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Solid Waste Management in India: A Brief Review

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Abstract In the twenty-first century, major emphasis should be levied on environmental safety and concern regarding human health. In this relevance, solid waste management need major attention. Awareness in society is profusely obligatory for minimization of solid waste generation. Careful study reveals that municipal solid waste (MSW) provides a major contribution to the total amount of solid waste. But e-wastes are the most frequently growing waste which is also an efficient source of various toxic elements. Globally, upsurge in the demand of nuclear energy enhances the generation of radioactive solid waste (RSW) that may be responsible for harmful effect of radiation. On the other hand, hospital solid wastes (HSWs) have great impact on environment and public health as it is the carrier of infectious diseases and other toxic elements. Biodegradable organics are the major content of agriculture solid waste (ASW) along with some pesticides and heavy metals. The total amount of solid waste (SW) is enhancing day by day, and as a consequence proper solid waste management (SWM) methods are necessary which could minimize the total amount of SW as well as its hazardous effect on environment. This review is focused on generation of different SWs and corresponding techniques of SWM starting from conventional tools to modern technique like refuse-derived fuel (RDF), pyrolysis, incineration together with their advantages and limitations.

Keywords Solid waste management · India · Resource efficiency
Utilization

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1 Introduction

In today's world, one of the most concerning issues is protection of human civilization from the threatening effect of man-made wastes. Indeed, wastes are the residue part of raw materials, which are generally unwanted after primary use. Among different waste materials, solid wastes are generated in our society through various humans' activities. In its consequence, population and their education level, monthly income is also a contributing factor in waste generation [1]. The waste management is easy for limited population [2]; however, in India due to rapid increase in population together with modern urbanization the lifestyle has also been simultaneously changed. In turn, this leads to amplification of solid wastes [2, 3]. In its connection, the improper solid waste management improvises the rigorous outcome on public health and environment. Consequently, solid waste management becomes a major concern in the twenty-first century [2].

Several hazardous solid wastes [4] from various sources are further characterized as organic, reusable and recyclable waste [5]. Solid wastes mainly includes village, agriculture, municipal and hospital solid wastes. Village wastes (VWs) contains a major part of decomposable and recyclable materials [6]. On the other hand, agriculture solid wastes (ASWs) may exert groundwater contamination and soil infertility [7]. Toxic organic materials and metals are the main sources of this contagious effect. The majority of solid wastes are originated from the municipalities where the amount is thousands of tons per day; municipal solid waste (MSW) contains all types of hazardous, non-hazardous and organic waste, and a few extents of MSW is compostable. The increasing rate of MSW generation annually is around 1–1.33% per capita. In India, the MSW generation rate per capita is around 0.2–0.5 kg per day in small towns [8]. MSW causes release of many toxic gases and substances which further can contaminate the soil, groundwater and the environment. Contamination of these toxic elements to the food chain results in harmful effect on the ecosystem [9]. In case of hospital solid wastes (HSWs), the scenario is more alarming! HSWs are generated during observation, diagnosing, treatment and curative process of a patient in any field of humans or veterinary. Production and testing of biological product also generate harmful waste. In general, HSW is hazardous, of which only 5% is non-infectious and remaining considered as infectious waste [1, 10–12]. Infectious wastes are expected that it is abounding of pathogens which are spreading or capable to cause disease to humans and animals. HSW may cause flare of dangerous disease like AIDS, hepatitis A, B, C, tuberculosis, pneumonia, diarrhoeal diseases, tetanus and whooping cough [1, 12, 13]. Some toxic chemicals such as dioxins and furans are generating from HSW which have significant harmful effect on health of animals and birds [14]. HSW contains some radioisotopes in very small extent which are used during therapeutic and diagnosis studies. These are mainly containing technetium-99, iodine-131, iodine-125, iodine-123, flourine-18, tritium and carbon-14. In its connection, another type of solid waste with detrimental effect is radioactive solid waste (RSW). RSW mainly contains uranium and plutonium.

These heavy metals are emitting health hazard elements like alpha, beta and gamma rays which may cause skin cancer, birth of defective child [11]. Major source of production of RSW is military weapon production sectors and nuclear power plants. The increasing demand of nuclear energy in producing electricity increases the uranium demand which subsequently enriches the amount of RSW. These heavy metals are discharging approximately 10,000–12,000 tons every year. Only, 30% of total discharged material is reprocessed and reused in storage condition [2].

In the era of globalization and fast life, electronic waste (e-waste) is one of the solid wastes generated every day in a mammoth rate. A survey reveals that approximately 4 out of 7 people in only 4 billion people of constitutional regions were generating e-waste around 41.8 million tonnes (MT) through all over the world in 2014. It is expected that sitting on growth rate 4–5% annually, the quantity of e-waste will reach around 49.8 MT by 2018 [15]. That huge quantity of e-waste is generating from the discarded electrical and electronic equipment. Rapid obsolescence of technology reduces the lifetime of electrical and electronic product which in turn results in a rapid enhancement in amount of e-waste [16]. E-waste contains toxic elements such as acids, polychlorinated biphenyls, hexavalent chromium (PVV) [15]. These may cause bronchial maladies, lung cancer, damage in liver and kidneys. Some heavy metals like lead, mercury, cadmium, arsenic are present in e-waste possessing serious effect on central nervous system, immunology system of our human body. On contamination to groundwater, these wastes may cause detrimental effect to children and cause several diseases (i.e. *Minamata*, *Itai-itai*) [17, 18].

In line with prior discussion, it could be understandable that the harmful effect of SW on human civilization is caused due to improper management of solid waste. To minimize the adverse effect and up growing quantity of solid waste, their proper management is very necessary [19]. Solid waste management (SWM) process includes various actions related to generation, storage, collection, transfer & transport, processing and disposal of solid wastes [3, 8]. Solid waste generation and its management depend on national income and legal policies of the nation. Application and maintenance of these facilities like collection, recycling, treatment and disposal of solid wastes needs a large amount of finance. Moreover, for waste treatment there needs a suitable locations which is gradually more difficult to find due to the most popular attitude Not In My Backyard (NIMBY) throughout all the communities. Reduce, Reuse, Recycle (3Rs) and integrated solid waste management, these pursue greater interested on waste prevention, reduction and waste recycling rather than waste treatment and disposal [2, 5]. Disposal of solid waste is very important and this disposal technique comprises landfilling, Incineration, pyrolysis, composting etc. [20].

The present study deals with different methods for safe disposal of the mountainous amount of solid waste in India. Different SWs and their generation have been discussed together with the safe disposal method starting from conventional method to modern plasma arc pyrolysis. The possible use of solid waste as efficient energy resources has also been emphasized.

2 Result and Discussion

Depending upon sources of solid waste is categorized in different types which needs more priority for discussion.

2.1 *Municipal Solid Waste (MSW)*

In search of better facilities and lifestyle, people day by day are moving towards the cities [2, 3]. Population boom and ongoing industrialization are also influencing factor for these migration which causes large amount of MSW generation including Biodegradable waste, Recyclable materials, Inert waste, Composite wastes, Hazardous waste, Toxic waste, construction and demolishing waste etc. [8]. Elements regarding to these wastes are given in Table 1. On viewing the elements weight, MSW contains major fraction of organic than ash and fine earth as well as paper and plastics, where glass and metals are present in very little amount which is shown in Fig. 1.

Table 1 Various municipal solid waste and corresponding sources

Type of MSW	Composition of waste	Sources
Biodegradable waste or organic waste	Food and kitchen waste, fruit and vegetable peels, green waste, yard waste (like garden trimming), wood, animal wastes, paper, rubber and leather	Household and kitchen, food processing industries, farms
Recyclable waste	Paper, cardboard, glass, bottles and jars, tin cans, aluminium cans, aluminium foil, metals, certain plastics, fabrics, clothes, tires, and textile	Office, shops, scraps yards, car and automobile industries, textile industries
Inert waste	Construction and demolition waste, dirt, rocks, debris, sands	Constructional sites, demolished buildings
Hazardous waste	Most paints, chemicals, tires, batteries, light bulbs, electrical appliances, Fluorescent lamps, aerosol spray cans, and fertilizers	Household, paint industries, chemical industries
Toxic waste	Including pesticides, herbicides and fungicides	Chemical industries, various pesticide and herbicide manufacturing industries

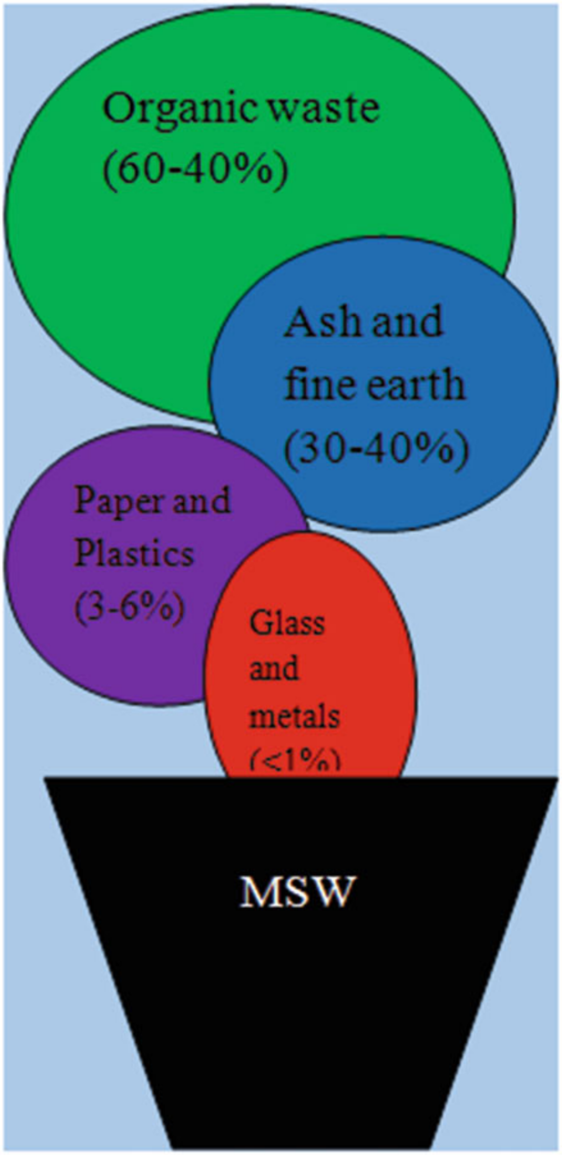

Fig. 1 Distribution of various waste elements under MSW (%)

2.2 Extent of MSW

In various countries with growing development and gradual improvement of national gross domestic product (GDP) the generation rate of MSW increases rapidly [5]. Nowadays, only in India MSW generation rate is eight times higher than 1947. Globally with a rate of incremental growth $\sim$1–1.33% annually, these amounts exceed 2 billion tons per year [8]. Organization for Economic Co-operation and Development (OECD) countries [2] contributes more in total amount of weight around 619 million tonnes, and as per capita USA holds the highest rate of 750 kg. India and China are the major contributors among the developing countries with a rate of 0.5 and 0.9 kg/day/capita, respectively [2]. In India every year, 48 million tonnes of MSW is generated including 7.2 Mt of industrial waste and 1.5 Mt of plastic waste [18]. On basis of GDP, it is expecting that by 2030 these rates will increase to 1.8 kg/day/capita in China. Meanwhile, China generates highest amount of MSW and India just exceed USA [2].

2.3 Radioactive Solid Waste

Nuclear power plants are the foremost and upcoming power source to compensate the demand of power for this increasing population. There are also backsides, each step including reprocessing of commerically utilized nuclear fuel for these nuclear power plants are responsible for radioactive waste generation. Nuclear weapon production for defence programme and research reactors also contributes to a greater extent [2, 21]. In USA, 95% of total volume of radioactive waste is generated by the defence research programme in which only 9% accounts for total radioactivity [21]. Uranium and plutonium are major contents with some other heavy metals like cerium and strontium in radioactive solid waste. These heavy metals emit radiation which has drastic effect on human health and environment [2, 21]. Some major accidents reveals the detrimental effect like Chernobyl disaster in Ukraine, Soviet Union (USSR) in 1986 and Fukushima Daiichi nuclear disaster in Japan in 2011. After that, there are high amounts of cancer [22], and thyroid cancer [22], birth defects, and tumours [2] were speeded up in epidemic rate which haunted victims. Moreover as an artefact, soil are also contaminated with heavy metals [2, 22]. Through food chain heavy metals are consumed by humans. After Chernobyl disaster, such type of metal pollutant like strontium-90 was found in root of plants and also in cow's milk. Consuming these as food, results in weakening of the bone and bone marrow which can cause bone cancer in humans [22].

2.4 Extent of Radioactive Solid Waste

Commercial nuclear power plants generate 290,000 tons of heavy metals per year. Only, 30% of heavy metals are generally recovered. Globally, the reprocessing capacity is only 5500 tonnes of heavy metal per year. Around 10,000–12,000 tonnes of heavy metals are produced from the spent fuel, most of which are kept in storage [2]. In USA, major defence research sites (like Savannah River, Hanford, West Valley Demonstration Project and Idaho Chemical Processing Plant) are contributing greater amount of waste with total 120 million Curies activity. An amount of 6900 metric tons of nuclear materials are discharged by Hanford site with a total activity of 44.6 million Curies [22], where uranium content is 4100 metric tons together with 15 metric tons of Cs and Sr [22].

2.5 Electronic Waste (E-Waste)

The term e-waste or waste electrical and electronic equipment (WEEE) includes entire electrical or electronic devices which are loosely discarded, surplus, obsolete, broken at the end of their lifetime [23, 24]. Concomitantly fast growing change in new technology with life-style the life span of earlier technology becomes reduced and obsoleted. These obsoleted products are enriching e-waste day by day [15, 16, 18]. For example, in 1992 the average lifetime of a computer is 4.5 years which is in certainly decreasing to 2 years and continuously decreasing resulting in major content in e-waste [17]. Thus, annually 130 millions of computers, TV, monitors are expelled form of use [17]. The lifetime and approximate mass of major electric equipment are shown in Fig. 2.

Availability of the technology and continuous growth in economy leads to rapid increase in GDP [5, 16]. Since a country's GDP is related to its total number of PCs, so increase in GDP enhances the purchase of electronic equipments that leads to increase in generation of e-waste globally. Globally, 20% increase in GDP causes generation of 20–50 metric tons of e-waste in last 6 years [16].

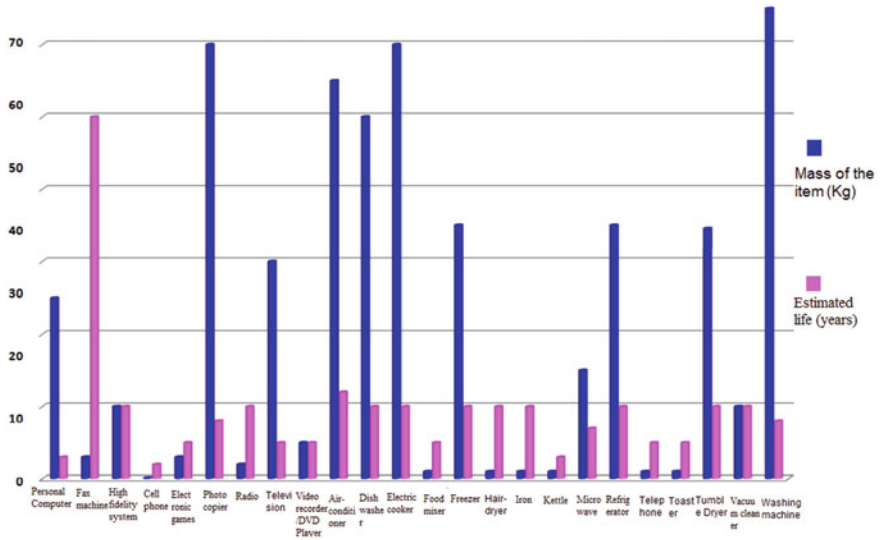

Fig. 2 Types of e-waste and their life cycle

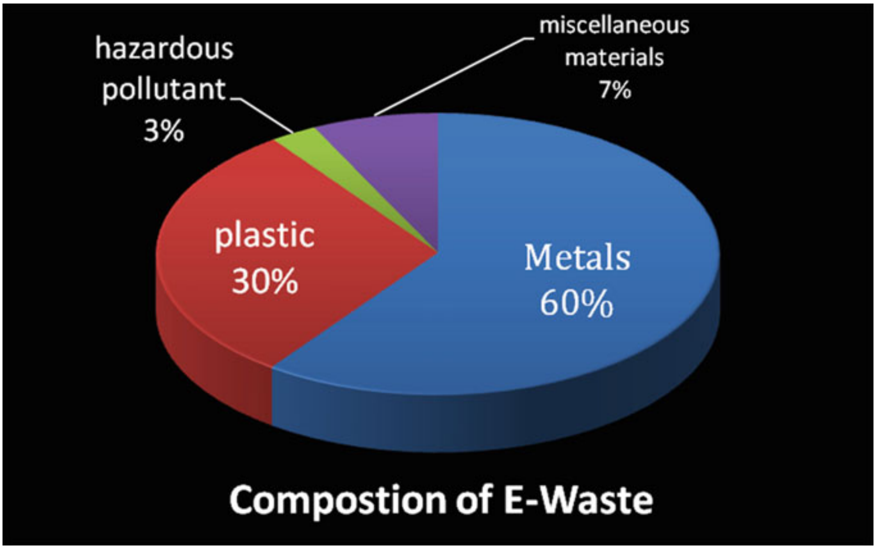

Fig. 3 Composition of e-waste

E-waste is broad composite of metals, plastic, hazardous pollutant and miscellaneous materials where in a greater extent heavy metals are present (Fig. 3) [16, 23].

Heavy metals and some halogenated compounds are mostly known for their drastic effect on human health. Since major source of these toxic substances is the composition of e-waste, there is an adverse effect of e-waste on human health [16]. The various sources of these substances and its effect and quantity per year are mentioned in Table 2 [16–18, 23].

2.6 *Extent of E-Waste*

Due to the rigorous exploitation of electronic goods with every passing day, the generation of e-waste is unavoidable. From 1998, only use of household electric appliance increases by 53.1% in 2002 [23]. These cause around 41.8 million tons (Mt) of e-waste only by 4 billion people up to 2014 which further increase to 49.8 Mt in 2018 around the world [15]. Globally, every year the amount of e-waste generation is about 20–50 Mt which has been increased with a growth rate 4–5% in recent days. In 2014, highest amount of waste is generated by Asia (16 Mt) and lowest position occupied by Oceania (0.6 Mt). Considering e-waste per habitat, Europe got highest rate of 15.6 kg/inhabitant and Oceania is next to it with a rate of 15.2 kg/inhabitant where Asia is so far with a rate 3.7 kg for each inhabitant [15]. Africa is generating the lowest amount of e-waste, only 1.7 kg as per inhabitant and

Table 2 Various toxic elements and its source, global quantity of generation per year and corresponding health effect

Substance	Source	Global quantity (tonnes)	Environmental and health effect
Metals and heavy metals			
Antimony (Sb)	Fire retardant, plastic computer housings and a solder alloy in cabling, also in melting agent in CRT glass	34,000	Antimony is carcinogen to human health. Due to this, various disorders arise like diarrhoea, stomach pain, vomiting, and inhalation of high antimony levels over a long time period may cause stomach ulcers
Arsenic (As)	Gallium arsenide within light-emitting diodes. Semiconductors, diodes, microwaves, solar cells		It can cause skin disease. Much chronic effects on human like lung cancer and impaired nerve signalling
Barium (Ba)	Spark plugs, getters in CRT vacuum tubes, electron tubes, fluorescent lamps filler for plastic and rubber, lubricant additives		It causes damage to the heart, mainly affects brain swelling, muscle weakness liver and spleen through short-term exposure
Beryllium (Be)	Power supply boxes which contain silicon-controlled rectifiers and X-ray lenses, motherboard, power supply boxes, relays and finger clips, also found in switchboards and printed circuit boards		Very carcinogenic which causes lung cancer, inhalation of fumes and dust causes chronic beryllium disease or beryllicosis
Cadmium (Cd)	Rechargeable NiCd batteries, fluorescent layer (CRT screens), pigments, printer inks and toners, chip resistors and semiconductors, photocopying machines (printer drums), solder, monitors, alloys, circuit boards	3,600	Irreversible toxic effects on human health especially in kidney cause neural damage; a long-time exposure causes *Itai-itai* disease, which causes severe pain in the joints and spine
Chromium (Cr)	Data tapes, floppy disks, galvanized steel plates and decorator or hardener for steel housing	198,000	Inhaling hexavalent chromium or chromium 6 can damage liver and kidneys and cause bronchial maladies including asthmatic bronchitis and lung cancer; it may cause DNA damage and permanent eye impairment
Copper (Cu)	Cabling, copper wires, printed circuit board. Tracks, pigments, copper ribbons	820,000	Its accumulation causes stomach cramps, nausea, liver damage, or Wilson's disease

(continued)

Table 2 (continued)

Substance	Source	Global quantity (tonnes)	Environmental and health effect
Lead (Pb)	CRT screens, glass panels, batteries, solder in printed circuit boards and gaskets in computer monitors, printed wiring boards	58,000	It has dangerous effect that damages the brain, nervous system, kidney and reproductive system and causes blood disorders. In foetuses and young children, even low concentrations of lead can damage the brain and nervous system
Lithium (Li)	Li batteries		Nursing baby may harm when lithium pass into breast milk, on inhalation of the substance may cause lung oedema
Mercury (Hg)	Fluorescent lamps that provide backlighting in LCDs, backlight bulbs or lamps, flat panel displays, in some alkaline batteries and mercury wetted switches	13.6	Chronic damage to the brain. Bioaccumulation in fishes causes respiratory and skin disorders. It can pass into mother's milk, impair foetus growth, and harm infants
Nickel (Ni)	Nickel–cadmium rechargeable batteries, electron gun in CRT, cathode ray tube and printed circuit boards	206,000	Allergy of the skin to nickel results in dermatitis, while allergy of the lung to nickel results in asthma and reduced lung function leads to lung cancers, bronchitis
Selenium (Se)	Older photocopying machines (photo-drums)		High concentrations of selenium consumption cause selenosis
Halogenated organic compounds			
PCB	Condensers, transformers	280	During combustion, printed circuit boards and plastic housings emit toxic vapours known to cause hormonal disorders
TBBA, PBB, PBDE	BFRs are used to reduce flammability in printed circuit boards and plastic housings, keyboards and cable insulation		Burning may cause toxic gas emission which causes various disorders in hormonal and neural system
CFC	Cooling unit, insulation foam		It is damaging the ozone layer which can lead to greater incidence of skin cancer
PVC	Cable insulation, computer housing		Incomplete and complete combustions generate toxic gas that causes air pollution and also produces dioxin that causes reproductive and developmental problems

1.9 Mt of e-waste generated by the whole continent. In comparison, South America (2.7 Mt), North America (7.9 Mt), Central America (1.1 Mt) generate a total amount of 11.7 Mt of e-waste that presenting per inhabitant generation is 12.2 kg [15]. In developing countries like India and China, e-waste generation is less than 1 kg/inhabitant/year where Hong Kong (21.5 kg/inhabitant), Singapore (19.6 kg/inhabitant) and Brunei (18.1 kg/inhabitant) are the top three Asian countries. However, highest amount of e-waste is generated by China (6 Mt) along with Japan and India of a total amount of 2.6 and 1.7 Mt, respectively, in Asia [15]. It is estimated that from 2007 to 2020 the e-waste generation only from old computers is hiked by 400 and 500% in China and India, respectively, where mobile phones will cause 18 times and 7 times increase [18].

2.7 Agriculture Solid Waste

Agriculture waste mainly covers the waste generated from agriculture fields, firms, hatcheries and woods. These wastes are highly enriched with biomass and reusable biodegrading materials [25]. These also have some other substances generated during various agricultural activities given in Table 3.

Wastage from agriculture field is the supplier of toxic compounds towards groundwater and surface water contamination [7, 25]. This wastage is coming from the excess use of fertilizer on fields where Nitrogen (N) and Phosphorus (P) are results of eutrophication of surface water. Eutrophication results allege boom and damage the ecological system of aquatic body. Thus, it increases the growth of aquatic weed and decreases the oxygen level which can cause death of flora and fauna. Excess use of pesticide may come in contact with living society which results in several health hazardous effects [26]. Poultry firm wastage is also contaminating the groundwater and surface water by generating heavy metals, pesticides and pathogens to soils. Most importantly, poultry waste contains nitric nitrogen (NO_3–N) which is responsible for 'blue baby' syndrome of human infants. In which bacterial reduction of NO_3^-converts to nitrite $\left(NO_2^-\right)$ which oxidizes iron in haemoglobin and results in the formation of methemoglobin. Methemoglobin choked the oxygen transport function which is called 'methemoglobinemia'. It increases the acidity in an adequate level for many bacterial functions in human stomach [25].

2.8 Extent of Agriculture Solid Waste

Agriculture solid waste composed with various wastes generated from different processes; for example, each year food processing units produces almost two million tons of solid wastes in which 40% is vegetable waste in USA. There is only 19% of total crop utilized for feeding and around 75% released to soil [25].

Table 3 Solid waste generation in various agriculture activities

Activity	Composition	Primary component
Leather tanning	Fleshing, hair biological sludge, grease, lime and chrome sludge, raw and tanned hide trimmings	Biodegradable organics, bacteria, chlorides, sulphide, nitrogen, chromium, grease
Animal production (feedlots)	Manures	Biodegradable organics are major content along with bacteria, nutrients, medicinal, salts, inorganic additives such as copper, arsenic
Sugar processing (beet sugar, raw cane bagasse, soil, pulp, lime animal feed bacteria, nutrients sugar, cane sugar refining)	Biological sludge, bagasse, soil lime mud, filter mud, pulp	Biodegradable organics, nutrients, bacteria
Crop production and harvest	Stover and straw	Biodegradable organics, bacteria
Fruit and vegetable processing	Biological sludge trimmings, peels, seeds and pits leaves and stems, soil	Biodegradable organics, nutrients, bacteria, salts, grease pesticides
Grain processing	Biological sludge, spilled grain	Animal biodegradable organics
Meat processing	Biological sludge product trimmings, bones feathers, hides, grease	Biodegradable organics, nitrogen, bacteria, chlorides
Timber production	Branches, leaves, small trees	Slowly biodegradable organics
Dairy product processing	Biological sludge	Biodegradable organics
Wood processing	Bark, small pieces, sawdust	Slowly biodegradable organics

2.9 Hospital or Biomedical Solid Waste (HSW or BSW)

The institutions like hospital and other healthcare centres are the places which provide treatment and assurance of public health irrespective of social and economic background. In the healthcare processing, these institutions may generate infectious waste which may be responsible for spreading diseases. These healthcare facilities are origin of vast wastes which are specifying as hospital waste. Hospital waste is also known as biomedical waste which can be defined as ‘any waste which is generated during diagnosis, treatment or immunization of human being or animals, or in research activities pertaining thereto, or in the production or testing of biological product’ [1].

Total hospital waste is generated from a health care establishment, research facilities, laboratories, and emergency relief donations. Generally, hospital waste is major content of non-hazardous and combustible materials. Remaining part is

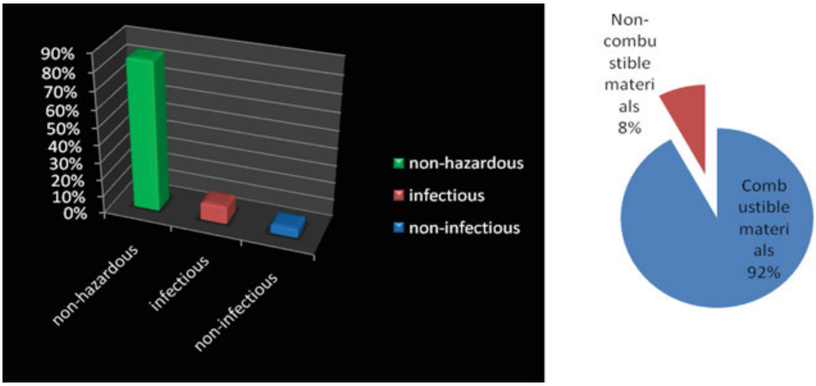

Fig. 4 Composition of hospital solid waste

consisting of infectious and non-infectious wastes [4, 10]. Percentages are given in Fig. 4.

Infectious wastes have hazardous effect on public health and environment. Where depending upon total amount of hospital waste in India, the percentage of infectious waste may vary from 15 to 35%; in USA the amount is ~15% [12]. Primary source of hospital waste are hospitals (Govt. hospitals/private hospitals/ nursing home), veterinary hospitals (including research centres), clinics, Primary health centres dispensaries, Medical colleges and research centres/paramedic services, Blood banks, mortuaries, autopsy centres, slaughter houses, Blood donation camps, Vaccination centres [12]. Other sources are household, acupuncturists, cosmetic piercing, funeral services, institutions for disabled persons [12]. Generated HSW are categorised in different ways, more general is tabulated depending on their source and composition in Table 4. Where also corresponding hazardous effect is also mentioned [1, 4, 10, 12, 27].

Focusing on the health issue related to HSW, sharps includes contaminated needles, broken glass, glass pipette, IV tubes, blades, slides it further classified in (i) sharps (contains contaminated or non-contaminated glass materials), (ii) radioactive sharps (contaminated with radioactive material such as in chemotherapy), (iii) chemical sharps (apparatus contaminated with chemotherapy drugs, broken thermometer contaminated with mercury). These cause severe effect of mercury contamination and spread infection like hepatitis, HIV, and some viral diseases [1, 28]. Other some infection are also potentially risky like plague, shigellosis, TB, diarrhoea, typhoid, VDRL, leprosy [29].

Infectious waste mainly generates from the material and equipment in contact with infected patient, body parts, discharge, blood, or fluid. Infectious wastes contains pathogens (i.e. fungi, bacteria, virus, parasite) which generates from pathological laboratories can be considered as pathological waste. Human and animal body parts are also recognized as anatomical waste [1, 5].

Table 4 Various categories of hospital waste

Category	Waste content	Source	Composition	Effect on environment
1	Human anatomical waste	Morgue, human anatomical research centres, hospitals	Human tissues, organs, body parts, foetuses, unused blood products	Can spread infectious disease like AIDS, hepatitis (A, B and C), influenza (H1N1)
2	Animal waste	All types of animal tissues, organs, body parts carcasses, bleeding parts, fluid, blood	Experimental animals used in research, waste generated by veterinary hospitals/ colleges, discharge from hospitals, animal houses	It can potentially spread various viral disease like haemorrhagic fever (Ebola), pledge
3	Microbiology and biotechnology waste	Wastes from laboratory cultures, stocks or specimens of micro-organisms used in research	Research laboratories, wastes from production of biological, toxins, dishes and devices used for cultures	Micro-organs can contaminate to environment and cause anthrax, meningitis
4	Waste sharps	Healthcare waste, clinical waste, hospitals, medicinal centres, research laboratories	Needles, syringes, scalpels, blades, glass, glass slides and cover slips, broken glass and splintered plastic, when contaminated with blood or other potentially infectious material	Various infected disease are spread through contaminated needles, syringes like AIDS, hepatitis (A, B and C), influenza (H1N1), anthrax and meningitis
5	Discarded medicines and cytotoxic drugs	Medicinal centre, hospital, chemotherapy centre, household	Outdated, contaminated and discarded medicines	The hazardous cytotoxic gas can serve as alkylating agent, antimetabolites and mitotic inhibitors
6	Solid waste	Various human and animal diagnosis and treatment centres	Blood contaminated cotton, dressings, soiled plaster casts, lines	It has the potential to spread diseases from the corresponding holder
7	Disposable solid waste	These types of waste are generated from more or less kind of biomedical centres	Tubing's, catheters, intravenous sets	They may be contaminated with heavy metal and harmful organic molecules

(continued)

Table 4 (continued)

Category	Waste content	Source	Composition	Effect on environment
8	Liquid waste	Every health centre including household, research laboratories, pathological centres	Waste generated from laboratory and washing, cleaning, housekeeping and disinfecting activities	Wastewater contains toxic substance like heavy metals, pathogens, which can cause contamination of groundwater and surface water
9	Incineration ash	Incineration plants of biomedical waste	Ash from incineration of any biomedical waste	Ash may contain neurotoxic element like mercury, its leach to food chain through water
10	Chemical waste	Disinfection section in health institutes, research laboratories	Chemicals used in production of biological and disinfection activities like insecticides	Disinfection, as insecticides

2.10 Extent of HSW

Depending upon national income and available waste treatment facilities, the total HSW generation varies nation to nation. In USA daily 10.7 kg of HSW is generated by a patient only in major hospitals in which 2.79 kg/bed/day is infected waste [10]. Those types of financially strong nations are generating waste normally 4–9 kg/bed/day, whereas moderated and lower income countries contribute 0.5–6 kg and 0.5–4 kg per each person of its population [1, 30]. As an example, Tanzania is generating around 0.3 kg of HSW per bed every day as well as Vietnam, Mongolia, Ecuador, Peru are also generating waste as per increasing order of per capita gross national income (GNI) which is shown in Fig. 5 [10].

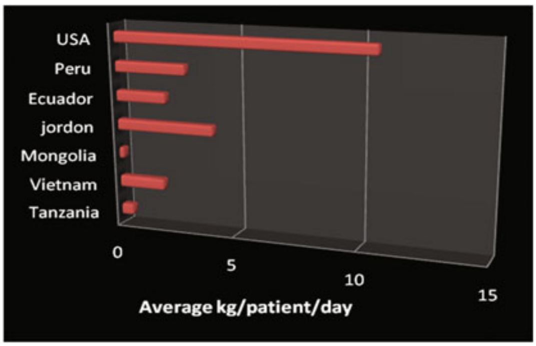

Fig. 5 Hospital waste generation with increasing order of per capita gross national income

In India, on basis of per bed/day HSW generation varies on type of hospital and its localization as government hospital generates 5–7 kg and private hospitals produce 2–4 kg in southern India. In the western India, the HSW is around 1–3 kg/bed/day for west India [1]. Only in Delhi, 65 tons of HSW is generating out of 6500 metric tons of total solid waste [27].

2.11 Solid Waste Management (SWM) Process

Globally, solid waste generation is growing day by day with the increasing population. Only in India, it is ranging around 0.2–0.6 kg/capita in cities which is generating 42 million tonnes of total solid every year, and these figures will cross 260 million tonnes in 2047 [20].

Therefore, for healthy environment proper integrated solid waste management (ISWM) is essential rather than conventional SWM which only involves waste collection, treatment and disposal. But ISWM focused on the reduction of waste at source, reuse of recovered resource and recycle of residue. With economic efficacy, reduction on environmental impact and ensuring multi-stakeholders participation the ISWM are more advantageous to the conventional waste management. The complete cycle of SWM contains waste collection, separation, storage, transportation, treatment and disposal [5].

Solid are waste are collected from various source and characterized upon there category like recyclability, combustibility, reusability, disposability and accordingly accumulate in corresponding places. As an example, hospital wastes are collected in different bins according to their colour code [12]. Stored solid wastes are transported to various treatment facilities like thermal, mechanical-biological, mechanical biological, material reclamation facility and some waste along with residual part of treatment facilities transported to final disposal [31].

Lack of awareness and modern facilities of proper waste management can cause serious health issues and environmental impact. The elementary level of waste management is not properly mentioned as an example during the production and collection of different categories (recyclable with hazardous) wastes are mixed. Furthermore, It is transported in inadequate manner like in tricycle, open truck using poor containers [32]. Rag pickers are responsible for recycle and reuse of this wastage with their bare hands [5]. After that, it goes for disposal in open land (dumping yard), incineration, combustion which liberates hazardous material that have various chronic effects on ecosystem [19]. Some of the treatment technology and disposal methodology are very usual and some are too specific for classified wastes (like hospital solid waste, municipal solid waste) [8, 12]. With limitation and advantage the main technologies in solid waste disposal and treatments are landfilling, composting, vermi-composting, biomethanation are the Mechanical Biological Treatment (MBT) methods [31] and some thermal treatments [33] like incineration, gasification and pyrolysis, plasma pyrolysis, production of Refuse-Derived Fuel (RDF) are the main technologies in solid waste disposal and treatment. RDF is also known as pelletization which is notable for municipal solid waste [20].

2.12 Mechanical Biological Treatment

Mechanical Biological Treatment (MBT) technologies are pre-treatment technologies for any waste treatment. Basically, MBT provides a diversion of SW from direct exposure of waste [34].

2.12.1 Landfilling

Landfilling is the most general and ultimate way of waste disposal though it ranked lowest in quality of waste management. All types of inert, remaining and residual part of waste treatment, organic waste, and mixed waste are dumped in lands which are the major source of greenhouse gases (CO_2, CH_4) [20, 31, 32]. Some heavy metals and organic material are responsible for groundwater contamination which results in lead, mercury, cadmium toxicity and other diseases [2, 13, 16]. Landfilling sites are breading house of insects, vermin which can spread malaria, cholera, etc., and rag pickers are searching this sites for their daily income, as a result but they are most exposed to, tetanus, respiratory problem, neural disorder [2]. People live around or downwind; these sites are also suffering from respiratory problem, headache and irritation due its odour [2, 20].

Advantage of landfilling [2, 8, 20]

- No need of highly skilled employees.
- Low cost for waste treatment.
- Highly potential for gas recovery which can use as source of energy.
- Through burying organic waste leads net gain for environment.

Limitation of landfilling

- Costly transportation to dumping land sites.
- Choke the drainage system and can contaminate both the groundwater and surface water.
- Major source of greenhouse gases.
- Need a large area of land for dumping.
- Birthplace for vermin, insect and may be origin of various diseases.

2.12.2 Composting

Farmers have been composting compostable organic material (cow dung, agro-waste) from the immoral time [20]. Micro-organism plays the main role in this technology for decomposition in various environments like warm, moist, aerobic and anaerobic [8, 20]. This technology is simple and commercially viable, and it is effectively applied in agricultural lands, fruit orchards, farmland, tea gardens, also in parks, gardens, etc. [20]. Some plants are established in Baroda, Mumbai, Calcutta, Delhi, Jaipur and Kanpur with capacities ranging from 150 to 300 tons per day during 1975–1980 [8].

Advantage of composting

- Augmentation in micronutrient deficiencies and improvement in soil texture.
- It maintains the soil health through increasing moisture-holding capacity and recycling nutrients into soil.
- It is very much straightforward and simple as well as cost-effective.
- Reduce the dependency on chemical fertilizer in agriculture field.

Limitation of composting

- Not suitable for all types of waste.
- Large open land required.
- Composting plants emits methane, odour and flies.
- Soil can contaminate with entering toxic materials.
- Lack of awareness and proper marketing of compost material [2, 8, 20].

2.12.3 Vermi-Composting

Vermi-composting is a process where biodegradable part of solid waste which is composted with the assistance of earthworms [8, 20]. Resultant part of vermi-composting is very much nutrient-rich, and further it can use for fertilization of agriculture field. *Pheretima* sp., *Eisenia* sp., *Perionyx excavates* sp., these worm species only survive in 20–40 °C and moisture ranges from 20 to 80% and responsible for generation of 50 MT of solid waste per day in town and cities [35]. These worms consume waste five times more than their body weight [8]. Largest vermi-composting plant with capacity of 100 MT/day is situated in Bangalore, India [20]. Some plants in Hyderabad, Bangalore, Mumbai and Faridabad are established for vermi-composting. Introduction of toxic materials in waste can kill these earthworms and the process requires a large area of land composting [8].

2.12.4 Anaerobic Digestion and Biomethanation

In recent time, this technology is less expensive for disinfection and stabilization of waste like farmland residue, industrial sludge and animal slurries [20]. The main objective of this process is generation of biogas which contains 50–60% of methane through composting of organic waste [8]. Production of bio-gas can source of power generation. The value-added part of this process is that the residual part is enriched with nutrients and could be as composting fertilizer which results in environmental a net gain. Efficiency and energy recovery of biomethanation are better than composting [8, 20]. In 3 weeks, 1 ton of waste produces 2–4 times of methane than the landfilling of 1 ton waste in 6–7 years and energy production of

100–150 kWh per tons [8]. These plants need less land area and treating in a closed system, and it also free from bad odour, rodent and fly menace, visible pollution. But the method is only suitable for biodegradable organic waste that is why before using this treatment waste must go through segregation [20]. In India, BARC has developed this technology which commercialized as Nisarguna Biogas Plant. Earlier A 5 MW power plant was established in Lucknow, India. Unfortunately due inadequate supply of waste it was close down. A few small-scale power plants are still actively working in Vijayawada [8, 20].

Globally there are many active plants of MBT, but Europe has most number of plant around 330 with a capacity ranges from 50000 to 305,000 tonnes annually where permitted capacity is 2,728,300 tonnes waste.

MBT plant at Waterbeach, Cambridgeshire operated by AmeyCespa with highest capacity of 179,000 tonnes per annum. Later on, a few successor MBT plants were established in Frog Island and Jenkins Lane, East London and Farington, Lancashire which are operated successfully with 180,000 tonnes capacity (by Shanks and Global Renewables). A plant in Bredbury Parkway, Stockport and Reliance Street, Manchester, run by Viridor Laing is capable of 100,000 tonnes of waste treatment per year. Cotesbach, Leicestershire and Southwark plants are controlled by New Earth Solutions and Veolia, respectively, with capacity ranging from 50,000 to 90,000 tonnes per year [34].

2.13 *Thermal Treatment*

The main aim of this technology is to minimize the release of toxic waste and treatment residual part, and principle technologies are incineration, gasification and pyrolysis [33].

2.13.1 Incineration

Incineration is subjected to disposal of solid waste through high-temperature combustion in control with proper way [8, 20, 31]. The incineration temperature belongs within the range 980 to 2000 °C [8]. At this high temperature, wastes are converted into ash as a residual part with emission of gaseous product gas. This process leads to destructions of toxic material as well as recovery of energy. Incineration reduces volume upto 80–90% of the total volume of combustible waste [8]. This feature can be developed with enough high temperature, and it reduces up to 5% of its original volume. Additionally this process is noise free, odorless and hygienic [8, 20]. These thermal plants can be constructed nearer to the source of the waste which will minimize the transportation cost. In developed countries like japan having insufficient place for landfilling, therefore such incineration methodologies are most commonly used in this countries keeping in mind lack of large area for landfill [8, 33].

Flipping other side, incineration may cause potential emission of pollutant like dioxins, furans and PAHs [2, 31, 33]. Among these persistent organic compounds more specifically polychlorinated dibenzo-p-dioxins, (PCDDs), polychlorinated dibenzofurans (PCDFs) and polychlorinated biphenyl (PCBs). PCDDs and PCDFs are the mostly coming out due to incomplete combustion of municipal waste, medical waste and household waste. SO_x, NO_x are also emitted by this process [2, 8, 20, 31, 33]. It needs large operation and high maintenance cost with skilled personnel [20].

In 1987 at Timarpur, Delhi an incineration plant installed Miljotecknik volunteer, Denmark, with a cost of Rs. 250 million for Delhi Municipal Corporation [8]. This plant has capacity of 300 tonnes per day and 3.75 mw of power generation [20]. But due to its low performance and high maintenance charge, it was forcedly shut down [8]. Solid wastes are high content of organic waste, inert material, moisture and wet containing wastes; this is why incineration is not a well-practiced scenario in Indian methodology [8, 20].

In small cities, this method is used in lesser extent only for hospitals and institution like BARC has constructed a plant in Trombay, Mumbai, for their institutional waste [8].

2.13.2 Pyrolysis

A substance when thermally degraded without oxygen that process is called pyrolysis [20, 33]. In pyrolysis, required temperature ranges is in between 300 and 850 °C and for thus a continuous external heat source is continuously required [33]. Synthetic gas and char are the products of pyrolysis of waste material. Carbon and non-combustible materials are the main constitution of char, wherein syngas like methane, carbon mono oxide, hydrogen are major content [20, 33]. These gases further can be used for fuel oil generation and condensed for wax and tar preparation [20].

2.13.3 Gasification

Gasification is a partial oxidation process of substance with insufficient oxygen and resulted in a process between the combustion and pyrolysis [33]. The operating temperatures are typically above 650 °C of this exothermic reaction [33]. Before application wastes are required to be dried and then segregated. During the operation the syngas so generated comprises of hydrogen, carbon monoxide and methane [8, 20]. This syngas can be used instead of natural gas as fuel gas and energy recovery could be possible with this method. In compared to incineration, gasification does not emit any toxic gas like SO_x, NO_x because of insufficient oxygen [20]. This process needs high amount of financial support and power source, and the efficiency can be affected by the presence of high moisture and inert content in waste [8, 20]. Production of high viscosity may cause in operation and its transportation [20]. After gasification, the solid non-combustible residual part needs proper handling and disposal. In plasma gasification technology high temperature (electric arc) is applied to the waste material thereby converting it to an inert residue (ash). This result in vitrification of the inert material accompanied with cracking of the tar component that eventually leads to emission of clean syngas [33]. Initially two gasification units are installed in India, first one (NERIFIER) by Narvreet Energy Research and Information (NERI) at Nohar, Hanungarh, Rajasthan and the second one at Gaul Pahari campus, New Delhi, Tata Energy Research Institute (TERI) gasification unit by Tata Energy Research Institute (TERI). NERIFIER operates with an efficiency of about 70–80%, and the waste treatment rate is $\sim$ (50–150) kg per hour [8].

2.13.4 Refuse-Derived Fuel (RDF)

This method is useful for producing improvised solid fuel or pellets which can further use in industrial furnace from mixed municipal solid waste [20]. As gasification, RDF is also capable of reduction of pollution and more in recovery of energy through producing power [8, 19, 20]. RDF is much prominent fuel when it is mixed with coal or that type of conventional fuel [8]. Although this expensive method requires well trained expertise to operate, however, owing to its efficiency in energy recovery process developing countries are applying this technique in large number [8, 20]. A RDF plant near Golconda dumping yard in Hyderabad, India, is constructed in 1996 with a capacity of 1000 tons waste feeding per day. This used to produce about 6.6 MW of power with 210 tonnes of pellets per day [8]. Another large-scale RDF plant is in installed Deonar, Mumbai, that operates by Excel India. In Bangalore the amount of production is about 5 tons of fuel pellets for domestic and industrial purpose by compacting 50 tons of MSW per day [8, 20]. A same type of plant is constructed by M/s Shriram Energy Systems Ltd. at Vijayawada which is operational since November 2003 [20].

3 Conclusion

Human civilization consciously or unconsciously is on the verge of generating a tremendous amount of solid wastes that consequence in serious health-related issues. ‘Prevention is better than cure’ is a very popular adage; abided by it here too prevention of these practices is superior to curing the detrimental effect on living system and environment. However, this can only be feasible by proper system of waste management and most significantly public awareness. Waste management not only deals with its treatment and disposal; it is a whole system that incorporates reduction of waste generation, collection, segregation and proper transportation to its corresponding recycling hub. Disposal of solid waste with conventional way is not so effective in reducing its noxious effect. As a consequence, for biodegradable waste, composting is a very useful method since here the residual part can be further used as fertilizer. Some disposal methods like gasification, pyrolysis, RDF can minimize the solid waste volume and its lethal effect. These methods are very efficient for generating fuel, for instance syn gas which can be a prominent source of energy in the recent future. Our research on different technologies such as plasma arc pyrolysis or autoclaving for safe disposal of solid waste is under active progress.

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