Reception: **July 5, 2024** | Acceptance: **November 21, 2024** | Publication: **February 1, 2025**

Waste Destination: A view of its impacts

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To quote this article:
Sánchez Sánchez, T. de J. El destino de la basura: una mirada a sus impactos. *Espacio I+D, Innovación más Desarrollo, 14*(39). https://doi.org/10.31644/IMASD.39.2025.a03

— Abstract—

The generation of Municipal Solid Waste (MSW) reflects the culture of a society, and inadequate management of it can have a negative impact on public health and the environment. In Mexico, approximately 120,128 tons of USW are generated per day (SEMARNAT, 2020). There are 2,203 registered Final Disposal Sites (FDS), of which 87% are uncontrolled sites, with sanitary landfills being the minority. The adverse effects of inadequate final disposal of MSW include air and water pollution, methane and leachate emissions, landscape degradation, and the proliferation of diseases due to the transmission vectors they harbor. This document aims to provide an overview of MSW disposal in Mexico, as well as its main environmental and social impacts.

Keywords:

Urban solid waste; final disposal; environment.

The problem with waste began when humans stopped being nomads and settled in fixed places (Córdoba-Meriño et al. 2018). Since then, the complexity and impact of waste management have increased over time. Have you ever wondered what happens to the garbage we generate daily? For many people, it remains a mystery, as they often dispose of their waste without reflecting on their final destination. However, garbage does not magically disappear, it just changes places, and if not handled properly, it can cause serious damage to the environment.

In Mexico, the problem of garbage continues to increase, due to factors such as population growth, industrial development, technological advances, changes in consumption habits, and the increased use of disposable products with slow biodegradability (SEMARNAT, 2015). This situation has worsened in the post-pandemic context, due to new habits such as the growth of e-commerce, which has generated a greater amount of cardboard packaging, plastics, and other materials used in shipments, as well as the high consumption of personal protection supplies such as antibacterial gel and face masks (Das et al. 2021; Oceana, 2023).

Final waste disposal represents a major challenge due to the high costs associated with the construction, operation, and maintenance of sites suitable for final disposal. Improper management can have serious consequences for both the environment and public health. Soil pollution, and the damage of aquifers and surface water bodies, are just some of the problems that can arise as a result of poor management (Jaramillo, 2002).

This work aims to explore the different aspects of municipal solid waste (MSW) management in Mexico. The structure of the document is organized as follows:

1. **What is MSW?**
   The definition and classification of MSW will be presented.
2. **How many MSW are generated in Mexico?**
   Statistics on the amount of waste generated in the country will be presented.
3. **MSW final destination**.
   We will describe how MSW is managed in Mexico, detailing the types of disposal sites.
4. **Residues after final disposal**
   We will analyze the by-products generated after the waste disposal.
5. **Environmental and population impacts due to the inadequate disposal of MSW.**
   The negative effects of poor waste management on public health and the environment will be explored further.

6. **Final comments.**
   Conclusions and recommendations will be offered to improve waste management in Mexico.

METHODS

A review of academic and scientific sources, government reports, and statistical data on the final disposal of solid waste in Mexico was carried out. The search was conducted through platforms such as PubMed and Google Scholar.

We chose scientific articles in English and Spanish, reports from agencies such as the Secretariat of Environment and Natural History (SEMAHN), the Secretariat of Environment and Natural Resources (SEMARNAT), and statistical data provided by the National Institute of Statistics and Geography (INEGI).

Selection criteria were based on relevance, academic quality, and publication period, prioritizing those documents published between 2002 and 2024.

The search terms used were:

- Management of solid waste
- Environmental impact of waste
- COVID Waste Management
- Generation of waste
- Waste Legislation in Mexico

These combinations made it possible to address key aspects related to the management, impact, and regulation of solid waste.

1. WHAT IS MUNICIPAL SOLID WASTE?

As a result of the daily life of human beings, waste is generated, such as in homes and public, private, and recreational dependencies, among others (Tello-Espinoza, 2018). All our human activities, from the production and consumption of goods and services, inevitably generate waste. Housing construction, for example, in addition to construction material waste such as concrete, bricks, and wood, can also generate hazardous waste such as paints and solvents. Every day we use public or private transport, a service that generates waste derived from maintenance and operation, such as used oils, worn tires, and discarded batteries, among others.

In today's digital age, even the most remote places have telecommunications services. The installation and maintenance of telecommunications

networks produce electronic and construction waste. In addition, electronic devices such as mobile phones, computers, and network equipment have relatively short life cycles, resulting in a constant accumulation of electronic waste (Oceana, 2023).

When the materials can no longer be used directly in the same activity where they were generated, they are considered waste. Although there are several definitions for the term "waste", in general, it is understood as any material that, once generated, is no longer useful to the person who generated it, which leads to the need to get rid of them.

The definition of solid waste, according to Tchobanoglous et al. (1994), is *"all waste arising from human and animal activities, which are normally solid and are disposed of as useless or not required"*. This concise definition states that any material that has lost its usefulness within the context in which it was generated becomes a waste, but may have potential as a secondary raw material in other processes. For example, used cooking oils can be collected and transformed into biodiesel by transesterification processes (Haq et al. 2021).

In Mexico, according to the General Law for the Prevention and Integral Management of Waste (LGPGIR), waste *"is any material or product that is discarded, which may be in a solid or semi-solid, liquid or gaseous state, contained in containers or deposits, and susceptible to valuation or subject to treatment or final disposal"*. These wastes are classified into municipal solid waste, special handling waste, and hazardous waste, according to their characteristics and origin.

According to Mexican Official Standard NOM-083-SEMARNAT-2003, municipal solid waste (MSW) is defined as:

> Waste generated in households, resulting from the disposal of materials used in their domestic activities, the products they consume and their containers, packaging, or wrappings; waste from any other activity in establishments or on public roads that generate waste with household characteristics, and waste resulting from the cleaning of public roads and places.

MSW includes a wide variety of materials, from organic materials such as food scraps and yard waste to containers, packaging, and wrappings used in daily activities, as well as textiles and urban cleaning waste, among others. These materials make up what is commonly known as trash.

2. HOW MUCH MUNICIPAL SOLID WASTE IS GENERATED IN MEXICO?

The generation of municipal solid waste (MSW) in Mexico is a common problem in all communities and its magnitude is directly related to the amount of waste generated (Tello-Espinoza, 2018). Over the last seven de-

cades, there has been a remarkable increase in MSW generation. In 1950, per capita generation was 0.300 kg/inhab/day. However, by 2012, this daily volume almost tripled, reaching 0.852 kg per inhabitant (SEMARNAT, 2012). It is estimated that in 2020 the volume amounted to 0.944 kg. According to the National Census of Municipal Governments and Territorial Districts, which is conducted every two years, at the national level, total generation is estimated at 108,146 tons per day, compared to 99,770 tons per day estimated in 2012 (INEGI, 2023). Regarding the state of Chiapas, a daily generation of 5,188 tons is estimated, which represents 4.8% of the national total (SEMAHN, 2022).

The increase in MSW generation is attributed to several factors, such as the growth of urban areas, industrial development, technological advances, and changes in the population's consumption habits (Jaramillo, 2002). These factors contribute to the complexity of the problem, as the waste generated tends to have an increasingly less biodegradable composition and a greater amount of toxic compounds (Köfalusi & Aguilar, 2006).

The COVID-19 pandemic accentuated this problem by significantly increasing the generation of waste such as disposable masks, antibacterial gel containers, and other personal protective equipment (Das et al. 2021; Yousefi et al. 2021). According to NOM-087-SEMARNAT-SSA1-2002, these materials are mostly classified as Biological-Infectious Hazardous Waste (BIWW) in hospital settings, and a considerable part ended up being part of the MSW due to their massive use by the general population. This situation shows deficiencies in the separation and final disposal systems since many of these wastes do not receive adequate management, increasing the risks of environmental contamination and public health.

Taken together, these factors have contributed to progressive environmental deterioration, highlighting the urgent need to address the problem comprehensively and sustainably to mitigate its negative impact on the environment and public health.

Article 10 of the LGPGIR establishes that the integral management of MSW is under the responsibility of municipal governments, from collection to final disposal. However, in practice, municipalities lack technical and financial capacities which makes it difficult to implement effective measures to address this problem comprehensively.

3. THE FINAL DESTINATION OF MUNICIPAL SOLID WASTE

The final disposal of MSW refers to their permanent deposit when they are considered to have lost their value. However, it is important to note that not all MSW end up in the same destination, as this depends largely on the effectiveness of policies, infrastructure, and management capacity

available in each municipality (Rodríguez & Montesillo, 2017). In addition, citizen culture in MSW management plays an important role, since it can influence the amount of waste generated, its disposal, participation in recycling programs, and the adoption of more sustainable practices in its management (Córdova-Merino et al. 2018; Kountouris,2022). In Mexico, many municipalities do not have adequate MSW management.

At the national level, there are 2,203 Final Disposal Sites (SDF) and Chiapas is among the states with the largest number of these sites, along with Chihuahua, Veracruz, and Oaxaca (Fig. 1, SEMARNAT, 2020). The most common final disposal practices are Sanitary Landfills (RS) and predominantly, Open Sky Landfills (TCA), commonly known as garbage dumps. These methods are described below.

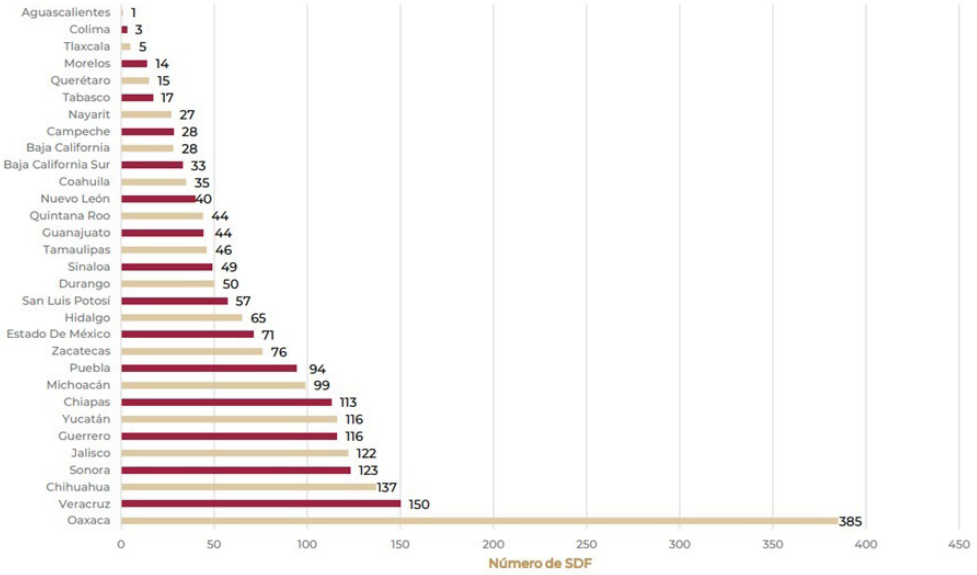

Figure 1. Sites of Final Disposal by the federative entity. Source: SEMARNAT, 2020

3.1 Sanitary Landfill (SL)

It is an engineering method designed to manage solid waste in a safe and controlled manner. In general terms, it consists of depositing the waste in waterproofed cells where they are compacted to reduce their volume and optimize the storage capacity of the site, daily they are coated with soil or other inert material to prevent the proliferation of sanitary vectors and bad odors. The by-products generated by the decomposition of waste must be properly managed to avoid environmental contamination (Jaramillo, 2002; Nájera-Aguilar et al. 2012). The Mexican regulation, NOM-083 SEMARNAT-2003, establishes the environmental specifications for the

selection of the site, design, construction, operation, monitoring, decommissioning, and complementary works of an SL.

SL are a safer and less environmentally damaging alternative compared to uncontrolled final disposal methods that allow for more orderly and efficient management of MSW contributing to long-term environmental sustainability.

3.2 Open Sky Landfills (OSL)

It is the oldest method for MSW disposal, which consists of depositing them directly to soil without any type of coating or environmental control on the by-products caused by the decomposition of organic matter (Fig. 2). These sites are often set on fire frequently since the garbage contains and generates combustible substances (Cerda, 2007), therefore, it is an inappropriate practice due to the adverse effects on the environment and public health. Most OSL are clandestine and have spread throughout Mexican territory occupying ravines and riverbeds, lakes and lagoons, abandoned mines, swampy areas, wastelands, and geologically unstable areas (Rojas-Valencia & Sahagún-Aragón, 2022).

Image 2. Open Sky Landfill, Berriozabal, Chiapas. Source: Own

Of these disposal sites, MSW is the only environmentally acceptable, provided they are designed, constructed, and operated under current regulations to minimize environmental impacts and public health risks. Unfortunately, in our country, the most common practice continues to be the use of Open

Sky Landfill, with more than 87% of the FDS operating under this method (INEGI,2020) due to ease and low cost of operation.

Currently, there are some alternative methods for the final disposal of MSW, such as recycling, composting, incineration, and waste-to-energy production (Cabrera, 2022). These methods seek to reduce the amount of waste sent to landfills to prolong their useful life and promote more sustainable management.

4. RESIDUES AFTER FINAL DISPOSAL

The decomposition of municipal solid waste in any FDS inevitably generates other wastes or by-products, mainly biogases, and leachates:

4.1 Biogas

It is a gaseous mixture produced by the fermentation of the organic fraction of solid waste disposed in FDS, composed mainly of methane (405-55%) and carbon dioxide (40-50%). Minor amounts of nitrogen, hydrogen sulfide, hydrogen, and oxygen and traces of carbon monoxide, ammonia, and aromatic hydrocarbons (Vaverková, 2019). The production and composition of the biogas released depends on the waste composition, moisture content, temperature, and the FDS age, among others. It is generated during the anaerobic decomposition of organic matter that begins between one or two years after it has been deposited and continues for about 15-25 years (Köfalusi & Aguilar, 2006; Rojas-Valencia & Sahagún-Aragón, 2022).

4.2 Leachate

Liquids are generated by the decomposition of waste and the filtration of rainwater through them. They are considered highly polluting due to their variable and heterogeneous chemical and microbiological composition. The content of contaminants in leachates (biodegradable and refractory organic material, humic components, heavy metals, inorganic salts), varies with time, generally in the first years of decomposition there is a rapid increase and with the years there is a slow decrease that can be for more than 50 years (Costa et al., 2019; Vaverková, 2019). However, their composition and concentration may vary depending on the nature of the waste in the same way as in biogas production.

The main difference in emissions between FDS is that, in OSL, biogas, and leachate are released without control, which has environmental and social repercussions.

5. ENVIRONMENTAL AND POPULATION IMPACTS DUE TO INADEQUATE MSW DISPOSAL

Inadequate MSW disposal management generates multiple problems affecting both the environment and communities. The main impacts include soil and water pollution, greenhouse gas emissions, the proliferation of diseases such as malaria and dengue fever, the presence of foul odors, blockage of drains and sewers, and damage to wildlife, such as suffocation of animals in plastic bags (Abubakar et al. 2022).

The aesthetic quality of the environment near the disposal sites is seriously affected by dust and the dispersion of light waste, such as plastics and paper. In addition, odors from the decomposition of organic waste, mainly due to the presence of ammonia and hydrogen sulfide, worsen the quality of life of nearby communities, as prolonged exposure to these volatile compounds has been associated with potential health risks, such as respiratory irritation, cancer, and even damage to the central nervous system (Wu et al. 2018). The excessive accumulation of waste favors the proliferation of harmful fauna. In many cases, deliberate fires are set to reduce the volume of waste and prolong the life of disposal sites. However, these fires generate air and soil pollution due to the toxic gases, ash, and smoke produced (Manjunatha et al. 2024). In addition, they contribute to the emission of greenhouse gases such as CO_2 and CH_4, accelerating global warming (Köfalusi & Aguilar, 2006; Abubakar et al. 2022). On the other hand, groundwater and surface water are threatened by the constant production of leachate.

Image 3. Environmental and population impacts due to the inadequate disposal of MSW. Source: Own elaboration based on Jaramillo (2002), Köfalusi and Aguilar (2006), and Abubakar et al. (2022)

Inappropriate MSW management constitutes a critical challenge with social and environmental implications (Fig. 3), which requires immediate attention. Understanding the associated environmental risks is important to effectively address the problem. To mitigate these impacts, it is essential to adopt sustainable approaches that not only promote the reduction and proper treatment of waste, but also encourage the participation of all sectors involved: governments, businesses, and citizens. The implementation of efficient public policies, together with greater social awareness of the importance of proper MSW management, will contribute to the protection of the environment and the well-being of communities, preventing even more serious consequences in the future. Only through a collective effort will it be possible to achieve a healthier and more sustainable environment for future generations.

6. FINAL THOUGHTS

Urban solid waste management in Mexico is a growing challenge that requires urgent and concrete measures. With an estimated daily generation of 108,146 tons/day nationally and 5,188 tons/day in Chiapas, inadequate

disposal systems have led to the proliferation of clandestine landfills and the accumulation of garbage in public spaces. This work shows the magnitude of the problem and the need to improve both the infrastructure for waste management and disposal and the strategies to reduce daily waste generation.

Promoting recycling, reuse, and reduction practices from the source can lead our country towards a circular economy model where resources remain in the production cycle as long as possible, aligning with the global goals of the UN Agenda 2030 and the Sustainable Development Goals (SDGs), especially SDG 12, which promotes responsible consumption and production.

While the government has a fundamental role in the creation of adequate infrastructure and public policies, the active participation of society is equally indispensable. Government policies should focus on implementing reduction, reuse, and recycling strategies, with special attention to sectors with high waste generation rates, such as industry and commerce. It is also essential to ensure strict compliance with environmental regulations, which are often ignored or insufficiently enforced.

Thus, this work contributes to the understanding of the challenges of urban solid waste management in Mexico, identifying the need to strengthen infrastructure and promote the circular economy as key strategies. To achieve this, a collective effort among all social actors is essential to build a cleaner, healthier, and more sustainable present for current and future generations.

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