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Measuring Effective Indicators for Waste Disposal in Order to Assess the Sustainable Environment: Application of Fuzzy Approach

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Abstract

Selecting appropriate locations for Municipal Solid Waste (MSW) management facilities, such as landfills, is an important issue in rapidly developing regions. Multiple alternatives and evaluation attributes need to be analyzed to finalize the locations of these facilities. The selection of a landfill site in an urban area is a critical issue due to the involvement of many parameters. The decisive parameters are environmental, economic, and social, some of them conflicting, making landfill site selection a tedious and complex process. Multi Attribute Decision Making (MADM) approaches are found to be very effective for ranking several potential locations and, hence, selecting the best among them based on the identified attributes. Therefore, this study presents a two-stage MADM model that also accounts for all possible combinations of locations. This study evaluates economic, environmental, social, and technical attributes based on realistic conditions. Based on the results, 15 attributes are first identified through a comprehensive literature review and with the help of municipal officials during field surveys. These attributes are categorized into four types, i.e., economic, technical, environmental, and social, based on their respective propensity.

In the second step, a statistical analysis questionnaire was distributed among the study population, and Cronbach's alpha was explained for all four main factors of the study. Therefore, in the last step, the rank of all research variables was calculated using the Nonlinear analysis method. Based on the results of this study, the technical variable was ranked first, the economic variable was ranked second, and the environmental and social variable was ranked third. This article has three theoretical, practical, and technical contributions. Also, this article provides a clear explanation of the theoretical contribution related to the accumulated knowledge, both in the introduction and theoretical background sections of the article. Therefore, studying the past research describes a relatively complete background of the planned theoretical contributions of this article compared to the previous research. Therefore, the theoretical contribution of this article solves the scientific gap about effective indicators for determining the location of waste disposal. From the point of view of practical contribution, this article presents practical concepts related to managers and experts and has practical suggestions presented in the conclusion section. Also, the technical contribution of this article is presented by combining fuzzy logic and Nonlinear mathematical programming.

Keywords: Municipal solid waste, Landfill, Sustainable environment, Multi attribute decision mmaking.

1 | Introduction

The growth of the urban population in developing countries is occurring more rapidly. Instinctively, urbanization itself is not the root of the problems associated with sustainability; however, unplanned and haphazard urbanization growth leads to many economic, social, and environmental challenges. Municipal Solid Waste (MSW) management is an example of one such challenge, directly associated with rapid urbanization. Rapid urbanization has enormously increased the amount of MSW generated in urban centers.

This MSW must be disposed of properly and promptly to avoid possible health and environmental hazards. Also, waste production is one of the most important sources of environmental threats. To deal with this problem, sanitary landfill has been accepted as a practical method in all countries. Choosing the right landfill is a major problem in waste management. Despite many efforts in the field of waste management to reduce waste from the source, recycling, and converting of waste into usable material have been done; however, in all these methods, some material must be buried.

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The production of solid waste is of major environmental concern since it can release organic and inorganic contaminants to water resources, pollute the food sources, and have esthetic impacts. In addition, solid waste biodegradation can release Greenhouse Gasses (GHGs) from landfill sites into the atmosphere, contributing to global warming. A proper solid waste management plan is of major importance to protect public health and contribute to sustaining the environment. It should cover the waste generation phase to the disposal process stages. Waste disposal methods include incineration, other thermal processes, recycling, landfilling, and composting. Many factors affect the selection of disposal methods, such as population, location, technology, etc. Among the mentioned methods, landfilling is still the most widely applied method used in developed countries.

The increasing development of urban areas and the uncontrolled increase of population have led to the production of various types of municipal waste, so selecting landfills for municipal waste is one of the important steps in urban waste management. Due to these places' destructive environmental, economic, social, and ecological effects, the landfill site must be selected carefully and through a scientific process. The waste management system comprises six main stages of waste generation, storage, collection, transportation, recycling, and disposal. Most of the financial and human resources are spent on collection and transportation. Collection, transportation, and waste landfills are done in different ways according to necessity and facilities.

Waste management problems are due to increased per capita waste production, the need for high levels of capital in physical infrastructure (incinerators, recycling facilities, and landfills), organizational barriers, and a wide range of stakeholders. The activities undertaken to optimize waste management services require the participation of all relevant departments for the success of all credible, transparent, socially sustainable activities, and as practical and appropriate as possible for the participants.

In the past decades, many studies have been conducted to identify the best viable location for landfilling. Some of the used procedures and methods include diagramming, grey systems theory (clustering), expert systems [1], Analytic Hierarchy Processes (AHP) [2], Geographic Information System (GIS) with AHP [3], Analytic Network Process (ANP), GIS with Weighted Linear Combination (GIS/WLC), the Simple Additive Method (SAM), fuzzy logic [1], Ordered Weighted Averaging (OWA) [4].

Each method shows specific advantages, disadvantages, and applicability that may change the final result, which in the case of landfill site selection is the ranking of the most suitable sites. In Multi-criteria Decision-Making (MCDM), five distinct steps can be taken: 1) determination of purpose: identification of the problem, which, for example, could be finding a new location for a landfill, 2) criteria identification: clarification of the requirements and converting them into criteria, 3) weights identification: allocation of weight to each criterion based on its importance via a MCDM method, 4) determination of alternatives: determination of viable options for comparison, and 5) evaluation of alternatives: finding the best option through evaluating and subsequently ranking each option (for example landfill sites) [5].

The primary purpose of the present study is to investigate an appropriate criteria location for a landfill site by considering environmental, economic, and socio-technical criteria at the macro level in Bushehr province by applying MCDM techniques. Bushehr province was selected as the case study in this research. Nevertheless, to the best of the authors' knowledge, no previous investigation has specifically reported the results of a systematic analysis of analysis for landfill site selection. Considering the scarcity of literature in this area, the fuzzy method-Factor Analysis (FA) was implemented as the first assessment for a sustainable landfill site selection. This research consists of three parts. In the first part, after reviewing the research literature, the indicators of the research model are expressed. In the second part, the main indicators of the research were analyzed using the basics of statistical science. Finally, in the third part, the weight and rank of all variables were determined using the fuzzy nonlinear technique.

2 | Literature Review

A literature review was carried out comprehensively to understand current knowledge published in the social performance field of waste management systems in general and in developing countries. This was achieved by reviewing the research studies published in leading international journals indexed in recognized databases over the last decade (e.g., JCR) by the Scopus searching tool. All the reviewed research studies were related to assessing any social aspect (exclusively or not) of waste management systems. Waste management practices can be divided into categories, ranging from waste collection and separation to waste recovery and recycling. While extensive literature exists regarding optimizing general waste collection and recovery operations, the literature on waste management in smart cities is limited. In this section, first, we will provide an overview of research on waste collection and recovery operations scheduling. Then we will discuss the most recent studies on waste management practices in smart cities.

To identify research gaps in waste collection problems in smart cities, first, we will review the literature on vehicle routing problems. To name a few studies, various heuristic and non-heuristic models have been offered in transportation literature for solving routing problems. Reed et al. [6] have proposed a dynamic model for capacitated vehicle routing problems using the ant colony system algorithm. Hemmelmayr et al. [7] have proposed a heuristic solution for solid waste collection as a periodic truck routing problem, where the collected waste can be delivered to some intermediate facilities, and not every collection point needs to be covered daily. Banditvilai and Niraso [8] have proposed a simulation framework for modeling the night shift solid waste collection in Phuket municipality, Thailand, and developed a heuristic approach for assigning waste collection zones and routings.

Waste management systems are normally optimized by taking the economic perspective into account, along with the environmental one, but generally leave aside the recommendation of the United Nations in 2014 of also considering the social point of view. However, to analyze and improve waste management systems, especially in developing countries, it is necessary to integrate socio-economical and environmental aspects into the decision-making process, such as the sustainable development concept proposes [9].

Population growth, public health concerns, and unwanted local settlements to build landfills around them are some of the problems that need to be overcome. In locating landfills, paying attention to environmental factors is very important because these pits may pose certain environmental hazards to the general public or the living environment around the area. Assessing hazardous waste landfills is complex because it requires data from various social and environmental areas. This data often involves the processing of significant amounts of spatial information that the GIS can use as an important tool for land use sustainability analysis [10].

Waste management has become one of the most complex issues facing countries today. In other words, in developed countries, if the rate of waste generated is between 0.8 and 1.4 kg/person/day is appropriate [11]. Compared to developed countries, the average generation rate of MSW in developing countries is 0.3–0.5 kg/person/day, but the management is inadequate and improper. So, SWM in various cities in developing countries is becoming a complicated challenge [12]. Instinctively, urbanization itself is not the root of the problems associated with sustainability; however, unplanned and haphazard urbanization growth leads to many economic, social, and environmental challenges. MSW management is an example of one such challenge, which is directly associated with rapid urbanization [13], [14].

Levels of service in solid waste collection strongly depend on the number of collection periods, collection points, and types of solid waste collected. Increasing the transport time increases the waiting time for the collection of useful waste at each shipment, thus reducing its efficiency. Environmental, political, economic, socio-cultural, and cultural conditions in any society widely affect municipalities' efforts and their decision-making process [15].

The increase in waste production is due to the increase in population and the exponential growth of urbanization. Most countries face many problems in waste management because their subsets do not have sufficient funding for waste management activities. Therefore, they need to develop a regular policy plan for waste management to minimize costs and overcome the challenges that arise. Therefore, waste disposal methods are used in most countries to overcome its accumulation in the community. Currently, CO2 in the atmosphere is reaching approximately 390 ppm, which leads to global warming. The rapid growth of urbanization, population, and environmental concerns have created a critical situation for waste management [16].

Recycling waste can be a less costly method than recycling options, which is why it attracts the attention of most city managers. Also, with the advancement of technology, landfilling does not seem to be a sustainable solution to the problem of waste accumulation. Landfills come with many concerns, such as pollution affecting landfill space shortage, which is scarce [17].

Different cities face different problems with waste managers. In most cities, the executive does not have a coherent waste collection policy. Most researchers have found that these problems occur in communities facing increasing populations, and local governments often do not have enough data. On the other hand, waste collection creates high costs for these communities, so waste collection and transportation are the most costly [18].

One of the important aspects of decision making is MCDM, which is divided into two categories: 1) continuous, which can be solved by Multi-Objective Decision-Making (MODM) methods to deal with the continuous problems, which include a very large number of alternative solutions that are not explicitly known at the beginning, and 2) discrete, that uses the Multi Attribute Decision Making (MADM) methods to solve the discrete problems, which has a finite number of alternative solutions that are known at the beginning [19]. MCDM ranks all the alternatives to find the optimum choice by applying a specific approach concerning different criteria [20]. Several MCDM methods have been applied for site selection in recent years, such as AHP, ANP, Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), Complex Proportional Assessment (COPRAS) method, Best Worst Multi-criteria (BWM) method and so forth [21].

Table 1 reports the results of reviewing internationally published studies in which different waste management systems were analyzed from at least a social perspective. The following issues were identified for each study: the waste fraction considered the analyzed aspects (environmental, economic, technical, or social), data sources, and the methodology applied to characterize the social impact.

Table 1. Comparison of the most related works.

Authors	Aspects				Data Source					Methodology
	Economic	Technical	Environmental	Social	Simulation Data	Primary Data (Specific Data)	Secondary Data (Generic Data)	Forecasting Data	Interviews/Questionnaires	
Babaee Tirkolaee et al. [22]	*	*	*		*	*				Mathematical modeling and optimization approach
Yadav et al. [23]	*	*	*	*					*	MADM approach
Rabbani et al. [10]			*		*	*				Optimization approach

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Table 1. Continued.

Authors	Aspects				Data Source					Methodology
	Economic	Technical	Environmental	Social	Simulation Data	Primary Data (Specific Data)	Secondary Data (Generic Data)	Forecasting Data	Interviews/Questionnaires	
Bovea et al. [24]	*	*	*		*		*			Simulation and optimization approach
Archetti et al. [25]		*			*	*				Exact algorithm
Jatinkumar Shah et al. [26]	*		*				*	*		Stochastic optimization
Boonmee et al. [27]	*		*		*			*		Mathematical modeling and optimization approach
Toro et al. [28]			*	*		*		*		Mathematical modeling and optimization approach
Yıldız et al. [29]	*		*			*			*	Application of questionnaires
Mirdar Harijani et al. [30]			*				*	*		Fuzzy AHP

3 | Model Development

After examining the theoretical foundations, mainly obtained from literature and new texts, the relevant conceptual model was designed. Based on the following model, the criteria for selecting a suitable place for landfilling municipal waste are classified into four categories. The main factors mentioned in the following model are geological criteria, environmental criteria, social criteria, and economic criteria. Also, to confirm the model's structure, the exploratory FA method has been used, the results of which will be mentioned in the research method section. The model of this research is finalized in *Table 2*.

Table 2. Identified evaluation attributes with their respective descriptions.

	Attributes	Descriptions
Economic	MSW generation	Proximity to the wards with the higher generation of MSW
	Land ownership	Land ownership by municipality/government to establish TSs
	Proximity to other facilities	Proximity of TS locations to the processing or landfill sites
	Overall cost	Optimal overall cost for the entire MSW management system
	Distance traveled	Total distance traveled by PCVs and SCVs
Technical	Interference with routine traffic	To avoid interference with the routine traffic of urban centers
	Size of land	Size of land available to build TSs
	Accessibility	Access to the TS locations through major roads
	Availability of basic amenities	Availability of electricity and water supplies to the locations
	Flexibility for size expansion	Flexibility to expand the capacity of TSs in the future
Environmental-social	Remoteness to water bodies	Euclidean distances of the TS location from water bodies
	Total emissions	Total vehicular emissions from PCVs and SCVs
	Protection from flood hazards	Euclidean distances of flood-prone areas from TSs
	Public acceptability	Acceptability of residents to have TSs
	Kids population density	Remoteness to areas with higher population densities of kids

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4 | Material and Methods

The proposed method for selecting appropriate locations for landfills consists of two basic assessment stages (as shown in *Fig. 1*): 1) identification of attributes and economic evaluation of all possible combinations and 2) evaluation of shortlisted alternatives using Nonlinear analysis method.

In stage one of the assessment, multiple pertinent attributes are identified based on a thorough literature review and field surveys. Further, a focused workshop with municipal officials is conducted to score alternatives concerning the selected attributes individually. The economic evaluation of all possible permutations and combinations is then performed for all potential locations of landfills. The second stage of the assessment consolidates the average scores given to all alternatives for the attributes. The following subsections provide a detailed description of these two assessment stages.

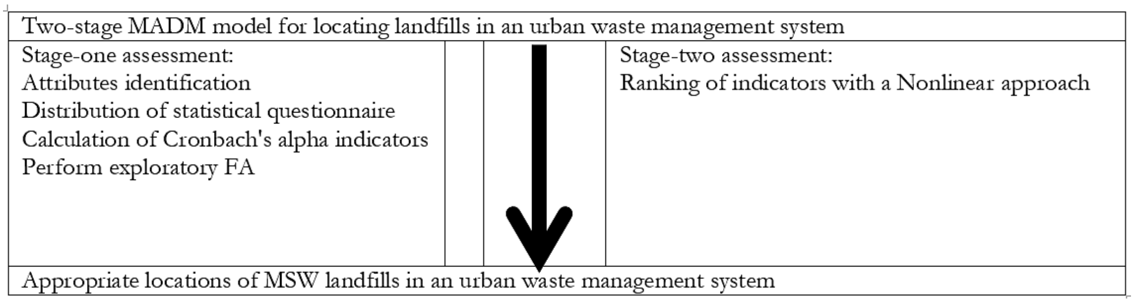

Fig. 1. Scheme describing the overall methodology.

4.1 | Stage-One Assessment

The stage-one assessment can be explained using the following steps:

Step 1. The 15 attributes are first identified through a comprehensive literature review and with the help of municipal officials during field surveys. These attributes are categorized into four types, i.e., economic, technical, environmental, and social (see *Table 2*), based on their respective propensity. Including all types of attributes in selecting the best locations for landfills provides a useful reference for the stakeholders with specialized knowledge about specific locations. After identifying the attributes, the next step is distributing a statistical questionnaire.

Step 2. With a quantitative modeling approach, this research pursues the goal of assessing and prioritizing each effective criteria for selecting a municipal waste disposal site. The data collection tool is a researcher-made questionnaire. The statistical population of the research is 150 university professors, students, and experts in urban planning management. Therefore, Cochran's method was used at a 5% error level and 95% confidence level to calculate the number of samples; 109 questionnaires were distributed to the statistical population, and 100 questionnaires were returned. In this research, Cochran's sampling formula was used to estimate the sample size, and the sample size was determined using the following formula:

$$n = \frac{\frac{z^2 \times pq}{d^2}}{1 + \frac{1}{N}\left[\frac{z^2 \times pq}{d^2} - 1\right]}. \quad (1)$$

n: statistical sample size.

P: The proportion of the trait in the statistical population. Here, P=0.5 is considered.

q: It is the proportion of absence of a trait in the statistical population. Here, since q=0.5 is considered, q=1-p is equal to 0.5.

Z: In this research, considering the significance level of 0.95, the value of Z is equal to 1.96.

d: Is the desired possible accuracy (error level) and is considered here as 0.05.

N: population size.

In this research, due to the limited statistical population, an available sampling method was used; in this way, the online questionnaire was shared with experts. Also, the size of the available population is considered to be 150 people, and based on placement in the Cochran formula, the sample size is 109 people. Also, the number of samples to be used in fuzzy nonlinear mathematical programming to rank the research indicators is ten people, consisting of university professors and experts in urban planning. The selection criteria of these people include the level of education in the field of urban planning and executive experience in the field of waste management.

Step 3. In this study, Cronbach's alpha method was used to assess the reliability of the questionnaire. The reliability of a measure is its ability to achieve consistent results. In this method (alpha calculation), reliability is operated as internal consistency, which forms the degree of internal correlation between items on a scale. *Table 3* shows the Cronbach's alpha value obtained for the main criteria of the research model. As it turns out, all the numbers obtained represent good values. Also, the Cronbach's alpha value of the whole questionnaire is 0.933, which is desirable.

Table 3. Cronbach's alpha value for each of the main criteria of the model.

Main Criteria of the Model	Cronbach's Alpha Coefficients
Economic	0.832
Technical	0.756
Environmental-social	0.789

Step 4. Exploratory FA is a statistical method used to identify the underlying categories of a set of items. In some studies, researchers first prepare a large number of items to measure the main phenomenon under study. Then, it is necessary to categorize these items in an orderly manner. The Exploratory Factor Analysis (EFA) EFA method helps to emerge different clusters according to the internal correlation between items. In each cluster, several elements have semantic correlation. Each cluster is called a factor. In this way, reaching specific and limited clusters from a large and scattered set of objects is possible. The researcher can choose a suitable title for that cluster based on the items placed in each cluster. FA is used to find out the underlying variables of a phenomenon or summarize a set of data. The primary data for FA is the correlation matrix between the variables. FA does not have predetermined dependent variables.

In other words, exploratory FA is one of the data clustering methods in the data mining field. This technique is used in management studies to identify the underlying factors of a set of questions. If you have identified many questions based on research literature or interviews and have no idea how to categorize them, you can use exploratory FA. FA, by creating a correlation matrix, shows that the variables are gathered in clusters so that the variables of each cluster are correlated with each other and are not correlated with other clusters. These clusters are the dimensions of the subject under investigation. The variables of each cluster are the measurement items of that dimension. Variables that do not correlate with other variables should be removed because the analyzed variables should have a reasonable correlation with some other variables of the analysis.

Two methods of measuring the proportionality of sample size for exploratory FA are the calculation of Kaiser-Mayer-Olkin (KMO) statistic and Bartlett's test of sphericity. The KMO sample adequacy index is specific to exploratory FA and shows whether the data are sufficient to perform exploratory FA calculations or not. KMO value must be greater than 0.5; some believe that the value of KMO should be greater than 0.9. Some texts state that if the KMO value is greater than 0.9, it is excellent, and if smaller

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than 0.5, it is unacceptable. Others believe that the value of this statistic is more than 0.7; the existing correlations are very suitable for FA. If it is between 0.5 and 0.69, you should be very careful, and if it is less than 0.5, it is not suitable for FA.

Also, to maximize the relationship between items and agents, the axes should be rotated. Rotating factors create the best combination of items and factor structure. The main goal of factor rotation is to transform the factor structure into a simple factor load structure that can be easily interpreted. The interpretation of the factors of the rotated matrix is much simpler than the interpretation of the factors of the unrotated matrix.

Usually, there are four orthogonal rotation methods, including Varimax, Quartimax, and Equamax, and two inclined methods, including Oblimin Direct and Promax. Among the group of rotation methods, the most popular and widely used method is varimax rotation. In varimax rotation, the independence between mathematical factors is preserved. From an engineering point of view, this issue means that at the time of rotation, the axes remain perpendicular. In other words, by keeping the angles of the list of factors, they remain perpendicular to each other. Through varimax rotation, the factors are transferred to new axes so that they can be interpreted through a set of test items with a simple structure that shows the main and relatively clear lines to arrive at the solutions. Although other rotation methods have different interpretations, they are all used to maximize the relationship between variables and some factors.

In this study, three factors have been identified as effective factors in selecting a suitable place for landfilling of municipal waste. For each of these factors, a separate FA should be performed. To factorize these variables based on the data extracted from 100 returned questionnaires, FA was performed several times, the outputs of which are shown in *Table 4*, respectively. In the first line of this table, the number of variables is mentioned, which are the indicators considered for the effective factors in choosing a suitable place for landfilling municipal waste. For example, the number of economic variables is 5. Considering that FA aims to explain the desired phenomena with a smaller number of primary variables, it is necessary to maintain factors that have formal or theoretical validity. Therefore, FA is repeated to achieve such a goal.

Table 4. Results of exploratory FA to select a suitable place for landfilling municipal waste.

	Economic	Technical	Environmental-Social
Number of variables	5	5	5
Number of repetitions of FA	1	1	3
KMO test	0.734	0.798	0.660
Bartlett test	0.0032	0.009	0.000

4.2 | Stage-Two Assessment

As mentioned in this study, the fuzzy nonlinear prioritization method has been used to measure the weight and rank of effective criteria for selecting the landfill of municipal waste. Since the fuzzy weight determination methods use the pairwise comparison matrix and are inspired by the definitive hierarchical analysis method, the reciprocal matrix (elements below the diameter) is explained (by inverting the numbers above the diameter), which leads to problems. In addition, sometimes decision makers may or may not want to make all the comparisons, so Mikhailov's nonlinear method is used in this study. The steps for using this method are as follows:

Step 1. Drawing the hierarchical tree: in this step, the structure of the decision hierarchy is drawn using the target and option target levels.

Step 2. Formation of a fuzzy decision matrix: agreed fuzzy decision matrices are formed based on the opinions of decision makers. Therefore, it is necessary to use fuzzy numbers in explaining people's preferences and polls, which is important in this study.

Certainty in a phenomenon indicates that the effective structures and variables in modeling that phenomenon are definitely obvious and clear, and there is no doubt about their occurrence and amount. Most common tools for conventional modeling have a strict, definitive, and precise nature that is the phenomena are mostly placed in two special situations, and instead of being compared with expressions such as more or less, they are separated only in the form of yes or no.

In other words, in this case, in the science of logic, a statement can be stated as true or false; in the theory of sets, a member can only belong to a set or not, and in optimization, it can only be about whether it is practical or not. The result of the analysis gave an opinion. But as it was said, partial uncertainty is inseparable in complex systems, which are mainly part of natural phenomena, and the use of mathematical language in these conditions does not seem safe. Consequently, the complexity and consequences of modeling in this situation are divided into two categories. First, real and real situations are not so strict and cannot be described accurately; this is beyond human control.

Therefore, the use of fuzzy triangular numbers in this research is due to the uncertainty in the phenomena, which is divided into two categories. The first category is caused by the lack of knowledge and information about a phenomenon and is referred to as probabilistic or random uncertainty. The theory of statistics and probabilities can model the phenomena that fall into this category. However, the second category is more dependent on understanding the concepts and providing accurate meanings of the studied phenomenon and is referred to as uncertainty caused by ambiguity. Uncertainties of this category can be analyzed by fuzzy logic and will be discussed further.

Defuzzification is a method to convert fuzzy numbers into definite numbers. This operation causes the results of fuzzy inference to be presented understandably for the audience. According to the scope of the application, various defuzzification methods are also provided, such as the surface center method, center of gravity method, Minkowski method, and CFCS algorithm. The purpose of all these methods is to transform fuzzy results into non-fuzzy or regular results. In a fuzzy system, fuzzification of the input elements is used first. After that, calculations are done by fuzzy method, and finally, the results must be de-phased. By defuzzifying the results of a fuzzy computing system, reports can be presented understandably for their users. The method of diffusing triangular numbers in this research is the center of gravity method. The reason for using the center of gravity method to defuzzify fuzzy numbers in this research:

I. Simplicity in use.
II. It can be used for an MCDM model with a combination of deterministic and fuzzy criteria.

Table 5. Linguistic scales for pairwise comparisons and their fuzzy equivalents.

Linguistic Values for Pairwise Comparisons	Triangular Fuzzy Scales
Preferred equally	(1, 2, 3)
Preferred moderately	(2, 3, 4)
Preferred strongly	(3, 4, 5)
Very strongly preferred	(4, 5, 6)
Extremely preferred	(5, 6, 7)

Step 3. To obtain the weight of the criteria and sub-criteria in the research model, it is necessary to calculate the alpha cut for the matrix of pairwise comparisons, solve the model, and finally integrate the weights in different levels of alpha to obtain the final weight. Therefore, the reason for using fuzzy Nonlinear programming in this research is to eliminate the stages of achieving the final weights. In this way, weights are obtained whose ratio is approximately applicable in the initial judgments $\widetilde{a_{ij}} = (l_{ij}, m_{ij}, u_{ij})$, in other words: $l_{ij} \leq \frac{w_i}{w_i} \leq u_{ij}$. Also, other reasons for using fuzzy Nonlinear programming in this research are:

I. The possibility of simulating human logic and thinking.
II. The possibility of creating two solutions or answers for a problem.
III. Suitable for solving problems with approximate answers.
IV. Ability to create nonlinear functions with arbitrary complexity.
V. Strong dependence on the researcher's opinion in creating fuzzy logic models.

Formulation and solution of the model: the model is formulated and solved using the upper and lower limits of the resulting matrix elements. The Nonlinear model used in this research is as follows:

$$\text{Maximise} \quad \lambda,$$
$$\text{s. t.} \tag{2}$$

$$\left(m_{ij} - l_{ij}\right)\lambda w_j - w_i + l_{ij} w_j \leq 0,$$

$$\left(u_{ij} - m_{ij}\right)\lambda w_j + w_i - u_{ij} w_j \leq 0, \tag{3}$$

$$\sum_{k=1}^{n} w_k = 1, \tag{4}$$

$$w_k > 0, \quad k = 1,2,\dots,n, \quad i = 1,2,\dots,n-1, \quad j = 2,3,\dots,n, \quad j > i. \tag{5}$$

Due to the non-linearity of the model, it can not be solved by the simplex method and must be solved using appropriate quantitative methods and software (such as Lingo). Positive optimal values for the λ index indicate that all weight ratios are completely true in the initial judgment. Still, if this index is negative, it can be seen that the fuzzy judgments are strongly inconsistent, and the ratio weight gain is almost always true of these judgments.

5 | Result and Discussion

The steps related to the evaluation and ranking of effective factors for a suitable place for landfilling of municipal waste in this research are divided into two main parts: 1) determining the matrix of pairwise comparisons based on the integration of experts, and 2) application of mathematical modeling in ranking and obtaining bringing the weights of the factors in the research model.

5.1 | Ranking of the Main Criteria of the Model

During the survey, based on the summary of expert opinions, the matrix of pairwise comparisons of the main criteria relative to each other is shown in *Table 6*.

Table 6. Ranking of the main criteria of the model.

	W_1			W_2			W_3		
W_1	-	-	-	-	-	-	-	-	-
W_2	2.40	3.30	5.60	-	-	-	-	-	-
W_3	2.2	2.98	4.5	1.09	2.05	4.02	-	-	-

$$\text{Maximise} \quad \lambda,$$
$$\text{S. t.}$$
$$3/30 - 2/40)\lambda w_1 - w_2 + 2/40 w_1 \leq 0,$$
$$5/60 - 3/30)\lambda w_1 + w_2 - 5/60 w_1 \leq 0,$$
$$2/98 - 2/2)\lambda w_1 - w_3 + 2/2 w_1 \leq 0,$$
$$4/5 - 2/98)\lambda w_1 + w_3 - 4/5 w_1 \leq 0,$$
$$2/05 - 1/09)\lambda w_2 - w_3 + 1/09 w_2 \leq 0,$$
$$4/02 - 2/05)\lambda w_2 + w_3 - 4/02 w_2 \leq 0,$$
$$w_1 + w_2 + w_3 = 1,$$
$$w_k \geq 0, \quad k = 1,2,3.$$

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As can be seen, the above model has been solved using Lingo software, and the importance of each of the main factors of the research model and the degree of compatibility λ have been calculated as shown in the table below. As shown in *Table 7*, a positive value for the λ compatibility index indicates acceptable matrix compatibility.

Table 7. Weight and ranking of factors related to the main dimensions of the research model derived from the fuzzy nonlinear model.

Main Criteria of the Model	Criteria Code	Weight	Rank	Value Object Function
Economic	W_1	0.3559699	2	
Technical	W_2	0.5136857	1	0.3677686
Environmental-social	W_3	0.1303444	3	

5.2 | Ranking of Economic Factors

During the survey, based on a summary of the opinions of matrix experts, the pairwise comparisons of economic factors with each other are shown in *Table 8*.

Table 8. Ranking of the economic criteria of the model.

	W1			W2			W3			W4			W5		
W1	-	-	-	-	-	-	-	-	-	-	-		-	-	-
W2	1.15	1.65	2.06	-	-	-	-	-	-	-	-		-	-	-
W3	1.65	2.71	3.74	1.65	2.71	3.74	-	-	-	-	-		-	-	-
W4	1.15	1.89	2.57	1	1.32	1.56	0.37	0.49	0.76	-	-	-	-	-	-
W5	1.13	1.39	2.47	1.1	1.29	2.39	0.8	0.9	1	0.9	1	1.5	-	-	-

$$\text{Maximise} \quad \lambda,$$
$$\text{S. t.}$$
$$1/65 - 1/15)\lambda w_1 - w_2 + 1/15 w_1 \leq 0,$$
$$2/06 - 1/65)\lambda w_1 + w_2 - 2/06 w_1 \leq 0,$$
$$2/71 - 1/65)\lambda w_1 - w_3 + 1/65 w_1 \leq 0,$$
$$3/74 - 2/71)\lambda w_1 + w_3 - 3/74 w_1 \leq 0,$$
$$2/71 - 1/65)\lambda w_2 - w_3 + 1/65 w_2 \leq 0,$$
$$3/74 - 2/71)\lambda w_2 + w_3 - 3/74 w_2 \leq 0,$$
$$1/89 - 1/15)\lambda w_1 - w_4 + 1/15 w_1 \leq 0,$$
$$2/57 - 1/89)\lambda w_1 + w_4 - 1/89 w_1 \leq 0,$$
$$1/32 - 1)\lambda w_2 - w_4 + w_2 \leq 0,$$
$$1/56 - 1/32)\lambda w_2 + w_4 - 1/56 w_2 \leq 0,$$
$$0/49 - 0/37)\lambda w_3 - w_4 + 0/37 w_2 \leq 0,$$
$$0/76 - 0/49)\lambda w_3 + w_4 - 0/76 w_3 \leq 0$$
$$1/39 - 1/13)\lambda w_1 - w_5 + 1/13 w_1 \leq 0,$$
$$2/47 - 1/39)\lambda w_1 + w_5 - 2/47 w_1 \leq 0,$$
$$1/29 - 1/1)\lambda w_2 - w_5 + 1/1 w_2 \leq 0,$$
$$2/39 - 1/29)\lambda w_2 + w_5 - 2/39 w_2 \leq 0,$$
$$0/9 - 0/8)\lambda w_3 - w_5 + 0/8 w_3 \leq 0,$$
$$1 - 0/9)\lambda w_3 + w_5 - w_3 \leq 0,$$
$$1 - 0/9)\lambda w_4 - w_5 + 0/9 w_4 \leq 0,$$
$$1/5 - 1)\lambda w_4 + w_5 - 1/5 w_4 \leq 0,$$
$$w_1 + w_2 + w_3 + w_4 + w_5 = 1,$$
$$w_k \geq 0 \quad k = 1,2,3,4,5.$$

As can be seen, the above model has been solved using Lingo software, and the importance of each of the economic factors of the research model and the degree of compatibility λ have been calculated as shown in the table below. As shown in *Table 9*, a positive value for the λ compatibility index indicates acceptable matrix compatibility.

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Table 9. Weight and ranking of factors related to the economic dimensions of the research model derived from the fuzzy nonlinear model.

Economic Criteria of the Model	Criteria Code	Rank	Weight	Value Object Function
MSW generation	W_1	1	0.2991997	
Land ownership	W_2	5	0.1162146	
Proximity to other facilities	W_3	4	0.1514756	0.3068245
Overall cost	W_4	2	0.2485399	
Distance traveled	W_5	3	0.1845702	

5.3 | Ranking of Technical Factors

During the survey, based on a summary of the opinions of matrix experts, the pairwise comparisons of technical factors with each other are shown in *Table 10*.

Table 12. Ranking of the environmental-social criteria of the model.

	W_1			W_2			W_3			W_4			W_5		
W_1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
W_2	2.16	3.27	5.65	-	-	-	-	-	-	-	-	-	-	-	-
W_3	1.42	3.32	4.3	1.32	2.67	3.4	-	-	-	-	-	-	-	-	-
W_4	1.09	2.18	2.87	0.95	1	1.1	0.7	1.6	2.3	-	-	-	-	-	-
W_5	1.15	1.89	2.57	0.8	0.9	1.56	0.37	0.49	0.76	0.8	0.99	1.31	-	-	-

$$
\begin{aligned}
&\text{Maximise} \quad \lambda,\\
&\text{S. t.}\\
&3/27 - 2/16)\lambda w_1 - w_2 + 2/16 w_1 \le 0,\\
&5/65 - 3/27)\lambda w_1 + w_2 - 5/65 w_1 \le 0,\\
&3/32 - 1/42)\lambda w_1 - w_3 + 1/42 w_1 \le 0,\\
&4/3 - 3/32)\lambda w_1 + w_3 - 4/3 w_1 \le 0,\\
&2/67 - 1/32)\lambda w_2 - w_3 + 1/32 w_2 \le 0,\\
&3/4 - 2/67)\lambda w_2 + w_3 - 3/4 w_2 \le 0,\\
&2/18 - 1/09)\lambda w_1 - w_4 + 1/09 w_1 \le 0,\\
&2/87 - 2/18)\lambda w_1 + w_4 - 2/87 w_1 \le 0,\\
&1 - 0/95)\lambda w_2 - w_4 + 0/95 w_2 \le 0,\\
&1/1 - 1)\lambda w_2 + w_4 - 1/1 w_2 \le 0,\\
&1/6 - 0/7)\lambda w_3 - w_4 + 0/7 w_2 \le 0,\\
&2/3 - 1/6)\lambda w_3 + w_4 - 2/3 w_3 \le 0,\\
&1/89 - 1/15)\lambda w_1 - w_5 + 1/15 w_1 \le 0,\\
&2/57 - 1/89)\lambda w_1 + w_5 - 2/57 w_1 \le 0,\\
&0/9 - 0/8)\lambda w_2 - w_5 + 0/8 w_2 \le 0,\\
&1/56 - 0/9)\lambda w_2 + w_5 - 1/56 w_2 \le 0,\\
&0/49 - 0/37)\lambda w_3 - w_5 + 0/37 w_3 \le 0,\\
&0/76 - 0/49)\lambda w_3 + w_5 - 0/76 w_3 \le 0,\\
&0/99 - 0/8)\lambda w_4 - w_5 + 0/8 w_4 \le 0,\\
&1/31 - 0/99)\lambda w_4 + w_5 - 1/31 w_4 \le 0,\\
&w_1 + w_2 + w_3 + w_4 + w_5 = 1,\\
&w_k \ge 0, \quad k = 1,2,3,4,5.
\end{aligned}
$$

As can be seen, the above model has been solved using Lingo software and the importance of each of the research model's environmental-social factors and the degree of compatibility λ have been calculated as shown in the table below. As shown in *Table 13*, a positive value for the λ compatibility index indicates acceptable matrix compatibility.

Table 13. Weight and ranking of factors related to the environmental-social dimensions of the research model derived from the fuzzy nonlinear model.

Environmental-Social Criteria of the Model	Criteria Code	Weight	Rank	Value Object Function
Remoteness to water bodies	W_1	0.1657970	5	
Total emissions	W_2	0.1690169	4	
Protection from flood hazards	W_3	0.1743852	3	0.07569974
Public acceptability	W_4	0.2357956	1	
Kids population density	W_5	0.1811216	2	

After obtaining the weight of the main criteria and sub-criteria of the model, the normalized weight of each sub-criteria and their final rank can be calculated, the calculations of which are shown in *Table 14*.

Table 14. Normalized weight of the research model.

No	Main Criteria	Weight	Attributes	Weight	Normalized Weight	Rank
1	Economic	0.355	MSW generation	0.299	0.106	2
			Land ownership	0.116	0.041	10
			Proximity to other facilities	0.151	0.053	9
			Overall cost	0.248	0.088	5
			Distance traveled	0.184	0.065	8
2	Technical	0.512	Interference with routine traffic	0.178	0.091	4
			Size of land	0.183	0.093	3
			Accessibility	0.258	0.132	1
			Availability of basic amenities	0.165	0.084	6
			Flexibility for size expansion	0.148	0.075	7
3	Environmental-social	0.133	Remoteness to water bodies	0.165	0.021	15
			Total emissions	0.169	0.022	14
			Protection from flood hazards	0.174	0.023	13
			Public acceptability	0.235	0.031	11
			Kids population density	0.181	0.024	12

6 | Conclusions and Recommendations

This research article aims to explain a novel two-stage MADM model ranking of appropriate criteria for selecting an MSW facility for landfills in urban centers. This model expands the conventional approach of only utilizing economic considerations for site selection models and includes other important attributes into the decision-making process; this makes the approach holistic. The model has produced an MSW collection system characterized by an optimum cost, minimal environmental emissions, and good suitability given societal and technical attributes.

These scores are aggregated to form a standard decision matrix for evaluation as per general MADM protocols. Decision makers should seek the most rational solution to an optimization problem according to their decision criteria. To that end, Multi criteria analysis can be crucial since the formulation potentialities are wide.

The results of this study show that three economic, technical, and environmental-social factors are effective in choosing a suitable place for municipal waste disposal. The weights related to the three variables were extracted by analyzing the decision decision matrices, which are shown in the figure below:

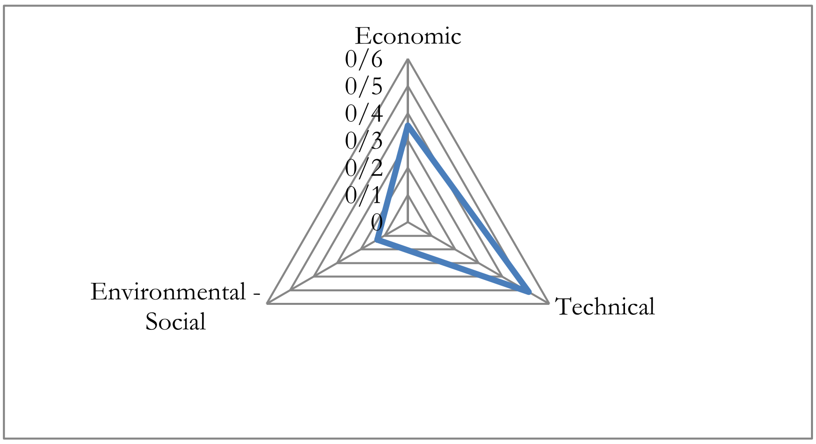

Fig. 2. Radar chart related to the main factors of the research model.

Based on the results of identifying, ranking, and prioritizing the components and factors related to each of them using the FMADM model, it has been determined that three economic components (including MSW generation, land ownership, proximity to other facilities, overall cost, and distance traveled); technical (interference with routine traffic, size of land, accessibility, availability of basic amenities, flexibility for size expansion); and environmental-social (including remoteness to water bodies, total emissions, protection from flood hazards, public acceptability and kids population density), in reducing production and separation of the origin of waste is effective with the participation of the people. In other words, these indicators can be used to select a suitable place for landfilling production waste in the city.

This article has three theoretical, practical, and technical contributions. Also, this article provides a clear explanation of the theoretical contribution related to the accumulated knowledge, both in the introduction and theoretical background sections of the article. Therefore, studying the past research describes a relatively complete background of the planned theoretical contributions of this article compared to the previous research. Therefore, the theoretical contribution of this article solves the scientific gap about effective indicators for determining the location of waste disposal. From the point of view of practical contribution, this article presents practical concepts related to managers and experts and has practical suggestions presented in the conclusion section. It has been tried to reduce the practical vacuum for evaluating the sustainable environment with practical suggestions to managers. Also, the technical contribution of this article is presented by combining fuzzy logic and nonlinear mathematical programming.

The methodology presented provides decision makers with a tractable tool that could be employed either by private investors or public authorities. The procedure could be easily adopted e with slight modifications and adjustments to the special requirements of the problem under consideration to solve similar problems in areas other than the one examined in the present analysis. The methodological framework is also not limited to supporting the specific decision; it can also be used to locate optimal sites for developing other types of required infrastructure, such as collection points, sorting centers, etc. Different criteria may be decided to be utilized in all those cases, but the overall methodology may remain practically unaltered.

Researchers are always faced with limitations in their research, some of which show themselves even at the beginning of their work. This research is not excluded from other research and has some shortcomings, which are mentioned in this part: Cross-sectional research is one of the limitations of any research. It is somewhat difficult to generalize the results of research that are cross-sectional and not longitudinal because the validity and reliability of data and opinions may have changed over time, or people may have made an incomplete estimate of the items when commenting on the research at the time of implementation. Have. Also, the non-cooperation of some of the statistical community in distributing questionnaires is another limitation of this research. Finally, there is a lack of accurate and

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complete acquaintance of experts with the concepts and definitions of some variables and items in the questionnaire, which may create a knowledge gap between academic experts and experts in the field of waste management and distort the result in different stages of carrying out this research.

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Appendix

Research questionnaire (1)

Dear respondent

The present questionnaire has been prepared and set up to conduct a scientific research. Your answers are considered completely confidential and they will only be used scientifically. Your sincere cooperation and accuracy in completing this questionnaire can be useful in achieving important results.

Thank you in advance for your time.

Very Agree	Agree	No Comment	Opposite	Very Opposite	Attributes	Main Criteria	No
					MSW generation	Economic	1
					Land ownership		
					Proximity to other facilities		
					Overall cost		
					Distance traveled		
					Interference with routine traffic	Technical	2
					Size of land		
					Accessibility		
					Availability of basic amenities		
					Flexibility for size expansion		
					Remoteness to water bodies	Environmental - Social	3
					Total emissions		
					Protection from flood hazards		
					Public acceptability		
					Kids population density		

Research questionnaire (2)

Dear respondent

The present questionnaire has been prepared and set up to conduct a scientific research. Your answers are considered completely confidential and they will only be used scientifically. Your sincere cooperation and accuracy in completing this questionnaire can be useful in achieving important results.

Thank you in advance for your time.

Answering method for *Tables 2* to *5*: to answer these tables that measure the importance of these skills relative to each other, you should use *Table 1*.

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Table 1. Linguistic scales for pairwise comparisons and their fuzzy equivalents.

Linguistic Values for Pairwise Comparisons	Triangular Fuzzy Scales
Preferred equally	(1, 2, 3)
Preferred moderately	(2, 3, 4)
Preferred strongly	(3, 4, 5)
Very strongly preferred	(4, 5, 6)
Extremely preferred	(5, 6, 7)

Table 2. Matrix of pairwise comparisons of the main criteria of the research model.

	Economic			Technical			Environmental-Social		
	L	M	U	L	M	U	L	M	U
Economic									
Technical									
Environmental-social									

Table 3. Matrix of pairwise comparisons of economic factors.

	MSW Generation			Land Ownership			Proximity to Other Facilities			Overall Cost			Distance Traveled		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
MSW generation															
Land ownership															
Proximity to other facilities															
Overall cost															
Distance traveled															

Table 4. Matrix of pairwise comparisons of technical factors.

	Interference with Routine Traffic			Size of Land			Accessibility			Availability of Basic Amenities			Flexibility for Size Expansion		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
Interference with routine traffic															
Size of land															
Accessibility															
Availability of basic amenities															
Flexibility for size expansion															

Table 5. Matrix of pairwise comparisons of environmental-social factors.

	Remoteness to Water Bodies			Total Emissions			Protection from Flood Hazards			Public Acceptability			Kids Population Density		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
Remoteness to water bodies															
Total emissions															
Protection from flood hazards															
Public acceptability															
Kids population density															