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RESEARCH ARTICLE

# A mathematical model for sustainable landfill allocation and waste management

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## Abstract

With a population of 7.4 billion, the world is experiencing rapid population growth, contributing to increased waste production and causing increased Landfill construction and usage. Selecting a landfill site is crucial to sustainable solid waste management because it guarantees that the waste produced in a community or area is disposed of safely. This study establishes an LP model for cities with high per capita waste generation that contemplates several cost considerations. Furthermore, waste management is addressed, with a particular emphasis on construction and demolition waste (CDW) and municipal solid waste (MSW), by including emission costs and the transportation cost of both of these wastes to their respective landfills. The result demonstrates how the most efficient landfill satisfying the requirements is allocated. A Python code was developed to determine the landfill allocation for MSW and CDW. Seven landfills are assigned to each city for MSW, and four landfills to the cities that met the CDW constraints and optimized the total cost of 4,25,03,971, which is the lowest amount required for the process of transporting both MSW and CDW from their collection areas to their respective dumping sites. This study aids in determining which landfills require additional development to accommodate their long-term usage.

**Keywords**: Landfill sites, Transportation cost, Emission cost, Landfill allocation, Cost Minimization, Sustainability, and Waste management.

## Introduction

Over the past few decades, the production of industrial, construction, and demolition (C&D) and municipal waste has rapidly increased in tandem with the steadily expanding industrial production and trade in many nations worldwide (Vaverkova, 2019). When choosing a suitable dumpsite location, environmental effects must be taken into account. Thus, choosing a location for a landfill is a lengthy and difficult procedure that requires evaluating several factors. From the perspective of environmental degradation and the well-being of people, the final disposal of solid debris is the most crucial step in the management process (Domingo et al., 2009). Landfills receive non-recyclable and non-reusable waste (Muthu Selvi et al., 2023).

In India, the average cost of running a landfill is between Rs 500 and Rs 1,500 for every ton of waste. Waste collection, transportation, treatment, and disposal are all included in this cost (Mongabay, 2021).

## Literature Review

Landfills were previously chosen solely based on land accessibility and not socio-environmental or scientific considerations (Talyan et al., 2008). However, the choice of the landfill site needs to incorporate societal, monetary, and ecological factors in addition to local rules. Consequently, a large number of criteria ought to be applied. Therefore, choosing a good landfill location is a difficult and time-consuming process (Chang et al., 2008).

Historically, solid waste (SW) has been dumped into or on top of the soils or oceans on earth's surface. SW is dumped in the earth's surface soils using physical structures called landfills. Across the previous century, landfilling has also been the most economical and environmentally responsible method of disposing of SW globally (Franchetti, 2009). Topography, engineering, soil science, land use, hydrogeology, sociology, and economics are just a fraction of the whole societal and ecological disciplines that must

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be thoroughly understood to evaluate trash managing sites (Babalola et al., 2011). The process of Convenient Landfill Site Selection (CLSS) contemplates several variables, such as land slope, topography, land use, climate, and distance from major roads and cities (Dursun et al., 2011). Some of these issues center on the enormous amounts of waste generated in urban areas. Furthermore, some of the contributing factors to the increase in MSW include inadequate resources, inefficient urban waste management, and expansive urbanism (Eskandari et al., 2015).

A unified, viable procedure that takes into account all the waste is required in place of a distinct waste management system for every kind of waste because of the fast urban shift, demographic expansion, economic progress, and increase in waste types (Sener et al., 2020). A sustainable SWM process requires policies and practices like landfilling, thermal treatment, recycling, reclaim, debris minimization, and others. Among these, the landfilling technique is widely recognized as the most extensively used approach for waste management (Rafew et al., 2021).

A system for trash management should be environmentally friendly, economically viable, and socially acceptable to be sustainable. Waste management can be made both efficient and sustainable by reducing service delivery costs and improving the effects that SW disposal has on local populations and other environmental factors (Simsel et al., 2022). The primary key objective of attaining sustainable progress is to locate appropriate landfills (Mousavi et al., 2022).

## Mathematical Model

### *Notations*

*Parameters*

$T_{ij}^1$ Transportation cost of MSW per ton

$T_{ij}^2$ Transportation cost of c & d per ton

$E_{ij}^1$ Emissoin price for MSW per ton

$E_{ij}^2$ Emission price per ton of c & d waste

$W_i^1$ Municipal waste generation rate from state i

$W_i^2$ Amount of C&D debris produced from state i

$C_j^1$ MSW Per day capacity of landfill j

$C_j^2$ CDW Per day capacity of landfill j

$\ddot{u}$ Distance from state i to landfill j

$D\ddot{u}$ The maximum allowable distance

*Decision variables*

$x_{ij}^1$ Amount of MSW transported from state i to dumpsite j

$x_{ij}^2$ Amount of c&d transported from state i to dumpsite j

*Index*

$i$ Index for states $\forall i = 1, 2, \ldots 7$

$j$ Index for landfills $\forall j = 1, 2, \ldots 20$

### *PROBLEM DESCRIPTION*

*Objective*

$$\text{Minimize Z} = \sum_{i=1}^{n} \sum_{j=1}^{m} (T_{ij}^1 * x_{ij}^1 + E_{ij}^1 * x_{ij}^1) + (T_{ij}^2 * x_{ij}^2 + E_{ij}^2 * x_{ij}^2)$$

*Subject to the constrain*

$$\sum_{j=1}^{m} x_{ij}^1 = W_i^1 \qquad \forall i = 1, 2, \ldots 7$$

$$\sum_{j=1}^{m} x_{ij}^2 = W_i^2 \qquad \forall i = 1, 2, \ldots 7$$

$$\sum_{i=1}^{n} x_{ij}^1 \le C_j^1 \qquad \forall j = 1, 2, \ldots 20$$

$$\sum_{i=1}^{n} x_{ij}^2 \le C_j^2 \qquad \forall j = 1, 2, \ldots 20$$

$$x_{ij}^1, x_{ij}^2 \ge 0, \qquad \forall i, j$$

$$dij \le Dmax \qquad \forall i, j$$

The model has been developed to manage two categories of waste: CDW and MSW. This model calculates the total expense of moving waste from collection locations to the designated landfills and aids in landfill allocation. For both types of waste, the defined objective function minimizes the overall cost of transportation and emissions. Constraints (1) and (2) make sure that every city's collected waste, including MSW and C&D waste, is placed in a landfill. The constraints (3) and (4) ensure that the landfill's capacity for both types of waste is not exceeded. Additionally, both kinds of waste allocation variables need to be non-negative, according to equation (5). Equation (6) guarantees that only landfills are within a feasible distance.

Table 1 below provides the data collected from the highest waste-generating cities in India, including the amount of municipal waste and construction waste produced, the number of dumpsites, and the capacity of each landfill.

## Result

The numerical data takes into account the amount of municipal and C&D waste generation, along with the

**TABLE 1:** The highest waste generation places and their landfills

| *Highest waste generator* | *MSW generation rate (ton/day)* | *CDW generation rate (ton/day)* | *Landfill sites* | *Per day capacity of the landfill* |
|---|---|---|---|---|
| | | | Bhalswa | 2000 |
| Delhi | 8289 | 3711 | Tehkhand | 2000 |
| | | | Ghazipur | 1950 |
| | | | Okhla | 1300 |
| Ahmedabad | 3000 | 1000 | Gyaspur | 500 |
| | | | Pirana | 2400 |
| Faridabad | 1200 | 300 | Bandhwari | 2000 |
| | | | Astoli | 1410 |
| Noida | 600 | 300 | Sector 123 | 600 |
| | | | Sector 145 | 1500 |
| Mumbai | 5481 | 919 | Deonar | 5500 |
| | | | Kanjurmarg | 6000 |
| | | | Dhapa | 3000 |
| Kolkata | 3798 | 702 | Garden reach | 100 |
| | | | Pramod nagar | 600 |
| | | | Mittaganahalli | 3200 |
| | | | Mavallipura | 3600 |
| Bengaluru | 4574 | 426 | Kannahalli | 500 |
| | | | Doddabidarakallu | 200 |
| | | | Chikkanagamangala | 300 |

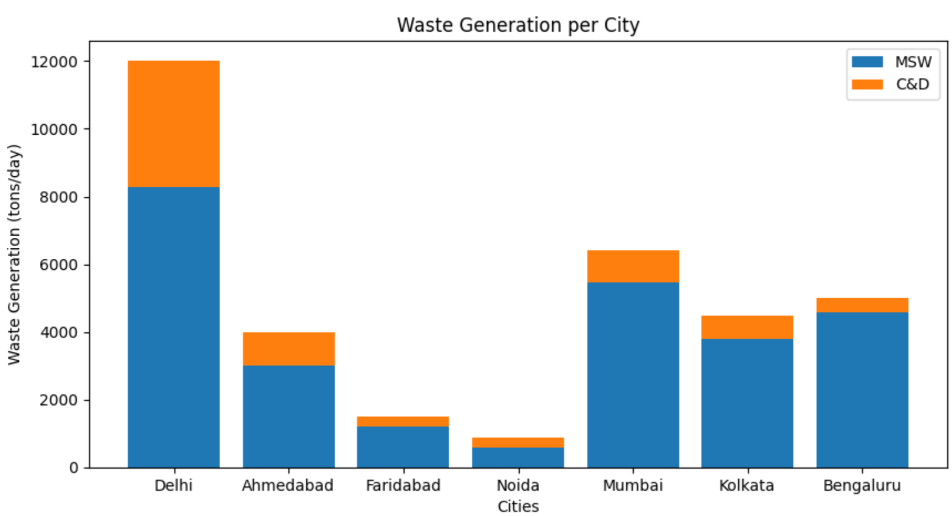


**FIGURE 1:** The waste generation rate of each city

distance, transportation cost, and emission cost from the dumpsite sites to the surrounding areas, namely the north, south, east, and west of the cities. The results obtained for MSW and CDW are represented below as figures, founded on a mathematical model that categorizes the waste generation, capacity, and distance constants. Every one of the seven locations is designated for the disposal of municipal waste; Tehkhand has been assigned to Delhi, Ahmedabad to Pirana, Faridabad to Bandhwari, Noida to Astoli, Mumbai to Deonar, Kolkata to Dhapa, and Bengaluru to Mavallipura. Four locations—Delhi to Bhalswa, Ahmedabad to Gyaspur, Mumbai to Deonar, and Kolkata to Pramod Nagar were assigned to their respective CDW landfills.

The results exhibit that not all of the twenty landfills in the states with the highest waste generation have the necessary resources to handle waste. The CDW in Faridabad,

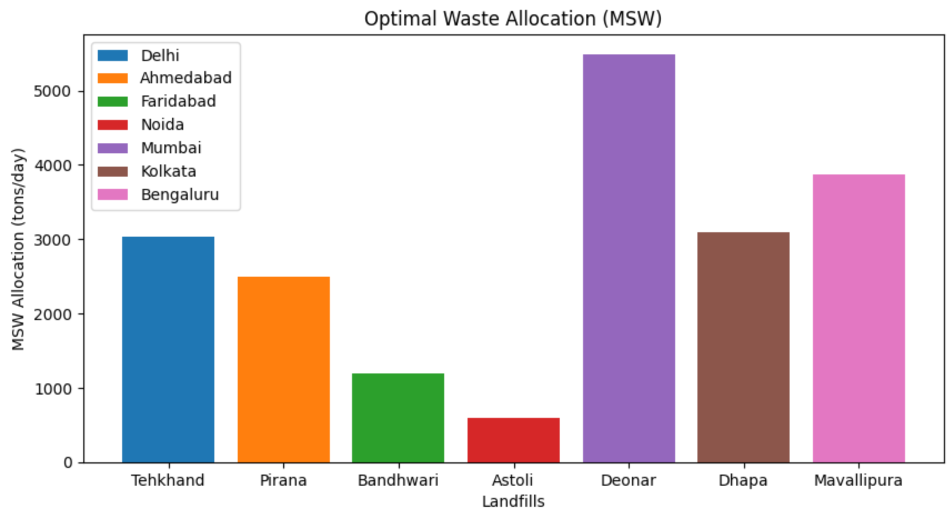


**FIGURE 2:** The Optimal waste allocation for municipal solid waste

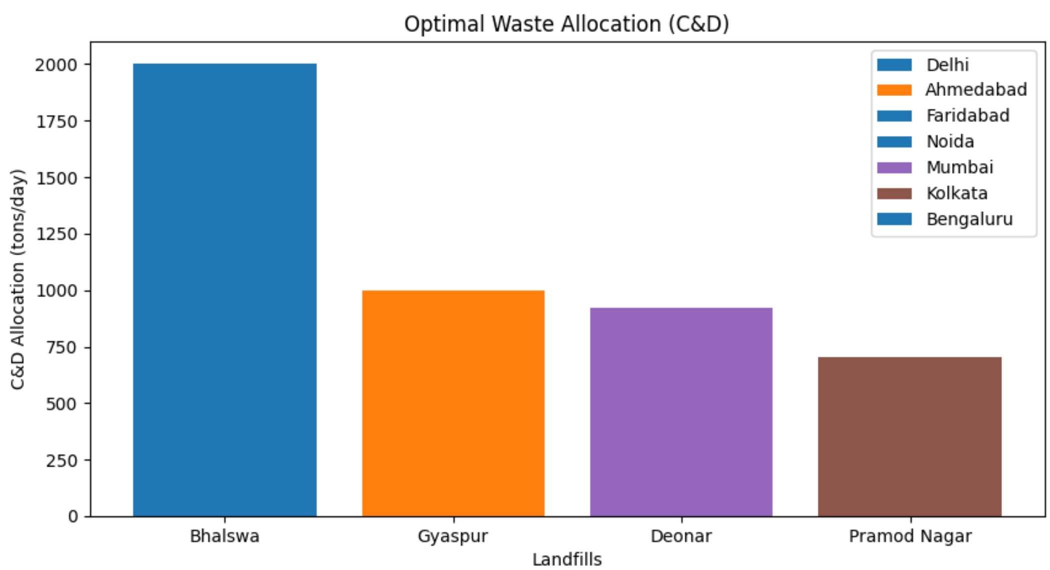


**FIGURE 3:** The Optimal waste allocation for C&D waste

Noida, and Bengaluru still needs to build a landfill that can handle construction waste in addition to municipal waste. Figures 2 and 3 represent the optimal waste allocation to landfills.

MSW and CDW will cost a total of Rs. 4,25,03,971 to transport all the debris from the collection points to its allocated landfill location.

## Discussion

Some waste materials will always need to be sent for disposal, even in cases where high levels of waste avoidance, reuse, and recycling are attained. Thus, the idea of a sustainable landfill ought to be put into practice. A landfill that safely integrates waste materials into the environment is considered truly sustainable (Vaverkova, 2019). Landfilling is still the most extensively used method for disposing of construction waste, even with efforts to encourage recycling and reuse. Given the limited space available for landfills and the potential harm to the environment and society, choosing the right location for a landfill is essential (Ding et al., 2018). By examining a specific region, Varanasi in India, it was observed that there are at least four places that fall under the "best suitable" category where there appears to be enough land for landfilling (Ohri et al., 2013).

## Conclusion

Landfill allocation is important because it helps to ensure that solid waste is managed and disposed of safely and efficiently. MSW and CDW have different characteristics and may require separate disposing methods. Separating municipal and construction waste is important because it reduces environmental impact and allows for more recycling. The results and discussion make it widely evident that proper landfill allocation is necessary and that municipal waste disposal options are more comprehensive than those for construction and demolition waste. The construction industry is expanding in emerging countries like India, but more attention is still needed to its disposal methods. One of the major environmental and social health issues in metropolitan areas is choosing the best location for waste disposal.

Furthermore, The optimized total cost value was estimated, and the waste was allocated for both MSW and CDW. The efficient landfills were allotted considering the transportation cost, emission cost, and time factors into account. For better waste management, Bengaluru, Noida, and Faridabad must build better landfills for CDW. Keeping processing landfills improved and properly run can result in a sustainable environment that improves human well-being.

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## Conflicts Of Interest

The authors declare no conflict of interest.

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