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10. Solid Waste Management

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Abstract:

Globally, with the growing population, the waste generation rates are increasing exponentially which poses a significant challenge in solid waste management. In 2016 nearly 2.01 billion tons of solid waste were generated, which equates to a carbon footprint per person per day is 0.74 kilograms. Due to rapid population growth and urbanization, it is anticipated to increase by 3.40 billion tons by 2050. This poses a significant environmental and emerging issue in India. Lack of appropriate SVM facility poses a significant challenge especially in highlands due to increased urbanization, remoteness, harsh climate topographical configuration increasing urbanization. Waste can be categorized as paper, plastic, metal. Solid waste management should be an eco-friendly process of collection, transport, storage and safe disposal of waste. It includes planning, organizing, and administration along with technical, legal, and financial support. Further, it also involves major activities starting from generation, followed by storage, collection, transport, processing, and safe disposal. Methods adopted must align with the principles including economy, aesthetics energy, and conservation.

Eligible MSW treatment methods are sanitary landfills, incinerators, dumpsites, waste open burning, recycling sites, composting plants, transfer stations, and anaerobic digesters. Environmental pollution and outbreak of vector-borne diseases result when the Municipal solid waste (MSW) is not managed properly. A wide range of economic, administrative, and social problems associated with SVM could be effectively managed by the implementation

of Legislation and regulations. Adoption of new approaches in SWM ensures that it is comprehensive, organized, and cost-effective, create wealth, and protects public health. Managing and reducing waste can be guided by the 5 R's principle: Refuse, Reuse, Reduce, Repurpose, and Recycle. This principle advises that recycling should be a last option.

10.1 Introduction:

Among the environmental issues, solid waste management has become a significant concern, mainly due to the rapid rise in the urban population, constituting 31.6% in a population of 1.210 million[1]. Annually .3 billion municipal solid waste (MSW) is generated which is expected to rise to about 2.2 billion tons by 2025[2]. The need for effective waste management arises as it increases proportionally to population and income.[3]. Due to the rapid rate of urbanization the municipalities face an extra burden in environmental and socio-economic leading to the depletion of natural resources. [4]. The per capita waste generated in India increases exponentially (0.26 kg/day to 0.85 kg/day)[4]. according to the central pollution control board (CPCB)[4].

Existing lines of evidence suggest that Municipal solid waste (MSW) disposed of without proper treatment results in the emission of greenhouse gases leading to land, water, and air pollution[5]. Currently, single-use plastics have become a global threat although they are biodegradable and less harmful[6]. In cities generation of plastics could lead to drainage choking in monsoons leading to flooding. Also, these micro plastics can cause disturbance in aquatic life leading to pollution of rivers and oceans leading to global warming, and ingenious extinction of species[7]. Plastic waste generated spans 300 million tonnes of which only 9% is generated plastic is recycled while the remaining reaches the ocean.

Generation of hazardous waste in cities from hospitals and industries premature death and breathing problems[8] Although India has emerged as a recycling market where the recycling is not done as prescribed[9]. Health issues originate due to improper municipal solid waste management in landfills attracts rodents, mosquitoes, scavengers, etc. The primary factor to consider for efficient solid waste management is the place where solid waste is produced. To have successful solid waste management, solid waste generation is the most crucial factor to consider. The amount of garbage produced varies between nations

based on public awareness, culture, and management. Additionally, it was shown that the generation of garbage was related to the nation's economic situation [10]. Existing evidence suggests that in comparison to the developing countries the generation of waste by the developed countries is comparatively higher

The quantity of garbage produced by Asian and African nations varies from 0.21 to 0.37 tonnes per capita per year [10], whereas the European nations produce 0.38 to 0.64 tonnes per capita per year (Intergovernmental Panel on Climate Change [IPCC], 2006) Example Japan and Hong Kong, which have greater GDPs than India and Vietnam, were found to produce more solid garbage. Table 10.1. The handling of MSWs at landfills attracts insects, and rats and mosquitoes can have negative health effects.

Table 10.1: Waste generation in a few Asian countries, as measured by the GDP.

Country	GDP (PPP) per capita estimated for 2007 (USD)	Waste generation (kg/capita/day)
Hong Kong	37 385	2.25
Japan	33 010	1.1
Singapore	31 165	1.1
Taiwan	31 040	0.667
South Korea	23 331	1.0
Malaysia	12 702	0.5-0.8
Thailand	9426	1.1
China	8854	0.8
Philip pines	5409	0.3-0.7
Indonesia	5096	0.8-1.0
Sri Lanka	5047	0.2-0.9

Country	GDP (PPP) per capita estimated for 2007 (USD)	Waste generation (kg/capita/day)
India	3794	0.3-0.6
Vietnam	3502	0.55
Lao PDR	2260	0.7
Nepal	1760	0.2-0.5

10.2 The Necessity of Solid Waste Management:

- Due to the rapid rise in population and increased urbanization significant increase in solid waste is observed which hampers the development of city or village [11]
- The major threats that arise due to solid waste is a health issues and bad odor.
- In India more than 1000 tonnes of solid waste is generated which is treated by landfilling which harms the land and marine environment [10].

SWM must be ensured with proper facility for segregation, collection, transport, and treatment of waste. This in turn reduces the transmittance and origin of diseases and reduces odor thereby improving the aesthetics of the city. SWM must be executed with eco-friendly approaches to achieve needful.

10.2.1 Characteristics of Solid Waste:

Solid waste consists of inefficacious or unwanted material that are often generated by human activities in commercial, residential, or industrial areas[12]. It is usually categorized in three ways, according to its-

Contents	organic material, metal, glass, plastic, paper etc
Origin	domestic, construction, industrial, commercial or institutional
Hazard potential	non-toxin, toxic, flammable, infectious, radioactive, etc

Further, solid waste is divided into two types- Non-municipal and Municipal solid wastes. Non-Solid Municipal Waste is a product that is produced along with the generation of Solid Waste (NMSW)[12].

Waste from the mining, farming, and industrial sectors is included. Municipal solid waste (MSW), also called garbage and rubbish, is produced by individuals, families, businesses, and institutions (like hospitals and schools)[12]. It may include electrical and electronic waste, biodegradable waste such as food scraps, and composite waste such as clothing, construction and demolition debris (CnD), hazardous waste (chemicals, paints, and spray), and medical waste (hypodermic needles, syringes, scalpels, medicines, tissue, and organs)[13]. Hazardous waste causes immediate danger when exposed to individuals or the environment. These materials are either toxic, ignitable, reactive, corrosive, radioactive, or infectious and originate from chemical production, manufacturing, hospitals, and other industrial activities[13]. Common household hazardous waste includes bleaches and cleaning products, pesticides, batteries, paints, electronics, and pharmaceuticals. On the other hand, the concern about electronic waste is escalating day by day. E-waste such as computer equipment, televisions, telephones, smartphones, and refrigerators contain various harmful elements like mercury, lead, and cadmium[14].

Globally, the rate of production of municipal solid garbage has reached 2.01 billion tonnes annually[15]. At least 33% of the entire trash generated from that is handled in an unsustainable and severe manner. The range of daily waste production per person worldwide is between 0.11 and 4.54 kilos, with an average of 0.74 kilogrammes[16]. High-income nations contribute around 34% (683 million tonnes) of the garbage produced globally, although having only about 16% of the global population. With urbanisation and population expansion, it is predicted that garbage production would rise exponentially until 2050, when it will reach 3.40 billion tonnes[16]. There is a link between waste production and income. In low- and middle-income countries, daily garbage production is expected to increase by 40%, whereas in high-income ones, it will increases by 19% by 2050[16].

India has experienced a sharp increase in rubbish production over the past few years. Everyday garbage production has increased by 1.3 percent annually to 450 grams per person[17]. Over the past few years, garbage generation in India has been rising quickly.

The amount of waste produced per person each day has climbed by 1.3 percent annually to 450 grams[18]. By 2031, urban India is anticipated to reach 4,50,132 tonnes of rubbish per day and 11,95,000 tonnes per day by 2050, according to the Task Force on Garbage to Energy's 2014 report[19].

10.2.2 Solid Waste Management Practice:

Waste management refers to the processes and actions involved in managing waste, from its inception to its disposal[20]. Solid waste management is generally regarded as a discipline that focuses on the controlled generation, storage, collection, transportation, recycling, treatment & disposal of solid wastes in a manner that best addresses a range of public health, environmental protection, aesthetic, practical, financial, engineering, city and regional planning, geography, administrative, legal and other environmental deliberation[21].

Solid waste management aims to minimize and eliminate detrimental effects of waste products on the environment and human health in order to encourage economic growth, a healthy environment, and a higher standard of living[3].

Poor management and Improper disposal of solid waste creates unsanitary conditions and breeding ground for vectors-borne diseases like West Nile virus, Lymphatic Filariasis, Onchocerciasis, Chagas, Leishmaniosis, Schistosomiasis, Yellow Fever, and Leishmaniosis [22]. Biomedical waste (infectious waste) is a serious threat to human health if not handled in a scientific and discriminate manner[22]. Open dumps or in improper landfills create serious negative impacts on the environment like soil and water bodies contamination creates loss of biodiversity; it releases dangerous gasses and leachates like methane, due to microbial decomposition, which contribute to climate change and air pollution. Improper waste management harms public health, hurts the environment and climate, and hinders economic growth[22].

10.2.3 Hierarchy of Solid Waste Management:

Waste management hierarchy is the guidelines that rank various waste management options based on relative desirability to achieve an economically efficient and environmentally

friendly waste management practice[23]. The standard hierarchy of waste management consists of five important steps in the form of an inverted pyramid; Prevention, Reuse, Recycling, Recovery and Disposal[23].

The most effective and environmentally preferred methodology in the hierarchy is **Prevention** which aims to reduce or totally prevent waste generation at the source[18]. This includes redesigning products, reducing packaging and toxicity, particularly at manufacturing by implementing eco-friendly materials such as organic cotton and bamboo. The second-best option is **Reuse**[23]. In addition to preventing, reusing scrap can have benefits in reducing waste. The third phase in the hierarchy of waste management is recycling because it requires more energy and resources to produce the end product[23]. Recycling reduces the demand for resources and the amount of waste that needs to be disposed of by landfilling. It involves segregating and sorting wastes and then processing them into raw materials. **Recovery** is usually ranked fourth in the hierarchy[23]. It includes conversion of non-recyclable waste materials into fuel, electricity or heat through various physical-chemical processes. This method reduces the toxicity and volume of waste by producing renewable energy sources such as biofuels which reduce carbon emission and fossil fuel dependency. Disposal, ranked lowest in hierarchy, entails disposing of wastes in or on the earth's mantle. Disposal is the least desirable method because it affects health and the environment[24].

10.2.4 Components of Solid Waste Management:

Sustainable, efficient and reliable management of solid waste can be broken down into five components to ensure minimization of its impact on social and human health, economy and environment[24].

10.2.5 Collection and Transport:

The first step towards solid waste management is collection and transport of waste from its source to transfer station. About three-quarters of the overall waste management budget goes toward this labour-intensive process[25]. Enclosed and compact trucks, with capacity up to 30 cubic meters, are used for waste collection from densely populated cities. These

collection vehicles travel to a transfer station, where garbage from various cars is collected in a tractor-trailer unit that is much larger. These trailers then transport roughly 76 cubic metres of garbage to a local facility for processing or disposal. Tons of trash can be handled daily by large transfer stations.

10.2.6 Separation and Recycle:

Separation, recovery, and reuse of economically valuable components from solid waste is called recycling[3]. Separation of waste is accomplished either at the source or at a central processing unit. It is usually carried out by individual citizens who separately place recyclables and non-recyclables waste at the curb for collection[26]. Centralized mechanical processing plants can also separate recyclable materials from garbage. However, recyclables recovered from such facilities lost quality due to the contamination with broken glass and moist garbage. Hence, for best practice, separation should be done by individuals[27]. A centralised material recycling facility, or MRF, processes recyclables. An electromagnetic separator removes tin and steel cans, and a vibrating screen separates shattered glass from the remaining components[27].

Then, an air classifier separates lighter glass containers from heavier plastic and aluminium containers, and at last, eddy-current separators separate aluminium from plastic. Whereas paper materials are stored by hands. Broken glass that has been recovered can be used as cullet for producing glass and in asphalt pavement. Cans made of scrap steel may be baled and transported to steel mills[27]. Aluminium has the highest value as a recyclable resource despite being one of the smallest parts of municipal solid trash, which can be reused by smelters[28].

Due to different polymeric materials, recycling of plastic is challenging. Mixed thermoplastics, however, are utilised to create inferior goods like "plastic timber.[6]" Recovered papers can be sent to paper and tissue mills. Rubber can be shredded and remodelled by vulcanization. In asphalt paving, shredded rubber can be used as an addition and as artificial turf. Discarded tires can be employed in recreational structures like swings for children in tire playgrounds[29].

10.3 Composting:

Composting is an eco-friendly and biological method of treating municipal solid waste which offers recycling and processing of both garbage and sewage sludge[29]. Under carefully controlled conditions, organic waste is allowed to decompose by microbes, which reduces their volume by around 50 percent. Humus or compost, the stabilised end result, has a texture and smell similar to soil and can be used as mulch.

The process includes isolation of decomposable materials from refuse, shredding or pulverizing with rotary shredders and hammer mills for a uniform mass of material and digestion of pulverized by enclosed mechanical facility or the open windrow method[30]. Windrows refers to the long and low mounds of refuse. Relatively, Open windrow composting requires large land areas and manual aeration, whereas mechanical composting systems employ closed digesters that mix and aerate the shredded waste with rotating vanes, reducing land requirement by about 85 percent[30]. Compost goes through the process of drying, screening, and granulating before it can be used as a mulch.

10.3.1 Energy Recovery through Waste Treatment:

Energy recovery, often known as waste-to-energy, is the process of converting non-recyclable trash into useful power or heat, or fuel, using a number of different techniques, such as combustion, pyrolysis, anaerobic digestion, gasification, and landfill gas recovery[31]. Often referred to as trash to energy, this process. These methods generate new sources of renewable energy, reducing carbon emission and methane production from landfills. Usually, Waste-to-energy plants either employ mass burn or refuse-derived fuel systems to operate, to generate electricity or steam[32]. The fact that differentiates both is the prior treatment or preparation. The mass burn method uses all refuse whereas combustible wastes are first separated from non-combustibles (metal and glass) in a refuse-derived fuel system before burning[32].The heat released from the combustion chamber converts water to steam, which is then converted into electricity by a turbine generator. The remaining ash is collected, filtered by a highly-efficient baghouse filter for removal of metal scrap and disposed into landfills. Apart from aerobic digestion or composting, compostable materials are treated anaerobically, to utilize the methane gas which is used as a fuel for

ovens, water heaters, homes, automobiles, kilns, turbines, etc.[33]. MSW is often converted into a combustible gas by gasification, which utilizes an additional reactant and a high temperature (up to 1000°C). Gasification and pyrolysis both resemble burning, however it is conducted without oxygen. Recovered gasses can be utilized with different energy technology[33]. Greater volume reduction and self-sustaining processing of waste are provided by both the processes, that's why it is used for hazardous and infectious biomedical waste treatment[34]. Chemical, thermal, and biological treatments of hazardous waste prior to disposal is crucial.

Ignorance and mismanagement may harm public health and the environment[35]. Chemical methods like ion precipitation, exchange, oxidation-reduction, and neutralization; thermal methods like multiple-hearth furnace, fluidized-bed incinerator, and rotary kiln; biological methods like fluidised bed bioreactors for ethanol and cellulose production, hydrolysis for organic acid recovery should be employed to reduce toxicity, recovery and disposal of hazardous solid wastes.

E-waste management basically relies on recycling and repurposing. Another class of contagious waste is biomedical and hospital waste, which are detoxified and recovered generally by autoclaving, plasma processing, gasification, microwaving, ultraviolet and Cobalt-60 produced gamma rays[36].

10.3.2 Disposal of Waste:

In order to reduce the impact of waste on the environment, completely waste material and by-products are finally disposed of after MSW treatment. Incineration and landfills are the most widely used disposal methods for MSW management[27].

10.3.3 Incineration:

Controlled Incineration involves combustion of waste at very high temperatures (800–1100 degrees Celsius), it is a dry oxidation process[37]. However, modern waste management approaches consider incineration as a process of energy recovery and waste treatment. Modern incinerators are equipped with extensive emissions control equipment such as electrostatic precipitators that separate the fly ash and acid gas, fabric baghouse filters, and

gaseous by-products before they end up in the atmosphere[37]. After secondary treatment, fly typically, bottom ash and ash are combined and dumped in landfills. Incinerators are particularly equipped for hazardous and biomedical waste disposal[38]. Double-chambered incinerators are used for pathological waste and rotary Kilns are used on heat resistant chemicals and genotoxic waste. Incineration is an expensive method and produces potentially dangerous dioxin (human carcinogens) emissions. The incineration process should be strictly controlled and efficiently executed so that the dioxin does not exceed the norm[39].

10.3.4 Landfills:

Landfilling is the primary method for disposal of waste. Proper waste management system adopts three types of landfills; Sanitary Landfills or MSW Landfills for municipal waste disposal; Hazardous Waste landfills; and Monofils, designated for single type of waste (e.g., construction waste)[40].

A landfill is a limited part of a site that is used to disperse waste in thin and compact layers. Multilayer approach is used to maximize depth up to whereas the compacted waste only takes up roughly a fifth of its original volume, it measures 3 meters (10 feet). To eliminate odor, wind-borne litter, pest and rodent problems, a layer of soil is deposited over the litter at the end of daily operations. Creating the final cap with a topsoil layer on completed landfill may support vegetative growth. Despite landfill being a simple concept, proper management is important, otherwise it will create public health concerns and negative impacts on the environment. Landfills cause soil water and air pollution[40]. Harmful emissions like benzene, toluene, ethylbenzene and xylene isomers and landfill leachate are potential dangers and adverse effects of landfilling that could harm human health.

10.3.5 Strategy for Sustainable Solid Waste Management:

Waste management is important for developing countries and cities to be sustainable and livable, but it remains a challenge for many. Waste management is a complex process that costs between 20% and 50% of the municipal budget[27]. An efficient, sustainable and socially responsible system is essential to conduct this important municipal function.

Confirming the correct application of the waste hierarchy across industries, private companies and households requires a comprehensive strategy with effective horizontal collaboration between local, regional, state councils and national levels, as well as local and vertical collaboration[27]. Financial investment, knowledge and technical expertise are all essential for the implementation and success of an effective waste management policy.

There are various practical problems associated with MSW management. Finding appropriate applications and suitable markets is the most strenuous problem with the recyclables.

Recycling alone won't the growing issue of managing and dumping solid waste[27]. There will always be room for solid residue that has no value. High transportation cost and competition with inorganic chemical fertilizer, generally reduce the agricultural demand for digested manure[27]. Improved infrastructure, closed dumps, treatment facilities and waste sorting, and the construction or refurbishment of landfills with bins, dumpsters, truck and transfer stations are the first steps towards sustainable MSW management. Long-term planning of tax and fee structures and concrete policies for the sphere of municipal waste management, and coordinated institutions will help governments improve waste cost control and recovery.

Public involvement and a change in behavior are necessary for a functional waste system. About 15–20% of the waste produced in most developing nations is collected, sorted, and recycled by informal workers in developing countries [27].Safe working conditions, educational opportunities, a social safety net and child labour restrictions will promote waste management practice at the individual and social level. Advancement of environmentally sound waste treatment and disposal technologies is required.

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