(Zand & Heir, 2020)
Japan	1.14	(Ali & Sion, 2014; Shekdar, 2009)
Singapore	1.10	(Ali & Sion, 2014; Shekdar, 2009)
South Korea	1.02	(Ali & Sion, 2014)
Malaysia	0.80	(Ali & Sion, 2014; Yunus, 2015)

Vietnam	0.55	(Ali & Sion, 2014)
Philippines	0.67	(Ali & Sion, 2014)
USA	2.0	(EPA, 2023)

3.3Municipal waste management in Halabja

The Service Department of Halabja Municipality, which operates under the General Directorate of Municipalities of Halabja, is responsible for the implementation of waste pickup and final disposal in the city of Halabja. Halabja City alone transports about 100 tons of waste daily, using municipal vehicles such as dumpers, tractors, and trucks. This results in an average of 1 kg of solid waste per person each day (Service Department of Halabja Municipality, 2023) The solid waste disposal site is an open-air landfill site situated in the northwest of Halabja city about 5 km away from the city centre with a longitude of 45°57'5716"E and a latitude of 35°12'.07"N.

The Halabja City Council uses the area as a landfill for industrial, medical, and municipal waste. Batteries, plastic, glass, and other recyclable and hazardous garbage are also dumped in this area. The land in the surrounding area is primarily utilized for cultivating food crops, primarily for commercial reasons. In the province of Halabja, various types of solid waste, such as home, hospital, and industrial garbage, are being disposed of or sometimes partially dumped near the city. This area is also used for agricultural purposes, particularly crop cultivation.

Municipal solid waste in Halabja is dumped in the open dump site with an area more than 10000 m². The site is located in a ditch several kilometers outside the city, near the village of Tapa Kura. Mohammed et al., (2018) have assessed the influence of waste disposal on the water and soil quality in the area near by the Halabja waste disposal site, demonstrated that the water quality is significantly negatively impacted by garbage disposal. This is because the trash leachate can enter surface water from open areas, consequently surface water has lowered the quality. On the other hand, when waste is burned in a waste disposal site, various gas pollutants may occasionally escape into the atmosphere. During rainy seasons, leachate from

the disposal area also flows into rivers and filters into ground water, which farmers completely rely on it for agricultural activities. Solid waste management is conducted by the responsibility of collecting solid trash company, including rubbish and useless materials, from residential and industrial locations and subsequently disposing of it in landfills, that is the only treatment is happening in Halabja which is collected six days a week in the studied city.

Halabja province is the most famous tourist destination in Iraq and Kurdistan region, that's why the GR on holidays is much higher than on the other days of the week. Sometimes, because of the financial crisis in the region the payment to collection and transportation company employers is not made properly. Therefore, sometimes solid waste remains into the house bin for some days

and made chaos in the city.

Figure 4 illustrated the distribution of weight percentages for various types of waste in Halabja city such as foodstuff, plastic, paper, cardboard, metal, glass, fabric, and textiles, which were recorded at 62%, 7%, 5%, 4%, 4%, and 6%, respectively, which relatively similar to the waste composition percentage in Erbil city in KR (Aziz et al., 2011). They found that in the urban area of Erbil, a study revealed the mean weight proportions of various waste categories including organic, plastic, paper, metal, glass, and cloth, which were recorded at 79.34%, 6.28%, 5.9%, 3.6%, 3.42%, and 1.45%, correspondingly. Additionally, Table 5 provided a comparison of municipal solid waste composition in various countries, including Iraq.

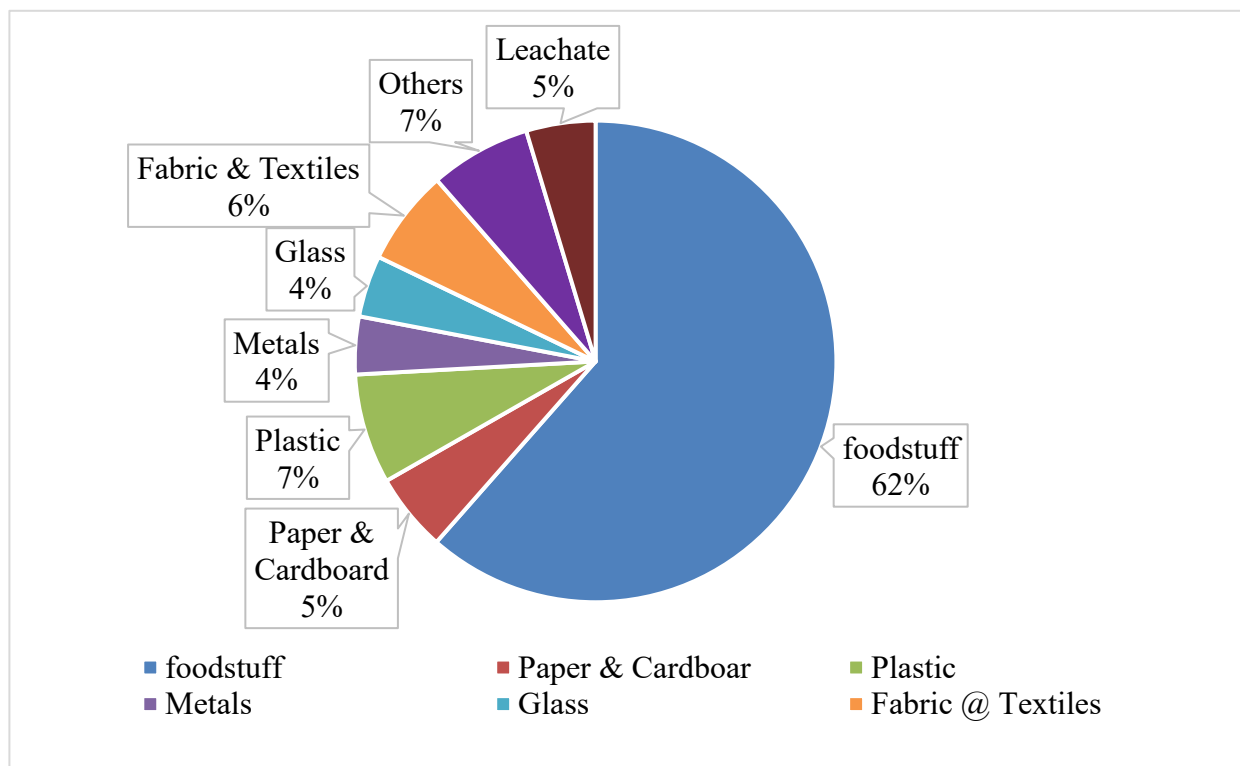


Fig. 4: Municipal Waste components of Halabja province for October 24, 2022 (Service Department of Halabja Municipality, 2023).

Table 5: Municipal waste composition in some countries (%).

Countries	Foodstuff (Organic)	Plastic	Paper	Metal	Glass
China	35.8	3.8	3.7	0.3	2
Iraq	55	25.2	7	3	2.9
USA	28.2	12.9	26.5	9	4.4
UK	38	7	18	8	7
Japan	26	9	46	8	7
Iran	72.59	5.01	9.46	2.57	1.86
Singapore	44.4	11.8	28.3	4.8	4.1

3.4 Future Prediction of Municipal waste management in Halabja Governorate

The economic, political, and demographic factors of Halabja governorate have had a noticeable impact on the GR values. Conversely, several factors such as lifestyle, income, education, environmental consciousness, religion, residential location, and day of the week have an impact on the different aspects of MSW. Table 6, Fig 5 showed the average GR in the Halabja which was 0.983 Kg/Capita/Day. According to the Halabja statistical office, the Halabja Governorate's population growth rate is 2.74% (Sakal, 1996; Tsukut et al., 2016; Rose et al., 2018; Yunus, 2015). We can use the data recorded in the past few years as calculated based on the following equations.

$$GR = \frac{\text{Weight of collected solid waste (kg)}}{\text{Population} \times \text{Duration}}$$

Average GR in the Halabja

$$\frac{(0.892 \times 112026) + (0.91 \times 115386) + (0.942 \times 118848) + (0.98 \times 122413) + (1 \times 126086) + (1.03 \times 129112) + (1.036 \times 132210) + (1.048 \times 135384)}{112026 + 115386 + 118848 + 122413 + 126086 + 129112 + 132210 + 135384}$$

$$= 0.983 \text{ Kg/Capita/Day}$$

Table 6: MSW amount and Generation Rate in Halabja Province 2016-2023.

Year	Population (thousands)	MSW amount (ton /day)	Per capita generation (kg/ capita /day)
2016	112026	100	0.892
2017	115386	105	0.91
2018	118848	112	0.942
2019	122413	120	0.98
2020	126086	126	1
2021	129112	133	1.03
2022	132210	137	1.036
2023	135384	142	1.048

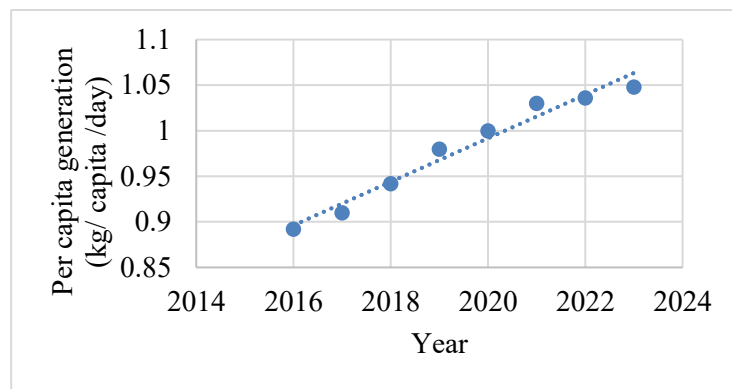


Fig. 5: the Generation Rate in Halabja Governorate.

The solid waste generated in this study was determined by considering the current population and the projected population growth rate in Halabja, as shown in Table 7 and Fig. 6.

Table 7: Predicted Municipal waste amount and GR in Halabja Governorate by 2050.

Year	Population (thousands)	MSW amount (ton /day)	Per capita generation (kg/ capita /day)
2016	112026	100	0.892
2017	115386	105	0.91
2018	118848	112	0.942
2019	122413	120	0.98
2020	126086	126	1
2021	129112	133	1.03
2022	132210	137	1.036
2023	135384	142	1.048
2024	139071	150	1.077
2025	142881	156	1.092
2026	146796	162	1.102
2027	150818	167	1.110
2028	154951	173	1.119
2029	159196	179	1.126
2030	163558	186	1.136
2031		168040	1.142
2032		172644	1.144
2033		177374	1.147
2034		182235	1.150
2035		187228	1.152
2036		192358	1.153
2037		197629	1.152
2038		203044	1.151
2039		208607	1.149
2040		214323	1.147
2041		220195	1.144
2042		226229	1.139
2043		232427	1.135
2044		238796	1.130
2045		245339	1.125
2046		252061	1.119
2047		258967	1.112
2048		266063	1.105
2049		273353	1.097
2050		280843	1.089

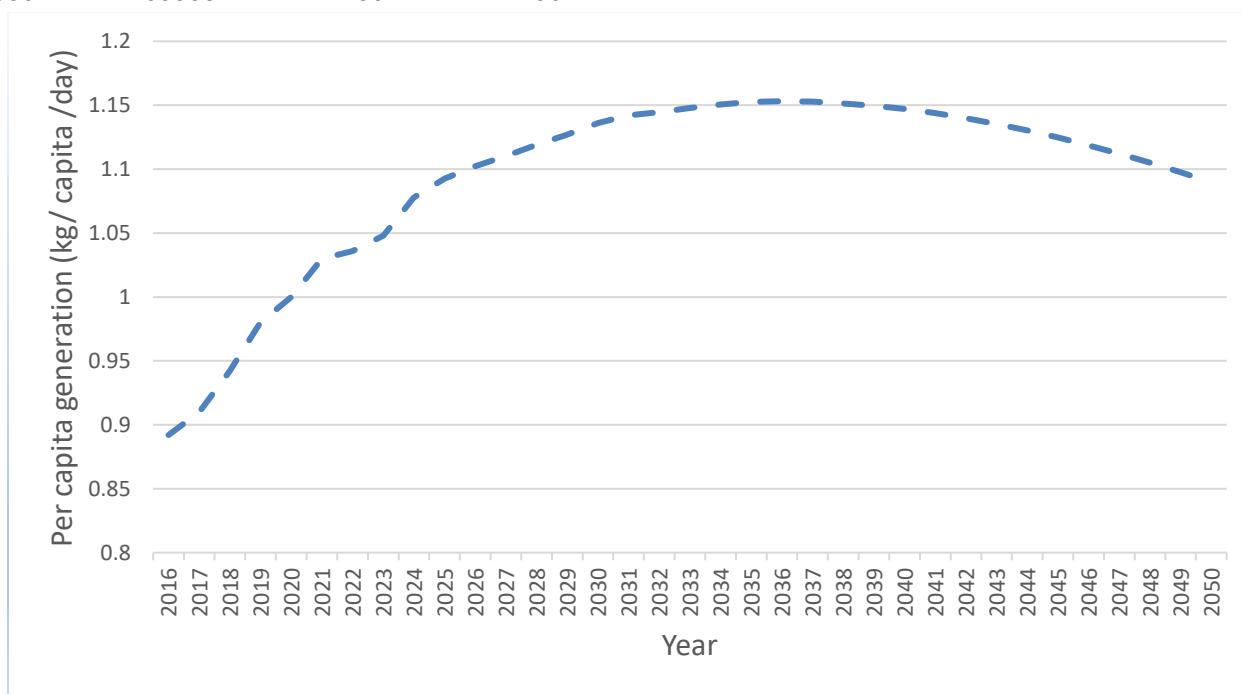


Fig. 6: Predicted GR in Halabja Province by 2050.

The results suggested that that the recommendations for controlling household solid waste in Halabja is crucial. Firstly, it is important to create and implement a collection strategy that takes source separation of trash into account. Subsequently, to reduce the amount of garbage created and to encourage source separation of waste, training and education programs for the general population should be developed. Also, to replace the current disposal method, a suitable new sanitary landfill should be set up to receive the growing amount of domestic solid waste in Halabja. Above all, a sufficient investment in domestic solid waste management systems is needed to build a recycling facility for valuable materials.

4. ONCLUSION

Municipal waste management in Halabja province normally is not standard. The collection, with no separation of waste composition, and disposed in the outskirts of the city and dumped is the only treatment is implemented in Halabja. The major hindrances to MSWM are the inadequate efficient dumping sites, and ineffective collection technique and disposal sites. The presence of an open dumpsite in Halabja has had a significant impact on the ecosystem, resulting in the contamination of soil, water, and air. Furthermore, it has an impact on human health. In landfills and dumpsites, there is a lack of methane collection and energy generation. The Halabja Province lacks the necessary infrastructure for the scientific recycling of materials such as plastic, metals, glass, and paper.

To protect the environment of the area from pollution, opening new scientific MSW landfills is essential. Population growth and economic growth in Halabja province are low, that's why the amount of municipal solid waste is high compared to the population and economic growth of the province. The result of the study indicate that the daily per capita waste generation will increase from 0.892 to 1.0897 kg from 2016 to 2050 in Halabja province. These values require a robust solid waste management plan.

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