



Emerging precautions of solid waste management

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Abstract

Annually, world generates 2.01 billion tones of solid wastes and it is expected to generate 2.2 billion tones of solid waste by 2025. Globally double the amount of waste generation was anticipated by 2050, hence an urgent action is required for this intricate problem in adopting better management techniques and recycling strategies. Unfortunately, poor management of wastes causes vulnerable effects to the society in terms of health. Waste management is the key infrastructure to be developed in society, but so far it is not recognized as much in many developing countries. Significant innovations and improvements are made in the last few decades globally, but still 2 to 3 billion people around the world lack access to waste collection services. The aim of this present study is to give an overview of different types of waste techniques that are effectively followed by different countries and the action plans need to follow. This review focuses on the global current scenario of waste generation, and its management methods with relevant literatures providing the upgrades in the phases of waste management services like collection and transport, various techniques adopted for waste management, policies and legislation, countries investment in waste management process and the impact of solid waste management during Covid-19. Collectively we conclude that Asian countries need to allot more fund for handling solid waste. Also with the available waste management technique, it is not possible to achieve zero waste. Therefore, more new techniques are needed to be adapted.

Keywords: Solid waste, Generation rate, Countries investment, Government policy acts, Covid-19 Solid waste; Generation rate; Countries investment; Government Policy acts; Covid-19.

Introduction

Managing solid waste is a challenging task all over the world and the major reason behind it is lack of social awareness, responsibilities together with a lack of novel solutions. Globally, it is noted that the waste generation rate increase with increasing income in other terms global urbanization paves the way for more waste generation (Kaza et al., 2018). In the past three decades, generation of the industrial and hazardous waste shifts more burdens on developing countries. Increase in population, migration to nearby cities, increasing city sizes and development of new cities also increases the waste per capita of developing countries. Another reason behind the waste heap is due to lack of coverage in waste

collection and as per the recent report around 2 billion people are unable to regularly access waste collection throughout the world ([Besen and Fracalanza, 2016](#)). Hence, improper management of waste can impose negative impact on public health, environment, productivity, tourism, economic status and damages associated with floods. Financial affordability is the biggest challenge for developing countries in handling solid waste and it needs much attention on cost-effective waste treatment techniques ([Ferronato and Torretta, 2019](#)). In another phase, the worldwide scenario of total waste has reached more than 2.01 billion of tonnes in 2016 ([Kaza et al., 2018](#)). The maximum quantity of 450–500 Mt waste generation was reported from East Asia and Pacific regions and the least quantities of waste was reported from the Middle East and North African regions. Based on the projected report on waste generation, 2050 may explore the maximum quantity of waste (700–750 million tons) will be high in East Asia and Pacific regions ([Kaza et al., 2018](#)). The Middle East, North Africa, East Asia and Pacific had no significant increasing pattern of waste generation when compared with 2016 records. But significant quantity of waste generation will be reported in Sub Saharan Africa and South Asia rather than Latin America and the Caribbean, North America, Europe and Central Asia in the future year 2050 ([Kaza et al., 2018](#)). Every year, India has generated 65 million tonnes of waste.

According to the report of the Ministry of Housing and Urban Affairs (MoHUA) 2020, the total waste generation level by Indian states (84,475 wards) was reported as 14, 7613 Mt/d ([Singh, 2019](#)). The current and future views of worldwide solid waste generation was shown in [Figure 1a, b](#). To implement the new ideas to manage the solid wastes in India, a report has been submitted by the parliamentary ‘Standing committee on Urban Development’ on Solid Waste Management including Hazardous Waste, Medical Waste and E-Waste in 2019. At the same time, the “action taken report” was also submitted in the parliament in March 2021, among 21 actions, only 14 actions have been accepted by the government and 2 actions are still awaited by the committee for approval ([Pavithra, 2021](#)). Recent literatures states that, the solid waste management is still in unsustainable condition notably as developing and underdeveloped countries are highly affected ([Ntagisanimana et al., 2021](#)). Initially, the influence of Covid-19 lockdowns towards the generation of solid waste ([Shrestha et al., 2020](#)) was positive but on later stages biomedical waste generation have been increased uncontrollably in the form of Personal Protective Equipment (PPE) equipment’s ([Das et al., 2020](#)). In general, two solutions are available for the reduction of wastages viz., no production of wastages or converting the wastages into another material. In current scenario, reaching zero waste is impossible because of the industrialization and urbanization but using an effective waste management, it is possible to control the waste. The effective waste management system will help to attain the future visions of complete recycling in such a way that waste materials could be used again as feed for another industry that will help to reduce the levels of waste. Generally, Solid Waste Management concerns the application of the principle of Integrated Solid Waste Management (ISWM) to municipal waste ([Ministry of Urban Development-India, 2013](#)). Understanding the key composition of waste is very important for proper handling of the waste. The composition of solid waste includes food waste, paper, plastic, metals.

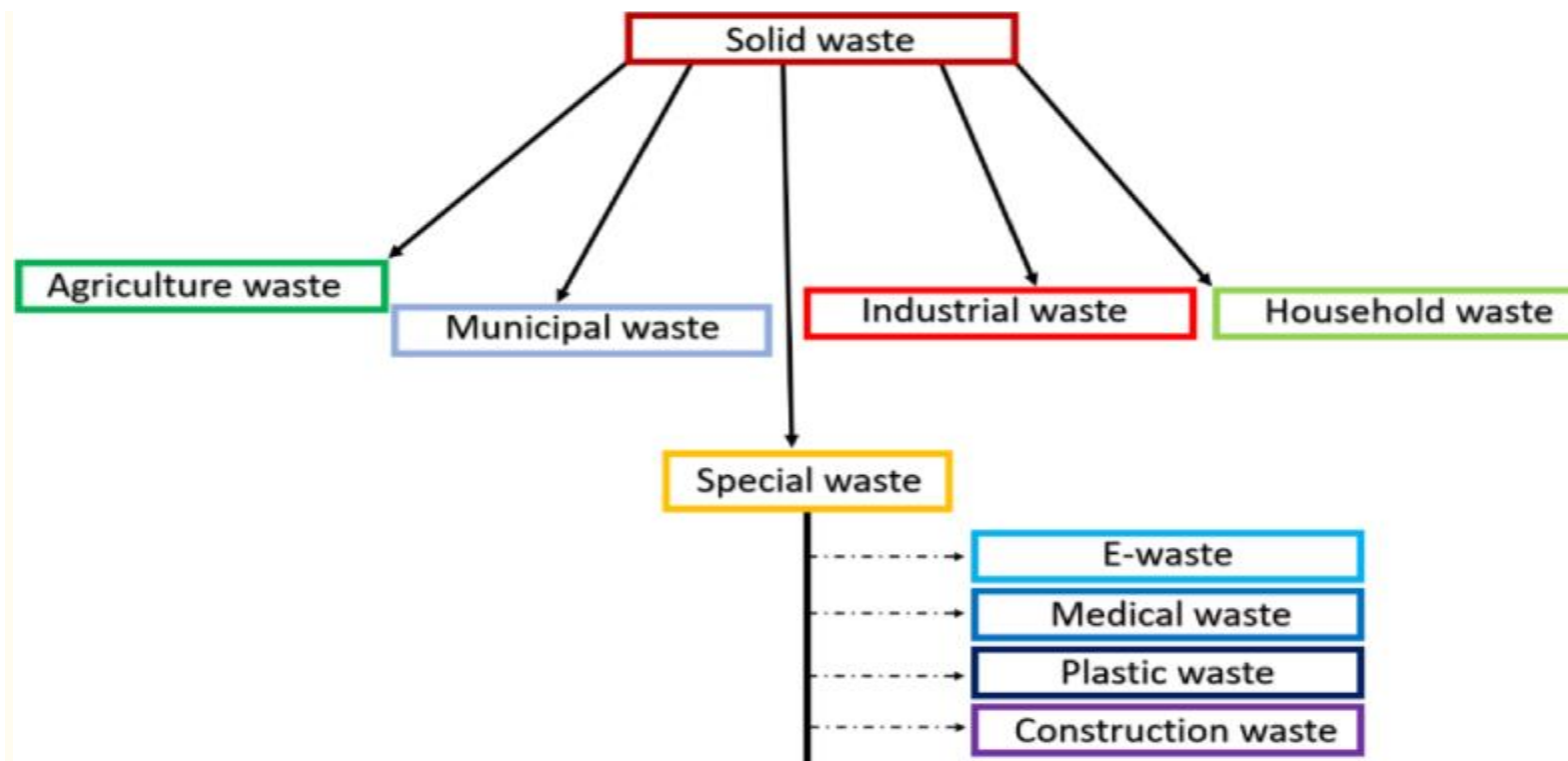
Waste management—overview

Generally, solid waste categorized into agricultural waste, municipal waste, industrial waste, house hold waste and special waste (e-waste, medical waste, plastic waste and construction waste) have shown in [Figure 1a, b](#). Plastic is widely used material around the world for different purposes and its usage is merged with people’s everyday life. The rapid urbanization and the modernization led to larger usage of plastic material and mostly plastics were used once (single-use plastics) and are immediately discarded. The greatest environmental health effect was caused by plastic waste, viz., 6.3 Mt of plastic waste have been generated in 2018 itself but only 9% was recycled and 12% was incinerated ([Alabi et al., 2019](#)). The mismanaged plastic waste (MPW) accumulated around 60 to 99 Mt globally in 2015 and this quantity

can be tripled to up to 155–265 Mty⁻¹ by 2060 ([Lebreton and Andrady, 2019](#)). Most of the plastic wastes were washed into the ocean, burned by incinerators and the residues or source is dumped in landfills. These huge volumes of plastic waste leads to very serious consequences, such as environmental pollution, food chain contamination, energy waste, biodiversity breakdowns, economic loss, impacts on wildlife with bioaccumulation of synthetic contaminants and plastic elements ([Nnorom and Odeyingbo, 2020](#)). There are four strategies to manage the plastic wastes, that are (A) landfilling, (B) incineration, (C) reduce, reuse, recycle, (D) Create awareness among the people

Notably, in human it causes birth defects, cancer, neurological problems, reproductive dysfunction, etc., Polyvinyl chloride (PVC) emission is the main reason for toxicity and usage of alternate form of PVC is encouraged that will reduce the toxin level and effect of plastics during incineration and landfill. Examples of PVC alternate that are used in the field of medicine include ambulatory products (steel), non-sterilized (polyolefin, polyethylene, polypropylene), blood products (silicon, stainless steel, Non-DHEP PVC), epidural catheters (polyamide, polyethylene, polyurethane), laparoscopy (polyurethane), intravenous (makrolon, glass, polystyrene), gloves surgical (nitriles, polychloroprene, polyurethane), Sterilized bags (polyurethane, polyolefin, polyester).

According to the recent global survey, generation of e-waste has been increasing at the rate of 2-million-ton metrics per yr (2014—approximately 41 million tonnes e-waste have been generated ([Kumar et al., 2017](#)), which equates generation of 49.8-million-ton metrics in 2018.



Categorization of Solid Waste. Viz., agricultural waste, municipal waste, industrial waste, house hold waste and special waste (e-waste, medical waste, plastic waste and construction waste).

Waste treatment Technologies. Most preferable options for waste disposal treatment technologies are open dump, recycling, sanitary landfill, landfill (unspecified), anaerobic digestion, composting, controlled landfill, incineration.

Bio-waste management

The prospective construction of high value-added chemicals and bioenergy with a negative feedback loop is called “bio-waste”. The bio-waste has created a direct impact on the greenhouse gases by illogical use of fossil fuels ([Aluko et al., 2021](#)), the influence of population on freshwater sources and energy demand for industrialization may trigger the chances of global warming. Importantly, as a major waste management system incineration and landfill processing are used, which emits greenhouse gases that can cause global warming ([Astrup et al., 2009](#); [Kim and Kim, 2010](#)). As per the Indian government guidelines, the sorting and segregation of waste into different specific containers for further steps of recycling and decomposing should be performed appropriately. Generally, the decomposing time of waste materials are varying from one to another. Decompose property lies on the nature of the material chemistry.

Common waste items decomposition time.

Waste Items	Decomposition time	Risk of Toxicity
Cigarette butts	18 months to 10 yrs	High (cadmium (Cd), lead (Pb) and arsenic (As)
Plastic bags	10-1,000 yrs	Dioxins: lethal persistent organic pollutants (POPs) and 2,3,7,8 tetrachlorodibenzo-p-dioxin (TCDD), agentorange
Tires	2000 yrs	benzene, metals such as lead, polycyclic aromatic hydrocarbons such as benzo(a)pyrene, and synthetic rubber components such as butadiene and styrene
Plastic bottles	450 yrs	dioxins, furans, mercury and polychlorinated biphenyls
Synthetic fabric	More than 100 yrs	polyester and nylon contributes to microplastic pollution
Disposable diapers	500 yrs	xylene and ethyl benzene
Batteries	100 yrs	Hydrogen, Hydrogen Sulphide, Arsenic Hydride and Antimony Hydride gases.
Clothes	6 months	nonylphenol, benzidine, formaldehyde, (heavy) metals
Leather	50 yrs	mineral salts, formaldehyde, coal-tar derivatives, and various oils, dyes, and finishes, some of them cyanide-based.
Sanitary pads and tampons	25 yrs	volatile organic compounds and phthalates

Black soldier fly processing

The Black Soldier Fly (BSF) is a novel approach to deal with the biowaste by insect larvae (*Hermetia illucens*). In principle, the BSF larvae have been used in the potential bio-waste conversion process by simulation of mid gut digestion to obtain high value-added products ([Rindhe et al., 2019](#)). Waste treated larvae contain $\pm 35\%$ protein and $\pm 30\%$ crude fat that could be used as an effective alternative as fishmeal as well as it can be used for fish and chicken farmers. Another important aspect of BSF larva is that it reduces the bacterial load of *Salmonella spp* for up to 80% and thereby reducing the risk of disease transmission ([Rindhe et al., 2019](#)). It is a cost-effective method which requires only lower budget

but effective in reducing the waste level up to 80% which helps to minimize the usage of landfilling and open dumping process. High frequency of nutrients, organic matters were carried by residues of the larvae and could be used for farming while reducing the soil depletion too. In an economic perspective, the production of biomass from high waste is about 25%. The BSF treatment system has 5 processing facility such as 1. BSF rearing unit (it has two separate units one is for breeding maintenance colonies in captivity and the second one is about larvae growth), 2. Waste receiving and pre-processing unit (collected wastes processed mechanically), 3. BSF waste treatment unit (Rearing process), 4. Product harvesting unit (end life cycle of the product), 5. post-treatment unit (larvae refining and residue processing). The refined larvae feed can be used as an animal feed such as fish and chicken while processed residue can be sold to the market.

Anaerobic digestion technologies

The chemical breakdown of a substance (fermentation) under the condition of lack of oxygen (anaerobic) is called anaerobic digestion that process carried out by anaerobic microbes. Generally, the process was used for the energy production from the domestic and industrial waste. The anaerobic digestion process is 100% renewable and their energy consumption for the process have been taken from the solar power system ([Energy, 2019](#)). The process of anaerobic digestion has three stages such as hydrolysis, acidification and methanogenesis ([Sikora et al., 2017](#)). The efficacy of the process depends on the level of enzymatic reactions of microbial activities in the fermentation process. The enzymes are considered as a key to the anaerobic digestion process as well as the electron transfer reactions and has an equal contribution in the production and recovering of carbon as energy (biogas) like methane ([Ferdes et al., 2020](#)). The waste materials will be transformed into methane and carbon dioxide in anaerobic digestion and it can be enhanced by special pathways ([Li et al., 2019](#)). General steps of anaerobic digestion include hydrolysis, fermentation, acetogenesis, and methanogenesis ([Sangeetha et al., 2020](#); [Wang et al., 2018](#)

Anaerobic fixed dome digester

Anaerobic digestion is the production of biogas (a mixture of methane (CH_4), carbon dioxide (CO_2), hydrogen (H_2), nitrogen (N_2), and hydrogen sulphide (H_2S) and bio solids using anaerobic microorganism ([Beychok, 1967](#); [Nasir et al., 2012](#)). According to the report of Environment and Infrastructure GTZ for the future worldwide have discuss the steps and process of anaerobic dome digester viz., the fixed dome plant is an immovable closed rigid circuit called compensation tank. Initially, the waste materials can be filled in the mixing tank through the inlet pipe and sand trap. The self-agitation process was handled by biogas pressure in a sudden blast that helps in mixing the reactor content. The slurry will be relocated to the compensation tank once the gas production begins. Generally, the plant is located in the underground so that it is not influenced by physical damage as well as space occupy. Similar circumstances have influenced the anaerobic bacteriological processes. The gasholder which is present in the upper region of the digester was adjusted to collect the reserve gas using the gas pipeline. The accumulated thick sludge can be allowed to exit by an outlet pipe. The gas storage of fixed dome is about 20 m^3 , gas pressure is 60–120 mbar, and time durability of unit is less than 20 yrs whenever the methane emission is high. The defined biogas engineers can only construct the plants but the manpower cost is affordable. The material demand is always there for processing and this system provides a high yield of biogas like methane, carbon dioxide and nitrogen ([Biogas, 2021](#)). Uche AM et al. have reported that 56.4% of methane gas, 35% of CO_2 and 6.9% of nitrogen was produced from cow dung and water hyacinth while the biogas has fixed in their staff canteen ([Uche et al., 2020](#)).

Biogas formation

Biogas production is one of the best method to generate energy from organic waste materials such as food scraps and animal waste under the anaerobic condition ([Schwarz. 2007](#)). Generally, the decomposition process has found to be provoked under the anaerobic condition. The fossil fuel energy demand and the frequent release of greenhouse gas levels are the major issues of the environment which has to be sorted out ([Cherubini et al., 2008](#)). The biogas formation has to cross four stages to reach the yield with the same theme of anaerobic digestion but with variations in the versions and plants. The insoluble organic polymers were breakdown in the process of hydrolysis which aids the acidogenesis step (conversion of sugars and amino acids into hydrogen, ammonia and carbon dioxide).).

Slow paralysis

Solar plants, filters, electric car batteries, DNA sequencing and drug delivery) and industrial processing and proceedings. The slow heating pyrolysis can be carried out in pyrolysis bioreactor either as batch type and/or fixed bed reactor and the parameters such as temperature, heating rate, size and amount of the input material can be varied for better optimization ([Vieira et al., 2020](#)). An effective bioenergy production has been obtained from pyrolysis of Ugandan biomass wastes. The biomass has been prepared from matooke peels and it was processed for the electricity and bioethanol production. Importantly, the results of biomass analyses have revealed the presence of high amount of cellulose and Zinc ([Yusuf and Inambao, 2020](#)). The cellulose, hemicellulose and lignin was eliminated from matooke peels during the process of pyrolysis. The obtained bio mass contains more amount of volatile matter which in turn confirms the progress of carbonization which helps in combustion process.

Collection, segregation and various treatments of municipal solid waste

In recent times, many advanced technologies were upgraded for the collection of waste materials. Smart waste bins and trash cans have been used for the collection of waste materials The Indian city Vellore has chosen for the discussion of possible collection methods for solid waste management in India. He also suggested that the Geographic Information System (GIS) will be one of the best method for the collection of wastes, estimation of vegetation land cover and transport optimization of waste materials

Controlled disposal and resource management

Nowadays, landfill is the popularly used method of waste disposal. However, the inappropriate disposal of construction and demolition waste was recognized as a major problem around the world. But direct disposal can cause serious environmental effects and other issues. Still, scientific waste disposal processes can slightly reduce the problems and provide the waste as resource and it further leads to economic and environmental benefits ([Domínguez et al., 2016](#)). Government policies and laws remain significant drivers for the all types of controlled disposal of waste.

Government policy and act

Several countries around the world have their own policies and acts to promote a safer environment and health through effective, efficient and responsible waste management practices. Mainly the policies will be formulated to increase the less waste generation, full resource recovery, clean environment and

carbon-neutral waste sector. A global agreement (The Basel Convention is an International Environmental Agreement (IEA) regulating movements was made in 1992 to handle the hazardous wastes, including WEEE. This agreement prohibiting the export of hazardous waste from OECD to non-OECD countries, is still to come in force. European Union's made legislation on Waste from Electrical and Electronic Equipment (WEEE) and it came into action in August of 2004, and that makes it mandatory on manufacturers and importers in EU states to take back their E-products from consumers and ensure environmentally sound disposal. Similarly, India has its own law and regulation including environmental policy and it is formulated newer environmental laws that is E-waste 2016. Union Ministry of Environment, Forests and Climate Change (MoEF & CC) has introduced the new Solid Waste Management Rules (SWM), 2016 and these management rules are applicable for plastic, e-waste, biomedical, hazardous and construction and demolition waste to emphasize promotion of waste to energy plants.

THE WASTE MANAGEMENT HIERARCHY



Triangular diagram of Waste Management Hierarchy. The order of preference for waste reduction and effective management are illustrated in the upward triangular diagram. Extended Producer Responsibility is an enforced plan of environmental protection strategy which increases the responsibility of the manufacturer for the entire use of the product, recycling and final disposal of the product. The e-product producer's responsibility is protracted to the post-consumer stage of a product. Another strategic plan is that the consumers should pay the increasing tax while purchasing the electronic device which cover the future cost of recycling. Tax credits are distributed to consumers who bring their electronic waste to be recycled and to agencies that collect electronic waste for recycling. This option is probably encouraged in the e-waste recycling market and may reduce the e-waste accumulation. Consumers need to pay a fee on purchase of an electronic device, in which the certain percentage of money is reimbursed when they

return the product to a certified recycler. This option provides end-of-life incentives for consumers to recycle their electronics. Consistent improvising the policies and increased social awareness may create the better environment by managing the waste.

Waste management—countries investment

One of the biggest burdens of all countries in the world is to produce the perfect waste management system to control the solid waste. Generally, the management system was categorized into incineration, recycling, open dump, sanitary landfill, composting, control landfill and unspecified landfill. Many countries are investing a percentage of money for waste management. The method of management system may be varied depending on the country's waste resources.

Industrial waste and environment

Manufacturing waste, chemical waste, mining waste, oil & gas waste, nuclear waste, power plant waste, and other wastes from different industries are considered as industrial wastes. Appropriate industrial waste management system is implemented to achieve considerable economic as well as environmental benefits ([Moo-Young, 2019](#)). The COVID-19 has negatively influenced in industrial waste because the 40% of medical waste was increased due to the usage of medical products during COVID-19. On the other hand, manufacturing activity of many industries has fallen drastically due to COVID-19 scenario that highly reduce the waste production. Whereas, from the pharmaceutical and medical sectors were producing hazardous wastages in higher production. Importantly, existing hazardous waste treatment capacity was overwhelmed in developing countries due to this pandemic. The municipal waste volumes are enormously increased and effectually overwhelming the existing waste collection and disposal systems.

Domestic waste

The widespread lockdown forces individuals to stay in home which substantially increases the domestic waste generation ([Rupani et al., 2020](#)). The generation of large amounts of domestic waste requires collection and recycling, but due to manpower shortages it was compromised in many countries. In UK Interrupted services have led to waste mismanagement increases of 300% in some rural communities. In recent days the urban areas are facing environmental prospects owing to migration and depletion of natural resources as 80–90% of municipal waste is disposed in land filled without proper management with open fire. In term of Municipal Solid Waste Management (MSWM) the challenges in the form of exponential population growth, high density of urban regions, various culture, moving food habits, and recent routines of life style problems are encountered.

Waste Management is one of the most important sanitary wall to prevent the spread of illnesses and diseases. Continuity of the waste services for municipal waste, hazardous industrial and healthcare waste and is probably carried out by the sanitary workers. So, it is must to ensure the health and safety precautions of waste workers by guiding them to frequently change and to clean with professional clothing, replacing professional gloves instantly following breakage or any incident of potential contamination, sanitizing vehicle cabins, regular facilities and other handling equipment's etc.

Future perspectives

Integrated Solid Waste Management System hierarchy mostly prefers at source reduction and reuse, recycling, composting, waste to energy conversion and least preference has been given to land filling. The policies should also ensure the following hierarchy—avoid, reuse, recycle, recover and dispose. For waste treatment, characterization of waste and choosing the appropriate techniques is more important example -3Rs strategy and awareness creation will help to reduce the plastic waste Worldwide. India has launched 2016 SWM Rules that address an important number of concerns, compliance remains weak but India has conducted more campaigns like Source Segregation Campaign (part of Swachh Bharat Mission) to motivate people to segregate their waste and it has been successfully achieved in most sections of waste management like waste generation

Conclusion

Solid waste is continuously increasing due to increasing population, urbanization and would be a biggest challenge due to its direct impact on public health and environment. In present scenario, waste collection, treatment and disposal procedures are to be upgraded for efficient management of solid waste. Lack of waste disposal facilities and unmanaged collection coverage are the major problems faced in developing countries which causes impact on environmental contamination. To ameliorate the numbers of trainees and proper awareness for the workers are an inevitable step to achieve the successful waste collection process. In training the front-line workers should be actively involved in assigned work with commitments which can be inherited through proper caring the workers by adopting labor welfares, hazard pay, sick leave, insurance, providing additional equipment's. Vehicle drivers should be trained in such a way to avoid accidents, obeying speed limit and gentle handling of brakes will increase fuel efficiency economically by 15–30% in highways (US department of Energy—Conserve Fuel), safe as well as speed up in the collection process. Proper communication and understanding between the driver and waste collector is essential to reduce delays as well as recent contexts like choosing the motorized or non-motorized vehicle will help to monitor waste collection. Choosing the right motorized or non-motorized vehicle based on street width aid to cover the inaccessible area. GPS enabled vehicle, Weigh Bridge, electronic on-board recorders, street camera, staff training, communication through technology are some of the recent advancements that can help to monitor waste collection process. The demand for landfilling space for handling solid waste disposal is also an essential factor in solid waste management system and that has to be focused worldwide. More importantly, collective reports explore some of the points which are very essential for solid waste management systems such as, the maximum quantity of waste (450–500 million tons) generated is reported from East Asia and Pacific regions..

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