**Investigation a model based on multicriteria decision making-GIS for the site selection of hospital waste disposal: a case study from Tehran, Iran**

**Abstract**

One of the most severe waste management challenges in metropolises is determining the best location for disposing of healthcare waste (HCW), which should take into account environmental, economic, social, geographical, technological, and legal factors. Expert scientific opinions affected this intricate problem. This study used a novel method for selecting HCW landfills in Tehran that relied on the fuzzy stepwise weight assessment ratio analysis method (FSWARA) and the geographic information technology system (GIS), which reduced comparisons in gathering expert opinions, simplified the selection process, and improved evaluation methods. The fuzzy Delphi approach was used to identify 9 criteria in the first place. The weight of each criteria was then calculated as information layers utilizing the FSWARA to produce the final maps for the relevant zones. Following that, the selected locations were ranked using the multi-attributive ideal-real comparative analysis method (MAIRCA), and the fourth point was chosen as the most suitable of the criteria with 34-degree slope, 1008 meters high, 3.4841 meters distance from fault, 8.4428 meters distance from surface water, 12 meters groundwater depth, 457 meters distance from residential areas, 6.4749.6 meters distance from hospitals, and 1598 meters' distance Finally, use the MOORA, TOPSIS, and VIKOR methodologies to compare and validate the findings' dependability. **Keywords:** Disposal site; Waste; Hospital; Location; FSWARA; Geographic information system; ~~GIS;~~ MAIRCA

1. **Introduction**

Blood, body parts, medical gadgets, medications, chemicals, diagnostic samples, dirty dressings, syringes and needles, and radioactive material are among the HCW created by medical operations in metropolitan cities. Improper HCW management puts the urban community and society, as well as city inhabitants, patients, and water supplies, at danger of harmful environmental contamination, which may result in a slew of social and environmental consequences for municipalities [1]. HCW segregation, storage, and transportation are all strictly regulated in many industrialized nations [2]. Many European member states have adopted the policy of ensuring landfill safety for thousands to millions of years [3]. When it comes to efficient healthcare waste management (HCWM), developing nations are found to be resource restricted [4]. Many metropolitan areas in developing nations are experiencing considerable environmental degradation and health hazards as a result of poorly constructed municipal waste management systems [5].Collection, transport, purification, recycling, and disposal are all part of HCWM [6]. For improved HCWM, there is a need for ecologically acceptable, safe disposal solutions [7]. According to Chauhan and Singh [8,] HCW disposal issues have garnered the greatest attention in the results of the presented literature, and optimization might be productively utilized for an effective HCWM system. As a result, one of the most important concerns in waste management is determining the best site for trash disposal facilities. Choosing a site for hospital waste disposal (HWD) is one of the most challenging and time-consuming tasks. It's tough to interpret these characteristics, as well as cost-related ones that need proper resource allocation. Furthermore, it is largely dependent on taking into account government regulations, which are based on the specific circumstances of the case study [6].Disposal locations should be examined in compliance with governmental standards, such as environmental, safety, health, social, economic, geographic, and other restrictions, to minimize negative environmental, health, social, and economic repercussions. As a result, HWD is logically in the hands of local governments and municipalities. As a result, one of the most difficult difficulties to handle in this scenario is the process of picking the most suitable sites [9].A suitable and principled site is regarded as the finest alternative for a city's long-term growth and environmental conservation, as well as one of the most essential HCWM solutions [10]. Indeed, by incorporating ecological, economic, and social aspects within the framework of sustainable urban development principles, the proper placement of waste disposal sites may achieve the eventual aim of HCWM regulations. As a result, substantial research on planning, developing, and siting HWD sites must be conducted, taking into account all relevant elements. Because it can readily handle a vast quantity of geographical and attributional data obtained from multiple sources, GIS is ideal for this sort of research [11]. The absence of multi-criteria decision making (MCDM) and optimum site suggestions is one of the limitations of using GIS for location selection. Combining GIS with MCDM to solve spatial problems is a well-accepted idea in a variety of sectors, including environment, ecology, transportation, urban and regional planning, waste management, hydrology, agriculture, forestry, geology, and site selection [12].In particular, the availability of many effective elements in the area of acceptable waste disposal site placement may assist decision-makers to adopt a system with high accuracy in terms of speed and convenience of use in operations [13]. Due to the participation of numerous factors, localization procedures are difficult, confusing, and tiring, while conventional approaches are incorrect, time-consuming, and expensive [14].As a result, resolving this issue would need a scientific and comprehensive approach to make an informed choice based on scientific principles. On the one hand, such a procedure necessitates issue structuring in a clear frame by including all criteria and aspects involved in decision making, and on the other hand, it necessitates the capability of conscious judgements without being confused. Furthermore, using MCDM approaches is one of the strategies utilized by researchers to overcome such difficulties by allowing for analysis and making the multi-criteria and challenging issue organized and systematic for the aim of offering a suitable strategy to reach logical conclusions [15]. Environmental, sociological, and economic elements are used to make sustainability choices [16]. As a consequence, picking numerous variables generates a plethora of information layers, as well as some efforts to discover an effective solution for doing analysis on any of these levels. As a consequence, attaining proper results unintentionally leads decision makers to adopt a system that is high in terms of speed and simplicity of use in operations. Regarding the standards of Environmental Protection Agency (EPA), municipality of the region, environmental specifications south of Tehran and several previous studies such as Eghtesadifard et al. [17], Sisay et al. [18], Tercan et al. [19], Chabok et al. [20], Danesh et al. [21], Feyzi et al. [22], Mortazavi-Chamchali and Ghazifard. [23], Abdullah et al. [24], Kamdar et al. [25], Ajibade et al. [26], Islam et al. [27], Saatsaz et al. [28], Yousefi et al. [29], Arca et al. [30], Yildirim& et al. [31], and Arabameri et al. [32], some criteria extracted with the most effect on location process are as follows: slope, height, soil type, distance from fault, distance from vegetation, distance from surface water, depth of groundwater, distance from residential areas, distance from hospitals, distance from wildlife species, power transmission lines, and distance from road.

*1.2. Definition of aim/problem and model architecture* ***should be 1.1***

1. The overall goal of this article was to find acceptable trash disposal facilities. Due to the complexity of the site selection issue, the multiple-criteria decision analysis (MCDA) model was recommended as a viable choice for conducting systematic analysis and making reasonable conclusions. While a large number of articles noted that ANP, AHP, and TOPSIS were mostly used in studies involving waste facility location, outranking methods like PROMETHEE and ELECTRE were mostly used to support waste management strategies, according to a systematic critical review of current practices on MCDM to support waste management reported by Coelho et al. [33], Chauhan and Singh. [8], a large number of articles noted that ANP, AHP, and TOPSIS were mostly used The weighting of indicators is recognized as one of the most significant elements in the problem solution process in many interdisciplinary decision-making situations. Kerulien et al. established the SWARA technique in 2010, and it is one of the newest ways. The ability to evaluate the correctness of the experts' judgment on the weight indicators offered throughout the process, the convenience of implementation, and the requirement for comparisons in not huge numbers are the most significant benefits of this technique over other comparable methods. Furthermore, specialists may discuss with one another using this model, resulting in more accurate outcomes than previous MCDM techniques. In addition, when compared to comparable approaches in actual situations, this method is more practical for experts and decision makers since it is easier to use and understand than many weighing methods such as hierarchical analysis (AHP, ANP...)This work also introduced MAIRCA, a revolutionary MCDM approach. This strategy has been shown to be more stable than others like TOPSIS and ELECTRE. One of the reasons for this is that various criteria are normalized differently. Methods that apply a linear model of input data normalization have more stability and rank consistently throughout sensitivity analysis, according to Pamucar, & Cirovi'. [35]. The MAIRCA approach, in particular, employs a linear normalization model. The MAIRCA approach was also chosen because of its basic mathematical equipment, solution stability, and the flexibility to integrate it with other methods. The MCDA model, which is based on the combined use of GIS and multi-criteria procedures such as fuzzy Delphi, FSWARA, and MAIRCA, is the turning point of this study, according to these views. In addition, Tehran, being one of the world's most populated and polluted cities, has a shortage of competent areas for HWD in waste management. As a result, city officials are looking for precise HWD centers to reduce environmental risks. In this study, we suggest appropriate places for the order management of HWD in the city of Tehran using mathematical methodologies.**Materials and methods**

*2.1 Criteria screening*

The fuzzy Delphi Method is a more sophisticated variant of the Delphi Method that uses triangulation statistics to calculate the distance between degrees of agreement within the expert panel [36]. It is a three-round structured and interactive procedure in which a questionnaire is gathered and the replies of participants (experts) are regulated [37].The fuzzy Delphi technique was used in phase 1 to identify and filter the most essential parameters involved in the selection of HWD locations. Such criteria have been identified in the literature or by professionals. The initial questionnaires were created by a group of five experts who chose the criteria from previous studies, as well as interviews with experts from the Water and Wastewater Organization, the Ministry of Roads and Urban Development in Tehran Province, the Department of Geography University of Tehran, and academic scholars. A 5-point scale was used to evaluate the replies. The questionnaires were first sent to 20 specialists in the area of HCWM. The replies, as well as the explanations for the experts' responses, were statistically reviewed and summarized when the findings were received. For each question, the defuzzified mean of expert views was incorporated in these bits of data. Excel software was used to process the replies in this step. Following that, the experts were given a simplified version of the reports so that they may make changes to their replies as they saw appropriate. The difference in the mean of the first and second surveys was used to analyze the outcomes of the second round as well. The mean difference of the second and third surveys was used in a third round of the same procedure. If the difference between the two phases was less than the threshold of 0.2 in the fuzzy Delphi technique, the survey procedure would be ended based on the first-time views and comparing them to the second-time findings. The criteria that had a defuzzified mean of expert views less than 8 were removed from the study's conceptual model. As a result of the third round's results, nine important criteria (slope, height, soil type, distance from fault, distance from surface water, depth of ground waters, distance from residential areas, distance from hospitals, and distance from road) in relation to hospital waste landfill selection were identified.*2.2 SWARA method*

The weights were measured using the fuzzy SWARA approach in this investigation. As a result, the SWARA approach is recognized as one of the weighing systems in which specialists play a major part in the weight computation and final judgment. The views of eight specialists from the investigated organization were employed for this purpose, with the weight of each criteria indicating its relevance. This technique enables experts' opinions on the significance of criteria in a logical decision-making process to be presented. In this case, the following procedure for finding the relative weights of criteria using the SWARA approach according to [34] may be used: Step 1: The criteria are classified in decreasing order (from large to small) and according to their intended relevance (expert views may be utilized to determine and classify the criteria). Step 2: Beginning from the second criterion, the respondent identifies the relative importance of the jth criterion regarding the previous criterion (j -1) for each criterion. According to [34], this ratio is called "comparative importance." From the mean𝒔𝒋. This ratio 𝒔𝒋 is the mean which is called the comparative importance.

Step 5: The relative weights of the jth criterion are identified as follows:

Where, 𝒘𝒋 shows the relative weight of the jth criterion and n represents the number of criteria. Where is the relative fuzzy weight of the jth criterion and n shows the number of the assessed criteria. Figure 1 shows an algorithm for identifying the weight of the criteria.

The calculations for each researched criterion's weight and relevance are presented in the table below (Table 1). The weights of the last column of criteria may also be used to prioritize the criterion. Finally, the criteria's final fuzzy weight was calculated and defuzified using the center of gravity approach. According to (Table 2), "slope" with a weight of 0.303 is the most important factor in determining the hospital waste disposal location. As a result, "Height" with a weight of 0.22 takes second place. Furthermore, "distance from road" has a weight of 0.122, while "distance from hospitals" has a weight of 0.019.*2.3 The study area*

The study area was a section of the south of Tehran, involving some regions like Ray Baqer Shahr, Kahrizak, and Qiyam Dasht (Fig. 2). Furthermore, ArcGIS 10.2 software was used for spatial preparation and processing of every parameter applying the spatial analysis functions (Table 3).

1. **Results and discussion**

The mapping organization provided a digital elevation model (DEM) with a resolution of 30\*30 m, and the research region was then divided by converting its coordinates to the universal transverse mercator (UTM) metric system. The belonging values between zero and one were calculated using reverse linear normalization [12]. They were more ideal for disposal site placement since the height and slope were lower. As a result, lower height and slope values acquire greater belonging values (Number one), whereas higher height and slope values receive lower belonging values (zero) [21, 22]. The transportation of garbage from source to destination is accelerated by access and proximity to a road and a hospital. As a result, the valuation was done using reverse linear normalization, and the road obtained a higher belonging value since it was closer to the hospital [21, 22]. Distance from faults, residential and metropolitan areas may all influence the placement of a disposal site, and the greater the distance, the better [23, 28]. As a result, linear normalization was performed, and with increasing distance, more belonging values were obtained. The depth of groundwater has also been demonstrated to influence disposal site placement, and closeness to groundwater has been identified as a cause of water contamination, followed by pollution of the environment, water, and soil resources [23, 28]. When the linear normalization method was utilized, the locations with deeper groundwater depths earned higher belonging values. It should be emphasized that using the inverse distance weighting interpolation (IDW) approach, the depth of groundwater [23, 28] was estimated in the whole area for the purpose of generating groundwater layers from tested wells collected from Tehran's water. Figure 3 depicts the intended maps with a degree of membership ranging from zero to one. Table 4 shows the positive and negative impacts of each input indicator, as well as their lowest and greatest values. As a consequence, the slope effectiveness is negative [38], which means that the greater the slope, the more negative the impact, whereas the fault has a positive effect. In conclusion, the greater the distance from the fault, the higher the value assigned to it as a good and desired attribute. Because soil type is a qualitative variable, unlike the other factors [39], it is required to quantify the soil type in this region. As a result, the ranking system was utilized to determine the degree of difficulty and weakness. Hard sandstone locations obtained the highest ranking of 10, places with a significant proportion of loose lime received the lowest ranking of 1, and areas with both received a ranking of 5.As a consequence, locations with a high ranking have good impacts, whereas those with a low ranking have negative effects. Because it is necessary to determine the appropriate areas for disposal sites by layering all of the input layers on top of each other and selecting common areas with a high overlap, the values of each layer should be normalized and then standardized between zero and one to make all layers comparable, so that the layers with higher values have no greater effect on location. Fuzzy functions or linear and reverse normalizations were utilized for this [40].In turn, linear normalization was used for layers such distance from faults, residential areas, groundwater level, surface waters, and soil type, while reverse normalization was utilized for elements like height, slope, distance from road, and negative treatment regions with negative efficacy [41]. It's worth noting that soil type has a beneficial influence after being scored from 1 to 10, with higher values having good benefits and lower ones having negative effects. Data standardization allows the meaning of data to be decoupled from the unit of measurement. As a result, in multivariate data analysis, standardized data were employed. For linear normalization, Eq. (4) was utilized, and for reverse linear normalization, Eq. (5) was used to balance the actual value of data between zero and one. As previously said, linear normalization is often used for data such as distance from fault, whereas reverse normalization is commonly used for data such as proximity to road and hospital, which is more beneficial as it becomes closer. Finally, the indications were combined to determine the best disposal location. To integrate and overlap the layers, a weighted linear combination was utilized. The resultant weight was multiplied by each index, which was then added to the other layers. Figure 4 depicts a map of acceptable and undesirable sites. Higher values, in particular, indicate more suited places. It is important to remember that the constraint area should be recognized and then eliminated from the final map.*3.1 Preparing constraint maps*

To build the constraint layer in the south of Tehran, all of the layers that potentially cause constraint were first made Boolean. As a result, such limitations are logical and irreversible, and they should be removed from the output map at some point [42].The restrictions explored in this work are listed in Table 5 [43]. As illustrated, the scenarios that may be applied were given number one, while the situations that cannot be applied were given number zero. Landscape layers, distinct geological features, and residential regions, and so on are all examples of information layers. As a result, if any of these places falls inside the scope of the study, that portion will be deleted using the first screening (Fig. 5) to show the limits in the south of Tehran. There was no height limitation since the area's height changed from 935 to 1852 m. (Fig. 5a). Other factors, such as slope, road, urban residential neighborhoods, and green space, were also taken into account. After applying the restriction maps, the final map of the HWD site placement in the south of Tehran is shown in Fig. 6. White regions represent limited areas that have been eliminated from the designated places, as illustrated. Three portions of the region were designated as "blue zones," or "extremely appropriate locations." There were three parts: northwest, central, and south-eastern; of these, the central section may be regarded a better choice than the others since it has greater access to the whole region. Although the north-eastern half of the city is closer to Tehran, it is not recommended owing to its closeness to residential neighborhoods. Table 6 shows the distance between each point and the required criteria, based on the received information. Figure 7 displays a total of eight points as chosen places in the middle area, while Table 6 shows the distance between each point and the intended criteria.*3.2.1 MAIRCA method*

The Logistics Research Center at Belgrade University of Defense (Serbia) created the MAIRCA approach in 2014. As a result, the method's major assumptions are for finding the difference between ideal and empirical weight values. The sum of these gaps for each criteria is the overall gaps for each of the possibilities seen. Finally, in this scenario, alternatives may be ranked, with the option with the fewest total number of gaps receiving the highest rating. Furthermore, when compared to the majority of the other criteria, this choice has the closest values to the empirical weights [44]. This method's methodology is broken down into eight stages, as follows: Step 1. Making the primary decision matrix (X). Criterion values:

Step 2: The equation or matrix X, is provided based on the decision maker's personal preferences or by surveying the consensus of experts’ decisions.

Step 3: Identifying the preferences for choosing option (), while choosing an option, the decision maker is neutral during this process.

Step 4: Identifying the preferences for choosing option (𝑷𝑨𝒊), while selecting an option, the decision maker is neutral during this process. Hence, the probability of choosing an option from m options is equal to the following:

In analyzing the decision-making (DM) process with the given probabilities, we proposed that the DM is neutral to the risk. Hence, choosing reliable options is equal to the following:

Step 5: Computing the theoretical evaluation matrix (𝑻𝒑).

 (8)

Theoretical evaluation matrix ( in the format of n × m (n: total number of criteria, m: total number of options). Elements of theoretical assessment matrix ()

was computed as the preference coefficient for each and standard weights.

Since the decision maker (DM) is neutral to the first selection of options, all preferences for all options is equal. Then, the following situations or equation can be gained by the above matrix or equation where n is the total number of criteria and is the theoretcial evalaution.

Step 6: Identification of the equation (matrix) of a real assessment

Since n is the total number of criteria, so m is the total number of options. Computing the elements of real assessment matrix (𝐓𝐫) by multiplying the elements of the real assessment matrix (𝐓𝐩) and initial decision matrix elements (X) was done based on the following equations:

a: For the kind of profit (i.e., the positive aspect), (i.e., the bigger criterion is desirable)

b: For the kind of cost (i.e., the negative aspect) (i.e., the smaller criterion is desirable)

: The matrices in the primary decision matrix.

: The biggest value with the initial matrix value.

: The smallest value with the initial matrix value.

Step 7: Computing the total gap matrix (G)

The elements of matrix can be computed as the gap between theoretical assessment tpij

and real assessment tpij or by subtracting the theoretical evaluation matrix Tp with the real assessment elements Tr.

where **n** shows the total number of criteria and **m** shows the total number of options.

Because the option was chosen with the smallest difference between theoretical assessment and real assessment .If option is for criterion, the value of theoretical evaluation would be equal to the real value (). Then, the gap for option for is . In fact, option for is regarded as the best option of. If option is for , it will have theoretical assessment value and the real value will become permited .Then, the gap for is . In fact, option for is known as the worst option of .

Step 8: Computing the values of final criterion fucntion () for options. The value of criterion functions is provided from the total gaps for options or only the addition of matrix G elements in the columns using the following equation:

The challenge of ranking HWD sites would be solved using the MAIRCA algorithm and an 8\*9 matrix termed the decision matrix (options). Table 6 contains the information for this matrix. This element would have no influence on the answer since all alternatives for soil type are equal to 1, therefore it would be ignored while its weight was split among the other assessment criteria. The decision matrix was then normalized, as shown in Table 7, using the normalization formulae. At last, the values of each of the options for all provided metrics were added together and the Q value was provided as shown in the above-mentioned table.

Following that, the Q values were sorted in ascending order, with lower Q values having higher ranks. The ranking of the chosen sites, as shown in Table 8, reveals that the fourth location (option) received the top rank among the eight selected places for the HWD site. However, the second, third, fourth, fifth, sixth, seventh, and eighth positions for HWD site in the southeast of Tehran province, respectively, were achieved by the sixth, fifth, third, second, eighth, seventh, and first locations .MAIRCA is a novel MCDA approach that should be compared to existing well-established methods. Location problems with TOPSIS and MOORA method [25, 31], selecting suitable site in waste management by the VIKOR method [45], and selection of landfill site using fuzzy AHP and fuzzy TOPSIS [16, 46] are just a few of the studies related to location selection decisions that have been commonly carried out using multi-criteria decision-making techniques. The techniques VIKOR, TOPSIS, and MOORA are offered as prominent for location ranking in the previously mentioned sources. In order to compare location ranking, the above-mentioned methodologies are compared to the MAIRCA method. Table 9 shows the results of alternative ranking based on criteria utilizing the MOORA, TOPSIS, and VIKOR techniques, as well as comparisons to the MAIRCA way of ranking choices. When the MAIRCA findings were compared to the MOORA, TOPSIS, and VIKOR techniques, it was discovered that the MAIRCA approach ranks the alternatives quite similarly to the VIKOR method. The fourth, sixth, fifth, third, second, eighth, seventh, and eighth positions obtained the first to eighth positions, respectively, in both procedures. Meanwhile, the fourth site rated top among the eight chosen locations in the MOORA and TOPSIS procedures, but the rankings were somewhat different in the other possibilities. One reason the MAIRCA and VIKOR approaches produced identical findings might be because they both employed the same data normalization procedure. The significant degree of correlation between the approaches validated the findings' comparability. As a consequence, all of the observed ranks were deemed credible for the purposes of the study.**4. Conclusions**

The fuzzy Delphi technique was utilized in this research to identify and filter the most essential variables involved in the selection of HWD locations (slope, height, soil type, distance from fault, distance from surface water, depth of ground waters, distance from residential areas, distance from hospitals, and distance from road).After that, by merging the layers and using the integrated model to find an acceptable disposal location, layer preparation, standardization, and weighing were decided. For the first time in the realm of challenges related to the HWD site placement, the FSWARA-MAIRCA was applied in this research. This technique uses a combination of data from numerous criteria to create an assessment index that aids decision-makers in selecting the optimum site by establishing the conditions for evaluating various criteria. The findings show that employing the fuzzy technique based on quantitative and qualitative criteria made the present research more successful.1: The decision maker may choose decision-making indices on an interval scale rather than a binary scale using both the FSWARA and MAIRCA methodologies for weighting criteria and ranking.

2: Using no scale conversion, the MAIRCA approach may apply qualitative measurements with descriptive or sequential scales in their natural state. The gap (distance) between ideal and empirical weight values is determined using the major assumptions of this approach. The sum of these gaps (distances) (in each criteria) indicates the overall gaps for each of the possibilities that were observed. Finally, in this scenario, the alternatives will be ranked, with the option with the fewest total gaps receiving the highest rating. Based on the maximal criterion, this option has the closest values to the empirical weights.3: Choosing places in regions where environmental regulations are strong. To decide the location of the HWD site in the southeast of Tehran, the hybrid technique was used to pick eight places as the preferable locations among the identified zones. Finally, based on the criteria of a 34-degree slope, 1008-meter height, 3.4841-meter distance from fault, 8.4428-meter distance from surface water, 12 meter groundwater depth, 457-meter distance from residential areas, 6.4749.6-meter distance from hospitals, and 1598-meter distance from road, the fourth point in the southeast of Tehran was chosen as the final location for the HWD site. Furthermore, the MOORA, TOPSIS, and VIKOR methodologies were utilized to rank the possibilities and verify the outcomes in this research. When the MAIRCA findings were compared to those from the MOORA, TOPSIS, and VIKOR techniques, it was discovered that all four methods chose the fourth location for HWD sites. **Availability of data and materials**

All data generated or analyzed during this research are involved in this paper.

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