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Review Article

Sustainable solutions for solid waste management: A Review

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Abstract

Population growth, rapid strides in urbanization and industrialization as well as inadequate expertise and infrastructures have made the management of solid waste as one of the most critical environmental issues in developing countries like India. It is estimated that more than 60% of the waste generated in such countries have the ultimate fate to reach the dumping sites. The unscientific disposal of waste causes adverse impacts on all components of environment. The deterioration of soil and water quality due to leachates in the areas near open dumping sites has been well documented. Besides, evidences are also being accumulated to show increased concentration of various pollutants like pesticides, heavy metals and other toxins in such areas. Consequently, the management of solid waste needs to be revamped in order to protect the living beings and to make certain the healthy existence of the environment for long time. The first step for sustainable solid waste management is the segregation of waste on site of generation of waste; where in, the recyclable wastes are separated from those of organic waste and other inorganic waste. In further seggregation, the organic wastes are sent for compositing and vermicompositing. Compositing is degradation of organic wastes by biological means under controlled aerobic/anaerobic conditions to form stable, odorless humus like end product whereas vermicompositing is a bio-oxidative process of decomposition of organic waste involving the combined action of earthworms *viz., Amynthas morrisi, Dendrovena veneta, D. bolaui, Eisenia andrei, E. foetida* etc. and other soil microorganisms. The remaining waste can either be incinerated (converted to ashes by burning at high temperatures) or sent for pyrolysis (split of organic wastes through thermal cracking and condensation extractions into gaseous, liquid and solid fractions in order to recover chemicals). Finally, the waste from which nothing can be recovered should be disposed in sanitary landfills (concreted low lying areas of city/town under an engineered operation and special design so that contaminants in disposed waste may not pollute nearby soil or water). The effective implementation of the above mentioned step wise sustainable solid waste management can certainly solve the environmental pollution problems to a great extent. However, the role of an individual to reduce the per capita waste still is the best remedy to solve this problem.

Keywords: Composting, Vermicomposting, Pyrolysis, Sanitary landfills.

1.1 Introduction

The global urbanization has resulted in increased volumes of solid waste all over the world. The generation of solid waste in developing countries like India has been reported to be many folds higher than those of the developed countries (Kansal, 2002; Garg, 2010). It is observed that solid waste generated in different cities of India (small, medium and large cities) is nearly 0.1 kg, 0.3-0.4 kg and 0.5 kg per capita per day, respectively (Joseph, 2002; Santra, 2005). Further, these values can probably increase significantly in the coming years as the country is going to attain the industrialized nation status by the year 2020 (CPCB, 2004). The main drawback of increasing waste is that the huge percentage of it is dumped daily in dumping sites which are fully open and are without proper management. This practice leads to occurrence of several dreadful environmental consequences and also increased health risks for the communities living nearby. In addition to causing outbreaks of diseases and epidemics, improper management of solid waste also caused deleterious effects on ecology (Jha *et al*., 2003; Sharholy *et al*., 2005; Rathi, 2006; Bundela *et al*., 2010).

Although the natural processes have enough capacity to dilute, disperse, degrade, absorb the unwanted materials (wastes), but due to attaining of saturation point, the natural processes alone cannot serve as the absolute remedial measure (Garg, 2010). Simultaneously, the deleterious consequences of unsafe disposal of solid waste had not only attracted the attention of researchers/ scientists throughout the world, but also ignited their minds to search for the new methods/techniques for safe disposal of wastes. Consequently, many techniques like recycling, pyrolysis, incineration, sanitary landfilling had been discovered that are well adopted worldwide to tackle the problem related to handling of solid wastes. Considering various aspects of solid wastes, the present article is an attempt to compile available information on composition and sources of solid waste, its impact on health/ecology as well as remedial measures.

1.2 Composition of solid waste

The major components of solid wastes include garbage, rubbish, incombustible ashes, street wastes as well as special wastes. Garbage mainly includes all types of biodegradable organic wastes collected from kitchens, hotels, restaurants etc. The major portion of garbage comprises of food articles, vegetable/fruit peelings etc. Rubbish includes either combustible (paper, plastic, textiles etc.) or incombustible (broken glass, crockery, metal, masonry etc.) materials. The incombustible ash mainly consists of ashes from industrial and household hearths. Street sweeping mostly includes fine dust, silt and sand along with the leaves, papers/wrappers etc. In addition to above four usual components, solid waste also includes special wastes such as, construction debris, abandoned appliances, automobiles and electronic wastes. In rural areas, however, the cattle dung and crop wastes comprise the dominating portion of solid waste (Santra, 2005; Garg, 2010).

1.3 Impacts of solid waste

The general observations and literature survey reveal that in all the developing countries, more than 60% of solid waste finds its way to reach the open dumping sites which not only destroys the scenic beauty by disturbing natural vegetation of the area but also poses threat to the living beings residing in/near such areas. Many studies have reported the adverse effects of open dumping sites on both environment and human health as discussed below.

1.3.1 Effects on ecosystem

The inadequate disposal of solid waste leads to environmental degradation as reported earlier (Damodaran *et al*., 2003; Visvanathan and Glawe, 2006). Many scientists are of the opinion that active or closed landfills produce leachates can be a major source of contamination for ground and surface waters (Meju, 2000; Ding *et al*., 2001; Kjelden *et al*., 2002). The leachates released from the dumping sites have been reported to seep down and caused the deterioration of ground water quality (Abu-Rukah and Al-Kojahi, 2001; Kelly and Wilson, 2002; Noraini, 2003; Bahaa-elden *et al*., 2010). The environmental degradation by open dumping sites of waste has also been witnessed to cause contamination of three main ecosystems viz., water, soil and air through leachates, direct contact, burning etc. Also, the spread of diseases by different vectors like insects, rodents and birds and release of harmful and poisonous gases like methane, carbon dioxide as well as dioxins by anaerobic decomposition of wastes are well documented (Nagayama *et al*., 1998a, 1998b; Sakai *et al*., 2001; Kunisue *et al*., 2004; Visvanathan and Glawe, 2006). The increased concentrations of heavy metals (Agamuthu, 2001; Agusa *et al*., 2003; Gupta *et al*., 2007) and pesticides like DDT, PBDE, PCBs and HCH have also been reported in many studies (Minh *et al*., 2004; IIyina, 2007). The various contaminants present in such areas disturb the ecosystem and pose the potential threat to the biodiversity of an area. Solid waste landfills on natural ecosystems of ‘Southern Caspian Sea Coastlines’ resulted in huge loss and decline in carrying capacity of aquatic and terrestrial bodies (Monavari *et al*., 2013). Furthermore, dumpsite at Mangwaneni area of Manzini city, Swaziland was studied for its harmful effects on environment and the health of the residents living in close proximity. It was observed that the dumpsite led to outbreak of flies, mosquitoes and rodents which transmit various diseases and recommended that the distance of dumpsites from human settlement areas should be more than 200 meters (Abul, 2010).

1.3.2 Effects on human health

The direct disposal of solid waste on the land also results in causing unsafe living conditions for the people residing in nearby areas of dumping sites. The outbreak of plague started with Black-death killed one third of European population of 14th century and claimed many more lives in subsequent years mainly due to the low standard of sanitation and lack of proper disposal management (Garg, 2010). Improper or poor collection of society's refuse has also caused the pneumonic plague in Surat city of Gujarat, India in September 1994 (Garg, 2010).

Kunisue *et al*. (2004) investigated breast milk from women living near municipal waste dumping sites of India, Combodia, Vietnam and Philippines and reported high content of dioxins and other related compounds such as polychlorinated dibenzo-p-dioxins (PCDD), polychlorinated dibenzofurans (PCDF), and coplanar polychlorinated biphenyls (PCB). Nagayama *et al*., (1998a and 1998b) observed the change in thyroid hormones in Japanese breast-fed infants due to the post natal exposure of infants to chlorinated dioxins and related compounds. Many other scientists (Zhou *et al*., 2001; Zhou *et al*., 2002) studied the change in thyroid hormones in breast-fed infants due to continuous exposure to chlorinated dioxins and related compounds. Many epidemiological studies have showed the incidence of illness in employes working at waste sites and on the resident population near such sites (Giusti, 2009).

Low birth rate, prematurity and different birth defects in children residing near hazardous waste sites have been reported (Geschwind *et al*., 1992). Besides this, the reproduction disorders and cancer induction in adults have also been documented (Morikawa *et al*., 1997). Various contaminants like heavy metals present in dumping sites are reported to cause different physiological problems like hypertension, sporadic fever, renal damage, cramps etc. (Rao and Sharma, 1998). Apart from causing the toxic effects, the contaminants of dumping sites can also pose potential damage to the gene pool.

Chakarborty and Mukherjee (2009) reported the mutagenicity of leachates of dumped coal fly ash. Some reports are available on genotoxic effects of incinerated ashes (Mouchet *et al*., 2006). Mouchet *et al*. (2006) reported genotoxicity of bottom ash of municipal solid waste incinerations employing Ames and *Xenopus laevis* micronuclei tests. The genotoxic effects of somatic cells of *Allium cepa* exposed to leachates of tannery solid wastes have been indicated by various scientists (Chandra *et al*., 2005). Genotoxic potential of soil samples contaminated by electronic wastes employing *Vicia faba* micronuclei test has been documented by Jan-Hui and Hang (2009).

Sankoh *et al*. (2013) determined the environmental degradation and health implications of solid waste disposal at Granville Brook dumpsite in Freetown, Sierra Leone which resulted in prevalence of high rate of malaria and other related diseases. Also, Alam and Ahmade (2013) in his study highlighted the sources of solid waste, type of wastes, methods of solid waste disposal and harmful impact of improper solid waste management on environment and living beings. The effects of solid wastes on different ecosystems like soil & water, plants, animals and humans were well documented by many scientists (Aljaradin and Persson, 2012; Magaji, 2012).

1.4 Remedial measures

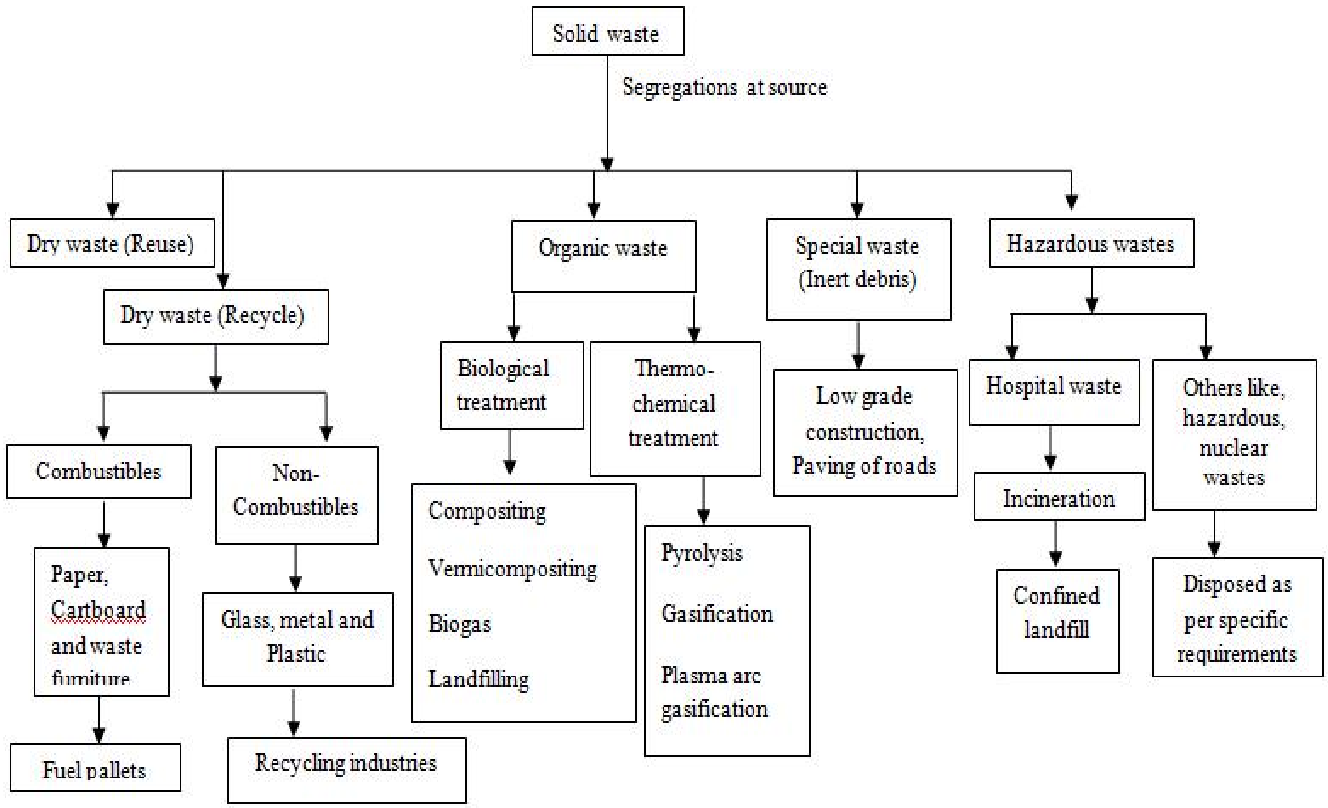
Sorting of waste is the first step to manage the solid waste, where in the materials, which can be recycled back, are separated out. Many studies have suggested recycling as a sustainable method of solid waste management (Bastida *et al*., 2008; Ngoc and Schnitzer, 2009). The biodegradable waste, after separation, can be converted to useful manure by compositing and vermicompositing. Compositing is a process of decomposition of organic waste in presence or absence of air (Castaldi *et al*., 2004; Bernal *et al*., 2008; Roca-Perez *et al*., 2009). During this process, the organic waste is first shredded to small pieces and dumped in a pit covered (aerobic)/not covered (anaerobic) in order to avoid the spreading of waste by vultures, rodents or cattles. The pit is sprinkled with water and material is turned regularly for proper aeration during aerobic process of compositing. On the other hand, vermicompositing represents a biooxidative process of stabilization of organic material involving the combined action of earthworms *viz.*, *Amynthas morrisi*, *Dendrovena veneta*, *D. bolaui*, *Eisenia andrei*, *E. foetida* etc. (Kaushik and Garg, 2003) and other microorganisms. Many studies have been conducted to estimate the biofertilizer potential of different types of solid wastes involving compositing (Francou *et al*., 2005; Ahmed *et al*., 2007) as well as vermicompositing (Chaudhari *et al*., 2000; Garg *et al*., 2006). Francou *et al*., (2005) used four types of wastes such as green waste, bio waste, sludge and municipal waste, while Ahmed *et al*. (2007) used tannery waste for the preparation of biofertilizers. All the studies showed that the nitrogen, phosphorus, potassium, carbon and C/N ratio were found to be enhanced in compost as compared to fresh waste.

Chaudhuri *et al*. (2000) studied chemical changes during vermicompositing of kitchen waste including remnants of fruits, vegetables and drained liquid of boiled rice using *Perionyx excavetus* and found that nitrogen, phosphorus and carbon contents were increased in vermicompositing. Garg *et al*. (2006) decomposed kitchen waste, agro-residues and institutional waste using *E. foetida* and found increased content of nitrogen, phosphorus and potassium. They opined that the vermicompost so produced was good quality manure. In another study, Suthar (2007) prepared vermicompost from waste material like yard manure, residues of cereal crops, cattle feeds, vegetable waste and household waste using *Perionyx santibarious* and reported that *P. santibarious* produced high nitrogen, phosphorus, potassium and low organic carbon and C/N ratio for vegetable waste. Mehta and Karnwal (2013) studied solid waste management in four different types of vermin-beds containing food, agricultural, medical and industrial wastes by vermi-compositing and its further use in crop improvements.

Among other processes, incineration is a waste treatment process involving the combustion of organic substances contained in waste materials. During this process, waste material gets converted into ash, flue gas and heat. In recent years, the new technology of waste-to-energy has also been widely recommended wherein the energy in the form of heat produced during burning is used for distillation purpose or for production of electricity. The various methods adopted to recover energy from wastes include gasification, plasma arc gasification, pyrolysis and aerobic digestion. The process that converts carbonaceous materials such as coal, petroleum, biofuel or biomass into CO and H_2 by reaction with the raw material at high temperature under controlled amount of O_2 and steam is known as gasification. The resulting mixture is called synthesis gas or syngas which is used as a fuel. Plasma arc gasification is a solid waste treatment technology which uses electrical energy at high temperature created by an electric arc gasifier. In a plasma converter, arc breaks down waste primarily into elemental gas and solid waste (slag). This process can be used to generate electricity in near future depending on the composition of input wastes thereby reducing the volume of waste being sent to landfills.
Thermo-chemical process, pyrolysis can be used to decompose the organic waste material at high temperature in the absence of oxygen. This process typically works under high pressure and temperature above 430°C (800° F).

A series of processes in which microorganisms break biodegradable solid waste material in the absence of O_2 can be termed as anaerobic digestion, which can be used for industrial and domestic purposes to generate energy. Malkow (2004) suggested pyrolysis and gasification as a novel and innovative technologies for energy sufficient and environmentally sound solid waste disposal. Khoo (2009) reported that out of different technologies of solid waste management, gasification and pyrolysis were the most cost-effective waste conservation systems. Velghe *et al*. (2011) investigated production of valuable products by pyrolysis of municipal solid waste containing carpet disposal waste, plastic/metal/drinking cartons, paper and synthetic materials residues.

The last option for the disposal of solid waste seems to be the sanitary landfilling. It is the method where all the waste, from which nothing can be recovered, disposed off in sanitary landfills (concreted low lying areas of city/town under an engineered operation and special design so that contaminants in disposed waste may not pollute nearby soil or water). Although sanitary landfills have been documented to cause the leaching problems (Sharholy *et al*., 2008; Troschinetz and Mihelcic, 2009), production of foul odors (Devkota *et al*., 2012), but yet many studies have indicated their advantages over the open dumping of wastes (Tatsi *et al*., 2003). The integrated solid waste management can be represented as given in flow chart. The effective implementation of stepwise sustainable solid waste management (as shown in Fig. 1) can certainly solve the problems related to handling, transport and disposal of solid waste, yet, emphasis must be given on reduction of waste at source by every individual and even by participation of different private sectors (Manandhar, 2002).



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