# Chapter: 1

# Introduction

## 1.1 Overview of MSW and Legacy Waste Issues

Municipal Solid Waste (MSW) management is a growing global challenge, exacerbated by rapid urbanization and population growth. The World Bank (2018) projects that the world will generate 3.40 billion tonnes of MSW annually by 2050, a 69% increase from the current level. In India, this issue is particularly severe (Solid Waste Management. [no date]). According to Singh (2022a), India loses over 1,250 hectares of land each year to MSW disposal (Singh 2022b). The National Green Tribunal, states that over 10,000 hectares of urban land are currently buried under 3,159 legacy waste dumpsites (Singh 2022a).

*Figure 1: Ragpickers at the Bhalswa landfill site on April 28, 2022, in New Delhi, India. Sanchit Khanna/Hindustan Times/Getty Images (Sud et al., 2022)*

These dumpsites pose significant environmental hazards, impacting both terrestrial and aquatic ecosystems. For instance, Naveen et al. (2018) and et al. (2017) highlighted the contamination of ground and surface water bodies by leachate from a landfill in Bangalore (Schöpke et al. 2017; Naveen et al. 2018). The study revealed issues like steep and unstable slopes, leachate accumulation, and runoff into ponds and open wells. India's situation is further complicated by a large number of unsegregated and indiscriminately dumped waste, contributing to nearly 5% of global greenhouse gas emissions (Bogner et al. 2008; Reddy et al. 2015; Emami et al. 2019) .

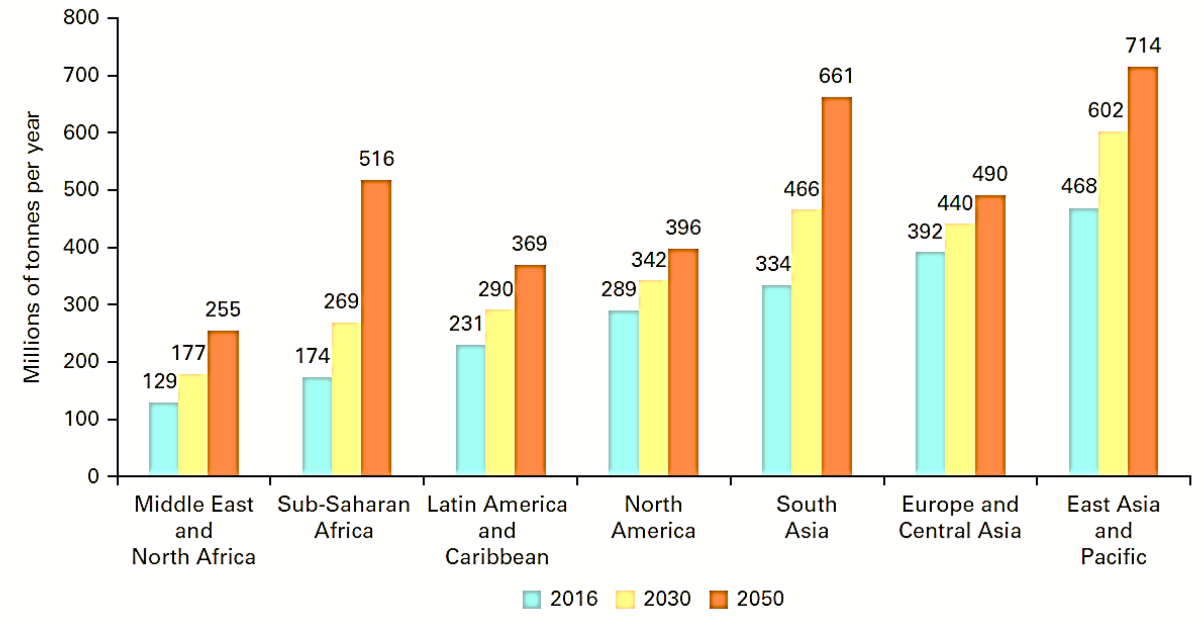

*Figure 2: Projected waste generation, by region (millions of tonnes/year) (World-bank)*

In the compelling visual captured at the Bhalswa landfill site in New Delhi (ref Figure 1), a lone ragpicker navigates the treacherous terrain amidst smouldering waste, illustrating the harsh realities and environmental challenges posed by unsustainable waste management practices. The graph (Ref Figure 2) illustrates the projected waste generation by region, measured in millions of tonnes per year, with an increasing trend from 2016 through 2050, according to a World Bank report. It shows Sub-Saharan Africa and East Asia and Pacific as the regions with the most significant expected increase in waste generation.

## 1.2. Legacy Waste and Landfill Mining

Legacy waste, consisting of long-accumulated untreated municipal solid waste in landfills, poses significant environmental and health risks. In India, as earlier discussed, these legacy waste sites occupy over 10,000 hectares of urban land, as estimated by the National Green Tribunal (Singh 2022a). This situation is further exacerbated by the limited land availability for new waste-processing facilities. According to the Swachh

Bharat report (2020), as much as 1,250 hectares of land is lost each year in India for municipal solid waste disposal(GOI [no date]).

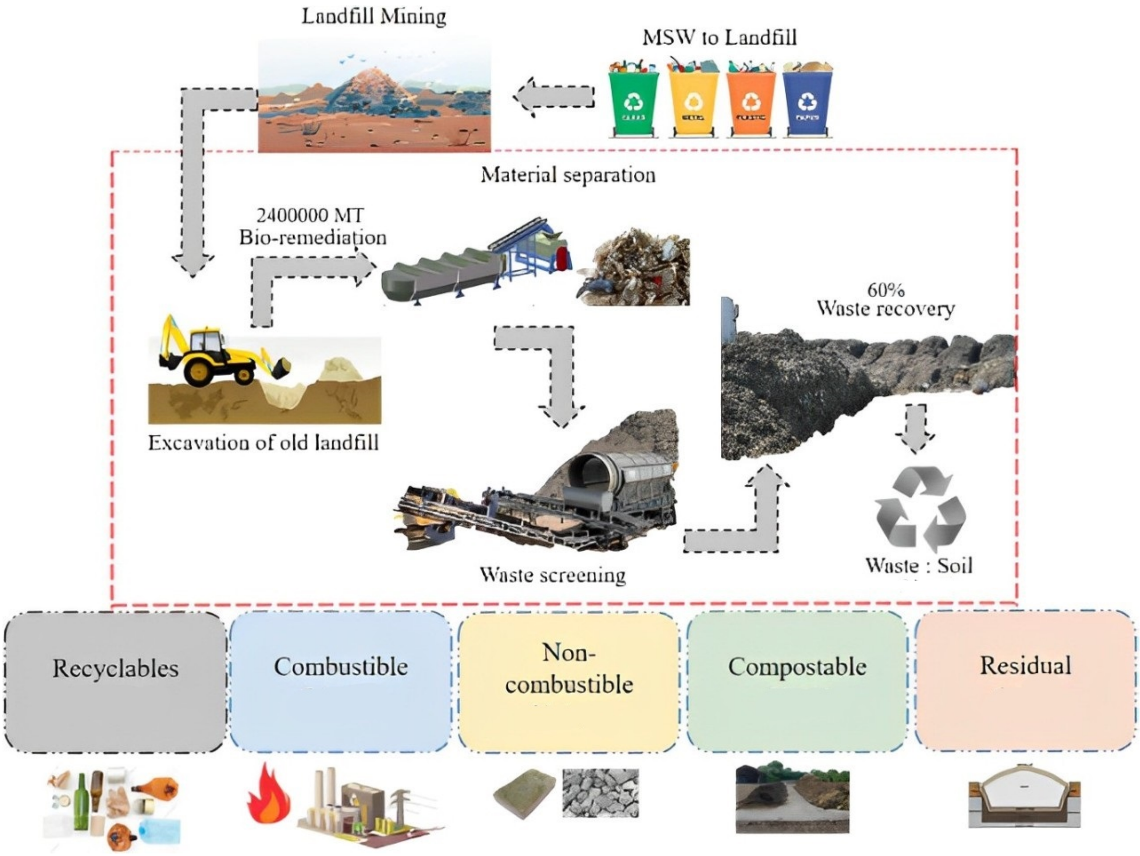

*Figure 3: Typical Landfill/dumpsite mining process (Source: (Bir et al., 2022))*

Legacy waste sites, often located close to urban areas, have become major pollution hubs, posing risks such as leachate formation, surface and groundwater pollution, and greenhouse gas emissions. Landfill mining AKA Biomining, as outlined by the Central Pollution Control Board, is emerging as a viable solution to the issue of these dumpsites (CPCB Annual Report 2020-21). It involves the scientific excavation, treatment, segregation, and utilization of aged MSW, also known as legacy waste. Figure 3 (Bir et al. 2022) depicts landfill mining and material recovery from MSW, involving excavation, bio-remediation, and material separation. The process results in 60% waste recovery, categorizing outputs as recyclables (0.476%), combustible (7.245%), non-combustible (29.97%), compostable (55.6%), and residual waste (6.65%). However, the byproducts of biomining, such as Refuse-Derived Fuel (RDF) and Soil-like material (SML), often pose challenges in their utilization (Dixit 2023) . On the other hand, RDF which is the non or less-decomposable part of aged MSW including plastic and other materials, is channelized to cement industries for energy recovery (The Hindu Bureau 2024). A study by Somani et al. (2020) revealed the high organic content and total soluble solids in Soil-like Material (SLM), significantly higher than that of local soils, indicating the need for proper treatment before disposal. The Centre, through the Swachh Bharat Mission 2.0, has committed a substantial investment (Rs 1,41,600 crore) for the remediation of all legacy dumpsites in the country by biomining, as per the guidelines of the Central Pollution Control Board (PIB Delhi 2021). Biomining is defined as the scientific process of excavation, treatment, segregation, and utilization of aged municipal solid waste (CPCB Annual Report 2020-21).

Cities like Indore, Bhopal, Ambikapur, Kumbakonam, and Tirupati have demonstrated successful biomining projects, where the reclaimed land has been utilized for various applications, including the development of waste-processing facilities and green spaces. However, the process of biomining is not without challenges. It involves complex waste composition, the need for advanced technological solutions, and concerns about the economic viability of the process (Dixit 2023).

*Figure 4: (a): GOI flagship scheme 'Swachh Bharat Mission' logo (b) Logo of "Garbage City free" (GFC) awarded to Indian cities based on their sustainable waste management practices*

The urgent need to reclaim prevailing dumpsites to ensure land availability and recycle untapped resources from old dumpsites is a critical step towards achieving "garbage-free cities" under the Swachh Bharat Mission 2.0 (GOI [no date]) (Logo of the flagship scheme shown in Figure 4. The comprehensive policy direction for the reuse of reclaimed land after biomining and proper disposal or utilization of bioproducts such as soil-like material and RDF is still evolving, underscoring the need for further research and policy development in this area. This study advocates for sustainable and circular economy-based applications for SML, emphasizing the need for in-depth characterization and responsible management (Naveen et al. 2018; Somani et al. 2020)

## 1.3. Municipal Solid Waste Fines and its Characteristics

In this study the mined soil-like-material (SML), also indicated as legacy waste fines (LWF) or broadly municipal solid waste fines (MSWF) as per requirement. Municipal Solid Waste Fines (MSWF) is a significant by-product of legacy waste biomining, comprising a substantial portion of the waste material in dumpsites. According to research conducted at the Indian Institute of Technology (IIT) Bombay, the composition of legacy waste from four different dumpsites in India primarily consists of fine soil/sand-like material, scrap polymeric and combustible materials, stones, and miscellaneous items. Studies analyzing the Deonar dumpsite in Mumbai found that waste older than 20 years comprised approximately 57% fine fraction, with an average of 44.4% across the dumpsite. The plastic fraction was around 11.4%, showing a declining trend with waste age, while metal and glass contents were found to be negligible (Chakraborty et al. 2021). Notably, the fine soil/sand-like material makes up approximately 44-75% of the legacy waste by weight (Sharma and Jain 2020).

The characteristics of MSWF vary greatly based on the age and management of the landfill. Older landfills typically have a higher fraction of residual organic waste or fine-fraction (mass remaining after microbial degradation). The higher proportion of fine soil-like material in the dumpsite is attributed to the microbial decomposition/degradation of the organic waste within the dumpsite. The scrap polymeric and combustible material, consisting of plastics, paper, cardboard, and textiles, varies between 4 and 19 percent by weight (Joseph et al. 2018). These findings highlight the need for a differentiated approach to managing MSWF, considering their varied composition and potential environmental impacts.

Given these characteristics, there is a growing emphasis on finding sustainable ways to utilize MSWF. Utilization options range from construction and geotechnical applications to the generation of energy through the production of Refuse-Derived Fuel (RDF). However, these applications must consider the environmental and health impacts, particularly in the context of the presence of heavy metals and other contaminants in MSWF. Sustainable utilization of MSWF is vital for advancing circular economy principles and achieving waste management goals.

## 1.4. Scope of MSWF in Civil and Construction Applications and Need for Sustainable Utilization

The utilization of Municipal Solid Waste Fines (MSWF) in civil engineering and construction offers significant potential for sustainable resource management. Studies have demonstrated that MSWF can effectively stabilize soft soils, enhancing their load-bearing capacity and durability, making it suitable for various geotechnical applications such as subgrade and embankment construction. For instance, incorporating MSWF into subgrade materials can significantly reduce the thickness of the bituminous layer required in road construction, leading to cost savings and improved sustainability.

### 1.4.1 Applications in Soil Stabilization and Construction

- **Soil Stabilization:** MSWF has shown promise in stabilizing soft and expansive soils, which are crucial for foundation stability in construction projects. For example, studies have indicated that adding MSWF to soil enhances its mechanical properties, such as compressive strength and shear strength. This makes the soil more stable and suitable for supporting structures, reducing the need for extensive foundation treatments (Kumar and Mittal 2019).
- **Subgrade and Embankment Construction:** Utilizing MSWF in road construction, particularly as a subgrade material, can significantly improve pavement performance (Ref. Figure 5 a). The addition of MSWF can increase the California Bearing Ratio (CBR) and reduce the required thickness of the bituminous layer, leading to cost savings and a reduction in the environmental footprint of construction projects. MSWF's properties, such as its compaction characteristics and load-bearing capacity, make it a viable alternative to traditional subgrade materials (Liu et al. 2011; N et al. 2017).
- **Backfill Material:** MSWF can be used as a backfill material in retaining walls and other geotechnical structures. Its stability and stress resistance are comparable to conventional materials, making it suitable for use in various construction scenarios. This application not only helps in managing waste but also provides a sustainable alternative to natural aggregates (Jayatheja et al. 2021a; Jayatheja et al. 2021b; Srivastava et al. 2022)
.
- **Landfill Cover and Reclamation:** MSWF has been explored for use in landfill covering and reclamation projects. Using MSWF as a cover material can help stabilize

waste dumps and reduce the risk of environmental contamination (Ref Figure 5 b). This application is particularly beneficial in urban areas where space for new landfills is limited (Xue et al. 2022).

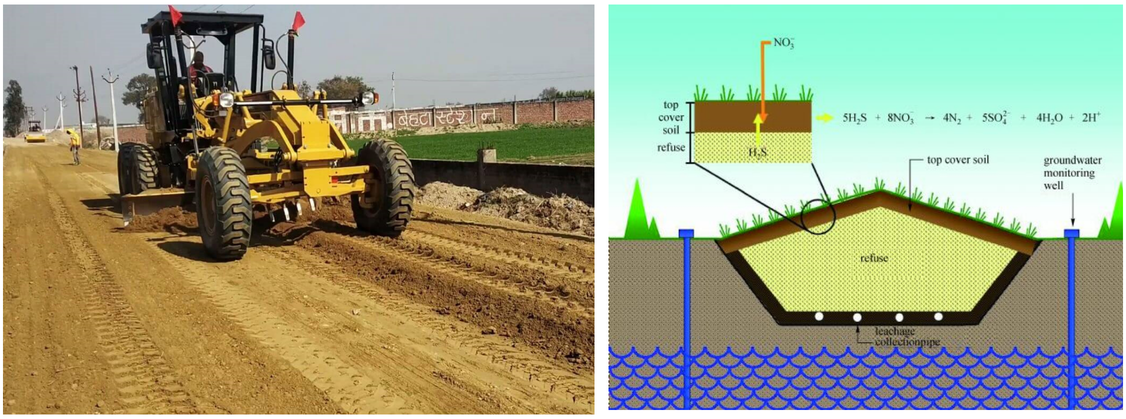

*Figure 5: (a) Illustration of subgrade preparation using stabilized soil, demonstrating its practical application in road construction. (b) Conceptual diagram of a landfill cover system incorporating engineered materials, highlighting potential applications of MSWF in waste management and environmental sustainability.*

## 1.5. Challenges in Utilization and Disposal of MSWF, Guidelines, and Present Practice

A major concern is the high content of organic matter, heavy metals, and total soluble solids in Soil-like Material (SLM), necessitating rigorous treatment prior to disposal or utilization to ensure safety and environmental compliance (Somani et al. 2020)

The "Guidelines for Disposal of Legacy Waste (Old Municipal Solid Waste)" issued by the Central Pollution Control Board (2019) highlights the potential of MSWF and soil-like material from legacy waste for applications beyond landfill mining. The bio-earth or fine fraction, rich in humus-rich organics, offers benefits for soil fertility enhancement. However, it often fails to meet the Fertilizer Control Order (FCO) standards for compost due to its significant soil or sand content. These guidelines propose its use in landscaping, gardening, and as a soil enricher for green areas or agricultural purposes. Yet, caution is advised as these applications pose potential hazards, particularly the risk of introducing heavy metals into the human food chain. Such applications, while mentioned in the guidelines, require prudent avoidance despite the emphasis on sustainable utilization. Current practices often involve dumping this fine fraction in low-lying areas or farmlands, which is environmentally unsustainable(’Singh 2021; VMC 2021; Singh 2024).

Instead of the aforementioned utilization methods, applying MSWF in geotechnical projects post-stabilization emerges as a more sustainable approach, with benefits elaborated in subsequent sections. The Central Road Research Institute (CRRI) has conducted geotechnical investigations on biomined MSWF for potential use in subgrade construction. Furthermore, the government's recent policy guideline from December 2023 on the use of inert material in National Highway construction offers an innovative perspective. However, the term “inert material” raises several concerns, as MSWF is not inherently inert. It requires comprehensive stabilization, both biological and mechanical, to meet the criteria set by the Ministry of Road Transport and Highways (MoRTH). This development underscores the necessity for further research and development in effectively implementing MSWF for large-scale civil engineering applications, ensuring material stability and safety (MoRTH 2023; Singh 2024). With this, public skepticism regarding the safety of waste-derived materials persists, hindering their acceptance in infrastructure projects. Addressing these issues requires clear regulatory frameworks and proactive public engagement to facilitate the sustainable adoption of MSWF .

## 1.6. Mechanical and Chemical Stabilization Waste before Utilization

Stabilization of contaminated waste, particularly Municipal Solid Waste Fines (MSWF), is essential before their disposal or utilization due to their complex composition, potential environmental risks, and weak bearing capacity or mechanical stability. Stabilization processes play a crucial role not only in reducing the mobility of these contaminants but also in enhancing the mechanical properties of the waste, thereby making it suitable for a range of applications. For instance, a study by Patil et al. (2023) effectively demonstrated the use of Landfill Mined Soil-like Fraction (LMSF) in addressing cracks in expansive soils, underscoring its potential in civil engineering applications (Patil et al. 2023).

In addition to biological stabilization, which primarily addresses biohazards, sustainable geotechnical stabilization is instrumental in immobilizing heavy metals and potentially increasing the mechanical strength of materials like MSWF. This makes them more suitable for environmentally safe civil engineering applications. Given these factors, it becomes imperative to adopt sustainable and environmentally friendly stabilization methods. Traditional approaches, such as the use of lime and cement, are being increasingly reconsidered due to their associated carbon emissions in manufacturing process. In contrast, biomaterials like biopolymers, such as Xanthan Gum and Agar Gum, and other biological technologies like microbial-induced calcite precipitation (MICP) have emerged as promising alternatives. These biodegradable polymers, produced by living organisms, offer an eco-friendly solution for stabilizing heterogeneous materials like MSWF, enhancing their mechanical properties, and reducing the leaching of contaminants (Biju and Arnepalli 2020; Bonal et al. 2021; Tian et al. 2022).

The need for stabilization underscores the importance of responsible and sustainable waste management practices, aligning with the goals of circular economy and environmental protection. Effective stabilization techniques can transform contaminated waste into valuable resources, contributing to the reduction of landfill space and the development of sustainable waste management solutions.

## 1.7. Potential of Biopolymer in Stabilization of Soil and Industrial Waste and Scope in Stabilization of MSWF

Though biopolymer application is diverse in various sectors as shown in the Figure 6, its utilization in the stabilization of soil and industrial waste, particularly Municipal Solid Waste Fines (MSWF), presents a promising sustainable alternative to conventional stabilization methods. Biopolymers, derived from natural sources as shown in the Figure 6, offer an eco-friendly approach, reducing the environmental impact compared to traditional stabilizers like lime or cement (Chang and Cho 2014; Dubey et al. 2022).

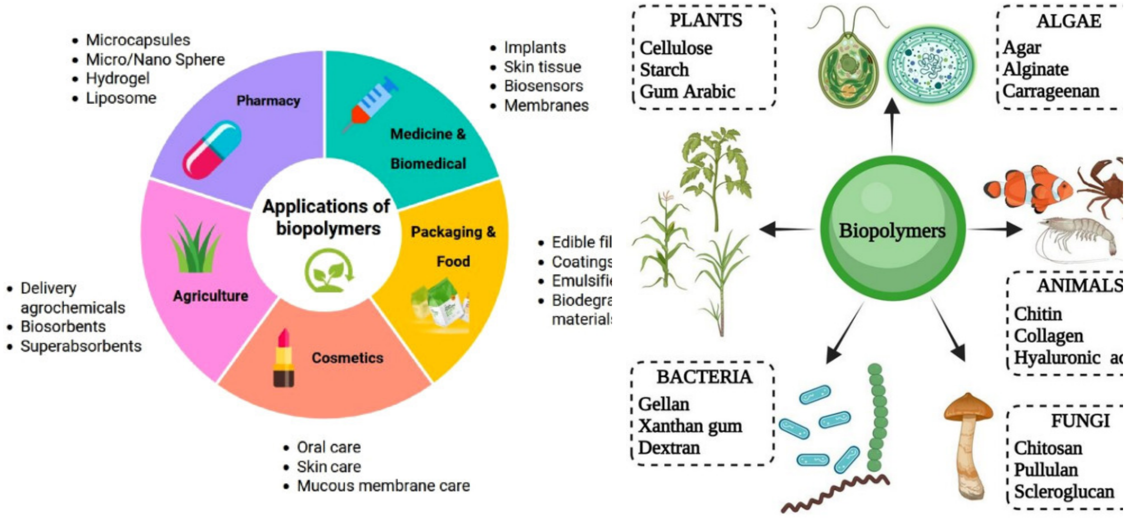

*Figure 6: (a) Common applications of Biopolymers: Broad range of biopolymer applications across different sectors, highlighting their versatility and sustainability. (b) Sources of Biopolymers: Diverse origins of biopolymers used in various applications*

Biopolymers such as Xanthan Gum and Agar Gum have been studied extensively for their effectiveness in improving the geotechnical properties of various soils and wastes. Research shows these biopolymers significantly enhance soil strength, reduce permeability, and improve overall stability. These characteristics are particularly beneficial in the context of MSWF, which often contains a mix of organic and inorganic materials with variable mechanical properties (Smitha et al. 2021; Hamza et al. 2023).

The application of biopolymers in stabilizing MSWF has multiple advantages. It not only improves the mechanical strength of the waste material, making it suitable for construction and other geotechnical applications but it also addresses environmental concerns by reducing the leaching of contaminants. This aligns with the principles of circular economy, offering a pathway to recycle and reuse waste materials in a sustainable manner. In this study, author utilize biopolymers like Xanthan Gum (derived from bacteria) and Agar Gum (derived from algae) for stabilizing Municipal Solid Waste Fines (MSWF) to enhance their geotechnical properties.

However, challenges remain in the widespread adoption of biopolymers for waste stabilization. These include the need for further research to optimize biopolymer dosages, understand long-term stability, and develop cost-effective production methods. The potential of biopolymers in the stabilization of MSWF opens new avenues in waste management, highlighting the need for continued research and policy support to harness this sustainable technology.

## 1.8. Circularity and Sustainability Aspects of Sustainable and Safe Utilization of MSWF in Geotechnical Application Post-Stabilization through Biopolymers

The circularity and sustainability aspects of utilizing Municipal Solid Waste Fines (MSWF) in geotechnical applications post-stabilization with biopolymers represent a significant advancement in waste management practices. This approach aligns with the principles of the circular economy, focusing on resource recovery, waste minimization, and the reduction of environmental impact (depicted in Figure 7).

*Figure 7: The circular economy model: Utilizing MSWF in civil engineering contributes to less raw material usage, waste reduction, and fewer emissions, promoting a sustainable and efficient waste management cycle (Source: European Parliament Research Service*

Post-stabilization, MSWF can be safely used in various geotechnical applications, such as in road construction, landfills, and as a fill material. The use of biopolymers for stabilization addresses environmental concerns associated with traditional stabilizers, offering a more sustainable solution. This method not only improves the mechanical properties of the waste but also reduces the leaching of contaminants, ensuring environmental safety.

The integration of MSWF in geotechnical applications post-stabilization is a step towards achieving sustainability goals, the linkages to various SDGs are shown in Table 1. It contributes to resource conservation by reusing waste materials, reduces the need for new landfills, and lowers greenhouse gas emissions. However, further research and development are needed to optimize the use of biopolymers, understand their long-term behaviour, and make this technology more economically viable.

*Table 1: Linkage of the study to the SDG goals*

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|  |  |  |
| **SDG 11: Sustainable Cities and Communities** | **SDG 12: Responsible Consumption and Production** | **SDG 13: Climate Action** |
| Repurposing MSWF for urban infrastructure supports sustainable, resilient, and environmentally friendly cities. | Stabilizing MSWF with biopolymers promotes resource efficiency and reduces waste, aligning with sustainable consumption and production patterns. | Reusing MSWF reduces landfill use and greenhouse gas emissions, supporting climate action goals. Biopolymers, with a lower carbon footprint, enhance these benefits. |

## 1.9. Study’s Objective in Brief

This study aims to evaluate the potential of biopolymer stabilization for Municipal Solid Waste Fines (MSWF) by assessing its geotechnical properties, long-term durability, and environmental sustainability. The research focuses on depth-wise property analysis, stabilization effects of Xanthan Gum (XG) and Agar Gum (AG), durability performance, and practical applications in geotechnical engineering. Additionally, the study examines the carbon footprint and sustainability aspects of biopolymer-treated MSWF as an alternative to traditional stabilizers.

## 1.10. Key takeaways and Way forward

- The introduction outlined the importance of sustainable utilization of MSWF and the potential role of biopolymer stabilization in enhancing geotechnical and chemical properties.
- The study's objectives and significance were clearly established, emphasizing the need for innovative solutions in waste management and civil engineering applications.
- A solid foundation was provided on MSWF, biopolymer stabilization, and their applications, setting the stage for the detailed analysis that follows.
- The next chapter, **Literature Review**, delve into existing research on legacy waste remediation and biopolymer applications, identifying gaps that this study aims to address. This will provide a comprehensive context for understanding the current state of knowledge and the innovative contributions this research seeks to make.