

# Sustainable Solid Waste Management through Landscaped Landfills

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## Abstract

**Background/Objectives:** The paper looks into an approach to develop landscape solution to landfill sites or an unused land which allows a sustainable disposal option of urban organic waste as well as a sustainable maintenance of land in urban areas. **Methods/Statistical Analysis:** The paper identifies landfills as specific examples of urban landscapes which can be transformed to landscaped landfills. Such a plan can be formulated only by knowing the quantity and quality of the waste generated the available resources and the environmental conditions of a particular region. This paper looks into an innovative approach where source separated biodegradable waste that is taken to a landfill could be a source for landscape development. **Findings:** As a result the paper describes a conceptual model for landscaped landfills where it considers two options; one is rehabilitating existing dump sites (due for a clean-up) and another for setting up new sites for disposal. For both these solutions the organic/biodegradable nature of the waste can provide nutrient for plant growth which is an essential element of landscape. However, for a continuous maintenance and management of such sites the model tries to integrate certain existing waste management techniques without overlooking the environmental risks associated. Further, the paper explains the cyclic process of landscaped landfills in three different phases which includes the dumping phase, degradation phase and the planting phase. The paper briefly outlines that the extent and intensity these phases are site specific and depends on the quantity and quality of the waste, plant growth period and climate. **Application/Improvement:** The model describes a strategy and methodology to convert landfills/open dumps or any vacant land into a fitting component of typical urban landscapes through enhancing its environmental significance and visual quality for sustainability.

**Keywords:** Environment, Landfills, Landscape, Solid Waste, Sustainability

## 1. Introduction

A significant increase is observed in the amount of solid waste generated in developing countries. Though the waste generated here is less when compared to their counterpart in developed nations, their limitation in collecting, processing or disposing the waste has led to an improper waste management system. In many cases, waste segregation at source does not happen or if it is done, then at disposal units, biodegradable and non-biodegradable waste are mixed up. By and large these disposal units are often open dumps or landfills<sup>1</sup>. This leads to serious threats to land and its resources and eventually affects the life of the people living there. But open dumping or

dumping on engineered landfills (in case of developed countries) has been a most widely used option these days. Due to urbanization the landfills which were located in the city outskirts earlier has been shifted and has now become part of urban landscape. In an Indian context as most of the landfills refer to open dumps sites (which are not sanitary landfills in most cases), the terminology used in this paper too mean the same.

Every country has different rules and regulations for disposing solid waste. The waste handling rules in India, MSW management rules 2000 highlights land filling as a last option in solid waste management and only non biodegradable wastes should be diverted to landfills<sup>2</sup>. This is with regards to the varied nature of the wastes

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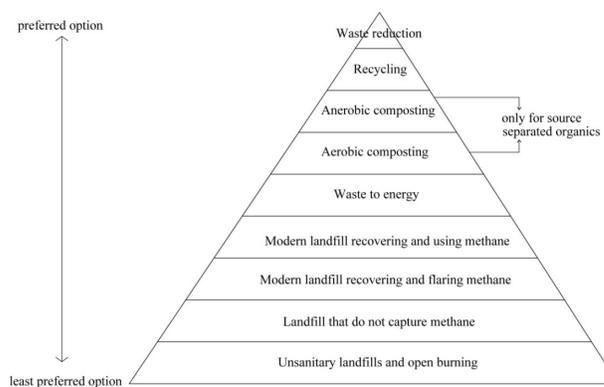
that are dumped in landfills and also no proper treatment or control measures are carried out in them. The physical and chemical characteristic of the solid waste vary depending on the population and geographical location. Biodegradable waste constitutes a major portion of the total waste world over<sup>3</sup>. Since these biodegradable wastes are generally disposed in open dumps/landfills among other wastes, the possibilities and potentials of these waste is less tapped. It is found that biodegradable waste can be a major nutrient source which can influence the vegetation in a landfill site. Besides imparting aesthetic value, vegetation on landfills plays a major role in controlling soil erosion and removing toxic contaminants. In addition, it avoids the possibility of such sites being areas of low quality both environmentally and aesthetically. But availability of land area for such dumps/landfills is one of the key issues in an urban city. Furthermore, land filling waste without any treatment can lead to long term environmental risks like leachate, green house gas emissions. In spite of all these issues, the paper aims to develop a framework for developing environmentally sound and socially acceptable sites for waste disposal. The main objective of this research paper is to understand the waste character and its appropriate disposal methods so that it can be a resource for landscape development. A further objective was to understand the possibilities of integrating waste management techniques like composting, land filling and their potential to provide nutrients to plant growth (which is an essential design element in landscaping). A third objective was to evolve a sensible planting regime which uses species suitable for a region, character/content of the waste for a successful cyclic development of landscape. This paper explores the idea of landscape development on open dumps/landfills with minimum environmental interventions thereby transforming landfills from a mere dumping site perspective to a sustainable landscaped landfill.

## 2. Review of Literature

### 2.1 Waste Characterization

Researches show that the character and composition of the waste depends on the size of the population and the geographical location which in turns dictate the waste management strategy. In general, at a global level biodegradable waste constitutes 60-70 % of the total waste<sup>3</sup>.

Landfill directive formulated by European Environmental Agency (EEA) encourages biodegradable waste to be diverted from landfills while promoting alternative waste management options such as recycling, composting, mechanical biological treatment and incineration. Mechanical biological processing or simple composting of MSW is suggested as one option for improving the landfill performance in the tropical region by reducing landfill emission<sup>4</sup>. A study using Life Cycle Assessment (LCA) shows that the incineration option to be more favourable than the landfill, recycling or composting options<sup>5</sup>. However, in an Indian condition, the economic modelling results showed higher running costs and lower associated jobs when compared to the other options like recycling. In India, the waste fraction is majorly organic in nature in spite of the change in composition due to lifestyle of the people<sup>6</sup>. Table 1 shows the composition of MSW in India with its regional variation<sup>7</sup>.



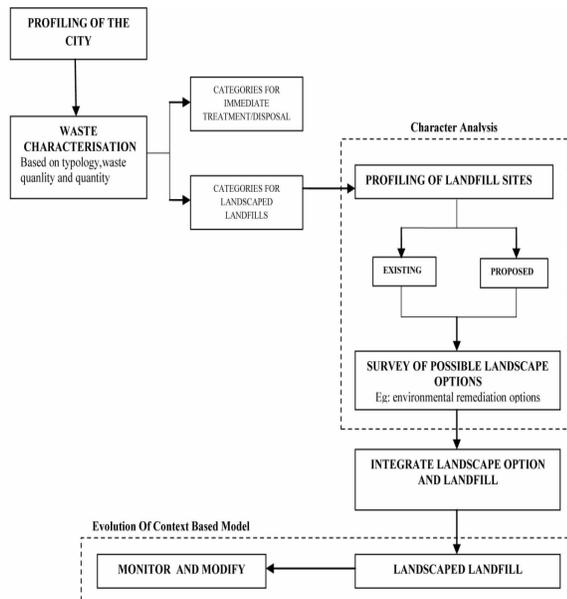
**Figure 1.** Sustainable waste management hierarchy.

Source<sup>7</sup>.

### 2.2 Sustainable Waste Management

The population increase and its allied development in an area have certainly had its impacts on waste generation, disposal rates and have eventually affected the environment. Sustainable waste management tries to tackle these long term impacts through reducing, recycling, and recovering resources from waste in an effective way without causing environmental or economical constraints. Figure 1 shows the hierarchy in sustainable waste management which says waste reduction, reuse and recycling are the most preferred methods. Composting is more successful with regards to material recovery and its reuse is concerned. Wastes that cannot be recycled are good source of energy recovery. But inappropriate ways of disposing

these waste ends up in open dumps/landfills causes various risks to environment and people which eventually makes it the least preferred option.



**Figure 2.** Landscaped landfills – a conceptual model.

With regards to organic waste, its decomposition and stabilization through various natural cycles forms the basis of recycling. As such composting is found to be the most cost effective and simple technology which can considerably reduce the waste volume<sup>8</sup>. It is said that 9% of MSW is treated by composting<sup>9</sup>. Full scale composting has already been established in many cities but their application on land for landscape development is limited. This may be due to poor marketing<sup>6</sup>. Aerobic composting can be done either by manual or mechanical means. Manual composting is carried out in smaller urban centres/neighbourhoods and mechanical composting is done in big cities<sup>10,11</sup>. Another method of processing organic waste is anaerobic digestion where, anaerobic microorganisms act on the waste in the absence of air to release methane (which can be used as bio gas for cooking), CO<sub>2</sub> and an organic residue which is good manure. In fact this process occurs naturally in a landfill/open dumps if the waste is not turned regularly. But this process is found to be slower than aerobic composting<sup>8</sup>. Researches in the field shows that if there is enough space available, then composting is a better option thereby reducing the load of collecting and transporting MSW to open dumps/landfills and thus reducing the pressure on them<sup>8</sup>.

More than 90% of Municipal Solid Waste (MSW) in cities and towns are directly disposed on land and open dumps without following the norms of sanitary land filling which is a recommended method for disposal of MSW<sup>8</sup>. Compaction, leveling and the cover of the waste are rarely observed and no leachate collection/recirculation system or landfill gas monitoring is done<sup>10</sup>. In these landfills, organic waste which constitute about half the total waste tend to decompose by natural process giving rise to odour, pest, insects which can lead to serious health issues. However in India disposing waste in open dumps/landfills would continue as an adopted practice, in which certain improvements shall be made to ensure sanitary landfills<sup>12</sup>. But an important issue these days, mainly in cities, is the limited space available for dumps/landfills or for processing waste. In certain cases the existing landfill capacity exceeds its limit<sup>1</sup>. A study by the energy and resources institute (earlier Tata Energy Research Institute) (TERI) says that if MSW is not properly handled, by 2047 the area of land occupied for MSW disposal will be 1400 sqkm where the area occupied in 2001 was only 240 sqkm<sup>13</sup>.

Urbanization and its impacts on the carrying capacity of an existing landfill or on providing space for a new landfill, has in total affected the urban landscape of many cities in developing countries. A thoughtful process of managing the potential organic waste of a city thereby recycling a major portion of MSW within the landfill site to create a distinctive urban landscape is more challenging. Any kind of upgradation measures must ensure that at every stage of the process environmental issues and aesthetics are not overlooked. In the next section environmental risks associated with solid waste land filling are explained.

## 2.3 Environmental Risks and its Control

Aerobic and anaerobic micro organisms degrade organic waste causing landfill gas and leachate. In addition to potential health hazards caused due to this, environmental impacts includes landfill settlement, unpleasant odour, vegetation damage, air pollution, ground water pollution, landfill fire and global warming.

### 2.3.1 Landfill Gas

When a waste is dumped in a landfill it undergoes aerobic phase initially and then an anaerobic phase which is dominant. During the anaerobic phase, organic mate-

**Table 1.** MSW composition in India

Region/City	MSW (TPD)	Compostables (%)	Recyclables (%)	Inerts (%)	Moisture (%)	Cal. Value (MJ/kg)	Cal. Value (kcal/kg)
Metros	51,402	50.89	16.28	32.82	46	6.4	1,523
Other cities	2,723	51.91	19.23	28.86	49	8.7	2,084
East India	380	50.41	21.44	28.15	46	9.8	2,341
North India	6,835	52.38	16.78	30.85	49	6.8	1,623
South India	2,343	53.41	17.02	29.57	51	7.6	1,827
West India	380	50.41	21.44	28.15	46	9.8	2,341
Overall Urban India	130,000	51.3	17.48	31.21	47	7.3	1,751

Source<sup>7</sup>

rial is converted to methane and carbon dioxide which forms more than 90% of the landfill gas. The quality of the landfill gas depends on the stage of decomposition in a landfill<sup>14</sup>.

### 2.3.2 Leachate

Soluble compounds in waste are removed by non uniform and intermittent percolation of water through the refuse resulting in leachate. Percolation of water is mainly due to the runoff. Precipitation, irrigation, groundwater intrusion and refuse decomposition due to microbial activity also add on to the leachate formation but to a lesser extent. The quality of leachate generated is site specific and a function of water availability and weather conditions as well as the character of the refuse, landfill surface and the underlying soil<sup>14</sup>. Laboratory and field studies have shown that there is microbial degradation of the organic content in the leachate under either aerobic or anaerobic conditions which are less toxic<sup>15</sup>. However it is found that leachate become toxic in landfills where domestic waste is disposed with industrial wastes.

### 2.3.3 Control Measures

In many cases landfill gas recovery system and collection and treatment system has been installed in order to prevent gas emission and its migration from the landfills. Other control measures are installation of impermeable barriers along the landfill boundary, passive venting and a hybrid system consisting of active and passive venting<sup>14</sup>. Injection of lime slurry and fly ash has been reported to control methane formation and stabilize landfills by inhibiting methanogenesis<sup>16</sup>. Leachate control measures

include volume and composition control, treatment and disposal or recirculation<sup>14</sup>. Ground water intrusion and leachate infiltration are reduced by covering the landfill base with clay or synthetic liners. Surface runoff can be collected in drainage channels or in a leachate collection system by designing the landfill cover on slopes<sup>14</sup>.

### 2.3.4 Environmental Remediation Measures

The control measures discussed above are implemented in MSW landfill sites where all kinds of wastes with differing composition is dumped. Since the topic covered by this paper at this level is only dealing with such issues to a limited extent, they are managed by the processes explained further. Any remediation measures adopted varies and depends on the site condition and its level of contamination. Researches show environmental remediation strategies must be the basis of any development in a degraded site<sup>17</sup>.

#### 2.3.4.1 Phytoremediation

Phytoremediation is a cleanup technology which uses green plants to remediate toxic contaminated sites which offers a viable solution to many environmental difficulties related to landfill rehabilitation. The plant selection and the type of phytoremediation application depend on the contaminants present, site conditions and the local flora. It is observed that methane which is a major content of Landfill Gas (LFG) is easily oxidized by having vegetation on landfill sites<sup>17</sup> thereby increasing evapotranspiration and thus enhancing bioremediation. Limitation of this process is that it is time consuming when compared to other conventional cleanup technologies<sup>18</sup>. Also, if the

contaminants are not within the root zone then the process applicability gets limited. However this issue can be solved by selecting plants with deep extending roots or by standard agricultural practices like ploughing or irrigating plants with contaminated waste water<sup>19</sup>. It is noted that not much studies are available in terms of the application of phytoremediation in the field of landscape architecture which involves planning, design and management of both natural and built environment<sup>1</sup>.

#### 2.3.4.2 Bioremediation

In this technology biodegradation of organic contaminant is stimulated by microbial population. This is done by making certain improvements like adding oxygen and exotic microbial species which destroys the contaminant and reduces the toxicity. In bioremediation most of the microbes are concentrated in the horizon of the soil which makes the degradation easier at that level. But this becomes difficult when the contaminant extends deeper. In such cases the nutrient supply for the microbial growth are provided by growing plants with deep extending roots. In this case phytoremediation and bioremediation are used synonymously. Also there are cases where biological activity of the soil is lost due to bioremediation and which makes vegetation on such sites difficult<sup>20</sup>. Currently different kinds of bioremediation technologies which include both in situ and ex situ processes are used for soil treatment.

#### 2.3.4.3 Bioreactor Landfill

Bioreactor landfill is another innovative way of managing solid waste which has received attention in last several years. Here transformation and stabilization of organic matter is done by enhancing microbial population in a sanitary landfill. For this certain management activities and operational modifications are required which includes shredding the waste, managing temperature, adjusting pH, adding liquids or nutrients. As a result, a rapid stabilization of the waste is observed with an increased gas yield and improved leachate quality. Apart from this bioreactor landfill reduces the post closure maintenance and risks associated. It should be noted that in such landfills, by stabilizing organic waste the capacity of landfill is increased thereby extending its life span.

To ensure a long term usage of a landfill site, a comprehensive landscape framework which complies with all environmental and regulatory rules has to be adopted.

For this a landfill which holds only bio degradable that can supply nutrient for vegetative growth has more scope. Dumping such waste on landfills leads to various environmental risks which can be nullified by environmental remediation techniques as discussed. However the suitability and extent of the treatment and remediation measures discussed to an Indian context has not been sufficiently studied in regards to sustainable waste management leaving a gap for research in this area.

## 3. Landfills as Potential Landscape Option

Generally, landfills are defined as a method of disposing waste on land in a more engineered manner so that it protects the environment. In many cities, waste dumped in landfills is of a heterogeneous nature due to lack of segregation and treatment. Due to various physical, chemical and biological processes, the biodegradable fraction in the waste in such landfills starts degrading causing landfill gas and leachate. Its toxicity aggravates due to the mixed nature of the waste causing risk to the environment. Landfills which were located in the city outskirts earlier have now become part of the city affecting its landscapes. It is understood that these landfill will continue to be a component of waste management since the waste management rules mandates that only end product of certain waste treatment technologies alone should go to landfills. But in most cases, improper treatment and maintenance of landfills has affected its visual stability making it an ignored and isolated part of the urban fabric which needs upgradation.

Urban landscapes are shaped by natural and social process that take place in an urban fabric. Thus it is significant from all its perspective, right form, parks, private open spaces, recreational areas to land used for dumping waste. As such, their locations and maintenance influences the built environment. The quality of waste that goes into the landfill and the potentials of such waste to develop landscape in an area need to be explored. Though landfills consist of various complex processes, the possibility of biodegradable waste to degrade easily and become a nutrient source in developing soft elements of landscape is an important component in developing landscaped landfills. Besides providing aesthetic value such landfill sites can help in controlling erosion and harmful contaminants.

In an attempt to conserve and develop landfills as a sustainable waste disposal area and simultaneously improve urban landscape, this paper explores alternatives such as upgrading existing landfills or creating new landfills. To achieve this, various treatment methods and remediation/cleanup techniques need to be integrated. Landfill mining is used as a first step in cleaning up existing landfills which can excavate and separate biodegradable and non biodegradables from the refuse. The organic waste thus separated and on further degradation can be good compost for soil or can itself be a planting medium in developing the soft elements in a landscape design. Other techniques like bio remediation are used to reduce the toxicity of the soil and thus improve the soil condition for plant growth. This can also be in combination with other clean up technologies like phytoremediation, depending on the contaminants of the existing landfill site. Researches in the field of phytoremediation show that plants with larger root system have capacity to treat contaminant at deeper levels. As a unique landscape element, the growth rate of the plants proposed in a landscaped landfill depends on various factors like climate and hydrologic condition of a site. Moreover, in a landscaped landfill where a cyclic process of the waste dumping and landscape development progresses alternatively, demands a careful selection of native plant species that has a faster growth rate in a particular condition.

## 4. Results and Discussion

In an integrated waste management system landfills have remained as the easiest method for disposal of waste which cannot be reduced, recycled or processed. But due to improper waste management and maintenance the landfills have become an unsightly part of urban landscapes which are often ignored. In an attempt to convert landfills to a crucial component of typical urban landscapes by exploring its environmental and visual significance the paper describes a methodology which can be adapted in a larger scale. The issue is of supreme relevance when in most urban context the landfill capacity exceeds its limit and site itself poses risks to health and environment. To accomplish the idea of converting landfills to landscaped landfills and thereby achieving a sustainable model the paper examines two options; one is rehabilitating existing dump sites (due for a clean-up) and another for setting up new sites for disposal. For both these solutions the organic/biodegradable character of the waste can provide

nutrient for plant growth which is an essential element of landscape. Figure 2 shows the conceptual model to explain how a context based landscape landfill is evolved.

However, for a continuous maintenance and management of landfills, one may have to use a number of support/ancillary process of waste management like composting, mechanical biological treatment, phytoremediation and bioremediation. In the case of upgrading or remediating an existing open dumpsite, organic fraction needs to be separated by landfill mining as an initial step. Also principles of phytoremediation which uses green plants for remediating sites can be used. The selection of plants depends on its growth pattern and life span while considering the climate and hydrologic conditions of the site. Identification, selection and maintenance of plant species will be a significant part of the planting regime in a landscaped landfill development and management. This will demand inputs from other allied disciplines such as agriculturists, environmentalists and engineers. In setting up new landfill sites (option 2) site selection strategies and construction methods along with environmental control measures has to be suitably devised. In either of these options, the dump sites continues to be a disposal base unit and requires a continuous upkeep and maintenance to progress itself to a quality landscaped landfill.

In short, a typical landscaped landfill will undergo three different phases. Phase I, a dumping phase where source separated organic waste is dumped in landfills. Phase II is a degradation phase where this organic waste is left to degrade aerobically which will be determined by various physical character of the waste. Phase III is a planting phase where the degraded content acts a nutrient source for plant growth. This stage includes planting, irrigating, pruning, harvesting, replanting and monitoring the whole process. From literature it is understood that for a selection of appropriate plant species on any landfill site is to use the endemic species. In addition, the plants chosen should improve the physical, chemical and biological status of the soil. Plant selection can be classified as fruit/flower bearing, leafy, legumes and tubers. Legumes can restore nitrogen in poor soil conditions. Grass can provide fine roots in the surface of the planting medium which can keep the soil loose and augment infiltration and aeration, thereby providing soil stabilization. Care should be taken so that such plants do not over dominate and restrict the growth of other plants on the landfill. Fast growing plants which are easy to plant and maintained in a given climate are preferred. In a landscaped landfill to

attain a cyclic process of dumping and developing vegetation, agricultural plants which give maximum yield in a shorter period of time can be selected. By doing so, after harvesting, the same site could be used for waste dumping and process can be continued.

A cyclic process as explained above depends on the time required for the plant growth. So plant species which has a longer growth period is not suitable. A systematic selection of plants and understanding its growth regime will be part of the urban scale development of landscaped landfill. However, the different growth patterns of the plant communities can be staged and transformed to specific landscape typologies which include ground covers, tall and medium shrubs etc as the case may be, thus making a frame work for urban landscape form. Climate is yet another determining factor of the decomposition process. During rainfall the time required for the degradation process gets extended. How exactly the process is affected due to change in climate is not explored in the current paper.

## 5. Conclusion

The paper explores the idea of developing landscape out of landfills by considering landfills as specific pattern of urban landscapes. This can be achieved by systematically segregating biodegradable waste from source and bringing them to landfills where it is degraded naturally over a specific period so that the high nutrients in it can support plant growth. In light of this, the paper considers two landfill contexts. One is remediating existing landfill which is due for a cleanup and other creating new landfills. In either of these options selecting appropriate varieties of plants considering location, climate, hydrology and its growth pattern is very crucial. In most upcoming cities where unsegregated waste that goes to landfills becomes a serious issue, a conceptual landscape framework of the discussed type can transform any open dump/landfill or any vacant land within a city or neighborhood to landscaped landfills without overlooking the environmental, functional and aesthetic quality of a landscape. By doing so it may no longer be necessary to view an open dumpsite as a mere disposal area rather to see it as a method for large scale processing of waste thereby urban waste are recycled and recovered in a sustainable manner.

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