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Solid Wastes: Characteristics, Composition and Adverse Effects on Environment and Public Health

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Globally, it is being observed that for social and economic growth of a country, urbanization, industrialization, and exploitation of natural resources play a major role, resulting in atmospheric pollution by generation of huge amount of solid wastes. They are discarded being hazardous and unwanted, which is neither liquid nor gas, in our surroundings contributing a lot to environmental contamination, causing serious ill effects on human / animal health, destroying aesthetic beauty etc. This review discusses the sources, causes, characteristics; key categories of solid wastes and their ill effects on the atmosphere, society, human being & animals and suggested management, which has already attained high importance worldwide. It is well embedded within the Sustainable Development Goals and their Management would certainly help in boosting the economy in many ways.

Keywords: Solid waste; industrial solid waste; municipal solid waste; hazardous solid waste; biomedical solid waste; COVID – 19 waste; e – waste; agricultural waste; radioactive solid waste.

1. INTRODUCTION

In present scenario solid waste is an important challenge to the environment and society. It can be any material, throw-away by human being. Solid waste consists of different substances that can be hazardous, toxic and recyclable etc. The rate of generation of the quality & quantity of

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solid waste is greatly accelerated as a result of industrialization, urbanization, flourishing economy, and upgraded living standard of people as well as increase in population. Solid waste can be controlled or uncontrolled. The major category of controlled waste is commercial & industrial waste, municipal solid waste, institutional waste and construction waste. Whereas, the agricultural waste, waste generated from mines, quarries and degrading operations usually considered as uncontrolled waste. Solid waste is a threat to the environment as it affects both biotic and abiotic components of the biosphere. Therefore, management of waste from its assortment, dispensation, transport and to disposal is very significant for the public health as well as to sustain aesthetics of environment. At the same time managing solid waste is also one the biggest challenge to the developing and even developed countries. Sometimes high cost of managing operations and lack of proper training for managing operations, are the factors that adversely affect the solid waste management. Generally, solid wastes are disposed off in the outskirt area of the city/village followed by either the process of burning or compressing [1-6]. This is not an acceptable practice from the health and environment perspective. In modern practice the solution of this problem of disposal are incineration, sanitary landfills and biological digestion etc [7-11]. Microorganisms also have an essential role in the decomposition of organic wastes by converting them into high value-added products instead of waste. Likewise, the valorization of organic solid waste can be carried out by composting and anaerobic digestion. This review gives an overview of waste, its sources, characteristic, waste management processes, and the health hazards associated with these.

2. DEFINITION OF WASTE

Wastes can be defined as leftovers, unwanted or unusable materials having no value. It can be any substance discarded after use as worthless, insignificant, defective by-product or any useless substance. Generally, it is generated from household, commercial, industrial and agricultural processes [12-14]. It is also called trash, garbage, junk or rubbish. As per “Basel Convention on the Control of Trans boundary Movements of Hazardous Wastes and Their Disposals” of 1989, Art. 2(1)“Wastes are substances or objects which are either disposed of or are intended to be disposed of or required to be disposed of by the provisions of national law.

3. TYPES OF WASTES

The volume and kinds of wastes are increasing all over the world due to growth of population, urbanization, industrialization and many anthropogenic activities. Generally, the generation of wastes is higher in quantities per capita in developed countries as compared to the developing countries. It is essential for Government bodies to have a clear acquaintance of waste being generated in order to develop robust and cost-effective waste management strategies. There are different categories of wastes based upon various criteria:

3.1 Based on the Legal Criteria

- *Domestic Waste-*
- *Industrial Waste–*

3.2 Based on (their) Disposal into Landfills

- *Inert Waste*
- *Non-hazardous Waste*

3.3 Biodegradable Waste

3.3.1 Special category

- *Radioactive Waste*
- *Sanitary Waste*
- *Construction and Demolition Wastes*.

3.4 Based on Characteristics (Region & seasons)

- *Liquid Waste*
- *Solid Waste*
- *Organic Waste*
- *Recyclable Waste*
- *Hazardous Waste*

4. SOLID WASTES

4.1 Generation of Solid Wastes

Solid wastes can be classified in many ways according to its source, composition, phase etc. Fig.1 shows different categories of solid wastes described by Solid Waste Management Rules,

2016. Another categorization of solid waste is based on its source that is depicted in Table. 1.

4.2 Characteristics of Solid Waste

Density: It is an important characteristic of solid waste while designing of landfills. It is defined as the weight per unit volume, expressed in kg/m^3 and represented by □. The density of different wastes is mentioned in Fig. 2.

Moisture Content: Moisture in solid waste increases its weight and plays an important role in/for incineration. Table 2 contains moisture content of some common wastes.

Particle Size Distribution (PSD): The Particle size distribution of solid wastes decides its suitability for process of mechanical treatment and in the process of sorting of wastes and recovery of materials [15]. The PSD is also used to determine permeability, compressibility and other physical properties of solid waste.

Permeability of Compacted Waste: Permeability is the property by virtue of that it allows other substances to pass through it. It depends upon the pore size distribution and surface area.

Degradation Period: Having knowledge of degradation period of solid waste is very vital before making waste management strategies. It can be from a few days to a few years. For example, organic wastes and paper takes a few days, cotton needs few months, wood, metal 10-15 years' time.

4.3 Factors Affecting Generation of Solid Wastes

Managing solid waste is the prime challenge in developing countries. Which is allied with the understanding of different factors affecting generation of solid wastes? There are a few factors listed below in Fig. 3 that mainly affect the generation of solid wastes in big or small cities.

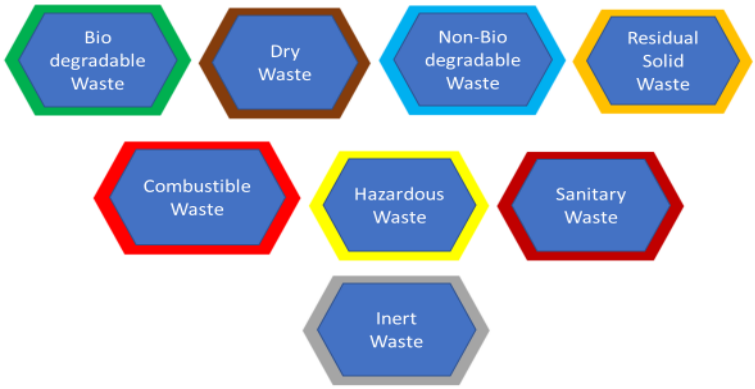


Fig. 1. Categories of solid waste as per solid waste management rules 2016 in India
Source: Ministry of Environment, Forests and Climate Change, Government of India (2016 a)

Table 2. Moisture content of some common wastes

Type of Waste		Range of Moisture Content in %	Typical Moisture Content in %
Domestic	Foodstuff wastes (mixed)	50 – 80	70
	Paper	4 – 10	6
	Plastics	1 - 4	2
	Courtyard Wastes	30 - 80	60
Commercial	Glass	1 - 4	2
Construction & Demolition	Mixed (demolition) wastes	4 - 15	8
Industrial	Chemical effluent	75 – 99	80
	Sawdust	10 - 40	20
	Wood (mixed)	30 - 60	35
Agricultural	Mixed farming waste	40 - 80	50
	Compost (wet)	75 - 96	94

Source: Christopher et al. [16]

Municipal Solid Waste	•Road cleaning and washing, agronomy, entertainment areas, water sources and sewage purification plants
Hazardous Solid waste	•Hazardous materials: mediacal waste, volatile materials, radiologicla stuffs, toxic products etc.
Industrial Solid Waste	•Manufacturing unit's, power plants, processing units, boiler house cinders, wood shavings, plastic, metal scraps.
Agricultural Solid Waste	•Dried plants and leaves from agricultural field, gardens and parks. Tree-trimmings, leaves, Crops, orchards, vineyards, dairies, farms etc.
Bio medical Solid Waste	•Contaminated plastic waste, bandages, cotten, tubes and syringe, human structural materials as, tissues, organs, body regions
Radioactive Solid Waste	•Demolished material,Hospitals, nuclear research lab, Resins, chemical sludges, and metal fuel cladding, Fission products and transuranic elements
E – Waste	•Parts of electronic devices, like monitor, speakers, keyboards, printers, mobiles, chaeger, landline phones, fax, cables etc.

Table 1. Types of solid waste based on its source [17]

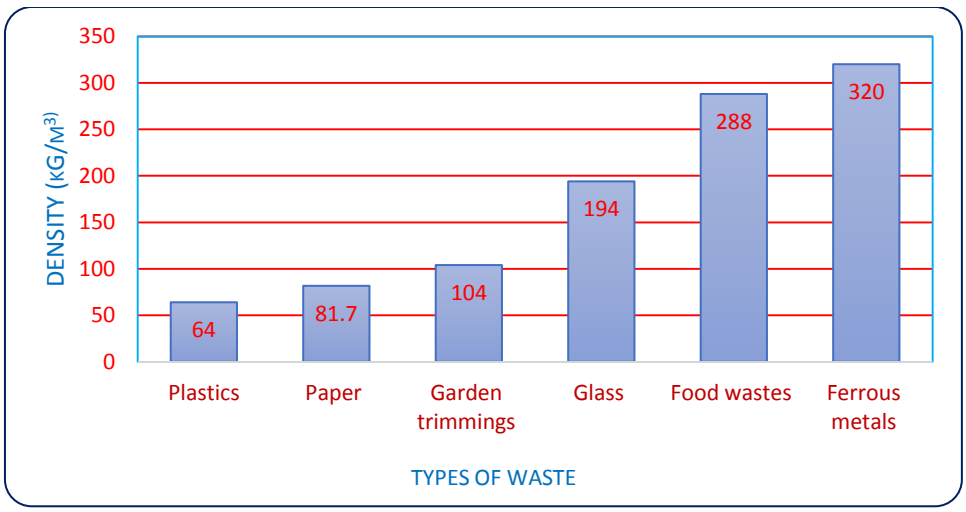


Fig. 2. Density of some common solid wastes
Source: Christopher et al. [16]

Fig. 3: Factors affecting generation of Solid Waste
Source: Astane et al. [18]

4.4 Hazardous Solid Waste

Hazardous wastes are the toxic substances with significant ill-effects on human, animals, plants and environment if not managed properly. These are generally non-degradable, biologically magnified, and poisonous; tend to cause disadvantageous effects on the environment. According to EPA, The United States Environmental Protection Agency, any discarded material in the form of solid, liquid, and gaseous state or any emissions if found to be toxic, combustible, corrosive, in nature or highly reactive above to the specified safety level is considered to be a hazardous waste [19].

As regards human toxicity, a waste is hazardous if:

(a)The oral LD 50 =/ >50 mg/kg

where, LD 50= the lethal dose of the toxic waste at which 50% of the experimental animals die as a result of oral ingestion.

(b) The inhalation LC 50 = 2 mg/kg

where, LC 50 = the lethal ambient concentration of the toxic material in mg/L of air causing 50% mortality to test rats during 4hours inhalation.

4.5 Characteristics of Hazardous Solid Waste

According to United Nation, explosiveness, flammability, oxidizing power, poisonous/ infectious, Radioactivity, Corrosivity and Toxicity (delayed or chronic or eco) are the characteristics of Hazardous wastes [20].

The general and specific characteristics are summarized below in Fig. 4.

4.6 Sources of Hazardous Waste

Hazardous waste is generated from hospitals, some types of household wastes, some industrial manufacturing units, petroleum and coal products manufacturing units, waste treatment plant and disposal processes, fertilizers, pesticides, iron and steel manufacturing wastes, research labs, mining sites etc. The common and significant sources are briefly discussed below:

4.6.1 Industries

Industrial waste is supposed to contain both, the non-hazardous and hazardous components. Therefore, it always requires a special treatment before disposal to ensure minimum harm to the environment. There are three major industries responsible to generate hazardous wastes (Table 3, [21].

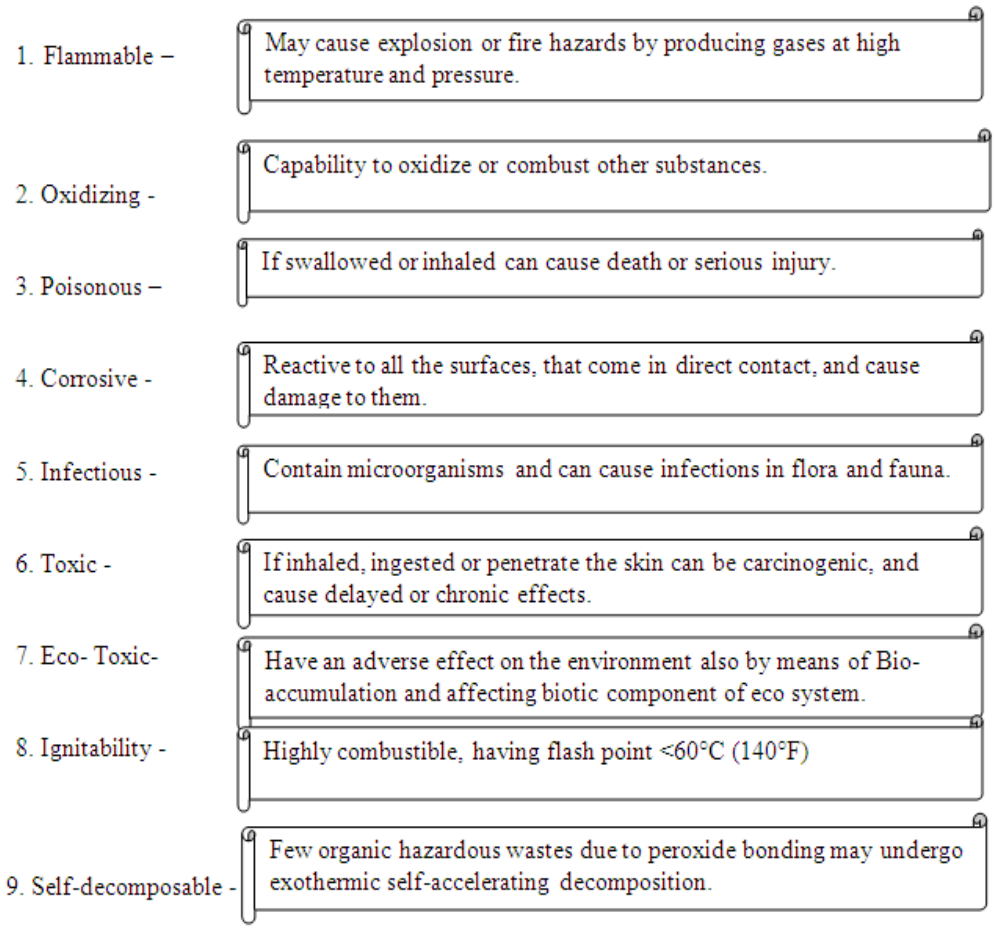


Fig. 4. Common characteristics of Hazardous wastes [22]

Table 3. Major industries producing hazardous wastes

SNo.	Name of the industry	Waste generated
1.	Chemical Manufacturing	Produces chemicals for industrial processes from metals, crude oil, minerals &natural gases etc. The common wastes generated are combustible solvents, lethal pesticides, and non-degradable chlorinated compounds, such as the polychlorinated biphenyls (PCBs) etc.
2.	Paint Manufacturing	Resins, solvents, drying oils, pigments and extenders are the raw materials used in paint industry. The major waste generated are empty raw material packages containing heavy elements, equipment cleaning solvents and spills,that potentially contaminate soil and ground water.
3.	Paper Manufacturing	Paper manufacturing involves a number of chemicals, inks, dyes. The gases emitted in this process are mainly Sulfur dioxide, carbon dioxide, NO_x, ammonia, along with nitrates, benzene and mercury as a byproduct.

4.6.2 Residential communities

A small amount of hazardous waste is also generated from residential communities such as insect repellants, paints, thinners, wood preservatives, pesticides, cleaning liquids, motor oils, anti-freezing agents, and materials from

discarded batteries etc. In industrialized countries, the percentage of household hazardous waste is about 0.5% (by weight) which is little higher than percentage in developing countries [23].

4.6.3 Hospitals

Medical facilities in hospitals generate waste like hazardous chemicals and some radioactive material. Biomedical waste generated from hospitals consists of infectious waste, sharp items, contaminated pharmaceutical products which need to be disposed of in a suitable way [24]. It includes Genotoxic waste which is cytostatic drugs, chemicals, materials, equipment, radioactive material and residues that are toxic to the cells. These wastes have mutagenic, teratogenic, and carcinogenic properties. Release of toxic substances in to the atmosphere may also occur due to the incineration of certain kinds of medical waste, particularly those containing heavy metals or chlorine.

4.6.4 Nuclear power plant and research labs

Nuclear waste from nuclear power plants and research labs is the primary source of hazardous radioactive waste. Which may be produced during many processes like production and application of radioisotopes, decommission of nuclear installations etc.

4.6.5 Mining

Mining comprises the process of extraction, beneficiation, dressing and further physical and chemical processing of wide range of metalliferous and non-metalliferous minerals by opencast and deep shaft methods. The major hazardous wastes is generated from physical and chemical processing of sulfide ore, metalliferous and non-metalliferous minerals. In addition other drilling waste from mining also found to contain oil and dangerous substances [25].

4.7 Agricultural Solid Waste

Agricultural solid waste is the left over obtained from activities such as growing, harvesting and storage of agricultural products like crops, herbs, fruits and vegetables. Besides the common Agro-waste like dry leaves, forest waste, weeds and sawdust, other waste like livestock waste, compost, oil, fodder plastics, pesticides, herbicides, poultry houses wastes, slaughter houses, animal farm house and veterinary medicines, are also considered as Agro-Waste. Although the material present in agro-wastes can benefit to society but having very less economic value than the cost of assortment, dispensation and transportation.

4.8 Types of Agriculture Waste

The types and composition of Agricultural waste based on the arrangement and kind of agricultural activities as given in Fig. 5 and depends upon the source too, as given in Fig. 6 [26]. Based on moisture content, they can be in liquids form, solids form or slurries. Generally, the liquid form contains 95% moisture content, solid form has 75 % or less, whereas semi-liquid (slurry) or semi-solid wastes contains 75% to 95% moisture content with 5-25 % solids content. Some wastes, such as manure, can change their consistency throughout the system or throughout the year.

4.9 Characteristics of Agro-waste

Chemical and physical characteristics of agro-wastes are of great importance for making waste management strategies, designing of waste management plant and for selecting equipment for the same. Important physical and chemical properties of Agro-waste with their units are mentioned below:

4.10 Physical Properties of Agricultural Waste

Weight: It refers as quantity or mass of the waste in lb.

Volume: It refers as space occupied by the waste in Cubic Units (ft^3; gal).

Moisture Content (MC): The fraction of a sample which is removed upon evaporation or oven drying at 103°C /217°F.

Total Solids (TS): The solid residue obtained after removal of water from waste material by evaporation.

Total Volatile Solids (TVS): That part of total solid waste, which is combustible in nature and obtained as volatile gases on heating up to 112°F/600°C.

Total Dissolved Solids (TDS): It refers to the fraction of total solids present in dissolved states

and can be obtained in filtrate after the process of filtration.

Total Suspended Solids (TSS): The part of total solids which stays on filter paper and removed after filtration is called TSS.

4.11 Chemical Properties of Agricultural Waste

***Nitrogen content (mg/L, µg/L*)**: Present as Total nitrogen (TN), Ammonia (NH_3), Ammonium Nitrogen (NH_4–N), Total kjeldahl nitrogen (TKN), Nitrate Nitrogen (NO_3–N).

Phosphorus Content (%; lb): It combines readily with oxygen and form acidic oxides like pentaoxide (P_2O_5). It is one of the plant nutrients, stimulates the growth of flower, seed, fruit, and hastens maturity.

Potassium Content (%; lb): It is also considered as a plant nutrient as it increases the yield of tubers, seed and stimulates the growth of stems as well as fights against diseases.

Bio-Chemical Oxygen demand (BOD): It represents the amount of oxygen consumed by microbes while degradation of organic material present in agro-waste under aerobic conditions at a given temperature. It measures the extent of pollution potential of waste materials that could be discharged to surface water.

Chemical Oxygen demand (COD) (lb of O_2): The estimated quantity of total oxygen that could be consumed in oxidation of the components present in waste material [27].

4.12 Generation of Agriculture Waste

India produces about 350 million tons of agricultural waste annually. Organic wastes can amount up to 80% of the total solid wastes produced in any farm of which fertilizer production can amount up to 5.27 kg/day/1000 kg live weight [28]. The waste generated is dependent on the categories of agricultural activities performed.

From Cultivation Activities The act of throwing storage bottles or containers of fertilizers, pesticides, and insecticides into the field after use is one of the sources of generating hazardous agro-waste. Excessive utilization of fertilizer than required for the plant also generates fertilizers itself as agro-wastes, which results in soil, water and air pollution.

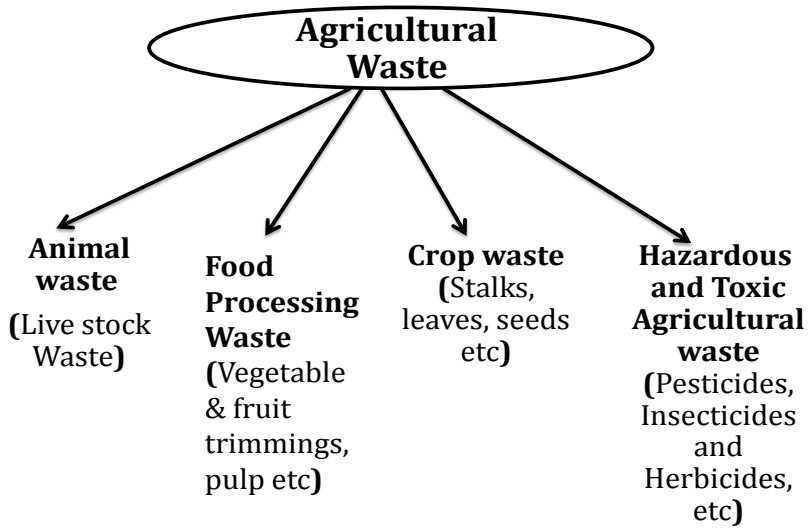


Fig. 5. Types of Agriculture Waste based on agriculture activities
Source: Mostafalou and Abdollahi, [26]

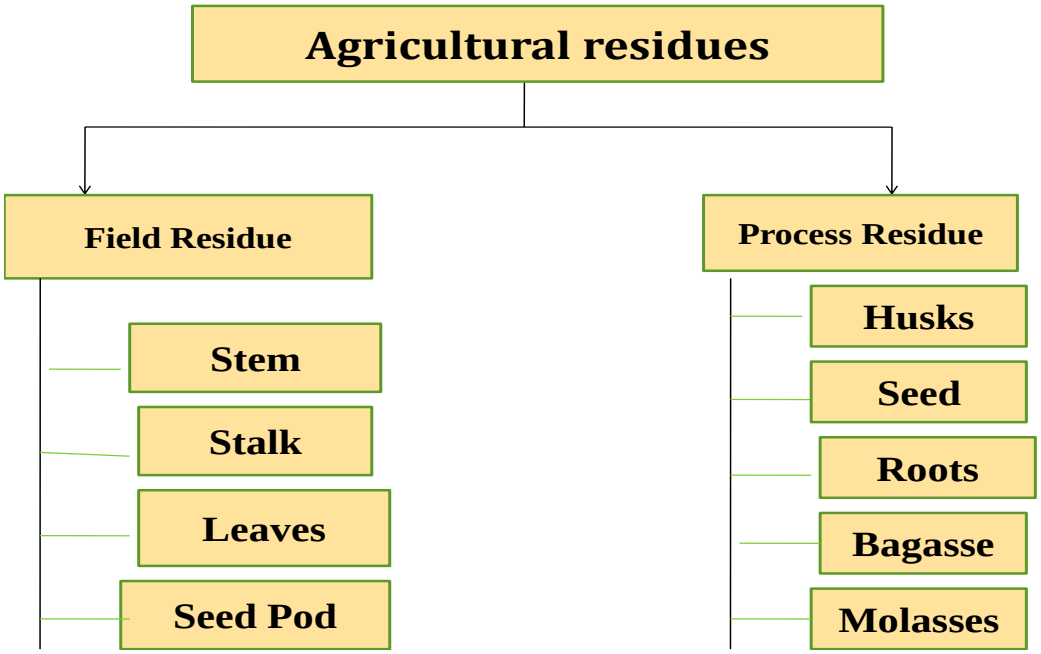


Fig. 6. Types of agro-waste based on
Source Mostafalou and Abdollahi, [26]

From Livestock Production The livestock activities include breeding, food and fodder, maintenance, slaughter, animal farming etc. The solid waste generated from livestock activities are mainly manure, from maintaining cleanliness, organic material in slaughterhouse, redundant food. The liquid waste generated as urine, cage wash water and wastewater from the bathing of animals, whereas air pollutants are CH_4, H_2S, NH_3 gases and bad aroma. The livestock waste contains 5-15% of the total volume organic matter, inorganic matter, many species of microorganisms, parasite eggs and 75–95% of total volume water is present [29].

From Aquaculture Aqua-culture includes activities like fish farming, shellfish farming, fishing and harvesting etc. Metabolic waste either dissolved or suspended, uneaten foods are majorly generated in aquaculture. Even in an appropriately managed farmhouse, approximately one third of the feed used becomes concrete waste after some moment.

4.13 Industrial Solid Waste

Industrial waste refers to the hazardous or nonhazardous waste generated through manufacturing or other industrial processes like chemical, food, paper, textile manufacturing units, mining and t construction activities, energy, water supply units etc. The study says that approximately 7.6 billion tons of industrial waste is produced and disposed off on site itself. There is no accurate estimate about the volume of universal waste exists, annually it is estimated millions to billions of tons and the largest quantity of total industrial waste production accounts from mining industry [30].

Types, Generation and Quantum of Industrial Solid Waste: Based on its characteristics and origin industrial solid waste is classified into different categories.

Hazardous &non-hazardous solid waste: Hazardous industrial waste poses a potential problem to the environment and public health, e.g., pesticides, metals etc. Whereas, nonhazardous industrial solid waste is that which does not harm to the environment and public health, e.g. Packaging material, card board, plastic, metals, glass, textile, rock, and organic waste [31]. Non – hazardous industrial waste can be defined as which are nether municipal waste nor meet EPA criteria of hazardous waste [32].

Biodegradable & non-biodegradable industrial solid waste: Biodegradable industrial solid waste constitutes approximately 85-90% of the solid industrial waste. Such waste can be decomposed by the microorganism and nontoxic

in nature. Generally, these wastes are generated from Cattle dung and compost, food processing industries, wool, paper industry, cotton industry, dairy, textile mills, and slaughter houses, etc. Some examples are paper, leather, wool, animal bones, wheat, etc. Biodegradable wastes do not require any special method of treatment. Combustion, gasification, composting, bio-methanation are the common methods used for their treatment [33-35].

Non-biodegradable industrial solid wastes (app10-15%) are those which cannot be decomposed by microorganisms. Hence, they contribute to environmental pollution and are a threat to living organisms. As these solid wastes do not decompose, therefore, they enter the bodies of animals and plants cause diseases, and become a cause of bio magnifications and stay in the environment for longer time period. They are generated by chemical industry, dye industry, metal industry, drugs industries, manure industries, radioactive wastes, polymers, metal scrap, fly ash, gypsum, silver foil, etc. However, with the innovation of recycling process of waste material, the waste products from one industry is being utilized in other industry, hence contribute to sustainability. Wastes from one industry are being treated and utilized in another industry.

4.14 Municipal Solid Waste

Municipal Solid Waste (MSW) is nonhazardous disposable material generated by residential communities, institutions, industries, agriculture, construction sites, streets and beech waste, sewage, sanitary waste, and commercial complexes. This is the most common and wide category of solid waste, generally called as trash or garbage, and made up of organic, and recyclable materials, whose disposal is managed by municipality. MSW is categorized as wet garbage and dry garbage. Wet garbage is majorly consist of food waste as vegetables and fruits peel, meat pieces, leftover food, eggshells and other food waste etc., whereas dry garbage consist of paper and plastic waste, wood and textile pieces, metal and glass pieces, polythene, tetra pack, newspaper, cardboard boxes, and aluminum foil, etc [36-39]. The typical composition of MSW mainly constitutes vegetables, grass, paper, plastic, glass and ceramic, where, vegetables cover the maximum percentage.

Table 4. Source and quantum of some major Industrial Solid Wastes

S N	Name of the solid waste	Source	Quantity (Million tons per annum)
1	Metal oxides and coke fines	Agglomeration process of iron ore	35.0
2	Brine mud (barium, strontium, calcium, and magnesium)	Generated during the drilling process & Caustic soda industry	0.02
3	Copper slag	Metallurgical residue, by product of copper extraction by smelting	0.0164
4	Fly ash	Coal combustion residuefrom coal fired electric and steam generation plants	70.0
5	Cement Kiln dust	Cement manufacturing plants	1.6
6	Mica scraper waste	Ceramic industry& Mica mining areas	0.005
7	Phosphogypsum (a mixture of gypsum along with phosphates, fluorides, and organic matter)	Phosphoric acid and Ammonium phosphate Plant	4.5
8	Red mud	By-product of extraction of alumina from bauxite	3.0
9	Iron tailing (solid waste from mines)	Process of iron ore beneficiation	11.25
10	Limestone wastes, stone waste (85%) and slurry (15%)	Mine garbage	50.0

Classification, Generation and Characteristics of Municipal Solid Waste: Generally, the collection and treatment of MSW depends upon the onsite conditions and its source, and accordingly it requires different methods for the treatment and after processing, produces different products. The classification of source of MSW has three classes: urban, industrial and rural. Under these divisions, several other classes are derived based on hierarchicy as shown in Fig.7.

The solid waste generated from different classes is mentioned below:

***Residential waste*:** Generated from residences, either houses or apartments, non – hazardous in nature, includes.

***Commercial waste*:** Generated from commercial stores, supermarkets, restaurants and hotels, non hazardous in nature.

Institutional waste: It generates from offices, educational institutes, theaters and stadiums, libraries, research institute, archaeological institute and recreation centers, etc.

***Construction and demolition waste*:** Non-hazardous by nature, generated from construction sites and demolition debris.

***Special waste*:** Non-hazardous waste generated by the sectors such as health centers, vehicle service centers, means of transportation, medical stores and automobile shops, etc.

Industrial waste: It is potentially hazardous in nature and generated by industrial processes of mining, production, processing and packaging etc.

***Agricultural and animal husbandry waste*:** Potentially hazardous, produced from the activities of agriculture and animal husbandry.

4.15 Radioactive / Nuclear Waste

Solid waste containing radioactivity as any unused objects that contains or is polluted with radioactive nuclei with concentration higher than the authorized levels as recognized by individual countries regulatory authorities is known as radioactive solid waste. There is a broad range of activities responsible for Radioactive Waste generation, for example; processes involved in nuclear plants, nuclear fuel cycle, radio diagnostics and radiotherapy, radiography of machinery, radioactive rays used for decontamination process, industrial waste, radioactive materials in mining, nonrenewable resources, mining through to fuel fabrication, reprocessing of used fuel, legacy waste, non-nuclear power waste etc. (International Atomic Energy Agency, The Management System for Facilities and Activities, IAEA, Vienna [40].

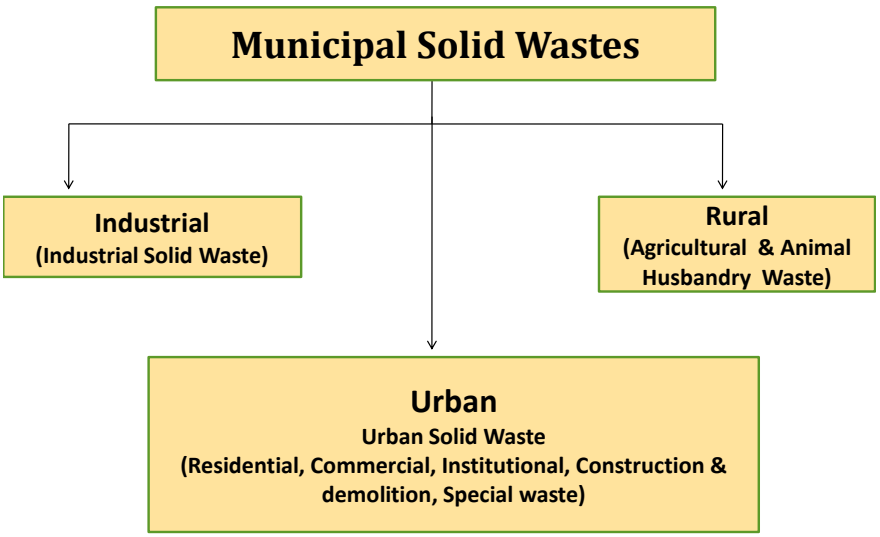


Fig. 7. Source classification of MSW

Table 5. Characteristics of municipal solid waste

Physical Characteristics	
Specific Weight/Density	It refers to uncompact waste i.e. weight of a substance/unit volume (e.g. kg/m3 , lb/yd^3)
Moisture Content (MC)	It refers to the percentage of the wet weight of the MSW material
Field capacity (FC)	This is water holding capacity of a sample under free drainage conditions and expressed as a % saturation. It's in the range of 50 - 60% saturation.
Hydraulic Conductivity, K	It refers as permeability and prediction of leachate production. MSW Range is 10^{-3} to 10^{-6} cm/s
Chemical Characteristics	
Loss of moisture	It takes place on drying at 105^0 C for 1 h at
Volatile Combustible Matter (VCM)	This is the matter obtained on heating the sample in closed crucible upto 95^0C, in the absence of air.
Fixed Carbon	This is amount of carbon obtained from the leftover of VCM
Ash Content	At 95^0C in an open crucible
Atomic composition	C, H, N, O, P,S etc
Fusing temperatures of Ash Clinker	Fusing temperatures: 1100 - 1200^{o}C
Biological Characteristics	
Biodegradability is the main biological characteristics of MSW in which organic fraction of MSW are converted biologically to volatile components and relatively inert inorganic and organic solvents.	

Source: Worrell and Vesilind, [41]

Important Facts

- The largest producer of nuclear power is United States.
- France is the second country in the world, having largest civilian nuclear program, with 59 reactors in operation and largest share of electricity generated by nuclear power.
- Plutonium is identified as 'the most poisonous and hazardous substance on earth'. Its hazardous nature due to the ionizing radiation it emits.

Classification, Properties &Sources of Radioactive Solid Waste: Solid wastes containing radioactive substance are classified on the basis of its radioactivity level, decay time and the sources from which they produce and the choice of the best methods for waste treatment, storage and their disposal. Table 6 shows the categories of radioactive solid waste (Petrangeli 2006).

It is being observed that the quantity of radioactive waste generated by industries is relatively more than the waste generated by nuclear power plants. Among the different wastes produced about 97% is low- or intermediate-level waste, only 0.2% is high-level waste.

Storage of Radioactive Wastes (RAW): The International Atomic Energy Agency (IAEA) is mainly authorized toward establish the standards and norms for the proper storage of RAW to minimize the danger to lives and environment. The safety standards of IAEA cover almost all the safety aspects such as radiation, storage, transportation, waste generation, storage, disposal etc. The duration of storage is subject to the half-life period or decay period of RAW. It may be few days, weeks or months depends upon its applicability. The storage of RAW is important for many reasons like it allows decay of short lived radioactive substance into stable and nonradioactive wastes while storage period. It reduces transport risks; it provides lag storage between waste generator, treatment, and disposal sites. The safety norms of IAEA help in the managing of radioactive wastes until disposal facilities are arranged [42].

Biomedical Solid Waste: Bio medical waste is a category of solid waste, which is produced from the hospitals, diagnostic centers, blood banks, medical and research lab facilities, and in researches pertaining to the testing of biologicals. All the categories of biomedical waste are mentioned in Schedule I, of the Biomedical Management rules, 2016 [43].

Characteristics & Types of Biomedical Solid Wastes: Different categories of biomedical waste are there based upon the characteristics of waste, source and mechanism of their disposal. Every country categorized their biomedical waste little differently. Fig. 9 shows the broad categories of the most common biomedical waste recommended by WHO [44].

Table 6. The category, characteristics and sources of radioactive/nuclear waste

Class	Property	Sources	Recommended Management
Very low-level waste (VLLW)	Average activity is around 10,000 Bq/kg, decays time is few months	Nuclear industry, Demolished debris such as plaster, metal, valves, piping, *etc.*	Temporary storage and conventional methods of disposal are suggested
Low- and intermediate-level waste – short lived (LILW-SL)	These are β emitters with a half-life period less than 30 years with limited content of emitted nuclides.	Research laboratories, hospitals and the nuclear fuel cycle	Compression or incineration are the suggested process for better management
Low- and intermediate-level waste – long lived (LILW-LL)	These are α-emitter having radioactivity level of 4000 Bq g^{-1}.	Cladding of nuclear fuel, reprocessing of nuclear waste, and reactor decommissioning	Smaller items and any non-solids may be solidified in concrete or bitumen for geological disposal.
High-level waste(HLW)	These are α-emitting nuclide containing the fission products and transuranic elements with radioactivity level more than 4000 Bq g^{-1} and decay heat (>2kW/m^3)	Fission products and transuranic elements	Deep geological disposal, cementation, immobilization and conversion into insoluble stable solid form to prevent its dispersion to the environment.

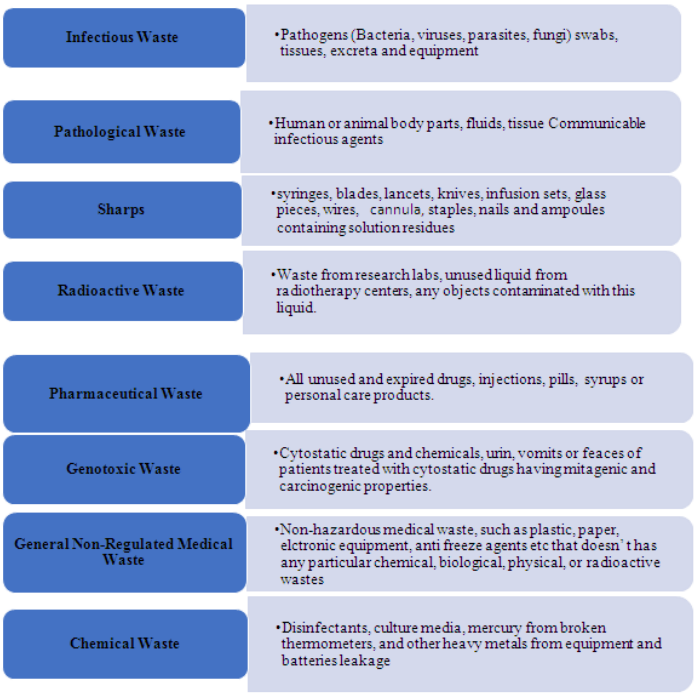


Fig. 8. Types of Biomedical Waste (BMW)

Table 7. Biomedical Wastes and their category

Color Coding of containers	Waste category
Red bag	Recyclable solid waste such as medicine bottles, bottles used for sample collection, used swabs, urine dipsticks, used drapes, vaginal stipules, any item contaminated with potentially infectious material. These materials can be either incinerated or deeply buried.
Yellow bag	Waste used in the treatment of infectious patients like bandage, gloves, mask, PPE kits, body fluids, body parts, cotton swab, discarded linen, other clinical laboratory waste., COVID – 19 waste etc.
Black bag	Noninfectious and nonhazardous waste generated from hospitals like polybags, leftover food and medicines, stationary items, packaging material etc.
White bag	These are puncture proof containers used to contain needles or all the sharp wastes.
Blue bag	Items made up of metal and plastic like syringes, ampules, glassware, metallic body implants etc. which can be recycled.

4.19 Handling of Biomedical wastes

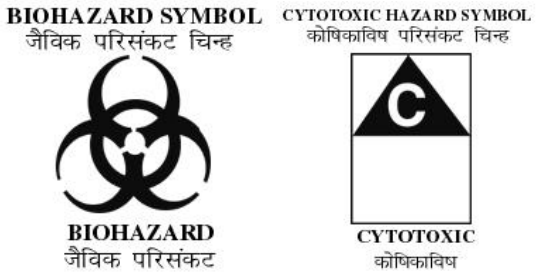
Proper handling of BMW is an important aspect to reduce the serious hazards to the environment and to the society. Collection and disposal of BMW is of great concern for healthcare works workers involved in the process of sanitation and the common people. Without proper sterilization it may lead to many serious and chronic diseases. The steps of handling with BMW are Segregation, storage and safe disposal. (Table7). The segregation of the waste is recommended by using different color-coding system of waste containers.

4.20 To manage COVID -19 waste

As per WHO and CPCB (Central Pollution Control Board) April 2020, the following guidelines be followed while handling the waste generated from COVID – 19. (Water, sanitation, hygiene, and waste management for the COVID-19 virus: interim guidance. Interim guidance [45].

- As per BMWM Rules 2016, the isolation for COVID-19 patients in the hospitals should be separated from general ward with proper arrangement of Yellow color-coded bins in the wards.
- For collection of COVID -19 wastes a double layered bag should be used to ensure no leakage and to have adequate strength. For this two bags are used together.
- Closed bags carrying COVID – 19 wastes must not be visible once a secondary container is closed. The bin used to store COVID waste should be labeled and kept in a separate storage room before handing it over to authorized staff of Common Bio-medical Waste Treatment and Disposal Facility (CBWTF).
- According to Central Pollution Control Board (CPCB) the feces from COVID-19 patients, should be kept in yellow bag/container like other biomedical waste.
- The container used for the collection of COVID waste should be disinfected with 1% sodium hypochlorite solution every day.
- Biomedical waste generated from home quarantine would also be treated as 'domestic hazardous waste', and shall be disposed as per guidelines of Biomedical Waste Management Rules, 2016.

There are different labels [46] meant for identification of particular type of Bio-medical waste during their storage and transportation as mentioned below:



E – Waste: In today's scenario, faster growth in IT and communication sector, upgradation of electronic items, force consumers to discard old electronic products and to buy upgraded version of devices. More and more electronic items such

as superior televisions, latest mobiles, and upgraded computing devices, smart phones or tablets, which are marketed at a fast pace all over the world, is an important reason for the rapid increase in production of electronic waste (e-waste) [47]. E – waste is a major class of solid waste, constitutes all the discarded, obsolete, nonfunctional electronic or electrical appliances. E-Waste defined by different agencies as mentioned below in Fig. 9.

E - Waste Generation and Composition: The reasons for E- Waste generations are interlinked, none of the reason is merely responsible, but together they contribute to a major environmental risk by E – waste. Broadly it can be summarized as below:

Technology advancement - Nowadays, electronic gadgets are getting replaced by new models because of fast advancement in technology and production of more innovative and user-friendly equipment's. Studies reveal that the average life of an electronic item in developed countries is maximum 2 years and it is estimated that by 2020 it reaches approximately 12.3 million tons. (UN University. [47] Review of Directive 2002/96 on Waste Electrical and Electronic Equipment (WEEE). Bonn, Germany, United Nations University, 2007. Available: http://ec.europa.eu/environment/ waste/weee/pdf/final_rep) [48].

Change in life style – With the time, there is a drastic change in living standard of middleclass population including lower and upper middle class. Because of usefulness, attraction of electronic appliance and ease of getting loan, in case unaffordable, ordinary people have also started using E – equipment's, like kitchen appliances, computers, laptops, printers, calculators, smart mobiles, transceivers, smart TVs, iPods, health checkup appliances, washing machines, refrigerators, vacuum cleaner and air conditioners etc. After a period, when these items become unfit for use, they lead to the generation of E – waste.

Increase in Population – Increase in Population is supposed to be the root cause of all the environmental problems. Electronic and electrical appliances are being used by human beings, therefore, increase in population act as a trigger in E – waste.

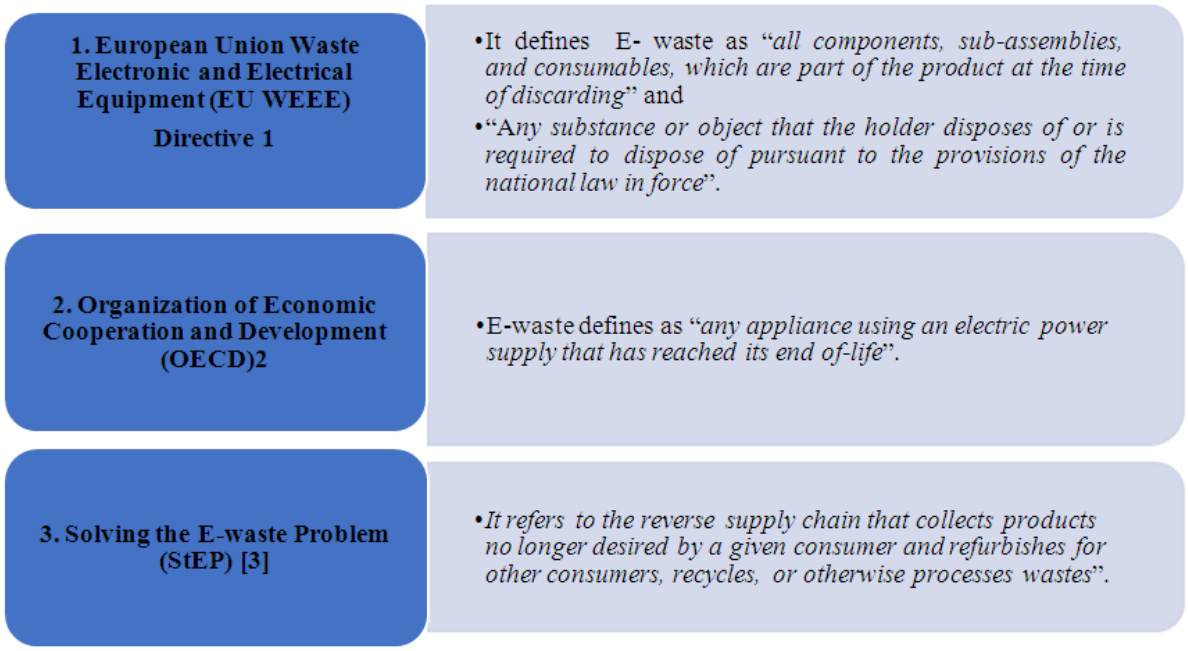


Fig. 9. Waste definitions by distinctive agencies

1. http://eurlex.europa.LexUriServ/LexUriServ.do?uri=CELEX:32002L0096:EN:NOT2003. [Access date: 25 May 2015] [49]

2. https://www.oecd-ilibrary.org/environment/extended-producer-responsibility_9789264189867-en 3. [47,50]

Fig. 10 shows the composition (in %) of a few common and important E – waste materials which shows that different type of metals, pollutants, different types of plastics, their mixture, cathode ray tubes (CRTs), circuit boards, ICs, cables, are major component of E-waste.

5. IMPACTS OF SOLID WASTE ON THE ENVIRONMENT &THREAT TO PUBLIC HEALTH

Solid waste generation, collection, treating and disposal of materials are one of the causes of air, water and soil pollution as well as that affects potential risk toward the human strength. Uncontrolled industrial waste along with municipal and biomedical waste contaminates the soil and ground water, which in turn affect the flora and fauna. The improper incineration contributes to the air pollution. Non-biodegradable heavy metals and chemicals present in the solid waste, undergo bio-magnification and passes from one level to another through food chain and collectively affect a bigger population. There are many other environmental problems arise due to the solid waste, mentioned as follows:

- Methane gas is a major contributor to the enhanced greenhouse warming and climate change. It can be produced as a result of the anaerobic respiration of microorganisms, which flourish in landfills [51].
- Synthetic plastic found in naturally flowing body of water ingested by birds and aquatic animals and become fatal for them.
- Accumulation of Solid waste resulted in high algal population.
- Percolation of leachates from harbor dumps to the soil, contaminate the underground water.
- Rubbish from wayside and throw away waste over big region cause aesthetic spoil to the biosphere.
- Burning of cloths, plastic, and rubber contaminate the atmosphere with toxic fumes.
- Decomposition of natural solid wastes emit obnoxious odor and contaminate the surroundings [52].
- A short-term effect of solid waste causes health problems as anxiety, asthma, congenital anomalies, dizziness, headache, eye and respiratory irritation, stress, and nausea. Whereas, long-standing health effects causes chronic illness like cardiovascular diseases, cancer, and brain, nerves, liver, lymph hematopoietic, lung and kidneys diseases [43].

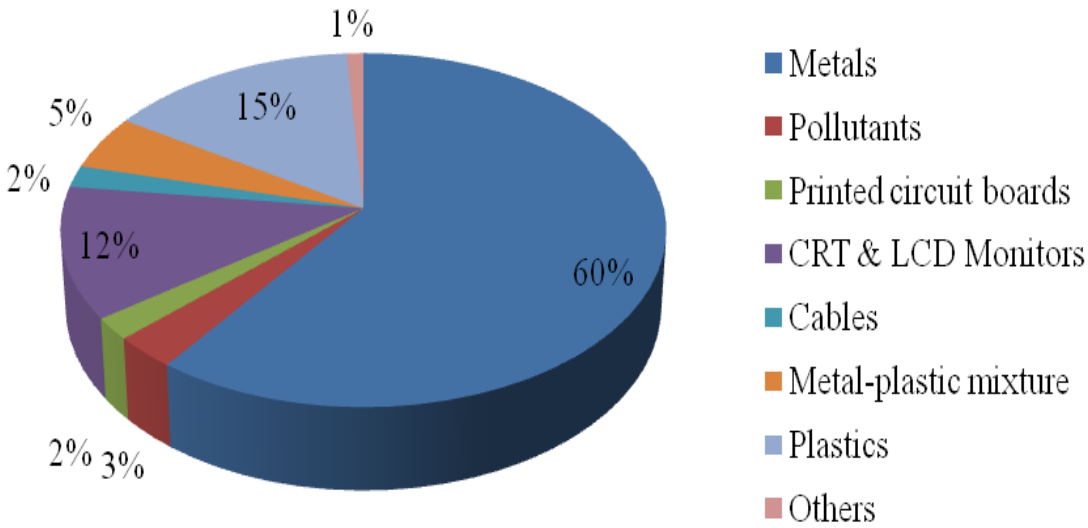


Fig. 10. The distinctive contents of E – Waste
(Electrical and Electronic Equipment Recycling Wastes) WEEE Source: Adapted from [24]

Table 8. Impacts of different types of solid wastes on public health & Environment and recommended managements

Types of Solid	Impacts of different types of solid wastes	Recommended Management
Municipal Solid Waste	It enhances approx. 4.53% of the organic matter and heavy metal content as Cu, Zn, Cd, Pb, Ni, and Cr in the soil It leads to low birth rate, liver cancer, congenital malfunctioning, neurological disorder, nausea and vomiting [53]. It causes chemical poisoning through inhalation, mercury toxicity, Uncontrolled wastes results in floods, high algal population in naturally flowing body of water. Degrade soil & water value [54]	Keep biodegradable waste in a non-corrosive container with a cover (lid). Store the waste as per the directions of Government of India, Ministry of Environment Biomedical Waste (Management & Handling) Rules, [55]
Hazardous Solid Wastes	Non-Hodgkin lymphoma and non-neoplastic disease, Liver, breast, bladder and testis cancers, asthma [56]. Neurological, respiratory, digestive, uro-genital, connective musculoskeletal, cognitive& behavioral deficits, diabetes and childhood neurological disorders [57,58].	These wastes can be treated by chemical (Ion exchange, precipitation, oxidation and reduction, and neutralization) thermal (Incineration), and biological methods (Bioremediation)
Industrial Solid Wastes	Increases toxicity, phytotoxicity, affects genetic activity and bio-concentration in ecosystem. Inhalation of dust containing solid waste as cotton, fungus, pollen grain, metal particles etc. badly affects respiratory tract and cause system/systemic effects. Percolation of leachates contaminates ground water and sub soil water, which effect in ingestion of hazardous substances by population. [59]	Biological Treatment (aerobic and anaerobic Method) Vacuum Evaporation (Waste water treatment) Physicochemical Treatment (Coagulation, flocculation, and sedimentation)
Agricultural Solid Wastes	Acute poisoning, emesis, twitching occurs in insecticides industries. Marsh gas from landfill site can cause enter in ozone layer and results in atmospheric destruction. Burnable erosion in human body. Decreases the growth of plants, Causes aquatic life disturbance. Changes soil structure and properties that affects biotic factor of soil.	Compositing/organic manure Substrates for edible fungi cultivation Traditional soap making Alternative energy sources and bio-fuel production
Biomedical Solid Wastes	Its presence in the environment contribute to many health problems like Skin infections, Lung infections, Parasitic infections, Spread of viral disease such as Bacteremia, Cholera, HIV, Hepatitis B, and Tuberculosis [25] Risk of contracting cancer [60] Contaminate groundwater sources. Radioactive particles generated from diagnostic technologies trigger several illnesses.	3 Rs" Reduce, Reuse and Recycle. That include generation, accumulation, handling, storage, treatment, transport and disposal. Waste minimization and Waste segregation.
Radioactive Solid Wastes	Leads to the probability of a cancer, leukemia and more immediate death [61] Through unhygienic food groups as fruits, vegetables, grain, dairy product, and groundwater, radioactive waste enters the food chain, that accumulates in the thyroid gland, and become a cause of beta radiation May contaminate agriculture as growing crops, cultivating soil, and livestock.	Radioactive solid waste management include characterization, pre-treatment, treatment, conditioning, storage, transportation and disposal.

Table 9. Impacts of specific solid wastes generated from different sources on public health

Waste	Effects	Reference
Heavy metals	• It may cause liver and bladder cancers, Tingling sensations in the hands, feet, and around the mouth, mental fogginess, anxiety and depression. • Consumption of Mercury affects liver, kidneys and human intelligence/brain/central nervous system, whereas, elevated contact of mercury causes visualization, communication and hearing impairments. Sometimes, it can become fatal also.	Fazzo [56]
PCBs and dioxins	• They Cause general toxicity, immune toxicity, neurotoxicity, negative effects on reproductively,	Bommanna and Shigeki [62]
Methane	• Emission of methane cause GHGs effect and climate change.	Alam and Ahmade [51]
Endocrine disrupting chemicals (EDCs)	• Presence of EDCs in the body of human or animal may result in development of Breast cancer, abnormal growth patterns and neuro problems.	Bergman [63]
Hydrocarbons	• Hydrocarbons tend to cause liver damage, tumors, cancer, abnormal retention of fat in the body (steatosis), headaches, nausea, leukemia, even damage to bone marrow.	Source: *National Environmental Engineering Research Institute* (https://vikaspedia.in/energy/environment/waste-management/hazardous-waste/hazardous-waste-source-and-health-effects) [63]
Carbon Monoxide	Exposure to Carbon monoxide causes headache, dizziness, vomiting, and nausea, breathlessness.	https://ephtracking.cdc.gov/showCoRisk.action
Pesticides	Numbness, respiratory depression, blurred vision, abdominal cramp, impaired memory, disorientation, insomnia etc.	Naveen et al. [64]
Nitrogen Compounds	Mutagenic, Genotoxic, lung cancer,	Chiang T, [65] Li et al. [66] Dennekamp et al. [67]
Benzene	Acute kidney congestion, myelofibrosis, affects liver, leukopenia, anemia, and thrombocytopenia, congestive gastritis	Tondel et al. [68] Midzenski et al. [69] Wilbur et al. [70]

6. CONCLUSIONS

Presence of solid waste in the environment is an alarming issue to the public health. Every year human beings are disposing billions of metric tons solid wastes. The solid waste sources are municipal, biomedical, hazardous, agriculture, industrial, e – waste and radioactive waste. Agricultural and industrial wastes were the largest contributors to the total annual production of solid waste, but in today's pandemic situation, biomedical waste is also contributing to greater extent. Increase in Population, rapid industrialization, booming economy, advancement in technology, and the sedentary lifestyle of human have significantly accelerated the rate, quality, quantity and composition of the solid wastes. Accumulation of each solid waste is probably the most visible in the form of pollution and can be experienced as hazard to the human health and environment [71]. The most

unsafe solid wastes are hydrocarbons, heavy metals, dioxins, pesticides, and radioactive elements which are generally generated from industries, hospitals, municipal waste, and agriculture activities .and are toxic, infectious, corrosive and generally non-bio-degradable in nature. The solid waste with such characteristics is a big threat to the society and environment. The inappropriate storage, bin assortment practices and transportation systems have greatly affected the characteristics of the solid wastes [72].

Government and Industries are making efforts in the management of solid waste material too. Before making strategies for management of unyielding waste to reduce, reuse or recycle, better understanding of the group of solid wastes, their composition, sources, and characteristics is very necessary. Whereas, public awareness and public attitude are the very important factors in reducing the generation of solid wastes.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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