EVALUATION OF THE MECHANICAL BIOLOGICAL TREATMENT PLANT LOCATION ALTERNATIVES USING FUZZY MULTI-CRITERIA DECISION MAKING APPROACH

(MEKANİK BİYOLOJİK ARITMA TESİSİ YER ALTERNATİFLERİNİN BULANIK ÇOK KRİTERLİ KARAR VERME YAKLAŞIMI İLE DEĞERLENDİRİLMESİ)

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LIST OF SYMBOLS

MSW	**:** Municipal Solid Waste
MBT	**:** Mechanical Biological Treatment
MCDM	**:** Multi Criteria Decision Making
GIS	**:** Geographic Information Systems
CLO	**:** Compost Like Output
BWM	: Best Worst Method
MCDA	**:** Multi Criteria Decision Analysis
AHP	**:** Analytic Hierarchy Process
ANP	**:** Analytic Network Process
TOPSIS	**:** Technique for Order Preference by Similarity to an Ideal Solution
ELECTRE	**:** ELimination Et Choice Translating Reality
VIKOR	**:** VIšeKriterijumska Optimizacija I Kompromisno Resenje
FAHP	**:** Fuzzy Analytic Hierarchy Process
FANP	**:** Fuzzy Analytic Network Process
PROMETHEE	**:** Preference Ranking Organization Method for Enrichment Evaluations
WASPAS	**:** Weighted Aggregated Sum Product Assessment
SAW	**:** Simple Additive Weighting
WLC	**:** Weighted Linear Combination
CODAS	: Combinative Distance-Based Assessment
DEMATEL	: The Decision Making Trial and Evaluation Laboratory
FLA	: Facility Location-Allocation
WEEE	: Waste Electrical and Electronic Equipment
CI	: Consistency index
CR	: Consistency Ratio

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ABSTRACT

Due to the increase in human population day by day, the amount of waste generated from the foods that consumed increases in the same direction. Today, with the increasing population and developing technology, the waste that is generated has become an important issue for countries. For a sustainable waste management process, waste collection, transfer, pre-treatment, and recycling issues should be analyzed in detail. Therefore, countries have aimed to apply appropriate recycling techniques by considering the characteristics of their location and multiple selection criteria. As a conclusion, meticulous work is required to determine the appropriate waste facility location.

The aim of this thesis is to determine the appropriate location for the mechanical biological treatment (MBT) plant in Istanbul. MBT provides that wastes become suitable for recycling by passing through the necessary processes before recycling. A pre-treatment facility is required in the Anatolian region of Istanbul, in order to increase the efficiency of the waste recycling facility. Therefore, an integrated fuzzy multi-criteria decision making (MCDM) model is developed for the MBT location selection problem. The proposed method comprises of geographic information system (GIS), fuzzy best worst method (BWM) and hierarchical fuzzy MCDM approach. First, alternatives for the site selection problem were determined using expert opinions and web-based GIS. Second, the criteria determined for the literature and expert opinions were weighted using the fuzzy best worst method. Finally, most suitable alternative was determined using hierarchical fuzzy MCDM approach.

Keywords: GIS, mechanical biological treatment, waste management, multi criteria decision making, fuzzy best worst method, hierarchical fuzzy MCDM approach, site selection.

ÖZET

İnsan nüfusunun her geçen gün artmasına bağlı olarak tüketilen besinler sonucu ortaya çıkan atık miktarı da aynı doğrultuda artmaktadır. Günümüzde artan nüfus ve gelişen teknoloji ile birlikte meydana gelen atıkları yönetebilmek ülkeler için önemli bir konu haline gelmiştir. Sürdürülebilir bir atık yönetim süreci için atığın toplanması, transfer edilmesi, ön işlemden geçirilmesi ve geri dönüşüm konuları detaylı bir şekilde analiz edilmelidir. Bu sebeple ülkeler bulundukları konumun özelliklerini ve birden fazla kriteri dikkate alarak uygun geri dönüşüm tekniklerini uygulamayı amaç edinmişlerdir. Belirlenen geri dönüşüm tekniğindeki atık tesislerinin hangi konumda yer alacağı kararı için ise titiz bir çalışma gerektiği sonucu doğmaktadır.

Bu çalışmada atığın geri dönüşümü öncesi gerekli işlemlerden geçirerek geri dönüşüme uygun hale gelmesini sağlayan mekanik biyolojik tesis (MBT) için İstanbul bölgesinde uygun tesis yer seçimi problemi üzerinde çalışılacaktır. İstanbul Anadolu bölgesinde atık geri dönüşüm tesisinin verimini arttırabilmek için ön işlem tesisine ihtiyaç bulunmaktadır. Bu nedenle, MBT yer seçimi problemi için entegre bir bulanık çok kriterli karar verme modeli geliştirilmiştir. Önerilen yöntem coğrafi bilgi sistemi, bulanık en iyi en kötü yöntem ve hiyerarşik bulanık çok kriterli karar verme yaklaşımından oluşmaktadır. Öncelikle yer seçimi problemi için alternatifler uzman görüşleri ve web tabanlı coğrafi bilgi sistemi kullanılarak belirlenmiştir. İkinci olarak, literatür ve uzman görüşleri ile belirlenen kriterler bulanık en iyi en kötü yöntemi kullanılarak ağırlıklandırılmıştır. Son olarak hiyerarşik bulanık çok kriterli karar verme yaklaşımı kullanılarak en uygun alternatif belirlenmiştir.

Anahtar Sözcükler : coğrafi bilgi sistemi, mekanik biyolojik arıtma, atık yönetimi, çok kriterli karar verme, bulanık en iyi-en kötü yöntemi, hiyerarşik bulanık MCDM yaklaşımı, yer seçimi.

1.INTRODUCTION

Municipal solid waste (MSW) is one of the major concern for developing countries as human activities increase. The increasing population and the rapid economic development have been causing to the great increase of the municipal solid waste in the world. The augmentation in the amount of waste with each passing day increases the importance of waste management. Successful waste management is not only the issue of prosperity but approach and choice of suitable concepts (Plavac et al., 2016). In other words, sustainable waste management is an extremely complex matter and various methods should be used for managing all materials and waste streams.

According to the European Union Waste Framework Directive, there are five steps in "Waste hierarchy" (Fig. 1.1). Prevention stage includes using less material in design and manufacture, keeping products for longer re-use and using less hazardous materials. Preparing for reuse stage includes, checking, cleaning, repairing, refurbishing whole items or spare parts. Recycling stage includes turning waste into a new substance or product. This part also includes composting if it meets quality protocols. Other recovery stage includes anaerobic digestion, incineration with energy recovery, gasification, fuel, heat power and some backfilling. Disposal stage includes landfill and incineration without energy recovery (Hu et al., 2015). While prevention stage is environmental most beneficial, disposal stage is environmental least beneficial. That’s why, waste disposal to landfill represents the least desirable option.

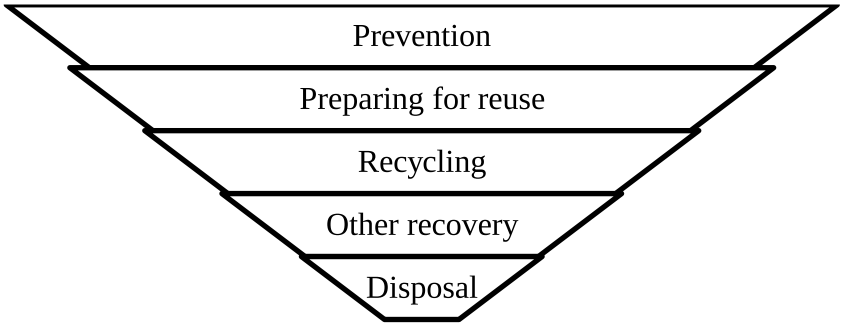

Figure 1.1 Waste hierarchy according to the EU Waste Framework Directive (European Commission, 2010)

Waste management strategies are categorized into four areas; production of materials, collection and transport, treatment or reprocessing, and final disposition. Production of materials include subparts such as waste sources, source separation, internal collection, production rates and waste types. Collection and transport include subparts such as collection, transport, transfer. Treatment or reprocessing include subparts such as physical, thermal and biological reprocessing. Physical reprocessing is composed from shredding, sorting and compacting. Thermal reprocessing is composed from incineration and gasification. Biological reprocessing is composed from anaerobic digestion and aerobic composting. Final disposition includes recycling and landfilling.

This study focus on treatment or reprocessing and final disposition parts in the waste management strategies. In the following, information on the contents of these parts are provided.

Landfilling: A landfill is more sort of a tightly sealed storage container (Demirbas, 2011). The most commonly used disposal method in most of the countries is sanitary landfill (Li et al, 2015). One of the most important reason for this volume can be increased with little addition of people and equipment in landfill areas. Also, operation and investment costs are not excessive. On the other hand, there are some disadvantages like landfill leachates contain an outsized number of compounds, a number of which may be expected to make a threat to health and nature if released into the natural environment (Demirbas, 2011). Landfill is not the best solution in the waste management system, more sophisticated and environment-friendly solutions must be develop.

Composting: Waste composting is process in which waste turns raw organic matter into stable products. Also, waste is digested by specific groups of microorganisms with the presence of oxygen. The process can be operated either by natural ways or by composting machines (Ayilara et al., 2020).

Incineration: Waste incineration is a method of waste disposal whereby high temperatures are used to sufficiently oxidize the combustible components in waste (Hu et al., 2015). Compared with landfills and composting, there are few advantages, such as taking up comparatively small space, decreasing the volume of waste and generating electricity. On the other hand, there are some disadvantages in this technique such as improper locations, excessive production of fly ash, lack of environmental impact assessments, high project investment, operation cost and the management difficulty (Hu et al., 2015., Li et al, 2015).

Material Recycling: Much of the waste are often recycled. Recycling reduces the quantity of waste that finishes up in landfill sites, while lowering on the quantity of material needed from the natural environment. Recycling also saves energy, recycling an aluminum can, for example, saves around 95% of the energy needed to make a new one from raw material (European Commission, 2010).

Mechanical Biological Treatment: MBT is a generic term composed of the combinations of several processes with the biological stabilization of organic matter via processes such as anaerobic digestion or composting. The aim of these plants is to separate the quickly biodegradable fraction of waste, as well as to recover recyclables from mixed waste streams (Montejo et al., 2013).

According to Di Lonardo et al. (2012) and Defra (2013), the objectives of MBT plants are

• Reducing the amount and weight of waste to be disposed of in landfills,

• Inactivation of biological and biochemical processes to minimize leachate and methane production and odour emissions,

• Immobilization of pollutants of the waste to be disposed of in order to reduce leachate contamination,

• Reduction of landfill settlement,

• Reduction of the duration of the landfill site aftercare,

• Diversion of non-biodegradable and biodegradable MSW going to landfill through the mechanical sorting of MSW into materials for recycling and/or energy recovery as refuse derived fuel,

• Diversion of biodegradable MSW going to landfill by:

-Reducing the dry mass of biodegradable municipal waste prior to landfill,

-Reducing the biodegradability of biodegradable municipal waste prior to landfill,

• Stabilization into a compost-like output (CLO) for use on land,

• Conversion into a combustible biogas for energy recovery,

• Drying materials to produce a high calorific organic rich fraction for use as refuse derived fuel.

The major goal of MBT plants is to minimize the environmental burdens of waste disposal by way of extensive stabilization. MBT can also help to recover valuable materials (TNA, 2018). These plants can be configured in several ways to achieve the required recycling, recovery and biodegradable municipal waste diversion performance. Figure 1.2 illustrates configurations for MBT plant and highlights the process steps (Defra, 2013).

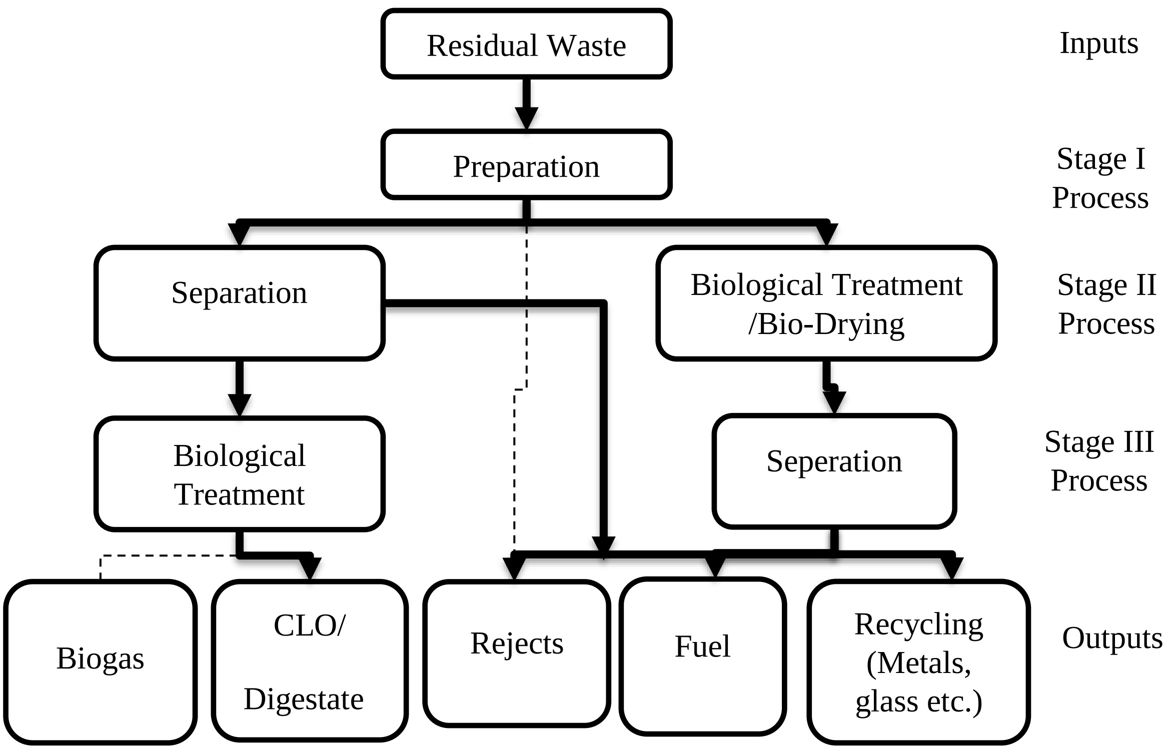

Figure 1.2 An Illustration of the Potential Mechanical Biological Treatment Options (Defra, 2013)

In MBT systems waste passes through several processes, but the processing is usually divided into two main stages: (1) mechanical and (2) biological treatment. In the mechanical part, waste is treated physically by processes such as drumming, splitting, shredding, crushing, grinding, milling, and similar physical treatment processes. On the other hand, in the biological part there are two primarily options such as aerobic and anaerobic, Table 1.1 summarizes the main categories of biological treatment. MBT waste can be turned into fuel or compost in this part.

Table 1.1 Main Categories of Biological Treatment

Options	Biological Treatment
I	Aerobic – Bio-drying / Bio-stabilization: partial composting of the (usually) whole waste.
II	Aerobic - In-Vessel Composting: may be used to either bio-stabilize the waste or process a segregated organic rich fraction.
III	Anaerobic Digestion: used to process a segregated organic rich fraction.

The input component is a MSW and output components consist of biogas, compost, CLO, refuse derived fuel and possibly the materials suitable for recycling. The quality of output components relies on the MSW composition. More efficient waste separation decreases complexity and capacity of MBT plants (Plavac et al., 2016).

The concept of MBT originated in Germany. Many reasons have been the major drivers for the development of this technology as regulatory restrictions on landfill space, subsequent landfill bans, the search for alternatives to incineration and increased costs of alternative disposal. The largest European markets where established MBT plants include Germany, Austria, Italy, Switzerland and the Netherlands, with others such as the UK growing fast (Defra, 2013).

In early 2017, Europe has a total of about 570 active MBT plants with a treatment capacity of 55 million tons. Some research indicates that new 120 facilities with an estimated capacity of about 10 million annual tons to be commissioned between 2017 and 2025 (The Market Report, 2017). Hence, the market size will continue to be increase in the coming years.

When considering the planning implications of an MBT facility the other issues that will need to be considered are common to most waste management facilities (Defra, 2013). One of the most important issue is facility siting.

In site selection process, the countries primary aim is to determine alternatives that ensure a suitable locate in terms of the appropriate criteria. Accomplishing these objectives depends pickily on considering the relationships between more than one criteria and alternative locates, and also depends on methods that determined.

Evaluation of the MBT plant location alternatives, which considers the need to trade-off multiple conflicting criteria inherent vagueness and imprecision, is a highly important multi-criteria group decision making problem. The classical MCDM methods that consider deterministic or random processes cannot effectively handle decision-making problems including imprecise and linguistic information. Furthermore, when a large number of performance attributes are to be considered in the evaluation process, it is generally preferred to structure them in a multi-level hierarchy in order to conduct a more effective analysis. For this reason, this thesis focuses on the detailed multi-criteria evaluation of MBT plant location alternatives to determine the most suitable one for asian side of Istanbul. The aim of this thesis is to propose a hierarchical fuzzy MCDM method that integrates GIS and fuzzy best worst method (BWM) for evaluating MBT plant location alternatives.

The remaining parts of this thesis are organized as follows. Section 2 presents a taxonomy and review of multi criteria decision making methods for site selection in waste management. In Section 3, a review of site selection criteria in terms of recycling technics such as landfill, incineration etc. will be explained. Section 4 reviews material and methods including geographic information systems (GIS), fuzzy set theory and decision making methods. Section 5 presents the application of the proposed models to Istanbul's MBT plant location selection problem. Finally, conclusions are provided in section 6.

2. LITERATURE REVIEW OF SITE SELECTION IN WASTE MANAGEMENT

The World Bank (2019m) report states that in 2016, the worlds' cities generated 2.01 billion tons of solid waste, amounting to a footprint of 0.74 kilograms per person per day. With rapid population growth and urbanization, annual waste generation is expected to increase by 70% from 2016 levels to 3.40 billion tons in 2050. Waste management process gets more remarkable as long as quantity of waste increases constantly. Also, as the quantity increases, the necessity for more efficient and suitable facilities increases. For the beginning of the process, the issue of determining the facility location becomes even more important. Locating MSW management facilities in a suitable location at optimal capacities is a complicated task including economic, technical, environmental and social challenges (Yalcinkaya and Kirtiloglu, 2020). For a sustainable site selection in waste management system, such challenges should be evaluated in detail and the process should be carried out pickily. Different models study the location decision problem using different location criteria. Determination of appropriate methods, suitable criteria, and alternative locations constitute the main topics for waste management site selection problems.

There are many studies about waste management site selection involving different methods. Recently, the basic multi-criteria decision making methods for site selection and waste management can be listed as follows: Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), ELimination Et Choice Translating REality method (ELECTRE), VIKOR, Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) and other hybrid methods, such as Fuzzy Analytic Hierarchy Process (FAHP), and Fuzzy Analytic Network Process (F-ANP) (Liu at al 2018).

Capability of MCDM methods by factoring both qualitative and quantitative criteria together with easy implementation led to utilize in a GIS environment to seek out suitable sites for regions in different countries (Guiqin et al (2009), Yesilnacar et al (2012), Rahimi et al (2019) etc.)

In this study, 65 articles were analyzed as a result of search using electronic database like web of knowledge and keywords like waste management and multi-criteria decision for site selection. This thesis covers only the journal articles, whereas proceeding papers, thesis and other manuscripts are not included. Also, these articles are scope of Science Citation Index Expanded, Social Sciences Citation Index and Arts, and Humanities Citation Index. The distribution of 65 articles with respect to the years and journals are summarized in Table 2.1 and Table 2.2, respectively.

Table 2.1 Distribution of the articles according to the years

Years	Number of Articles
1997	1
2001	1
2002	1
2004	1
2006	1
2007	3
2008	1
2009	3
2010	3
2011	1
2012	3
2013	2
2014	4
2015	4
2016	7
2017	4
2018	6
2019	7
2020	12

Table 2.2 Distribution of the articles according to the journals

Journal	**Number of Articles**
Waste Management	10
Environmental Earth Sciences	8
Sustainability	4
Waste Management & Research	4
Environmental Monitoring and Assessment	4
Journal of Cleaner Production	3
Environmental Science and Pollution Research	3
Journal of Environmental Management	3
European Journal of Operational Research	2
Fresenius Environmental Bulletin	2
Arabian Journal of Geosciences	2
Polish Journal of Environmental Studies	2
Journal Of Environmental Engineering And Landscape Management	2
Journal Of Multi-Criteria Decision Analysis	1
Land Use Policy	1
International Journal of Geographical Information Science	1
Journal of Environmental Planning and Management	1
International Journal of Digital Earth	1
International Journal of Environmental Research and Public Health	1
Building and Environment	1
Bulletin of Engineering Geology and the Environment	1
KSCE Journal of Civil Engineering	1
Applied Sciences	1
Journal of Engineering and Technological Sciences	1
Journal of Material Cycles and Waste Management	1
Sustainable Cities and Society	1
Applied Ecology and Environmental Research	1
Environmental Research	1
Computers & Industrial Engineering	1

There is a significant growth in the number of articles published between 2016 and 2020. Waste Management published 10 articles (15.15%) and Environmental Earth Sciences published 8 articles (12.12%) throughout all period. Iran and Turkey are countries where have most publications in waste management site selection problems (Figure 2.1).

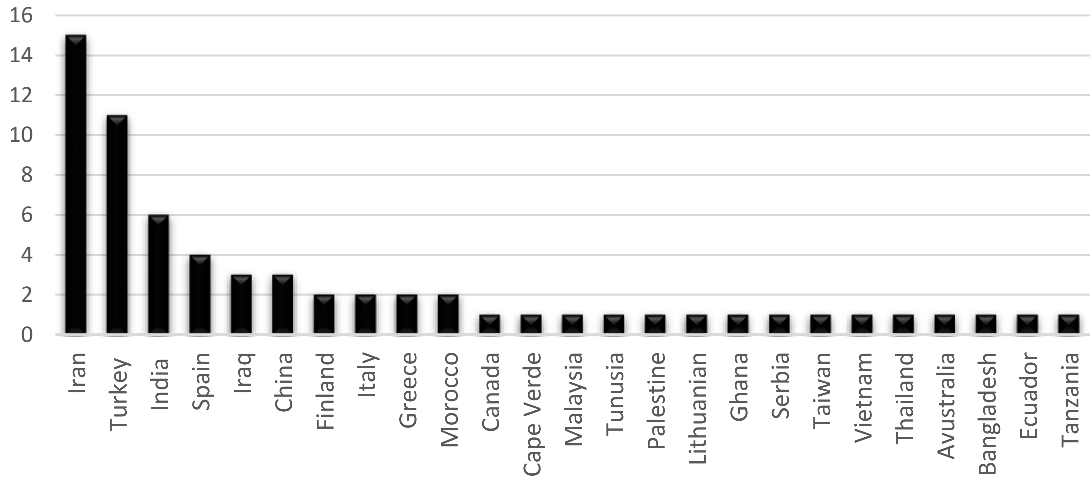

Figure 2.1 Distribution of the articles according to the countries

In the following sub-sections the site selection process methods are described. Sub-sections 2.1, 2.2, and 2.3 present the deterministic approaches, non-deterministic approaches, and integrated approaches for site selection in waste management, respectively.

2.1 Deterministic Approaches

10 articles (15.38%) have focused on the use of deterministic analytical methods including mathematical programming and multi-criteria decision making approaches.

2.1.1 Multi-Criteria Decision Making Approaches

9 out of 65 papers (13.84%) employed deterministic multi-criteria decision making techniques to select the most appropriate site for waste management. Deterministic MCDM techniques for site selection include AHP, ANP, ELECTRE, PROMETHEE, Delphi, Weighted Aggregated Sum Product Assessment (WASPAS) and TOPSIS are the most prevalently used methods.

Feo and Gisi (2010) proposed new approach including AHP for criteria weighting tool o rank a list of suitable municipal solid waste. The proposed method was applied to the siting of a composting plant in Italy.

Tuzkaya et al. (2007) applied analytic network process method for locating undesirable facility in İstanbul, Turkey. In addition, sensitivity analysis was used considering benefits, opportunities, costs and risks among alternatives.

Norese (2004) describes a phase of the decision process to evaluate and rank some selected possible plant location sites using Electre. A group worked to identify the criteria to analyse of the location of plants one for the incinerator and the other for the waste-disposal plant. ELECTRE method is used to compare these sites and rank them with the aim of selecting the best sites. Banias at al. (2010) evaluated multiple criteria for the optimal location of a waste management facility. Electre III is used as a strong parameter analysis realised for the area under consideration, in order to evaluate and compare all suitable alternatives.

Hokkanen and Salminen (1997) designed a decision support system for the location of a waste treatment facility using Promethee I and II. Queiruga et al. (2008) are applied the discrete multi-criteria decision method PROMETHEE in order to rank the alternatives for waste electrical and electronic equipment (WEEE) plant.

Zakaria et al. (2012) applied a two-round Delphi survey for siting an integrated hazardous waste disposal facility in Malaysia. Online Delphi survey was used due to useful and effective when both time and costs are limitations.

Zavadskas et al (2015) proposed a new extension of WASPAS method, namely WASPAS-SVNS which is governed by a single-valued neutrosophic set for incineration site selection in Lithuanian.

Yadav et al (2020) used TOPSIS further evaluate the standard decision matrix for waste transfer stations site selection in India. The mean and standard deviation of their relative closeness are also showed graphically.

2.1.2 Mathematical Programming

1 out of 65 papers (1.51%) employed mathematical programming model composed of mixed integer programming.
Vaillancourt and Waaub (2001) applied EUGENE that is a sophisticated mixed integer linear programming for location of waste management facility in Canada.

2.2 Non-deterministic Approaches

Non-deterministic analytical methods such as fuzzy MCDM methods, stochastic methods and game theory were also employed for site selection in waste management. 5 out of 65 (7.69 %) have focused on the use of non-deterministic analytical methods.
Ekmekçioğlu et al. (2010) proposed a modified fuzzy TOPSIS methodology for the choice of appropriate disposal method and site for municipal solid waste for two phase study. Beskese at al. (2014) selected the most appropriate alternative landfill site using fuzzy TOPSIS in İstanbul.

Ekmekçioğlu et al. (2010) applied fuzzy AHP for criteria weights methodology in the choice of appropriate disposal method and site for two phase study. Beskese et al. (2014) used to fuzzy AHP for evaluate the criteria in landfill site selection. Nazari et al. (2012) applied fuzzy AHP for assess and analysis of alternatives of the best site of landfills in Iran.

Lahdelma et al. (2002) analyzed location for a waste treatment facility in Finland using the stochastic multicriteria acceptability analysis.
Hu et al. (2015) aimed to reveal the important factors which influence the location selection of incinerators using game theory analysis. In other words, the study used a game theory model to analyze the relationships among the four participants of incineration plants.

2.3 Integrated Approaches

Integrated approaches combined different analytical methods to deal with waste site selection problems. 50 out of 65 (76.92%) employed integrated techniques, which point out a wider acceptability and use of these methods compared to deterministic and non-deterministic approaches. Especially GIS, which enables the visualization and analysis of the data of the Earth, is used by integrating with other methods in location selection problems. For this reason, integrated approaches are presented as GIS-based and not GIS-based.

2.3.1 GIS Based Integrated Approaches

39 out of 65 (60%) employed GIS based integrated techniques because of collection, storage and visualization advantages. In Table 2.3, integrated methods for site selection in GIS environment are presented. The studies details are presented in chronological order.

Table 2.3 Methods for site selection in GIS Environment

METHOD(S)	AUTHORS
GIS, AHP	Guiqin et al (2009), Tavares at al. (2011), Dimopoulou et al (2013), Baba et al (2014), Jamshidi et al. (2015), Yıldırım and Güler (2016), Riznic and Pucar (2016), Ansari et al (2017) , Güler and Yomralıoglu (2017),Yousefi et al (2018),Mora and Pelaez (2020),Kazuva et al (2020),Sumathi et al.(2007)
GIS, AHP, WLC	Khan and Samadder (2015), Bahrani et al.(2016),Islam et al (2020)
GIS, FAHP	Kaveh et al (2016), Abdulhasan et al (2019), Chabok et al (2020), Sadhasivam et al (2020), Yalcinkaya and Kirtiloglu (2020)
GIS, FAHP AND TOPSIS	Hanine et al(2017)
GIS, AHP, TOPSIS	Khorsandi et al (2019)
GIS, TOPSIS	Yıldırım et al (2018), Ozkan et al (2020)

GIS, WLC	Bosompem et al (2016), Ansari et al (2019)
GIS, WLC, ANP	Motlagh and Sayadi (2015), Danesh et al (2019)
GIS, SAW	Yesilnacar et al (2012)
GIS, AHP, SAW, CODAS	Karakus et al (2019)
GIS, DEMATEL, FANP	Feyzi et al (2019)
GIS, DEMATEL, AHP	Asefi et al (2020)
GIS, WLC, AHP, FUZZY SET THEORY, ELECTRE	Aydi et al (2013)
GIS, FUZZY BWM, FUZZY MULTIMOORA	Rahimi et al (2019)
GIS, DEMATEL, ANP, K-MEANS, WASPAS, MOORA, COPRAS	Eghtesadifard et al (2020)
GIS, FUNCTION ANALYSIS SYSTEM TECHNIQUE	Delgado and Tarantola (2006)
GIS, SUITABILITY INDEX	Sharifi et al. (2009)
GIS, WEIGHTED OVERLAY	Maguiri et al (2016)

Delgado and Tarantola (2006) explored the joint use of global sensitivity analysis, GIS and multi-criteria evaluation to find the best place a hazardous waste landfill. Sumathi et al. (2007) addressed the siting of a new landfill using AHP and overlay analysis through GIS. Guiqin et al (2009) used AHP and GIS to manipulate and present spatial data for landfill site selection problem in Beijing, China. Also, they used suitability maps in GIS environment for create the final composite suitability map. Sharifi et al. (2009) used GIS to identify suitable sites before evaluate various sites with suitability index for hazardous waste landfill sitting. Tavares at al. (2011) combined AHP and GIS method for selection incineration plant. Yesilnacar et al (2012) applied multi criteria decision analysis (MCDA) integrated with GIS to find the best suitable landfill site. They also used simple additive weighting method (SAW) to locate the candidate landfill sites in Sanlıurfa, Turkey. Dimopoulou et al (2013) applied combining AHP and GIS method for the site location of waste disposal facilities. The AHP technique was used in weights assignment process for the criteria. Aydi et al (2013) used the framework including fuzzy set theory, weighted linear combination (WLC) and AHP in a GIS environment for suitable landfill site selection. Then, these sites were ranked using the ELECTRE III method. Baba et al (2014) used AHP with integrated GIS for landfill site selection instead of existing insufficient site. Jamshidi et al. (2015) applied GIS program for landfill site selection using AHP for relative weight to each particular criterion. Motlagh and Sayadi (2015) proposed integration of GIS and ANP methods for landfill site selection. The integration provided a mechanism with which complex issues can be thoroughly explored and immediate feedback for decision-makers can be provided. Also, WLC was used for the suitability of each cell for landfil. Khan and Samadder (2015) determined the most acceptable landfill sites with suitability ranking using repetitive application of AHP and WLC in GIS.

Yıldırım and Güler (2016) used AHP and GIS techniques jointly for identify suitable solid waste disposal sites in Turkey. Kaveh et al (2016) develop MCDA process, which combines GIS analysis with a FAHP, to determine suitable sites for landfill construction in Iran. Bosompem et al (2016) used of the WLC method in a GIS environment for siting of transfer station for municipal solid waste. Bahrani et al. (2016) used maps, in landfill site selection, in GIS system as well as fuzzy functions standardized all criteria maps. Weighting of criteria was performed by AHP using expert choice application and WLC was chosen for integration of maps. Riznic and Pucar (2016) analysed the newly planned landfill sites by combining geospatial databases in GIS and AHP methods. Maguiri et al (2016) performed the choice of the landfill site using GIS and remote sensing methods.

Güler and Yomralıoglu (2017) presented GIS for with the ability to work with large volumes of spatial data and AHP approach for selecting the alternative for landfill site selection in Istanbul, Turkey. Ansari et al (2017) used GIS and AHP for select the best sites for landfill. AHP were used for constructing a matrix of sequences of pair-wise comparisons between criteria. They also used "Map Algebra—Single Output Map Algebra” in GIS. Hanine et al (2017) determined the candidate locations for landfill in Morocco using the combination of On-Line Analytical Processing and GIS (OLAP/GIS). On the other hand, Fuzzy AHP was used to analyze the structure of the site selection problem and obtain the weights of the qualitative and quantitative criteria. End of the study TOPSIS method was applied to classify the alternative sites based on their overall performance. Yousefi et al (2018) carried out a study of landfill site selection combining

GIS and AHP method. Yıldırım et al (2018) created a model combining GIS and MCDM technique such as TOPSIS for landfill site selection in Turkey.

Rahimi et al (2019) obtained criteria weights by applying the group fuzzy BWM and then generated suitability maps based on GIS analysis for landfill sites. These sites were analyzed and ranked using group fuzzy MULTIMOORA method. This study is different from the previous researches due to group fuzzy BWM for weighting criteria is more reliable compared to the other common methods. Khorsandi et al (2019) applied the AHP for weigh the layers and TOPSIS for prioritize the identified regions in landfill site selection in Iran. Then, each region were weighed in GIS. Karakus et al (2019) used GIS and MCDM methods such as AHP and SAW. Evaluation of alternative areas defined by AHP and SAW methods were conducted with the help of Combinative Distance-Based Assessment (CODAS) for landfill site selection in Turkey. Ansari et al (2019) determined criteria in order to use in GIS. WLC method was used for criteria weightings and the suitability index map was used for candidate landfill sites. Feyzi et al (2019) applied the decision making trial and evaluation laboratory (DEMATEL) for identify the interrelations between factors. Then, Fuzzy ANP ranked them in regard to importance. In the end, they used GIS for final weights the layers of each of the sub-criteria for siting municipal solid waste incineration power plant in the north of Iran. Abdulhasan et al (2019) applied AHP and fuzzy logic methods in GIS environment, remote sensing, for landfill site selection in Iraq. Fuzzy logic was shown to be more accurate than AHP. This study showed that AHP, Fuzzy logic and GIS can be integrated for waste management decision issues related to site selection. Danesh et al (2019) determined some criteria which normalized by fuzzy method. ANP method combined with the WLC method determined the weight of the criteria. Also, in this study, GIS environment is used for hazardous waste disposal site selection in Iran.

Lately, Asefi et al (2020) used by integrating AHP and DEMATEL methods in a GIS enviroment for evaluating the suitability for landfill siting in Australia. Islam et al (2020) used integrated methods in the GIS environment using an AHP and WLC, to generate a comprehensive suitability map for landfill site selection in Bangladesh. Ozkan et al (2020) proposed a integrated methodology which included hesitant fuzzy linguistic term sets - based TOPSIS and GIS for landfill site selection in Samsun, Turkey. Chabok et al

(2020) used the fuzzy AHP approach combined with GIS in order to select the appropriate locations, for MSW landfill sites in Iran. Eghtesadifard et al (2020) used fuzzy logic in GIS environment in order to identify the important sites for MSW landfill. It was proposed new integrated model which regulated by DEMATEL and ANP before the k-means clustering algorithm was used for grouping. The criteria were identified through Delphi and their relative importance was calculated through the integrated DEMATEL ANP method. Finally, WASPAS, MOORA and COPRAS ranked the candidate sites. Mora and Pelaez (2020) applied AHP method integrated with a GIS for sanitary landfill site selection in Ecuador. Kazuva et al (2020) used to AHP for assign relative weight and evaluate each criterion in landfill site selection in Tanzania. In addition, it was used multivariate data in GIS environment. Sadhasivam et al (2020) used pair-wise comparison matrix through AHP and fuzzy linear membership gived rating of each class for landfill site selection criteria. The weighted linear combination had been adopted as an overlay technique in GIS environment. Finally, The Solid Waste Landfill Suitability Index for each pixel was calculated. Yalcinkaya and Kirtiloglu (2020) used fuzzy AHP integrated with GIS environment using real world data in selection of solid waste incineration plant sites in İzmir, Turkey.

2.3.2 Multi-Criteria Decision Making Based Integrated Approaches Except GIS Environment

11 out of 65 (16.92 %) employed MCDM based integrated techniques not including GIS environment. In Table 2.4, integrated methods for site selection except GIS environment are presented. The studies details are presented according to chronological.

Table 2.4 Methods for site selection except GIS environment

METHOD(S)	AUTHORS
FUZZY TOPSIS, AHP	Önüt and Soner (2007)
FUZZY TOPSIS, FUZZY AHP	Chauhan and Singh (2016), Wichapa and Khokhajaikiat (2018)
AHP, ANP	Beltran et al. (2010)
FANP, TOPSIS	Wang et al (2018)

FANP AND WLC	Soroudi et al (2017)
DEMATEL, FANP	Soroudi et al (2018)
DEMATEL BASED ANP (DANP), VIKOR	Ming Liu et al (2018)
VIKOR, BWM, STEEP	Kumar (2020)
VIKOR, FUZZY SET THEORY	Liu at al. (2014)
BWM, INTERVAL ROUGH NUMBERS	Yazdani et al (2020)

Önüt and Soner (2007) applied first time both fuzzy TOPSIS and AHP based methodology is applied to solve the solid waste transshipment site selection problem in Istanbul, Turkey. Beltran et al. (2010) used both hierarchy model (AHP) and network-based model (ANP) for selection municipal solid waste plant. Liu at al. (2014) applied VIKOR method in order to determine the priority ranking of alternatives for selecting the best site in China. Fuzzy set theory and VIKOR method is proposed to deal with the suitable disposal site selection problems in the MSW management system. Chauhan and Singh (2016) proposed new methodology composed of interpretive structural modelling-fuzzy AHP- fuzzy TOPSIS for selecting a sustainable location of healthcare waste disposal facility in India. Soroudi et al (2017) studied to optimize municipal solid waste landfill siting yeast using ANP algorithm and fuzzy logic. They also applied the WLC method to create a landfill suitability map.

Ming Liu et al (2018) proposed DEMATEL technique, combined the influential weights of Dematel based ANP (DANP) modified VIKOR method to build a new hybrid modified multiple attribute decision-making model for food waste composting facilities site selection problem. Wang et al (2018) proposed FANP method and TOPSIS for solid waste to energy plant location selection in Vietnam. In first phase, FANP was used to determine the weight of criteria then the TOPSIS model was used for ranking alternatives in the final stage. Soroudi et al (2018) used DEMATEL and ANP approach for municipal solid waste landfill sitting. First, the interaction of criteria was determined implementing DEMATEL then ANP structure was developed to weigh the criteria. Then, criteria and constraints were standardized with fuzzy and Boolean logic, respectively. Wichapa and Khokhajaikiat (2018) proposed new hybrid model combining three techniques for solving the facility location-allocation (FLA) problem of infectious waste disposal. Firstly, Fuzzy

AHP–Fuzzy TOPSIS method were evaluated for the weights of each candidate location. Then the combined Fuzzy AHP – Fuzzy TOPSIS – FLA model, hybrid model, were proposed. Kumar (2020) used the VIKOR method in order to ranking of four location alternatives four WEEE plant. Also, a novel integrated STEEP (social, specialized, financial, natural, and political measurements)- BWM -VIKOR framework is utilized for identifying the sustainable WEEE recycling plant location in Mumbai. Yazdani et al (2020) proposed a new BWM with interval rough numbers for healthcare waste disposal location decisions in Spain.

3. REVIEW OF SITE SELECTION CRITERIA IN WASTE MANAGEMENT

Among the 65 studies examined, different kind of facility types had been took part for site selection problem. For instance: waste treatment facility, incineration facility, landfill, transshipment site, WEEE plant and composting plant. Determined evaluation criteria for these facilities will be presented in next section, respectively.

3.1 Waste Treatment Facility

14 out of 65 (21.53 %) studies relevant to waste treatment site selection problem. Details of waste treatment facility location selection criteria are described chronologically.

Hokkanen and Salminen (1997) used main factors such as economic, technical natural-enviromental, man and the built-up environment as site selection criteria for four alternatives in eastern Finland. Economic factors include operation, building and transportation costs while technical factors include manageability of plant waters and linking with the existing infrastructure. Natural environment factors include ground water, surface water, ecological and lanscape impacts. Finally, man and the built-up environment factors include recreational use, effects on the standard of housing, cultural history, health and noise level. The alternative locations for the facility were considered based on 14 criteria by 28 decision makers. Vaillancourt and Waaub (2001) determined main criterias such as water/soils, air, noise, odor, local planning, traffic, fauna/flora, health/security, landscape and development perception for waste management facility in Canada. Lahdelma et al. (2002) evaluated four alternatives in terms of 17 criteria such as ground water, surface water, nature, fragmentation, smells, pest animals, noise pollution, road safety, landscape, population, services, business, recreation, transport costs, real-estate value, current land use and planned land use for selection waste treatment facility in Finland. Norese (2004) are determined 14 main criteria for selection the waste-disposal site like accessibility by motorway and railway, distance from the nearest motorway, impact on the local traffic, presence of environmental ‘‘loads’, results in differential waste collection, population, necessity of new roads or improvement of existing roads, risk to ground-water table, impact on landscape, agricultural value, agricultural ‘‘vocation’’ in the territory, natural value, size of the site and natural habitat protection in Italy. Tuzkaya et al (2007) determined criteria deal with social, enviromental and national economy perception composed of 36 subcriteria for location undesirable facility in Turkey. Beltran et al. (2010) used main criteria like plant exploitation costs, facilities and infrastructures, environmental issues, legal requirements, composed of total 21 subcriteria for six candidate MSW plant sites in Spain. Zakaria et al. (2012) identified environmental, economic and social criteria to be considered for the disposal facility selection in Malaysia. The findings show that environmental criteria have priority in regard of social and economic criteria. Dimopoulou et al (2013) examined seven criteria like slope, land use, visibility from settlements, distance from quarries, settlements, main road network and nature sites, for sustainable disposal of marble stone wastes in the Drama Marble production area in Northern Greece.

Liu at al. (2014), for selection disposal site in China, are determined some criteria such as adjacent land use, climate, road access and cost. Chauhan and Singh (2016) determined main criteria such as distance, waste disposal site exposure to public, availability of land, cost, sensitivity towards environment, quantity of healthcare waste, area, road condition for location of healthcare waste disposal facility. Yıldırım and Güler (2016) utilized 12 decision criteria for solid waste disposal sites in Turkey (i.e., lithology, aquifer type, distance from lineaments, distance from landslides, land use, distance from settlements, distance from roads, distance from surface waters, distance from springs and wells, elevation, aspect, and slope). Wichapa and Khokhajaikiat (2018) used some criteria like infrastructure, public utilities, traffic, geological, area size, features of area, flooding in the past, density of population, municipal administrators, ability of municipalities, distance from communities and public water resources, for location of infectious waste disposal in Thailand. Danesh et al (2019) examined criteria such as slope, elevation, soil texture and depth, land use, geology, erosion, aspect, rain, evaporation, distance from some areas (protected areas, fault, roads, rivers, airport, coastline, residential areas, aquifers, flood plains, industrial areas, cultural sites, wells and springs) for hazardous waste disposal site selection in Iran. Yazdani et al (2020) used costs, risks, geographic and geologic conditions, availability of workforce, local and territorial rules, level of satisfaction among residents, the proximity to the urban and city infrastructure as criteria for healthcare waste disposal location decisions in Spain.

3.2 Incineration Facility

7 out of 65 (10.77 %) studies relevant to incineration site selection problem. Details of incineration facility location selection criteria are described chronologically.

Norese (2004) determined some criteria for selection the incinerator site in Italy; as incremental traffic impact on local congestion, energy saving, suitability and availability of the area, flooding risks from minor channels and rivers, economic damage to town areas due to the possible decrease of property values, economic damage to agricultural activities, negative impact on re-qualification or development projects, previous environmental ‘‘loads’’ around the site, visual impact. For the incineration plant selection in Cape Verde, Tavares et al. (2011) used criteria like waste and fly ash transportation costs, distance from electrical grid, coast line, road network and urban centres, potable water demand, land orientation, land cover, terrain slope, elevation, land-use type, pollution dispersion and visual impact. Zavadskas et al (2015) addressed by assessing engineering, social, economic and environmental factors in incineration site selection. Engineering factors include distance to some places such as a route of the centralized heat network, high-pressure gas pipe, power transmission grid, the water supply network, industrial and domestic waste water networks, the surface water drain. Enviromental factors include Impact on air, level of noise, impact on entrails of the earth (soil) and groundwater in case of an accident and distance to the center of the city. Social factors include level of satisfaction among residents in relation to the site selection and mean population per 1 km2 in the territory of the analyzed alternative. Finally, economic factor includes useful floor area of residential dwellings situated in the locality of the planned project. Hu et al. (2015) determined criteria involving various factors from the environment, economy, society and public health for incineration plant selection. (cost of construction and trash transportation, difficulty in obtaining land, condition of trash transportation road, relationship with affiliated facilities, relationship with other municipal projects and facilities nearby, impact on the usage of land influenced, local historical sites and local scenic spots, land ecosystem, water ecosystem, air pollution, impact of incineration plants' construction and operation on local residents, waste transportation towards local residents, local traffic).

Wang et al (2018) determined four main categories such as economic, technical, environmental and social for solid waste to energy plant location selection in Vietnam. Also, cost (construction, operational, maintanance), potential demand, distance to landfill, transfer station, city, electric network, solid waste quantity, impact on the ecological environment, effect on life quality of resident, temperature, regional economic benefit, government policy and public support were used for subcriterion. Feyzi et al. (2019) determined some criteria such as elevation, slope, ground water depth, soil texture, geology, land use and distance from some areas (rivers, protected areas, road, railway, electrical grid, landfill, tourist attractions and urban centers) for siting waste incineration power plant in Iran. Yalcinkaya and Kirtiloglu (2020) examined slope, surface area, elevation, MSW availability, proximity to main roads, transfer stations, transformers and power lines as criteria for selection incineration plant in İzmir, Turkey.

3.3 Landfill

36 out of 65 (55.38 %) studies relevant to landfill site selection problem. Landfill site selection criteria are presented in the Table 3.1 according to their authors because of understandable. Largest number of studies belong to landfill site selection problem.

Table 3.1 Landfill site selection criteria

Criteria	Authors
Soil Conditions (texture, depth, permeability etc.) and Topography	Delgado and Tarantola (2007), Sharifi et al.(2009), Nazari et al (2012), Baba et al (2014), Beskese et al. (2014), Motlagh and Sayadi (2015), Khan and Samadder (2015), Bahrani et al.(2016), Soroudi et al(2017), Chabuk et al (2017), Hanine et al(2017), Soroudi et al (2018), Yousefi et al (2018), Yıldırım et al (2018), Khorsandi et al (2019), Alkaradaghi et al (2019), Asefi et al (2020), Islam et al (2020), Ozkan et al (2020), Chabok et al (2020), Eghtesadifard et al (2020), Mora and Pelaez (2020), Kazuva et al (2020), Sadhasivam et al (2020)

Surface Waters (water supply resources, lake, river, streams etc.)	Delgado and Tarantola (2007), Sumathi et al.(2007), Guiqin et al (2009), Nazari et al (2012), Yesilnacar et al (2012), Aydi et al (2013), Beskese et al. (2014), Jamshidi et al. (2015), Motlagh and Sayadi (2015), Khan and Samadder (2015), Maguiri et al (2016), Bahrani et al.(2016), Riznic and Pucar(2016), Soroudi et al(2017), Chabuk et al (2017), Güler and Yomralıoglu (2017), Yousefi et al (2018), Yıldırım et al (2018), Rahimi et al (2019), Khorsandi et al (2019), Karakus et al (2019), Abdulhasan et al (2019), Alkaradaghi et al (2019), Asefi et al (2020), Ozkan et al (2020), Chabok et al (2020), Eghtesadifard et al (2020), Mora and Pelaez (2020), Kazuva et al (2020), Sadhasivam et al (2020)
Wetlands	Sharifi et al. (2009), Nazari et al (2012), Aydi et al (2013), Kaveh et al (2016), Khorsandi et al (2019), Chabok et al (2020), Eghtesadifard et al (2020)
Groundwater Quality	Delgado and Tarantola (2007), Guiqin et al (2009), Sharifi et al.(2009), Nazari et al (2012), Baba et al (2014), Jamshidi et al. (2015), Khan and Samadder (2015), Kaveh et al (2016), Chabuk et al (2017), Yousefi et al (2018), Rahimi et al (2019), Khorsandi et al (2019), Karakus et al (2019), Alkaradaghi et al (2019), Asefi et al (2020), Islam et al (2020), Ozkan et al (2020), Kazuva et al (2020)
Slope	Delgado and Tarantola (2007), Guiqin et al (2009), Nazari et al (2012), Yesilnacar et al (2012), Jamshidi et al. (2015), Motlagh and Sayadi (2015), Khan and Samadder (2015), Kaveh et al (2016), Bahrani et al.(2016), Riznic and Pucar(2016), Soroudi et al(2017), Chabuk et al (2017), Güler and Yomralıoglu (2017), Soroudi et al (2018), Yousefi et al (2018), Yıldırım et al (2018),Rahimi et al (2019), Khorsandi et al (2019), Abdulhasan et al (2019), Alkaradaghi et al (2019), Islam et al (2020), Ozkan et al (2020), Eghtesadifard et al (2020), Mora and Pelaez (2020), Sadhasivam et al (2020)
Elevation/Altitude	Guiqin et al (2009), Nazari et al (2012), Yesilnacar et al (2012), Baba et al (2014), Kaveh et al (2016), Bahrani et al.(2016), Soroudi et al(2017), Chabuk et al (2017), Yıldırım et al (2018), Rahimi et al (2019), Khorsandi et al (2019), Alkaradaghi et al (2019), Asefi et al (2020), Islam et al (2020), Ozkan et al (2020), Kazuva et al (2020)
Land Values	Delgado and Tarantola (2007), Guiqin et al (2009), Nazari et al (2012), Güler and Yomralıoglu (2017), Hanine et al(2017), Karakus et al (2019), Islam et al (2020), Eghtesadifard et al (2020), Kazuva et al (2020)
Land use / Land cover	Sumathi et al.(2007) , Guiqin et al (2009), Nazari et al (2012), Yesilnacar et al (2012), Aydi et al (2013), Baba et al (2014), Beskese et al. (2014), Jamshidi et al. (2015), Motlagh and Sayadi (2015), Khan and Samadder (2015), Kaveh et al (2016), Maguiri et al (2016), Bahrani et

	al.(2016), Riznic and Pucar(2016), Soroudi et al(2017), Chabuk et al (2017), Güler and Yomralıoglu (2017), Hanine et al(2017), Yousefi et al (2018), Yıldırım et al (2018), Rahimi et al (2019), Khorsandi et al (2019), Karakus et al (2019), Alkaradaghi et al (2019), Asefi et al (2020), Islam et al (2020), Ozkan et al (2020), Eghtesadifard et al (2020), Mora and Pelaez (2020), Kazuva et al (2020), Sadhasivam et al (2020)
Geology/Lithology	Sumathi et al.(2007), Sharifi et al.(2009), Nazari et al (2012), Yesilnacar et al (2012), Kaveh et al (2016), Maguiri et al (2016), Bahrani et al.(2016), Riznic and Pucar(2016), Soroudi et al(2017), Güler and Yomralıoglu (2017), Hanine et al(2017), Soroudi et al (2018), Yıldırım et al (2018), Rahimi et al (2019), Khorsandi et al (2019), Karakus et al (2019), Alkaradaghi et al (2019), Islam et al (2020), Ozkan et al (2020), Kazuva et al (2020), Sadhasivam et al (2020)
Climatologic Conditions (wind direction, precipitation, temperature etc.)	Sharifi et al.(2009), Nazari et al (2012), Beskese et al. (2014), Jamshidi et al. (2015),Khan and Samadder (2015), Riznic and Pucar(2016), Soroudi et al(2017),Hanine et al(2017),Soroudi et al (2018),Yıldırım et al (2018),Rahimi et al (2019) , Islam et al (2020),Ozkan et al (2020),Eghtesadifard et al (2020),Mora and Pelaez (2020),Kazuva et al (2020)
Sensitive Sites (protected /historical areas, natural parks, archeological sites etc.)	Delgado and Tarantola (2007),Sumathi et al.(2007),Guiqin et al (2009),Nazari et al (2012),Baba et al (2014),Motlagh and Sayadi (2015), Bahrani et al.(2016),Riznic and Pucar(2016), Soroudi et al (2017),Chabuk et al (2017),Güler and Yomralıoglu (2017), Yıldırım et al (2018),Rahimi et al (2019), Abdulhasan et al (2019),Chabok et al (2020), Mora and Pelaez (2020).
Settlements (urban and village) and Residential Areas	Sharifi et al.(2009),Nazari et al (2012),Yesilnacar et al (2012), Aydi et al (2013),Beskese et al. (2014),Motlagh and Sayadi (2015),Khan and Samadder (2015),Kaveh et al (2016), Bahrani et al.(2016), Chabuk et al (2017),Güler and Yomralıoglu (2017),Hanine et al(2017),Soroudi et al (2018),Yousefi et al (2018),Yıldırım et al (2018) ,Rahimi et al (2019),Khorsandi et al (2019),Karakus et al (2019), Abdulhasan et al (2019), Alkaradaghi et al (2019),Asefi et al (2020), Ozkan et al (2020),Chabok et al (2020), Eghtesadifard et al (2020) ,Mora and Pelaez (2020),Sadhasivam et al (2020)
Population	Delgado and Tarantola (2007), Aydi et al (2013), Bahrani et al.(2016), Güler and Yomralıoglu (2017), Yıldırım et al (2018),Asefi et al (2020), Islam et al (2020),Eghtesadifard et al (2020), Sadhasivam et al (2020)
Roads/ Railways	Guiqin et al (2009), Nazari et al (2012), Yesilnacar et al (2012), Aydi et al (2013),Baba et al (2014),Beskese et al.

	(2014), Jamshidi et al. (2015),Motlagh and Sayadi (2015), Khan and Samadder (2015),Kaveh et al (2016), Maguiri et al (2016),. Bahrani et al.(2016),Riznic and Pucar(2016),Soroudi et al(2017),Chabuk et al (2017) , Güler and Yomralıoglu (2017),Hanine et al(2017),Soroudi et al (2018), Yousefi et al (2018), Yıldırım et al (2018), Rahimi et al (2019), Karakus et al (2019), Abdulhasan et al (2019), Alkaradaghi et al (2019),Asefi et al (2020),Ozkan et al (2020), Chabok et al (2020), Eghtesadifard et al (2020), Mora and Pelaez (2020),Kazuva et al (2020),Sadhasivam et al (2020)
Airport	Guiqin et al (2009), Nazari et al (2012),Yesilnacar et al (2012), Khan and Samadder (2015),Soroudi et al(2017), Güler and Yomralıoglu (2017),Soroudi et al (2018), Mora and Pelaez (2020)
Industrial Sites	Yesilnacar et al (2012),Motlagh and Sayadi (2015),Bahrani et al.(2016) ,Soroudi et al(2017),Yousefi et al (2018),Rahimi et al (2019), Abdulhasan et al (2019), Chabok et al (2020),Sadhasivam et al (2020)
Faults	Sharifi et al.(2009),Nazari et al (2012), Jamshidi et al. (2015), Motlagh and Sayadi (2015), Bahrani et al.(2016), Riznic and Pucar(2016), Soroudi et al(2017), Soroudi et al (2018), Yousefi et al (2018),Rahimi et al (2019),Khorsandi et al (2019), Ozkan et al (2020),Chabok et al (2020)
Infrastructure (power lines, pipelines etc.)	Nazari et al (2012),Yesilnacar et al (2012), Motlagh and Sayadi (2015), Bahrani et al.(2016),Riznic and Pucar(2016), Soroudi et al (2017),Chabuk et al (2017),Soroudi et al (2018),Yousefi et al (2018),Yıldırım et al (2018),Khorsandi et al (2019),Alkaradaghi et al (2019),Chabok et al (2020) .
Accessibility from Waste Production Centres	Delgado and Tarantola (2007), Guiqin et al (2009) , Nazari et al (2012), Aydi et al (2013), Jamshidi et al. (2015), Maguiri et al (2016), Bahrani et al.(2016),Güler and Yomralıoglu (2017), Hanine et al(2017), Abdulhasan et al (2019)
Risk (geo-technical, etc.)	Delgado and Tarantola (2007)
Air Quality	Sumathi et al.(2007)
Aquifers	Yesilnacar et al (2012)
Culture	Aydi et al (2013), Riznic and Pucar(2016), Soroudi et al(2017), Yıldırım et al (2018).
Potential Sites for Future	Nazari et al (2012), Maguiri et al (2016),Riznic and Pucar(2016)

3.4 Transshipment Site

3 out of 65 (4.62 %) studies relevant to transshipment site selection problem. Details of transshipment site selection criteria are described chronologically.

Önüt and Soner (2007) determined five criteria such as proximity to industrial solid waste, proximity to household solid waste, transportation simplicity, necessity and proximity to residential area for the solid waste transshipment site selection problem in İstanbul, Turkey. Bosompem et al (2016) used seven main criteria like geology, slope, and distance to highway, residential areas, faults, generation centers, rivers and streams in Ghana. Yadav et al (2020) determined criteria for selecting location of transfer station including MSW generation, land ownership, proximity to other facilities, overall cost, distance traveled, interference with routine traffic, size of land, accessibility, availability of basic amenities, flexibility for size expansion, remoteness to water bodies, total emissions, protection from flood hazards, public acceptability, kids population density.

3.5 WEEE Plant

2 out of 65 (3.08 %) studies relevant to WEEE plant selection problem. Details of WEEE plant location selection criteria are described chronologically.

Queiruga et al. (2008) proposed site selection objectives such as economic, infrastructural and legal. Economic objectives compose of land, personnel and energy costs. Infrastructural objectives compose of facility access, proximity to metal and nonmetal recycling plants and to dangerous substance management facilities, proximity to inhabited areas, absence of other WEEE recycling plants and availability of labor. Legal objectives compose of availability of a local waste processing programs and environmental grants for Spain. Kumar (2020) applied WEEE site selection by considering the socio-economic, political, legal, and environmental dimensions. Social criteria include social acceptance, social network, create new job opportunities for locals and economic development, maintaining the living standard, impact on tourism. Technical criteria include proximity with electronic manufacturing cluster, availability of renewable resource, availability of skilled workforce, road and rail network, accessibility and system reliability. Environmental/ Natural criteria includes suitability of land use, hydro-geological condition of the location, distance from residential areas, distance from surface and ground water resources, biodiversity conservation, impact of emissions and pollution. Economic criteria include land acquisition cost for recycling plant site, energy resources acquisition cost, Logistics transportation maintenance cost of recycling plant, number of existing competitors, waste availability, slope and faults criteria. Policy and legal criteria include waste disposal subsidy, support from local authorities, tariffs and tax preferences, financial support for low carbon and climate change (LCR) infrastructure, compliance with RoHS directives and ISO certification, ease of environmental grants and funds.

3.6 Composting Plant

3 out of 65 (4.62 %) studies relevant to composting plant selection problem. Details of composting plant location selection criteria are described chronologically.

For selection composting plant, Feo and Gisi (2010) adopted 10 criteria such as population density of the municipality, distance from the motorway, waste production barycentricity, interference of the additional traffic with local roads, accessibility, capacity of traffic splitting, cost of the area, economic damages, absence of areas of the highest value for natural habitats and absence of heavy plants. Ekmekçioğlu et al (2010) used to determine the optimum RDF combustion plant location in İstanbul using hydrology, site capacity, adjacent land use, climate, flora/fauna, road access, cost, topography and soils as the criteria. Ming Liu (2018) determined environmental, economical and social dimensions for selection food waste composting facilities site selection. Environmental dimension includes site topographic geomorphic characteristics, distance from residential areas, land use suitability and distance from environmental sensitive areas. Economical dimension includes transportation and land acquisition costs, proximity to major infrastructure system, the amount of competitors. Finally, social dimension includes visibility impact, new job opportunities, economical impact, public health and safety.

4. MATERIAL AND METHOD

4.1 Geographical Information System

GIS is being used as tool for spatial data models, data structure and data handling in a geographic environment (Raju, 2006) Although the GIS history dates back to 1960, stable data structure to store and analyze map data became dominant in the early 1970's (Raju, 2006). For ability of GIS to fulfill its basic functions main elements must be together. These; hardware, software, data, people, and method (Güler,2016). GIS is used to assist users in location-based decision-making processes around the world. Due to GIS, spatial data is stored in a software environment and it creates an auxiliary decision support system for decision makers by presenting visual information. According to Malczewski's study, there are 319 GIS-MCDM articles between 1994 and 2004. There are several challenges in real-world spatial problems. Using MCDM and GIS integration methods to solve these challenges will be beneficial in managing the decision process.

With the development of the Internet, web-based GIS has also developed. Web GIS provides the opportunity to create a database with only internet connection and presents this data to different users without having to be on the same network. It also ensures that the maps are up-to-date and dynamic.

Countries support the development of online mapping tools to easy access to spatial data. Nationalmap from Austria and ATLAS from Turkey are examples. The common goal of those who want to develop these systems is to reach the right data, to use the data effectively and to ensure that it can be shared. All these will make and improve the spatial analysis process better.

4.2 Fuzzy Set Theory

Zadeh (1965) introduced the fuzzy set theory to overcome problems with uncertainty, vagueness etc. for real life issues. A fuzzy set (class) $\tilde{A}$ is defined by a membership function, which related to each point in x in the universe of discourse X a real number in the interval [0,1]. Membership function represented grade of membership of x in $\tilde{A}$. Based on Zadeh's article, some definitions are given in the following section briefly.

Definition 1: A fuzzy set $\tilde{A}$ is convex if and only if for all x_1 and $x_2 \in X$:

$$min\left(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)\right) \leq \mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2), \qquad \lambda \in [0,1] \tag{4.1}$$

Definition 2: α cut is defined as (4.2)

$$\tilde{n}^{\alpha} = \{x_i : \mu_{\tilde{n}}(x_i) \geq \alpha, x_i \in X\} \quad where \;\; \alpha \in [0,1]$$

$\tilde{n}^{\alpha}$ is a limited nonempty bounded interval contained in X and it can be noted by $\tilde{n}^{\alpha} = [n_l^{\alpha}, n_u^{\alpha}], n_l^{\alpha}$ and n_u^{α} are the lower and higher bounds respectively of the closed interval.

Definition 3: A triangular fuzzy number $\tilde{n}$ can be defined by a triplet (l, m, u). l, m, and u respectively represent the lower, modal, and upper value. The membership function $\mu_{\tilde{n}}(x)$ is defined as

$$\mu_n(x) \begin{cases} 0, & x < l \\ \dfrac{x-l}{m-l}, & l \leq x \leq m \\ \dfrac{u-x}{u-m}, & m \leq x \leq u \\ 0, & x > u \end{cases} \tag{4.3}$$

Definition 4: The graded mean integration representation (GMIR) of triangular fuzzy number shows in equation 4.4. Let $\check{a}_j = (l_j, m_j, u_j)$ and

$$R(\check{a}_j) = \frac{l_j + 4m_j + u_j}{6} \tag{4.4}$$

4.3. Fuzzy Best Worst Method

Rezai (2015) introduced a new method that called Best Worst method to solve MCDM problems. This method is based on choosing the most important and least important criteria among the criteria by the decision makers and comparing these criteria according to other criteria. Guo and Zhao (2017) extended this method from BWM to fuzzy environment called fuzzy best worst method. In the following paragraph, steps will be presented for the determination of fuzzy weights.

Step 1: Determination of the set of criteria. There are n criteria; $\{C_1, C_2, ... C_n\}$.

Step 2: Identification of the best (most important) criterion and the worst (least important) criterion. Best criterion is called C_B and worst criterion is called C_w.

Step 3: Comparison of the best criterion to the rest of criteria with fuzzy vector.
The obtained fuzzy Best-to-Others vector is: $\tilde{A}_B = (\tilde{a}_{B1}, \tilde{a}_{B2}, \cdots, \tilde{a}_{Bn})$. It can be known that $\tilde{a}_{BB} = (1, 1, 1)$.

Step 4: Comparison of the worst criterion to the rest of criteria with fuzzy vector.
The fuzzy Others-to-Worst vector can be obtained as: $\tilde{A}_W = (\tilde{a}_{1W}, \tilde{a}_{2W}, \cdots, \tilde{a}_{nW})$. It can be known that $\tilde{a}_{WW} = (1, 1, 1)$.

Step 5: Calculate the optimal fuzzy weights.
Optimal fuzzy weights $\tilde{w}^* = (\tilde{w}_1^*, \tilde{w}_2^*, ..., \tilde{w}_n^*)$ and optimal ξ^* are obtained by solving the nonlinear model (4.5).

$$
\begin{aligned}
&\text{Min } \xi^* \\
&\text{s.t} \\
&\left| \frac{l_B^w, m_B^w, u_B^w}{l_j^w, m_j^w, u_j^w} - l_{Bj}, m_{Bj}, u_{Bj} \right| \le (k^*, k^*, k^*) \\
&\left| \frac{l_j^w, m_j^w, u_j^w}{l_W^w, m_W^w, u_W^w} - l_{Jw}, m_{jW}, u_{jW} \right| \le (k^*, k^*, k^*) \\
&\textstyle\sum_j R(\breve{w}_j) = 1 \qquad\qquad (4.5) \\
&l_j^w \le m_j^w \le u_j^w
\end{aligned}
$$

$l_j^w \geq 0$

$j=1,2\ldots n$

where $\tilde{\xi} = (l^{\xi}, m^{\xi}, u^{\xi}); l^{\xi} \leq m^{\xi} \leq u^{\xi}$ and $\tilde{\xi}^* = (k^*, k^*, k^*); k^* \leq l^{\xi}$.

Step 6: Check the reliability of fuzzy preference comparisons with the consistency ratio (CR).

Guo and Zhao obtained consistency index (CI) by solving equation (4.6) for different u_{BW}, and the maximum possible ξ. Fuzzy linguistic scale and Consistency index (CI) are listed in table 4.1.

$$\xi^2 - (1 + 2u_{BW})\xi + (u_{BW}^2 - u_{BW}) = 0 \tag{4.6}$$

$$CR = \xi^* / CI \tag{4.7}$$

If consistency ratio (CR) less than 0.1 ($CR < 0.1$), result is acceptable.

Table 4.1 Fuzzy linguistic scale and Consistency index (*CI*) for fuzzy BWM (Guo and Zhao, 2017).

Linguistic terms	**Membership function**	**Consistency index (*CI*)**
Equally importance (EI)	(1,1,1)	3.00
Weakly important (WI)	(2/3,1,3/2)	3.80
Fairly Important (FI)	(3/2,2,5/2)	5.29
Very important (VI)	(5/2,3,7/2)	6.69
Absolutely important (AI)	(7/2,4,9/2)	8.04

4.4 Hierarchical Fuzzy MCDM Approach

Karsak (2002) proposed a method that based on the proximity to the ideal solution for problems which including both crisp and fuzzy data. This method is called Distance-based fuzzy MCDM approach and is based on the multi-criteria decision-making method known as TOPSIS. Karsak and Ahiska (2005) proposed a Hierarchical Fuzzy MCDM Approach for problems which including multi-level structures. So, distance-based fuzzy MCDM algorithm proposed by Karsak is extended to hierarchical fuzzy MCDM

Approach by Karsak and Ahiska. Proposed model by Karsak and Ahiska (2005) comprises of two phases. The second phase of this method will be used in this study.
In the following paragraph, steps of second phase of hierarchical fuzzy MCDM Approach is presented.

Step 1: Build the decision matrix considering the alternatives. Identify the fuzzy evaluations related to the qualitative criteria and the crisp values related to the quantitative criteria.

Step 2: Normalize the data in order to obtain that unit-less and comparable criteria values. Considering benefit and cost related criteria the normalized values are calculated with linear scale transformation.

$$y'_{ijk} = \begin{cases} \dfrac{y_{ijk} - y_{jk}^{-}}{y_{jk}^{*} - y_{jk}^{-}}, & k \in CB_j\,;\ \ i = 1,2,\ldots,m\,;\ \ j = 1,2,\ldots,n \\ \dfrac{y_{jk}^{*} - y_{ijk}}{y_{jk}^{*} - y_{jk}^{-}}, & k \in CC_j\,;\ \ i = 1,2,\ldots,m\,;\ \ j = 1,2,\ldots,n \end{cases} \tag{4.8}$$

y'_{ijk} presents the normalized value of y_{ijk}, which is the crisp value assigned to alternative *i* with respect to the sub-criterion *k* of criterion *j* *m* is the number of alternatives, *n* is the number of criteria, CB_j is the set of benefit-related crisp sub-criteria of criterion *j* and CC_j is the set of cost-related crisp sub-criteria of criterion *j*, $y_{jk}^{*} = \max_i y_{ijk}$ and $y_{jk}^{-} = \min_i y_{ijk}$. The normalized values for crisp data can be represented as $\tilde{y}_{ijk} = (y'_{aijk}, y'_{bijk}, y'_{cijk})$ in triangular fuzzy number format, where $y'_{aijk} = y'_{bijk} = y'_{cijk} = y'_{ijk}$.

Step 3: Aggregate the performance values of alternatives at the sub-criteria level to criteria level via fuzzy multiplication as :

$$\tilde{x}_{ij} = (x_{aij}, x_{bij}, x_{cij}) = \frac{\sum_k \tilde{w}_{jk}^{1} \otimes \tilde{y}_{ijk}}{\sum_k \tilde{w}_{jk}^{1}}, \forall i, j \tag{4.9}$$

where $\tilde{x}_{ij}$ represents the aggregate performance rating of alternative i with respect to criterion j, $\tilde{w}_{jk}^{1}$ indicates the importance weight assigned to sub-criterion k of criterion j, and $\otimes$ is the fuzzy multiplication operator.

Step 4. Normalize the aggregate performance values obtained in step 3 at criteria level using a normalization procedure, which results in the best value to be equal to 1 and the worst one to be equal to 0, as follows:

$$\tilde{r}_{ij} = (r_{aij}, r_{bij}, r_{cij}) = \left(\frac{x_{aij} - x_{aj}^{-}}{x_{cj}^{*} - x_{aj}^{-}}, \frac{x_{bij} - x_{aj}^{-}}{x_{cj}^{*} - x_{aj}^{-}}, \frac{x_{cij} - x_{aj}^{-}}{x_{cj}^{*} - x_{aj}^{-}}\right), \forall i, j \tag{4.10}$$

where $x_{cj}^{*} = \max_{i} x_{cij}$, $x_{aj}^{-} = \min_{i} x_{aij}$, and $\tilde{r}_{ij}$ denotes the normalized aggregate performance rating of alternative i with respect to criterion j.

Step 5. Define the ideal solution $A^{*} = (r_1^{*}, r_2^{*}, \ldots, r_n^{*})$ and the anti-ideal solution $A^{-} = (r_1^{-}, r_2^{-}, \ldots, r_n^{-})$, where $r_j^{*} = (1,1,1)$ and $r_j^{-} = (0,0,0)$ for $j = 1, 2, \ldots, n$.

Step 6. Calculate the weighted distances from ideal solution and anti-ideal solution (D_i^{*} and D_i^{-}, respectively) for each alternative as

$$D_i^{*} = \sum_{j} 1/2 \left\{max(w_{aj}^{1}|r_{aij} - 1|, w_{cj}^{1}|r_{cij} - 1|) + w_{bj}^{1}|r_{bij} - 1|\right\}, i = 1,2,\ldots,m \tag{4.11}$$

$$D_i^{-} = \sum_{j} 1/2 \left\{max(w_{aj}^{1}|r_{aij} - 0|, w_{cj}^{1}|r_{cij} - 0|) + w_{bj}^{1}|r_{bij} - 0|\right\}, i = 1,2,\ldots,m. \tag{4.12}$$

Step 7. Calculate the proximity of the alternatives to the ideal solution, P_i^* , by considering the distances from ideal and anti-ideal solutions as

$$P_i^* = {D_i^-}/{(D_i^* + D_i^-)}, i = 1,2,\ldots,m. \qquad (4.13)$$

Step 8. Rank the alternatives according to P_i^* values in descending order. Identify the alternative with the highest P_i^* as the best alternative.

4.5 Proposed Model

In this study, a new integrated method is proposed in order to determine the location of the MBT facility. The steps of proposed method, starting with the determination of the key criteria and extending to the selection of the most suitable place among the alternatives, are presented in the following paragraph.

Step 1: Identifying key criteria for MBT site selection
The key criteria in a hierarchical structure will be determined by considering the information in the literature and the opinions of the experts.

Step 2: Identifying suitable alternatives for MBT
Suitable alternative areas will be determined by mapping the criteria within a web-based geographical information system software, ATLAS. In this stage, experts' opinions will be taking a consideration as well as GIS.

Step 3: Obtain the decision matrix according to decision makers
After the criteria and alternatives will be determined, the experts first will be evaluated the criteria and then the alternatives according to the criteria. Three experts will be made evaluation.

Step 4: Determining the weights of the criteria
Fuzzy Best Worst Method will be applied to determining the weights of criteria. Each expert first chooses the best and worst of the main criteria and creates comparison

matrices by evaluating these criteria according to the others. By considering the comparison matrix of each expert, the fuzzy best worst method is applied and the criterion weights are calculated according to each expert. Final criterion weights are calculated by averaging the weights considering that each expert's opinion is equal. These stages are applied for each sub criterion respectively, after the main criteria.

Step 5: Assessment and analysis of alternatives

The second phase of Hierarchical Fuzzy MCDM Approach proposed by Karsak and Ahiska (2005) will be used for ranking alternatives from best suitable to worst suitable in this study.
The flow chart of the proposed model for this study is presented in Figure 4.1.

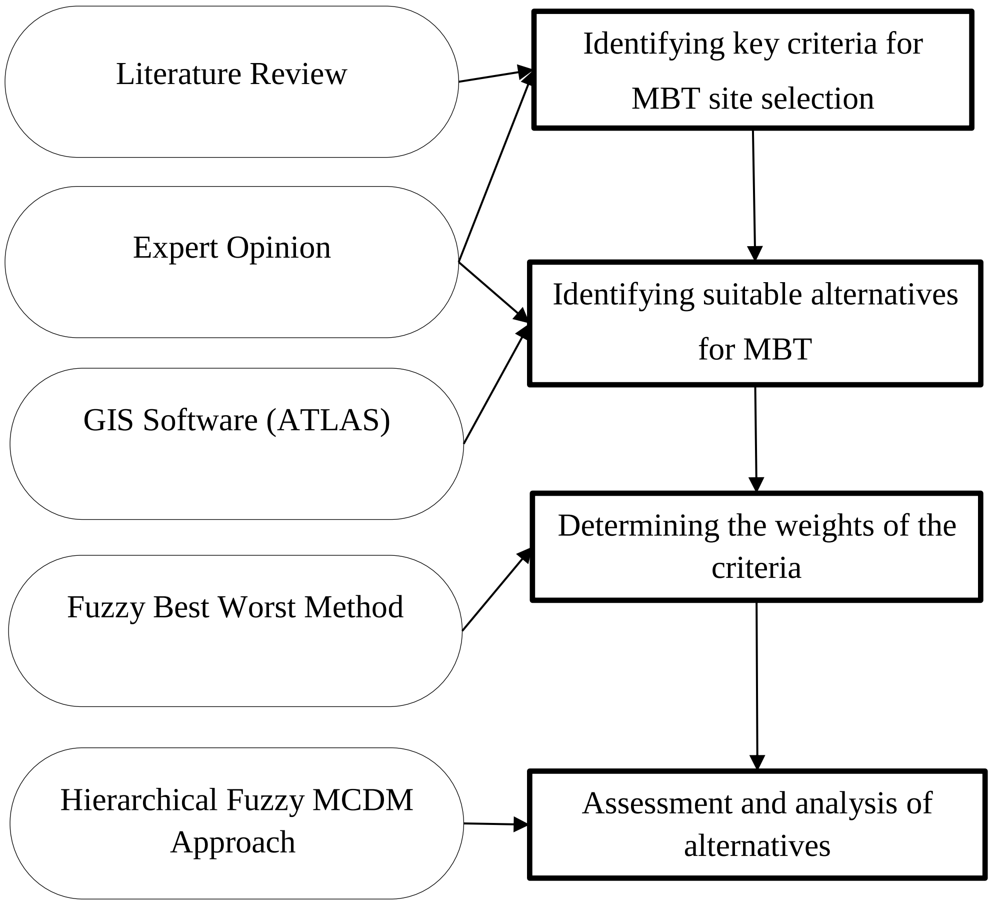

Figure 4.1 Flow chart of the proposed model

5. APPLICATION

5.1 Problem Definition

Istanbul is a most crowded megacity in Turkey and the country's business, economic, cultural, education and historic center. "It is also one of the largest agglomerations in Europe and the fifth largest city in the world in terms of population within city limits" (World Population Review, 2020).

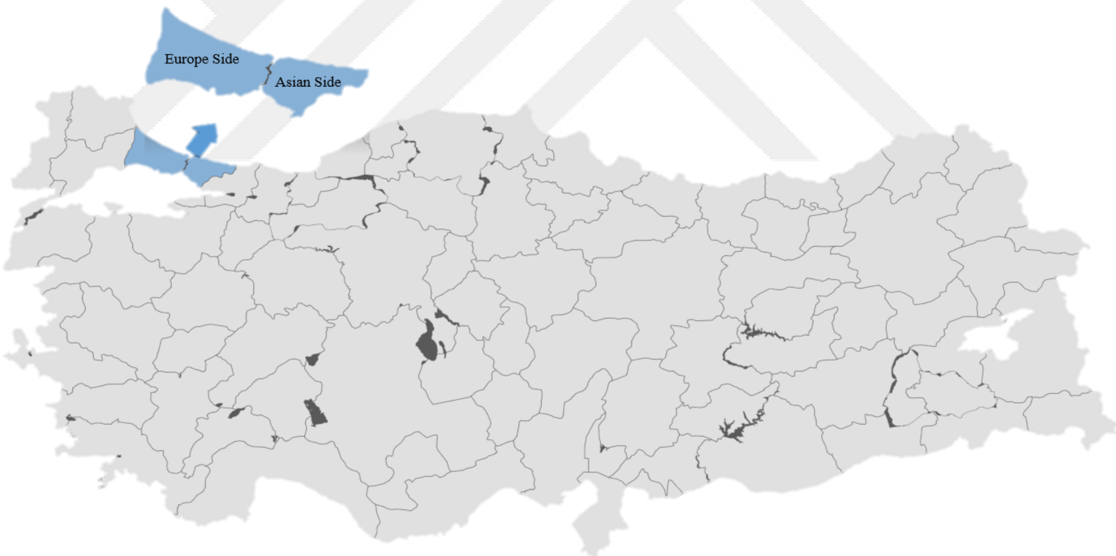

Figure 5.1 Location of Istanbul for Turkey

Solid waste is an important environmental problem because of growing population in Istanbul. The quantity of waste in Istanbul in 2019 has increased by 31% compared to 2010. According to years, total quantity of solid waste is shown in Table 5.1

Table 5.1 Total Quantity of Solid Waste in Istanbul

Years	Total Quantity of Solid Waste in Istanbul (Ton /year)
2010	4.674.960
2011	4.877.401
2012	5.065.113
2013	5.596.885
2014	5.875.132
2015	6.100.765
2016	6.234.424
2017	6.485.132
2018	6.429.886
2019	6.136.663

Istanbul province has 25 districts (3,474.35 km²) from Europe side and 14 districts (1,868.87 km²) from Asian side. Istanbul Asian side districts are named Adalar, Ataşehir, Beykoz, Çekmeköy, Kadıköy, Kartal, Maltepe, Pendik, Sancaktepe, Sultanbeyli, Şile, Tuzla, Ümraniye, and Üsküdar. Approximately 6000 tons solid waste are produced per day in these districts as Figure 5.2 (İstanbul Metropolitan Municipality, 2020)

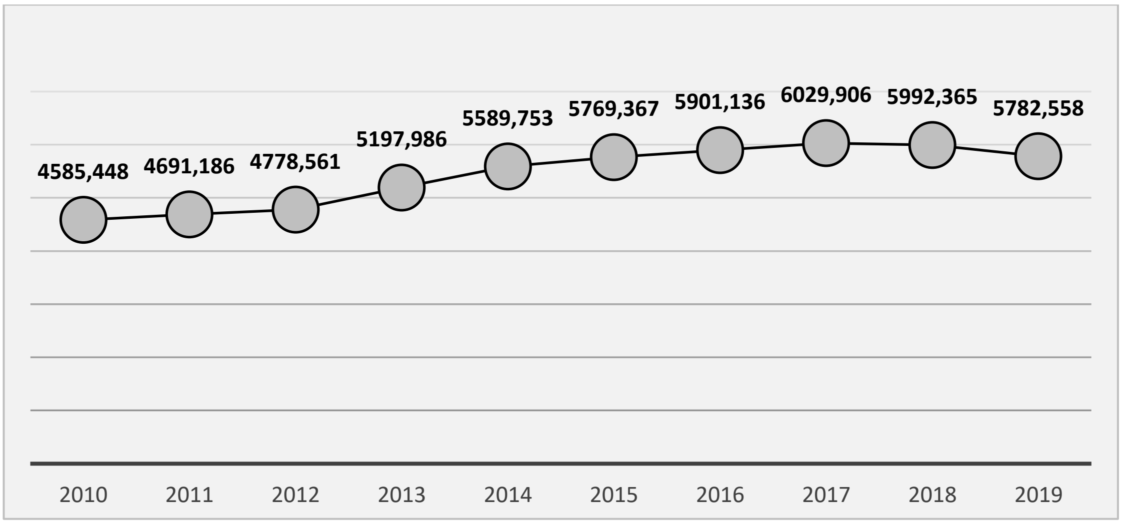

Figure 5.2 Amount of Solid Waste in Asian Side of Istanbul (ton/per day)

Some regulations of recently updated through Ministry of Environment and Urbanisation in Turkey; "It is essential to use environmentally compatible physical, chemical, biological or thermal technologies in order to ensure the recovery of municipal waste in accordance with the zero-waste management system. Pre-treatment facilities and capacities where these technologies are used are established so that at least 60% by weight of the amount of municipal waste collected in 2035 can be recovered" (T.C Resmi Gazete).

The existing facilities on the Anatolian side of Istanbul are as in Figure 5.3. Currently there is only one pre-treatment facility. A pre-treatment facility is needed in order to use waste recycling facilities more efficiently in the Anatolian region of Istanbul. In this study, the location problem of MBT facility, which is a pre-treatment facility for Istanbul Anatolian Region, will be studied in accordance with the published regulation. For this reason, it has been examined in the literature on the problem of location selection.

Figure 5.3 The existing facilities on the Anatolian side of Istanbul

5.2 Application of the Proposed Model

5.2.1 Identifying key criteria for MBT site selection

When the literature is examined, there is no study related to the MBT facility location problem. Therefore, considering both the studies on different facility types in the literature and expert opinions, location selection criteria for the MBT facility have been established as in Table 5.2. Otherwise Figure 5.4 shows that hierarchical structure for criteria.

Table 5.2 MBT Site Selection Criteria

CRITERIA	DEFINITION
***F_1* Environmental Factors**	
C_1 Fauna/Flora	The management of insects, birds and harmful animals is a significant factor in maintaining environmental stability and public health. The facility should be distance from areas where impressed these factors.
C_2 Faults	The facility should be geologically adequate and not vulnerable to earthquakes, volcanoes, landslides and erosion.
C_3 Basin area	The facility should not be located in areas that are not suitable for settlement in water basins.
***F_2* Technical / Economic Factors**	
C_4 Infrastructure	The facility location should be in a good place regarding infrastructure. Access to sewerage, electricity and water resources should be possible.
C_5 Slope and Elevation	As the slope increases, the land suitability decreases. The facility location should be suitable areas about slope and elevation.
C_6 Distance from existing facilities	In order to minimize the transportation cost, the facility should not be too far from other waste facilities.
C_7 Land use	Consideration should be given to existing and potential developments at the site and adjacent areas.
C_8 Land Values	Choosing among the state-owned lands for economic benefits.
C_9 Roads	The facility should be close to main roads for transportation cost advantage.
C_{10} Waste quantity	The facility should be closer to the districts that generate the most waste.
***F*3. Social Factors**	
C_{11} Public concern - Distance from residential areas	It was noted that people are more concerned about the odours and noise from waste disposal facilities. Under national guidelines, MSW can not be build within 500 m of urban areas. In addition, given the cost of transportation, it should not be too distant from residential areas.
C_{12} Distance from sensitive sites	The facility should be distance from historical, touristic and cultural areas.
C_{13} Population	Due to public concern, the facility should not be taken close to the regions where the population is very dense.

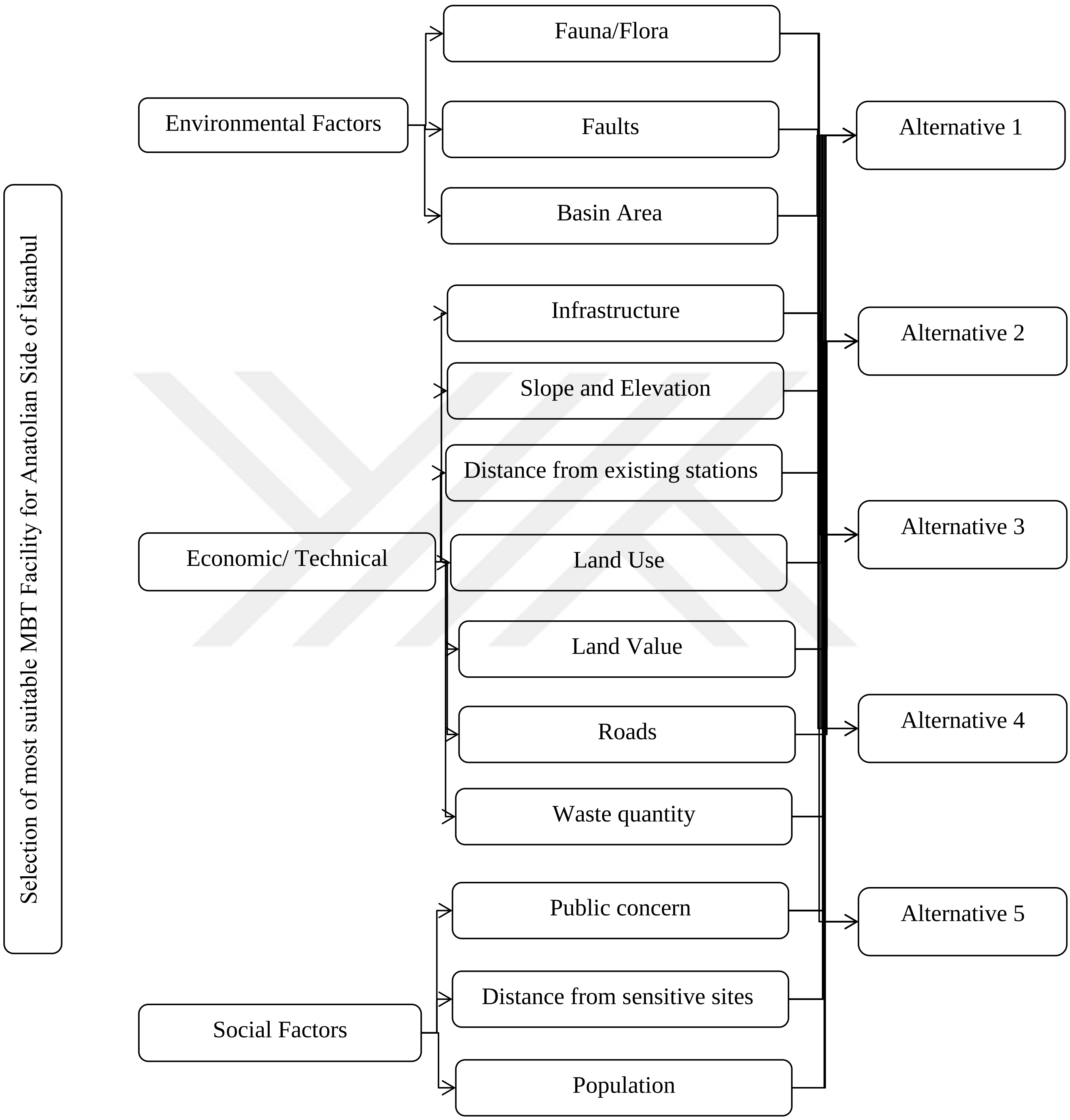

Figure 5.4 Hierarchical structure for criteria

5.2.2 Identifying suitable alternatives for MBT

Expert opinions and open data portals were used to determine location alternatives.
In this study, ATLAS, a web-based software, developed by the Ministry of Environment and Urbanization was used. ATLAS was developed to establish a national geographical information system.
In this study, it has been tried to determine alternative locations for the MBT facility by filtering criteria according to open data. Figure 5.5 shows Istanbul on ATLAS.

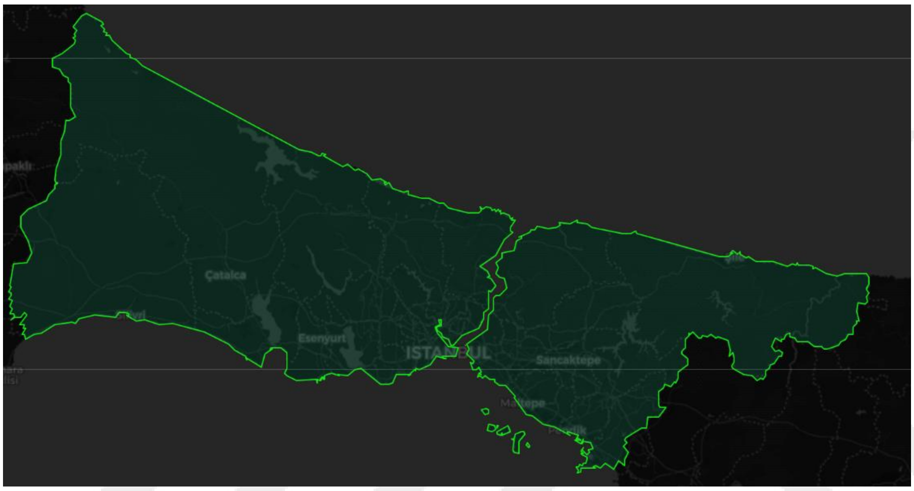

Figure 5.5 View of Istanbul on Atlas

In Figure 5.6, special environmental protection areas, nation gardens, nature parks, recreation area, special afforestation areas, nursery ground, honey forests, wild animal settlement area, wildlife protection and development areas, nature protected areas, national parks and urban forests filtered on ATLAS.

Figure 5.6 Filtered that some environmental attributes

In Figure 5.7, monumental trees, site and cave areas are filtered on ATLAS.

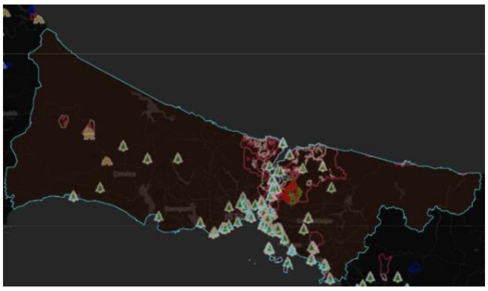

Figure 5.7 Monumental Trees, site and cave areas

In Figure 5.8, filtering was made on ATLAS according to wind and water erosion attributes. Figure 5.9, and 5.10 for İstanbul region, illustrates that Turkey Earthquake Hazards maps created by the Disaster and Emergency Management Presidency (AFAD).

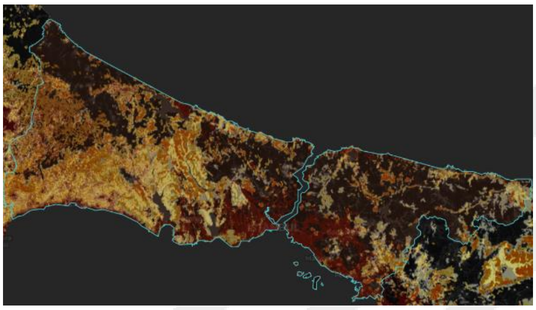

Figure 5.8 Wind and water erosion attributes on ATLAS

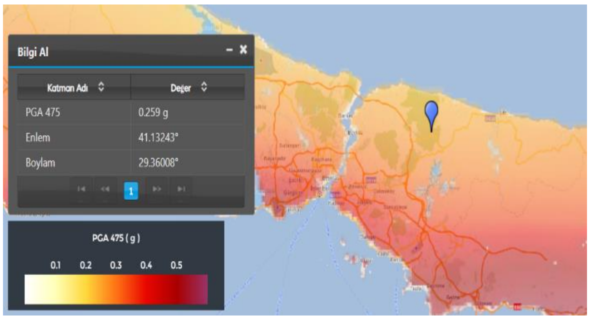

Figure 5.9 Earthquake Hazards density map

Figure 5.10 Earthquake Hazards map with Peak Ground Acceleration Value

On the Istanbul Metropolitan Municipality (IMM) City Map, it is seen that the basin areas are filtered as regards from the maximum protection zone to long protection zone. (Figure 5.11)

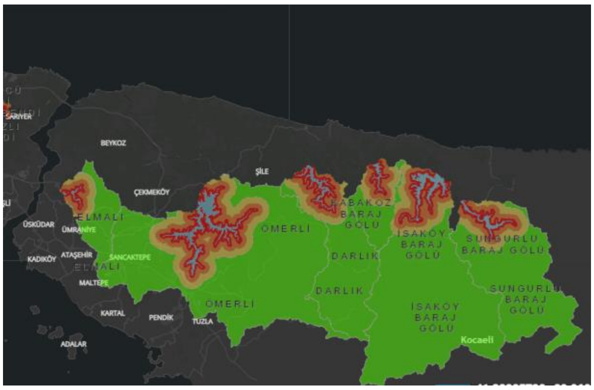

Figure 5.11 Basin areas for Istanbul

In Figure 5.12, the terrain slope and steepness map were filtered according to the RUSLE-LS factor, and the Shuttle Radar Topography Mission (SRTM) data for elevation in Figure 5.13 were filtered.

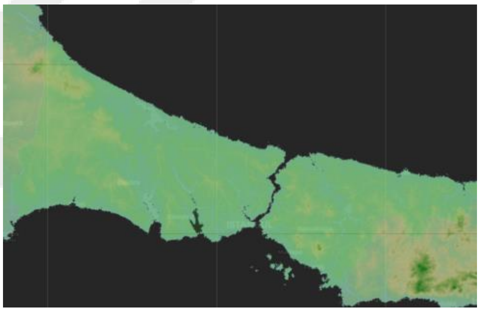

Figure 5.12 Slope map for Istanbul

Figure 5.13 Elevation map for Istanbul

The projects planned in the Istanbul region can be followed on the website prepared by IMM in Figure 5.14.

Figure 5.14 Planned projects for Istanbul

For land values, scoring was made by considering the nominal land value map (Mete, 2019) in Figure 5.15.

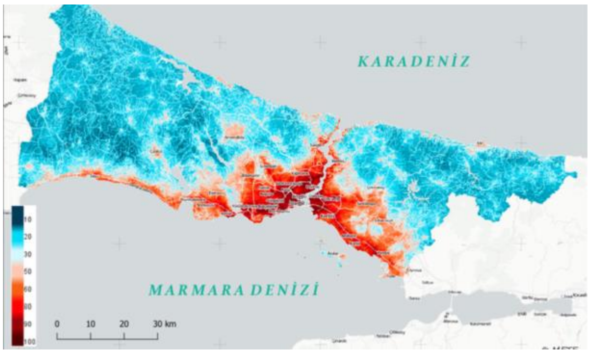

Figure 5.15 Nominal land value map

In Figure 5.16, the map of the main roads is linked via ATLAS.

Figure 5.16 Main roads in Istanbul

Figure 5.17 shows the 2019 population density grid map on the ATLAS.

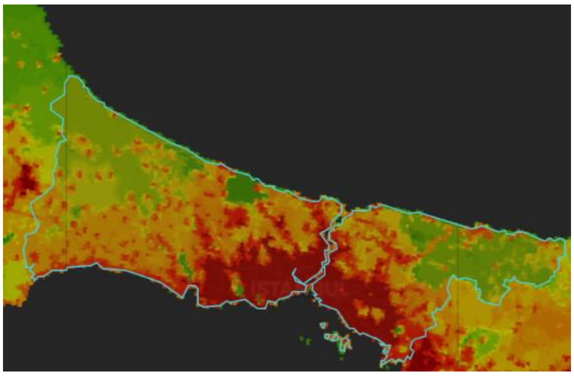

Figure 5.17 Population density for Istanbul

Using all these maps with expert's opinion, alternative locations for the MBT facility were determined. Expert opinions and filtered maps in the geographic information system have been of great importance in determining alternative locations. Using all this information, the places in Figure 5.18 were chosen as five alternatives.

Figure 5.18 Existing facilities and alternatives

5.2.3 Obtain the decision matrix according to decision makers

As a result of discussions with experts from ISTAC INC., Istanbul Environment Management Industry and Trade Company, we have defined the decision matrix for the alternatives and criteria. The evaluations of three environmental engineers who are experts in their fields are considered. Experts have been working in ISTAC for about ten, seven and five years, respectively. The impact of each expert is considered equal. In the following section, criteria and alternatives evaluated by experts will be presented.

5.2.4 Determining the weights of the criteria

After determining the location selection alternatives and decision matrix, multi-criteria decision-making techniques were applied. In the first step, criterion weights were calculated using the fuzzy best worst method. By solving models for each expert in Lingo 16.0 software, the fuzzy weights of criteria were calculated. Final fuzzy weights were found as considering experts equal to each other.
Table 5.3 shows that the linguistic terms can be expressed by fuzzy numbers needed for criteria weighting using fuzzy BWM. Using these membership function, weights of main

criteria, environmental criteria, technical/economic criteria and social criteria were calculated respectively.

Table 5.3 Linguistic term set for BWM

Linguistic terms	Membership function
Equally importance (EI)	(1,1,1)
Weakly important (WI)	(2/3,1,3/2)
Fairly Important (FI)	(3/2,2,5/2)
Very important (VI)	(5/2,3,7/2)
Absolutely important (AI)	(7/2,4,9/2)

Step 1. Determine the best and the worst for main criteria

Table 5.4 and Table 5.5 show the best and worst criteria that experts have selected for the main criteria. They also show linguistic terms of criteria in the form of best to others and other to worst for experts' opinion. F_1, F_2, F_3 represent environmental factors, technical/economic factors and social factors respectively.

Table 5.4 Linguistic evaluations by each expert for best main criteria

Experts Panel	**Best Factor**	**Best to Others**		
		F_1	F_2	F_3
Expert 1	$\boldsymbol{F_2}$	VI	EI	VI
Expert 2	$\boldsymbol{F_1}$	EI	FI	VI
Expert 3	$\boldsymbol{F_1}$	EI	FI	VI

Table 5.5 Linguistic evaluations by each expert for worst main criteria

Factors	**Expert 1 Worst Factor**	**Expert 2 Worst Factor**	**Expert 3 Worst Factor**
Others to Worst	$\boldsymbol{F_3}$	$\boldsymbol{F_3}$	$\boldsymbol{F_3}$
$\boldsymbol{F_1}$	FI	FI	VI
$\boldsymbol{F_2}$	VI	WI	AI
$\boldsymbol{F_3}$	EI	EI	EI

Fuzzy numbers that corresponding to linguistic terms have been shown in Table 5.6

Table 5.6 Fuzzy numbers of Best to Others and Others to Worst

Experts Panel	Best Criteria	Worst Criteria	Fuzzy preferences achieved from linguistic terms			
				F_1	F_2	F_3
Expert 1	F_2	F_3	$A_{bj}^{[1]}$	(5/2,3,7/2)	(1,1,1)	(5/2,3,7/2)
			$A_{jw}^{[1]}$	(3/2,2,5/2)	(5/2,3,7/2)	(1,1,1)
Expert 2	F_1	F_3	$A_{bj}^{[2]}$	(1,1,1)	(3/2,2,5/2)	(5/2,3,7/2)
			$A_{jw}^{[2]}$	(5/2,3,7/2)	(2/3,1,3/2)	(1,1,1)
Expert 3	F_1	F_3	$A_{bj}^{[3]}$	(1,1,1)	(3/2,2,5/2)	(5/2,3,7/2)
			$A_{jw}^{[3]}$	(5/2,3,7/2)	(7/2,4,9/2)	(1,1,1)

Step 2. Calculate the optimal fuzzy weights of main criteria

The nonlinearly constrained optimization problem was constructed by each expert as follows.

For expert 1:

min $\xi*$

s.t.

$l_2 - 2.5*u_1 - \xi*u_1 \leq 0;\ l_2 - 2.5*u_1 + \xi*u_1 \geq 0;$

$m_2 - 3*m_1 - \xi*m_1 \leq 0; m_2 - 3*m_1 + \xi*m_1 \geq 0;$

$u_2 - 3.5*l_1 - \xi*l_1 \leq 0; u_2 - 3.5*l_1 + \xi*l_1 \geq 0;$

$l_2 - 2.5*u_3 - \xi*u_3 \leq 0; l_2 - 2.5*u_3 + \xi*u_3 \geq 0;$

$m_2 - 3*m_3 - \xi*m_3 \leq 0; m_2 - 3*m_3 + \xi*m_3 \geq 0;$

$u_2 - 3.5*l_3 - \xi*l_3 \leq 0; u_2 - 3.5*l_3 + \xi*l_3 \geq 0;$

$l_1 - 1.5*u_3 - \xi*u_3 \leq 0;\ l_1 - 1.5*u_3 + \xi*u_3 \geq 0;$

$m_1 - 2*m_3 - \xi*m_3 \leq 0;\ m_1 - 2*m_3 + \xi*m_3 \geq 0;$

$u_1 - 2.5*l_3 - \xi*l_3 \leq 0; u_1 - 2.5*l_3 + \xi*l_3 \geq 0;$

$$\frac{1}{6}*(l_1 + 4*m_1 + u_1) + \frac{1}{6}*(l_2 + 4*m_2 + u_2) + \frac{1}{6}*\ (l_3 + 4*m_3 + u_3) = 1;$$

$l_1 \leq m_1 \leq u_1;\ l_2 \leq m_2 \leq u_2;\ l3 \leq m_3 \leq u_3; l_1 > 0;\ l_2 > 0;\ l_3 > 0;\ \xi \geq 0$

For expert 2:

Min $\xi*$

s.t.

$l_1 - 1.5*u_2 - \xi*u_2 \leq 0;\ l_1 - 1.5*u_2 + \xi*u_2 \geq 0;$

$m_1 - 2*m_2 - \xi*m_2 \leq 0; m_1 - 2*m_2 + \xi*m_2 \geq 0;$

$u_1 - 2.5 * l_2 \ - \xi * l_2 \ \leq \ 0;\ u1 - 2.5 * l_2 + \xi * l_2 \ \geq \ 0;$

$l_1 - 2.5 * u_3 \ - \xi * u_3 \ \leq \ 0;\ l_1 - 2.5 * u3 + \xi * u_3 \ \geq 0;$

$m_1 - 3 * m_3 - \ \xi * m_3 \leq \ 0;\ m_1 - 3 * m_3 + \xi * m_3 \ \geq 0;$

$u1 - 3.5 * l_3 \ - \xi * l_3 \leq \ 0;\ u_1 - 3.5 * l3 + \xi * l_3 \ \geq 0;$

$l2 - \frac{2}{3} * u_3 \ - \xi * u_3 \ \leq \ 0; l_2 - \frac{2}{3} * u_3 + \xi * u_3 \ \geq 0;$

$m2 - 1 * m_3 - \ \xi * m_3 \leq \ 0;\ m_2 - 1 * m_3 + \xi * m_3 \ \geq 0;$

$u2 - 1.5 * l_3 \ - \xi * l_3 \leq \ 0;\ u_2 - 1.5 * l_3 + \xi * l_3 \ \geq 0;$

$\frac{1}{6} * (l_1 + 4 * m_1 + u_1) + \frac{1}{6} * (l_2 + 4 * m_2 + u_2) + \frac{1}{6} * \ (l_3 + 4 * m_3 + u_3) = \ 1;$

$l_1 \leq m_1 \leq u_1;\ l_2 \leq m_2 \leq u_2;\ l_3 \leq m_3 \leq u_3;\ l_1 > 0;\ l_2 > 0; l_3 > 0;\ \xi \ \geq \ 0$

For expert 3:

Min ξ*

s.t.

$l_1 - 1.5 * u_2 - \xi * u_2 \ \leq \ 0;\ l_1 - 1.5 * u_2 + \ \xi * u_2 \ \geq \ 0;$

$m_1 - 2 * m2 - \xi * m_2 \ \leq \ 0;\ m_1 - 2 * m_2 + \xi * m_2 \ \geq 0;$

$u_1 - 2.5 * l_2 \ - \xi * l_2 \ \leq \ 0;\ u_1 - 2.5 * l_2 + \xi * l_2 \ \geq \ 0;$

$l_1 - 2.5 * u3 \ - \xi * u_3 \ \leq \ 0; l_1 - 2.5 * u_3 + \xi * u_3 \ \geq 0;$

$m_1 - 3 * m3 - \ \xi * m_3 \leq \ 0;\ m_1 - 3 * m_3 + \xi * m_3 \ \geq 0;$

$u_1 - 3.5 * l_3 \ - \xi * l_3 \leq \ 0;\ u_1 - 3.5 * l_3 + \xi * l_3 \ \geq 0;$

$l_2 - 3.5 * u3 \ - \xi * u_3 \ \leq \ 0; l_2 - 3.5 * u_3 + \xi * u_3 \ \geq 0;$

$m_2 - 4 * m_3 - \ \xi * m_3 \leq \ 0; m_2 - 4 * m_3 + \xi * m_3 \ \geq 0;$

$u_2 - 4.5 * l_3 \ - \xi * l_3 \leq \ 0;\ u_2 - 4.5 * l_3 + \xi * l_3 \ \geq 0;$

$\frac{1}{6} * (l_1 + 4 * m_1 + u_1) + \frac{1}{6} * (l_2 + 4 * m_2 + u_2) + \frac{1}{6} * \ (l_3 + 4 * m_3 + u_3) = \ 1;$

$l_1 \leq m_1 \leq u_1;\ l_2 \leq m_2 \leq u_2; l_3 \leq m_3 \leq u_3;\ l_1 > 0;\ l_2 > 0;\ l_3 > 0;\ \xi \ \geq \ 0$

Final fuzzy weights for main criteria were found as like Table 5.7. *CR* < 0.1 is acceptable.

Table 5.7 Fuzzy weights of main criteria

Factor	Expert 1	Expert 2	Expert 3
***F*1**	(0.175,0.245,0.288)	(0.511,0.558,0.558)	(0.485,0.485,0.566)

F_2	(0.562,0.599,0.599)	(0.204,0.249,0.295)	(0.298,0.332,0.539)
F_3	(0.148,0.169,0.184)	(0.17, 0.202,0.226)	(0.138,0.138,0.157)
ξ	0,551	0,236	0,599
CR	0,082	0,035	0,089

Table 5.7 Fuzzy weights of main criteria (cont.)

Factor	Final fuzzy weights
F_1	(0.390,0.429,0.471)
F_2	(0.355,0.393,0.478)
F_3	(0.152,0.170,0.189)

Step 3. Determine the best and worst for environmental criteria

Table 5.8 and Table 5.9 show the best and worst criteria that experts have selected for environmental criteria. They also show linguistic terms of criteria in the form of best to others and other to worst for experts' opinion. C_1, C_2, C_3 represent fauna/flora, faults and basin area criteria respectively.

Table 5.8 Linguistic evaluations by each expert for best environmental criteria

Experts Panel	Best Factor	Best to Others		
		C_1	C_2	C_3
Expert 1	C_3	AI	FI	EI
Expert 2	C_3	VI	AI	EI
Expert 3	C_3	VI	AI	EI

Table 5.9 Linguistic evaluations by each expert for worst environmental criteria

Factors	Expert 1 Worst Factor	Expert 2 Worst Factor	Expert 3 Worst Factor
Others to Worst	C_1	C_2	C_2
C_1	EI	FI	FI
C_2	WI	EI	EI
C_3	AI	AI	AI

Fuzzy numbers that corresponding to linguistic terms have been shown in Table 5.10

Table 5.10 Fuzzy numbers of Best to Others and Others to Worst

Expert Panel	Best Criteria	Worst Criteria	Fuzzy preferences achieved from linguistic terms			
				C_1	C_2	C_3
Expert 1	C_3	C_1	$A_{bj}^{[1]}$	(7/2,4,9/2)	(3/2,2,5/2)	(1,1,1)
			$A_{jw}^{[1]}$	(1,1,1)	(2/3,1,3/2)	(7/2,4,9/2)
Expert 2	C_3	C_2	$A_{bj}^{[2]}$	(5/2,3,7/2)	(7/2,4,9/2)	(1,1,1)
			$A_{jw}^{[2]}$	(3/2,2,5/2)	(1,1,1)	(7/2,4,9/2)
Expert 3	C_3	C_2	$A_{bj}^{[3]}$	(5/2,3,7/2)	(7/2,4,9/2)	(1,1,1)
			$A_{jw}^{[3]}$	(3/2,2,5/2)	(1,1,1)	(7/2,4,9/2)

Step 4. Calculate the optimal fuzzy weights of environmental criteria

By solving models (Appendix A.) for each expert the fuzzy weights of environmental criteria were calculated. Final fuzzy weights were found as like Table 5.11.

Table 5.11 Fuzzy weights of environmental criteria

Factor	Expert 1	Expert 2	Expert 3
C_1	(0.147,0.168,0.181)	(0.177,0.237,0.277)	(0.177,0.237,0.277)
C_2	(0.202,0.244,0.284)	(0.129,0.144,0.155)	(0.129,0.144,0.155)
C_3	(0.553,0.597,0.597)	(0.595,0.628,0.628)	(0.595,0.628,0.628)
ξ	0,45	0,354	0,354
CR	0,056	0,044	0,044

Table 5.11 Fuzzy weights of environmental criteria (cont.)

Factor	Final fuzzy weights
C_1	(0.167,0.214,0.245)
C_2	(0.153,0.177,0.198)
C_3	(0.581,0.618,0.618)

Step 5. Determine the best and worst for technical/economic factors

Table 5.12 and Table 5.13 show the best and worst criteria that experts have selected for the technical/economic factors. They also show linguistic terms of criteria in the form of best to others and other to worst for experts' opinion. C_4, C_5, C_6, C_7, C_8, C_9, C_{10} represent infrastructure, slope and elevation, distance from existing stations**,** land value, land use, roads, waste quantity criteria respectively.

Table 5.12 Linguistic evaluations by each expert for best technical/economic criteria

Experts Panel	Best Factor	Best to Others						
		C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Expert 1	C_8	VI	VI	FI	FI	EI	FI	FI
Expert 2	C_7	FI	FI	WI	EI	FI	FI	WI
Expert 3	C_8	WI	FI	FI	WI	EI	FI	FI

Table 5.13 Linguistic evaluations by each expert for worst technical/economic criteria

Factors	Expert 1 Worst Factor	Expert 2 Worst Factor	Expert 3 Worst Factor
Others to Worst	C_5	C_5	C_5
C_4	FI	WI	WI
C_5	EI	EI	EI
C_6	FI	WI	WI
C_7	FI	FI	FI
C_8	VI	FI	FI
C_9	FI	FI	FI
C_{10}	FI	FI	FI

Fuzzy numbers that corresponding to linguistic terms have been shown in Table 5.14

Table 5.14 Fuzzy numbers of Best to Others and Others to Worst

Experts	BC	WC	Fuzzy preferences achieved from linguistic terms				
				C_4	C_5	C_6	C_7
Expert 1	C_8	C_5	$A_{bj}^{[1]}$	(5/2,3,7/2)	(5/2,3,7/2)	(3/2,2,5/2)	(3/2,2,5/2)
			$A_{jw}^{[1]}$	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)
Expert 2	C_7	C_5	$A_{bj}^{[2]}$	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)	(1,1,1)
			$A_{jw}^{[2]}$	(2/3,1,3/2)	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)
Expert 3	C_8	C_5	$A_{bj}^{[3]}$	(2/3,1,3/2)	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)
			$A_{jw}^{[3]}$	(2/3,1,3/2)	(1,1,1)	(2/3,1,3/2)	(3/2,2,5/2)

Table 5.14 Fuzzy numbers of Best to Others and Others to Worst (cont.)

Experts	BC	WC	Fuzzy preferences achieved from linguistic terms			
				C_8	C_9	C_{10}
Expert 1	C_8	C_5	$A_{bj}^{[1]}$	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)
			$A_{jw}^{[1]}$	(5/2,3,7/2)	(3/2,2,5/2)	(3/2,2,5/2)
Expert 2	C_7	C_5	$A_{bj}^{[2]}$	(3/2,2,5/2)	(3/2,2,5/2)	(2/3,1,3/2)
			$A_{jw}^{[2]}$	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)
Expert 3	C_8	C_5	$A_{bj}^{[3]}$	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)

$A_{jw}^{[3]}$	(3/2,2,5/2)	(3/2,2,5/2)	(3/2,2,5/2)

Step 6. Calculate the optimal fuzzy weights of technical/economic factors

By solving models (Appendix A.) for each expert the fuzzy weights of environmental criteria were calculated. Final fuzzy weights were found as like Table 5.15.

Table 5.15 Fuzzy weights of technical/economic criteria

Factor	Expert 1	Expert 2	Expert 3
C_4	(0.081,0.092,0.115)	(0.09,0.105,0.105)	(0.121,0.146,0.159)
C_5	(0.059,0.063,0.074)	(0.08,0.097,0.0106)	(0.08,0.097,0.106)
C_6	(0.123,0.155,0.182)	(0.121,0.146,0.159)	(0.094,0.105,0.105)
C_7	(0.123,0.155,0.182)	(0.168,0.219,0.241)	(0.135,0.161,0.161)
C_8	(0.225,0.225,0.239)	(0.112,0.146,0.161)	(0.168,0.219,0.241)
C_9	(0.123,0.155,0.182)	(0.112,0.146,0.161)	(0.112,0.146,0.161)
C_{10}	(0.123,0.155,0.182)	(0.135,0.161,0.161)	(0.112,0.146,0.161)
ξ	0.551	0.499	0.499
CR	0,082	0,09	0,09

Table 5.15 Fuzzy weights of technical/economic criteria (cont.)

Factor	Final fuzzy weights
C_4	(0.097,0.114,0.126)
C_5	(0.073,0.086,0.064)
C_6	(0.113,0.135,0.149)
C_7	(0.142,0.178,0.195)
C_8	(0.168,0.197,0.214)
C_9	(0.116,0.149,0.168)
C_{10}	(0.123,0.154,0.168)

Step 7. Determine the best and the worst for Social factors

Table 5.16 and Table 5.17 show the best and worst criteria that experts have selected for the social factors. They also show linguistic terms of criteria in the form of best to others and other to worst for experts' opinion. C_{11}, C_{12}, C_{13} represent public concern, distance from sensitive sites and population criteria respectively.

Table 5.16 Linguistic evaluations by each expert for best social criteria

Experts Panel	**Best Factor**	**Best to Others**		
		C_{11}	C_{12}	C_{13}
Expert 1	C_{12}	WI	EI	FI
Expert 2	C_{12}	WI	EI	FI
Expert 3	C_{12}	FI	EI	FI

Table 5.178 Linguistic evaluations by each expert for worst social criteria

Factors	**Expert 1 Worst Factor**	**Expert 2 Worst Factor**	**Expert 3 Worst Factor**
Others to Worst	C_{13}	C_{13}	C_{13}
$\boldsymbol{C_{11}}$	WI	WI	FI
$\boldsymbol{C_{12}}$	FI	FI	FI
$\boldsymbol{C_{13}}$	EI	EI	EI

Fuzzy numbers that corresponding to linguistic terms have been shown in Table 5.18.

Table 5.18 Fuzzy numbers of Best to Others and Others to Worst

Experts Panel	**BC**	**WC**	**Fuzzy preferences achieved from linguistic terms**			
				$\boldsymbol{C_{11}}$	$\boldsymbol{C_{12}}$	$\boldsymbol{C_{13}}$
Expert 1	C_{12}	C_{13}	$A_{bj}^{[1]}$	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)
			$A_{jw}^{[1]}$	(2/3,1,3/2)	(3/2,2,5/2)	(1,1,1)
Expert 2	C_{12}	C_{13}	$A_{bj}^{[2]}$	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)
			$A_{jw}^{[2]}$	(2/3,1,3/2)	(3/2,2,5/2)	(1,1,1)
Expert 3	C_{12}	C_{13}	$A_{bj}^{[3]}$	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)
			$A_{jw}^{[3]}$	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)

Step 8. Calculate the optimal fuzzy weights of social factors

By solving models (Appendix A.) for each expert the fuzzy weights of environmental criteria were calculated. Final fuzzy weights were found as like Table 5.19.

Table 5.19 Fuzzy weights of social criteria

Factor	**Expert 1**	**Expert 2**	**Expert 3**	**Final fuzzy weights**

C_{11}	(0.271,0.331,0.345)	(0.271,0.331,0.345)	(0.241,0.319,0.349)	(0.261,0.327,0.346)
C_{12}	(0.334,0.431,0.488)	(0.334,0.431,0.488)	(0.435,0.498,0.498)	(0.368,0.453,0.491)
C_{13}	(0.222,0.254,0.279)	(0.222,0.254,0.279)	(0.169,0.204,0.225)	(0.204,0.237,0.261)
ξ	0.303	0.303	0.438	
CR	0,057	0,057	0,082	

Table 5.20 indicates that weights of all sub-criteria and main criteria briefly.

Table 5.20 Weights of all sub-criteria and main criteria

Criteria/Sub-criteria	**Importance Weight**
Enviromental Factor (F_1)	(0.390, 0.429, 0.471)
Fauna/ Flora (C_1)	(0.167, 0.214, 0.245)
Faults (C_2)	(0.153, 0.177, 0.198)
Basin area (C_3)	(0.581, 0.618, 0.618)
Technical/Economic Factor (F_2)	(0.355, 0.393, 0.478)
Infrastructure (C_4)	(0.097, 0.114, 0.126)
Slope and elevation (C_5)	(0.073, 0.086, 0.064)
Distance from existing stations (C_6)	(0.113, 0.135, 0.149)
Land value (C_7)	(0.142, 0.178, 0.195)
Land use (C_8)	(0.168, 0.197, 0.214)
Roads (C_9)	(0.116, 0.149, 0.168)
Waste quantity (C_{10})	(0.123, 0.154, 0.168)
Social Factor (F_3)	(0.152, 0.170, 0.189)
Public concern (C_{11})	(0.261, 0.327, 0.346)
Distance from sensitive sites (C_{12})	(0.368, 0.453, 0.491)
Population (C_{13})	(0.204, 0.237, 0.261)

5.2.5 Assessment and analysis of alternatives

Table 5.21 and Figure 5.19 show that how the linguistic terms can be expressed by fuzzy numbers needed to assess alternatives using hierarchical fuzzy MCDM Method.

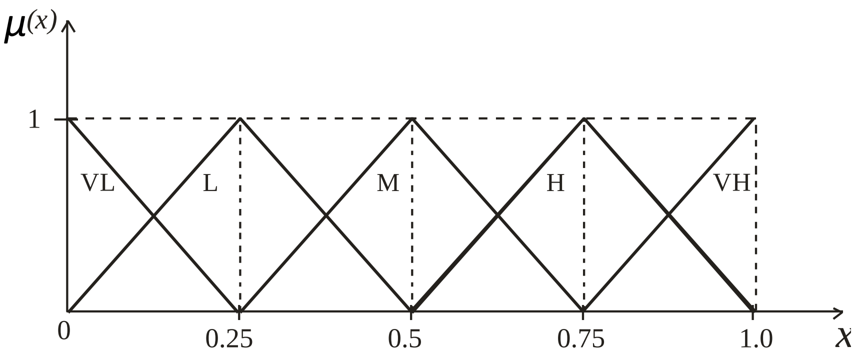

Figure 5.19 Fuzzy term set

Table 5.21 Linguistic term set for hierarchical fuzzy MCDM Method

Linguistic Variables	Fuzzy Number
Very Low	(0, 0, 0.25)
Low	(0, 0.25, 0.5)
Medium	(0.25, 0.5, 0.75)
High	(0.5, 0.75, 1)
Very High	(0.75, 1, 1)

Step 1. Each expert evaluated the alternatives by considering the sub-criteria. Evaluation results are shown in table 5.22. Then, the aggregated evaluation fuzzy number table in Table 5.23 is created by considering the effect of each expert equally.

Table 5.22 Ratings of alternatives for each expert

Sub-Criteria	Expert Panel	A_1	A_2	A_3	A_4	A_5
C_1	E1	M	M	M	VH	H
	E2	M	H	M	VH	L
	E3	H	H	M	M	M
C_2	E1	H	L	VL	M	L
	E2	H	L	VL	M	L
	E3	H	L	VL	M	L
C_3	E1	VH	H	VH	VH	H
	E2	VH	H	VH	VH	H
	E3	VH	H	VH	VH	H
C_4	E1	M	M	H	M	M
	E2	VL	L	L	H	L
	E3	VL	L	H	H	M
C_5	E1	M	M	L	VL	L
	E2	M	M	L	VL	L
	E3	M	M	L	VL	L
C_6	E1	(16,25,56)	(14,36,53)	(21,34,43)	(3,37,50)	(19,48,72)
	E2	(16,25,56)	(14,36,53)	(21,34,43)	(3,37,50)	(19,48,72)
	E3	(16,25,56)	(14,36,53)	(21,34,43)	(3,37,50)	(19,48,72)
C_7	E1	H	H	M	L	M
	E2	VH	H	M	VL	M
	E3	VH	H	L	VL	M
C_8	E1	H	M	M	L	M
	E2	H	M	M	L	M
	E3	H	M	M	L	M
C_9	E1	(0.675,1.067,1.2)	(0.1, 0.25,0.4)	(0.5, 3, 5)	(0.25, 0.45, 0.7)	(0.2, 1.5, 3)

	E2	(0.675,1.067,1.2)	(0.1,0.25,0.4)	(0.5, 3, 5)	(0.25, 0.45, 0.7)	(0.2, 1.5, 3)
	E3	(0.675,1.067,1.2)	(0.1,0.25,0.4)	(0.5, 3, 5)	(0.25, 0.45, 0.7)	(0.2, 1.5, 3)
C_{10}	E1	VH	H	M	VL	M
	E2	VH	H	M	VL	M
	E3	VH	H	VL	L	M
C_{11}	E1	(0.681, 0.728, 0.745)	(0.577,0.6, 0.785)	(0.55,1.32,1.5)	(3.37,3.58, 3.67)	(1.1,1.4, 1.7)
	E2	(0.681, 0.728, 0.745)	(0.577,0.6, 0.785)	(0.55,1.32,1.5)	(3.37,3.58, 3.67)	(1.1,1.4, 1.7)
	E3	(0.681, 0.728, 0.745)	(0.577,0.6, 0.785)	(0.55,1.32, 1.5)	(3.37, 3.58, 3.67)	(1.1,1.4, 1.7)
C_{12}	E1	H	H	M	VH	H
	E2	M	H	H	M	M
	E3	L	L	M	H	VH
C_{13}	E1	(38, 39, 42)	(62,212,362)	(60,62,62)	(22, 25,27)	(37,38,45)
	E2	(38, 39, 42)	(62,212,362)	(60,62,62)	(22, 25,27)	(37,38,45)
	E3	(38, 39, 42)	(62,212,362)	(60,62,62)	(22, 25,27)	(37,38,45)

Table 5.23 Aggregated ratings of alternatives for sub-criteria

Sub-criteria	A_1	A_2	A_3	A_4	A_5
C_1	(0.333,0.583, 0.833)	(0.416, 0.667, 0.917)	(0.25, 0.5, 0.75)	(0.583,0.833, 0.917)	(0.25, 0.5, 0.75)
C_2	(0.5, 0.75, 1)	(0, 0.25, 0.5)	(0, 0, 0.25)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)
C_3	(0.75, 1, 1)	(0.5, 0.75, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0.5, 0.75, 1)
C_4	(0.083,0.167, 0.417)	(0.083, 0.333, 0.583)	(0.333, 0.583, 0.833)	(0.417, 0.667, 0.917)	(0.167, 0.417, 0.667)
C_5	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0, 0, 0.25)	(0, 0.25, 0.5)
C_6	(16,25,56)	(14,36,53)	(21,34,43)	(3,37,50)	(19,48,72)
C_7	(0.667, 0.917, 1)	(0.5, 0.75, 1)	(0.167, 0.417, 0.667)	(0, 0.083, 0.333)	(0.25, 0.5, 0.75)
C_8	(0.5, 0.75, 1)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)
C_9	(0.675, 1.067,1.2)	(0.1, 0.25, 0.4)	(0.5, 3, 5)	(0.25, 0.45, 0.7)	(0.2, 1.5, 3)
C_{10}	(0.5, 0.667,0.75)	(0.5, 0.75, 1)	(0.167, 0.333, 0.583)	(0, 0.083, 0.333)	(0.25, 0.5, 0.75)
C_{11}	(0.681, 0.728, 0.745)	(0.577, 0.6, 0.785)	(0.55,1.32,1.5)	(3.37, 3.58, 3.67)	(1.1, 1.4, 1.7)

***C*₁₂**	(0.25, 0.5, 0.75)	(0.333, 0.583, 0.833)	(0.333, 0.583, 0.833)	(0.5, 0.75, 0.917)	(0.5, 0.667, 0.917)
***C*₁₃**	(38, 39, 42)	(62,212,362)	(60,62,62)	(22, 25,27)	(37,38,45)

In the following steps, calculations of A_1 will be shown and remaining computations will be performed in a similar way.

Step 2. By using equation (4.8), the crisp data is normalized as given below.

Fauna/ flora is a benefit criterion, and $y_{11}^{*} = \max_{i} y_{i11} = 0.917$ and $y_{11}^{-} = \min_{i} y_{i11} = 0.25$

Then, we obtain;

$$\tilde{y}_{111} = \left(y'_{a111}, y'_{b111}, y'_{c111}\right) = \left(\frac{0.333 - 0.25}{0.917 - 0.25}, \frac{0.583 - 0.25}{0.917 - 0.25}, \frac{0.833 - 0.25}{0.917 - 0.25}\right)$$

$$= (0.124, 0.33, 0.874\ )$$

Faults is cost criterion and $y_{12}^{*} = \max_{i} y_{i12} = 1$ and $y_{12}^{-} = \min_{i} y_{i12} = 0$

Then, we obtain;

$$\tilde{y}_{112} = \left(y'_{a112}, y'_{b112}, y'_{c112}\right) = \left(\frac{1 - 1}{1 - 0}, \frac{1 - 0.75}{1 - 0}, \frac{1 - 0.5}{1 - 0}\right) = (0, 0.25, 0.5)$$

Basin area is benefit criterion and $y_{13}^{*} = \max_{i} y_{i13} = 1$ and $y_{13}^{-} = \min_{i} y_{i13} = 0.5$

Then, we obtain,

$$\tilde{y}_{113} = \left(y'_{a113}, y'_{b113}, y'_{c113}\right) = \left(\frac{0.75 - 0.5}{1 - 0.5}, \frac{1 - 0.5}{1 - 0.5}, \frac{1 - 0.5}{1 - 0.5}\right) \quad = (0.5, 1, 1)$$

Infrastructure is cost criterion and $y_{21}^{*} = \max_{i} y_{i21} = 0.917$ and $y_{21}^{-} = \min_{i} y_{i21} = 0.083$

Then, we obtain,

$$\tilde{y}_{121} = (y'_{a121}, y'_{b121}, y'_{c121}) = \left(\frac{0.917-0.417}{0.917-0.083}, \frac{0.917-0.167}{0.917-0.083}, \frac{0.917-0.083}{0.917-0.083}\right)$$

$$= (0.60, 0.899, 1)$$

Slope and elevation are cost criterion $y_{22}^{*} = \max_{i} y_{i22} = 0.75$ and $y_{22}^{-} = \min_{i} y_{i22} = 0$

Then we obtain

$$\tilde{y}_{122} = (y'_{a122}, y'_{b122}, y'_{c122}) = \left(\frac{0.75-0.75}{0.75-0}, \frac{0.75-0.5}{0.75-0}, \frac{0.75-0.25}{0.75-0}\right)$$

$$= (0, 0.333, 0.667)$$

Distance from existing stations is cost criterion and $y_{23}^{*} = \max_{i} y_{i23} = 72$ and $y_{23}^{-} = \min_{i} y_{i23} = 3$

Then we obtain

$$\tilde{y}_{123} = (y'_{a123}, y'_{b123}, y'_{c123}) = \left(\frac{72-56}{72-3}, \frac{72-25}{72-3}, \frac{72-16}{72-3}\right)$$

$$= (0.232, 0.681, 0.812)$$

Land use is cost criterion and $y_{24}^{*} = \max_{i} y_{i24} = 1$ and $y_{24}^{-} = \min_{i} y_{i24} = 0$

Then we obtain,

$$\tilde{y}_{124} = (y'_{a124}, y'_{b124}, y'_{c124}) = \left(\frac{1-1}{1-0}, \frac{1-0.917}{1-0}, \frac{1-0.667}{1-0}\right)$$

$$= (0, 0.083, 0.333)$$

Land value is cost criterion and $y_{25}^{*} = \max_{i} y_{i25} = 1$ and $y_{25}^{-} = \min_{i} y_{i25} = 0$

Then we obtain,

$$\tilde{y}_{125} = \left(y'_{a125}, y'_{b125}, y'_{c125}\right) = \left(\frac{1-1}{1-0}, \frac{1-0.75}{1-0}, \frac{1-0.5}{1-0}\right)$$

$$= (0, 0.25, 0.5)$$

Roads are cost criterion and $y_{26}^{*} = \max_{i} y_{i26} = 5$ and $y_{26}^{-} = \min_{i} y_{i26} = 0.1$

Then we obtain,

$$\tilde{y}_{126} = \left(y'_{a126}, y'_{b126}, y'_{c126}\right) = \left(\frac{5-1.2}{5-0.1}, \frac{5-1.067}{5-0.1}, \frac{5-0.675}{5-0.1}\right)$$

$$= (0.776, 0.803, 0.883)$$

Waste quantity is benefit criterion and $y_{27}^{*} = \max_{i} y_{i27} = 1$ and $y_{27}^{-} = \min_{i} y_{i27} = 0$

Then we obtain,

$$\tilde{y}_{127} = \left(y'_{a127}, y'_{b127}, y'_{c127}\right) = \left(\frac{0.5-0}{1-0}, \frac{0.667-0}{1-0}, \frac{0.75-0}{1-0}\right)$$

$$= (0.5, 0.667, 0.75)$$

Public concern is benefit criterion and $y_{31}^{*} = \max_{i} y_{i31} = 3.67$ and $y_{31}^{-} = \min_{i} y_{i31} = 0.55$

Then we obtain,

$$\tilde{y}_{131} = \left(y'_{a131}, y'_{b131}, y'_{c131}\right) = \left(\frac{0.681-0.55}{3.67-0.55}, \frac{0.728-0.55}{3.67-0.55}, \frac{0.745-0.55}{3.67-0.55}\right)$$

$$= (0.042, 0.057, 0.063)$$

Distance from sensitive sites is benefit criterion $y_{32}^{*} = \max_{i} y_{i32} = 0.917$ and $y_{32}^{-} = \min_{i} y_{i32} = 0.25$

Then we obtain,

$$\tilde{y}_{132} = (y'_{a32}, y'_{b132}, y'_{c132}) = \left(\frac{0.25-0.25}{0.917-0.25}, \frac{0.5-0.25}{0.917-0.25}, \frac{0.75-0.25}{0.917-0.25}\right)$$

$$= (0, 0.375, 0.75)$$

Population is cost criterion and $y^*_{33} = \underset{i}{max} y_{i33} = 362$ and $y^-_{33} = \underset{i}{min} y_{i33} = 22$

Then we obtain,

$$\tilde{y}_{133} = (y'_{a133}, y'_{b133}, y'_{c133}) = \left(\frac{362-42}{362-22}, \frac{362-39}{362-22}, \frac{362-38}{362-22}\right)$$

$$= (0.941, 0.95, 0.953)$$

Table 5.24 presents normalized data related to sub criteria.

Table 5.24 Normalized data related to sub-criteria

Sub-criteria	***A*1**	***A*2**	***A*3**
***C*1**	(0.124, 0.33, 0.874)	(0.249,0.625,1)	(0, 0.375, 0.75)
***C*2**	(0, 0.25, 0.5)	(0.5, 0.75, 1)	(0.75,1,1)
***C*3**	(0.5, 1,1)	(0, 0.5, 1)	(0.5, 1,1)
***C*4**	(0.6, 0.899, 1)	(0.4, 0.7, 1)	(0.1, 0.4, 0.7)
***C*5**	(0, 0.333, 0.667)	(0, 0.333, 0.667)	(0.333, 0.667, 0.75)
***C*6**	(0.232,0.681,0.812)	(0.275,0.522,0.841)	(0.42,0.551,0.739)
***C*7**	(0, 0.083, 0.333)	(0, 0.25, 0.5)	(0.333,0.583, 0.833)
***C*8**	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)
***C*9**	(0.776,0.803,0.883)	(0.939,0.969, 1)	(0, 0.408, 0.918)
***C*10**	(0.5, 0.667,0.75)	(0.5, 0.75, 1)	(0.167, 0.333, 0.583)
***C*11**	(0.042,0.057,0.063)	(0.009,0.016,0.075)	(0,0.247,0.307)
***C*12**	(0, 0.375, 0.75)	(0.124, 0.499, 0.874)	(0.124, 0.499, 0.874)
***C*13**	(0.941,0.95,0.953)	(0, 0.441,0.882)	(0.882,0.882,0.883)

Table 5.24 Normalized data related to sub-criteria (cont.)

Sub-criteria	***A*4**	***A*5**

***C*1**	(0.49,0.874,1)	(0, 0.375,0.75)
***C*2**	(0.25,0.5,0.75)	(0.5,0.75,1)
***C*3**	(0.5, 1,1)	(0, 0.5, 1)
***C*4**	(0, 0.3, 0.6)	(0.3, 0.6, 0.9)
***C*5**	(0.677, 0.75,0.75)	(0.333, 0.667, 0.75)
***C*6**	(0.319,0.507,1)	(0,0.348, 0.768)
***C*7**	(0.667, 0.917, 1)	(0.25,0.5,0.75)
***C*8**	(0.5, 0.75, 1)	(0.25, 0.5, 0.75)
***C*9**	(0.878,0.929,0.969)	(0.408,0.714, 0.98)
***C*10**	(0, 0.083, 0.333)	(0.25, 0.5, 0.75)
***C*11**	(0.904,0.971,1)	(0.176, 0.272,0.369)
***C*12**	(0.375,0.75,1)	(0.375,0.625,1)
***C*13**	(0.985,0.991, 1)	(0.932,0.953,0.956)

Step 3. Using equation (4.9), sub-criteria values are aggregated to factor level as given below.

$$\tilde{x}_{11} = (x_{a11}, x_{b11}, x_{c11}) =$$

$$\frac{\big((0.167, 0.214, 0.245) \otimes (0.124, 0.33, 0.874)\big) \oplus \big((0.153, 0.177, 0.198) \otimes (0, 0.25, 0.5)\big) \oplus ((0.581, 0.618, 0.618) \otimes (0.5, 1,1))}{(0.167, 0.214, 0.245) \oplus (0.153, 0.177, 0.198) \oplus (0.581, 0.618, 0.618)}$$

$$= (0.346, 0.726, 0.877),$$

$$\tilde{x}_{12} = (x_{a12}, x_{b12}, x_{c12}) =$$

$$\frac{\big((0.097, 0.114, 0.126) \otimes (0.6, 0.899, 1)\big) \oplus \big((0.073, 0.086, 0.064) \otimes (0, 0.333, 0.667)\big) \oplus ((0.113, 0.135, 0.149) \otimes (0.232, 0.681, 0.812))}{\big((0.097, 0.114, 0.126)\big) \oplus (0.073, 0.086, 0.064) \oplus (0.113, 0.135, 0.149) \oplus (0.142, 0.178, 0.195) \oplus (0.168, 0.197, 0.214) \oplus (0.116, 0.149, 0.168) \oplus (0.123, 0.154, 0.168)}$$

$$\oplus \frac{\big((0.142, 0.178, 0.195) \otimes (0, 0.083, 0.333)\big) \oplus \big((0.168, 0.197, 0.214) \otimes (0, 0.25, 0.5)\big) \oplus \big((0.116, 0.149, 0.168) \otimes (0.776,0.803,0.883)\big) \oplus ((0.123, 0.154, 0.168) \otimes (0.5, 0.667,0.75))}{\big((0.097, 0.114, 0.126)\big) \oplus (0.073, 0.086, 0.064) \oplus (0.113, 0.135, 0.149) \oplus (0.142, 0.178, 0.195) \oplus (0.168, 0.197, 0.214) \oplus (0.116, 0.149, 0.168) \oplus (0.123, 0.154, 0.168)}$$

$$= (0.284, 0.503, 0.68),$$

$$\tilde{x}_{13} = (x_{a13}, x_{b13}, x_{c13}) = \frac{((0.261, 0.327, 0.346)\otimes((0.042,0.057,0.063))\oplus \big((0.368, 0.453, 0.491)\otimes(0, 0.375, 0.75)\big) \oplus \big((0.204, 0.237, 0.261)\otimes(0.941,0.95,0.953)\big)}{(0.261, 0.327, 0.346)\oplus(0.368, 0.453, 0.491)\oplus (0.204, 0.237, 0.261)}$$

$$=(0.244,0.407,0.582)$$

Table 5.25 presents factor level aggregated values.

Table 5.25 Factor level aggregated values

Factors	A_1	A_2	A_3
Enviromental	(0.346, 0.726,0.877)	(0.132,0.571 ,1)	(0.451, 0.868, 0.943)
Technical/ Economic	(0.284, 0.503, 0.68)	(0.34, 0.576, 0.821)	(0.229,0.429,0.758)
Social	(0.244,0.407,0.582)	(0.058,0.33, 0.624)	(0.27,0.507,0.697)

Table 5.25 Factor level aggregated values (cont.)

Factors	A_4	A_5
Enviromental	(0.456,0.886,0.954)	(0.085, 0.517, 0.943)
Technical/ Economic	(0.439,0.621,0.832)	(0.25, 0.536, 0.873)
Social	(0.689, 0.878,1)	(0.449, 0.588, 0.791)

Step 4. Aggregated values are normalized as given below in table 5.26. 0 indicates the worst value and 1 indicates the best value.

$x_{c1}^{*} = \max_{i} x_{ci1} = 1$ and $x_{a1}^{-} = \min_{i} x_{ai1} = 0.085$, then we find

$$\tilde{r}_{11} = (r_{a11}, r_{b11}, r_{c11}) = \left(\frac{0.346 - 0.085}{1 - 0.085}, \frac{0.726 - 0.085}{1 - 0.085}, \frac{0.877 - 0.085}{1 - 0.085}\right)$$
$$= (0.285, 0.641, 0.866)$$

$x_{c2}^{*} = \max_{i} x_{ci2} = 0.873$ and $x_{a2}^{-} = \min_{i} x_{ai2} = 0.229$, then we find

$$\tilde{r}_{12} = (r_{a12}, r_{b12}, r_{c12}) = \left(\frac{0.284 - 0.229}{0.873 - 0.229}, \frac{0.503 - 0.229}{0.873 - 0.229}, \frac{0.68 - 0.229}{0.873 - 0.229}\right)$$
$$= (0.085, 0.425, 0.7)$$

$x_{c3}^{*} = \max_{i} x_{ci3} = 1$ and $x_{a3}^{-} = \min_{i} x_{ai3} = 0.058$, then we find

$$\tilde{r}_{13} = (r_{a13}, r_{b13}, r_{c13}) = \left(\frac{0.244 - 0.058}{1 - 0.058}, \frac{0.407 - 0.058}{1 - 0.058}, \frac{0.582 - 0.058}{1 - 0.058}\right)$$
$$= (0.197, 0.370, 0.556)$$

Table 5.26 presents normalized values of aggregate performance ratings.

Table 5.9 Normalized values of aggregate performance ratings

Factors	A_1	A_2	A_3
Enviromental	(0.285,0.641,0.866)	(0.051,0.531,1)	(0.4,0.856,0.938)
Technical/ Economic	(0.085,0.425,0.7)	(0.172,0.539,0.919)	(0,0.311,0.821)
Social	(0.197,0.370,0.556)	(0,0.289,0.6)	(0.225,0.477,0.678)

Table 5.26 Normalized values of aggregate performance ratings (cont.)

Factors	A_4	A_5
Enviromental	(0.405,0.875,0.95)	(0,0.472,0.938)

Technical/ Economic	(0.326,0.609,0.936)	(0.032,0.477,1)
Social	(0.67,0.870,1)	(0.415,0.563,0.778)

Step 5. We define the ideal and the anti-ideal solutions as

$$A^* = \big((1,1,1),(1,1,1),(1,1,1)\big),$$

$$A^- = \big((0,0,0),(0,0,0),(0,0,0)\big),$$

Step 6. We calculate the weighted distances from ideal and anti-ideal solutions as follows:

$$D_1^* = 1/2\,\{max(\,0.39 * |0.285-1|, 0.471 * |0.866-1|) + 0.429 * |0.641-1|\}$$
$$+\,1/2\,\{max(\,0.355 * |0.085-1|, 0.478 * |0.7-1|) + 0.393 * |0.425-1|\}$$
$$+\,1/2\,\{max(\,0.152 * |0.197-1|, 0.189 * |0.556-1|) + 0.17 * |0.37-1|\}$$

=0.61

$$D_2^* = 1/2\,\{max(\,0.39 * |0.051-1|, 0.471 * |1-1|) + 0.429 * |0.531-1|\}$$
$$+\,1/2\,\{max(\,0.355 * |0.172-1|, 0.478 * |0.919-1|) + 0.393 * |0.539-1|\}$$
$$+\,1/2\,\{max(\,0.152 * |0-1|, 0.189 * |0.6-1|) + 0.17 * |0.289-1|\}$$

=0.6595

$$D_3^* = 1/2\,\{max(\,0.39 * |0.4-1|, 0.471 * |0.938-1|) + 0.429 * |0.856-1|\}$$
$$+\,1/2\,\{max(\,0.355 * |0-1|, 0.478 * |0.821-1|) + 0.393 * |0.311-1|\}$$
$$+\,1/2\,\{max(\,0.152 * |0.225-1|, 0.189 * |0.678-1|) + 0.17 * |0.477-1|\}$$

=0.564

$$D_4^* = 1/2\,\{max(\,0.39 * |0.405-1|, 0.471 * |0.95-1|) + 0.429 * |0.875-1|\}$$
$$+\,1/2\,\{max(\,0.355 * |0.326-1|, 0.478 * |0.936-1|) + 0.393 * |0.609-1|\}$$
$$+\,1/2\,\{max(\,0.152 * |0.67-1|, 0.189 * |1-1|) + 0.17 * |0.87-1|\}$$

=0.376

$D_5^* = 1/2\,\{max(\,0.39 * |0-1|, 0.471 * |0.938-1|) + 0.429 * |0.472-1|\}$

$+ 1/2\,\{max(\,0.355 * |0.032-1|, 0.478 * |1-1|) + 0.393 * |0.477-1|\}$

$+ 1/2\,\{max(\,0.152 * |0.415-1|, 0.189 * |0.778-1|) + 0.17 * |0.563-1|\}$

=0.664

$D_1^- = 1/2\,\{max(\,0.39 * |0.285-0|, 0.471 * |0.866-0|) + 0.429 * |0.641-0|\}$

$+ 1/2\,\{max(\,0.355 * |0.085-0|, 0.478 * |0.7-0|) + 0.393 * |0.425-0|\}$

$+ 1/2\,\{max(\,0.152 * |0.197-0|, 0.189 * |0.556-0|) + 0.17 * |0.37-0|\}$

=0.675

$D_2^- = 1/2\,\{max(\,0.39 * |0.051-0|, 0.471 * |1-0|) + 0.429 * |0.531-0|\}$

$+ 1/2\,\{max(\,0.355 * |0.172-0|, 0.478 * |0.919-0|) + 0.393 * |0.539-0|\}$

$+ 1/2\,\{max(\,0.152 * |0-0|, 0.189 * |0.6-0|) + 0.17 * |0.289-0|\}$

=0.756

$D_3^- = 1/2\,\{max(\,0.39 * |0.4-0|, 0.471 * |0.938-0|) + 0.429 * |0.856-0|\}$

$+ 1/2\,\{max(\,0.355 * |0-0|, 0.478 * |0.821-0|) + 0.393 * |0.311-0|\}$

$+ 1/2\,\{max(\,0.152 * |0.225-0|, 0.189 * |0.678-0|) + 0.17 * |0.477-0|\}$

=0.766

$D_4^- = 1/2\,\{max(\,0.39 * |0.405-0|, 0.471 * |0.95-0|) + 0.429 * |0.875-0|\}$

$+ 1/2\,\{max(\,0.355 * |0.326-0|, 0.478 * |0.936-0|) + 0.393 * |0.609-0|\}$

$+ 1/2\,\{max(\,0.152 * |0.67-0|, 0.189 * |1-0|) + 0.17 * |0.87-0|\}$

=0.92

$D_5^- = 1/2\,\{max(\,0.39 * |0-0|, 0.471 * |0.938-0|) + 0.429 * |0.472-0|\}$

$+ 1/2\,\{max(\,0.355 * |0.032-0|, 0.478 * |1-0|) + 0.393 * |0.477-0|\}$

$+ 1/2\,\{max(\,0.152 * |0.415-0|, 0.189 * |0.778-0|) + 0.17 * |0.563-0|\}$

=0.776

Step 7. We calculate the proximity of the alternatives to the ideal solution as follows:

$P_1^* = 0.675/(0.61 + 0.675)$ =0.525

$P_2^* = 0.756/(0.6595 + 0.756)$ =0.534

$P_3^* = 0.766/(0.564 + 0.766)$ =0.576

$P_4^* = 0.92/(0.376 + 0.92)$ =0.709

$P_5^* = 0.776/(0.664 + 0.776)$ =0.539

After applying Fuzzy Best Worst and Hierarchical Fuzzy MCDM Method were obtained rank among the alternatives. Table 5.27 shows that fourth alternative is most suitable place to be MBT facility. On the other hand, first alternative is least suitable place to built MBT facility.

Table 5.27 Ranking of the alternatives

A_i	P_i^*	Ranking
A_1	0.525	5
A_2	0.534	4
A_3	0.576	2
A_4	0.709	1
A_5	0.539	3

6. CONCLUSION

Site selection is one of the most important issue of all modern engineering projects and structures in many countries (Yıldırım and Güler, 2016). Last decades, numerous studies were applied for site selection process in waste management. In the first stage of this thesis, the methods applied in the literature were examined. According to literature review, GIS and AHP integrated method is used mostly for decision locating of facility in waste management. Integrated MCDM- GIS method can generate an efficient approach which can manage time, costs, visualization and errors of the decision -making process in site selection (Eghtesadifard et al, 2020).

In the second stage of this thesis, the criteria used in different kind of facility types in waste management location selection problems have been examined. The most study belong to the landfill site selection problem. There is no study about MBT facility location problem as a result of search using keywords like waste management and multi-criteria decision on electronic database. In this study, criteria were determined for the MBT facility location selection problem, considering the literature and expert opinions.

Next, location alternatives were determined using the web-based geographic information system and expert opinions. Finally, fuzzy MCDM methods are used to select the appropriate alternative.

Fuzzy set theory is known as an effective way to evaluate processes that cannot be determined with net values or random values. For this reason, it seems appropriate to apply fuzzy set theory in waste facility location selection problems.

In this thesis, fuzzy best worst method proposed by Guo and Zhao (2017) and the hierarchical fuzzy MCDM algorithm proposed by Karsak and Ahiska (2005) have been integrated for MBT location selection problem in Asian side of İstanbul. While fuzzy BWM was used to determine the criteria weights, hierarchical fuzzy MCDM algorithm was used for the appropriate alternative ranking.

After the evaluation, the ranking obtained according to the integrated model that comprised BWM and the hierarchical fuzzy MCDM algorithm is $A_4 \succ A_3 \succ A_5 \succ A_2 \succ A_1$. Using the proposed method, we obtained the fourth alternative as the best alternative for MBT facility. The reason why this alternative is the best alternative is that it is not in the basin area, it is close to the existing facilities, the land value and land use are suitable. This alternative remarks because it fulfills important criteria.

The contributions of this research are as follows. This thesis creates a roadmap for the MBT facility needed in the Anatolian Side of Istanbul, and according to the literature search results, there is no other study conducted on the location of MBT facility. The proposed method handles vagueness and uncertainty employing fuzzy set theory. Furthermore, fuzzy BWM, which does not need to conduct pairwise comparison among all criteria, is employed to determine the criteria weights. BWM reduces the computational effort and provides more effective analysis. Moreover, the developed distance based hierarchical fuzzy model identifies the most favorable alternative via both maximizing the distance to the anti-ideal solution and minimizing the distance to the ideal solution. Finally, GIS that presents spatial data on web environment is utilized. Web-based GIS offers ease of use and provides the opportunity to evaluate over ready data.

This study is expected to be pioneer about this field. The use of geographic information system with open data also makes this study special. In future studies, applications should be made by integrating different methods as in this study in waste management. Besides, the extensions of the fuzzy set theory can be employed in order to handle hesitancy occurred in the decision problem.

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APPENDICES

Appendix A.

BWM model for optimal fuzzy weights of environmental criteria

The nonlinearly constrained optimization problem was constructed by each expert as follows. Lingo software codes are presented.

For expert 1:

min $\xi*$

s.t.

$l3 - 3.5*u1 \le \xi*u1;\ l3 - 3.5*u1 \ge -\xi*u1;$
$m3 - 4*m1 \le \xi*m1;\ m3 - 4*m1 \ge -\xi*m1;$
$u3 - 4.5*l1 \le \xi*l1;\ u3 - 4.5*l1 \ge -\xi*l1;$
$l3 - 1.5*u2 \le \xi*u2;\ l3 - 1.5*u2 \ge -\xi*u2;$
$m3 - 2*m2 \le \xi*m2;\ m3 - 2*m2 \ge -\xi*m2;$
$u3 - 2.5*l2 \le \xi*l2;\ u3 - 2.5*l2 \ge -\xi*l2;$
$l2 - 2/3*u1 \le \xi*u1;\ l2 - 2/3*u1 \ge -\xi*u1;$
$m2 - 1*m1 \le \xi*m1;\ m2 - 1*m1 \ge -\xi*m1;$
$u2 - 1.5*l1 \le \xi*l1;\ u2 - 1.5*l1 \ge -\xi*l1;$
$(l1 + 4*m1 + u1) + (l2 + 4*m2 + u2) + (l3 + 4*m3 + u3) = 6;$
$l1 \le m1;\ m1 \le u1;\ l2 \le m2;\ m2 \le u2;\ l3 \le m3;\ m3 \le u3;$
$l1 > 0;\ l2 > 0;\ l3 > 0;\ \xi \ge 0;$

For Expert 2 and Expert 3

Min $\xi*$

s.t.

$l3 - 2.5*u1 \le \xi*u1;\ l3 - 2.5*u1 \ge -\xi*u1;$
$m3 - 3*m1 \le \xi*m1;\ m3 - 3*m1 \ge -\xi*m1;$
$u3 - 3.5*l1 \le \xi*l1;\ u3 - 3.5*l1 \ge -\xi*l1;$
$l3 - 3.5*u2 \le \xi*u2;\ l3 - 3.5*u2 \ge -\xi*u2;$
$m3 - 4*m2 \le \xi*m2;\ m3 - 4*m2 \ge -\xi*m2;$
$u3 - 4.5*l2 \le \xi*l2;\ u3 - 4.5*l2 \ge -\xi*l2;$
$l1 - 1.5*u2 \le \xi*u2;\ l1 - 1.5*u2 \ge -\xi*u2;$
$m1 - 2*m2 \le \xi*m2;\ m1 - 2*m2 \ge -\xi*m2;$

$u1 - 2.5 * l2 \ \leq \ \xi * l2;\ u1 - 2.5 * l2 \ \geq \ -\xi * l2;$
$(l1 + 4 * m1 + u1)\ +\ (l2 + 4 * m2 + u2)\ + (l3 + 4 * m3 + u3)\ =\ 6;$
$l1 \leq\ m1;\ m1 \leq u1;\ l2 \leq\ m2;\ m2 \leq u2;\ l3 \leq\ m3;\ m3 \leq u3;$
$l1 > 0;\ l2 > 0;\ l3 > 0;\ \xi\ \geq\ 0;$

BWM model for optimal fuzzy weights of technical/economic factors

For expert 1:

minξ*

s.t.

$l8 - 2.5 * u4\ \leq\ \xi * u4;\ l8 - 2.5 * u4\ \geq -\xi * u4;$
$m8 - 3 * m4\ \leq\ \xi * m4;\ m8 - 3 * m4\ \geq -\xi * m4;$
$u8 - 3.5 * l4\ \leq\ \xi * l4;\ u8 - 3.5 * l4\ \geq\ -\xi * l4;$
$l8 - 2.5 * u5\ \leq\ \xi * u5;\ l8 - 2.5 * u5\ \geq -\xi * u5;$
$m8 - 3 * m5\ \leq\ \xi * m5;\ m8 - 3 * m5\ \geq -\xi * m5;$
$u8 - 3.5 * l5\ \leq\ \xi * l5;\ u8 - 3.5 * l5\ \geq\ -\xi * l5;$
$l8 - 1.5 * u6\ \leq\ \xi * u6;\ l8 - 1.5 * u6\ \geq -\xi * u6;$
$m8 - 2 * m6\ \leq\ \xi * m6;\ m8 - 2 * m6\ \geq -\xi * m6;$
$u8 - 2.5 * l6\ \leq\ \xi * l6;\ u8 - 2.5 * l6\ \geq\ -\xi * l6;$
$l8 - 1.5 * u7\ \leq\ \xi * u7;\ l8 - 1.5 * u7\ \geq -\xi * u7;$
$m8 - 2 * m7\ \leq\ \xi * m7;\ m8 - 2 * m7\ \geq -\xi * m7;$
$u8 - 2.5 * l7\ \leq\ \xi * l7;\ u8 - 2.5 * l7\ \geq\ -\xi * l7\ ;$
$l8 - 1.5 * u9\ \leq\ \xi * u9\ ;\ l8 - 1.5 * u9\ \geq -\xi * u9;$
$m8 - 2 * m9\ \leq\ \xi * m9;\ m8 - 2 * m9\ \geq -\xi * m9;$
$u8 - 2.5 * l9\ \leq\ \xi * l9;\ u8 - 2.5 * l9\ \geq\ -\xi * l9;$
$l8 - 1.5 * u10\ \leq\ \xi * u10;\ l8 - 1.5 * u10\ \geq -\xi * u10;$
$m8 - 2 * m10\ \leq\ \xi * m10;\ m8 - 2 * m10\ \geq -\xi * m10;$
$u8 - 2.5 * l10\ \leq\ \xi * l10;\ u8 - 2.5 * l10 \geq\ -\xi * l10;$
$l4 - 1.5 * u5\ \leq\ \xi * u5;\ l4 - 1.5 * u5\ \geq -\xi * u5;$
$m4 - 2 * m5\ \leq\ \xi * m5;\ m4 - 2 * m5\ \geq -\xi * m5;$
$u4 - 2.5 * l5\ \leq\ \xi * l5;\ u4 - 2.5 * l5\ \geq\ -\xi * l5;$
$l6 - 1.5 * u5\ \leq\ \xi * u5;\ l6 - 1.5 * u5\ \geq -\xi * u5;$
$m6 - 2 * m5\ \leq\ \xi * m5;\ m6 - 2 * m5\ \geq -\xi * m5;$
$u6 - 2.5 * l5\ \leq\ \xi * l5;\ u6 - 2.5 * l5\ \geq\ -\xi * l5\ ;$
$l7 - 1.5 * u5\ \leq\ \xi * u5;\ l7 - 1.5 * u5\ \geq -\xi * u5;$
$m7 - 2 * m5\ \leq\ \xi * m5;\ m7 - 2 * m5\ \geq -\xi * m5;$
$u7 - 2.5 * l5\ \leq\ \xi * l5;\ u7 - 2.5 * l5\ \geq\ -\xi * l5;$
$l9 - 1.5 * u5\ \leq\ \xi * u5;\ l9 - 1.5 * u5\ \geq -\xi * u5;$
$m9 - 2 * m5\ \leq\ \xi * m5;\ m9 - 2 * m5\ \geq -\xi * m5;$
$u9 - 2.5 * l5\ \leq\ \xi * l5;\ u9 - 2.5 * l5\ \geq\ -\xi * l5;$
$l10 - 1.5 * u5\ \leq\ \xi * u5\ ;\ l10 - 1.5 * u5\ \geq -\xi * u5;$
$m10 - 2 * m5\ \leq\ \xi * m5;\ m10 - 2 * m5\ \geq -\xi * m5;$
$u10 - 2.5 * l5\ \leq\ \xi * l5;\ u10 - 2.5 * l5\ \geq\ -\xi * l5;$
$(l4 + 4 * m4 + u4) + (l5 + 4 * m5 + u5) + (l6 + 4 * m6 + u6) +$
$(l7 + 4 * m7 + u7) + (l8 + 4 * m8 + u8) +\ (l9 + 4 * m9 + u9) +$

$(l10 + 4 * m10 + u10)\ =\ 6;$
$l4 \leq\ m4;\ m4 \leq u4;\ l5 \leq\ m5;\ m5 \leq u5;\ l6 \leq\ m6;\ m6 \leq u6;$
$l7 \leq\ m7;\ m7 \leq u7;\ l8 \leq\ m8;\ m8 \leq u8;\ l9 \leq\ m9;\ m9 \leq u9;$
$l10 \leq\ m10;\ m10 \leq u10;\ l4 > 0;\ l5 > 0;\ l6 > 0;\ l7 > 0;$
$l8 > 0;\ l9 > 0;\ l10 > 0;\ \xi\ \geq\ 0;$

For expert 2:

Min ξ*

s.t.

$l7 - 1.5 * u4\ \leq\ \xi * u4;\ l7 - 1.5 * u4\ \geq -\xi * u4;$
$m7 - 2 * m4\ \leq\ \xi * m4;\ m7 - 2 * m4\ \geq -\xi * m4;$
$u7 - 2.5 * l4\ \leq\ \xi * l4;\ u7 - 2.5 * l4\ \geq\ -\xi * l4;$
$l7 - 1.5 * u5\ \leq\ \xi * u5;\ l7 - 1.5 * u5\ \geq -\xi * u5;$
$m7 - 2 * m5\ \leq\ \xi * m5;\ m7 - 2 * m5\ \geq -\xi * m5;$
$u7 - 2.5 * l5\ \leq\ \xi * l5;\ u7 - 2.5 * l5\ \geq\ -\xi * l5;$
$l7 - 2/3 * u6\ \leq\ \xi * u6;\ l7 - 2/3 * u6\ \geq -\xi * u6;$
$m7 - 1 * m6\ \leq\ \xi * m6;\ m7 - 1 * m6\ \geq -\xi * m6;$
$u7 - 1.5 * l6\ \leq\ \xi * l6;\ u7 - 1.5 * l6\ \geq\ -\xi * l6\ ;$
$l7 - 1.5 * u8\ \leq\ \xi * u8\ ;\ l7 - 1.5 * u8\ \geq -\xi * u8;$
$m7 - 2 * m8\ \leq\ \xi * m8;\ m7 - 2 * m8\ \geq -\xi * m8;$
$u7 - 2.5 * l8\ \leq\ \xi * l8;\ u7 - 2.5 * l8\ \geq\ -\xi * l8;$
$l7 - 1.5 * u9\ \leq\ \xi * u9\ ;\ l7 - 1.5 * u9\ \geq -\xi * u9;$
$m7 - 2 * m9\ \leq\ \xi * m9;\ m7 - 2 * m9\ \geq -\xi * m9;$
$u7 - 2.5 * l9\ \leq\ \xi * l9;\ u7 - 2.5 * l9\ \geq\ -\xi * l9;$
$l7 - 2/3 * u10\ \leq\ \xi * u10;\ l7 - 2/3 * u10\ \geq -\xi * u10;$
$m7 - 1 * m10\ \leq\ \xi * m10;\ m7 - 1 * m10\ \geq -\xi * m10;$
$u7 - 1.5 * l10\ \leq\ \xi * l10;\ u7 - 1.5 * l10 \geq\ -\xi * l10;$
$l4 - 2/3 * u5\ \leq\ \xi * u5;\ l4 - 2/3 * u5\ \geq -\xi * u5;$
$m4 - 1 * m5\ \leq\ \xi * m5;\ m4 - 1 * m5\ \geq -\xi * m5;$
$u4 - 1.5 * l5\ \leq\ \xi * l5;\ u4 - 1.5 * l5\ \geq\ -\xi * l5;$
$l6 - 2/3 * u5\ \leq\ \xi * u5;\ l6 - 2/3 * u5\ \geq -\xi * u5;$
$m6 - 1 * m5\ \leq\ \xi * m5;\ m6 - 1 * m5\ \geq -\xi * m5;$
$u6 - 1.5 * l5\ \leq\ \xi * l5;\ u6 - 1.5 * l5\ \geq\ -\xi * l5;$
$l8 - 1.5 * u5\ \leq\ \xi * u5\ ;\ l8 - 1.5 * u5\ \geq -\xi * u5;$
$m8 - 2 * m5\ \leq\ \xi * m5;\ m8 - 2 * m5\ \geq -\xi * m5;$
$u8 - 2.5 * l5\ \leq\ \xi * l5;\ u8 - 2.5 * l5\ \geq\ -\xi * l5;$
$l9 - 1.5 * u5\ \leq\ \xi * u5\ ;\ l9 - 1.5 * u5\ \geq -\xi * u5;$
$m9 - 2 * m5\ \leq\ \xi * m5;\ m9 - 2 * m5\ \geq -\xi * m5;$
$u9 - 2.5 * l5\ \leq\ \xi * l5;\ u9 - 2.5 * l5\ \geq\ -\xi * l5;$
$l10 - 1.5 * u5\ \leq\ \xi * u5\ ;\ l10 - 1.5 * u5\ \geq -\xi * u5;$
$m10 - 2 * m5\ \leq\ \xi * m5;\ m10 - 2 * m5\ \geq -\xi * m5;$
$u10 - 2.5 * l5\ \leq\ \xi * l5;\ u10 - 2.5 * l5\ \geq\ -\xi * l5;$
$(l4 + 4 * m4 + u4) + (l5 + 4 * m5 + u5) + (l6 + 4 * m6 + u6) +$
$(l7 + 4 * m7 + u7) + (l8 + 4 * m8 + u8) +\ (l9 + 4 * m9 + u9) +$
$(l10 + 4 * m10 + u10)\ \ =\ 6;$

$l4 \leq m4;\ m4 \leq u4;\ l5 \leq m5;\ m5 \leq u5;\ l6 \leq m6;\ m6 \leq u6; l7 \leq m7;\ m7 \leq u7;$
$l8 \leq m8;\ m8 \leq u8;\ l9 \leq m9;\ m9 \leq u9;\ l10 \leq m10;\ m10 \leq u10;$
$l4 > 0;\ l5 > 0;\ l6 > 0;\ l7 > 0;\ l8 > 0;\ l9 > 0;\ l10 > 0;\ \xi \geq 0;$

For expert 3

Min ξ*

s.t.

$l8 - 2/3 * u4 \leq \xi * u4;\ l8 - 2/3 * u4 \geq -\xi * u4;$
$m8 - 1 * m4 \leq k * m4;\ m8 - 1 * m4 \geq -k * m4;$
$u8 - 1.5 * l4 \leq k * l4;\ u8 - 1.5 * l4 \geq -k * l4;$
$l8 - 1.5 * u5 \leq k * u5;\ l8 - 1.5 * u5 \geq -k * u5;$
$m8 - 2 * m5 \leq k * m5;\ m8 - 2 * m5 \geq -k * m5;$
$u8 - 2.5 * l5 \leq k * l5;\ u8 - 2.5 * l5 \geq -k * l5;$
$l8 - 1.5 * u6 \leq k * u6;\ l8 - 1.5 * u6 \geq -k * u6;$
$m8 - 2 * m6 \leq k * m6;\ m8 - 2 * m6 \geq -k * m6;$
$u8 - 2.5 * l6 \leq \xi * l6;\ u8 - 2.5 * l6 \geq -\xi * l6;$
$l8 - 2/3 * u7 \leq \xi * u7;\ l8 - 2/3 * u7 \geq -\xi * u7;$
$m8 - 1 * m7 \leq \xi * m7;\ m8 - 1 * m7 \geq -\xi * m7;$
$u8 - 1.5 * l7 \leq \xi * l7;\ u8 - 1.5 * l7 \geq -\xi * l7;$
$l8 - 1.5 * u9 \leq \xi * u9;\ l8 - 1.5 * u9 \geq -\xi * u9;$
$m8 - 2 * m9 \leq \xi * m9;\ m8 - 2 * m9 \geq -\xi * m9;$
$u8 - 2.5 * l9 \leq \xi * l9;\ u8 - 2.5 * l9 \geq -\xi * l9;$
$l8 - 1.5 * u10 \leq \xi * u10;\ l8 - 1.5 * u10 \geq -\xi * u10;$
$m8 - 2 * m10 \leq \xi * m10;\ m8 - 2 * m10 \geq -\xi * m10;$
$u8 - 2.5 * l10 \leq \xi * l10;\ u8 - 2.5 * l10 \geq -\xi * l10;$
$l4 - 2/3 * u5 \leq \xi * u5;\ l4 - 2/3 * u5 \geq -\xi * u5;$
$m4 - 1 * m5 \leq \xi * m5;\ m4 - 1 * m5 \geq -\xi * m5;$
$u4 - 1.5 * l5 \leq \xi * l5;\ u4 - 1.5 * l5 \geq -\xi * l5;$
$l6 - 2/3 * u5 \leq \xi * u5;\ l6 - 2/3 * u5 \geq -\xi * u5;$
$m6 - 1 * m5 \leq \xi * m5;\ m6 - 1 * m5 \geq -\xi * m5;$
$u6 - 1.5 * l5 \leq \xi * l5;\ u6 - 1.5 * l5 \geq -\xi * l5;$
$l7 - 1.5 * u5 \leq \xi * u5;\ l7 - 1.5 * u5 \geq -\xi * u5;$
$m7 - 2 * m5 \leq \xi * m5;\ m7 - 2 * m5 \geq -\xi * m5;$
$u7 - 2.5 * l5 \leq \xi * l5;\ u7 - 2.5 * l5 \geq -\xi * l5;$
$l9 - 1.5 * u5 \leq \xi * u5;\ l9 - 1.5 * u5 \geq -\xi * u5;$
$m9 - 2 * m5 \leq \xi * m5;\ m9 - 2 * m5 \geq -\xi * m5;$
$u9 - 2.5 * l5 \leq \xi * l5;\ u9 - 2.5 * l5 \geq -\xi * l5;$
$l10 - 1.5 * u5 \leq \xi * u5;\ l10 - 1.5 * u5 \geq -\xi * u5;$
$m10 - 2 * m5 \leq \xi * m5;\ m10 - 2 * m5 \geq -\xi * m5;$
$u10 - 2.5 * l5 \leq \xi * l5;\ u10 - 2.5 * l5 \geq -\xi * l5;$
$(l4 + 4 * m4 + u4) + (l5 + 4 * m5 + u5) + (l6 + 4 * m6 + u6) +$
$(l7 + 4 * m7 + u7) + (l8 + 4 * m8 + u8) + (l9 + 4 * m9 + u9) +$
$(l10 + 4 * m10 + u10) = 6;$
$l4 \leq m4;\ m4 \leq u4;\ l5 \leq m5;\ m5 \leq u5;\ l6 \leq m6;\ m6 \leq u6;\ l7 \leq m7;\ m7 \leq u7;$
$l8 \leq m8;\ m8 \leq u8;\ l9 \leq m9;\ m9 \leq u9;\ l10 \leq m10;\ m10 \leq u10;$
$l4 > 0;\ l5 > 0;\ l6 > 0;\ l7 > 0;\ l8 > 0;\ l9 > 0;\ l10 > 0;\ \xi \geq 0;$

BWM model for optimal fuzzy weights of social factors

For Expert 1 and Expert 2

Min ξ*

s.t.

$$
\begin{aligned}
&l12 - 2/3 * u11 \le \xi * u11 ; \ l12 - 2/3 * u11 \ge -\xi * u11; \\
&m12 - 1 * m11 \le \xi * m11; \ m12 - 1 * m11 \ge -\xi * m11; \\
&u12 - 1.5 * l11 \le \xi * l11; \ u12 - 1.5 * l11 \ge -\xi * l11 ; \\
&l12 - 1.5 * u13 \le \xi * u13 ; \ l12 - 1.5 * u13 \ge -\xi * u13; \\
&m12 - 2 * m13 \le \xi * m13; \ m12 - 2 * m13 \ge -\xi * m13; \\
&u12 - 2.5 * l13 \le \xi * l13; u12 - 2.5 * l13 \ge -\xi * l13; \\
&l11 - 2/3 * u13 \le \xi * u13 ; \ l11 - 2/3 * u13 \ge -\xi * u13; \\
&m11 - 1 * m13 \le \xi * m13; m11 - 1 * m13 \ge -\xi * m13; \\
&u11 - 1.5 * l13 \le \xi * l13; \ u11 - 1.5 * l13 \ge -\xi * l13 ; \\
&(l11 + 4 * m11 + u11) + (l12 + 4 * m12 + u12) + (l13 + 4 * m13 + u13) = 6; \\
&l11 \le m11; \ m11 \le u11; l12 \le m12; \ m12 \le u12; l13 \le m13; \ m13 \le u13; \\
&l11 > 0; \ l12 > 0; \ l13 > 0; \ \xi \ge 0;
\end{aligned}
$$

For Expert 3

Min ξ*

s.t.

$$
\begin{aligned}
&l12 - 1.5 * u11 \le \xi * u11 ; \ l12 - 1.5 * u11 \ge -\xi * u11; \\
&m12 - 2 * m11 \le \xi * m11; \ m12 - 2 * m11 \ge -\xi * m11; \\
&u12 - 2.5 * l11 \le \xi * l11; \ u12 - 2.5 * l11 \ge -\xi * l11 ; \\
&l12 - 1.5 * u13 \le \xi * u13 ; \ l12 - 1.5 * u13 \ge -\xi * u13; \\
&m12 - 2 * m13 \le \xi * m13; \ m12 - 2 * m13 \ge -\xi * m13; \\
&u12 - 2.5 * l13 \le \xi * l13; u12 - 2.5 * l13 \ge -\xi * l13; \\
&l11 - 1.5 * u13 \le \xi * u13 ; \ l11 - 1.5 * u13 \ge -\xi * u13; \\
&m11 - 2 * m13 \le \xi * m13; \ m11 - 2 * m13 \ge -\xi * m13; \\
&u11 - 2.5 * l13 \le \xi * l13; \ u11 - 2.5 * l13 \ge -\xi * l13; \\
&(l11 + 4 * m11 + u11) + (l12 + 4 * m12 + u12) + (l13 + 4 * m13 + u13) = 6; \\
&l11 \le m11; \ m11 \le u11; l12 \le m12; \ m12 \le u12; l13 \le m13; \ m13 \le u13; \\
&l11 > 0; \ l12 > 0; \ l13 > 0; \ \xi \ge 0;
\end{aligned}
$$

BIOGRAPHICAL SKETCH