ASMI SEHRA

SOLID WASTE and E-WASTE MANAGEMENT

Waste Management for a Greener Tomorrow: Solid and E-Waste Strategies

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ABSTRACT

The problem with the generation of solid waste and e-wastes continues to pose significant environmental and public health challenges to countries globally. The dissertation aimed to examine the scope of solid waste and e-waste management practices/strategies and challenges to provide recommendations for better protection of the environment and public health. A critical review of literature desk research was adopted. The review showed that solid wastes can be categorized based on source (i.e., municipal solid waste (MSW), industrial waste, healthcare waste and e-waste) or safety (hazardous and non-hazardous waste). The review also identified that the most common stages in solid waste management after generation include collection, transportation, treatment/processing and disposal. The study found that contracting third parties for each of these stages was an important strategy for municipals. Landfilling was found to be the most adopted strategy globally for the disposal of solid wastes, although effectiveness varied between high-to-middle- and low-income countries. The best method for e-waste management was observed to be recycling and reusing. The review also observed that the dumping of e-waste in developing countries by developed countries continued to be a key challenge. The review's recommendations to improve solid waste and e-waste management included creating citizen and industrial-level awareness, government budgeting for solid waste management (SWM) and effective legislation. The main limitation of this study was overdependent on secondary sources due to a limited number of primary studies on the topic. Future studies should consider more primary studies.

KEYWORDS: Solid Waste, E-Waste, Environment, Public Health, Municipal Solid Waste

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CHAPTER 1: INTRODUCTION

1.1 Background

Statistics by the United Nations Environmental Programme (UNEP) (2023) show that annually, approximately 11.2 billion tonnes of solid waste are collected worldwide with the decay of the organic proportion of this waste causing contributing about 5% of greenhouse gas (GHG) emissions. Also, statistics by the Hazardous Waste Haulers (HWH) (2023) indicate that worldwide, more than 2 billion municipal solid waste (MSW) is produced every year, which is expected to rise to 3.4 billion tonnes by 2050. Besides, it has been shown that more than 90% of the waste generated is mismanaged in developing, low-income countries, where waste volume is expected to triple by 2050 (HWH, 2023). Moreover, the largest producers of MSW are China and the US, which generate more than 200 million metric tonnes while 31 million tonnes are generated by the UK (Alves, 2023). Also, the World Bank (2023) report showed that developed or high-income countries, which comprise 16% globally, generated more than 683 million tons (34%) of the world's solid waste. Overall, such a report demonstrates a positive correlation between a country's income level and waste generation.

Solid wastes are produced at large proportions that are adequate to distort social health and natural ecosystems (Bui et al., 2022; Ferronato et al., 2019). In India, for example, about 143,449 metric tons of MSW are generated each day, of which 111,00 metric tons are collected with only 35,602 metric tons of the collected MSW treated (Kumar et al., 2017). In the UK, a staggering 100 billion pieces of plastic packing are thrown away annually, which on average amounts to 66 items per household per week (Tiseo, 2023). However, UNEP (2023) report shows that of all the streams of waste, those from electronic and electrical equipment containing complex, new hazardous materials presents the largest increasing problem in both developing and developed country. The

UNEP's (2023) statement on e-waste is confirmed by Shahabuddin et al. (2023) who found that the major solid waste category generated globally is e-waste, with Europe being the leading generator and collector of e-waste followed by Asia, America, Oceania and Africa. The major challenge of solid and e-waste management is attributed to the collection, inhomogeneity of waste, sorting, prevention of further waste, low energy density, cost-effective recycling and emissions (Kaya and Kaya, 2019; Shahabuddin et al., 2023). Unfortunately, whereas a range of solid waste and e-waste management approaches have been reviewed (Kiddee et al., 2013; Andeobu et al., 2021; Sharma et al., 2021), there is a very limited number of studies that have attempted to establish the effectiveness of these solid waste management (SWM) approaches. This review capitalizes on this gap by presenting a critical review of approaches used in solid waste and e-waste management to determine their effectiveness and recommend how SWM can be improved.

1.2 Problem Statement

There is vast evidence acknowledging the devastating implications of uncontrolled solid and e-waste generation and ineffective management. For instance, the UNEP (2023) reported that poor waste management that ranged from ineffective disposal to non-existing collection systems increased the potential for the contamination of soil and water as well as air population. The UNEP (2023) report is consistent with Siddiqua et al. (2022) discovery that unsanitary, open landfills were channels for water and soil contamination, which then increased the risks for infections and transmission of diseases. Equally, Saha et al. (2021) found that dispersing debris not only polluted ecosystems but also led to dangerous substances from industrial garbage and electronic waste putting strain on the urban dwellers' health as well as the environment. These findings suggest that solid waste causes both direct and indirect impacts on people and the environment, which are even felt more by marginalized social groups or developing countries. Therefore, considering the devastating negative impacts of solid and e-wastes and the lack of definitive, more effective SWM strategies, there is a need to undertake a study seeking to establish the effectiveness of currently recommended strategies in the management of solid wastes.

1.3 Research Question

What is the effectiveness of current solid waste and e-waste management in the mitigation of environmental degradation and prevention of negative human health outcomes?

1.4 Research Aim/Objectives

This dissertation aims to examine the scope of solid waste and e-waste management practices/strategies and challenges to provide recommendations for better protection of the environment and public health. The study is undertaken based on the following objectives.

- To identify different categorizations and sources of solid waste and e-waste.
- To critically determine the implications of solid waste and e-waste on the environment and public health.
- To evaluate current strategies used in the management of solid waste and e-waste.
- To examine contemporary challenges in the effective management of solid waste and e-waste
- To provide recommendations for best solid waste and -e-waste management practices.

1.5 Significance of the Study

Solid waste and e-waste present the biggest challenge in efforts towards Sustainable Development Goal 15 (SDG 15) which focuses on “Life on Land” including other SDGs (WasteAid, 2016). Subsequently, the execution of this study is expected to provide insightful information on how people, institutions and governments can strive towards the realization of SDG 15. Also, the successful completion of this study offers insights to waste management agencies as well as municipalities on best SWM practices that should be implemented for the realization of a world free from the negative effects of waste. Lastly, through this study, it will be possible to generate insights that guide efforts towards addressing environmental degradation as well as climate change associated with poor SWM. Such may contribute to the realization of Net-Zero Emissions (NZEs) by 2050, which comprises a normative International Energy Agency (IEA) (2023) scenario presenting the pathway for the achievement of net zero CO_2 emissions by 2050.

1.6 Research Outline

This dissertation is grouped into six chapters. The first chapter is the introduction, which sets the direction as well as the goals of this study. The second chapter is the methodology that provides the steps utilized in the retrieval of studies as well as themes guiding the execution of this dissertation. Chapter three examines the different categories of solid waste and e-waste including the major sources of these wastes. The fourth chapter intrigues the various effects of solid waste and e-waste on both the environment and public health. The fifth chapter critically evaluates some of the barriers and strategies adopted in the management of solid wastes and e-wastes with more focus on Ahmedabad Municipal Corporation (AMC) in Gujarat, India. The last chapter provides a summary of the dissertation and recommendations for improving the management of solid wastes and e-wastes.

CHAPTER 2: METHODOLOGY

In examining the dynamics surrounding solid waste and e-waste management desk (secondary) research method, which embodies the exploration of a topic by collecting and analyzing data from previous research and existing documents, was adopted as utilized in previous studies (Gazzeh et al., 2022; Balogun et al., 2022). While the adoption of desk research offered a solid basis for making arguments including elaborating a line of thought on solid/e-wastes, it was far less expensive and less time-consuming, which implies that it offered fast, credible insights on the topic. Throughout the dissertation, a critical literature review design was utilized to offer a more in-depth examination of how knowledge of solid waste and e-waste management has changed over time. Noteworthy, a critical literature review embodies the critical analysis and evaluation of numerous sources on a specific topic (Snyder, 2019). Therefore, adopting this design offered the flexibility of using a wide range of sources to guide the understanding of current solid waste and e-waste management practices and how such practices be enhanced. The methodology section embodied three iterative phases as outlined in Figure 1 below, and included scoping, collection of relevant literature and data analysis.

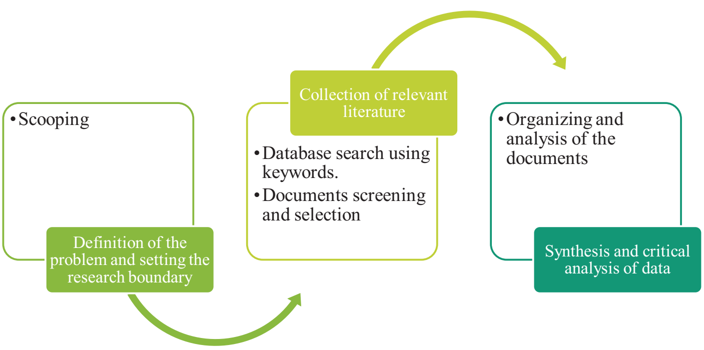

Figure 1: Research Method Flow Chart

First, the scoping phase involved the definition and understanding of the various components of solid waste and e-waste management based on the stated aim and objectives. The goal was setting the dissertation's boundary and scope, which was exploring the dynamics of solid waste and e-waste management concerning the environment and public health impacts, which was focused internationally as the study boundary. The scoping phase was also critical in guiding the identification of relevant search terms or keywords to be applied in the second stage.

The second phase of the methodology embodied the identification and collection of appropriate literature from online sources. Several databases were utilized in searching sources for use in this study and these included Scopus, JSTOR, ScienceDirect, and Web of Science. Additional sources were retrieved from the Google Scholar search engine, general Google search, search from reference lists of the retrieved articles, cross-referencing and grey literature. To achieve the search, a combination of keywords/phrases and Boolean Operators (BOs) was utilized. These included "solid waste" OR "e-waste" OR "municipal solid waste" AND "sources" OR "cause" AND "types" OR "categories" AND "strategies" OR "approaches" OR "methods" OR "challenges" OR "barriers" OR "obstacles".

The inclusion criteria encompassed literature that was related to solid waste and e-waste, strategies, challenges and management of solid/e-wastes to ensure a match to the dissertation aim and objectives, literature published in the English language since the target is an English-speaking audience and literature published from 2010 to provide up-to-date practices in the management of solid waste and e-waste. The inclusion criteria also included journal articles, reports, website content and expert opinion reports to expand the breadth of understanding on the current state of solid waste and e-waste management. Also, both primary and secondary literature were included to increase the depth of insights utilized in this dissertation. On the other hand, the exclusion criteria included literature not focused on solid-waste and/or e-waste due to being irrelevant to the study aim/objectives, literature published before 2010 owing to its outdated nature and literature published in other languages as it would be time-consuming to make translations to fit the scope of this study. The inclusion/exclusion criteria are summarized in Table 1 below.

Table 1: Inclusion/Exclusion Criteria

Inclusion	Exclusion
• Literature on solid waste and e-waste, strategies, challenges and management of solid/e-wastes. • Literature published in the English language. • Literature published from 2010. • Journal articles, reports, website content and expert opinion reports. • Primary and secondary literature.	• Literature not focused on solid waste and/or e-waste. • Literature published before 2010. • Literature published in other languages.

2.1 Search Strategy

Retrieval of key literature included placing the keywords on the database search interfaces and searching with the help of Boolean Operators. Refining of the search process in the databases was made using truncation and filters such as year (2010-2023), language (English), and article type (Journal article, reports etc.) amongst others that ranged from one database to another. The researcher assessed the suitability of each retrieved source through a quick scanning of their title and abstract to ensure they matched at least a single aspect of the aim/objectives. The search strategy is summarized in Table 2 below.

Table 2: Search Strategy

Database/Source	Keywords	BOs	Keywords	Initial Results	Filters/Truncation	Final Results
Scopus	"Solid waste" AND "sources" AND "types" AND "Strategies"	OR OR OR OR	"e-waste" OR "municipal solid waste" AND "Cause" AND "Categories" AND "Approaches" OR "methods" OR "challenges" OR "barriers" OR "obstacles".	234	Year (2010-2023) Language (English) Article Type (Journal articles, Reports)	12
JSTOR	"Solid waste" AND "sources" AND "types" AND "Strategies"	OR OR OR OR	"e-waste" OR "municipal solid waste" AND "Cause" AND "Categories" AND "Approaches" OR "methods" OR "challenges" OR "barriers" OR "obstacles".	165	Year (2010-2023) Language (English) Article Type (Journal articles, Reports)	17
ScienceDirect	"Solid waste" AND "sources" AND "types" AND "Strategies"	OR OR OR OR	"e-waste" OR "municipal solid waste" AND "Cause" AND "Categories" AND "Approaches" OR "methods" OR "challenges" OR "barriers" OR "obstacles".	185	Year (2010-2023) Language (English) Article Type (Journal articles, Reports)	28
Web of Science	"Solid waste" AND "sources" AND "types" AND "Strategies"	OR OR OR OR	"e-waste" OR "municipal solid waste" AND "Cause" AND "Categories" AND "Approaches" OR "methods" OR "challenges"	112	Year (2010-2023) Language (English) Article Type (Journal articles, Reports)	9

Database/Source	Keywords	BOs	Keywords	Initial Results	Filters/Truncation	Final Results
			OR "barriers" OR "obstacles".			
Google Scholar	"Solid waste" AND "sources" AND "types" AND "Strategies"	OR OR OR OR	"e-waste" OR "municipal solid waste" AND "Cause" AND "Categories" AND "Approaches" OR "methods" OR "challenges" OR "barriers" OR "obstacles".	263	Year (2010-2023) Language (English) Article Type (Journal articles, Reports)	26
Google	"Solid waste" AND "sources" AND "types" AND "Strategies"	OR OR OR OR	"e-waste" OR "municipal solid waste" AND "Cause" AND "Categories" AND "Approaches" OR "methods" OR "challenges" OR "barriers" OR "obstacles".			8
Reference lists and cross-referencing						10
TOTAL						110

The last phase of the methodology involved organizing, analyzing and synthesizing the data collected from the selected literature. The selected literature was organized based on the similarity of their topics or findings, although some fit into more than one group or category. Each work was thoroughly reviewed and examined and themes related to solid waste and e-waste were collated, harmonized, synthesized and finally summarized as shown in Table in appendix one. The themes were generated by first reading the content of each document and identifying recurrent patterns, ideas and concepts related to the study. The recurrent patterns, concepts and ideas were then merged to form themes used in this study.

CHAPTER 3: CATEGORIZATION AND SOURCES OF SOLID WASTE AND E-WASTE

3.1 Introduction

This chapter presents the different definitions of wastes, solid wastes and e-waste, the classification of solid wastes and e-wastes including their sub-categories and a conclusion summarizing the chapter.

3.2 Definition of Waste, Solid Waste and E-waste

The definition underpinning waste is critical when it comes to the classification of materials or substances as wastes (Arikan et al., 2017). Nonetheless, an article by the UK Government (2023) emphasizes the definition of waste as a critical step towards guiding the formulation of policies on waste management including the application of regulatory controls for the protection of human health and the environment. Subsequently, waste is defined as materials that should or are disposed of without being resold to other companies, or people and is associated with collection, transportation and disposal costs (Abdel-Shafy and Mansour, 2018).

On the other hand, the World Health Organization (WHO) (2023) defines solid waste as any type of trash, garbage, refuse or discarded material while the Environmental Protection Agency (EPA) (2023) describes solid waste as any material that has been discarded or abandoned. Both the EU (2023) and the UK Government (2023) defines solid waste as any non-liquid object or substance that the holder discards, is required to discard or intends to discard in line with EU Directive 2008/98/EC. However, section 261.4(a) of the Code of Federal Regulations (CFR) (2023) excludes several wastes as not falling under the solid waste definition. These include domestic sewage and associated mixtures, point source discharge, irrigation return flow, radioactive waste, in-situ mining, pulping liquors, spent sulphuric acid, spent wood preservatives, coke by-product wastes, excluded scrap metal, used cathode ray tubes amongst others (Code of Federal Regulations (CFR), 2023). Also, globally, e-wastes are understood as any electronic appliance that has a cord, a plug, or a battery and is no longer usable or has reached its usable lifespan (Saha et al., 2021; Shredall SDS Group, 2022). The WHO (2023) and EPA (2023) consider that e-waste falls under the solid waste group, which is consistent with Kawai and Tasaki's (2016) statement that solid wastes constitute e-waste amongst others. The varying definitions of solid wastes insinuate the complex nature of understanding the intersections of various aspects that constitute solid wastes or their categorisations.

3.3 Classification of Solid Wastes and e-Wastes

Different scholars and organizations have provided different categorisations of solid waste. For instance, the WHO (2023) recognizes that solid wastes can be categorised based on where the waste is generated, for instance, municipal solid waste (MSW), e-waste or health care waste. On the other hand, Kawai and Tasaki (2016) categorize wastes as hazardous or non-hazardous.

3.3.1 Municipal solid waste/non-hazardous

Non-hazardous solid wastes tend to be generated from relatively small-scale sources and public spaces, which may explain their attribution as MSW (Kawai and Tasaki, 2016; Abdel-Shafy and Mansour, 2018). MSW comprise household (HH) waste, demolition and construction debris, waste from streets, and sanitation residue (Inter-Organizational Programme for the Sound Management of Chemicals (IPSMC), 2013). Statistics by Development Aid (2023) showed that by 2022, about 2.01 billion tons of MSW was generated and is expected to reach 3.40 billion in the next 30 years, representing a 70% increase. Besides, a study by Bello (2018) found that an increase in urbanization as well as changing food habits and lifestyles was the major cause of the rapidly increasing generation of MSW. Also, garbage, which mostly comes from commercial and residential complexes has further been categorised into organic waste (i.e., kitchen waste, fruits, vegetables), toxic waste (i.e., paints, chemicals, batteries, pesticide and fertilizer containers), recyclable (i.e., glass, paper, plastics) and soiled (i.e., hospital wastes like cloth soiled with blood or other bodily fluids) (Bello, 2018). These categorisations suggest that although a few wastes may be hazardous, most of them are non-hazardous. Such may be explained by the fact that people interact and generate these wastes in their routine life.

3.3.2 e-Wastes

Electrical and electronic wastes (e-wastes), fluorescent lamps, batteries and spray cans that have been discarded by households are classified as MSW, although they tend to contain hazardous substances (Asari and Sakai, 2011; Manggali and Susanna, 2019). E-waste has been categorised into different groups such as temperature exchange equipment (i.e., freezers, fridges), lamps (i.e., LED lamps, fluorescent lamps), screens (i.e., laptops, TVs, tables), large equipment (i.e., electric stoves, washing machines, clothes dryers), small IT equipment (i.e., mobile phones, routers, GPS, calculators) and small equipment (electric kettles, microwaves, vacuum cleaners) (Shredall SDS Group, 2022). As observed above, most of the e-wastes is non-hazardous, which is justified by the fact that people are routinely exposed to them, but Tansel (2017) and Chatterjee and Abraham (2017) posit that the generation of e-wastes continues to rise significantly, hence posing significant strain in efforts towards effective solid waste management. The major source of the rising trend in the generation of e-waste has been attributed to rapidly advancing technologies, shorter product life cycles and increasing consumer demands (Şahin, 2017). These factors may help in explaining why e-waste has become among the fasted growing waste streams globally, but they can also be utilised in stressing the significance of e-waste when it comes to solid waste management commitments. Most importantly if the environment and public health were to be protected, these revelations emphasize addressing e-waste from the industries producing electronic devices.

3.3.3 Hazardous solid wastes

Hospital and industrial wastes are considered hazardous as they constitute a variety of toxic substances, although certain HH wastes (i.e., old batteries, paint tins, shoe polish, medicine bottles and old medicines) are also hazardous (Andersen, 2015; Soliman and Moustafa, 2020; El-Khateeb, 2022). Conversely, infectious wastes such as blood and needles from clinics and hospitals are designated as specially controlled wastes (Ikeda, 2017; Rutala and Weber, 2015), but Kawai and Tasaki (2016) argue that their categorisation as MSW may vary from country to country. In industries, the main generators of hazardous wastes include chemical, metal, paper, dye, refining and rubber goods (Singh and Singh, 2017). Studies by scholars such as Jerie (2016) and Bol and Tobé (2015) have established that while hazardous solid waste poses significant risks to animals, humans and the environment, the level of attention being directed at their management remains ineffective in most countries, especially developing ones. Nonetheless, data shows a rising trend in the generation of hazardous wastes globally. For instance, statistics by The World Counts (2023) demonstrate that globally, more than 400 million tons of hazardous wastes are produced annually, which is a 400 times increase in just a single generation. In addition, EPA (2023a) shows that in 2021 alone, a staggering 3.3 billion pounds of Toxics Release Inventory (TRI) chemicals were released or disposed of into the environment, although there was a decrease in the release of TRI chemicals to the air by 26% between 2011 and 2021. These statistics justify the current health issues associated with the environment, but they also point to the importance of concerted efforts towards reducing the production of hazardous solid wastes.

3.3.4 Conclusion

Chapter 3 has covered different definitions of wastes, solid wastes and e-waste and the classification of solid wastes and e-wastes. On the classification of solid wastes, the chapter has highlighted municipal wastes, hazardous wastes and e-wastes. The chapter has also noted that the definition of waste, as well as the different classifications of waste, is key in guiding solid waste management. Moreover, the chapter has noted that the sources of solid wastes are numerous and range from industrial, urban, agricultural, construction and demolition, biomedical and healthcare wastes.

CHAPTER 4: IMPLICATIONS OF SOLID WASTE AND E-WASTE ON THE ENVIRONMENT AND PUBLIC HEALTH

4.1 Introduction

This chapter presents a critical discussion of how solid waste and e-waste impact the environment and human health. The chapter is grouped into impacts of solid waste on the environment with a focus on water pollution, climate change and land pollution, environmental impacts of e-wastes, impacts of solid wastes on public health and a summary of the chapter.

4.2 Impacts of Solid Waste on the Environment and Public Health

The UNEP (2023) report indicated that poor waste management, which ranged from non-existing collection systems to disposal methods caused air pollution and resulted in soil and water contamination. Equally, the WHO (2023) points out that open and unsanitary landfills lead to the contamination of drinking water, which can result in infection and transmission of diseases. Besides, the dispersal of debris has been shown to contribute to the pollution of ecosystems and the hazardous substances from e-wastes or industrial garbage putting a strain on the environment and the health of urban netizens (UNEP, 2023; Li and Achal, 2020). Therefore, it can be observed that solid waste and e-waste have profound negative effects on both the environment and public health.

4.2.1 Effects on the environment

Abdel-Shafy and Mansour (2018) argue that the disposal of solid wastes is a widespread and stringent problem in both rural and urban spaces, but mostly in developing countries. Responding to Abdel-Shafy and Mansour (2018), Siddiqua et al. (2022) add that in developing countries, several drains and canals are often utilized in dumping varieties of garbage as a source of domestic inorganic and organic waste. Nonetheless, the lack of effective solid waste collection systems, the absence of convenient landfills and the blocking of the open canals and drains by the huge dumping have been implicated to cause severe environmental degradation (Mama et al., 2021). Notably, most of this garbage is paper and plastics as well as several other toxic materials. Mama et al. (2021) and Kaur et al. (2023) acknowledge that these toxic materials epitomize hazardous effects on the environment owing to the breakdown of their degradable constituents, which adds substantial loads of biochemical oxygen demand (BOD) to the local natural ecosystems. These reports acknowledge that solid wastes cause significant negative impacts on the environment. However, it is also critical to understand that the scale of these effects including the pathways may vary significantly due to many factors (i.e., country's regulations, generation levels etc.).

4.2.2 Water pollution

Pollutants such as total organic carbon (TOC) and other compounds with phosphorous have been linked with eutrophication, which entails the destruction and pollution of water bodies (Dimberg and Bryhn, 2015). For instance, a study by Obrist-Farner et al. (2019) demonstrated that TOC led to the accumulation of 505 cm of sediment within 370 years in Lake Izabal in Guatemala, which resulted in the deterioration of not only water quality but also shifts in the functioning of the aquatic ecosystem. The impacts of eutrophication arising from improper solid waste management were also observed in China, where toxic algal blooms cut off drinking water supplies for more than 10 million people at Lake Taihu and 650,000 individuals along the shores of Lake Erie in the US/Canada (Advanced Science News, 2019). Moreover, Lacey et al. (2018) also emphasize the impact of eutrophication on Lake Rostherne Mere in the UK, which has a well-documented history of anthropogenic catchment disturbances. Subsequently, the eutrophic Lake of Rostherne Mere has become a unique site for the investigation of human impacts on lacustrine environments by the organic geochemistry of lake sediments from solid wastes (Lacey et al., 2018). Therefore, the potential negative impact of ineffective solid waste management on the environment cannot be disputed. Such a revelation is made against the backdrop of the role of water bodies in the maintenance of biodiversity and a balanced ecosystem, which stresses the fundamental role of effective SWM in preventing environmental deterioration.

4.2.3 Climate change

Solid wastes have also been linked to climate change problems through several pathways. For instance, an article by EPA (2020) indicates that some of the increases in GHG emissions can be attributed directly to solid waste. EPA's (2020) statement mirrors Yaashikaa et al. (2022) revelation that solid wastes contributes to GHG emissions by generating methane when anaerobic decomposition of waste in landfills occurs. Similarly, the combustion of solid waste has been associated with the emission of nitrous oxide, which contributes to air pollution (Kumar et al., 2019). For instance, the EPA (2020) details that methane from solid waste decay has 21 times the global warming potential of C02 and NO. Similar to EPA’s (2020) revelation, the Intergovernmental Panel on Climate Change (IPCC) (2014) indicated that the decomposition of biodegradable solid wastes in anaerobic conditions resulted in approximately 2.9% and 18% of the GHG and methane emissions respectively. In line with the IPCC (2014) report, Aleluia and Ferrão (2016) indicate that the global warming effect of methane is about 25 times higher than that of CO2 emissions. Indirectly, it should be understood that methane from the decay of solid wastes in landfills has been associated with explosions and fires, which cause significant changes in the climate (Kumar et al., 2017). What can be observed from these findings and reports is that solid waste poses a significant threat to climate change. Such an effect may be direct as through emissions of methane and GHG emission, but it can also trigger other events such as fires whose contribution to GHG emissions is enormous. Noteworthy, any rise in global temperature owing to climate change has a ripple effect on the environment, which insinuates that solid wastes may have a cycle of destruction to both the climate and the environment.

4.2.4 Land pollution

An article by the Texas Disposal Systems (2023) shows that the implications of solid waste on land degradation are attributed to unsustainable agricultural practices, inappropriate disposal of hazardous and non-hazardous wastes, mining and illegal dumping and littering. In line with the Texas Disposal Systems (2023), Iravanian and Ravari (2020) demonstrated that deterioration occurs as a result of MSW (hazardous and non-hazardous) that accumulate either on the surface of the land while others leach inside, resulting in the contamination of the groundwater and soil. Ostensibly, when distinct waste materials and pollutants (i.e., heavy metals, plastics, litter etc.) find their way to the land surface and leach into the soil, they tend to degrade the natural composition of the soil. Kumar et al. (2015) posit that over time, such alterations to the natural compositions result in secondary pollutants such as phthalic and fumaric acids. These pollutants can have devastating effects on water and soil biodiversity, besides permeating through the food chains.

There are various ways that solid wastes find their way on land, one of them being roadside littering and dumping. A 2020 study, *Keep America Beautiful*, revealed that there are about 50 billion pieces of litter along roadways and waterways in the US, which represented 152 litter items for each US citizen (Roof, 2021). The same problem has been observed in the UK, where above two million pieces of litter are dropped daily in the UK, with annual quantities of littering having increased by 500% since 1960 (Planet Earth Games, 2022). Whereas most roadside littering may be accidental, scholars such as Zambezi et al. (2021) and Maier (2019) agree that such is often careless or intentional. Nonetheless, irrespective of whether it is intentional, accidental or careless, littering poses profound negative impacts on land, where these solid wastes leach to the ground or alter the soil compositions in a range of pathways. Any altered soil structure or composition comes with substantive ripple negative effects on the environment. Therefore, the implications of solid waste on land are vast, but the most intriguing effect would occur when it causes irreversible damage to the environment. Subsequently, the weight that such imposes on the need for effective solid waste management becomes a fundamental concern.

4.3 Environmental Impacts of E-wastes

Of all the solid wastes, reports show that e-wastes are amongst the most hazardous substances that are disastrous to the environment (Verma, 2020; Rao, 2014; Sahin, 2017). A report by the Global e-Waste Monitor (2021) revealed that of 53.6 million metric tonnes of e-waste produced in 2019, only 9.3 million metric tons (17%) of this was collected and recycled. The Global E-waste Monitor (2021) further indicated that given that e-waste is the fastest-growing waste stream in the world, its impact remains the most concerning new-era environmental challenge. In this regard, the United Nations (UN) (2015) issued a warning that due to the continuing consumer demand for electronic devices, there is going to be a "tsunami of e-waste" if the management of e-waste is not undertaken efficiently. What these reports insinuate is that the e-waste menace poses an impending danger to the environment, but the highest degree of its impact would be realised when there is complacency in their management.

Just as observed above, the disposal of e-wastes is a profound issue faced across many regions of the world and is associated with environmental deterioration by directly leading to water and soil contamination, air pollution and climate change (Verma, 2020; Iravanian and Ravari, 2020). However, due to the nature of e-wastes, the mechanisms through which such impacts occur may be distinct from other solid wastes. Iravanian and Ravari (2020) and Andeobu et al. (2021) posit that e-wastes are much more hazardous compared to other MSWs as electric and electronic gadgets contain thousands of components comprising of deadly metals and chemicals such as lead, nickel, barium, chromium, brominated flame retardants, polyvinyl chlorides (PVC), phthalates and antimony. Li and Achal (2020) and Madkhali et al. (2023) acknowledge that the release of these toxic materials, especially lead, causes significant environmental contamination that has varying far-reaching health implications on organisms. For instance, when dismantled, the crude forms of e-wastes cause toxic emissions that result in air pollution and exposure of workers to harmful substances (Madkhali et al., 2023). Moreover, Li and Achal (2020) and Gupta and Nath (2020) found that disposing of e-waste in landfills affects groundwater, especially when lead leaches underground, resulting in significant impacts to both land and sea animals. In addition, the effect of waste rechargeable batteries when disposed on landfills or burned in incinerators poses a significant danger to the environment. In this regard, Verma (2020) and Kuchhal and Sharma (2019) found that they release toxic materials that contaminate the environment. Comparatively, the extraction of metals utilised in electronic devices using mercury amalgamation or the acid bath method has also been shown to contribute to environmental degradation (Begum, 2013). What these insights clarify is that the scale of negative impacts caused by e-wastes is profound. Such may suggest why having robust e-waste management strategies is a matter of urgency, but most importantly remind waste generators of their role in environmental deterioration and the need to act. Therefore, it can be deduced that besides the increasing generation of e-wastes due to the higher demand for electronic devices, approaches to minimise the generation of e-waste as well as manage them when they occur should attract the attention of a range of stakeholders.

4.3.1 Impacts on the public health

There are great public health risks associated with improper handling of solid wastes and scholars such as Ziraba et al. (2016) claim that these risks are more pronounced for workers in the field. For the general public, the major health risks are often indirect, which implies they arise from the breeding of disease vectors, especially rats and flies. But there are specific risks associated with the handling of solid wastes from clinics and hospitals (Kuchibanda and Mayo, 2015). According to Alam and Ahmade (2013), the concentration of heavy metals along the food chain poses a specific danger to public health, which may be explained by the association between MSW and liquid industrial effluents constituting heavy metals that are discharged into sewerage/drainage system or even the open dumping sites for MSW. The result of such discharge or disposition may be obstruction of storm waters resulting in floods, chemical poisoning, low birth weight (due to lead), neurological diseases, mercury toxicity, cancer, and congenital malformations amongst others (Alam and Ahmade, 2013; Kuchibanda and Mayo, 2015). For instance, a study by Balali-Mood et al. (2021) found that long-term exposure to some substances (i.e., lead, mercury etc.) was linked with circulatory, nervous, endocrine and reproductive system damage alongside bones, kidneys and liver. In other studies, e-wastes were associated with headaches, skin damage, nausea, vertigo, duodenal and gastric ulcers and chronic gastritis (Verma, 2020; Shamim et al., 2015; Alabi and Bakare, 2017). Additionally, a study by Sedha et al. (2021) reported that phthalates (i.e., DEHP) were associated with negative effects in the development of testis for male children while Beltifa et al. (2017) have shown that DIDP and DINP may be associated with damage to kidneys and the liver. Most of these observations may be explained by the toxic, carcinogenic or neurotoxic nature of e-wastes and other solid wastes. The implications of these health outcomes may be immense socially, economically and politically, including the unforeseen danger of the future general population's health. Therefore, one of the major concerns of improper handling of waste, besides environmental destruction is the effect on mankind, which suggests the need for proper solid waste management.

4.4 Conclusion

The chapter has presented the impacts of solid waste on the environment and focused on water pollution, climate change and land pollution, environmental impacts of e-wastes and impacts of solid wastes on public health. The chapter has noted that the impacts of e-wastes on public health and the environment may be a more concerning problem due to the high demand for electronic devices.

CHAPTER 5: CURRENT STRATEGIES USED IN THE MANAGEMENT OF SOLID WASTE AND E-WASTE

5.1 Introduction

This chapter covers different approaches or methods utilized in the management of solid wastes. These include solid waste collection, transportation, treatment/processing and disposal. Also, the section has highlighted some of the strategies utilised in the management of e-wastes as well as the challenges inhibiting the effectiveness of SWM. A summary of the chapter is also presented at the end of the chapter.

5.2 Solid Waste Management Strategies

Solid waste management (SWM) is amongst the most essential services in ensuring that toxic substances do not pose significant negative effects on the environment and public health. Hoornweg and Bhada-Tata (2012) and Kumar and Agrawal (2020) found that whereas environmental/health impacts, costs and service levels may vary dramatically from country to country, SWM is contentiously the most fundamental municipal service and may be considered a prerequisite for other actions by the municipals. Whereas there are different models for SWM, some of which are country-specific, the Integrated Solid Waste Management System (ISWM) report of Ahmedabad city, which is the 7th largest Metropolis in India, offers significant insights on effective protection of the environment and public health from the toxicity arising from solid wastes and e-wastes (Ahmedabad Municipal Corporation, 2012). Notably, recent investigations revealed that E-wastes from developed countries majorly ended up being disposed of in Asian countries such as India and other developing countries, which suggests the increasing challenges created for effective SWM in these countries (Begun, 2013; Demajorovic et al., 2016). The case of SWM in Ahmedabad city is particularly relevant to this study considering the steady population increase and major construction boom, which scholars such as Mani and Singh (2016) and Mittal et al. (2017) attributed to the increase in solid waste generation. Besides, the city is a hub of information technology, scientific industries and education (Ahmedabad Municipal Corporation, 2012). India's Ministry of Environment and Forest (MoEF) issued a notice (25th September 2000) subject to Environment Protection Act 1986 (EPA 1986) mandating all Indian towns and cities to undertake MSW management under the established Municipal Solid Waste Rules (MSWR) 2000 (AMC, 2012). There are five stages recommended by the MoEF for effective SWM, which represent the typical pathway that different countries follow in their SWM efforts. These include generation, collection, transportation, processing/treatment and disposal stages, which are highlighted in Figure 1 below. An examination of the status of each of these stages internationally concerning Ahmedabad city's ISWM may offer intriguing insights prompting further actions by the global community or national or local governments.

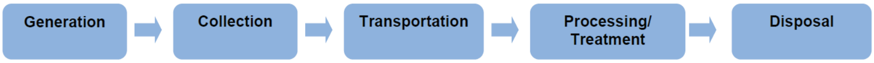

Figure 1: Ahmedabad City's ISWM Process

5.3 Solid Waste Collection

In Ahmedabad city, approximately 3,500 metric tons of solid waste are generated every day compared to 143,449 metric tons generated across India daily (AMC, 2012; Kumar et al., 2017). In Ahmedabad city, about 61% of the waste is collected using municipal bins including sweeping from streets, which is undertaken throughout the year by more than 11,000 workers (AMC, 2012). Also, the Ahmedabad Municipal established the concept of Door/Gate to Dump concept, which involves the appointment of contractors to collect waste from residential units every morning and from commercial units every evening using closed Hydraulic Euro III vehicles (AMC, 2012). A simplified outline of the concept is shown in Figure 2 below.

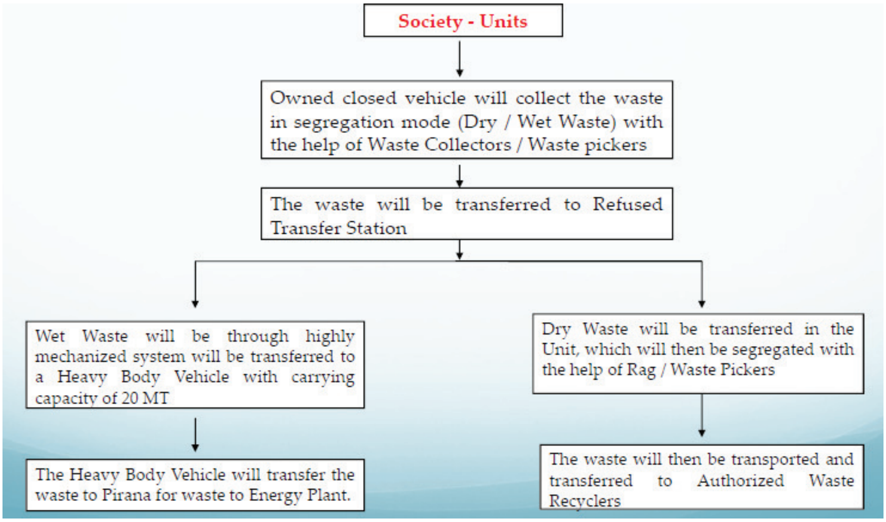

Figure 2: Door-to-Door System (Ahmedabad Municipal Corporation, 2018)

The concept of Gate to Dump involves trucks with movable gate doors or other inventions where the wastes are collected (KentLynn and Solomon, 2023). There are many innovations around the dump trailer gates for trucks, most of which are customized for specific MSW collection processes (KentLynn and Solomon, 2023). However, there are criticisms that they sometimes encounter breakdowns of the hydraulic systems, which Castejon et al. (2016) observed tends to make them somehow unreliable. However, despite these criticisms, the use of gates to dump trucks for door-to-door solid waste collection has proven to be effective in Ahmedabad Municipal (AMC, 2012; Government of India, 2020). Many countries have also adopted the gate-to-dump concept for door-to-door waste collection, especially in developed countries (i.e., UK, US, France, China etc.). Indisputably, the gate-to-dump collection system proves to be an efficient waste collection technique, with the Ahmedabad city bearing testimony to its effectiveness. However, even with the gate/door-to-dump system attesting to be a more effective form of solid waste collection, it undoubtedly comes with significant costs, especially in their acquisition, fuel and personnel. Such becomes a disadvantage to developing countries that cannot afford such resources. These challenges would however be insignificant compared to the efficiency that a municipality would gain in its MSW management efforts, hence suggesting why even developing countries need to consider investing in them.

A cheaper method would be lifting bins/containers, whose use may be widespread in Ahmedabad city and other cities globally. The IMSW system report shows that in Ahmedabad city, about 757 locations have been established as waste collection points and comprise 803 closed body 7m^3 community storage bins (Ahmedabad Municipal Corporation (AMC), 2018). Ahmedabad municipal ensures that lifting of the containers is undertaken daily, which then results in the collection of 500 TPD of waste (AMC, 2018). The lifting bins system is monitored using RFID and GPS tags (Figures 3 and 4), which is critical in ensuring that wastes are collected and moved daily from each of the six zones. An article by Inflibet (2018) reveals that solid waste collection containers may either be hauled container system or a stationary container system. Each of these categories has its advantage, but it is the overall efficiency achieved for solid waste collection that is considered crucial. Other solid waste collection processes adopted in Ahmedabad Municipal include waste collection from sweeping roads, collection of demolition and construction waste, scrubbing of roads using Road Sweeping Machines and the collection of segregated kitchen waste from restaurants and hotels (AMC, 2018). Other waste collection systems include the collection of e-wastes, bio-medical waste, carcasses/animal waste, toilets and open defecation sites via machines. These systems and processes have played a significant role in improving the quantities of waste collected.

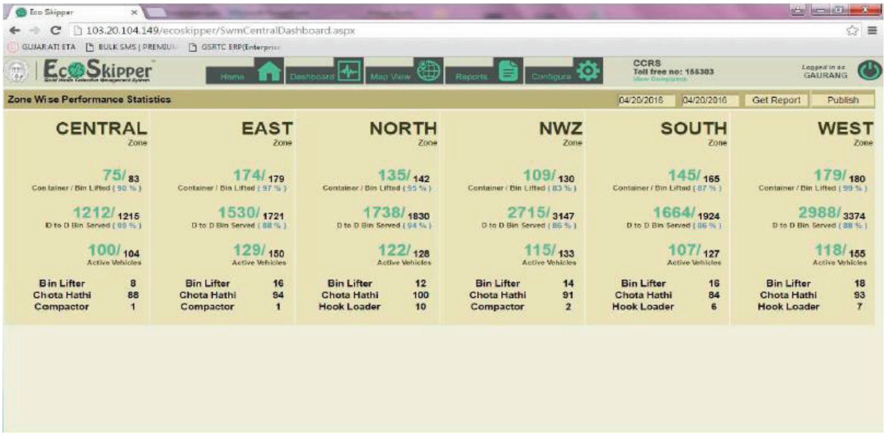

Figure 3: RFID and Central Statistics (AMC, 2018).

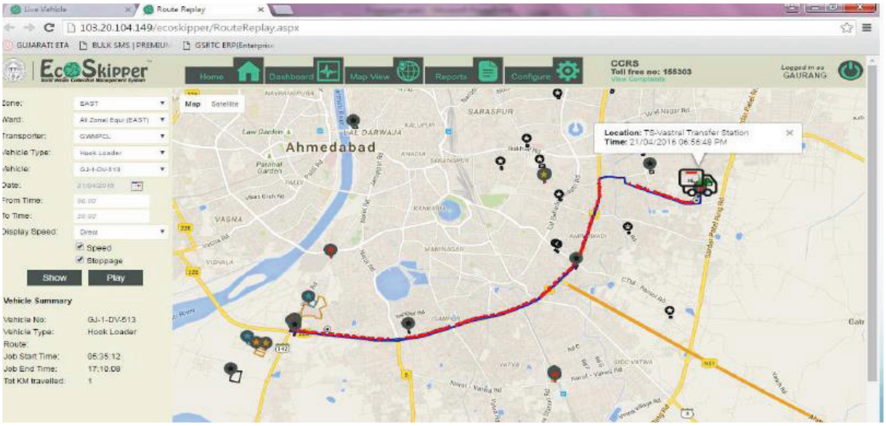

Figure 4: GPS and Central Statistics (AMC, 2018).

5.4 Solid Waste Transporation

Transportation is acknowledged to be a critical part of MSW management and tends to determine how much of the waste is effectively collected daily. According to Judd (2021), effective transportation of solid wastes, just as in the collection, disposal or storage, requires best practices, especially between waste management facilities. For instance, Nguyen-Trong et al. (2017) suggested that for short-haul solid waste transporters, the planning of the vehicle routes is fundamental. Nguyen-Trong et al. (2017) statement reflects Sulemana et al.'s (2018) recommendation that the hauling routes should not overlap. What such a recommendation implies is that micro-routing in planning specific paths to be followed by drivers or even macro-routing for balancing between collection and transportation should be efficient and not overlap. Also, technologies have been applied in ensuring more efficient transportation of solid wastes (Sahin, 2017; Shahabuddin et al., 2023). In Ahmedabad, RFID and GPS have been effectively deployed in tracking the transportation of solid waste from collection points to processing/treatment centres (AMC, 2012, 2018). Moreover, Judd (2021) describes the use of "The LogisticsFramework", which constitutes several core software modules (i.e., geotrack, ticketing and dispatch) that helps in the optimization of waste transportation routes and the identification of best solid waste transportation approaches. These revelations suggest that whereas the transportation of solid wastes has been crucial in the MSW management efforts, the use of technology and best practice may be the most needed element for more efficient transfer of solid wastes to compaction or treatment centres.

5.5 Solid Waste Treatment/Processing

Suardi et al. (2018) and Erguven and Kanat (2020) agree that internationally, solid waste treatment/processing is the most important stage that determines the solid wastes' implications to the environment and public health. Rajaram et al. (2016) and Lee et al. (2021) reveal different processes that are often involved in solid waste treatment, which include incineration, treatment, composting, shredding, grinding, separation, and reduction of volume amongst others. However, Lee et al. (2021) note that exceptions are made on what constitutes solid waste processing. For instance, shredding, grinding, landscaping or even land clearing for wastes or converting unstained, unpainted and untreated wood into mulch or other useful items are disregarded as treatment/processing (Lee et al., 2021). An article by Karthikeyan et al. (2018) reveals that whereas the amount of solid waste generation and collection is high in India, only a few industries have treatment processes or treat these wastes. However, India's Municipal Solid Waste Rules (MSWR) 2000 offers a comprehensive guideline and mandate for the promotion of effective treatment and processing of solid wastes. Developed countries such as the UK mandates industries to treat their wastes under the provisions of the Environmental Protection Act 1990 (EPA 1990) and the Controlled Waste Regulations 2012 (CWR 2012) (Legislation.gov.uk, 2023; Legislation.gov.uk, 2012). In the US, the treatment/processing of the wastes is enforceable under the Resource Conservation and Recovery Act 1976 (RCRA 1976) mandates industries and states to ensure efficient treatment/processing of solid wastes (EPA, 2023b). What can be deduced from such is that having legislation or laws is critical in ensuring effective treatment/processing of solid wastes while equally protecting public health and the environment. However, it is also critical to note that different countries have unique procedures for the treatment and processing of solid wastes, but they all have common goals of either disposing of treated wastes, recycling or reusing the wastes.

Unfortunately, whereas there are well-established collection, storage, separation and transportation procedures in countries such as US, UK or India, most treated solid wastes still find their way to nearby dump sites, public landfills and waterways when untreated (Nanda and Berruti, 2021; Das et al., 2019; Kumar and Agrawal, 2020). For instance, both Priti and Mandal (2019) and Karthikeyan et al. (2018) reported that there were significant shortages in the capacity for solid waste treatment, especially in Class II cities in India. Such demonstrates that logistical issues may pose a significant threat in the treatment and processing of solid wastes. Nonetheless, the city of Ahmedabad offers a good example of overcoming some of the inherent challenges faced with the treatment and processing of solid wastes (AMC, 2012). One of them is partnering and collaborating with external agencies or companies. Scholars such as Olukanni and Nwafor (2019) and Saadeh et al. (2019) confirm AMC's (2012) approach, stressing that public-private partnerships are an important step to ensuring effective SWM. For instance, as indicated in its report, AMC entered into an agreement with Excel Industries for the conversion of 500 tons of MSW into compost, with UPL Djai Power Ltd for the processing of 250 tons of MSW a day into fluff and pellets/RDF (AMC, 2012, 2018). These reports are an indication that despite various challenges, especially encompassing logistical issues, outsourcing solid waste treatment and processing offers additional capacity beyond that provided by the city municipalities to enhance the quantity of solid waste treated and processed on a routine basis.

5.6 Disposal of Solid Waste

There may not be a big difference in operational meanings of solid waste treatment/processing and disposal, but Yuan et al. (2020) contend that the latter represents the final stage that wastes would ever reach in the MSW management process. In Ahmedabad, the major method employed in the disposal of solid wastes is landfilling (AMC, 2012). The Ahmedabad municipal established a new scientific landfill site at Gyaspur, which covers approximately 12.88 ha of land and a capacity of 11.50 lakh MT, which was expected to be used in the disposal of wastes for more than 6 years pending the establishment of other disposing sites (AMC, 2012).

Also, an article by the Department for Environment, Food and Rural Affairs (2023) reveals that landfilling is the most common solid disposal method in the UK, although incineration, anaerobic digestion and other methods (i.e., pyrolisis, gasification and composting) have been employed. Also, statistics by the European Environmental Agency (EPA) (2023) showed that since 2021, 49.6% of all municipal wastes generated in the EU were composed or recycled with targets placed at 60% for recycling and reuse by 2030. In the US, most MSW is managed through land disposal units, which embody landfills, land treatment, land farming and surface impoundments (EPA, 2023). Further, a World Bank (2023) report revealed that landfilling is the most common strategy for disposing of solid wastes globally. The report also indicated that 37% of the waste is disposed of in sanitary landfills that are fitted with landfill gas collection systems (World Bank, 2023). Moreover, open dumping is attributed to approximately 31% of the solid waste, 19% is recovered via composting and recycling and 11% is incinerated as final disposal (World Bank, 2023). From these data, it can be observed that landfilling remains the most popular SWM approach, but it is also worth noting the outcomes of landfilling or how the landfills are handled have a large bearing on the per-capita income of countries.

For example, both Hoşoğlu (2022) and the World Bank (2023) acknowledge that adequate waste disposal, which is characterised by controlled landfills or even more stringently operated facilities is almost the preserve of high and upper-to-middle-income countries. What such a revelation suggest is that lower-income nations overall rely on open dumping for solid waste disposal, which confirms Srivastava and Pathak's (2020) report that argues that the open dumping menace is a serious problem in developing countries. In this respect, the World Bank (2023) indicates that in low-income countries, 93% of solid waste is dumped compared to 2% in high-income countries. As such, the disposal of solid wastes remains a big challenge, especially in developing countries, but such highlights the need for concerted global efforts towards SWM. Such a statement may be made against the backdrop of landfilling, but it is also worth noting that developed countries still have a higher hand in the adoption of other solid waste disposal methods such as incineration amongst others.

5.7 Management of E-wastes

E-waste is particularly a threat in developing countries and reports by scholars such as Demajorovic et al. (2016) and Srivastava and Pathak (2020) attribute such an issue to dumping by developed countries. For instance, about 500,000 tons of e-waste from the UK is illegally dumped in other countries annually (WasteManaged Limited, 2023). However, Verma (2020) and Aleluia and Ferrão (2016) agree that such behaviour does not imply that e-wastes do not pose significant environmental and public health threats to developed countries. Scholars such as Verma (2020) further reveal issues related to e-wastes as comprising the short life cycle of electronic devices, but when such would be coupled with the high demand for electronic devices, the results become the enormous generation of e-wastes. Subsequently, the creation of robust policies on banning e-waste dumping as well as effective tools countering e-waste-associated challenges may be promising interventions.

The contemporary practices and process in the management of e-wastes is distinct and also vary from country to country. In developing countries, Sthiannopkao and Wong (2013) and Awasthi et al. (2016) observed that effective management of e-wastes entailed the creation of recycling facilities. In light of such an observation, having centralized points of e-waste collection, where the economies of scale attract investments for facilities tasked with disassembling and dismantling e-wastes for recycling and disposal would be suggested. Nonetheless, Al-Rahmi et al. (2018), Kiddee et al. (2013) and Andeobu et al. (2021) demonstrate that developed countries take steps higher to manage e-wastes, focusing on the use of several tools such as life cycle assessment (CLA), multi-criteria analysis (MCA), material flow analysis (MFA) and extended producer responsibility (EPR). Through the use of these tools, Al-Rahmi et al. (2018), Kiddee et al. (2013) and Andeobu et al. (2021) acknowledge that emphasis is directed at the development of eco-design devices for the success of e-waste management practices. Also, proper collection, recovery, and recycling of the e-material using safe approaches, disposing of e-wastes via proper techniques and forbidding the transfer of used electronics to developing countries have been reported as initial efforts in the effective management of e-wastes (Kiddee et al., 2013). Although landfilling of solid wastes is the most common disposal method (Sthiannopkao and Wong, 2013), Kiddee et al. (2013) and Rao (2014) discouraged the use of this technique for e-wastes, especially such as refrigerators, TVs and washing machines. Kiddee et al. (2013) and Rao's (2014) arguments are confirmed by a study by Kumar et al. (2016), which has demonstrated that e-waste may be associated with a significant level of toxicity to the environment. However, studies on the severe negative impacts of landfilling e-wastes are in their infancy stages, but the perceived risks due to the presence of chemicals such as lead, mercury and chromium amongst others offer a stronger justification for why landfilling is unsuitable for e-waste management.

Besides, considering the significant poisonous emissions that may be linked with the incineration of e-wastes (Pramila et al., 2012; Begum, 2013), it becomes acknowledgeable that incineration of e-wastes would not be a suitable management option. However, such exceptions are not exclusive as some categories of e-wastes may have insignificant risks for leaching on landfilling or emission of poisonous substances when incinerated than others. Scholars such as Begum (2013) and Madkhali et al. (2023) believe that the best e-waste management strategies would be recycling and reusing, which has well been utilized in countries such as Saudi Arabia.

Therefore, these revelations offer insights that recycling and re-use are the most effective strategies that could be adopted for the management of e-waste. Nonetheless, one of the areas that lack emphasis on e-waste management is citizen awareness, which may be attributed to the higher rates of e-wastes on open dumping sites.

5.8 Challenges/Barriers to Effective Solid Waste and E-waste Management

Numerous challenges make it difficult to have effective solid waste and e-waste management practices, but they can range from one residential, industrial, government or country to another. For instance, it is critical to note that households are a critical point of SWM and scholars such as Asari and Sakai (2011) claim that being bulk generators of kitchen waste and other wastes, their role in supporting municipals in managing wastes cannot be overlooked. Studies such as those by Guo et al. (2018) and Prado et al. (2020) found that having a few on-site composting solutions or even the responsible segregation of their wastes may have a significant impact on the reduction of the burden of urban waste management infrastructure. Nonetheless, some challenges make SWM at household levels challenging. These include the lack of waste segregation at the site, inadequate segregation techniques available, slow adaptations of in-house composting techniques, lack of technologies to monitor in-house waste generation and management and the lack of awareness on the importance of taking SWM as a civic duty (Thakur et al., 2021; Wang et al., 2021). These studies highlight household challenges as more practical in scope, but they also mirror the need for having SWM campaigns targeted at instilling proper attitudes and conscience in individual citizens to participate in solid waste and e-waste management.

Also, scholars such as Karthikeyan et al. (2018) contend that despite existing guidelines and legislations on SWM, the major limitation or challenge is their enforcement. It should be understood that binding laws can act as deterrents for laxity in SWM practices. However, when the laws and guidelines are weak, most industries or even management in the municipals may not demonstrate an adequate level of concern to implement them, hence creating a cycle of environmental destruction and public health outbreaks. The Environmental Law Institute (ELI) (2014) reveals other challenges as constituting a lack of financial resources, a lack of authority and shortage of staff in the SWM process and a lack of standardized waste management protocols. In addition, Ongoro (2020) examined challenges in solid waste management in developing countries and identified poor infrastructure, lack of technology, inadequate financing, inadequate or weak regulatory and legal tools and lack of public awareness. These challenges have been reported to inhibit effective of SWM (Karthikeyan et al., 2018; ELI, 2014; Ongoro, 2020), but they also clarify the areas that should be addressed if effective solid waste management was to be achieved. However, even with their resolution, the influence of country-specific dynamics should not be ignored, especially considering the differences observed between developed and developing countries.

5.9 Conclusion

This chapter has presented a discussion of the various strategies adopted in the management of solid wastes. The major strategies discussed include solid waste collection, transportation, transportation, processing/treatment and disposal. Each of these strategies has been discussed about methods adopted in the Ahmedabad Municipal Council. Also, the chapter has examined some of the strategies utilised in the management of e-wastes as well as the challenges inhibiting the effectiveness of SWM.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

7.1 Summary

The focus of this review was the examination of the solid waste and e-waste management practices/strategies and challenges to find ways that could be implemented for preventing environmental destruction and public health problems. On the first objective on solid waste categorizations, the review notes that solid wastes may be classified based on source (i.e., municipal solid waste (HH, demolition and construction debris, street wastes, sanitation residue), industries (chemicals, metal, paper, rubber etc.), healthcare wastes (needles, gloves etc.) and e-wastes) or safety (hazardous or non-hazardous).

Secondly, the results of this review show that solid waste and e-waste have profound implications for the environment and public health. In the environment, the review notes that solid wastes cause water pollution, air pollution (climate change) and land pollution. Besides, e-wastes are observed to be associated with significant environmental destruction due to associated metals and chemicals, which can influence lands, water and air when incinerated. The impacts of solid waste on public health are observed to involve the breeding of disease vectors, the concentration of heavy metals along food chains, low birth weight (due to lead), neurological diseases, mercury toxicity, cancer, congenital malformations and damage to bones, kidneys and liver. Also, the review observes that e-wastes components (i.e., phthalates (DEHP)) are associated with headaches, skin damage, nausea, vertigo, duodenal and gastric ulcers and chronic gastritis.

Thirdly, this study identified four stages used in SWM after their generation, which is largely based on MoEF recommendations on collection, transportation, processing/treatment and disposal. Several techniques such as Door/Gate to Dump, lifting bins/containers, sweeping roads, collection of demolition and construction waste, scrubbing of roads using Road Sweeping

Machines and the collection of segregated kitchen waste from restaurants and hotels are observed to be effective in solid waste collections. Besides, whereas having different kinds of vehicles is critical in the transportation of solid wastes to compactors or processing plants, this review finds that most of the available wastes cannot be transported efficiently by relying on municipal resources only. On the treatment, this review observes different techniques such as incineration, treatment, composting, shredding, grinding, separation, and volume reduction amongst others. Nonetheless, the treatment and processing of solid wastes is observed to be the most challenging stage for most countries. On the other hand, the review reveals that whereas different techniques are available for disposing of solid wastes such as incineration, anaerobic digestion and other methods (i.e., pyrolisis, gasification and composting) are present, landfilling is the most common technique adopted in many countries. However, landfilling is more efficient in developed countries than in developing countries.

The review also stresses that the most effective strategy for e-waste management is recycling and reuse. Such a recommendation is made against the backdrop of the fact that landfilling or incinerating e-wastes poses significant environmental and public health risks compared to other solid wastes. Lastly, several challenges were identified to inhibit effective solid waste and e-waste management. These include the lack of waste segregation at the site, slow adaptations to in-house composting techniques, lack of technologies, lack of awareness, lack of financial resources, lack of authority, shortage of staff in the SWM process and lack of standardized waste management protocols. In developing countries, the review revealed poor infrastructure, lack of technology, inadequate financing, inadequate or weak regulatory and legal tools and lack of public awareness as key challenges to effective SWM.

7.2 Implications of the Study

The results of this review have several implications for municipals, environmentalists, public health and policymakers. First, the results offer insights from different studies, agencies and countries on what has been tried in attempts to offer more efficient SWM systems, processes or practices. Subsequently, municipals can consider and evaluate the adoption of these practices to enhance their SWM practices. Secondly, the results of this study emphasize the importance of having robust and effective SWM practices on the environment and public health. The emphasis may guide environmentalists and public health experts to address issues with different solid wastes and e-wastes to mitigate associated risks. Lastly, this review has clarified the fact that regulatory weaknesses continue to be a big challenge in ensuring effective SWM practices. Subsequently, the review may provide insights to policymakers to create more robust legislations and guidelines to ensure more compliance with established SWM protocols.

7.3 Recommendations

To improve solid waste and e-waste management, this review makes the following recommendations. First, there is a need to create awareness of the importance of reducing the generation of waste (i.e., e-wastes) in industries as well as proper management of waste at residential levels. Such awareness should deliver the message on the potential impacts of improper solid waste management on the environment and public health. Secondly, just as the government budgets for other key functions, it should also allocate a budget for waste management. Such can ensure that there are adequate funds for the acquisition of key infrastructure as well as contract other parties to help in enhancing waste collection, transportation, treatment and disposal. Such finances can also be utilized in hiring enough staff to run the solid waste management functions, acquire technologies such as GPS and RFID for tracking solid waste collection and transportation and cater for other functions. Lastly, effective solid waste and e-waste management would be achieved if there were stronger legislation against laxity by industries in the management of solid wastes, against dumping of used electronic devices in other countries and that mandates household-level accountability in the solid waste and e-waste management cycles. These legislations should be accompanied by severe penalties for non-compliance, which can ensure they are binding to all parties in the solid-waste generation, collection, transportation, treatment and disposal path.

7.4 Limitations

The current review's strength is that it utilized a range of sources that enabled the incorporation of diverse insights from scholars, agencies, institutions and other bodies, but several limitations were observed. First, most of the materials used in this review are secondary sources, which was attributed to a very limited number of primary studies on the topic. Such could have increased the potential for bias in this study, thus influencing the internal validity of the report. Also, despite the broad nature of this review's topic, most of the studies used in this review examined only specific aspects of waste management with a limited number of them on e-wastes. Subsequently, much of the time was spent seeking different sources to establish and assemble different aspects to enable the completion of this review.

7.5 Future Research

Considering the above limitations, there is a need for more primary studies on the topic to provide more first-hand data with reduced bias about the effectiveness of current solid waste and e-waste management strategies. In addition, there is a need for more studies on e-wastes, especially considering the increasing demand for electronic devices and the subsequent high rate of e-waste generation.

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Appendix One: Thematic Table

No.	Themes	Literature
Theme 1	Categorization and sources of solid waste and e-waste	Arikan et al., 2017; UK Government, 2023; Abdel-Shafy and Mansour, 2018; Kawai and Tasaki, 2016; WHO, 2023; EPA, 2023; EU, 2023; CFR, 2023; Saha et al., 2021; Shredall SDS Group, 2022; Inter-Organizational Programme for the Sound Management of Chemicals, 2013; IPSMC, 2023; Development Aid, 2023; Bello, 2018; Asari and Sakai, 2011; Manggali and Susanna, 2019; Tansel, 2017; Chatterjee and Abraham, 2017; Alves, 2023; Ewastemonitor.info, 2020; Şahin, 2017; Andersen, 2015; Soliman and Moustafa, 2020; El-Khateeb, 2022 Ikeda, 2017; Rutala and Weber, 2015; Singh and Singh, 2017; Jerie, 2016; Bol and Tobé, 2015; The World Counts, 2023; EPA; 2023a).

No.	Themes	Literature
Theme 2	Implications of solid waste and e-waste	UNEP, 2023; WHO, 2023; Li and Achal, 2020; Abdel-Shafy and Mansour, 2018; Abdel-Shafy and Mansour, 2018; Siddiqua et al., 2022; Mama et al., 2021; Kaur et al., 2023; Dimberg and Bryhn, 2015; Obrist-Farner et al., 2019; Advanced Science News, 2019; Lacey et al., 2018; EPA, 2020; Yaashikaa et al., 2022; Intergovernmental Panel on Climate Change (IPCC), 2014; Aleluia and Ferrão, 2016; Kumar et al., 2017; Texas Disposal Systems, 2023; Iravanian and Ravari, 2020; Kumar et al., 2015; Roof, 2021; Planet Earth Games, 2022; Zambezi et al., 2021; Maier, 2019; Verma, 2020; Rao, 2014; Sahin, 2017; Global e-Waste Monitor, 2021; United Nations (UN), 2015; Li and Achal, 2020; Madkhali et al., 2023; Verma, 2020; Kuchhal and Sharma, 2019; Li and Achal, 2020; Gupta and Nath, 2020; Begum, 2013; Ziraba et al., 2016; Kuchibanda and Mayo, 2015; Alam and Ahmade, 2013; Kuchibanda and Mayo, 2015; Balali-Mood et al., 2021; Shamim et al., 2015; Alabi and Bakare, 2017; Sedha et al., 2021; Beltifa et al., 2017; Hoornweg and Bhada-Tata, 2012; Kumar and Agrawal, 2020;
Theme 3	Current strategies used in the management of solid waste and e-waste	Hoornweg and Bhada-Tata, 2012; Kumar and Agrawal, 2020; Ahmedabad Municipal Corporation (AMC), 2012; Begun, 2013; Demajorovic et al., 2016; Kumar et al., 2017; KentLynn and Solomon, 2023**;** Castejon et al., 2016; Government of India, 2020; AMC, 2018; Inflibet, 2018; Judd, 2021; Nguyen-Trong et al., 2017; Sulemana et al., 2018; Sahin, 2017; Shahabuddin et al., 2023; Suardi et al., 2018; Erguven and Kanat, 2020; Rajaram et al., 2016; Lee et al., 2021; Karthikeyan et al., 2018; Legislation.gov.uk, 2023; Legislation.gov.uk, 2012; EPA, 2023b; Nanda and Berruti, 2021; Das et al., 2019; Nwafor, 2019; Saadeh et al., 2019; Yuan et al., 2020; Department for Environment, Food and Rural Affairs, 2023; European Environmental Agency (EPA), 2023; World Bank, 2023; Hoşoğlu, 2022; Srivastava and Pathak, 2020; WasteManaged Limited, 2023; Aleluia and Ferrão, 2016; Sthiannopkao and Wong, 2013; Awasthi et al., 2016; Al-Rahmi et al., 2018; Kiddee et al., 2013; Andeobu et al., 2021; Rao, 2014; Kumar et al., 2016; Pramila et al., 2012; Begum, 2013; Madkhali et al., 2023; Asari and Sakai, 2011; Guo et al, 2018; Prado et al., 2020; Thakur et al., 2021; Wang et al., 2021; Karthikeyan et al., 2018; Environmental Law Institute (ELI), 2014; Ongoro, 2020)

Asmi Sehra is presently a student of class 11 in The New Tulip International School, Ahmedabad with passion for issues concerning the environment. She has done her internship with the Ahmedabad Municipal Commission (AMC) in Solid Waste, and E- Waste management since last 2 years with the aim to protect the environment, health of the people around us and most importantly to contribute in city issues through data analysis, research, creating awareness to find better solution through integration of technology with environmental in a sustainable manner. Besides, she is a science enthusiast with keen interest in fields of bioscience, space and Artificial Intelligence.

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