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Mathematical Model for Optimal Solid Waste Management and Disposal in Bida Metropolis, Niger State, Nigeria

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Abstract: *The improper handling and disposal of solid wastes cause threats to human health and the environment. One reason for the improper handling and disposal of these wastes is that not much consideration is usually given to the logistical aspects of solid waste systems. In this study, mathematical model of solid waste management (SWM) is presented for Bida metropolis, Niger state. This study developed a mixed-integer optimization model for SWM of Bida, Niger State Nigeria. The model optimizes the total cost of SWM, which includes the cost of transporting different types of waste between other locations plus the fixed cost of establishing and maintaining/operating some facilities. In this paper, waste disposal and management in Bida metropolis was modeled. The optimal cost of Eight Million, Six Hundred and Ninety Seven Thousand, Four Hundred and Fifty Naira (N8, 697,450.00) per year is obtained. In order to improve solid waste management in Bida, the municipal authority and private companies need to formulate more strategies and implement technological innovations necessary for effective disposal and recycling of solid waste at optimal cost.*

Keywords: Bida Metropolis, Cost Optimization, Mathematical Model, Optimization Techniques, Solid Waste Management

Introduction

Solid waste in particular, is usually made up of complex biodegradable and non-biodegradable substances (Barma *et al.*, 2014). The compositional volumes and weights vary from one location to another, depending on population size and culture/lifestyle. Solid waste contains not only valuable and often reusable materials such as metals, glass, paper, plastics, and food remain, but also an ever-increasing amount of hazardous waste. Some wastes such as lead, manganese from batteries, cadmium, and arsenic from fluorescent tubes, pesticides, and bleaches are hazardous. Discarded electronic sets such as computers, toys, handsets, and television waste a range of toxic chemicals that occur in solvents, paints, disinfectants, and wood preservatives.

The SWM is one of the challenging issues in urban cities due to various interrelated factors suchasoperationalcostsandenvironmentalconcerns.Asoneofthemostsignificantconstraintsof SWM, the cost can be effectively economized by efficient planning approaches (Asefi *et al.*, 2015; Barma and Modibbo, 2022). The SWM continues to be a big challenge in urban areasworldwide, especially in villages, where solid waste increases at an alarming rate, particularly in underdeveloped countries (Sabeen *et al.*, 2016). United Nations Environment Programme (2015) opined that the first Global Waste Management Outlook, published by the United Nations Environment Programme (UNEP) and the International Solid Waste Association (ISWA) in 2015, highlighted the need for greater detail on the generation and management of waste at the regional level. The first Africa Waste Management Outlook published by the UNEP in June 2018 responded to this global call. The Africa Waste Management Outlook sets out the current state of SWM in Africa, including waste governance, the associated environmental, social and economic impacts of waste, and the opportunities waste provides through appropriate solutions and financing mechanisms.

To keep the environment green and clean, monitoring and disposing of waste is very important these days. Improper disposal and poor monitoring of collected waste and waste bins can cause serious damage to human lives. This waste can spread various life threatening diseases that in turn harm the lives of a whole city and country as well.

Nowadays, cities are facing various problems, such as small parking spaces (Awaisi *et al.*, 2019) waste management, communication barriers in traditional systems, and health issues to name a few (Din *et al.*, 2019; Islam *et al.*, 2020). All these problems directly affect the living of humans in their daily routine lives (Jan *et al.*, 2019).

Many mathematical models have been developed to study the treatment of hazardous wastes by physical, chemical, thermal, and biological processes. Additionally, mathematical programming techniques such as linear programming, dynamic programming, and network models have been used to aid in managing the logistical aspects, such as finding the optimal location and size of facilities, of hazardous and nonhazardous wastes. Linear programming models are used in the identification of cost effective configuration of transportation routes, transfer stations, processing facilities, and secure long-term storage impoundments.

Several models have been designed for integrated SWM systems. Although these models are a proper means for helping decision-makers and engineers in the integrated SWM planning process, each of them has considered only a certain portion of the SWM sections. In the present study, a mathematic model was used to optimize the current system of SWM in Bida metropolis of Niger state.

Waste management is crucial for every country since it directly affects the health of its people and their environment. For example, in some developing countries like Nigeria, cholera outbreaks are common in congested and showery areas. Therefore, an efficient and effective SWM is necessary. Olapiriyakul *et al.* (2019) asserted that inefficient or poorly designed waste management systems affect society and the economy. Perhaps, excessively long waste transportation routes can negatively impact a large share of the population and increase transportation costs. Also, the successful establishment of sustainable SWM is dependent on the network design and transportation planning; thus, minimizing transportation costs is unavoidably one of the most critical issues in designing SWM policy for any metropolitan.

Materials and Methods

The data for this study is collected from journals, questionnaires, scavengers, and vendors of solid waste to get the prices of recoverable and reusable wastes. A mixed-integer mathematical programming model was formulated to analyse the data using lingo software version 18.0

Model Assumptions

The assumptions are intended to formulate the mixed integer programming model which was used to model Solid Waste Management System for Bida metropolis of Niger state. These assumptions are as follow:

1. It is assumed that all generated solid waste in Bida metropolis of Niger state are collected from the sources to the collection centres and then transferred to the landfills.
2. In Bida metropolis of Niger state, there is no waste separation at the sources. Waste separation is done at the collection centres where the scavengers are allowed to do the separations.
3. Industrial and institutional wastes are transferred to the nearest collection centre at the expense of their generators.
4. Transportation cost is proportional to both the distance travelled and the carried load.
5. The collection of waste is done at the time when there is no traffic jam.
6. The distances are measured from the centroid of either the streets or the facilities.

Mathematical Formulation of the Model

Generally, the model is represented by the network in Figure 2. There are m sources and n destinations, each represented by a node. The function (f) represents the routes linking the sources and destinations. f(i, j) joining source i to destination j carries two pieces of information: the transportation cost per unit, sign and the amount shipped, xij. The amount of supply at source i is Si, and the amount of demand at destination j is dj. The objective of the model is to determine the unknowns' xij that will minimize the total transportation cost while satisfying the supply and demand restrictions.

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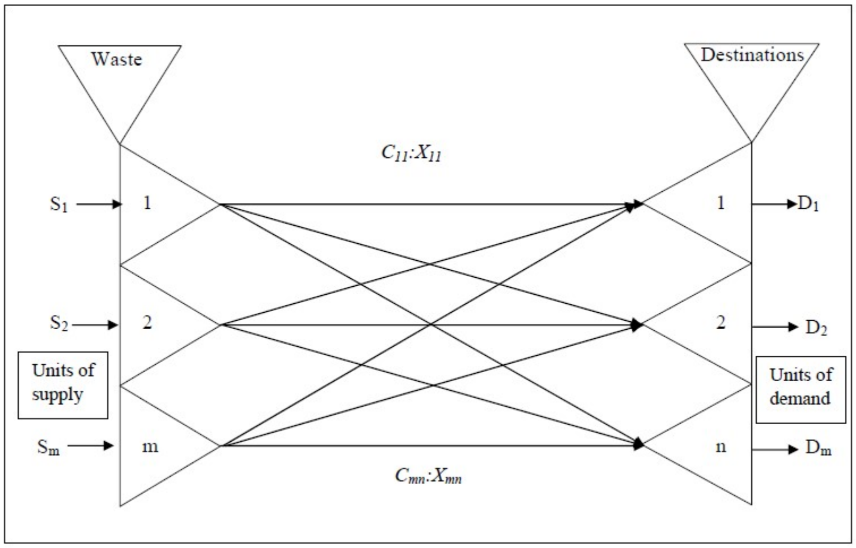

Figure 1: Schematic diagram of Solid Waste Disposal

Considering the above notations, the model can be stated mathematically formulated as:

$$Minimize \quad Z = \sum_{i=1}^{m} \sum_{j=1}^{n} c_{ij} x_{ij} \qquad (1)$$

Subject to constraints:

$$\sum_{j=1}^{n} x_{ij} \leq S_i ; i = 1, 2, ..., m \qquad (2)$$

Where

$$\sum_{i=1}^{n} x_{ij} \leq D_i ; j = 1, 2, ..., n \qquad (3)$$

$$x_{ij} \geq 0 \; for \; all \; i \; and \; j$$

The objective function minimizes the total cost of transportation (Z) between various sources and destinations. The constraint i in the first set of constraints ensures that the total units transported from the source i is less than or equal to its supply. The constraint j in the second set of constraints ensures that the total units transported to the destination j is greater than or equal to its demand.

Data Presentation

Every ward is considered as a generation node. There are fourteen (14) wards in Bida metropolis hence fourteen (14) generation nodes are calculated. The amount of waste generated from different ward and the distance of generation node from dumpsites is provided in Table 2. Three disposal sites have been considered in the model. On the basis of area (hectares) and location from each node of dumping sites we are considering their capacities for Mokwa Road, Minna Road and Lemu Road as 3024, 2000, 4600 MTs respectively. It is also considering that when the waste amount generated in one community exceed the capacity, the expansion of limited waste collected or transported to corresponding dumping sites must be planned under such condition so that result solved by this method is not vary.

Table 1: Waste generated per year from Bida (W_i) and distance from generation node to dumpsite

S/N	Ward	Distance in Km			Supply W_i (ton) 2021
		Mokwa Road	Minna Road	Gaba Road	
1	Bariki	43.75	59.25	35.4	666
2.	Ceniyan	21.5	29.5	19.1	504
3.	Dokodza	42	58	33.4	806
4.	Kyari	26	42	28.4	791

5.	Landzun	14.25	22.25	16.3	534
6.	Masaba II	30.25	46.75	34.9	673
7.	Masaba I	35.25	43	46.3	868
8.	Masaga II	42.5	38	50.5	845
9.	Masaga I	57	48	40.4	727
10.	Mayaki Ndajiya	71	59	45.9	667
11.	Nassarafu	5.5	17	14.3	504
12.	Umaru Majigi II	2	14	17.7	617
13.	Umaru Majigi I	18.5	32	46.7	732
14.	Wadata	31	13.25	36.3	690
	Capacity	**3024**	**2000**	**4600**	**9624**

The above table gives distances from various ward check post to the nearest dumping ground.

Table 2: Cost of waste transportation per tonne

S/N	Ward	Distance (Km)			Supply W_i (ton) 2021	Optimal Cost (N) 2021
		Mokwa Road	Lemu Road	Minna Road		
1	Bariki	3.5	5.0	4.7	666	582,750
2.	Ceniyan	4.5	3.2	5.1	504	403,200
3.	Dokodza	3.2	5.4	6.2	806	644,800
4.	Kyari	5.6	3.3	4.9	791	652,575
5.	Landzun	5.7	3.5	4.5	534	467,250
6.	Masaba II	5.3	3.4	4.9	673	572,050
7.	Masaba I	3.6	4.8	5.9	868	781,200
8.	Masaga II	5.4	4.3	2.9	845	612,625
9.	Masaga I	6.4	4.5	3.3	727	599,775
10.	Mayaki Ndajiya	4.2	6.3	6.9	667	700,350
11.	Nassarafu	7.1	6.4	5.1	504	642,600
12.	Umaru Majigi II	6.9	4.5	5.6	617	694,125
13.	Umaru Majigi I	7.2	4.8	6.2	732	878,400
14.	Wadata	2.7	6.8	7.5	690	465,750
	Total				**9624**	**8,697,450**

Note: cost of waste transportation per tonne per kilometre is N250.00

Results and Discussion

The main purpose of our work is to determine the optimal cost of solid waste disposal and from the result obtain in table 2 above, the optimization of the current situation shows that the optimal cost of waste disposal in Bida local Government of Niger State for the 2021 is Eight Million, Six Hundred and Ninety Seven Thousand, Four Hundred and Fifty Naira (N8, 697,450.00). The transportation cost per tonne for each route ism determine by multiplying the distance travelled with transportation cost per tonne per kilometre and the waste disposed per year. The transportation cost per tonne per kilometre is fixed at N250.00 which is obtained from the questionnaire administered.

Conclusion and Recommendation

In this research, waste disposal and management in Bida metropolis was modeled with the concept of having collection centers. It should be noted that the proposed model results in a least transportation cost of Eight Million, Six Hundred and Ninety Seven Thousand, Four Hundred and Fifty Naira (N8, 697,450.00) per year. Furthermore, the study shows that there is need for additional waste disposal and collection centers. However the current system of waste management in Bida is found to be inefficient. There is need for improvement in structure, organization and efficiency of both the former and informal waste management sectors in Bida. In order to improve solid waste management in Bida, the municipal authority and private companies need to formulate more strategies and implement technological innovations necessary for effective disposal and recycling of solid waste at optimal cost.

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