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Original Research

Multi-Level Data Envelopment Approach for Performance Evaluation of MSW Generated in Urban Area of Madhya Pradesh, India

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Abstract

With growing environmental legislation and growing public awareness of the importance of pursuing sustainable growth, developed nations are increasingly recognizng the value of waste reduction, recycling, and reuse maximisation. MSWM efficiency is the focus of this study, which also attempts to identify the most effective ways to put MSWM policies into practice and make significant strides in increasing MSWM efficiency. This empirical study examines the ecological and economic performance of MSWM for 26 major cities of Madhya Pradesh state, India in 2016 to 2020. A non-parametric approach, Data Envelopment Analysis (DEA) method has been employed. More precisely, output-oriented DEA models have been used to analyse both constant and variable returns to scale in the context of environmental performance. The results from the DEA CRS model indicate that 12 units were efficient in 2016-2017, 10 units in 2017-2018, 13 units in 2018-2019, and 16 units in 2019-2020. In contrast, the DEA VRS model predicts that the number of efficient units were from 16 in 2016-17 to 14 in 2017-18 to 17 in 2018-19 and 19 in 2019-2020. Additionally, the Shapiro-Wilk normality test shows that the distribution of efficiency scores is not normal. Out of the 26 units analysed, 15 have an efficiency score of 1, indicating they are technically efficient. The mean efficiency score for all units is 0.959, with 57.7% of units having an efficiency score of 1. Only 3.8% of units have an efficiency score between 0.7 and 0.8. The study finds that the Northern and Central large cities have higher efficiencies compared to the Eastern and Southern regions. Cities in the north, centre, and south had Potentially Toxic Elements (PTEs) that were comparatively less. The PTE of western cities was comparably more, while the eastern region's efficiency distribution was dispersed.

Keywords: municipal waste management, multi-stage DEA, pilot cities, sustainable construction, management efficiency

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Introduction

Municipal Solid Waste (MSW) is one of the major problems in many cities across the globe, particularly in developing nations [1, 2]. MSW is described as waste created locally by families, businesses, and government agencies. Food waste, clothes, paper, packaging, grass clippings and other solid wastes are included. However, hazardous and infectious waste, as well as sewage, are not included [3]. Multiple environmental and public health problems have been linked to improper Municipal Solid Waste Management (MSWM), which has been widely documented. It includes activities such as MSW generation, Collection, storage, and transportation, as well as processing and disposal [4, 5]. The MSWM is one of the important fundamental services of given municipal governments [6, 7]. Several changes have been done in the solid waste industry during the previous few decades to deal with rising population, growing resource demand, greater urbanisation, and economic development [8]. These are promoting the circular economies, which attempt to retain the value of materials, and resources for as long as possible by recurring them into the product after they have served their purpose and limiting waste generation, is one of these developments [9, 10]. Moving towards sustainable waste management practices is necessary for progressing toward a more sustainable and green economy and society, where people's health and environmental preservation take priority [11, 12]. Globally, MSWM is very difficult and expensive task for municipalities to complete [13, 14]. Despite the fact that fewer than half of the population has access to this service, municipalities in developing nations typically invest 25 to 55 percent of their municipal inexpensive on MSWM [15, 16]. For assessing and examining the revenue potential for businesses engaged in the collection and treatment of municipal solid waste [17], suggests a new economic efficiency indicator. It is demonstrated that the indicator may be a beneficial tool for producing insightful data that will benefit waste management organisations and decision-makers [18]. The two primary techniques for evaluating efficiency in the literature at this time are Stochastic Frontier Analysis (SFA) and Data Envelopment Analysis (DEA) [2]. SFA cannot be used to assess a system with many output indicators, but DEA may assess the relative effectiveness of a system made up of numerous heterogeneous decision-making units (DMUs) with multiple outputs. The series-parallel structure of China's industrial operating system comprises several inputs and numerous outputs. The effectiveness of the industrial operating system may therefore be evaluated more effectively using DEA with a network structure [19].

Methodologically, both parametric and non-parametric methodologies may be employed to assess the performance of MSW service management [17, 18]. By developing a set of parameters for the manufacturing technology, efficiency was examined using an econometric approach. SFA is the most commonly used parametric technique since the analyst must make numerous assumptions regarding the distribution of the efficient frontier, such as partial and exponential [20, 22, 23], therefore SFA has a significant limitation. While non-parametric methods, on the other hand, do not need the definition of a functional form for the production technique. The efficient frontier is built utilising linear programming methods using observed input and output data. Data Envelopment Analysis (DEA) is the most extensively used non-parametric approach [19, 24-27]. In developed nations such as Portugal, Spain, and Italy, both parametric and nonparametric methodologies have been employed to assess the environmental performance of the solid waste sector [20, 24, 28-31].

MSWM efficiency measurement has slowly grown in popularity among researchers. The researchers [32, 33] used a variety of approaches to assess the technical effectiveness of MSW collection facilities in seventy municipalities of Spanish, including DEA, FDH (functional data analysis), and others (free disposal hull). The inputs included the total number of containers, trucks, and direct workers. They have collected and recycled tonnes of gathered organic garbage. [34] used a one-stage The DEA will evaluate the municipal sector in the Murcia Region. In the instance of waste collection, personnel expenses and current transfers were employed as input indicators. The amount of domestic waste collected, as well as the amount of commercial and industrial waste collected, the number of business enterprises, households, industries and where waste is collected daily was one of the outputs. When compared to, culture, green, spaces, sports, water supplies and police, the efficiency of waste disposal were moderate. [35] for 34 cities has utilised a single stage DEA model using capital expenditure for MSW maintenance and building as inputs, i.e., Fixed Assets Investment in Municipal Ecocommunal Sanitation Facilities. Some results included the amount of MSW transported in a closed truck and the frequency with which MSW was treated in a way that rendered it safe. It appears from the statistics that MSWM efficiency can and should be enhanced. According to the data, MSWM efficiency should be enhanced. [36] used a three-stage DEA model to assess the efficacy of various kitchen waste giving out systems. They were able to come up with some more effective disposal ways. [18] examined the MSWM scenario in La Paz using benchmark indicators, waste flow analyses and waste aware. The study quantified waste disposal coverage, recovered, and recycling systems. Further indicated that its unable to recycle, collect waste, or generate income. [37] employed a three-stage DEA to measure total-factor efficiency in Belt and Road Initiative nations. A system, which contained four input, one output, and three environmental indicators, were developed. DEA will be carried out at the third stage, utilising both discretionary and non-discretionary input variables. The newly acquired values are added as an input to the original DEA framework, which uses a combined non-discretionary input to account for the uncontrolled environmental elements. By excluding any DMU from the prospective reference set that has a better environment than the unit under examination, this approach limits the comparison set [38]. Three-stage DEA is a three-step analysis process that starts with a traditional BCC model. Banker, Charnes, and Cooper came up with the DEA model, moves on to a stochastic frontier analysis (SFA) to get rid of random interference and the outside environment, and ends with a traditional BCC-DEA that uses the stage's adjusted data to estimate real efficiency. The DEA model is successfully implemented in various fields to solve the complicated problems the reviews from web of science has been done.

Furthermore, numerous researchers have used qualitative approaches to assess MSWM's effectiveness. According to the review, the researchers have previously conducted research on MSWM efficiency. However, in India, DEA has rarely been used analysis the overall efficacy of MSW management. Most of the recent research relied on standard DEA models. Because environmental variables and random mistakes continue to have an influence on MSWM efficiency, the accuracy of the calculated efficiency must be enhanced. DEA in three stages eliminates the external environment and random interference. India is a country that is rapidly developing and has a large population. As a result, India has a number of environmental challenges, one of which is the urgent requirement to improve both living standards and ecosystems. The management of municipal solid waste (MSW) is one of the critical problems that endanger India's progress in the areas of environmental quality and urbanisation. Over the course of 20 years, MSW generated millions of tonnes of garbage in the state of Madhya Pradesh (2001-2020). The improper and inefficient disposal of municipal solid waste has resulted in major environmental issues. Traditional ways of getting rid of trash, like putting it in a landfill, are hard to do because there isn't enough land. According to the research objectives, the management effectiveness of MSWM must be thoroughly investigated, MSWM policy implementation for high efficiency must be identified, and a breakthrough in increasing MSWM efficiency must be discovered. The multi-stage DEA model is used in this study to guide the research process. This creates a reasonable indicator system for assessing the efficiency of MSWM. The study looks at the true efficiency of 26 cities in Madhya Pradesh state, India, from 2016 to 2020, after controlling for the environment and random interference. The effect of the environment parameters on the efficiency of MSWM is also being investigated separately. The waste management facilities were step in Madhya Pradesh to make MSWM Effectives in the last few years and the waste characterisation as per Central pollution control board has been analysed. Moreover, a comprehensive assessment of MSWM's of the state is conducted. The studies of the management effectiveness of the MSW categories used in these pilot cities, as well as geographical disparities, are also presented. Furthermore, we identify the sources of low efficiency and propose viable interventions to increase the efficiency of MSWMs in the field. Effective management of MSWM is a most important task in making "beautiful India".

In recent years, there has been a growing recognition in developing nations of the importance of pursuing sustainable growth through waste reduction, recycling, and reuse maximisation. However, in India, research on the effectiveness of Municipal Solid Waste Management (MSWM) has been limited. To address this gap, this study focuses on MSWM efficiency in 26 major cities in Madhya Pradesh state, India between 2016 and 2020. Using the Data Envelopment Analysis (DEA) method, the study measures the ecological and economic performance of MSWM and identifies the most effective ways to implement MSWM policies. This study evaluates the environmental and economic effectiveness of waste management systems in 26 major cities of Madhya Pradesh state in India from 2016 to 2020 using DEA methodology and publicly available data. ULBs (urban local bodies) and population are inputs in our input-output model, along with MSW created, which includes food, fruit, vegetables, wood, straw, paper, cardboard, cotton, plastic, polythene, and bakelite. The amount of MSW handled, utilized, and landfilled was then selected as outputs. We purposefully did not include the amount of collected MSW as an input because it could result in the more effective ULB generating more waste, which we do not consider desirable. The study aims to identify the most effective ways to put waste management policies into practice and increase waste management efficiency. The paper is structured into five sections, starting with a description of the study area, followed by the materials and methodologies used in the study. The fourth section presents the results from the DEA model, which show that waste management efficiency is poor, but varies by region. Finally, policy suggestions are discussed in the fifth section.

Study Area

Near the geographic centre of India, next to the former British Central Province, and separated into many ecozones is Madhya Pradesh, Central India, located at geographic centre of 21°06'-26°30' North and 74°00'-82°51' East) (Fig. 1). The State of Madhya Pradesh covers 308,245 square kilometres, or roughly 9.5 percent of the entire area of the nation (3,287,263 square kilometres). According to the Census 2001, the State had a population of 60,348,023, with a density of 196 people per square kilometre. It is a state with rapid population growth that has undergone

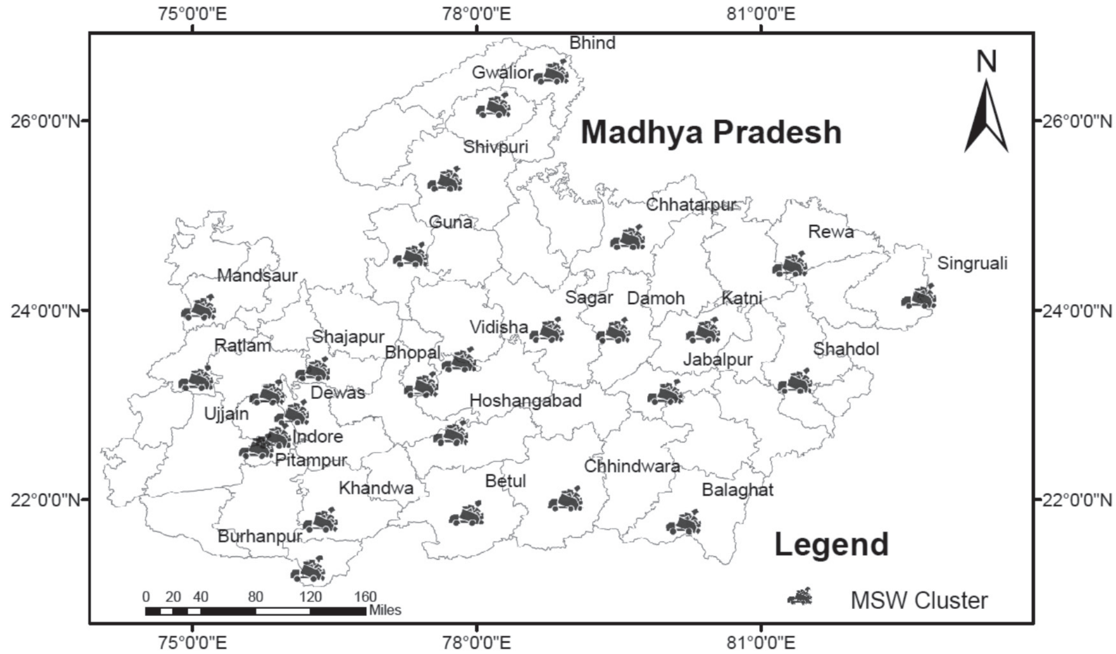

Fig. 1. Location of Study Area: Madhya Pradesh (Central India) with their MSW collection point.

significant change over the past 100 years. Towns in the State expanded from 97 in 1901 to 368 in 2001 that is almost 27% and it is excepted 32% growth in 2030 as shown in the Fig. 1. Over the past two decades, municipal solid wastes (MSW) have increased dramatically in quantity and undergone significant qualitative change as a result of the population boom and determined initiative for economic success and growth. MSW management has grown to be a significant problem that calls for scientific management through the application of policies, enforcement of laws, and strengthening of municipal authorities.

Research Methodology

The Three-Stage DEA Model's Research Methods

SFA (Stochastic Frontier Analysis) is a parametric technique [5, 25] whereas DEA of the non-parametric method are two prevalent methods for calculating relative efficiency [39]. DEA is a statistical tool used to assess the effectiveness of decision-making units (DMUS). It eliminates the need for subjective weighing and enhances the precision and normalisation of efficiency analysis result [38]. In recent years, sustainable construction has grown in importance in India. In India, MSWM must seek environmental, economic, and social benefits, necessitating the use of a multi-input, multi-output indicator system to assess MSWM efficiency. Because SFA can only evaluate the efficiency of a single output, DEA is especially useful for analysing MSWM [35]. Therefore, the present study employs DEA to assess MSWM efficiency.

As research on the DEA model has progressed, approaches such as one-stage DEA, two-stage DEA, three-stage DEA, and others have emerged. A single-stage DEA cannot eliminate random and external interference. Two-stage DEA is merely a regression study of the influencing factors, unable to adapt to raw data and appropriately determine the efficiency value. A three-stage DEA is a hybrid of traditional DEA and SFA. Furthermore, because it can exclude the influence of environmental factors and random errors, efficiency measurement is more objective and precise than one-stage DEA and two-stage DEA. It is commonly used to evaluate environmental efficiency, agricultural water use efficiency, scenic spot operational efficiency, learning-teaching technological efficiency, industrial eco-efficiency, and traffic cop efficiency. The three-stage DEA approach is an important branch of the DEA model system [40].

It reduces the influence of external environmental factors and random errors using the standard DEA method. As a result, the calculated efficiency figure is more practical and reliable [41]. The research examines data from 38 Asian countries, container terminals in, China, India Hong Kong, Bangladesh, Indonesia, Korea, Japan, Pakistan, the Sri Lanka, Philippines, Vietnam and Thailand (CIY, Containerisational International, 2012). The validity of results is increased when numerous methodologies are used in a study [42]. These uses are clear in port benchmarking studies [32]. Therefore, DEA and FDH are crucial to the study's ability to evaluate the technical effectiveness of the container terminal and contrast outcomes. A container terminal is technically efficient if, when compared to another container terminal, it achieves the highest throughput while requiring the least number of resources (equipment, infrastructure, and technology).

A container terminal's technical efficiency can be expressed as follows:

Technical efficiency = Actual productivity Reference productivity.

It is well acknowledged in all academic fields that DEA and FDH can be used as a tool for benchmarking research. Based on the inputs and outputs of the decision-making units, the DEA virtual frontier that defines the best in class is estimated (DMUs, in this case, container terminals). Then, to gauge technical efficacy, other DMUs are evaluated against the best in their respective classes.

Data envelopment analysis is a potent non-parametric technique for assessing and enhancing the relative effectiveness of a collection of independent and homogenous z Decision Making Units (DMUs) It was introduced by [33, 43]. Efficiency is defined as: in a process with a single input and single output.

$$\text{Efficiency} = \text{output/input} \tag{1}$$

The efficiency of a process with multiple inputs and outputs is typically stated as:

$$\text{Efficiency} = \text{weighted sum of outputs} \text{ /weighted sum of inputs} \tag{2}$$

The definition above has a problem with the weights used. This issue is resolved by the DEA approach by adding a unique weighting scheme for each and every DMU. In fact, [44] suggested that the greatest efficiency for a DMU k_0 can be determined by addressing the following issue:

$$max_{w,v} h_o = \frac{\sum_{j=1}^{n} w_j y_{jk_o}}{\sum_{j=1}^{m} v_i x_{ik_o}} \tag{3}$$

subject to:

$$\frac{\sum_{j=1}^{n} w_j y_{jk}}{\sum_{j=1}^{m} v_i x_{ik}} \leq 1 \quad \mathrm{k} = 1, \ldots, \mathrm{z} \quad w_j v_i \geq \varepsilon \;\; \forall\, j, i, \tag{4}$$

where, z represents the number of units, m and n is the number of inputs and outputs respectively, w_j is weight given to output j whereas v_i is weight given to input i; ε represents the small positive number.

This model maximises the weighted output to weighted input ratio of the k_0th DMU under the restriction that the same ratio for the other DMUs should not be greater than unity, which is the maximum efficiency. Depending on its efficiency, the k_0th DMU will either be efficient in comparison to the other DMUs if it equals one or inefficient if it is less than one. Although the aforementioned equations are not linear, this issue has been reduced to a straightforward fractional linear programming issue [45].

DEA models are classified as either input-oriented or output-oriented. The former favours potential improvements in resource utilisation, whereas the latter examines potential improvements in produced outputs by evaluating a DMU's relative efficiency in terms of the maximum radial contraction to its input levels or expansion to its output levels that are feasible under efficient operation, respectively. For each technology, DEA models also resolve linear programming issues by satisfying Constant Returns to Scale (CRS) and Variable Returns to Scale (VRS). While VRS depicts the prospect of a growing, constant, or diminishing return to scale in production technology, CRS expresses the concept that output will fluctuate in proportion to inputs. The DEA methodology is a well-known way to figure out how effective a system is. It does this by figuring out how effective each DMU is, and it also helps policymakers make decisions by suggesting actions and policies that can make underperforming units more effective. As a result, this strategy can help public and private policymakers' direct choices toward more effective systems.

Results and Discussions

The rapid growth in MSW generation necessitates the implementation of appropriate management systems. MSW mishandling is not helping the environment. As a result, MSWM is given more weight in many countries. MSWM efficiency has been one of the metrics used to judge the degree of urban governance. It has the capacity to indicate the amount of ecological civilization in cities. The ratio of new economic value to environmental effects, or the ratio of additional environmental advantages to economic expenditure, is a typical definition of eco-efficiency. True MSWM efficiency is defined by the capacity to remove external environmental and random disturbance interference. MSWM levels in today's cities vary substantially. A precise assessment of MSWM efficiency is critical for policymakers.

DEA

Because DEA is a deterministic approach, it implicitly overlooks random errors and general deviations from the technological frontier, which means that DEA estimates may be influenced by sample variances. However, this has not been taken into account in many technical efficiency benchmarking studies in the port industry, and they advocate utilising bootstrapping as a standard process in every DEA application to improve estimation accuracy.

Technical Efficiency and Service Level

The idea of technical efficiency as a driver of any area's competitiveness has been thoroughly investigated

[16]. Existing literature views less technical efficiency (TE<1) of central India as a negative feature. To account for the effect of scale size on the performance of the unit under analysis, both CRS and VRS specifications of the output-oriented DEA model were applied in this study. The study compares only four years and more exactly 2016-17, 2017-18, 2018-19 and, 2019-20. It should be noted that there is currently no information provided on waste expenses for more recent years. Fig. 2 displays the technical efficiency using VRS model in four consecutive years. The assumptions made about returns to scale (CRS vs VRS) and the disposability of the "Unsorted" output vary amongst models (strong disposability vs weak disposability). The cost of MSW service is used as the same input in all models, and the sorted waste fractions are used as the same output subset in all models. The performance of the MSW service has significantly improved during the past few years. Table 1 illustrates DEA results of various input-oriented models evaluate constant return to scale efficiency, Variable return to scale efficiency, Scale efficiency and Return to Scale (RTS).

Table2 shows the efficiency scores of different clusters based on Model 3 of DEA. The clusters are compared on the basis of CRS efficiency, VRS efficiency, SF efficiency, and RTS. From the table, it can be observed that the efficiency scores of the clusters vary across the different measures. Bhopal has a constant efficiency score across all the measures, while other clusters show some degree of variation. Shivpuri and Indore show an increasing trend in efficiency scores across the measures, while Hoshangabad, Vidisha, Bhind, Rewa, Damoh, and Chhatarpur show a decreasing trend. Overall, the efficiency scores of the clusters can provide valuable insights for decision-makers to improve the efficiency and productivity of the clusters in the future.

The output-oriented DEA model's CRS and VRS specifications have both been implemented in this study in order to fully account for the effect of scale size on the performance of the unit under investigation. The study compares four consecutive years and more exactly 2016-17, 2017-18, 2018-19, and 2019-20. It should be emphasized that at present time, information on waste costs from more recent years is not accessible. Fig. 3 displays the comparison of DEA CRS and DEA VRS for the selected studied stations for the studied year. The ecological effectiveness of MSW also exhibits a minor fluctuation during the studied years, according to our results. With regard to VRS model, the average efficiency score of the whole sample from 2016-17, 2017-18, 2018-19, and 2019-20 shows a slight increase (Fig. 3). The national action plan for municipal solid waste management's policies, which aim to increase the rate of trash reduction and recycling as well as to reward efficient waste management by imposing penalties

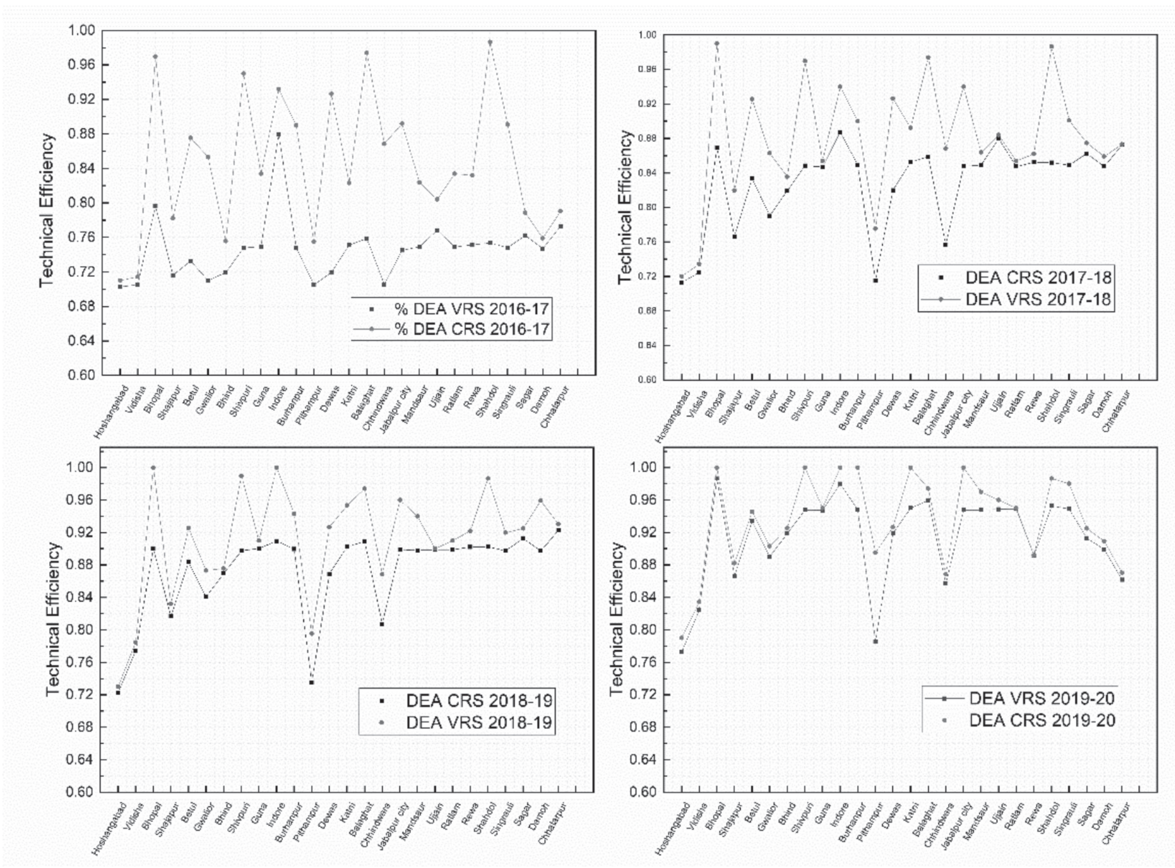

Fig. 2. Comparison of DEA CRS and DEA VRS for the selected stations.

Table 1. Summary of DEA Models based on their input and output Variables.

Model no.	Output variables	Input variables
Model-I	a. Population in '000 b. Area of service (Km^2) c. Waste collected (MT/year) d. Waste Separation (MT/year)	a. Waste utilised (MT/year) b. Waste treated (MT/year)
Model-II	a. Population in '000 b. Area of service (Km^2) c. Waste collected (MT/year) d. Waste Separation (MT/year)	a. Waste utilised (MT/year) c. Landfilled (MT/year)
Model-III	a. Population in '000 b. Area of service (Km^2) c. Waste collected (MT/year) d. Waste Separation (MT/year)	a. Waste utilised (MT/year) b. Waste treated (MT/year) c. Landfilled (MT/year)

Table 2. Efficiency of various MSWM Models for the selected Cluster.

S.NO	Cluster	Model	CRS Efficiency	VRS Efficiency	SF Efficiency	RTS
1	Hoshangabad	III	0.74	0.77	0.76	Decreasing
2	Vidisha	III	0.76	0.82	0.79	Decreasing
3	Bhopal	III	1.00	0.99	0.99	Constant
4	Shajapur	III	0.88	0.87	0.87	Constant
5	Betul	III	0.93	0.93	0.93	Constant
6	Gwalior	III	0.88	0.89	0.89	Increasing
7	Bhind	III	0.89	0.92	0.90	Decreasing
8	Shivpuri	III	1.00	0.95	0.97	Increasing
9	Guna	III	0.95	0.95	0.95	Constant
10	Indore	III	1.00	0.98	0.99	Increasing
11	Burhanpur	III	1.00	0.95	0.97	Increasing
12	Pithampur	III	0.90	0.79	0.84	Increasing
13	Dewas	III	0.93	0.92	0.92	Constant
14	Katni	III	1.00	0.95	0.98	Increasing
15	Balaghat	III	0.97	0.96	0.97	Increasing
16	Chhindwara	III	0.87	0.86	0.86	Constant
17	Jabalpur city	III	1.00	0.95	0.97	Increasing
18	Mandsaur	III	0.97	0.95	0.96	Increasing
19	Ujjain	III	0.96	0.95	0.95	Constant
20	Ratlam	III	0.95	0.95	0.95	Constant
21	Rewa	III	0.89	0.95	0.92	Decreasing
22	Shahdol	III	0.99	0.95	0.97	Increasing
23	Singrauli	III	0.98	0.95	0.96	Increasing
24	Sagar	III	0.92	0.96	0.94	Decreasing
25	Damoh	III	0.91	0.95	0.93	Decreasing
26	Chhatarpur	III	0.87	0.97	0.92	Decreasing

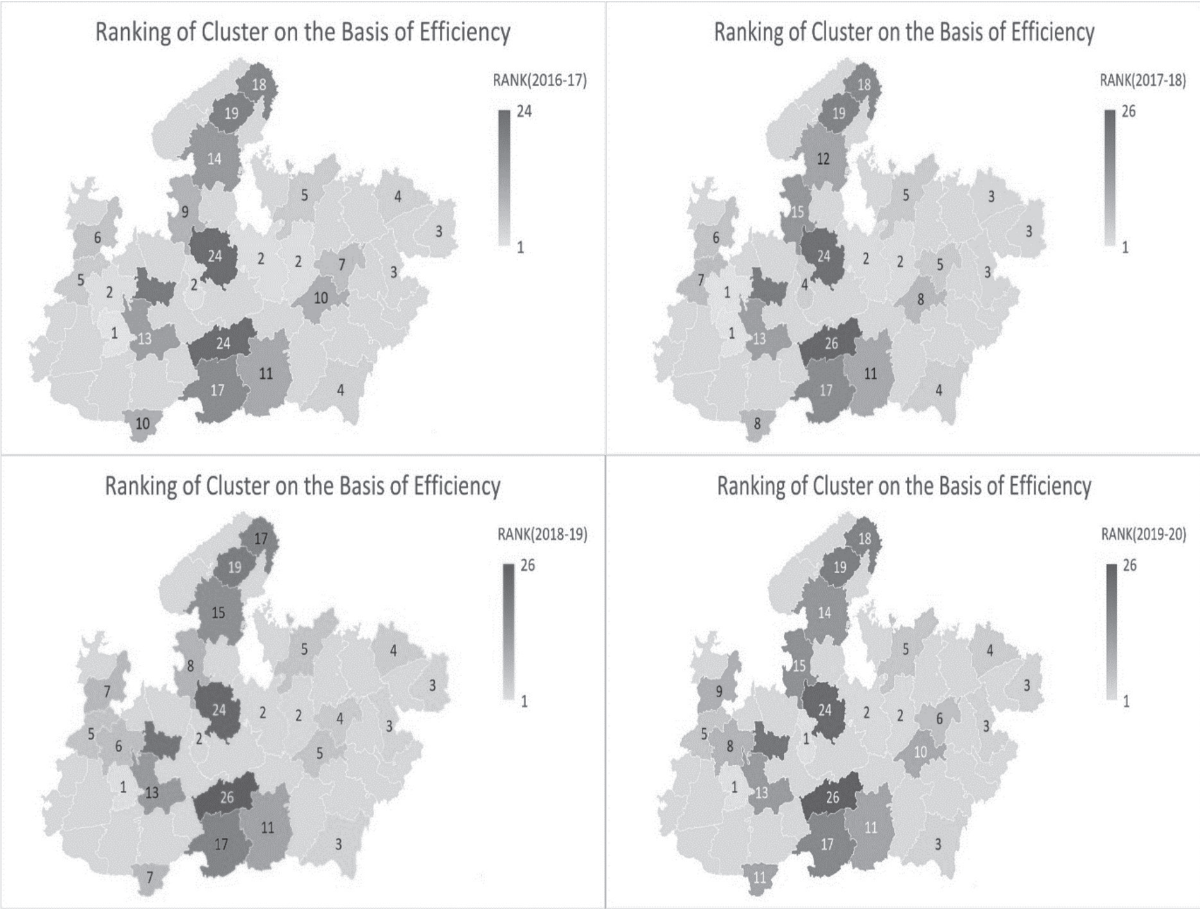

Fig. 3. Ranking of cluster on the basis of efficiency.

for standards not met, have a positive impact on this trend.

Because of the nature of the service, which involves expenditures and lengthy adaptation times, the little rise in score values highlight the slowness with which sustainable waste management techniques are implemented. However, it should be noted that the number of towns that get the maximum efficiency score varies modestly over time, with little effect on the overall trend. To calculate technical efficiency from the CRS and VRS production boundaries, two output-oriented DEA models were used. The CRS DEA model findings show that of the 26 units examined, 12, 10, 13, and 16 are efficient in 2016-17, 2017-18, 2018-19, and 2019-20, respectively. The VRS DEA model, on the other hand, assumes that altering inputs does not result in a corresponding change in outputs; hence the number of efficient units becomes 16 in 2016-17, 14 in 2017-18, 17 in 2018-19, and 19 in 2019-2020.

The results of the DEA models show that there is a significant amount of spatial variation among the towns of Madhya Pradesh that were considered, but only a small amount of difference between the years that were considered. As shown in Fig. 4, The DEA scores of SWM ecological efficiency are very varied and vary according to geographical localization, with the Northern and Southern regions scoring lower than the East, Centre, and Western regions. The ranking has remained relatively stable over the years at the regional level, even though some of the towns in the north and south have experienced a slight drop in their standing while others in the east, west, and centre have seen an improvement (Fig. 4). The differences in waste services quality and management that exist across the nation's various geographical regions are at least partially attributable to the socioeconomic characteristics that are unique to each individual region. In fact, there is a positive relationship between the number of people living in the Eastern, Central, and Southern parts of the country, their level of education, age, employment, and income, and how much they want to help reduce waste and improve recycling.

Municipal Solid Waste Processing Rate

The 12 chosen cities, out of a total of 26 studied stations, are working to close the efficiency gap so that they can achieve 90-100 percent in their waste processing. However, there is still a lot of work to be done, and cities are currently working to improve the efficiency of their processing. Waste separation at the source is a necessary and non-negotiable condition for a waste management ecosystem to be considered sustainable. When waste is mixed at the point

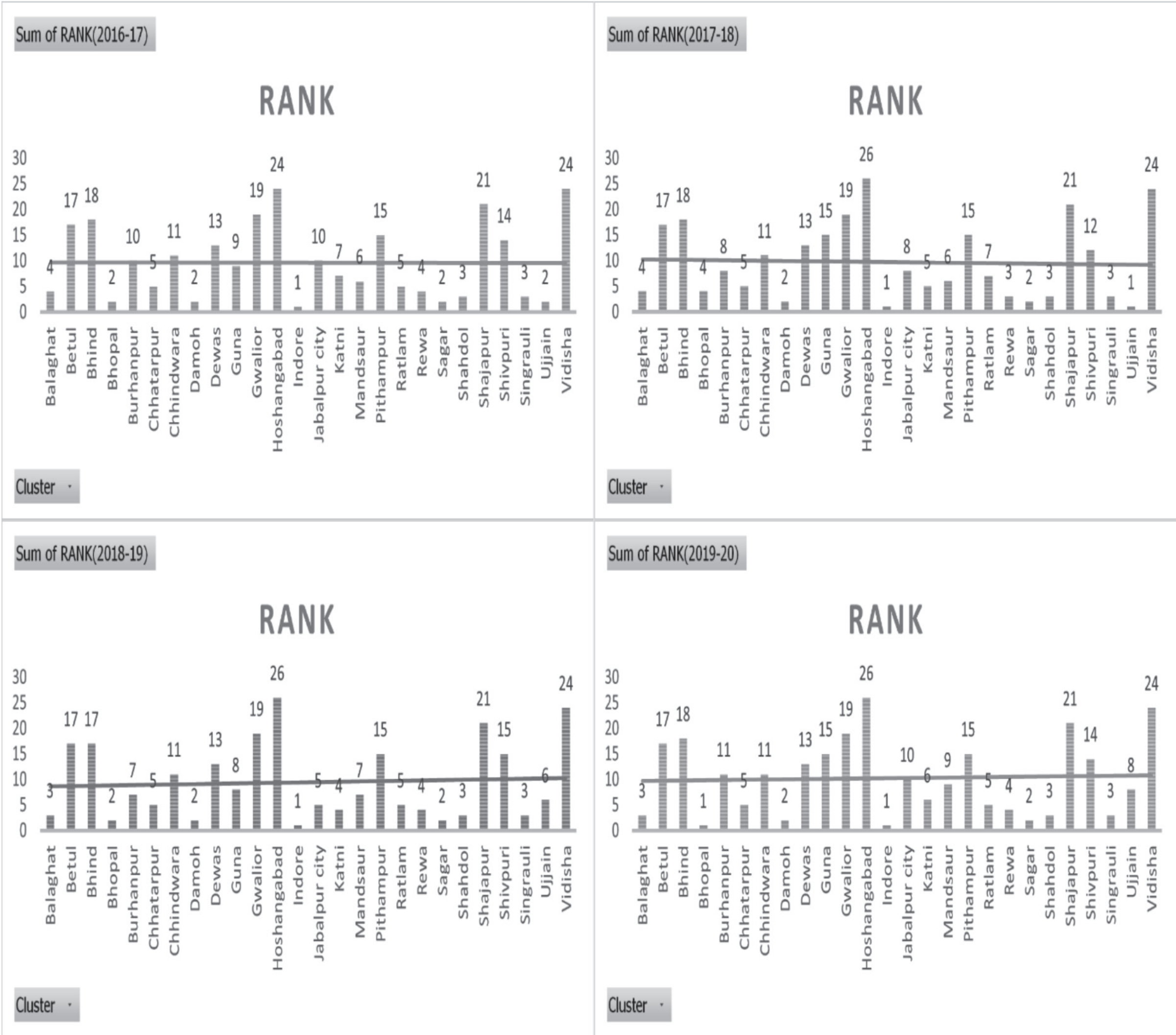

Fig. 4. Year -wise ranking of cities based on MSWM.

of generation, it leads to a variety of problems. The risk of contamination of recyclable materials is significantly increased when mixed waste is present, and the economic potential of recyclable materials is significantly diminished as a result. Even if garbage is going to be burned to produce energy, it is still important to sort it out first. It has been demonstrated on multiple occasions that municipalities that sort their solid waste are better able to appreciate the true value of their waste products. Fig. 4 displays the year wise Ranking of cities on the basis of MSWM for the selected studied stations according to the analysis.

The city of Indore had a strong communications strategy in place in order to bring about a behavioural change at a mass level. The objective was to instil a sense of pride in citizens regarding their segregation. This was followed by a string of bylaws and a rigorous monitoring system being put into place to ensure compliance with the regulations. As soon as segregation was completed, the city began an investigation to determine the population and the amount of waste produced in each ward. A route plan was developed based on the findings of this investigation. The requirements for the number of vehicles and employees needed to collect waste from each ward were determined. In the field of waste management in India, the city of Indore has risen to the top as a leader and a champion thanks to practises such as source segregation, the participation of all stakeholders, and good governance. More than half of the solid waste that we produce as a nation is comprised of organic materials, making it the single largest component of our waste stream. This indicates that if we take care of our organic waste, we will be able to eliminate the waste problems that are affecting half of our 26 waste-wise cities. In addition to that, water makes up three-quarters of all the organic waste. It is common knowledge that the majority of a city's budget goes toward the collection and transportation of solid waste in Indian cities. This means that we are spending the money that is provided to us by taxpayers as well as using fossil fuels in order to move water from one location to another. Because of this, it is imperative that we manage our organic waste in locations that are geographically as close to its sources as is practicable.

That is precisely what these cities have been able to accomplish in recent years. The shift occurred as a result of the cooperation of local residents, who were required to organise their garbage in an appropriate manner and turn it over to municipal employees who were responsible for providing daily collection services for garbage. Several initiatives with a primary focus on changing people's behaviours made this realisation a reality. Along with Bhopal, Damoh, Shahdol, and Balaghat, the city of Indore has achieved success thanks to a wide variety of thoughtfully designed systems. 100 percent source separation, 100 percent collection, and a 99.6 percent efficient treatment facility For the purposes of making planning, monitoring, and carrying out decisions more straightforward, the 85 municipal wards have been subdivided into 19 zones, with each zone consisting of four to six wards. Because of how well the informal sector has been integrated and how well a monitoring system has been set up, the cities of Indore and Bhopal in the state of Madhya Pradesh have changed a lot and are now among the top 10 cities in the country.

The use of innovative waste management technology is critical to making the system more sustainable. This can be accomplished by assuring effective waste collection and transportation; increasing the quantity of waste that can be recycled; minimising the amount of energy and resources required for waste treatment; and, most significantly, monitoring waste management activities. The majority of India's technological advancements in garbage management and treatment are still in their early stages. The recovery of wealth from garbage should be coordinated with the transformation of India's waste management sector, and this transformation should be coordinated with novel technological alternatives that can be replicated throughout the country. These cities have improved and streamlined the ground-level mechanism for collecting waste and effectively processing and recycling it by making effective use of technologies such as satellite navigation systems, wireless technology, wide area communications networks, machine-to-machine interaction, and the internet of things, as well as innovative mobile and web-based applications.

Consuming resources, in one form or another, is an integral part of our day-to-day lives, and this fact alone encapsulates a fundamentally straightforward reality. This consumption results in waste, which must be disposed of in a manner that is responsible, efficient, and as effective as possible. Municipalities are generally in charge of waste collection and disposal. Many communities face difficulty managing the ever-increasing amounts of waste that must be managed as a result of this predicament. This is especially important in metropolitan areas, where the number of individuals using these services is growing. Municipal solid waste (also known as MSW) management is still regarded as one of humanity's top priorities in the twenty-first century. Communities are implementing the integrated solid waste management model, which entails reducing waste before it enters the waste stream, reusing waste generated for recovery through recycling, and disposing of waste through environmentally sound combustion facilities and landfills that meet policy standards as they develop. Improper solid waste management is known to be a major contributor to a variety of environmental issues, including climate change (for example, greenhouse gas emissions from landfills), ecosystem disruption (for example, heavy metal emissions into air, soil, and surface water), and resource depletion (for example, recycling processing methods for a few particular key minerals or metals that are either non-existent or inefficient). Because the amount of solid waste is growing so quickly, it is important to come up with good management systems that can deal with these environmental problems in a methodical way and, in the long run, help society become more environmentally friendly.

Conclusions

This article discusses the challenges faced by Madhya Pradesh in managing its municipal solid waste and the importance of efficient waste management for urban areas. The study uses a Data Envelopment Analysis-based method to analyze the efficiency of waste-to-energy systems and provide guidelines for municipalities to manage their solid waste. The technical efficiency of 26 Madhya Pradesh states over a four-year period (2016-2020) is analysed using two output-oriented DEA models. The study shows that inadequate solid waste management affects consumer well-being and has policy consequences. The average level of technical inefficiency ranges between 27% and 39%, and the overall loss in technical efficiency ranges from 19% to 30%. The inefficiencies of average output owing to congestion and scale are also discussed. The study concludes that population density has a positive impact on the pace of waste collection, and reducing waste production per person increases the percentage of waste collected in separate containers. The findings have significant implications for both existing literature and policymakers.

The DEA analysis of the clusters based on Model 3 shows interesting findings. The clusters have been ranked based on their efficiency scores in terms of CRS, VRS, and SF. It can be observed that Bhopal has a constant efficiency score across all the measures. On the other hand, other clusters show some degree of variation in their efficiency scores. Shivpuri and Indore exhibit an increasing trend in their efficiency scores across all measures, whereas Hoshangabad, Vidisha, Bhind, Rewa, Damoh, and Chhatarpur show a decreasing trend in their efficiency scores. It is worth noting that the efficiency scores of the clusters can provide valuable insights for decision-makers to improve the efficiency and productivity of the clusters in the future.

In conclusion, the DEA analysis provides a useful tool to evaluate the performance of clusters in terms of efficiency and productivity. The findings of the study can help decision-makers to identify the strengths and weaknesses of the clusters and take appropriate measures to improve their performance.

– Municipal solid waste management is a crucial issue due to population growth in urban areas and the state of Madhya Pradesh faces significant challenges in managing municipal solid waste.
– The current study analyzes the technical efficiency of waste-to-energy systems in Madhya Pradesh over a four-year period using Data Envelopment Analysis.
– Inadequate solid waste management has negative impacts on consumer well-being and highlights the need for legislative action to address waste penalties and improve implementation and enforcement of environmental standards.
– The study identifies areas of inefficiency in MSW service, including resource consumption, organization and planning, and appropriate service size or congestion efficiency.
– The study finds that population density has a positive impact on the pace at which waste is collected separately. The study's findings have significant implications for both existing literature and policymakers.
– Overall, the study concludes that MSWM efficiency is poor and is expected to improve. Furthermore, the study highlights that MSWM effectiveness varies by region, with positive management efficiency according to MSW classification observed in only eight pilot cities. This study offers valuable insights into the need for increased focus on waste reduction and efficient MSWM policies in India.

Abbreviation

1. MSWM = Municipal Solid Waste Management.
2. DEA = Data Envelopment Analysis
3. CRS= Constant Return to Scale
4. VRS = Variable Returns to Scale
5. PTE= Potentially Toxic Element
6. MSW = Municipal Solid Waste
7. SFA = Stochastic Frontier Analysis
8. FDH = Functional Data Analysis
9. DMU = Decision Making Unit
10. SWM = Solid Waste Management
11. TE = Technical Efficiency

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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