Solid, Liquid and Hazardous Waste Management

Chandan Kumar

KHANNA PUBLISHERS®

Investing in Learning®

SOLID, LIQUID AND HAZARDOUS WASTE MANAGEMENT

Chandan Kumar

KHANNA PUBLISHERS®
Investing in Learning®
Operational Office
4575/15, Onkar House, Ground Floor,
Opp. Happy School, Daryaganj, New Delhi-110002
Phones : 011-45033819 • *Mob*. 09811541460, 09650669626
email : contactus@khannapublishers.in

Published by :

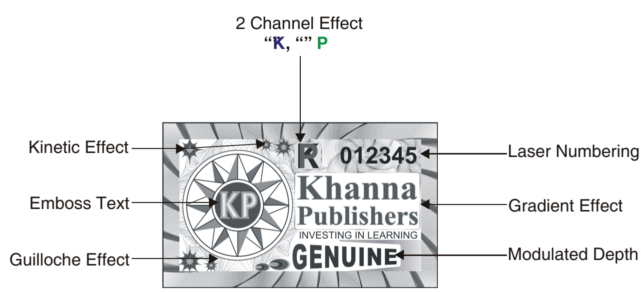
Romesh Chander Khanna & Vineet Khanna
for KHANNA PUBLISHERS
2-B, Nath Market, Nai Sarak
Delhi-110 006 (India)

Website : www.khannapublishers.in

Hologram & Description

To all readers of our books, to prevent yourself from being defrauded by piraters, please make sure that there is an Hologram on the cover of our books with the below specifications. If you find any book without Hologram and Description, please mail us at **contactus@khannapublishers.in**

Thanking you



ISBN No.: 978-93-92549-34-2

***First Edition:* 2025**

Preface

The growing concern for environmental sustainability and public health has made waste management one of the most pressing challenges of our time. With rapid urbanization, industrialization, and population growth, the generation of solid, liquid, and hazardous wastes has increased significantly, posing threats not only to ecosystems but also to human well-being. Addressing these challenges requires a comprehensive understanding of scientific principles, engineering practices, legal frameworks, and sustainable technologies.

This book, Solid, Liquid and Hazardous Waste Management, is an attempt to provide students, researchers, and professionals with a systematic and holistic approach to the subject. It covers the fundamental concepts, classification, collection, storage, treatment, and disposal methods for different types of waste, while also highlighting modern techniques such as recycling, resource recovery, and waste-to-energy. Special emphasis has been placed on the Indian scenario, contemporary regulatory frameworks, and recent amendments to waste management rules, ensuring that the content remains both relevant and practical.

The first edition has been carefully structured to meet the academic requirements of undergraduate and postgraduate courses in environmental engineering, civil engineering, architecture, urban planning, and allied disciplines. At the same time, it is designed to serve as a useful reference for practitioners, policymakers, and researchers working in the field of waste management.

This book is the result of continuous learning, research, and interaction with students and experts. I express my gratitude to my teachers, colleagues, and peers whose encouragement and insights have enriched this work. I am also thankful to my students, whose curiosity and questions inspired me to present the subject in a clear and comprehensive manner.

It is my hope that this book will contribute in some measure to spreading awareness, promoting sustainable practices, and guiding readers towards innovative solutions in waste management. Constructive feedback and suggestions for improvement from readers are most welcome and will be invaluable for future editions.

—Chandan Kumar

Acknowledgements

The completion of this book has been made possible through the encouragement, guidance, and support of several individuals and institutions to whom I express my sincere gratitude.

First and foremost, I bow in reverence to Thakur Ji Maharaj, whose divine blessings have been the guiding light in every step of my academic and personal journey. I also wish to acknowledge the invaluable inspiration and guidance of my teachers and mentors, specially Krishna Murari sir whose insights into environmental engineering and waste management have shaped my understanding of the subject and motivated me to undertake this work. Their scholarly influence has been instrumental in the preparation of this volume.

I am deeply grateful to my colleagues and peers in academia and industry for their constructive suggestions and discussions, which enriched the scope and depth of the book. Special thanks are due to students whose curiosity, enthusiasm, and questions have constantly challenged me to refine the presentation of concepts and examples.

I also acknowledge with gratitude the contributions of various government agencies, professional bodies, and regulatory authorities, whose published reports, guidelines, and rulebooks provided authoritative reference material, particularly in the Indian context.

To my family, I owe my deepest appreciation to my beloved Brothers and Sisters for their constant encouragement, patience, and unwavering support during the preparation of this manuscript. I express my heartfelt gratitude to my parents, whose blessings and values have been a guiding force throughout my academic journey. I am profoundly thankful to my wife Priti, for her patience, encouragement, and constant support during the preparation of this manuscript. Above all, I dedicate this effort to my beloved sons, Shivansh and Suryansh, whose presence has been a source of joy, motivation, and strength.

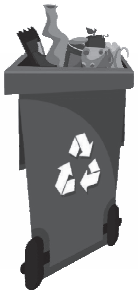
Finally, I express my thanks to the publishers for their professional assistance in bringing this first edition to print.

While every effort has been made to ensure accuracy and completeness, I welcome constructive feedback and suggestions from readers to further improve the quality of future editions.

—Chandan Kumar

Contents

SECTION 1



CHAPTER

1

Introduction to Solid Waste Management

1.1. INTRODUCTION

Solid wastes are being produced since the beginning of civilization. During the early period, solid wastes were conveniently and unobtrusively disposed of as the density of population was low with large open land space.

With the advent of industrialization and urbanization, the problems of waste disposal have increased. High population density, intensive land use for residential, commercial and industrial activities have led to adverse impact on the environment. Gaseous and liquid discharges from solid waste impact the environment very badly. Hence solid waste management is needed.

1.1.1. Classification of the Solid Waste Generated in Society

Because of the heterogeneous nature of solid waste, no single method of classification is entirely satisfactory. In some cases it is important for the solid waste specialist to know the source of waste, so that the classification as domestic, institutional, commercial, street waste, industrial waste, construction and demolition waste etc. is useful.

For other situations, the type of waste-garbage, rubbish, ash, hazardous waste, etc. which gives a better indication of its physical and chemical characteristics is more useful.

The three types—garbage, rubbish, and ashes, form the bulk of municipal waste and originate from households, institutions and commercial areas.

The classification of waste is as follows:

1. **Domestic/Residential Waste:** This category of waste comprises the solid wastes that originate from households. These wastes are generated as a consequence of household activities such as cooking, cleaning, repairs, hobbies, and redecoration and contain empty containers packaging, clothing, book, writing paper, and furnishings.
2. **Commercial Waste:** Included in this category are solid wastes that originate from offices, wholesale and retail stores, restaurants, hotels, markets, warehouses, and other commercial establishments.
3. **Institutional Waste:** Institutional wastes are those arising from institutions such as schools, universities, hospitals, and research institutes.
4. **Municipal Waste:** Municipal wastes include wastes resulting from municipal activities and services such as street waste, commercial waste, and market waste. However, the term is commonly applied in a wider sense to incorporate domestic, institutional and commercial wastes as well.
5. **Street Waste:** The term applies to the waste that is collected from streets, walkways, alleys, and vacant areas. Street waste includes paper, cardboard, plastic, dirt leaves and other vegetable matter discarded by the road users.
6. **Agricultural:** This mainly consist of spoiled food grains and vegetables, agricultural remains, litters etc., generated from field, orchards, vineyards, farms, etc.
7. **Industrial waste:** Included in this category is the discarded solid material of manufacturing processes and industrial operations. However, solid wastes from small industrial units and ash from power plants are frequently disposed of at municipal landfill sites.

8. **Sewage Waste:** The solid by products of sewage treatment are classified as sewage waste. They are mostly organic and derive from the treatment of organic sludge's from both the raw and treated sewage.
9. **Hazardous Wastes:** Hazardous waste may be defined as a waste of industrial, institutional or consumer origin which, because of its physical-chemical or biological characteristics is potentially dangerous to humans and the environment.

1.2. MEANING OF DIFFERENT SOLID WASTE

1.2.1. Domestic Waste

Domestic waste also known as "municipal solid waste", is the waste that is generated as a result of the ordinary day-to-day activities at homes and is:

1. Either taken from the homes by or on behalf of the person who generated the waste; or
2. Collected by or on behalf of a local government/bodies as part of a waste collection and disposal system.

1.2.2. Commercial Waste

Commercial waste can be defined as 'any waste generated as a result of carrying out a business or commercial activity, including associated lawn and garden trimmings (cut grass, leaves etc.) from normal maintenance of the business premises'. Commercial waste also includes rubbish produced by the customers *i.e.*, food wrappers and containers.

1.2.3. Industrial Waste

Industrial waste is the waste produced by industrial activity which includes any material that becomes useless during a manufacturing process such as that of factories, mills and mines. Also industrial solid waste means solid waste generated by manufacturing or industrial processes and it normally does not include the hazardous waste as it is a separate category of solid waste.

1.2.4. Market Waste

Market waste is that waste which is generated out of marketing activities. It is primarily organic waste, such as leaves, skins and unsold food, discarded at or near food markets.

1.2.5. Agricultural Waste

Agricultural waste, which includes both natural (organic) and non-natural wastes, is a general term used to describe waste produced on a farm by various farming activities. These activities may include dairy farming, horticulture, seed growing, livestock breeding, grazing land, market gardens, nursery plots and woodlands.

1.2.6. Biomedical Waste

Biomedical waste is that waste which is of medical or medical laboratory origin packaging, unused bandages, infusion kits etc.), as well research laboratory waste containing biomolecules or organisms that are restricted to be released to environment.

Discarded needles are also considered as biomedical waste whether they are contaminated or not, due to the possibility of being contaminated with blood and their ability to cause injury when not properly enclosed and disposed off.

1.2.7. E-waste

E-waste is that waste which consists of discarded electrical or electronic devices. All electronic scrap components, such as CRTs, may contain contaminants such as lead, cadmium, beryllium, or brominated flame retardants.

Even in developed countries recycling and disposal of e-waste may involve significant risk to workers and communities and great care must be taken to avoid unsafe exposure in recycling operations and leaking of materials such as heavy metals from landfills and incinerator ashes.

1.2.8. Hazardous Waste

Hazardous waste is the waste that can have substantial or potential threats to public health or the environment. These wastes are either flammable (or ignitable), reactive, corrosive or toxic or combination of these. For example, dry cleaners, automobile repair shops, hospitals slaughterers, and photo processing centers may all generate hazardous waste.

Some hazardous waste generators are larger companies such as chemical manufacturers, electroplating companies and oil refineries.

1.2.9. Institutional Waste

Waste generated at institutions such as schools, libraries, hospitals, prisons etc. is known as *institutional waste*. It may include metal and glass pieces, plastic, yard waste, food waste, corrugated containers, paper and card board waste.

1.2.10. Construction and Demolition Wastes

Construction and demolition wastes are the waste materials generated by the construction, refurbishment, repair and demolition of houses, commercial buildings and other structures. It mainly consists of earth, stones, concrete, bricks, lumber, roofing materials, plumbing materials, heating systems and electrical wires, and parts of the general municipal waste stream. But when generated in large amounts at building and demolition sites, it is generally removed by contractors for filling low lying areas and by urban local bodies for disposal at landfills.

1.2.11. Sewage Wastes

The solid by-products of sewage treatment are classified as sewage wastes. They are mostly organic and derive from the treatment of organic sludge from both the raw and treated sewage.

The inorganic fraction of raw sewage such as grit is separated at the preliminary stage of treatment, but because it contains putrescible organic matter which may have pathogens, must be buried/disposed off without delay. The bulk of treated, dewatered sludge is useful as a soil conditioner but its use for this purpose is uneconomical. The solid sludge therefore enters he stream of municipal wastes unless special arrangements are made for its disposal.

1.3. SOURCES OF SOLID WASTE

1.3.1. Various Sources of Solid Waste

Following are the sources of solid waste:

1. **Residential:** This includes wastes from residential houses like dwellings, apartments etc. and consist of leftover food, vegetables peels, plastic, clothes, ashes, etc.
2. **Commercial:** This refers to waste generated from restaurants, hotels, motels, stores, markets, auto repair shops, medical facilities, etc. and consist of leftover food, glasses, metals, ashes, etc.
3. **Institutional:** This includes waste coming from educational, administrative and public buildings like prisons etc. and consist of paper, plastic, glasses, etc.
4. **Municipal:** This mainly refers to waste from various municipal activities like construction and demolition, street cleaning, landscaping, etc. and consist of leaf matter, dust, building debris, waste water treatment plant, residual sludge, etc.
5. **Industrial:** This mainly consists of waste generated from various industrial activities and consist of process wastes, ashes, construction and demolition wastes, hazardous wastes etc.
6. **Agricultural:** This includes wastes coming from fields, orchards, vineyards, farms, etc. and consist of agricultural remains, spoiled vegetables and grains, litter, etc.
7. **Open Areas:** This mainly refers to waste from streets, alleys, parks, playgrounds, beaches, highways, recreational areas, etc.

1.3.2. Types of Solid Waste

1. Municipal waste
2. Hazardous waste
3. Bio-medical waste
4. Electronic waste
5. Industrial waste.

1.4. CLASSIFICATION OF SOLID WASTE

Solid waste can be classified based on its source as residential, agricultural, commercial industrial, institutional or healthcare waste. It can also be classified as hazardous or non-hazardous and also as biodegradable or non-biodegradable. Another word used in the context of biodegradable solid waste is putrescible, which means the waste which decomposes (rots down) quite quickly. Waste can also be classified as combustible or non-combustible depending on whether it will burn or not.

Table 1.1. Classification of Solid Waste

Main Classification	*Type*	*Short Description*	*Examples*
Hazardous	Solid or semi-solid	Substances that are either ignitable, corrosive, reactive, infectious or toxic.	Some obsolete pesticides such as DDT, dieldrin, etc.
Non-hazardous waste	Putrescible	Easily decomposable/biodegradable solid waste.	Food waste
	Non putrescible	Non-biodegradable solid waste. It includes combustible and non-combustible waste.	Plastic bags, bottled water containers, tin cans, etc.

1.4.1. Hazardous Waste

It can be solid or semisolid and is either ignitable, corrosive, reactive, infectious or toxic or a combination of these. Examples include pesticides such as DDT, dieldrin etc.

1.4.1.1. *Characteristics of Hazardous Waste*

1. **Ignitability:** Ignitable wastes create fires under certain conditions or are spontaneously combustible, or have a flash point less than 600 (140°F).
2. **Corrosivity:** Corrosive wastes are acids or bases (pH less than or equal to 2 or greater than or equal to 12.5) that are capable of corroding metal containers, such as storage tanks, drums and barrels.
3. **Reactivity:** Reactive wastes are unstable under "normal" conditions. They can cause explosions, toxic fumes, gases, or vapours when mixed with water.
4. **Toxicity:** Toxic wastes are harmful or fatal when ingested or absorbed (*e.g.*, containing mercury, lead etc.). When toxic wastes are disposed off on land, contaminated liquid may drain (leach) from the waste and pollute ground water. Toxicity is defined through a laboratory procedure called the *Toxicity Characteristic Leaching Procedure*.

1.4.2. Non-hazardous Waste

Non-hazardous waste is that waste which is not substantial or potential threat to public health or the environment. It can further be classified as follows:

1. **Putrescible:** It is that waste which is easily decomposable/biodegradable solid waste. For example, Food waste.
2. **Non-putrescible:** It is that waste which is non-biodegradable solid waste, it includes combustible and non-combustible waste. For example, Plastic bags, bottled water containers, tin cans, etc.

Table 1.2. Difference between Hazardous and Non-hazardous Solid Waste

Sr. No.	*Hazardous waste*	*Non-hazardous*
1.	Waste which is either ignitable, corrosive, reactive, infectious or toxic or combination of these is called as hazardous waste.	Waste which is not potential threat to public health and environment is called as non-hazardous waste.
2.	Requires special management considerations, because the treatment method for one of the hazards may be inappropriate for the treatment of another.	Simple treatment and disposal methods. Can be used for all types of non-hazardous waste like landfilling.
3.	Cost of treatment and disposal of waste is more.	Treatment and disposal cost is less.
4.	Examples: Industrial waste, E-Waste, biomedical waste.	Examples: Food waste, plastic bags, tin cans etc.

Table 1.3. Hazardous and Non-hazardous Substances, their Origin and Health Effects

Hazardous Substances	*Origin*	*Health effects*
Lead	Solder in PCS (Printed Circuit Board).	Damage to nervous system, kidney, brain development of children.
Mercury	Tubes, PCS, thermostats.	Chronic damage to brain, skin disorder, memory loss, muscle weakness.
Cadmium	Chip resistor and semiconductor.	Kidney and lever damage, neural damage
Hexavalent chromium	Corrosion protection of steel plates.	Asthamatic bronchitis, DNA damage.
Barium	Front panel of CRT.	Muscle weakness, damage to heart/level/spleen.

Hazardous Substances	*Origin*	*Health effects*
Beryllium	Motherboard.	Carcinogenic, skin disease, beryllicosis.
Plastic	Cabling/Computer housing.	Immune system damages, hormone interference.
Substances	Origin	Health effects
Non-hazardous Substances:		
Tin	Obtained from the mineral cassiterite.	Tin dust can irritate the skin and delicate tissue.
Copper	Ore of cuprite	Long-term exposure to copper can cause irritation of the nose, mouth and eyes and it causes headaches, stomachaches, dizziness, vomiting and diarrhea.

Aluminium, Iron, Germanium, Silicon, Nickel, Lithium, Zinc, Gold are some more non-hazardous substances.

Table 1.4. Classification of Solid Waste with Examples

Type	*Examples*
Food waste (Garbage)	Waste from preparation, cooking and serving of food market refuse, waste from handling, storage and sale of meat and vegetables.
Rubbish	Combustible (primarily organic) paper, cardboards, cartons, wood boxes, plastics, rags, clothes, beddings, leather, rubber, grass, leaves, yard trimmings. Non-combustible (primarily inorganic) metals, tin cans, metal foils, dirt, stones, bricks, ceramics, crockery, glass bottles, other mineral refuse.
Ashes and residues	Residues from fires used for cooking and for heating buildings, cinders, clinkers, thermal power plants.
Bulky waste	Large auto parts, tyres, stoves, refrigerators, other large appliances, furniture, large crates, branches of trees, etc.
Street waste	Street sweepings, dirt, leaves, catch basin dirt, animal droppings, content of litter, receptacles, dead animals.
	Dead animals: Small animals: cats, dogs, poultry, etc. Large animals: Horses, cows, etc.
Construction and demolition waste	Plumber, roofing and sheathing scrap, rubble, broken concrete, plaster, conduit pipes, insulating wires, etc.
Industrial waste and sludges	Solid wastes resulting from industry processes and manufacturing operations, such as food processing wastes, boiler house cinders, wood, plastic and metal scraps and shavings etc., sludge of sewage treatment plants and septic tanks, coarse screenings, grit, etc.
Hazardous waste	Pathological waste explosives radioactive material toxic waste etc.
Horticulture waste	Tree trimmings, leaves, waste from parks and gardens etc.

1.5. PHYSICAL AND CHEMICAL CHARACTERISTICS OF MUNICIPAL SOLID WASTE

National Environmental Engineering Research Institute (NEERI) has carried out extensive studies on Physical and Chemical characteristics of solid waste from 43 cities during 1970–94.

1.5.1. Physical Characteristics

Density, moisture content, size of waste constituents, specific weight or weight of waste per unit volume, particle size and distribution, field capacity/percentage of moisture in wet solid and calorific value are the main physical characteristics of solid waste.

1. **Density:** 50–290 kg/m^3. Knowledge of the density of waste *i.e.*, mass per unit volume is essential for the design of all elements of the solid waste management system.
2. **Moisture Content:** 05–60%. Moisture content is a critical determinant in the economic feasibility of waste treatment by incineration, since energy must be supplied for evaporation of water and in raising the temperature of the water vapour.
3. **Size Distribution:** 1–50 cm. The measurement of the size distribution of particles in the waste stream is important because of its significance in the design of mechanical separators and shredders.

4. **Field Capacity:** Field capacity is defined as 'total amount of moisture held in a waste matter under gravity'. It is important as it controls the rate of leachate generation and permeability.
5. **Permeability of Compacted Waste:** The hydraulic conductivity of compacted waste is an important physical property to a large extent which governs movement of liquid and gases in landfill.
6. **Porosity:** It represents the amount of voids per unit overall volume of material.
   - The calorific value ranges between 800–1000 kcal/kg.
   - The paper content generally varies between 2.9–6.5 and increases with the increase in population.
   - The plastics, rubber and leather contents are lower than the paper content, and do not exceed 1 except in metropolitan cities.
   - The metal content is also low, *viz.* less than 1. The low values are essentially due to the large scale recycling of these constituents. The paper is recycled on a priority basis while the plastics and glass are recycled to a lesser extent.
   - The biodegradable fraction is quite high, essentially due to the habit of using fresh vegetables in India. The high biodegradable fraction also makes it necessary for frequent collection and removal of solid waste from the collection points.
   - The ash and fine earth content of Indian municipal solid waste is high due to the practice of inclusion of the street sweepings, drain silt, and construction and demolition debris in municipal solid waste. The proportion of ash and fine earth reduces with increase in population due to improvements in the road surfaces.
   - High ash and earth content increases the densities of municipal solid waste which are between 350 and 550 kg/m^3 in Indian cities.

1.5.2. Chemical Characteristics

- A knowledge of chemical characteristics of waste is essential in determining the ability of any treatment process. Chemical characteristics include (1) Chemical; (2) Bio-chemical; and (3) Toxic.
- Chemical characteristics include pH, nitrogen, phosphorus and potassium (N-P-K), total carbon, C/N ratio, calorific value.
- The chemical characteristics indicate that the organic content of the samples on a dry weight basis ranges between 20–40%.
- The nitrogen, phosphorus and potassium content of the municipal solid waste ranges between 0.5–0.7%, 0.5–0.8% respectively.
- Knowledge of the chemical characteristics is essential in selecting and designing the waste processing and disposal facilities.
- Ragpickers are observed to be more active in bigger cities. They prefer to remove paper, plastics, rags and packaging and such other material, which is light and also have a high calorific value.
- The remaining waste hence tends to have a higher inert content and a lower calorific value. The demolition activity is observed to increase with population leading to increased inert content and reduced organic content in MSW.
- Bio-chemical characteristics include carbohydrates, proteins, natural fibre and biodegradable factor.
- Toxicity characteristics include heavy metals, pesticides, insecticides, Toxicity test for leachate (TCLP) etc.

1.5.3. Some Characteristics of Solid Waste

1. **pH:** The pH of fresh solid waste is normally around 7. During decomposition, it tends to become acidic, and stabilized solid waste has an alkaline pH.
2. **Organic Content:** The knowledge of organic content helps to assess the feasibility of biological processing - composting and anaerobic digestion.
3. **Carbon Content:** The carbon is determined by using the New Zealand formula in which the percent organic matter is divided by 1.724.
4. **Nitrogen Content:** Nitrogen, phosphorus and potash values are important in composting.
5. **Toxicity:** Toxicity characteristics include heavy metals, pesticides, insecticides etc.

1.5.4. Proximate Analysis of Solid Waste

- Determination of fixed carbon, volatile combustible matter, moisture and ash content of the waste in order to estimate its capability as a fuel is called proximate analysis of solid waste.
- The fixed carbon, volatile combustible matter can be burnt while moisture and ash not. The vapourization of the moisture consumes heat.

1.5.5. Method of Analysis (Tests)

1. **Moisture:** Determination from the loss of weight by heating at 105°C for one hour.
2. **Volatile combustible matter:** The additional loss of weight after ignition at 950°C in a covered crucible.
3. **Fixed carbon:** Combustible residue after the volatile combustible matter is removed; ignition at 600–900°C.
4. **Ash:** The weight of residue after combustion in an open crucible.

   Percentage fixed carbon = 100% – % moisture – % ash – % volatile matter. It does not provide any information of possible pollutants emitted during combustion. These data are determined by ultimate analysis.

1.5.6. SWM System

A SWM system refers to a combination of various functional elements associated with the management of solid wastes. The system facilitates the collection and disposal of solid wastes in the community at minimal costs, while preserving public health and ensuring little or minimal adverse impact on the environment. The functional elements that constitute the system are:

1. **Waste Generation:** Wastes are generated at the start of any process, and thereafter, at every stage as raw materials are converted into goods for consumption. The source of waste generation determines quantity, composition and waste characteristics. For example, wastes are generated from households, commercial areas, industries, institutions, street cleaning and other municipal services. The most important aspect of this part of the SWM system is the identification of waste.
2. **Waste Wtorage:** Storage is a key functional element because collection of wastes never takes place at the source or at the time of their generation. The heterogeneous wastes generated in residential areas must be removed within eight days due to shortage of space and presence of biodegradable material. Onsite storage is of primary importance due to aesthetic consideration, public health and economics involved. Some of the options for storage are plastic containers, conventional dustbins (of households), used oil drums, large storage bins (for institutions and commercial areas), etc. Obviously, these very greatly in size, form and material.
3. **Waste Collection:** This includes gathering of wastes and hauling them to the location, where the collection vehicle is emptied, which may be a transfer station *i.e.*, intermediate station where wastes from smaller vehicles are transferred to larger ones and also segregated), a processing plant or a disposal site. Collection depends on the number of containers, frequency of collection, types of collection services and routes. Typically, collection is provided under various management arrangements, ranging from municipal services to franchised services, and under various forms of contracts.

   Note that the solution to the problem of hauling is complicated. For instance, vehicles used for long distance hauling may not be suitable on particularly economic for house-to-house collection. Every SWM system, therefore, requires an individual solution to its waste collection problem.
4. **Transfer and Transport:** This functional element invoices:
   - The transfer of wastes from smaller collection vehicles, where necessary to overcome the problem of narrow access lanes, to larger ones at transfer stations;
   - The subsequent transport of the wastes, usually over long distances, to disposal sites.

   The factors that contribute to the designing of a transfer station include the type of transfer operation, capacity, equipment, accessories and environmental requirements.
5. **Processing:** Processing is required to later the physical and chemical characteristics of wastes for energy and resource recovery and recycling. The important processing techniques include compaction, thermal volume reduction, manual separation of waste components, incineration and composition.
6. **Recovery and Recycling:** This includes various techniques, equipment and facilities used to improve both the efficiency of disposal system and recovery of usable material and energy. Recovery involves the separation of valuable resources from the mixed solid wastes, delivered at transfer stations or processing plants. It also involves size reduction and density separation by air classifier, magnetic device for iron and screens for glass. The selection of any recovery process is a function of economics, *i.e.*, costs of separation versus the recovered-material produces. Certain recovered materials like glass, plastics, paper, etc., can be recycled as the have economic value.
7. **Waste Disposal:** Disposal is the ultimate fate of all solid wastes, by they residential wastes, semi-solid wastes from municipal and industrial treatment plants, incinerator residues, composts or other substances that have not further use to the society. Thus, land use planning becomes a primary determinant in the selection, design and operation of landfill operations. A modern sanitary landfill is a method of disposing solid waste without creating a nuisance and hazard to public health. Generally, engineering principles are followed to confine the wastes to the smallest possible area, reduce them to the lowest particle volume by compaction at the site and cover them after each day's operation to reduce exposure to vermin. One of the most important functional element of SWM, therefore, relates to the final use of the reclaimed land.

In Fig. 1.1, we show you a typical SWM system with its functional element and linkages.

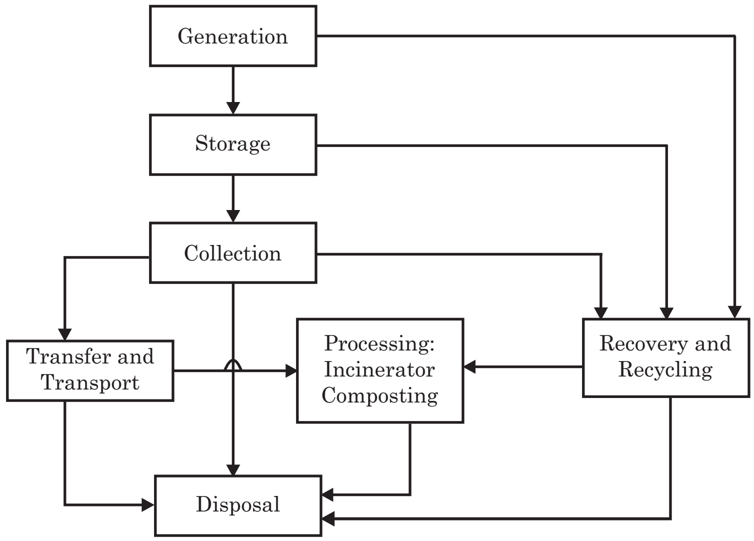


Fig. 1.1. Typical SWM System: Functional Elements.

1.5.7. Factors Affecting SWM System

Many factors influence the decision-making process in the implementation of a SWM system. Some of the factors that need to be considered in developing a SWM system are listed below:

1. **Quantities and Characteristics of Wastes:** The quantities of wastes generated generally depends on the income level of a family, as higher income category tends to generate larger quantity of wastes, compared to low-income category. The quantity range from about 0.25 to about 2.3 kg per person per day, indicating a strong correlation between waste production and per capita income. One of the measures of waste composition (and characteristics) is density which ranges from 150 kg/m^3 to 600 kg/m^3. Proportion of paper and packaging materials in the waste largely account for the differences. When this proportion is high, the density is low and vice versa. The wastes of high density reflect a relatively high proportion of organic matter and moisture and lower levels of recycling.
2. **Climate and Seasonal Variations:** There are regions in extreme north (> 70° N Latitude) and south (> 60° S Latitude), where temperatures are very low for much of the year. In cold climates, drifting snow and frozen ground interfere with landfill operations, and therefore, trenches must be dug in summer and cover materials stockpiled for winter use. Tropical climates, on the other hand, are subject to sharp seasonal variations from wet to dry season, which cause significant changes in the moisture content of solid waste, varying from less than 50% in dry season to greater than 65% in wet months. Collection and disposal of wastes in the wet months are often problematic.

   High temperatures and humidity cause solid wastes to decompose for more rapidly than they do in colder climates. The frequency of waste collection in high temperature and humid climates should, therefore, be higher than that in cold climates. In sub-tropical or desert climate, there is no significant variation in moisture content of wastes (due to low rainfall) and low production of leachate from sanitary landfill. High winds and wind blown sand and dust, however, cause special problems at land fill sites. While temperature inversions can cause airborne pollutants to be trapped near ground level, landfill sites can affect groundwater by altering the thermal properties of the soil.
3. **Physical Characteristics of an Urban Area:** In urban areas (*i.e.*, towns and cities), where the layout of streets and houses is such that access by vehicles is possible, door-to-door collection of solid wastes is the accepted norm either by large compaction vehicle or smaller vehicle. The picture is, however, quite different in the inner and older city areas where narrow lanes make service by vehicles difficult and often impossible. Added to this is the problem of urban sprawl in the outskirts (of the cities) where population is growing at an alarming rate. Access ways are narrow, unpaved and tortuous and therefore, not accessible to collection vehicles. Problems of solid waste storage and collection are most acute in such areas.
4. **Financial and Foreign Exchange Constraints:** Solid waste management accounts for sizable proportions of the budgets of municipal corporations. This is allocated for capital resources, which go towards the purchase of equipments, vehicles, fuel and labour costs. Typically, 10–40% of the revenues of municipalities are allocated to solid waste management. In regions where wage rates are low, the aim is to optimism, vehicle productivity.

The unfavourable financial situation of some countries hinders purchase of equipment and vehicles, and this situation is further worsened by the acute shortage of foreign exchange. This means that the balance between the degree of mechanisation and the size of the labour force becomes a critical issue in arriving at the most cost-effective solution.

5. **Cultural Constraints:** In some regions, long-standing traditions preclude the intrusion of waste collection on the precincts of households, and therefore, influence the collection system. In others, where the tradition of caste persists, recruits of the labour force for street cleaning and handling of waste must be drawn from certain sections of the population, while others will not consent to placing storage bins in their immediate vicinity. Social norms of a community more often than not over-ride what many may consider rational solutions. Waste management should, therefore, be sensitive to such local pasterns of living and consider these factors in planning, design and operation.
6. **Management and Technical Resources:** Solid waste management, to be successful, requires a wide spectrum of workforce in keeping with the demands of the system. The best system for a region is one which makes full use of indigenous crafts and professional skills and/or ensures that training programmers are in place to provide a self-sustaining supply of trained workforce.

1.6. INTEGRATED SOLID WASTES MANAGEMENT

The cardinal principle in wastes management is 3*R*'s *e.g.*, reduction, reuse and recycling. An integrated solid wastes management system is based on this principle. It requires a comprehensive approach for each stage of solid wastes management *e.g.*, generation, collection, processing and final disposal. Important components of such a system include the following:

1. Wastes Minimization at Source
2. Material Recovery and Recycling
3. Wastes Transformation
4. Volume Reduction before Disposal
5. Wastes Disposal
6. Database Management

1.6.1. Wastes Minimization

Wastes should be ideally minimized at the source of its generation. Reduction can be affected in many ways but the following techniques are commonly employed.

1. Minimizing the amount of the material used in the manufacture of a product
2. Increasing the useful life of the product
3. Reducing the amount of material used for packaging and marketing of consumer goods.

Material balance studies and environmental audits of industries can effectively help in devising strategies for reducing wastes generation.

Wastes reduction can also be achieved in household and commercial units through increased public awareness of improved buying pattern and through reuse of products. For example, the same carry bag can be used repetitively instead of taking a new bag for shopping every time.

1.6.2. Material Recovery and Recycling

Municipal solid wastes consist of various materials *e.g.*, paper, cardboard, plastics, metals, glass, rubber. Many of these components are suitable for recycling and reuse. The process involves separation and collection of these materials, preparation of materials for reuse and remanufacture. Significant amount of money can be earned through selling out of these recovered materials. It efficiently reduces the quantity of wastes and thus reduces the load on the disposal facilities which in turn reduces the cost of handling and disposal. For instance, fusing of glass particles to clay for making ceramic tile blocks and use of plastic bottles, videotapes, etc. for making polyester fiber for manufacturing of carpets and clothes are some of the viable options. Similarly producing aluminium or steel from recycled metals requires 95% less energy than that is required for production of these metals from ores.

1.6.3. Wastes Transformation

Wastes transformation is the physical, chemical or biological conversion of wastes for any beneficial purpose *e.g.*, energy recovery. A number of processes such as composting, anaerobic digestion, incineration, pyrolysis, gasification, and pelletization are employed for this purpose. Several byproducts of these processes in the form of manure, energy etc., can be recovered. Selection of a suitable technique depends upon the objective of waste transformation as well as on the composition of wastes.

1.6.4. Volume Reduction

Volume reduction of wastes is carried out before its final disposal. It includes size reduction through shredding, size separation through screening and volume reduction through compaction. Volume reduction of wastes also reduces the land area requirement for its landfill disposal.

1.6.5. Wastes Disposal

Wastes that can not be recycled or transformed need to be disposed off. Residues from various wastes transformation processes also need final disposal. Long term options of wastes disposal are: disposal on land, disposal deep below the earth surface and disposal at the ocean bottom.

Disposal on land is one of the oldest and most common methods. Disposal on scientifically designed engineered landfill sites is necessary to prevent groundwater contamination and for the protection of environment.

1.6.6. Database Management

Availability of precise and reliable data is of utmost importance in the planning and design of any environmental system. The data should not only be available in records but should be instantaneously accessible to the planners and engineers. The importance of easy accessibility can not be over emphasized. Many of the data are constantly changing and needs to be regularly updated.

Database management should be an integral part of the solid wastes management system. Precise, relevant and reliable data are necessary for selection of various treatment and disposal techniques. It also helps in developing indigenous technologies suitable for a particular type of waste composition. The database should include composition of wastes, physical, chemical and biological properties of wastes and information regarding, equipment, staff and facilities available for collection, transportation and disposal of wastes.

With the use of Remote Sensing, Geographic Information System (GIS) and IT paraphernalia now commercially available, it is now possible to collect all this data and make it accessible to the users instantaneously.

1.7. SOLID WASTE MANAGEMENT TECHNIQUES

Waste management techniques in accordance with the waste hierarchy include waste prevention/reduce at source, reuse, recycle, recovery and disposal of solid waste with prevention at source to be given first preference to the disposal being the last preferred alternative.

1.7.1. Solid Waste Management Hierarchy (4R of Solid Waste Management Hierarchy)

The main aim of waste hierarchy is to generate minimum amount of waste and obtain maximum benefits from products.

Following are the various stages in SWM hierarchy:

1.7.1.1. *Prevention*

Preventing the use of such raw material in production which produces maximum solid waste and selecting the alternative raw materials.

1.7.1.2. *Minimization*

If such alternative raw materials are less possible then minimize the use of raw materials producing more waste by implementing different techniques.

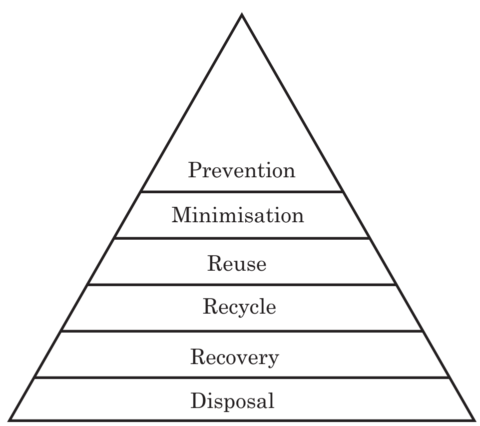


Fig. 1.2. Solid Waste Management Hierarchy.

1.7.1.3. *Reuse*

It is the next desirable option in which some materials are repeatedly used again and again for same purpose.

1.7.1.4. *Recycle*

In this stage, collection, sorting of recyclable products is done and then they are manufactured into new products.

Solid, Liquid and Hazardous Waste Management

About the Author

Chandan Kumar, B.Tech, M.Tech, is presently pursuing his **Ph.D. in Civil and Environmental Engineering at the Indian Institute of Technology (IIT) Patna**. He is currently serving as an **Assistant Professor at Government Engineering College, Bhojpur**, under the **Department of Science, Technology and Technical Education, Government of Bihar**.

He has over **10 years of teaching experience** in engineering education and **2.5 years of dedicated research experience** as a **Senior Research Fellow**. His areas of expertise include **solid and liquid waste management, hazardous waste treatment, environmental sustainability, and wastewater engineering**.

Throughout his career, he has been actively involved in academic instruction, mentoring, and research, contributing to the advancement of knowledge in civil and environmental engineering. His academic journey reflects a blend of **pedagogical dedication and research-oriented practice**, making him a strong advocate for sustainable environmental solutions.

This book, *Solid, Liquid and Hazardous Waste Management*, represents his endeavor to provide a **comprehensive and structured resource** for students, researchers, and practitioners, bridging fundamental concepts, practical applications, and regulatory frameworks in the field of waste management.

Salient Features of the Book

- **Comprehensive Coverage:** Provides a systematic treatment of solid, liquid, and hazardous waste management, including biomedical, radioactive, e-waste, batteries waste, plastic waste, and construction & demolition waste.
- **Academic Orientation:** Content is aligned with the prescribed syllabi of major technical universities in India, making it suitable for undergraduate and postgraduate engineering courses.
- **Structured Presentation:** Each chapter begins with an introduction, followed by detailed theoretical discussions, case studies, and end-of-chapter exercises and multiple choice questions.
- **Illustrations and Diagrams:** Richly supported with schematics, flow charts, and tables to enhance conceptual clarity and visualization of processes.
- **Case Studies and Indian Context:** Real-world examples and case studies, particularly from Indian cities and industries, strengthen the practical application of concepts.
- **Regulatory Frameworks:** Up-to-date coverage of national legislations such as the Solid Waste Management Rules, 2016, Hazardous Waste Rules, Biomedical Waste Rules, E-Waste Rules, Plastic Waste Rules, Radioactive waste, Batteries Waste, Environmental Impact Assessment, Environmental Protection Act and Environmental Clearance process in India and their latest amendments.
- **Exercises for Practice:** Review questions, numerical problems, and objective-type questions are provided to test understanding and prepare students for examinations and competitive tests.
- **Emerging Trends:** Special emphasis on modern technologies, sustainable practices, resource recovery, waste-to-energy, circular economy approaches, and smart waste management systems.
- **Multi-disciplinary Utility:** Designed not only for civil and environmental engineering students but also for students of architecture, urban planning, public health, and environmental sciences.
- **Reference Resource:** Serves as a reliable reference for practitioners, policymakers, and researchers engaged in waste management and environmental sustainability.

KHANNA PUBLISHERS®
ISO 9001:2015
4575/15, Onkar House, Ground Floor
Opp. Happy School, Daryaganj, New Delhi-110002
Phones: 011-45033819, 9811541460, 9650669626
E-mail: contactus@khannapublishers.in

Website:
www.khannapublishers.in

9 789392 549342