



Sustainable landfill site selection for hazardous waste using a GIS-based MCDM approach with G-number information

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Abstract

This study aims to present a new integrated framework based on the decision-making techniques and geographic information system (GIS) in order to select the best landfill for hazardous waste. To consider the uncertainty in this process, the G-number theory is used, which includes two components of importance and necessity so as to increase accuracy in choosing the optimal location. In the first stage of this proposed approach, the factors influencing the selection of a suitable site for burying hazardous waste have been identified in three groups, including environmental, social, and economic factors. In the following, the weights of these 13 criteria are calculated using the stepwise weight assessment ratio analysis (SWARA), in order to reduce the ambiguity in attributing weights to the criteria by incorporating the SWARA method and the Importance–Necessity concept (G-number) and to present a novel method, namely the G-SWARA method. By decreasing levels of ambiguity in the final results through the addition of the Necessity and Importance concepts, in the next step, 10 potential locations proposed as the most suitable options by using GIS spatial analysis system have been analyzed and ranked using the weighted aggregated sum product assessment (WASPAS) method based on G-number and site number 6 with 261.97 hectares was ranked first. To evaluate the ranking, the results were compared with F-WASPAS and WASPAS methods, and it was found that the results of the proposed method are more reliable. Sensitivity analysis was also performed to show the degree of ranking stability in different scenarios.

Keywords Site selection · Hazardous waste · Geographic information system · SWARA · WASPAS · G-number theory

1 Introduction

In the current century, rapid and growing population growth in countries, especially in developed and developing countries, on the one hand, and increasing migration from rural to urban areas, on the other hand, have led to increased consumption and thus increased waste and waste products in metropolitan areas (Ghouschi et al., 2020). Elimination of

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these substances is one of the major challenges of urban and environmental management and is one of the costly problems related to municipalities (Zhao & Huang, 2019). Safe and sustainable management of medical waste or waste products from health products due to environmental and public health risks is a global concern (Ranjbarzadeh, 2021). In many parts of the world, there is still the issue that after transporting and collecting garbage, regardless of its harms and damages, the garbage is piled up in the nearest accessible place, unprincipled or unhealthy, and then buried. For this reason, most of these areas, since they are not selected scientifically and logically, do not have the potential to accept waste and cause irreparable damage such as groundwater pollution, environmental degradation (damage to forests, pastures, and wildlife), and greenhouse gases to the area (Zhao & Huang, 2019).

Selecting the right place is a special process because, on the one hand, it affects public health and the ecosystem and, on the other hand, it must consider different approaches such as political, social, cultural and aesthetic issues, and so on. Almost until the last 50 or 60 years, not much attention was paid to the burial of waste in the world, and in most parts of the world, the same traditional methods were used to accumulate and collect waste and burn it in open areas. The people's general idea was to reduce the amount of waste and pollution in this way. Gradually, managers and experts in this field realized that in this way, pollution is transformed from one type to another, because the burning of waste in the open air causes the pollution of the mentioned materials (Ghouschi et al., 2021a).

On the other hand, in the definition of waste, it is stated that waste is a liquid, solid and gaseous material resulting from human activities that are directly or indirectly produced and is redundant from the point of view of producers and can no longer be used (Gómez-Delgado & Tarantola, 2006). According to many waste researchers, it contains all the waste materials that are recycled for reuse and put back into the consumption cycle (Rabbani et al., 2018; Sakir et al., 2020; Sardar et al., 2018; Stern & Kumi-Boateng, 2019). However, waste sludge and hazardous waste can also be defined in this range; in other words, hazardous waste includes all solid and semi-solid materials and even liquids that are not worth keeping. In the meantime, all infectious and harmful wastes from hospitals, health centers, medical diagnostic laboratories, and other similar centers are called hazardous waste (Gautam et al., 2019). Thus, identifying and burying hazardous materials and waste requires proper and standardized criteria and well-codified planning to provide the necessary facilities from an environmental, economic, and social perspective (Margallo et al., 2019). According to the study of Keller et al. (Keller, 2012), these criteria can include morphological conditions, groundwater, rain distribution, and soil type. Additionally, Sener et al. (2010) used the criteria, including geology, hydrology, land use, slope, and altitude. Chamchali and Ghazifard (2019) also considered soil erosion as a criterion for landfilling.

Care and urgent in selecting the right place to bury waste, especially hazardous waste, requires precise specialized tools and systems. For this reason, in recent years, engineers and experts have played an important role in selecting the best and most suitable site for these materials by using precise systems such as geographic information system (GIS) (Abdulhasan et al., 2019; Gómez-Delgado & Tarantola, 2006; Soroudi, et al., 2018; Yang et al., 2014). Decision making can be considered as the choice of the best alternative among a set of alternatives according to a number of effective criteria (Haseli et al., 2020, 2021). On the other hand, the process of choosing the best landfill for hazardous waste can be considered as a decision-making problem in which decision makers deal with different alternatives and criteria. In such problems, decision makers are tried to prioritize the potential sites by considering different criteria according to international standards. In this regard, in the recent years, various multiple-criteria

decision-making (MCDM) methods including analytic hierarchy process (AHP), analytic network process (ANP), and other similar ones have been widely used to determine the weights of the identified criteria and select the most suitable location for hazardous waste landfills (Afzali et al., 2014; Akintorinwa & Okoro, 2019; Eldrandaly, 2013; Gbanie et al., 2013; Hanine et al., 2016; Rahmat et al., 2017).

As mentioned, experts and specialists in geological sciences determine the appropriateness or inappropriateness of the site, considering various criteria. These data may be ambiguous and uncertain due to different time and place conditions. To tackle the unreliability of outputs resulted from uncertain environment, many studies use the fuzzy logic, first introduced by Zadeh (1965) in 1965, to solve landfill site selection. Among these studies, Khan and Faisal (2008), Banar et al. (2007), Babalola and Busu (2011), and Danesh et al. (2019) used the integrated fuzzy approach based on the ANP and the GIS. Nazari et al. (2012) and Aksoy and San (2019) engaged the AHP method to weigh and rank the selection of landfills using uncertain and dynamic data. In this regard, Şener et al. (2010) conducted a study in Turkey, combining the AHP method and a study to bury waste. They used six layers of information and divided the study area into four floors ranging from appropriate to very appropriate. Liu et al. (2014) and Kabak et al. (2018) introduced an approach based on multi-objective optimization on the basis of ratio analysis (MULTIMOORA) method and GIS to locate sanitary landfill considering the environmental factors. A combination of decision-making methods has also been used to facilitate the assessment and improve occupational safety and health performance in the field of transportation based on fuzzy environment to reduce conflict rates (Jiménez-Delgado, 2019). Haddad et al. (2021) also used the fuzzy TOPSIS method to evaluate suppliers in the oil and gas industry using four HSE criteria. Hariz et al. (2017) used a combination of AHP, VIKOR, and preference ranking organization method for enrichment of evaluations (PROMETHEE) methods to select the best landfill site. There have been limited studies on the weighting of criteria by the best–worst method (BWM), such as Pamučar et al. (2017) research on decision-making for the installation of wind turbines, Hafezalkotob and Hafezalkotob (2017) study about the role of olive harvesting devices in environmental degradation, and Ren et al. (2017) research on sustainable evaluation to select the necessary technology for urban wastewater control, and some studies are also about the circular economics assessment in the location of green environment in industrial centers (Dou et al., 2017; Shan, et al., 2016; Wei et al., 2020; Zhao et al., 2018). Ghoushchi et al. (2021a) have used decision-making methods in a spherical fuzzy environment to select a suitable location for disposal of medical waste. They used SWARA method to weigh the criteria chosen by the experts and WASPAS method to rank the locations.

In summary, in the use of fuzzy (uncertain) numbers versus crisp numbers, there is the advantage that instead of a single number, a range of numbers with a probability of acceptance is considered (Dong et al., 2020). This theory is able to shape the mathematical model into obscure concepts and provides the basis for controlling and deciding in uncertainty conditions (Kosko, 1994; Lv et al., 2020; Orujov et al., 2018). Due to the use of fuzzy concepts and models and the coordination of output data with the real environment of the criteria, it can be expected that the use of fuzzy data will provide the desired and appropriate result in solving the problem of choosing the optimal location for hazardous landfill waste. In issues such as selecting the optimal site for landfilling hazardous waste that requires careful and appropriate decision making, information plays a key role, and this information should have the least ambiguity and the least uncertainty to make these decisions accurate and reliable. Many methods, such as the fuzzy set theory proposed to solve

decision-making problems, can consider the ambiguity and uncertainty of real-world issues in various ways.

Generally, the information for planning and decision making is mainly captured with uncertainty. Therefore, human rationality alone cannot fulfill the demands and objectives of the organizations. That is to say, the existence of uncertainty in determining the exact weights in weighting methods based on experts' objectives can lead to an increase in the levels of ambiguity (Orujov et al., 2018). To address this shortcoming, Ghouschi and Khazaeili (2019) proposed the Importance–Necessity concept, namely G-numbers, to decrease ambiguity in the decision-making process. G-numbers include two fuzzy variables and indicate in the form of triangular fuzzy numbers. The primary aim of this method is to reduce the uncertainty of information based on I (Importance) and N (Necessity) components. I and N are linguistic variables.

According to the importance of the studied problem, the main aim of this study was to introduce an integrated framework based on the MCDM techniques and GIS to select the best landfill for hazardous waste in which different effective factors in the uncertain environment are considered. To apply the uncertainty in this process, a new concept entitled G-number theory (Ghouschi & Khazaeili, 2019) has been used. This theory was proposed to investigate uncertain information and reduce uncertainty, which is based on the concepts of importance and necessity in the form of a regular pair and based on fuzzy numbers. In fact, the importance of an activity or an indicator is its value and importance in relation to the existing environment and conditions, but sometimes it happens that despite the importance of some activities or indicators, there is no need to do them or there is very little necessity (Ghouschi, 2021; Jafarzadeh Ghouschi et al., 2020). It should also be noted that in a process, sometimes there are several important and potential issues, but there are only a few special issues that have a necessity to do. Until now, the concepts of importance and necessity have been used in the same way in decision-making issues, and the component of necessity in decision-making issues has been ignored as an independent component. The ordered triple is referred to as G-valuation. X is unspecified, I is the Importance and N is the Necessity component; I and N can get the value of X . For instance, an increase in the budget of education (Medium, High) is a group of G-valuations and called a G-information. The concepts of many decision-making issues can be expressed as G-information (Ghouschi & Khazaeili, 2019). Thus, this study tries to design a new integrated MCDM approach based on G-number theory and GIS outputs to address the problem of locating hazardous waste landfills. In the proposed approach, each of the criteria and options is evaluated according to their importance and necessity according to the opinion of experts. In fact, in order to locate the landfill of hazardous waste in Tabriz metropolis, 13 different criteria were considered by G-stepwise weight assessment ratio analysis (SWARA) method, taking into account the concepts of importance and necessity, and then, they were weighed in groups in an uncertain environment. Necessity is the comprehensive form of urgency, which has not gained enough attention from researchers; they mainly consider the Importance concept in MCDM issues (Zavadskas et al., 2014). Necessity may resolve ambiguity and represent real-world decision making in a better and more precise way. This concept is called G-numbers. According to the advantages of the G-SWARA method, such as simultaneous consideration of Importance and Necessity in the form of linguistic variables, it can be strongly useful for decision support systems in dealing with complex problems. Then, using GIS, 10 potential and suitable points for hazardous waste landfills were identified, and finally, these places were ranked by G-weighted aggregated sum product assessment (WASPAS) method. In the present study, linguistic variables like triangular fuzzy numbers (TFN) for Importance and Necessity concepts are used. Furthermore, a new

approach has been proposed, which enhances the capability of ambiguity reduction in the decision-making process.

The rest of this study is organized as follows: In Sect. 2, preliminaries, including fuzzy theory concepts, are discussed. In Sect. 3, the research framework and the methods of weighting the criteria and ranking the options, namely G-SWARA and G-WASPAS, are expressed. In addition, the analysis of the GIS in solving the problems related to the location of the landfill of hazardous waste is also stated. In Sect. 4, the introduction of case study in is done in which the proposed approach is implemented. In Sect. 5, the analysis of results from the implementation of the proposed approach in the case study is provided. Finally, in Sect. 6, the conclusions and development suggestions of this study are presented.

2 Preliminaries

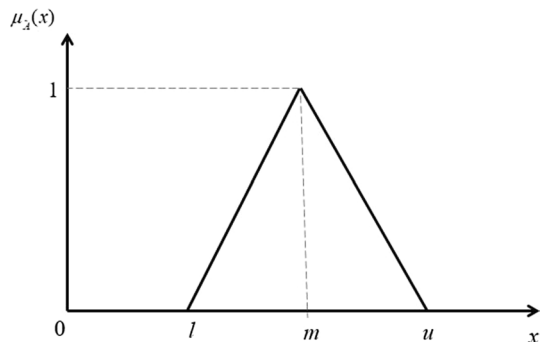
In this study, linguistic variables have been used for the concepts of importance and necessity of G-number, and a new approach has been proposed to improve the decision makers' ability to reduce ambiguity in decision-making issues. To achieve this goal, in this section, some essential definitions are introduced as basic concepts that are used in Sect. 3.

Fuzzy number: A fuzzy set is a membership function that shows the membership rate in the range between 0 (without full membership) and 1 (with full membership) $R \rightarrow [0, 1]$. The membership function of the fuzzy number is defined as $A = \{(x; \mu_A(x)) | x \in X\}$ in which $\mu_A(x)$ is the membership of the element x defined in the definite set A (Rahmat et al., 2017).

Triangular fuzzy number (TFN): A set of three members (l, m, u) is a TFN, and its membership function (l, m, u) is \tilde{A} (see Eq. 1). This function is positive when $l \geq 0$ (Zadeh, 1965). In this study, the TFN is used. Figure 1 shows the diagram of a TFN, and the values of $l, m,$ and u are the highest, mean, and lowest values, respectively.

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-l}{m-l} & l \leq x \leq m \\ 1 & x = m \\ \frac{u-x}{u-m} & m \leq x \leq u \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

Fig. 1 A triangular fuzzy number



G-number: This number is defined as the set $G = (\tilde{I}, \tilde{N})$. The components of necessity and importance that are displayed as \tilde{I} and \tilde{N} are the fuzzy numbers of this set $\tilde{I} = (l_I, m_I, u_I)$ which is a function of importance and $\tilde{N} = (l_N, m_N, u_N)$ which is a function of the necessity of this set. These numbers are positive when $l_I \geq 0$ and $l_N \geq 0$ (Ghouschi & Khazaeili, 2019).

The two numbers $G_1 = [(l_I^1, m_I^1, u_I^1), (l_N^1, m_N^1, u_N^1)]$ and $G_2 = [(l_I^2, m_I^2, u_I^2), (l_N^2, m_N^2, u_N^2)]$ are positive numbers which are G-Number and λ is the main variable of this number. Their mathematical equations are as follows (Ghouschi & Khazaeili, 2019):

$$\begin{aligned}
 (i) \quad G_1 \oplus G_2 &= [(a_I^1 + a_I^2, b_I^1 + b_I^2, c_I^1 + c_I^2), (a_N^1 + a_N^2, b_N^1 + b_N^2, c_N^1 + c_N^2)] \\
 (ii) \quad G_1 \ominus G_2 &= [(a_I^1 - c_I^2, b_I^1 - b_I^2, c_I^1 - a_I^2), (a_N^1 - c_N^2, b_N^1 - b_N^2, c_N^1 - a_N^2)] \\
 (iii) \quad G_1 \otimes G_2 &= [(a_I^1 a_I^2, b_I^1 b_I^2, c_I^1 c_I^2), (a_N^1 a_N^2, b_N^1 b_N^2, c_N^1 c_N^2)] \\
 (iv) \quad G_1 \oslash G_2 &= [(a_I^1 / c_I^2, b_I^1 / b_I^2, c_I^1 / a_I^2), (a_N^1 / c_N^2, b_N^1 / b_N^2, c_N^1 / a_N^2)] \\
 (v) \quad \lambda G_1 &= [(\lambda a_I^1, \lambda b_I^1, \lambda c_I^1), (\lambda a_N^1, \lambda b_N^1, \lambda c_N^1)]
 \end{aligned}
 \tag{2}$$

This section illustrates how a G-number can convert to a fuzzy number. The conversion of G-number to TFN according to the components $G = (\tilde{I}, \tilde{N})$ which includes the component of the importance of $\tilde{I} = (l_I, m_I, u_I)$ and the component of the necessity of $\tilde{N} = (l_N, m_N, u_N)$ is as follows. The values of α and β for each criterion or alternative are determined by the experts based on self-identification.

$$G = \alpha \times \left(\frac{l_I + 2m_I + u_I}{4} \right) + \beta \times \left(\frac{l_N + 2m_N + u_N}{4} \right); \quad \beta = 1 - \alpha.
 \tag{3}$$

According to Eq. (3), the value of G is calculated based on α and β which indicate the non-negative weight of the components of importance and necessity, respectively. It means that whenever α is increased, the value of β needs to be decreased. It should be noted that, due to the advantages of G-number theory, the following outputs can be achieved by applying this theory in decision-making process (Ghouschi & Khazaeili, 2019):

- Simultaneous awareness of the importance and necessity of an index or activity (increasing awareness).
- Necessity arguments for deciding on an acceptable issue (reducing uncertainty).
- Increasing the sensitivity and accuracy of managers and decision makers toward choices and priorities (reducing ambiguity).
- Justifying the necessity of performing activities in addition to their importance, considering the desired time (reducing the consequences of not performing some activities in time).

3 Research method

The main purpose of this study was to provide a new solution for choosing a suitable place for landfilling hazardous waste using the GIS and extended MCDM methods in an uncertain environment. This framework is done in four phases, beginning from identifying criteria till selecting the sustainable landfill site based on the using G-number. Therefore, in the first phase, the factors influencing the selection of a suitable place for landfilling hazardous waste include the slope of the study area, height floors (DEM), urban population

density, rural areas, faults of the study area, main river, distance from the main road, soil type, vegetation, rainfall, distance from the airport, groundwater (such as aqueducts and wells), and the amount of evaporation. These criteria have been identified according to the rules and documents of the four valid organs including instructions of the Iranian Department of Environment (IDOE), criteria and rules provided by the Management and Planning Organization of Iran (MPO), criteria and rules of the United States Environmental Protection Agency (EPA) and criteria and rules of Water, Soil and Air Protection Agency (British Columbia) and previous scientific studies. In the following phases, using the G-SWARA method, the weight of each criterion is determined by experts and specialists, and by analyzing the GIS after removing the inappropriate points, the best place for landfilling hazardous waste is achieved. In the fourth phase, according to the outputs of the previous phases, the proposed locations are ranked by G-WASPAS method, and among the alternatives, the most suitable site for landfilling hazardous waste is identified. The algorithm for solving the location problem of landfilling hazardous waste is shown in Fig. 2.

3.1 Necessity criteria for landfilling hazardous waste (selection of sustainable criteria)

Selecting the right criteria to solve the location problem is of the importance in decision-making models. In general, many features may be available to solve such problems. For this reason, experts must consider the criteria that have the greatest and most important impact on the selection of landfills for hazardous waste. The existence of paradoxical criteria in a normal situation in choosing a landfill, which is a real problem, shows the importance of using MCDM decision tools. The selection of appropriate criteria for landfilling hazardous waste is based on the geographical characteristics of the landfill, specialized assessments, national standards, and the availability of information.

3.2 G-SWARA method

One of the decision-making methods with multiple features that are used to calculate the weight of the criteria in the uncertainty environment is the fuzzy SWARA (F-SWARA) step-by-step evaluation method. The SWARA method was first proposed by Keršuliene et al. (2010). In this method, experts (respondents) have a main role in determining the weight of the criteria. Main feature of this method is possibility of estimating experts and pundits in relation to the importance of criteria in the process of determining their weight (Keršuliene et al., 2010). This method allows decision makers to estimate the importance ratio of criteria in the process of determining their weights and do less pairwise comparisons (Dorosti, et al., 2020; Ghouschi et al., 2021b; Jafarzadeh Ghouschi et al., 2020). SWARA method gives decision makers and policymakers the opportunity to prioritize based on the current state of the environment and the economy (Cui et al., 2021). In other methods, such as analytic hierarchy process (AHP) or analytic network process (ANP), our model is based on expert criteria and evaluations that affect rankings. Therefore, SWARA can be helpful for our case. However, existence of ambiguity in the words of answerers or imperfect information led the SWARA method to be developed as Fuzzy SWARA method. This method can also be used as an expert-based method for calculating weights. In this method, first the criteria are arranged according to their importance and then the experts are asked to determine the importance of each criterion compared to the previous criterion. In this study, the SWARA method has been extended based on the G-number theory.

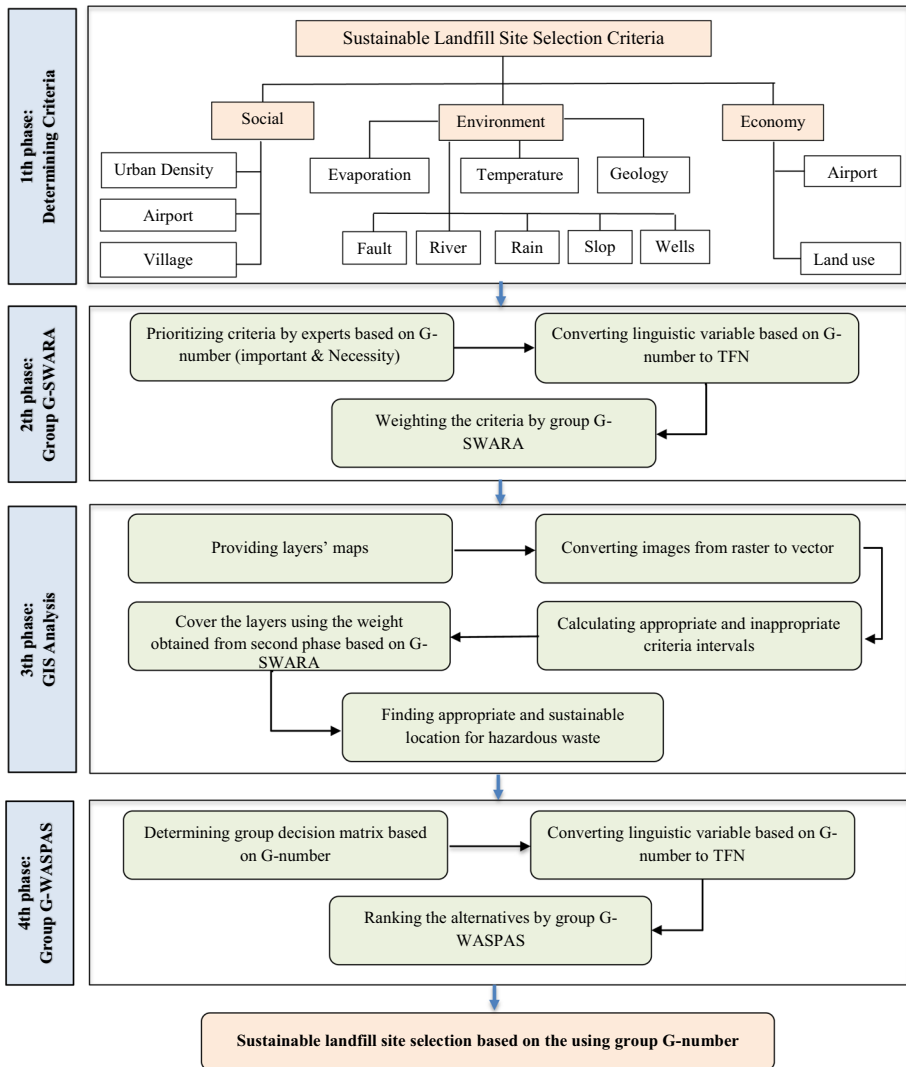


Fig. 2 Flowchart of the proposed methodology

Transformation rules are obtained for converting $G = (\hat{I}, \tilde{N})$ linguistic arrays to G-number. The number consists of two fuzzy components I and N which indicate the importance and necessity, respectively. The values of α for the G-numbers must be specified. The steps of this new method, namely G-SWARA method, are as follows:

Step 1: Specialists and experts arrange the criteria from the most important to the least important, in descending order based on personal opinion.

Step 2: According to the initial opinions, experts should assign linguistic variables to the relative importance of j criteria in relation to previous $j-1$ criteria. After that, the specialists determine the value of the two components of importance and necessity according to Table 1. As a result, a G-number is formed for each criterion.

Table 1 Linguistic variables taking into account the components of importance and necessity for weighting the criteria

Linguistic Variables(I)	TFN	Linguistic Variables(N)	TFN
Equally Important (EI)	(1,1,1)	Very High Necessity (VHN)	(1,1,1)
Moderately less Important (MOLI)	(2/3,1,3/2)	High Necessity (HN)	(0.75,1,1)
Less Important (LI)	(2/5,1/2,2/3)	Medium Necessity (MN)	(0.50,0.75,0.90)
Very less Important (VLI)	(2/7,1/3,2/5)	Week Necessity (WN)	(0.35,0.50,0.75)
Much less Important (MULI)	(2/9,1/4,2/7)	Very Week Necessity (VWN)	(0.20,0.35,0.50)

Step 3: In this stage, after determining the components of importance and necessity for weighting the criteria in the form of linguistic variables using (Table 1), the values of importance and necessity (*I, N*) are converted to TFN according to Eq. (3). Then, the necessary weight is added to each criterion based on the experts' opinions. For example, consider a number that is a relative importance and necessity for the *j* criterion in the form of linguistic variables (EI, HN). By substituting the required values according to Table 1, its value is formed as [(1,1,1), (0,75,1,1)] and the value of G-number will be equal to (0.0625α + 0.9375) by using Eq. (3). The numerical value is between 0 and 1, which is determined by experts and shows the non-negative weight of the component of the importance and necessity. Other TFN conversions will be according to Table 2.

Step 4: Based on the results obtained in step 3, the coefficient \tilde{q}_j is calculated as the fuzzy weight coefficient using Eq. (4):

$$\tilde{q}_j = \frac{\tilde{q}_j - 1}{\tilde{G}'_j} \tag{4}$$

Step 5: Finally, by evaluating the “*n*” criterion, the “*j*” weight of the criterion is calculated based on Eq. (5).

Table 2 The rules for converting the G-number to TFN based on linguistic variables for weighting criteria

Linguistics Variables	TFN Conversion	Linguistics Variables	TFN Conversion
(EI,VHN)	1	(LI,WN)	0.525—0.009 α
(EI,HN)	0.0625α + 0.9375	(LI, VWN)	0.35—0.166α
(EI,MN)	0.275α + 0.725	(VLI,VHN)	1—0.579α
(EI,WN)	0.475α + 0.525	(VLI, HN)	0.937- 0.516α
(EI,VWN)	0.65α + 0.35	(VLI, MN)	0.725- 0.304α
(MOLI, VHN)	0.041 α + 1	(VLI,WN)	0.525- 0.104α
(MOLI, HN)	0.103 α + 0.937	(VLI, VWN)	0.35- 0.071α
(MOLI, MN)	0.316 α + 0.725	(MULI,VHN)	1—0.749α
(MOLI, WN)	0.516 α + 0.525	(MULI, HN)	0.937- 0.686α
(MOLI, VWN)	0.691 α + 0.35	(MULI, MN)	0.725- 0.474α
(LI,VHN)	1—0.484 α	(MULI,WN)	0.525- 0.274 α
(LI, HN)	0.937- 0.421 α	(MULI, VWN)	0.35 — 0.099α
(LI, MN)	0.725—0.209α		

$$\tilde{w}_j = \frac{\tilde{q}_j}{\sum_{j=1}^n \tilde{q}_j} \quad (5)$$

3.3 GIS analysis

The GIS can integrate multiple layers of criteria into one map. Satellite images, topographic maps, and computational analysis-based data are commonly included in the GIS (Kabak et al., 2018). In this study, satellite images, topographic maps, and maps of the study area obtained from responsible organizations and other sources, including digital maps, are used.

GIS analysis has two stages: pre-analysis (preliminary analysis) and main analysis. In the preliminary stage, since the input layers and the collected data are very different in terms of form, size, coordinate system, and scale, it is necessary to integrate the information and maps. At this stage, all maps (except land use and geological maps) should be saved as pixel maps that can be rearranged; then, with the reclassification tool and using the weight (score) obtained from the G-SWARA method, this weight is assigned to each category (class) (Hariz et al., 2017). In the main stage of GIS analysis, Euclidean distances, calculation of appropriate and inappropriate distances and elimination of inappropriate distances and integration of maps are done and, finally, by overlapping all layers, suitable places for landfilling hazardous waste are obtained.

3.4 G-WASPAS method

The fuzzy WASPAS (F-WASPAS) method is one of the new multi-criteria decision-making methods that acts like WASPAS, is based on objective data, and is used in very sensitive cases considering the certainty of the system (Zavadskas et al., 2012). This method is based on objective data and used in sensitive cases considering the certainty of the system (Akbari et al., 2020; Zavadskas et al., 2012). In fact, this method is a combination of two MCDM techniques, namely weighted sum model (WSM) and weighted product model (WPM), and due to easiness and mathematical ability to propose accurate outcomes, in contrast to WSM WPM has been widely welcomed, and with a value of λ as an interface, the ranking is done based on two final indicators (Ali et al., 2021; Ghouschi et al., 2021a). The final output of F-WASPAS is a k_i function that can help rank other alternatives. In this study, the F-WASPAS method has been expanded by the G-number and G-WASPAS method is used to rank the potential alternatives for landfilling hazardous waste. The steps of G-WASPAS method are as follows:

Step 1: Determination of the decision matrix with the G-number components as follows:

$$D = \begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{m1} & \cdots & d_{mn} \end{bmatrix}; d_{ij} = \left[\left(l_{ij}^s, m_{ij}^s, u_{ij}^s \right), \left(l_{ij}^t, m_{ij}^t, u_{ij}^t \right) \right]; i = 1, \dots, m; j = 1, \dots, n \quad (6)$$

Step 2: Linguistic variables are assigned to the decision matrix elements in the first step. Assume that the G-number is $G = (\tilde{I}_{ij}, \tilde{N}_{ij})$, where \tilde{I}_{ij} is the component of

importance and \tilde{N}_{ij} is the component of necessity and their values can be determined by specialists and experts from Table 3. For example, assuming that if the selection of specialists and experts is the importance of alternative i over criterion j equal to very high important (VHI) and its necessity equal to medium high necessity (MHN), G-number will be $[(9,10,10), (0.75,0.8,0.9)]$, and according to the conversion rules mentioned in Eq. (3), its value will be equal to $G = 8,938 \alpha - 0.812$. Other TFN-related conversions are shown in Table 4.

Step 3: According to the first and second steps, based on Eq. (7), the matrix related to the TFN is formed and the necessary transformations are performed.

$$\tilde{D} = \begin{bmatrix} (L_{11}^{\bar{d}}, M_{11}^{\bar{d}}, U_{11}^{\bar{d}}) & (L_{12}^{\bar{d}}, M_{12}^{\bar{d}}, U_{12}^{\bar{d}}) & \dots & (L_{1n}^{\bar{d}}, M_{1n}^{\bar{d}}, U_{1n}^{\bar{d}}) \\ \vdots & \ddots & \ddots & \vdots \\ (L_{m1}^{\bar{d}}, M_{m1}^{\bar{d}}, U_{m1}^{\bar{d}}) & (L_{m2}^{\bar{d}}, M_{m2}^{\bar{d}}, U_{m2}^{\bar{d}}) & \dots & (L_{mn}^{\bar{d}}, M_{mn}^{\bar{d}}, U_{mn}^{\bar{d}}) \end{bmatrix} \quad (7)$$

Step 4: In this step, the decision matrix is normalized (see Eq. 8).

$$\tilde{d}_{ij} = \begin{cases} \frac{\tilde{d}_{ij}}{\max \tilde{d}_{ij}} & \text{for } j \text{ beneficial} \\ \frac{\min \tilde{d}_{ij}}{\tilde{d}_{ij}} & \text{for } i \text{ non-beneficial} \end{cases}, \tilde{d}_{ij} = (L_{mn}^{\bar{d}}, M_{mn}^{\bar{d}}, U_{mn}^{\bar{d}}) \quad (8)$$

Step 5: The weight of the fuzzy normalized \tilde{d}_{ij} decision matrix for WSM and WPM using Eqs. (9 and 10), respectively, is calculated:

$$\tilde{Q}_i = \sum_{j=1}^n \tilde{d}_{ij} \tilde{w}_j \quad (9)$$

$$\tilde{P}_i = \prod_{j=1}^n \tilde{d}_{ij}^{\tilde{w}_j} \quad (10)$$

Then, by diffusing the above values, these values are converted to crisp numbers using Eqs. (11 and 12):

Table 3 Linguistic variables for different modes of ranking alternatives

Linguistic Variables (I)	TFN	Linguistic Variables (N)	TFN
Very High Important (VHI)	(9,10,10)	Very High Necessity (VHN)	(1,1,1)
High Important (HI)	(8,9,10)	High Necessity (HN)	(0.90,1,1)
Medium High Important (MHI)	(6,7.5,9)	Medium High Necessity (MHN)	(0.75,0.80,0.90)
Fair Important (FI)	(5,6,7)	Medium Necessity (MN)	(0.50,0.60,0.75)
Medium Low Important (MLI)	(3,4.5,6)	Medium Low Necessity (MLN)	(0.20,0.35,0.50)
Low Important (LI)	(1,2,3)	Low Necessity (LN)	(0.10,0.20,0.35)
Very Low Important (VLI)	(0,1,2)	Very Low Necessity (VLN)	(0,0.10,0.20)

Table 4 The rules for converting the G-number to TFN based on linguistic variables for ranking alternatives

Linguistics Variables	TFN Conversion	Linguistics Variables	TFN Conversion
(VHI,VHN)	$8.75\alpha + 1$	(FI,MLN)	$5.65\alpha + 0.35$
(VHI,HN)	$8.775\alpha + 0.975$	(FI,LN)	$5.788\alpha + 0.212$
(VHI,MHN)	$8.938\alpha + 0.812$	(FI,VLN)	$5.9\alpha + 0.1$
(VHI,MN)	$9.138\alpha + 0.612$	(MLI,VHN)	$3.5\alpha + 1$
(VHI,MLN)	$9.4\alpha + 0.35$	(MLI,HN)	$3.525\alpha + 0.975$
(VHI,LN)	$9.538\alpha + 0.212$	(MLI,MHN)	$3.688\alpha + 0.812$
(VHI,VLN)	$9.65\alpha + 0.1$	(MLI,MN)	$3.88\alpha + 0.612$
(HI,VHN)	$8\alpha + 1$	(MLI,MLN)	$4.15\alpha + 0.35$
(HI,HN)	$8.025\alpha + 0.975$	(MLI,LN)	$4.288\alpha + 0.212$
(HI,MHN)	$8.188\alpha + 0.812$	(MLI,VLN)	$4.4\alpha + 0.1$
(HI,MN)	$8.388\alpha + 0.612$	(LI,VHN)	$\alpha + 1$
(HI,MLN)	$8.65\alpha + 0.35$	(LI,HN)	$1.025\alpha + 0.975$
(HI,LN)	$8.788\alpha + 0.212$	(LI,MHN)	$1.188\alpha + 0.812$
(HI,VLN)	$8.9\alpha + 0.1$	(LI,MN)	$1.388\alpha + 0.612$
(MHI,VHN)	$6.5\alpha + 1$	(LI,MLN)	$1.65\alpha + 0.35$
(MHI,HN)	$6.525\alpha + 0.975$	(LI,LN)	$1.788\alpha + 0.212$
(MHI,MHN)	$6.688\alpha + 0.812$	(LI,VLN)	$1.9\alpha + 0.1$
(MHI,MN)	$6.88\alpha + 0.612$	(VLI,VHN)	1
(MHI,MLN)	$7.15\alpha + 0.35$	(VLI,HN)	$0.025\alpha + 0.975$
(MHI,LN)	$7.288\alpha + 0.212$	(VLI,MHN)	$0.188\alpha + 0.812$
(MHI,VLN)	$7.4\alpha + 0.1$	(VLI,MN)	$0.388\alpha + 0.612$
(FI,VHN)	$5\alpha + 1$	(VLI,MLN)	$0.65\alpha + 0.35$
(FI,HN)	$5.025\alpha + 0.975$	(VLI,LN)	$0.788\alpha + 0.212$
(FI,MHN)	$5.188\alpha + 0.812$	(VLI,VLN)	$0.9\alpha + 0.1$
(FI,MN)	$5.388\alpha + 0.612$		

$$\tilde{Q}_i = \frac{1}{3} (L_i^Q + M_i^Q + U_i^Q) \tag{11}$$

$$\tilde{P}_i = \frac{1}{3} (L_i^P + M_i^P + U_i^P) \tag{12}$$

Step 6: The numerical value of k related to alternative i is calculated in order to rank the optimal location for landfilling hazardous waste based on Eqs. (13 and 14):

$$k_i = \lambda \sum_{j=1}^m \bar{Q}_i + (1 - \lambda) \sum_{j=1}^m \bar{P}_i; 0 \leq \lambda \leq 1; 0 \leq k_i \leq 1 \tag{13}$$

$$\lambda = \frac{\sum_{i=1}^m \bar{P}_i}{\sum_{i=1}^m \bar{Q}_i + \sum_{i=1}^m \bar{P}_i} \tag{14}$$

4 Case study

The proposed method used in this study to solve a location problem has been used to select the best landfill for hazardous waste in a real area. The city of Tabriz, the capital of East Azerbaijan province, is located in the northwestern corner of Iran with an area of approximately 1781 square kilometers. For this reason, it is the third largest city in Iran (in terms of area). This city is located at 46- and 25-degree east longitude and 38- and 2-degree north latitude of the Greenwich meridian (Fig. 3). Its approximate altitude varies from 1300 to 2100 m above sea level. The city of Tabriz consists of two mountainous areas and a plain, the height of which is 1310 m above sea level and up to 2100 m in mountainous areas. The city is surrounded on the north and south by the mountains of Aun Ibn Ali (Eynali) and Sahand and has an average annual rainfall of 310 mm. Two rivers pass around and inside Tabriz: Talkhehroud or Ajichai, permanent rivers that pass through the northwest of the city and the seasonal river Qorichi, which joins Ajichai after passing through the center of Tabriz in the northwest of the city. According to the 1395 (2016) census, this city has a population of 1,733,033 people. According to the published statistics of Tabriz University of Medical Sciences, the city has 11 governmental educational hospitals, 8 non-governmental public hospitals, and 6 private. Total offices, laboratories, and other medical centers in Tabriz reach 5,071 units. According to the statistics published by the General Department of Environment of East Azerbaijan in 1397 (2018), the amount of hospital waste produced in Tabriz includes 1700 kg of infectious, 8345 kg of sharp, and 13,360 kg of household waste.

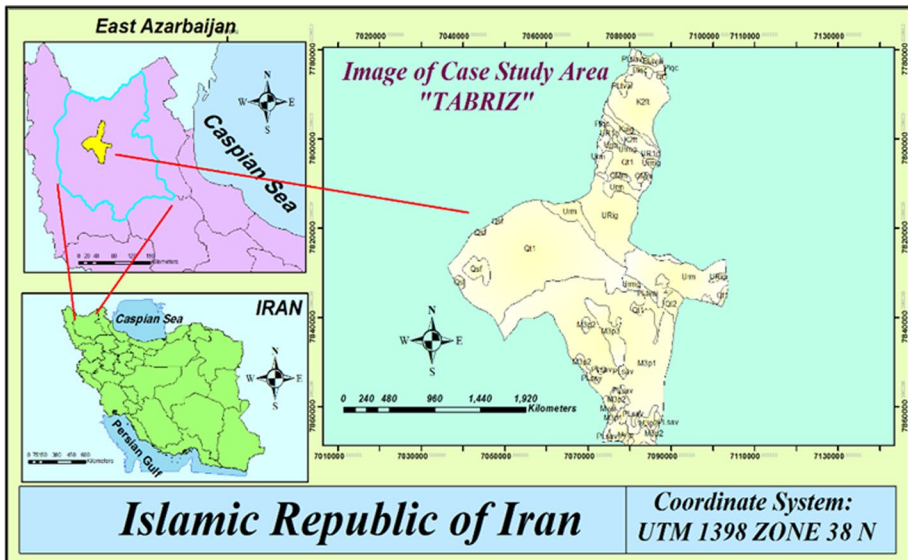


Fig. 3 Geographical location of Tabriz in the map of Iran

5 Analysis of the results

5.1 Selecting sustainable criteria and indicators for landfilling hazardous waste

At this stage, according to the field and geographical conditions of the region and previous polls and expert opinions, as well as environmental standards of Iran Department of Environment (IDOE), the selected factors have been determined based on three categories in thirteen criteria: A) environmental criteria including *C1* to *C8*; B) economic including *C9* and *C10* criteria; and C) social including *C11* to *C13*. These criteria are summarized in the following.

Distance from groundwater (C1): One of the most important threats to landfill hazardous waste is the production of leachate at the landfill, which pollutes groundwater resources. This issue is very important in Iran because it is located in one of the rain fed regions of the world and suffers from a lack of water resources.

Distance from the surface water (C2): The landfill should not be near surface water, as their leachate may enter water sources and contaminate surface water.

Distance from the fault (C3): The seismicity of the study area and the existence of seismic activity in different parts of the region indicate that it is geologically active and there is a network of active and seismic faults. For this purpose, the landfill site must be located at a suitable distance from the faults in order to prevent the risk of leakage of hazardous waste leachate.

Soil material (C4): In terms of soil science, the percentage of triple particles of clay, sand and silt, which determines the permeability of the soil, is very important in choosing the landfill site, which means that the higher the percentage of sand in the soil structure of the region, it becomes more permeable. The best type of soil for landfilling hazardous waste is soil that combines clay or silt with clay, as this type of soil has both good adhesion and low permeability.

Elevation (C5): Checking the height of the study area is another parameter that should be considered in locating the landfill site, because, first of all, areas with altitudes above sea level will have lower temperatures in the cold intervals of the year, which will cause problems in burying and covering the surface layer. Second, creating a hazardous landfill at a higher altitude is not cost-effective.

Land slope (C6): Land slope is significant for transportation and constructing access roads, as well as controlling surface water flow around the landfill (Liu et al., 2014). Any increase in slope leads to infiltration of contaminated leachate into adjacent demographic areas, especially to high-altitude changing areas. In this study, the slope map is calculated based on a 30-m digital map.

The amount of evaporation (C7): The presence of evaporation in different areas of an area will cause steam and increase the temperature and humidity. This will lead to greenhouse gases and CO₂ and other chemical gases in places that are used as landfills and as a result will cause unpleasant odors in the area and other contaminants.

Temperature (C8): Another criterion for choosing a landfill is the average annual temperature because low temperatures lead to severe problems in landfill operations. On the other hand, very high temperatures can lead to major problems such as higher levels of pollution and the spread of diseases and infections.

Distance from main road (C9): According to the environmental standard (Dong et al., 2020), if the landfill is far from the road, the cost of transporting waste will increase and

will not be affordable, and if it is close to the road, it will cause aesthetic problems and create a bad smell and scatter the garbage in the path of moving vehicles.

Land use (C10): Land use involves the use of land to meet various human needs. Agricultural, industrial, mineral, wildlife, and recreational lands are examples of land use. The value of land ownership depends on its type of use and also the type and severity of pollution is directly related to the usage. Therefore, before constructing a landfill site in the area, it is necessary to identify the different uses in it.

Urban Density (C11) and Rural Areas (C12): Dangerous waste landfills should be located away from urban areas and at a suitable distance from demographic and residential centers, because they will spoil the view of the city both aesthetically and will cause dissatisfaction among the people for health reasons. Considering that the amount of land suitable for choosing a landfill site will be very high, the cost of buying land for a landfill site near the city will be very high, which will be a negative factor economically, and the development and expansion of the city in the coming years should also be considered.

Distance from the airport (C13): According to the International Standards Guide, the minimum distance between the landfill site and the international airport must be more than 3 km in order to avoid the bird collection route. The city of Tabriz has an international airport that must comply with the necessary rules and regulations for locating a landfill site.

It should be noted that layers for locating problem solving are shown in Fig. 4. In this figure, maps (a) to (n), respectively, indicate “the elevated floors of the study area,” “distance from the airport,” “land use,” “distance from the flood (channel),” “slope of the study area,” “appropriate distance from groundwater (wells and aqueducts),” “the amount of evaporation,” “the amount of rain distribution,” “the distance from the main river,” “the distance from the fault,” “the distance from the urban centers,” “the distance from rural areas,” “the distance from the main road,” and “the type of soil.”

According to the contents mentioned in this section, the components of importance and necessity related to the G-number are used according to the experts. A three-member team specializing in waste management and the environmental organization has been used. The main criteria for selecting an expert in this research are work experience (more than 12 years of experience) and familiarity with the concepts of hazardous waste and environmental sustainability. Based on this, three specialists have been selected, including an environmental expert, a hazardous waste expert and a health expert with 12–15 and 13 years of experience, respectively. For example, the distance from surface waters such as a sub-river, where no water has flowed for decades due to drought, is of higher importance according to the standards. However, due to the necessity, it has a lower score. Appropriate and inappropriate intervals of each criterion are specified in Table 5.

5.2 Weighing the criteria by Group G-SWARA method

In this section, after identifying effective criteria in solving the problem of landfilling hazardous waste, these criteria are evaluated by a group of three environmental and waste management experts. Then, by solving Eq. (5), the weight of each of the criteria is obtained. As stated in Sect. 3.2, G-SWARA method involves group comparisons and has higher accuracy and less uncertainty, especially in the case of expert opinions. Table 6

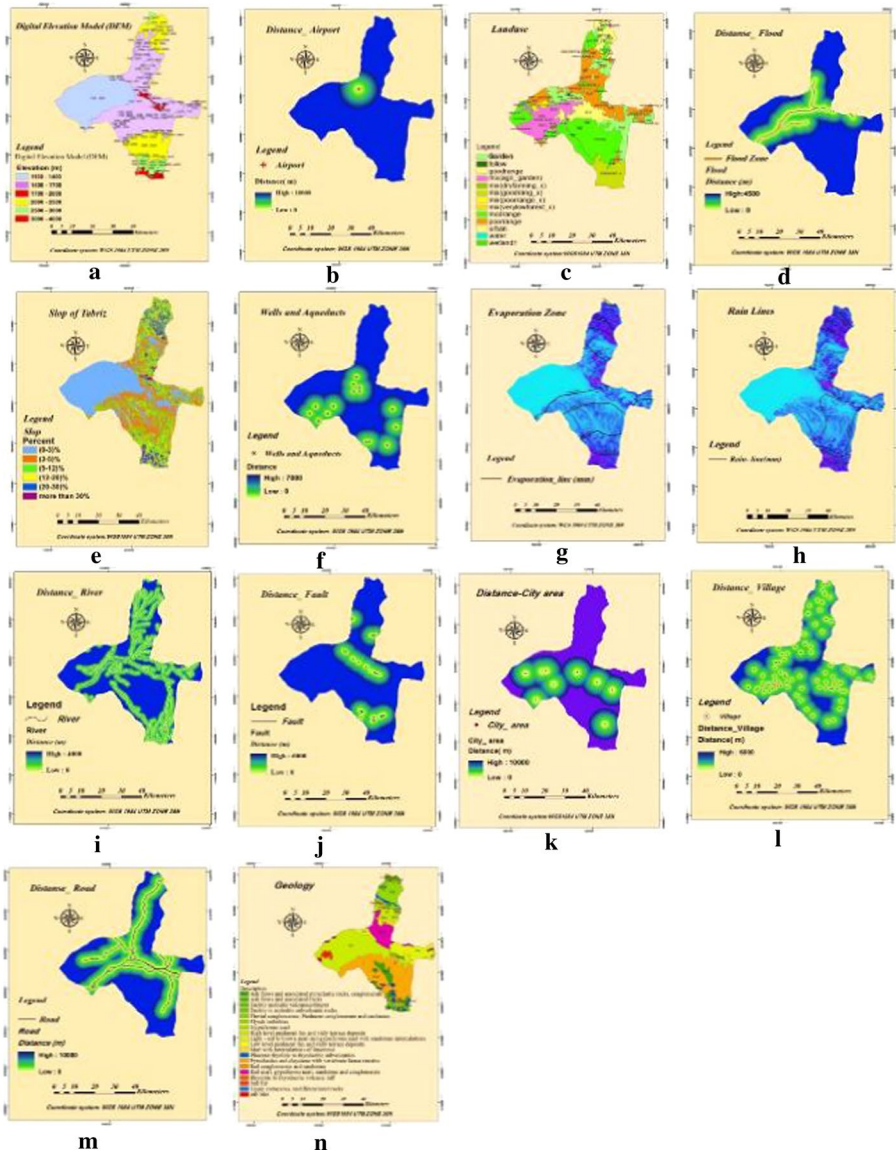


Fig. 4 Layers for locating problem-solving

indicates the priorities of identified criteria for landfilling hazardous waste based on the concept of necessity.

In the next step, for example, based on the opinion of DM1, the method of obtaining the weight of the criteria is presented through the G-SWARA method (Table 7). In the G-SWARA method, the Importance (α) and Necessity (β) for each specific case should be determined by the decision makers. Therefore, in this case, α and β have been identified equally to 0.5; it means that based on experts' recognition, the non-negative

Table 5 Standard distances of each criterion for locating hazardous waste landfills (Chabuk et al., 2016; Khoshand et al., 2018; Monavvari et al., 2012; Uyan, 2014)

I,N	Evaporate	River	Aqueduct	Geology*	Fault	Airport	Rain	Elevation	Slop	Land use	City	Village	Road
L	≥ 3000 mm	0–200	0–250	PcPh, K1c, J1, Plms, Qr	0–100, 100–400	0–3 km	750–900	≥ 2100	≤ 3% ≥ 30%	Residential areas, gardens	0–3 km	0–800	0–2 km, 18–20 km
VL													
ML	2250–3000	200–500	200–400	Qf1l, E1c, E2c, OM -ql, PTR	400–500	3–4 km	650–750	1950–2100	20–30%	Irrigated farming, cliffs, pasturages with high density	3–5 km	800–1.5 km	2–4 km, 16–18 km
M		500–1 km	400–1.5 km	Ksml, TRJs, Cl, com, Ek, Ekq		4–5.5 km	500–650			Pasturages with average density			4–6 km, 14–16 km
MH	1500–2250	1–3 km	1.5–5 km		1.5–5 km	5.5–7 km		1850–1950	12–20%	Pasturages with low density	5–7 km	1.5–2 km	6–8 km, 12–14 km
H	1000–1500			Qf2, Klsol, Pck, PCmt2			300–500	1750–1850	5–12%		7–10 km	2–3 km	8–10 km, 10–12 km
VH		≥ 3 km	≥ 5 km	Eabvt, Ogr-di	≥ 5 km	≥ 7 km	≤ 300 mm	1500–1750	3–5%	Uncultivated lands			

*PcPh limestone and sandstone; K1c red conglomerate and sandstone; J1 red mangiferous chert; Plms marl, shale, sandstone, and conglomerate; Qr: travertine; Qf1 high-level piedmont fan and valley terrace deposit; E1c pale red, polygenic conglomerate and sandstone; E2c sandstone (conglomerate); OM-ql massive too thick-bedded reefal limestone; PTR undifferentiated Permo-Triassic sedimentary rocks; Ksml dark gray shale and sandstone; TRJs marl, shale, sandy limestone, and sandy dolomite; Cl dark red medium-grained arkosic sandstone and micaceous siltstone (LALUN FM); com arkosic sandstone; Ek gypsum, marl, limestone; Ekqy marl, limestone; Qf2 low-level piedmont fan and valley terrace deposit; Klsol gray thick-bedded to massive orbitolina limestone; Pck dull green-gray salty shales with subordinate intercalation of quartzitic sandstone; PCmt2 low-grade, regional metamorphic rocks (green schist facies); Eabvt andesitic to basaltic volcanic tuff; Ogr-di granite to diorite. (Hariz et al., 2017; Sardar et al., 2018)

Table 6 Prioritization of the necessity criteria for landfilling hazardous waste according to experts

DM1	G-Number	DM2	G-Number	DM3	G-Number
River(C1)	(EI,HN)	River(C1)	(EI,HN)	River(C1)	(EI,HN)
Zheology(C4)	(E,H)	Zheology(C4)	(E,H)	Zheology(C4)	(E,H)
Slop(C6)	(E,M)	Aqueduct(C2)	(E,M)	Aqueduct(C2)	(E,M)
Aqueduct(C2)	(E,H)	Slop(C6)	(E,H)	Slop(C6)	(E,M)
Village(C11)	(MOL,VH)	Village(C11)	(E,VH)	Village(C11)	(E,H)
Urban density(C12)	(MOL,M)	Urban density(C12)	(E,VH)	Urban density(C12)	(MOL,M)
Road(C9)	(MOL,VH)	Rain Distribution(C8)	(E,VH)	Rain Distribution(C8)	(MOL,W)
Rain Distribution(C8)	(MOL,W)	Road(C9)	(MOL,VH)	Road(C9)	(MOL,M)
Fult(C3)	(VL,M)	Airport(C13)	(MOL,VH)	Airport(C13)	(MOL,VH)
Airport(C13)	(L,H)	Fult(C3)	(MOL,H)	Fult(C3)	(L,H)
Land use(C10)	(VL,M)	Evaporation(C7)	(L,VH)	Evaporation(C7)	(L,M)
Evaporation(C7)	(VL,W)	Elevation(C5)	(VL,M)	Elevation(C5)	(L,VH)
Elevation(C5)	(VL,W)	Land use(C10)	(VL,H)	Land use(C10)	(VL,M)

weights of Importance and Necessity have the same value in hazardous waste landfills selection. The final weights obtained from Eq. (5) in the final steps of the group G-SWARA method for the 13 criteria are shown in Table 8.

As mentioned, decision makers are confused about information and data in the real world. To reduce uncertainty in the ambiguity, the researchers introduced the fuzzy concept (Zadeh, 1965). Therefore, based on recent research in fuzzy numbers, it is possible to consider the concepts of necessity and importance that try to reduce the ambiguity of information in the data (Ghouschi & Khazaeili, 2019). According to Table 8, the ranking of the criteria by the G-SWARA method shows that the “distance from the river and geology” criterion has the highest score and the “height” criterion has the lowest score.

5.3 The GIS analysis based on the weights obtained by group G-SAWRA method

By displaying each criterion as a map in the GIS and using *Arc GIS 10.5* software and then by overlapping each of the criteria maps (layers), maps of the appropriate and inappropriate points of each class of criteria (environmental, economic, and social) were obtained by classification in GIS (Fig. 5: sections A to C). And by removing the inappropriate spots, the most suitable place for landfilling hazardous waste was obtained in 10 points with a total area of 1455.65 hectares (Fig. 5: sections D to E). These points indicate that the study area has the potential space required to accept the landfill of hazardous waste, including hospital infectious waste and so on. In Fig. 5, maps (A) to (D), respectively, show “the area of the study area,” “criteria used for this research,” “suitable and unsuitable location obtained in three social, environmental, and economic categories,” and “the suitable place for landfill waste based on the area of each point.”

Table 7 The result of calculating the weight of the criteria based on the opinion of the first expert (DM 1)

Criteria	G-Number	Convert	$\tilde{C}_j = \tilde{s}_j \oplus \tilde{I}$	$\tilde{q}_j = \frac{\tilde{q}_j - 1}{\tilde{C}_j}$	$\tilde{w}_j = \frac{\tilde{q}_j}{\sum_{j=1}^n \tilde{q}_j}$
River(C1)	(EI,HN)	(1, 1, 1)	(1.0000, 1.0000, 1.0000)	(1.0000, 1.0000, 1.0000)	(0.5070, 0.4970, 0.4840)
Zheology(C4)	(E,H)	(1, 1, 1)	(2.0000, 2.0000, 2.0000)	(0.5000, 0.5000, 0.5000)	(0.2530, 0.2480, 0.2420)
Slop(C6)	(E,M)	(1, 1, 1)	(2.0000, 2.0000, 2.0000)	(0.2500, 0.2500, 0.2500)	(0.1260, 0.1240, 0.1210)
Aqueduct(C2)	(E,H)	(1, 1, 1)	(2.0000, 2.0000, 2.0000)	(0.1250, 0.1250, 0.1250)	(0.0630, 0.0620, 0.0600)
Village(C11)	(MOL,VH)	(0.77, 1, 1.35)	(1.7700, 2.0000, 2.3500)	(0.0530, 0.0630, 0.0710)	(0.0260, 0.0310, 0.0340)
Urban density(C12)	(MOL,M)	(0.62, 0.93, 1.32)	(1.6200, 1.9300, 2.3200)	(0.0230, 0.0320, 0.0440)	(0.0110, 0.0160, 0.0210)
Road(C9)	(MOL,VH)	(0.77, 1, 1.35)	(1.7700, 2.0000, 2.3500)	(0.0100, 0.0160, 0.0250)	(0.0040, 0.0080, 0.0120)
Rain Distribution(C8)	(MOL,W)	(0.57, 0.85, 1.28)	(1.5700, 1.8500, 2.2800)	(0.0040, 0.0090, 0.0160)	(0.0020, 0.0040, 0.0070)
Fult(C3)	(VL,M)	(0.35, 0.46, 0.55)	(1.3500, 1.4600, 1.5500)	(0.0030, 0.0060, 0.0120)	(0.0010, 0.0020, 0.0050)
Airport(C13)	(L,H)	(0.52, 0.65, 0.77)	(1.5200, 1.6500, 1.7700)	(0.0020, 0.0040, 0.0080)	(0.0007, 0.0018, 0.0030)
Land use(C10)	(VL,M)	(0.35, 0.46, 0.55)	(1.3500, 1.4600, 1.5500)	(0.0010, 0.0030, 0.0060)	(0.0005, 0.0012, 0.0027)
Evaporation(C7)	(VL,W)	(0.31, 0.38, 0.51)	(1.3100, 1.3800, 1.5100)	(0.0010, 0.0020, 0.0040)	(0.0003, 0.0009, 0.0021)
Elevation(C5)	(VL,W)	(0.31, 0.38, 0.51)	(1.3100, 1.3800, 1.5100)	(0.0000, 0.0010, 0.0030)	(0.0002, 0.0006, 0.0016)

Table 8 The final weight of the 13 criteria by group G-SWARA method

Criteria	DM1	DM2	DM3	Final weight
River(C1)	(0.5070, 0.4970, 0.4840)	(0.5000, 0.5000, 0.4990)	(0.4900, 0.4000, 0.4800)	(0.5010, 0.4970, 0.4910)
Zheology(C4)	(0.2530, 0.2480, 0.2420)	(0.2500, 0.2500, 0.2490)	(0.2400, 0.2400, 0.2000)	(0.2500, 0.2400, 0.2450)
Slop(C6)	(0.1260, 0.1240, 0.1210)	(0.1250, 0.1250, 0.1240)	(0.2490, 0.2460, 0.2440)	(0.1250, 0.1240, 0.1220)
Aqueduct(C2)	(0.0630, 0.0620, 0.0600)	(0.0620, 0.0620, 0.0620)	(0.0600, 0.0600, 0.0600)	(0.0620, 0.0620, 0.0610)
Village(C11)	(0.0260, 0.0310, 0.0340)	(0.3120, 0.3170, 0.3180)	(0.0300, 0.0300, 0.0300)	(0.0290, 0.0310, 0.0320)
Urban density(C12)	(0.0110, 0.0160, 0.0210)	(0.0150, 0.0150, 0.0155)	(0.0160, 0.0180, 0.0190)	(0.0140, 0.0160, 0.0180)
Road(C9)	(0.0040, 0.0080, 0.0120)	(0.0070, 0.0078, 0.0077)	(0.0090, 0.0100, 0.0130)	(0.0070, 0.0090, 0.0100)
Rain Distribution(C8)	(0.0020, 0.0040, 0.0070)	(0.0034, 0.0039, 0.0042)	(0.0040, 0.0060, 0.0080)	(0.0030, 0.0040, 0.0060)
Fult(C3)	(0.0001, 0.0002, 0.0050)	(0.0015, 0.0019, 0.0023)	(0.0021, 0.0030, 0.0045)	(0.0010, 0.0020, 0.0040)
Airport(C13)	(0.0007, 0.0018, 0.0030)	(0.0006, 0.0009, 0.0013)	(0.0120, 0.0140, 0.0230)	(0.0008, 0.0010, 0.0020)
Land use(C10)	(0.0005, 0.0012, 0.0027)	(0.0003, 0.0005, 0.0007)	(0.0070, 0.0010, 0.0019)	(0.0005, 0.0010, 0.0017)
Evaporation(C7)	(0.0003, 0.0009, 0.0021)	(0.0002, 0.0003, 0.0005)	(0.0060, 0.0070, 0.0080)	(0.0003, 0.0006, 0.0012)
Elevation(C5)	(0.0002, 0.0006, 0.0016)	(0.0001, 0.0002, 0.0003)	(0.0002, 0.0004, 0.0007)	(0.0002, 0.0004, 0.0009)

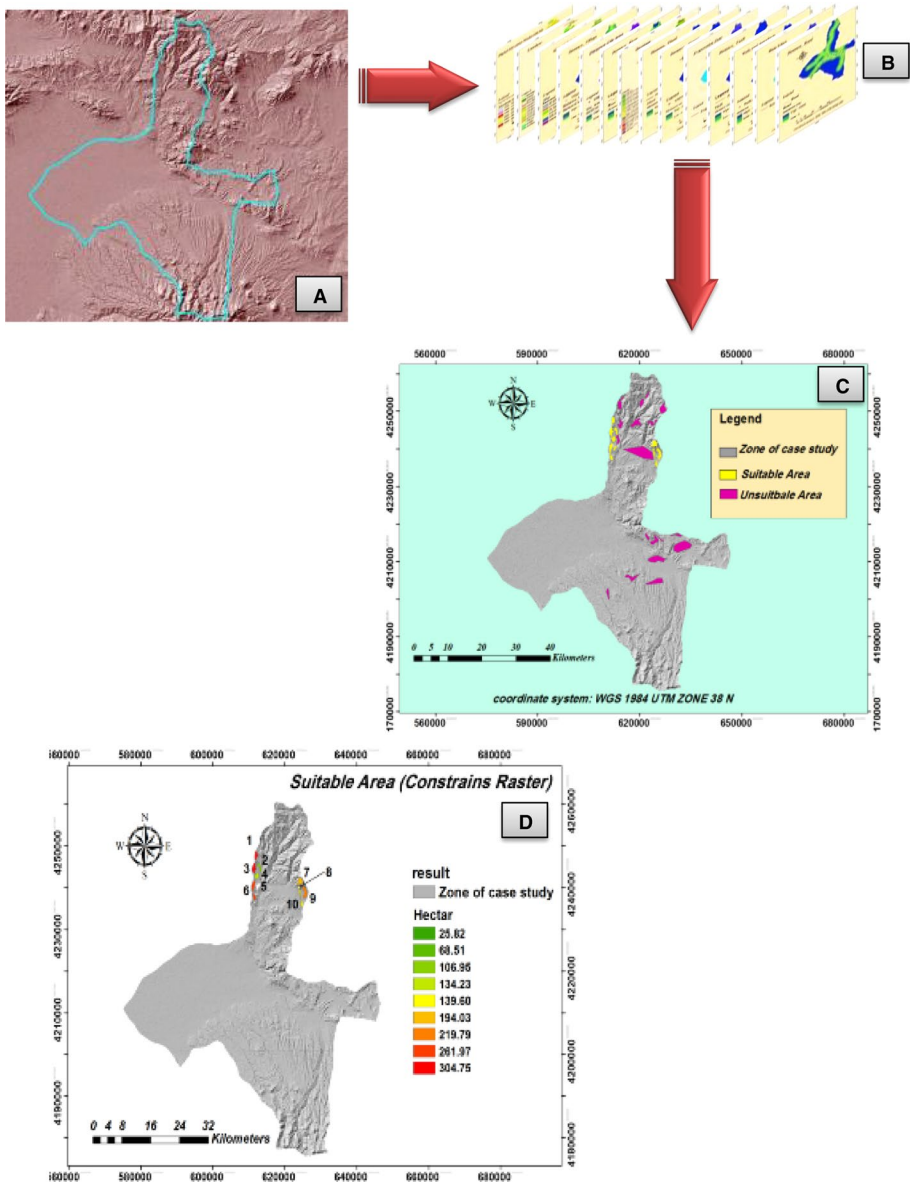


Fig. 5 The GIS analysis based on the obtained weights

5.4 Prioritization of selected sites by group G-WASPAS method

At this stage, in order to prioritize the alternatives obtained from the GIS step, the initial fuzzy decision matrix, in the form of G-number and considering the components of importance and necessity and in groups according to the expert opinions, and based on the first and second steps and Table 3 of the G-WASPAS method is written (Table 9).

Table 9 Matrix of linguistic variables based on G-number and expert opinions

	DM 1	DM 2	DM 3	DM 1	DM 2	DM 3	DM 1	DM 2	DM 3	DM 1	DM 2	DM 3
C1				C2			C3			C4		
A1	(V ₁ ,VH)	(V ₁ ,MH)	(G,VH)	(V ₁ ,M)	(V ₁ ,M)	(V ₁ ,M)	(ML,VH)	(F,H)	(ML,VH)	(H,M)	(H,M)	(H,M)
A2	(V ₁ ,MH)	(H,H)	(V ₁ ,MH)	(MH,L)	(F,L)	(MH,L)	(L,H)	(ML,VH)	(L,H)	(H,L)	(H,L)	(H,M)
A3	(MH,VH)	(MH,VH)	(MH,MH)	(F,VH)	(ML,H)	(F,VH)	(VL,MH)	(L,H)	(VL,MH)	(MH,VL)	(MH,VL)	(MH,VL)
A4	(H,H)	(H,H)	(F,VH)	(ML,H)	(ML,H)	(ML,H)	(ML,MH)	(H,MH)	(H,MH)	(F,MH)	(F,MH)	(F,MH)
A5	(H,MH)	(MH,VH)	(ML,H)	(V ₁ ,H)	(V ₁ ,VH)	(V ₁ ,H)	(H,M)	(MH,MH)	(MH,M)	(V ₁ ,M)	(V ₁ ,M)	(V ₁ ,M)
A6	(MH,MH)	(H,H)	(H,H)	(MH,MH)	(H,H)	(H,MH)	(MH,L)	(F,M)	(F,M)	(H,L)	(H,L)	(H,L)
A7	(H,M)	(MH,MH)	(MH,MH)	(H,M)	(MH,M)	(MH,M)	(MH,VL)	(MH,L)	(F,VL)	(V ₁ ,VL)	(V ₁ ,VL)	(H,VL)
A8	(MH,L)	(MH,M)	(VH,VH)	(MH,L)	(F,L)	(F,L)	(F,VH)	(F,H)	(ML,VH)	(V ₁ ,M)	(V ₁ ,M)	(V ₁ ,M)
A9	(F,VL)	(F,L)	(H,H)	(ML,L)	(ML,L)	(ML,L)	(ML,H)	(ML,H)	(L,H)	(H,L)	(H,L)	(H,L)
A10	(H,MH)	(ML,VL)	(MH,MH)	(L,VL)	(L,VL)	(L,VL)	(VH,MH)	(V ₁ ,M)	(V ₁ ,MH)	(V ₁ ,VL)	(V ₁ ,VL)	(H,VL)
C5				C6			C7			C8		
A1	(H,M)	(H,M)	(H,M)	(MH,M)	(MH,M)	(MH,M)	(VH,M)	(VH,M)	(VH,M)	(VH,M)	(VH,M)	(VH,M)
A2	(MH,L)	(H,M)	(MH,M)	(H,MH)	(H,MH)	(H,MH)	(MH,L)	(F,L)	(MH,L)	(F,L)	(F,L)	(MH,L)
A3	(H,VL)	(MH,L)	(H,L)	(MH,M)	(MH,M)	(MH,M)	(F,VH)	(ML,H)	(F,VH)	(ML,H)	(ML,H)	(F,VH)
A4	(MH,L)	(H,VL)	(MH,VL)	(H,L)	(H,L)	(H,L)	(ML,H)	(ML,H)	(ML,H)	(ML,L)	(ML,L)	(ML,VL)
A5	(F,VL)	(F,M)	(F,M)	(V ₁ ,M)	(V ₁ ,M)	(V ₁ ,M)	(V ₁ ,H)	(VH,VH)	(V ₁ ,H)	(VH,VH)	(VH,H)	(VH,H)
A6	(F,M)	(F,L)	(F,L)	(MH,MH)	(MH,MH)	(MH,MH)	(H,MH)	(H,H)	(VH,MH)	(H,H)	(VH,MH)	(H,MH)
A7	(ML,L)	(ML,VL)	(ML,VL)	(ML,VL)	(F,M)	(F,M)	(MH,M)	(MH,M)	(H,M)	(MH,M)	(H,M)	(MH,M)
A8	(ML,VL)	(L,M)	(ML,M)	(H,VH)	(H,VH)	(H,VH)	(F,L)	(F,L)	(MH,L)	(F,L)	(MH,M)	(F,L)
A9	(L,H)	(VL,H)	(L,H)	(L,H)	(L,H)	(L,H)	(ML,L)	(ML,L)	(ML,L)	(ML,L)	(ML,L)	(ML,L)
A10	(VL,MH)	(L,MH)	(VL,MH)	(VL,MH)	(VL,MH)	(VL,MH)	(L,VL)	(L,VL)	(L,VL)	(L,VL)	(L,VL)	(L,VL)
C9				C10			C11			C12		
A1	(F,H)	(ML,VH)	(F,H)	(H,M)	(H,M)	(H,M)	(ML,VH)	(ML,VH)	(F,H)	(F,H)	(F,H)	(ML,VH)
A2	(ML,VH)	(L,H)	(ML,VH)	(MH,M)	(MH,L)	(H,M)	(ML,VH)	(L,H)	(ML,VH)	(ML,VH)	(ML,VH)	(ML,VH)
A3	(L,H)	(VL,MH)	(L,H)	(H,L)	(H,VL)	(MH,L)	(L,H)	(VL,MH)	(L,H)	(L,H)	(L,H)	(L,H)
A4	(H,MH)	(VH,MH)	(H,MH)	(MH,VL)	(MH,L)	(H,VL)	(H,MH)	(VH,MH)	(H,MH)	(H,MH)	(H,MH)	(VH,MH)

Table 9 (continued)

	DM 1	DM 2	DM 3	DM 1	DM 2	DM 3	DM 1	DM 2	DM 3	DM 1	DM 2	DM 3
A5	(MH, MH)	(MH, M)	(MH, MH)	(F, M)	(F, VL)	(F, M)	(MH, MH)	(H, M)	(MH, MH)	(MH, MH)	(MH, MH)	(H, M)
A6	(F, M)	(F, L)	(F, M)	(F, L)	(F, M)	(F, L)	(F, M)	(MH, L)	(F, M)	(F, M)	(F, M)	(MH, L)
A7	(MH, L)	(F, VL)	(MH, L)	(ML, VL)	(ML, L)	(ML, VL)	(MH, L)	(MH, VL)	(MH, L)	(MH, L)	(MH, L)	(MH, VL)
A8	(F, H)	(ML, VH)	(F, H)	(ML, M)	(ML, VL)	(L, M)	(F, H)	(F, VH)	(F, H)	(F, H)	(F, H)	(F, VH)
A9	(ML, H)	(L, H)	(ML, H)	(L, H)	(L, H)	(VL, H)	(ML, H)	(ML, H)	(ML, H)	(ML, H)	(ML, H)	(ML, H)
A10	(VH, M)	(VH, MH)	(VH, MH)	(VL, MH)	(VL, MH)	(L, MH)	(VH, M)	(VH, MH)	(VH, M)	(VH, M)	(VH, M)	(VH, MH)
C13												
A1	(F, H)	(F, H)	(ML, VH)	(ML, VH)	(F, H)	(ML, VH)	(ML, VH)	(ML, VH)	(ML, VH)	(ML, VH)	(ML, VH)	(ML, VH)
A2	(ML, VH)	(ML, VH)	(L, H)	(L, H)	(ML, VH)	(L, H)	(L, H)	(L, H)	(L, H)	(L, H)	(L, H)	(L, H)
A3	(L, H)	(L, H)	(VL, H)	(VL, H)	(L, H)	(VL, H)	(VL, H)	(VL, H)	(VL, H)	(VL, H)	(VL, H)	(VL, H)
A4	(H, MH)	(H, MH)	(VH, MH)	(VH, MH)	(H, MH)	(VH, MH)	(VH, MH)	(VH, MH)	(VH, MH)	(VH, MH)	(VH, MH)	(VH, MH)
A5	(MH, MH)	(MH, MH)	(H, M)	(H, M)	(MH, MH)	(H, M)	(H, M)	(H, M)	(H, M)	(H, M)	(H, M)	(H, M)
A6	(F, M)	(F, M)	(MH, L)	(MH, L)	(F, M)	(MH, L)	(MH, L)	(MH, L)	(MH, L)	(MH, L)	(MH, L)	(MH, L)
A7	(MH, L)	(MH, L)	(MH, VL)	(MH, VL)	(MH, L)	(MH, VL)	(MH, VL)	(MH, VL)	(MH, VL)	(MH, VL)	(MH, VL)	(MH, VL)
A8	(F, H)	(F, H)	(F, VH)	(F, VH)	(F, H)	(F, VH)	(F, VH)	(F, VH)	(F, VH)	(F, VH)	(F, VH)	(F, VH)
A9	(ML, H)	(ML, H)	(ML, H)	(ML, H)	(ML, H)	(ML, H)	(ML, H)	(ML, H)	(ML, H)	(ML, H)	(ML, H)	(ML, H)
A10	(VH, M)	(VH, M)	(VH, MH)	(VH, MH)	(VH, M)	(VH, MH)	(VH, M)	(VH, MH)	(VH, M)	(VH, M)	(VH, M)	(VH, MH)

To rank the alternatives by group method based on Eq. (7) in the third step of G-WASPAS, the group decision matrix turns into a matrix of TFNs. The columns of this matrix are related to the alternatives (suggested locations for landfilling hazardous waste) and the rows represent the criteria determined by the experts based on the importance and necessity of G-number. These obtained results are shown in Table 10. In the following, the fuzzy values presented in Table 10 are normalized according to Eq. (8) in the fourth step of G-WASPAS. The outputs of implementation of this method are shown in Table 11.

Also, based on Eqs. (9 and 10) of the group G-WASPAS method, the values of Q_i and P_i are calculated, and these calculations are shown in Table 12. To facilitate the calculation of these numbers, based on Eqs. (11 and 12) in the fifth step, they have converted to crisp numbers.

Finally, based on Eq. (13) in the sixth step of the G-WASPAS method, alternatives are ranked by considering $\lambda=0.4676$, the results of which are shown in Table 13. Based on the available findings, the comparison of outputs of conventional WASPAS method with the new methods of the F-WASPAS and the group G-WASPAS methods with $\alpha = 0.5$ is shown in Table 14.

According to Table 14, site number 1 with 261.97 hectares is ranked first and site number 10 is ranked 10 when the conventional method of WASPAS is used. In contrast, in order to reduce uncertainty in pairwise comparisons, the F-WASPAS method was used in the ranking, so sites 6 and 7 were ranked first and second and site 5 was ranked third in Table 14 with three points decrease. This suggests that prioritization, based on current methods, has not been fully implemented due to the lack of weighting on each of the points obtained from the GIS, and this leads to confusion among experts and decision makers in the field of planning. In the proposed method, using the group G-WASPAS method and considering the components of importance and necessity independently, according to experts and specialists, has led to solving the problem of incomplete prioritization. Therefore, in order to reduce ambiguity in pairwise comparisons of criteria and alternatives, the G-WASPAS method was proposed. As a result, areas 6, 10, and 7 were ranked first to third, respectively, as suitable and sustainable sites for landfilling hazardous waste. It is necessary to explain that the way the mathematical model works in the mentioned methods is the same and the authors have made an unbiased comparison between these methods and have preserved the nature of pairwise comparisons which is the main input of this model. The change in the results presented in Table 14 is only due to the simultaneous consideration of the components of importance and necessity in an uncertainty environment using the proposed method of this study.

5.5 Sensitivity analysis

Sensitivity analysis is a typical measure to quantify the impact of uncertainty on overall simulation/prediction uncertainty. A variety of sensitivity analysis techniques have been developed (Helton, 1993; Saltelli, 2004). In this study, the rank of criteria has been obtained based on a different value of α . According to the experts, a balance value contributed to the Importance and Necessity components. In this regard, a sensitivity analysis has been done for case study to demonstrate the ranking and consistency rate in different scenarios.

Table 15 shows the rank of criteria in case study by considering different values for α . It seems that in all scenarios, criterion C1 is ranked 1 and criterion C5 is ranked 13.

Table 10 The conversion of linguistic variables related to ranking of alternatives based on expert opinions

	C1	C2	C3	C4	C5	C6	C7
A1	(2.67, 4.18, 5.95)	(4.48, 5.95, 6.88)	(2.03, 3.50, 5.27)	(5.28, 6.40, 7.23)	(1.35, 2.98, 4.75)	(5.22, 6.82, 7.88)	(3.13, 4.90, 6.43)
A2	(3.72, 5.48, 7.25)	(2.02, 3.62, 5.38)	(1.60, 2.60, 4.13)	(5.27, 6.62, 7.68)	(2.07, 3.10, 4.50)	(4.02, 5.35, 6.68)	(2.77, 4.53, 6.30)
A3	(3.80, 5.57, 7.33)	(4.18, 5.95, 7.63)	(1.88, 3.05, 4.52)	(4.02, 5.35, 6.68)	(0.97, 2.00, 3.60)	(4.33, 6.10, 7.73)	(0.23, 1.00, 2.77)
A4	(2.53, 3.73, 5.28)	(1.87, 2.93, 4.70)	(4.23, 6.00, 7.53)	(4.33, 6.10, 7.73)	(5.83, 6.13, 7.40)	(2.85, 4.37, 6.13)	(5.75, 7.28, 8.28)
A5	(2.70, 4.20, 5.83)	(2.25, 3.88, 5.65)	(4.70, 5.78, 6.78)	(2.85, 4.37, 6.13)	(6.97, 8.37, 9.23)	(4.20, 5.28, 6.28)	(6.63, 8.00, 8.83)
A6	(2.50, 3.80, 5.33)	(0.23, 0.95, 2.42)	(6.68, 8.15, 9.08)	(4.65, 6.42, 8.02)	(4.62, 5.92, 6.98)	(6.68, 8.15, 9.08)	(7.00, 8.53, 9.53)
A7	(4.93, 6.45, 7.68)	(0.80, 1.87, 3.63)	(4.18, 5.40, 6.63)	(3.42, 5.18, 6.82)	(6.23, 8.00, 9.23)	(3.72, 4.93, 6.40)	(2.72, 4.48, 6.25)
A8	(6.75, 7.83, 8.53)	(4.90, 6.43, 7.43)	(3.15, 4.48, 6.02)	(1.50, 2.40, 4.00)	(1.37, 2.00, 3.40)	(1.52, 2.62, 4.38)	(0.70, 1.40, 2.63)
A9	(4.72, 6.18, 7.65)	(5.93, 7.30, 8.13)	(3.33, 5.10, 6.57)	(4.42, 5.53, 6.53)	(0.83, 1.80, 3.17)	(1.23, 2.40, 3.87)	(1.70, 3.23, 5.00)
A10	(5.52, 7.28, 8.75)	(4.07, 5.83, 7.60)	(3.73, 5.50, 6.97)	(6.32, 7.72, 8.58)	(6.37, 7.97, 9.03)	(5.60, 7.13, 8.13)	(6.72, 8.12, 8.98)
	C8	C9	C10	C11	C12	C13	
A1	(6.63, 8.00, 8.83)	(1.02, 2.78, 4.55)	(4.55, 6.18, 7.28)	(2.67, 4.28, 6.05)	(0.23, 0.95, 2.42)	(1.37, 2.00, 3.40)	
A2	(7.00, 8.53, 9.53)	(3.25, 5.02, 6.78)	(6.23, 7.60, 8.43)	(3.27, 5.03, 6.80)	(0.80, 1.87, 3.63)	(4.33, 6.10, 7.73)	
A3	(2.72, 4.48, 6.25)	(7.12, 8.72, 9.70)	(3.63, 5.40, 7.17)	(3.40, 5.17, 6.93)	(4.90, 6.43, 7.43)	(2.85, 4.37, 6.13)	
A4	(0.70, 1.40, 2.63)	(2.33, 3.40, 5.17)	(4.80, 6.57, 8.25)	(0.72, 1.73, 3.27)	(5.93, 7.30, 8.13)	(3.72, 4.93, 6.40)	
A5	(1.70, 3.23, 5.00)	(6.32, 7.72, 8.58)	(6.27, 7.87, 8.93)	(0.37, 1.25, 2.85)	(4.07, 5.83, 7.60)	(1.52, 2.62, 4.38)	
A6	(6.72, 8.12, 8.98)	(3.13, 4.45, 5.98)	(6.62, 8.02, 8.88)	(2.65, 4.15, 5.78)	(0.83, 1.80, 3.17)	(1.23, 2.40, 3.87)	
A7	(0.23, 1.00, 2.77)	(0.37, 1.27, 3.03)	(3.73, 5.20, 6.43)	(4.03, 5.40, 6.63)	(6.37, 7.97, 9.03)	(0.97, 2.00, 3.60)	
A8	(5.75, 7.28, 8.28)	(3.03, 4.80, 6.57)	(2.55, 4.08, 5.85)	(7.20, 8.43, 9.13)	(0.23, 0.95, 2.42)	(5.83, 6.13, 7.40)	
A9	(0.70, 1.93, 3.70)	(7.57, 8.97, 9.73)	(6.47, 8.07, 9.13)	(4.47, 6.23, 7.60)	(4.33, 6.10, 7.73)	(6.97, 8.37, 9.23)	
A10	(1.40, 2.23, 3.60)	(5.47, 7.07, 8.13)	(6.55, 8.08, 9.08)	(5.33, 6.87, 8.00)	(2.85, 4.37, 6.13)	(1.70, 3.23, 5.00)	

Table 11 Normalization of fuzzy values obtained from scoring options by experts

	C1	C2	C3	C4	C5	C6	C7
A1	(2.67, 4.18, 5.95)	(4.48, 5.95, 6.88)	(2.03, 3.50, 5.27)	(5.28, 6.40, 7.23)	(1.35, 2.98, 4.75)	(5.22, 6.82, 7.88)	(3.13, 4.90, 6.43)
A2	(3.72, 5.48, 7.25)	(2.02, 3.62, 5.38)	(1.60, 2.60, 4.13)	(5.27, 6.62, 7.68)	(2.07, 3.10, 4.50)	(4.02, 5.35, 6.68)	(2.77, 4.53, 6.30)
A3	(3.80, 5.57, 7.33)	(4.18, 5.95, 7.63)	(1.88, 3.05, 4.52)	(4.02, 5.35, 6.68)	(0.97, 2.00, 3.60)	(4.33, 6.10, 7.73)	(0.23, 1.00, 2.77)
A4	(2.53, 3.73, 5.28)	(1.87, 2.93, 4.70)	(4.23, 6.00, 7.53)	(4.33, 6.10, 7.73)	(5.83, 6.13, 7.40)	(2.85, 4.37, 6.13)	(5.75, 7.28, 8.28)
A5	(2.70, 4.20, 5.83)	(2.25, 3.88, 5.65)	(4.70, 5.78, 6.78)	(2.85, 4.37, 6.13)	(6.97, 8.37, 9.23)	(4.20, 5.28, 6.28)	(6.63, 8.00, 8.83)
A6	(2.50, 3.80, 5.33)	(0.23, 0.95, 2.42)	(6.68, 8.15, 9.08)	(4.65, 6.42, 8.02)	(4.62, 5.92, 6.98)	(6.68, 8.15, 9.08)	(7.00, 8.53, 9.53)
A7	(4.93, 6.45, 7.68)	(0.80, 1.87, 3.63)	(4.18, 5.40, 6.63)	(3.42, 5.18, 6.82)	(6.23, 8.00, 9.23)	(3.72, 4.93, 6.40)	(2.72, 4.48, 6.25)
A8	(6.75, 7.83, 8.53)	(4.90, 6.43, 7.43)	(3.15, 4.48, 6.02)	(1.50, 2.40, 4.00)	(1.37, 2.00, 3.40)	(1.52, 2.62, 4.38)	(0.70, 1.40, 2.63)
A9	(4.72, 6.18, 7.65)	(5.93, 7.30, 8.13)	(3.33, 5.10, 6.57)	(4.42, 5.53, 6.53)	(0.83, 1.80, 3.17)	(1.23, 2.40, 3.87)	(1.70, 3.23, 5.00)
A10	(5.52, 7.28, 8.75)	(4.07, 5.83, 7.60)	(3.73, 5.50, 6.97)	(6.32, 7.72, 8.58)	(6.37, 7.97, 9.03)	(5.60, 7.13, 8.13)	(6.72, 8.12, 8.98)
	C8	C9	C10	C11	C12	C13	
A1	(6.63, 8.00, 8.83)	(1.02, 2.78, 4.55)	(4.55, 6.18, 7.28)	(2.67, 4.28, 6.05)	(0.23, 0.95, 2.42)	(1.37, 2.00, 3.40)	
A2	(7.00, 8.53, 9.53)	(3.25, 5.02, 6.78)	(6.23, 7.60, 8.43)	(3.27, 5.03, 6.80)	(0.80, 1.87, 3.63)	(4.33, 6.10, 7.73)	
A3	(2.72, 4.48, 6.25)	(7.12, 8.72, 9.70)	(3.63, 5.40, 7.17)	(3.40, 5.17, 6.93)	(4.90, 6.43, 7.43)	(2.85, 4.37, 6.13)	
A4	(0.70, 1.40, 2.63)	(2.33, 3.40, 5.17)	(4.80, 6.57, 8.25)	(0.72, 1.73, 3.27)	(5.93, 7.30, 8.13)	(3.72, 4.93, 6.40)	
A5	(1.70, 3.23, 5.00)	(6.32, 7.72, 8.58)	(6.27, 7.87, 8.93)	(0.37, 1.25, 2.85)	(4.07, 5.83, 7.60)	(1.52, 2.62, 4.38)	
A6	(6.72, 8.12, 8.98)	(3.13, 4.45, 5.98)	(6.62, 8.02, 8.88)	(2.65, 4.15, 5.78)	(0.83, 1.80, 3.17)	(1.23, 2.40, 3.87)	
A7	(0.23, 1.00, 2.77)	(0.37, 1.27, 3.03)	(3.73, 5.20, 6.43)	(4.03, 5.40, 6.63)	(6.37, 7.97, 9.03)	(0.97, 2.00, 3.60)	
A8	(5.75, 7.28, 8.28)	(3.03, 4.80, 6.57)	(2.55, 4.08, 5.85)	(7.20, 8.43, 9.13)	(0.23, 0.95, 2.42)	(5.83, 6.13, 7.40)	
A9	(0.70, 1.93, 3.70)	(7.57, 8.97, 9.73)	(6.47, 8.07, 9.13)	(4.47, 6.23, 7.60)	(4.33, 6.10, 7.73)	(6.97, 8.37, 9.23)	
A10	(1.40, 2.23, 3.60)	(5.47, 7.07, 8.13)	(6.55, 8.08, 9.08)	(5.33, 6.87, 8.00)	(2.85, 4.37, 6.13)	(1.70, 3.23, 5.00)	

Table 12 Qi and Pi values of WSM and WPM

Alternatives	WPM	Pi	WSM	Qi
	Product	Crisp	Sum	Crisp
A1	(0.479, 0.541, 0.903)	0.65761	(0.180, 0.419, 1.038)	0.54548
A2	(0.496, 0.611, 0.965)	0.69063	(0.195, 0.440, 1.052)	0.56207
A3	(0.472, 0.567, 0.849)	0.62924	(0.180, 0.407, 0.930)	0.50592
A4	(0.512, 0.624, 0.971)	0.70237	(0.195, 0.441, 0.097)	0.57770
A5	(0.529, 0.644, 1.011)	0.72797	(0.206, 0.451, 1.179)	0.61168
A6	(0.613, 0.801, 1.421)	0.94520	(0.272, 0.602, 2.164)	1.01274
A7	(0.556, 0.675, 1.067)	0.76622	(0.238, 0.495, 1.252)	0.66161
A8	(0.538, 0.599, 0.843)	0.66010	(0.247, 0.464, 1.006)	0.57220
A9	(0.526, 0.611, 0.851)	0.66286	(0.221, 0.456, 0.946)	0.54122
A10	(0.610, 0.732, 1.056)	0.79963	(0.282, 0.570, 1.151)	0.66766
	Σ	7.24181	Σ	6.25830

Table 13 The final result of the ranking of the necessary options for landfilling hazardous waste

Alternatives	Qi	Pi	Ki	Rank
A1	0.5455	0.65761	0.59746	9
A2	0.5621	0.69063	0.62167	6
A3	0.5059	0.62924	0.56309	10
A4	0.5777	0.70237	0.6355	5
A5	0.6117	0.7280	0.66559	4
A6	1.0127	0.9452	0.98143	1
A7	0.6616	0.76622	0.7101	3
A8	0.5722	0.6601	0.61295	7
A9	0.5412	0.66286	0.59761	8
A10	0.6677	0.79963	0.72884	2

Table 14 Comparison of three different methods of ranking hazardous waste landfills

Alternatives	WASPAS		F-WASPAS		G-WASPAS	
	Score	Rank	Score	Rank	Score	Rank
A1	0.496681	1	0.64615	4	0.59746	9
A2	0.248341	2	0.60694	5	0.62167	6
A3	0.12417	3	0.4373	8	0.56309	10
A4	0.062085	4	0.30923	10	0.6355	5
A5	0.030963	5	0.65552	3	0.66559	4
A6	0.016657	6	0.8054	1	0.98143	1
A7	0.009112	7	0.72956	2	0.7101	3
A8	0.005072	8	0.34594	9	0.61295	7
A9	0.002875	9	0.47068	7	0.59761	8
A10	0.001662	10	0.57018	6	0.72884	2

Table 15 Sensitivity analysis for different values of α in case study

Criteria	Scenario 0 ($\alpha=0$, $\beta=1$)	Scenario 1 ($\alpha=0.1$, $\beta=0.9$)	Scenario 2 ($\alpha=0.2$, $\beta=0.8$)	Scenario 3 ($\alpha=0.3$, $\beta=0.7$)	Scenario 4 ($\alpha=0.4$, $\beta=0.6$)	Scenario 5 ($\alpha=0.5$, $\beta=0.5$)	Scenario 6 ($\alpha=0.6$, $\beta=0.4$)	Scenario 7 ($\alpha=0.7$, $\beta=0.3$)	Scenario 8 ($\alpha=0.8$, $\beta=0.2$)	Scenario 9 ($\alpha=0.9$, $\beta=0.1$)	Scenario 10 ($\alpha=1$, $\beta=0$)
C1	1	1	1	1	1	1	1	1	1	1	1
C2	4	4	5	4	4	4	3	3	4	5	4
C3	9	8	9	9	8	9	8	9	9	8	6
C4	3	2	3	2	2	2	4	2	2	2	5
C5	13	13	13	13	13	13	13	13	13	13	13
C6	2	3	2	3	3	3	2	4	3	3	2
C7	11	12	12	12	11	12	12	12	12	12	11
C8	8	9	8	8	9	8	9	8	8	9	8
C9	7	6	7	7	6	7	7	7	7	7	9
C10	10	11	11	11	10	11	11	11	11	11	10
C11	5	5	4	5	7	5	5	5	5	4	3
C12	6	7	6	6	5	6	6	6	6	6	7
C13	12	10	10	10	12	10	10	10	10	10	12

6 Conclusion

In the recent years, importance of the elimination of waste has been increased in order to control its adverse effects on environment. In this regard, sustainable landfill site selection for hazardous waste is turned into important problem. This study tried to present an integrated SWARA-WASPAS-GIS framework based on G-number theory by considering uncertainty in decision-making process. The use of G-number theory in the decision-making process is to eliminate ambiguity while considering the components of importance and necessity simultaneously. Therefore, the results are close to reality. In addition, it can be used as a model for location issues, especially in cities with similar geographical and environmental conditions. Studying the location of hazardous and sustainable landfills with a proposed approach has the following theoretical and practical benefits: (1) The G-SWARA and group G-WASPAS methods provide managers with the opportunity to reflect their decisions more effectively and realistically because real data on the location of hazardous waste landfills are, to some extent, associated with uncertainty. (2) In this study, various quantitative and qualitative criteria were examined in three categories. It is clear that real criteria lead to more accurate results. (3) The results of this study, which are based on a combined decision-making process, can provide good guidance for managers related to the waste and the environment organization. For future studies, researchers can implement the proposed method in other case studies with the aim of verifying its capability and applicability in various fields. Besides, the G-numbers theory can be synchronized with other MCDM methods and group decision making to reduce the ambiguity of information in the process of ranking various alternatives. The limitations of this study include the lack of causal relationships between the criteria that can be addressed using fuzzy cognitive mapping based on G-numbers theory, and we will conduct our research by integrating MCDM methods into spherical fuzzy sets.

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