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From Waste to Wealth

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ISBN 978-981-99-7551-8 ISBN 978-981-99-7552-5 (eBook)
https://doi.org/10.1007/978-981-99-7552-5

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

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Preface

In a world facing ever-increasing environmental challenges, the need to address waste management and sustainability has become more urgent than ever before. The book *From Waste to Wealth* explores the transformative potential of waste and seeks to unlock its hidden value, turning what was once discarded into valuable resources and opportunities. This book is a comprehensive compilation of innovative research and practical solutions that can help us in the transition of a linear economy to a circular one, where waste is no longer seen as a burden, but rather as a valuable asset.

The journey begins with an insightful introduction to various types of waste; shedding light on the diverse forms of waste we encounter in our daily lives and industries. Understanding the environmental effects and threats posed by waste is crucial, as we delve into the intricacies of how waste impacts ecosystems, human health, and the overall sustainability of our planet. The book underscores the importance of adopting mitigation strategies to minimize waste's detrimental effects and create a more sustainable future.

With a comprehensive overview of waste typology on a global scale, readers gain valuable insights into the magnitude of the waste management challenge across different regions. This global perspective lays the foundation for the subsequent exploration of specific waste management approaches and their potential to transform waste into wealth.

The agricultural and farming sector plays a significant role in waste generation. *From Waste to Wealth* provides readers with an understanding of the opportunities presented by agricultural waste. By embracing sustainable agriculture practices and innovative economic growth strategies, we can unlock the untapped potential of agro-waste and foster a harmonious relationship between agriculture and the environment. Additionally, the book delves into the potential of crop waste for renewable energy production, exploring novel technologies and models for assessing the surplus biomass power potential in various regions.

The industrial sector, too, faces its share of waste management challenges. This book covers various approaches to sustainable industrial waste management, including the valorization of microplastics and carbon dioxide, as well as the utilization of fly ash, naphtha plastic, and other industrial by-products to produce valuable materials and energy sources.

Energy production from waste presents an exciting frontier in sustainability. The book showcases various techniques to harness renewable energy from biomass, agricultural waste, and other bio-waste sources. These energy production methods not only provide a sustainable energy solution, but also contribute to waste reduction, ensuring a more circular and efficient approach to energy generation.

Construction and building materials also play a crucial role in waste management. This book explores the effective utilization of waste materials like tannery waste, waste rubber, and plastic waste in the construction industry, paving the way for greener and more eco-friendly building practices.

The book continues its exploration into waste management and utilization in various industries, including the pharmaceutical sector, paper industry, and more. By adopting innovative technologies and methodologies, industries can turn waste into valuable bioactive compounds and micro/nanomaterials, contributing to a more sustainable and circular industrial landscape.

"Innovative Approaches and Technologies for Waste Utilization" showcases ground breaking research on managing floral waste, plastic waste, and other organic solid waste. The focus here is on harnessing the potential of waste for economic growth and sustainable practices, especially in the areas of biodegradable films, biofuels, and biogas production.

The book culminates with a dedicated section on "Renewable Energy Production Using Crop Waste." Recognizing the immense potential of crop waste as a renewable energy source, this chapter explores how we can maximize crop waste utilization to drive sustainable energy production and enhance environmental preservation.

From Waste to Wealth is a collaborative effort of researchers, scholars, and practitioners committed to promoting sustainable practices and turning the challenges of waste management into opportunities for prosperity. It is our hope that this book will serve as a valuable resource for policymakers, educators, industry professionals, and all stakeholders seeking to navigate the journey from waste to wealth and build a more sustainable, circular, and prosperous future. We express our sincere appreciation to each contributor for their exceptional input in shaping "From Waste to Wealth." Your commitment, expertise, and support have played an indispensable role in the success of this project, and we are profoundly thankful for your contributions. First and foremost, we want to convey our gratitude to Sarada Paul Roy for her thorough language corrections across the entirety of the book. Her meticulous attention to detail has significantly elevated the overall quality of the text. To our cherished family members, their unwavering love, encouragement, and support have been a constant wellspring of motivation throughout this journey. We are deeply grateful for their steadfast belief in our vision and for standing by us. A special acknowledgement goes to Loyola D'Silva, Senior Editor at Springer Singapore, for his exceptional support and prompt approval of this project. His guidance has been invaluable in bringing this endeavour to fruition. We also recognize the outstanding project coordination provided by Vidyaa Shri Krishna Kumar, Project Coordinator, and Sivananth

S Siva Chandran, Production Editor, both from Springer Nature Chennai, India. Your commendable efforts during the proof preparation and typesetting stages have been crucial to the project's success. Lastly, we extend our appreciation to Sudhany Karthick, Project Manager at Springer Nature Straive, Trichy, India, for her meticulous handling of proof preparation and queries. Her dedication ensured the seamless and timely completion of the book publication. To all involved, thank you for your extraordinary contributions. This book would not have been possible without your hard work, unwavering dedication, and steadfast support.

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Introduction and Waste Management

Chapter 1
Introduction to Various Types of Wastes

Abdul Rafey, Kunwar Pal, Kamal Kishore Pant, Ejaz Ahmad, and Sreedevi Upadhyayula

Abstract The increase in urbanization has paralleled itself with the rise in human population owing to the activities essential for fulfilling the basic requirements and improving the lifestyle of the masses. This improvement has, however, resulted in a tremendous amount of waste generation. Waste is an inevitable byproduct of most human activities, and as living standards have risen and economies have been developed around the world, especially in the Asian and Pacific regions, substantial amounts of industrial hazardous waste and biomedical waste have been added to the waste stream. Both types of waste (industrial hazardous waste and biomedical waste) have the high potential to cause severe environmental and human harm. Solid and liquid waste management is a significant social issue that must be addressed with cutting-edge technology to protect public health and the environment. Thus, developing effective and efficient solid waste management plans requires a thorough understanding of the type of waste, its characteristics, and the quantities being produced. This chapter will give an overview of solid and liquid wastes such as municipal solid, hazardous, biomedical, radioactive, construction, demolition, electronic, battery, and sewage sludge. The chapter will also briefly cover the current trend of solid and liquid waste generation around the globe and in India. This chapter would serve as a primary knowledge base for researchers, stakeholders, and environmental engineers in solid waste management.

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R. K. Arya et al. (eds.), *From Waste to Wealth*,
https://doi.org/10.1007/978-981-99-7552-5_1

Keywords Environment · Liquid waste · Municipal solid waste · Solid waste · Waste management

1.1 Introduction

Waste generation is a key term that is unavoidable and linked with most anthropogenic activities. Global economic growth and a rise in lifestyle standards have led to an increase in the quantity of waste generated and its complexity. A substantial amount of industrial hazardous and biomedical waste has been introduced to the waste stream due to industrial diversification and healthcare facility expansion, which may harm human health and the environment. Various waste types are produced from distinct sources, such as wastewater and sewage sludge, hazardous waste (HW), biomedical waste (BMW), construction and demolition (C&D) waste, municipal solid waste (MSW), and radioactive waste.

Developing an effective and efficient management plan for controlling waste requires a thorough knowledge of the categories and capacities of different wastes produced. Although characterization and quantification form the basis for management and intervention in some developed nations, systematic waste surveying is given little priority elsewhere, and quantities, characteristics, seasonal variations, and long-term waste generation trends need to be better understood. While there is an absence of comprehensive or reliable data, specific overarching trends and commonalities can be seen at the country level.

1.2 National and International Waste Generation Scenario

Globally, around 2.01 billion tons of MSW are produced annually, of which 33% needs to be handled in an environmentally sustainable manner. The daily per capita waste generation is around 0.74 kg, but it varies largely between 0.11 and 4.54 kg depending on the type of nation. Around 34% (683 million tons) of the waste is produced by high-income nations, which constitute 16% of the global population.

Waste management is one of the most pressing development challenges in India as well. According to estimates, India generates about 62 million tons of MSW annually, which is anticipated to increase to 165 million tons by 2031, most of which is dumped onto dumpsites or landfills. Various studies have indicated that the unscientific disposal of mixed waste generates harmful gases and leachates, causing health and environmental hazards. Most Indian cities and their urban local bodies (ULBs) lack adequate funding, infrastructure, and space for scientific waste disposal and thus find it difficult to install and operate large-scale waste processing and treatment technologies. Further, to store the projected quantity of untreated solid waste, 1240 hectares of additional land is estimated to be required yearly, a waste of valuable land resources.

1.3 Overview of Solid Waste

Wastes include any resources no longer needed by a person, household, institution, or industry. They can include waste from any source, including byproducts or finished goods from manufacturing and consumption. Solid waste implies "solid or semi-solid domestic waste, including industrial and institutional waste, market waste, road sweepings, silt collected from surface drains, horticulture waste, C&D waste, and BMW (MoEFCC, 2016c)."

According to Agenda 21 of the United Nations Environment Program, all domestic and non-hazardous waste, commercial and institutional wastes, construction debris, and street sweepings form solid wastes. These wastes should be handled with caution if they exhibit hazardous qualities. As a result of being contagious and dangerous, BMW and HW are classified as different entities. The significant differences in waste treatment and disposal issues between rural and urban areas and between developing and developed countries are caused by differences in community and country wealth, levels of urbanization and industrialization, and the intensity of agricultural activities. Each sort of waste will be briefly introduced in this chapter.

1.3.1 Municipal Solid Waste

MSW includes used/discarded objects from homes, institutions and commercial facilities, public spaces, and parks. MSW includes food packaging, garden, yard trimmings, used furniture, discarded clothes, food waste, cartons, newspapers, paper boards, old electrical and electronic equipment, and used batteries (Pandey et al., 2022). Figure 1.1 depicts the broad classification of MSW, which comprises organics, recyclables, and inert (Pandey et al., 2022).

Almost 33% of the 2 billion tons of MSW currently produced worldwide are not collected by municipalities (Waste Atlas, 2018). By 2050, the World Bank predicts that 3.4 billion tons of MSW will be generated worldwide (Kaza et al., 2018). About 70% of the total MSW the municipalities collect is dumped in landfills or dumpsites, whereas the rest is recycled and used for energy recovery, which amounts to 19% and 11%, respectively. Nearly 3.5 billion people in the 7.9 billion population of the planet (US Census Bureau, 2023) need access to even the most basic waste management systems. The amount of MSW produced is influenced by several factors, such as food habits, living standards, intensity of commercial activity, and seasons. Planning for collection and disposal systems can benefit from quantity variation and generation information.

By the year 2050, the overall amount of waste produced in low-income nations is anticipated to have more than tripled. In terms of absolute waste output, the Middle East and North Africa region currently produce 6% of the world's waste, followed by East Asia and the Pacific with 23%. Food waste comprises the majority of global waste, accounting for 44%. 38% of waste comprises dry recyclables (glass,

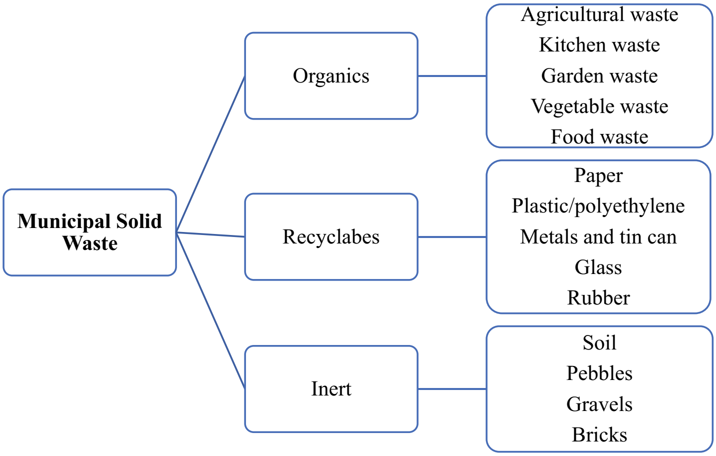

Fig. 1.1 Classification of MSW. Modified from Pandey et al. (2022)

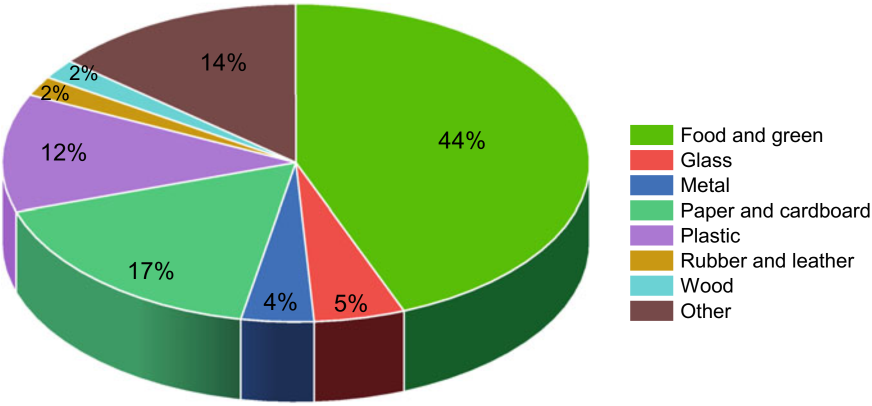

Fig. 1.2 Global waste composition. Redrawn from Kaza et al. (2018) (Open access)

metal, paper, and cardboard). Waste composition varies significantly by income level. With a rise in income levels, the proportion of organic materials decreases. Higher-income nations use more materials like paper and plastic than lower-income nations. Figure 1.2 depicts the global waste composition (percent) (Kaza et al., 2018).

1.3.2 Hazardous Waste

India has produced enormous amounts of waste during the past 40 years due to the immense manufacture of various chemicals and energy and other developmental activities like agriculture, urbanization, and health care, and surprisingly, all have been dumped into the environment. Most living organisms are seriously threatened by these wastes, which come in the form of solids, liquids, and gases and carry numerous potential environmental risks.

Numerous studies have shown that improper waste disposal causes air, surface water, groundwater, soil, and biota contamination through volatilization and fugitive emissions, groundwater seepage, leaching/infiltration, erosion, and bioaccumulation. The main environmental issue with landfilling waste is the likelihood of leachate generation, contaminating ground water and endangering nearby surface waters and groundwater wells (Christensen et al., 1994).

Hazardous waste is defined as a waste or a combination of wastes that, when left untreated or disposed of improperly, pose a significant risk to human health or the environment due to their quantity, concentration, physical, chemical, or infectious properties and can lead to an increase in mortality or an increase in severe and irreversible illness. The legal definition of hazardous waste under Section 3 (14), Hazardous Waste Management and Handling Rules, 1989, amendment Rules 2002 and 2003 is: Hazardous waste poses a threat to human health or the environment due to its physicochemical, corrosive, reactive, combustible, or explosive properties, whether existing alone or combined with other wastes or chemicals (MoEFCC, 2016b).

Different waste streams carry varying degrees of risk, and it makes economic sense to rank wastes based on the risk they pose and to determine whether the chemical components of waste streams are compatible or incompatible with developing an efficient waste management program. For instance, wastes having aluminum or alkaline cleaners tend to combine to form a more hazardous or toxic compound. On the other hand, waste that contains some chemicals can assist in reducing the risks associated with the toxicity of other chemicals. In contrast to waste having only mercury, waste having selenium and mercury is presumed to cause less toxicity.

Table 1.1 lists the processes that produce hazardous waste (Wilkes et al., 1980). The waste is hazardous if the quantity exceeds the prescribed threshold limit. The level of risk that wastes pose may vary on many factors, such as physical characteristics, reactivity (fire and explosion), biological effects (bioavailability, ecotoxicity), indirect effects resulting from pathogens/vectors, detoxification potential, leaching potential and local conditions (temperature, humidity, etc.).

1.3.3 Biomedical Waste

BMW is defined as solid/liquid waste produced during diagnosis, treatment, or immunization of humans or animals used in research, production, or testing, including food waste, wood, leather, paper, textiles, glass, rubber, plastics, metal, used therapeutic medicines, ceramics, and any intermediate products.

The improper disposal of BMW has adverse health impacts on humans and the surrounding environment. The BMW generation in India is more than 500 tons per

Table 1.1 Hazardous waste-generating processes (Wilkes et al., 1980)

Industries/process	Hazardous waste
Plastic	Chlorine compounds
Pesticides	Phosphate and chlorine compounds
Medicines	Hg and Zn metals and organic solvents
Paints	Organic residues and solvents, pigments, and heavy metals
Oil, gasoline, and other petroleum products	Phenols, heavy metals, ammonia, salts, acids, caustics
Metals	Phenols and heavy metals, organic solvents, pigments, cyanides, and fluorides
Leather	Heavy metals and organic solvents
Textiles	Heavy metals and chlorine compounds, dyes

day (t/d), out of which only 300 t/d is treated through common BMW treatment facilities (159 in number) or captive (in-house) treatment facilities. There are 600 BMW incinerators (common and captive incinerators), 2250 autoclaves, 200 microwaves, 150 hydroclaves, and 8,000 shredders in India. Out of 600 incinerators, only 400 are provided with air pollution control devices, and 200 operate without proper air pollution control devices (Pandey et al., 2022).

1.3.4 Radioactive Waste

Nuclear power produces a substantial quantity of energy from a small amount of fuel with relatively little waste generation, which is radioactive and needs to be treated carefully. Since the first commercial nuclear power station began operating in the 1950s, about 440 power reactors with an installed capacity of 390,589 MWe are currently used to generate about 10% of the world's electricity. The installed capacity of the 22 operational reactors in India is 6780 MWe.

The term "radioactive waste" refers to any item with radionuclides present, either directly or indirectly, in concentrations or activities above the defined clearance levels by the regulatory agencies. Radioactive waste is created during the breakdown and disposal of nuclear reactors and other nuclear facilities. The wastewater emitted by the nuclear industry seriously harms the environment and people. Radioactive substances, including U^{235}, U^{238}, Np^{237}, Cs^{137}, and other actinide compounds, can be found in the effluent from the nuclear industry. When radioactive waste is mixed with hazardous waste, it is termed mixed waste. The International Atomic Energy Agency provides guidelines for managing radioactive waste, and each country has its regulations for managing radioactive waste (US NRC, 2019).

The radioactive waste from nuclear power plants is by far the most dangerous. It is classified as high-level radioactive waste since some of the radioactive elements in the waste have half-lives of over 10,000 years (half-life is the time for the radioactivity in the element to decay to half its value). All other waste is considered low-level radioactive waste since the half-lives range from 5 to 15 years. The time taken by half of an individual radionuclide's atoms to decay and lose half of their radioactivity is known as the half-life. The handling of radionuclides with long half-lives is facilitated by their propensity to be alpha and beta emitters, whereas those with short half-lives generate more penetrating gamma rays. All radioactive waste eventually turns into non-radioactive substances. The more radioactive an isotope is, the faster it decays (Kumar et al., 2021).

The negative side of nuclear power production is that large amounts of spent fuel are accumulated near the power plants. About one-third of the fuel rods, called spent fuel rods, are removed from a power plant when they lose their fission capacity. These rods are highly radioactive and are stored in steel or concrete casks to shield against radiation. Many power plants use wet storage, where the casks containing the rods are stored in pools of water near the plant. However, many power plants also use dry storage in gas-cooled storage areas in addition to wet storage. The ultimate disposal of high-level radioactive waste will be in deep rock repositories to isolate the radioactive waste from the environment for a period of greater than 10,000 years. Many countries, including India, are investigating sites for these repositories. Building and maintaining these repositories for thousands of years will be very expensive. Technologies for reprocessing this waste to produce valuable byproducts and reduce the radioactive hazard from the waste are being pursued by many countries. However, plutonium production as a byproduct is a primary concern under the Non-Proliferation Treaty signed by nuclear nations.

Depending on the radioactivity level, radioactive waste is often categorized as low-level waste (LLW), intermediate-level waste (ILW), or high-level waste (HLW) (World Nuclear Association, 2022).

(a) **Low-level waste**: LLW is radioactively enriched to less than 12 giga-becquerels per ton (GBq/t) of beta-gamma activity or 4 GBq/t of alpha activity. LLW doesn't require shielding while being handled or transported and is acceptable for disposal in facilities near the surface. Hospitals, businesses, and the nuclear fuel cycle all produce LLW. It comprises items like paper, rags, tools, clothing, filters, etc., that typically have trace quantities of radioactivity. LLW is usually compressed or burned before disposal to reduce its volume. LLW makes up about 90% of the radioactive waste's overall volume but only 1% of its radioactivity. Long-lived radionuclides are only present in LLW at relatively low activity concentration levels, while short-lived radionuclides are present at greater activity concentration levels.

(b) **Intermediate-level waste**: ILW should be considered while developing or picking storage and disposal facilities because it is less heat-producing than LLW (2 kW/m^3) but is more radioactive. The need for shielding is more significant in the case of ILW due to its higher radiation levels. The most frequent elements of ILW are resins, chemical sludges, metal fuel cladding, and contaminated debris after reactor decommissioning. To dispose of smaller materials and non-solids, concrete or bitumen can be used to solidify them. It comprises 4% of the radioactivity of the entire volume of radioactive waste and makes up around 7% of it.

(c) **High-level waste**: For long-term safety, waste with high concentrations of short and long-lived radionuclides requires better containment and separation from the environment. Most of these wastes include uranium fuel from nuclear power reactors that have been "spent" or are no longer effective at generating energy. High-level waste (HLW) is created during the "burning" of uranium fuel in nuclear reactors. HLW contains the fission byproducts and transuranic elements created in the reactor core. Only 3% of the waste produced is high level, although it is 95% radioactive. HLW has both long-lived and short-lived components, depending on how long it will take for a particular radionuclide's radioactivity to decrease to levels deemed to be non-hazardous for people and the environment. HLWs are risky because they briefly expose people to deadly radiation doses. These HLW isotopes could infiltrate food systems if they enter groundwater or rivers. The dose produced by this indirect exposure would be significantly lower than direct exposure, but a far greater population could be exposed.

1.3.5 Construction and Demolition Waste

C&D waste is generated during any civil structure's construction, remodeling, repair, and demolition (MoEFCC, 2016a). Inert and non-biodegradable items like concrete, brick aggregates, tiles, plastic, wood, glass, metals, excavated soil, rock fragments, etc., are typically found in C&D waste (CPCB, 2017). The quantity and composition of C&D waste may vary depending on the kind of structure and the scale of construction, demolition, or renovation activities (Faruqi & Siddiqui, 2020).

In both developed and developing nations, extensive urbanization has fueled unending construction. In 2016, the rate of urbanization reached 54.3% globally and currently has reached around 55% resulting in the excess production of C&D waste. From 2015 to 2035, 1.5 billion more people are expected to live in urban areas, which is further anticipated to be 68% by 2050.

The generation of C&D waste exceeded 3.0 billion tons in 2012, and the increase in trend continues, with China being the largest producer of C&D waste with a value of about 1.13 billion tons in 2014 after exceeding 1 billion tons in 2012 (Akhtar & Sarmah, 2018; Lu et al., 2016). In India, the generation is believed to be between 10 and 12 million tons annually, or between 8.29 and 9.95 kg.capita^{-1} year^{-1} (Ram & Kalidindi, 2017). According to some estimates, India was the world's second-largest producer of C&D waste in 2013, producing roughly 0.53 billion tons of C&D waste (Akhtar & Sarmah, 2018). 30–50% of the total solid waste produced worldwide comprises C&D waste (Akhtar & Sarmah, 2018; Gálvez-Martos et al., 2018; Hoornweg & Bhada-Tata, 2012; Wing-Yan Tam & Lu, 2016).

1.3.6 Electronic Waste

Electrical and electronic equipment (EEE) usage directly affects worldwide economic growth. EEE is essential in modern societies and is raising the standard of living, but because of the resource intensity it can produce and use, it also serves as a counter-example to improving living standards. EEE is increasing due to increased urbanization and mobility associated with increased incomes and further industrialization in some regions. EEE is disposed of after usage, creating a waste stream that includes valuable and hazardous materials.

The worldwide generation of e-waste in 2019 was approximately 53.6 million metric tons (MMT) and is anticipated to reach 74.7 Mt by 2030, and the recent record from 2020 showed that approximately 7 to 20% of e-waste is exported as used or discarded products or imported in a country as per the existing legislation (Shittu et al., 2021). EEE is consumed at higher rates, has shorter life cycles, and has limited refurbishing options, all contributing to the growing amount of e-waste. Figure 1.3 represents the global e-waste generation trend from 2010 to 2019 (Forti et al., 2020).

Asia produced the most e-waste in 2019 (24.9 Mt), followed by America (13.1 Mt) and Europe (12 Mt), while just 2.9 Mt and 0.7 Mt of e-waste were produced in Africa and Oceania, respectively. Figure 1.4 represents specific continents' e-waste generation, collection, and recycling trends in 2019 (Forti et al., 2020). Figure 1.4 shows

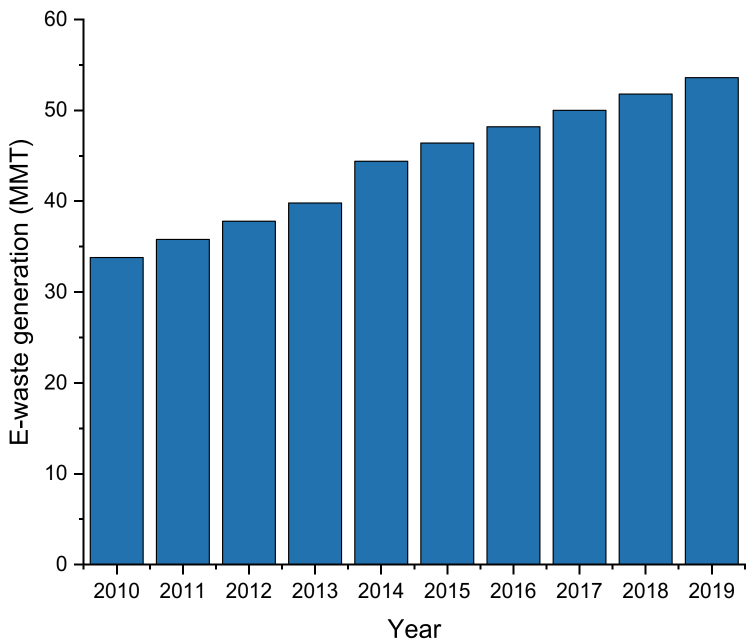

Fig. 1.3 Global e-waste generation (2010–2019). Redrawn from Forti et al. (2020) (Open access)

that only Europe and Oceania managed to have a higher collection and recycling rate for e-waste; however, the rest of the continents somehow managed to cater to limited e-waste en route toward recycling. Asia is reported to have the lowest rate of collection and recycling of e-waste compared to the amount it generates annually. Figure 1.5 displays the kinds of electrical and electronic equipment and the parts, consumables, and spares covered within the rules (MoEFCC, 2022).

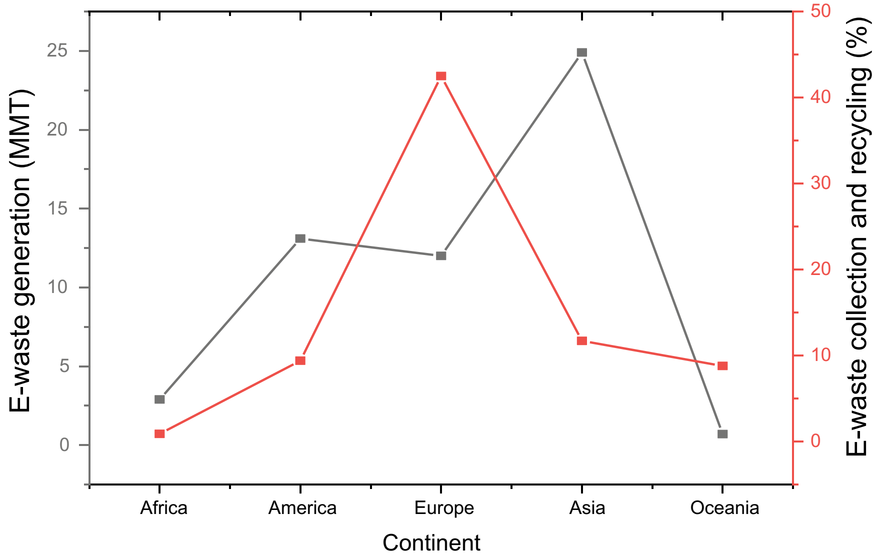

Fig. 1.4 E-waste generation, collection, and recycling in different continents during 2019. Redrawn from Forti et al. (2020) (Open access)

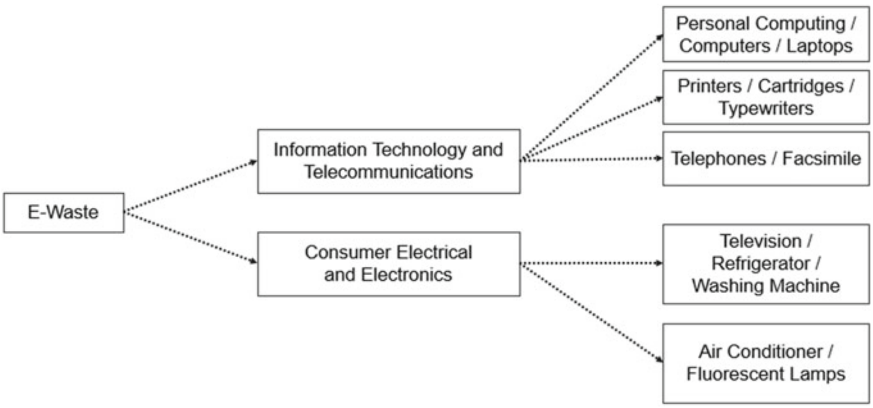

Fig. 1.5 Categories of electrical and electronic equipment. Redrawn from MoEFCC (2022) (Open access)

E-waste consists of rare metals like platinum, silver, gold, cobalt, and rare earth metals such as neodymium and high qualities of aluminum and tin (Das et al., 2021; Ma et al., 2016). European Union, in the year 2017, identified 27 critical raw materials based on their presence in the e-waste. The identified list of raw materials was further updated, and 35 raw materials are currently documented. Identifying critical raw materials is essential as they are considered economically important and have a high supply risk. For example, LCD uses indium coating, and if the usage of indium at the present rate continues for over the next 13 years, then indium will get depleted from the earth (Fig. 1.5).

The complex mixture of materials and components that make up electronic waste contains hazardous material, and if it is not correctly managed, it can have a negative impact on the environment and human health. In addition, creating modern electronics necessitates using expensive and scarce materials (electronics production uses about 10% of the world's gold). There is an immediate demand to revisit the current e-waste management practices and recycling infrastructure, creating awareness and clearing up the problem using a robust, cost-effective, and safe technique. The "reuse and refurbish" precept needs to be implemented to control e-waste springing and effectively encourage reduction and e-waste recycling.

1.3.7 Battery Waste

Worldwide, the usage of batteries in the chemical, automotive, and electronics industries is expanding rapidly. Electric reticulation or transportation is no longer needed because of batteries' portability, high energy density, and low maintenance requirements (Rarotra et al., 2020). However, battery technology has a short life expectancy, necessitating regular replacement. Heavy metals like manganese, lead, cadmium, and lithium, as well as other currently recognized pollutants that are usually regarded as having high ecotoxicity, are present in significant amounts in the most common battery types (Guo et al., 2018; Kang et al., 2013).

According to data from the US Environmental Protection Agency (EPA) (Rarotra et al., 2020), more than 180,000 tons of battery waste, including more than 86,000 tons of alkaline batteries and 14,000 tons of rechargeable batteries, are disposed of in the US annually (Rarotra et al., 2020; Song et al., 2017). In 2013, 570,000 tons of battery waste were produced in China. Large amounts of battery waste are now posing significant environmental and health risks as it contains a variety of toxic substances (Delvasto et al., 2016; Ilankoon et al., 2018; Xu et al., 2008; Zheng et al., 2018).

Batteries can be categorized as chemical, physical, or biological. Chemical batteries can be further divided into primary and secondary. Primary batteries have a high life-cycle cost but cheap initial costs, replaceability, and are disposable and non-rechargeable. They are also suitable for portable applications. Figure 1.6 represents the broad classification of batteries (Winfield et al., 2012).

Lead–acid batteries fall under the hazardous waste category and should not be mixed with other waste and disposed of. Toxic chemicals, such as lead and sulphuric

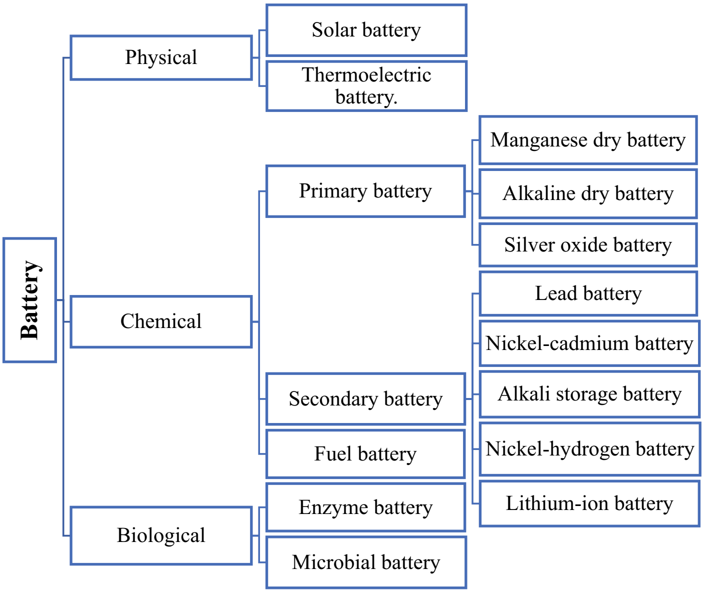

Fig. 1.6 Classification of batteries. Reproduced from Winfield et al. (2012) (Open access)

acid, are present in roughly 2–3 L each in lead-acid batteries. Lead accumulation in the environment has acute and chronic effects on plants, animals, and microorganisms. Humans' central and peripheral neurological systems, circulatory systems, and kidneys have all been documented to be harmed by lead. Of the total lead discovered in landfills, 40% comes from consumer gadgets/electronics (Kaushal et al., 2015).

As the market for electronic mobile devices expands and efforts to electrify the world's fleet of vehicles are successful, the demand for energy storage devices is anticipated to soar. However, this increase is not accompanied by adequate worldwide regulation, leading to improper production and disposal methods that expose possible harmful compounds to the environment. Thus, an urgent requirement for an efficient management approach to safely handle and recover precious resources utilized in battery manufacture has arisen due to the large-scale generation of battery waste.

1.4 Overview of Liquid Waste

To protect the quality of our water resources, monitoring and controlling pollution sources and outflows is crucial. Contaminated waterbodies put both human health and ecosystem function in peril. Uncontrolled discharges may cause eutrophication, the buildup of heavy metals and other pollutants, and contamination of drinking water sources. Wastewater production has been continuously rising over time due to population growth, improvements in the water supply, rising living standards, and economic expansion. Globally, municipal wastewater production totals 380 billion m^3 annually. Wastewater generation is expected to increase by 24% by 2030 and by 51% by 2050 (Qadir et al., 2020). Although wastewater is a valuable and sustainable source of water, energy, and nutrients, it continues to be seen as a problem because of the widespread belief that it is a source of pollution that requires rigorous treatment.

Apart from some shifts due to regional variations, it is estimated that globally, 80% of the total produced wastewater is discharged into the environment without proper treatment. According to the United Nations, high-income countries treat, on average, 70% of the wastewater they generate. This ratio falls to 38% in upper middle-income countries, whereas in lower middle-income countries, it falls to 28%. Only 8% of the wastewater generated in low-income nations receives any treatment.

Rivers, streams, wells, and lakes are tapped in metropolitan areas to provide water for home and industrial purposes. Wastewater production amounts to about 62,000 Ml/d, of which only 18,883 Ml/d, or just one-third, is treated. The other two-thirds are left untreated. It either dissipates into the ground, where it could contaminate groundwater, or is released into the natural drainage system, where it can contaminate places downstream. Municipal sewage can be defined as "liquid waste originating from a public place/community, and composed of domestic wastewater and discharge from industrial facilities." It contributes significantly to water contamination in India, especially in metropolitan areas. In India, just 38% of urban residents have access to sanitary facilities.

Wastewater generation has dramatically expanded along with metropolitan areas' drinking water supplies. Wastewater will contaminate the nearby freshwater supplies if not adequately collected and cleaned. Moreover, the cumulative effects of untreated wastewater can have a negative effect on the ecology and the general public's health. Urban environmental management is the most urgent issue as the worldwide urbanization trend continues. Making sure that essential human services like water and sanitation are always available is one of the obstacles that urban planners must overcome. Human waste continues to accumulate, and untreated wastewater directly contributes to the contamination of nearby freshwater resources.

1.5 Conclusion

The amount of solid waste generated varies substantially between nations, and a nation's economic standing significantly impacts the nature of solid waste. To help managers successfully manage the steadily growing volume of solid wastes with more flexibility, solid waste management pathways should be examined based on their long-term economic viability. One notion that can be considered a step in the right direction for global sustainable waste management is investment in the solid waste industry. Waste management cannot be left entirely up to civic organizations; instead, governments should actively include regular citizens by raising awareness and using a participatory approach.

Improving wastewater monitoring and management should be a part of the sustainable solution to the current water problem. The eagerness to pay for wastewater collection, treatment, and monitoring is often lower than for drinking water services, especially in countries with low environmental and public health regulations. In addition, the value of employing treated wastewater as a controllable, renewable resource for industry, agriculture, and energy production is sometimes underestimated. A paradigm change in the pattern of wastewater management is needed to protect better resources linked with drinking water and aquatic ecosystems and to enable sustainability, climate change mitigation, and adaptation. To lessen the financial burden on wastewater treatment plants and to improve environmental advantages, treated wastewater should also be included in the river basin's water balance.

Acknowledgements Abdul Rafey acknowledges the Prime Minister Research Fellowship Scheme for the financial support and the Indian Institute of Technology Delhi. Kunwar Pal would like to thank and acknowledge the Ministry of New and Renewable Energy. K.K. Pant and Ejaz Ahmad thank the Office of the Principal Scientific Advisor to the Government of India and acknowledge the project Solid Waste Management under Delhi Research Implementation and Innovation (DRIIV).

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