Comparative analytical study of the results of environmental risk assessment of urban landfills approach: bowtie, network analysis techniques (ANP), TOPSIS (case study: Gilan Province)

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Abstract  Most landfill projects run in a dynamic and complex environment; therefore, uncertainty and risk are inherent. To improve the performance and reduce the damage caused by waste, risk study and its management have become necessary in implementing landfill location projects. As a result of the biodegradation of organic matter in waste, landfills produce various materials such as leachate, and gas. Therefore, it is necessary to conduct environmental risk assessments so that the destructing factors and their effects on the environment can be identified, and subsequently, control and management solutions offered. In the present study, the author has identified the most critical risks of construction phases and operation of landfills in Gilan province, using the Analytic Network Process (ANP), Delphi, and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) techniques. According to the results, the environmental sector represents the highest risk in the construction and operation phases. Therefore, solutions for reducing or eliminating adverse outcomes have been proposed according to the bowtie method. Solutions to reduce or eliminate the adverse effects of leachate leakage from the landfill floor that causes pollution and infiltration into groundwater: installation of a conventional control system. Routing of landfill gases by passing soil filters at the highest points of landfills using the bowtie method is recommended. The results showed that anthropogenic activities related to sanitary landfilling of waste have greatly affected Gilan province in recent years.

Keywords  Risk assessment · Landfill · BowTie software · Analytic Network Process · TOPSIS

Introduction

In the areas where waste disposal projects are carried out, sensitive and vulnerable environmental conditions are created for the receiving environment. These projects can affect the quality of underground water, air quality, soil, and existing habitats. They cause dangers such as fire, explosion, accidents, and encroachment of manpower and machinery. The existence of these broad dimensions and the risk-taking nature of these types of projects make it inevitable and necessary to conduct environmental risk assessment studies in landfills. Conducting risk assessment studies in this research is important from the point of view that the issue of urban waste landfills can be approved among construction plans and projects. These projects have short- and long-term effects on the environment during the
construction and operation stages. Increasing population growth in developing countries has produced significant solid waste, posing an environmental challenge locally and globally (Paul et al., 2019; Van Fan et al., 2018). Landfilling is currently a common method of disposal that minimizes health and environmental hazards (Ahuwalia & Patel, 2018; Paul et al., 2019; Yousefian et al., 2020). Risk assessment refers to identifying, analyzing, and systematically addressing risks. Assessing occupational risks in landfills reduces the health and safety effects. Unnatural deaths, congenital disabilities, outbreaks of cancers, respiratory diseases, reduced mental health, and increased cardiovascular disease are adverse consequences of landfills (Thongyuan et al., 2021; Vinti et al., 2021). One of the most critical challenges in the risk assessment process is the impact of expert judgment on risk assessment and prioritization (Aminbakhsh et al., 2013; Linkov et al., 2006). A study by Salvaraji et al. (2020) indicates that the collection of waste simultaneously increases the risk of exposure to hazardous substances. Due to the COVID-19 pandemic, workers collecting and transporting waste are among the most at-risk groups, and biological agents remain a risk factor for employees until preventive measures are taken (Salvaraji et al., 2020). Si et al. (2012), in their research, stressed the high level of poisoning risk to residents in material leaks. According to a study by Salhofer et al. (2008), preventive measures in waste management have the highest efficiency, priority, and lowest costs (Guerrero et al., 2013; Zohoori & Ghani, 2017). The study results conducted by Chen (2007) show that the most critical ecological risks in the area are the threat to the health of residents, soil pollution around the landfill, and reduced habitat security.

A combination of decision-making methods and risk assessment methods can be utilized to minimize the effect of the specialist review. Decision analysis techniques allow reasoning in conditions of uncertainty (Brown, 2012; Wang et al., 2004). Decision-making processes comprehensively identify the best alternatives available. The model “multiple criteria decision-making” (MCDM) can make decisions more efficient and transparent. For this reason, decision criteria must be weighed. Weighting should be done for all options according to the purpose of the research (Bell et al., 2003; Mühlbacher & Kaczynski, 2016). The network analysis process (ANP) model was used to improve the accuracy in identifying landfill risks and reducing environmental hazards (Ferretti, 2011; Tuzkaya et al., 2008). The results of the research by Saleh et al., 2020) have shown that the environmental effects of the landfill in the operation phase are less than in the construction phase. An ANP hybrid multi-criteria decision-making technique can prioritize risks or aspects based on their importance (Dada, 2021; Fauzey et al., 2015). The ANP method forms a nonlinear network or system in cases where the interdependencies are two-way. It can be very effective to use the ANP method because the risk factors are interconnected. Tamošaitienė et al. (2021) used the Delphi method to prioritize risk. They identified significant environmental risks and then evaluated and prioritized the parameters using the TOPSIS method. The bowtie model actually combines an error tree diagram and an event tree to show risk control parameters to reduce risks (Ferdous et al., 2013). The bowtie model is a structured technique for risk assessment in cases where qualitative approaches seem inappropriate in performance. Given the nature of the landfill, identifying hazards (Das et al., 2021) in the risk and determining a solution to control them in the form of a risk assessment process is inevitable; therefore, the use of Bowtie software has the advantage of extracting quantitative results. Safety and environmental risk assessments are commonly applied to places and workers but are often overlooked by the general public and surrounding areas. Used in assessing safety hazards and assessing important environmental aspects. One of the most powerful and increasingly popular risk assessment models is the bowtie method. This approach is similar in nature to conventional risk management. It is important because of the connection between risk control and management system. Also, in addition to analysis, this method can also help to feel confident in accurate risk management. Therefore, the combination of ANP and TOPSIS method with bowtie results are more accurate.

**Materials and methods**

**Introduction of the study area**

The first step to knowing exactly the impact of activities in each project is to determine the scope of studies. The study scope is classified into two areas: the implementation site and the environmental area, which is the area of project implementation directly affected by the implementation operation and its consequences. All construction operations, installation of facilities and equipment, machine traffic, and other functions related to the project are carried out during the construction phases and process
at the construction site. Environmental area refers to the area that is directly and indirectly affected by the effects of project implementation.

The general situation of waste disposal in Gilan province

In many large population centers like Gilan province, problems of urban waste disposal are exacerbated by climatic, cultural, and geographical characteristics and natural circumstances like high groundwater stagnation, sociocultural, and economic conditions, and poor urban planning. Given that the sanitary landfill project is carried out in two phases, this study can help identify the risks in the construction and operation phases. A sanitary landfill does waste disposal in Gilan province. In this province, there are 23 landfills with an area of 126 hectares. These landfills receive more than 1500 tons of waste per day. The largest landfill in Gilan province is Saravan, with a landfill capacity of 750 tons per day. Saravan forest waste landfill surveys reveal that the selected site is unsuitable for the environment. Due to the increased leachate production, the area topography, and its proximity to the rivers, the leachate is disposed of in the Siahroud (Zarjoub) river, which has polluted a large area in the region. About 25 hectares of forest land in this area have been destroyed so far. If we assume the current trend continues and consider the population growth factor, the number of landfill sites in the next 25 years will reach about 45 hectares, which means the destruction of another 20 hectares of Saravan forest lands in near future. One of the main objectives of this study is to identify and prioritize the risk of municipal landfills. In a way that is easy to understand risk can be managed more effectively. One of the problems for landfill project managers is identifying and dealing with potential risks; identifying and prioritizing risks is an essential issue in management. Using the results of this study, the risks of landfill projects in the construction and operation phase can be reduced. These landfills pose a major threat to the degradation and depletion of ecosystem resources and services. Using the bowtie model can control, prevent, and reduce the environmental, health, and safety effects of landfills in Guilan province. Figure 1 shows the landfill and leachate infiltration into surface water.

Gilan province has an area of 14,000 km². The geographical coordinates are 36° and 33 min to 38° and 27 min north latitude and 48° and 32 min to 50° and 36 min east longitude. The amount and specification of waste landfills in Gilan and the location of the mentioned projects are presented in Table 1. Surveys show that the spatial distribution of the population and the population share in the urban settlements of Gilan province are not balanced. The cities located in the Jalgei region have a higher population share. The cities located in the southern mountains have a smaller share of the population distribution. Meanwhile, Rasht City has more than 46% of the urban population. This is the reason why Rasht City has the highest statistics for waste production. Access roads to waste disposal centers are in relatively good condition. There is not much traffic in the area.

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**Fig. 1** The landfill and leachate infiltration into surface water
Figure 2 shows the distribution of urban waste disposal and access roads to waste disposal centers in Gilan province. There are 23 landfills in this province. The highest amount of waste is produced in Rasht (750 tons per day). The area allocated to this municipal waste landfill is very small. Rasht is the capital of Gilan province. The lowest waste production is in Pareh Sar (6 tons per day).

This research is practical in terms of purpose and is descriptive-analytical based on the type of method. In this research, the bowtie method has been used as the primary method, and the Delphi method, Analytic Network Process (ANP), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) technique have been used as complementary methods. To determine the number of required experts, ten questionnaires were completed by ten experts as a pre-test. According to the obtained standard deviation and degree of freedom 1, the confidence interval of 0.96 was obtained by Cochran’s relation of 9.4. To increase the accuracy, ten people were considered experts (number of samples). The reliability of the questionnaires was calculated by Cronbach’s alpha coefficient of 0.96, so it can be regarded as reliable. Figure 3 shows a diagram of the implementation of the risk assessment process showing a comparative analysis of municipal landfills.

The weighting of indicators using the network analysis process (ANP)

By reviewing similar articles and research, conducting field visits to the region, and using land evaluation and planning reports, the required information was collected, and study areas were identified. Then, using the Delphi technique, high risks were identified.

To determine the activities and essential effects of waste disposal operations, it is necessary to form an expert group to complete the ANP model questionnaire and comment on the activities and possible risks in the waste disposal process.

Network model construction: the acquisition of weights and the importance of factors are determined using Eq. (1). In this equation, \( n \) represents the number of criteria/options, and \( N_c \) represents the number of pairwise comparisons. In completing the pairwise comparison questionnaire, the nine spectra suggested by Sa’ati in Table 2 have been used. In this step, a network structure and a list of interdependencies are drawn between their components.

\[
N_c = n.(n - 1)/2
\]  

(1)

Forming a matrix of pairwise comparisons and calculating weight vectors related to each criterion and option: at this stage, the vectors of each criterion and option were calculated for each expert through pairwise comparisons according to Eq. (2).

\[
A = \begin{bmatrix}
1 & a_{12} & \cdots & a_{1n} \\
a_{21} & 1 & \cdots & a_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
a_{n1} & a_{n2} & \cdots & 1
\end{bmatrix}
\]

(2)

In this study, to complete the results, it is necessary to take the geometric mean according to Eq. (3) from all the matrices obtained from Delphi experts. In this relation, \( A_{ij} \) represents the element obtained from the

| No | City          | Population | Landfill rate (tons per day) | Area (hectares) |
|----|---------------|------------|------------------------------|-----------------|
| 1  | Rasht         | 748,711    | 750                          | 20              |
| 2  | Asalem        | 10,040     | 10                           | 2               |
| 3  | Astara        | 62,814     | 50                           | 50              |
| 4  | Astane Ashrafieh | 58,963  | 40                           | 15              |
| 5  | Kiashahr      | 13,753     | 20                           | 4               |
| 6  | Langarud      | 101,782    | 75                           | 5               |
| 7  | Manjil        | 17,396     | 10                           | 1               |
| 8  | Rahimabad     | 30,166     | 12                           | 4               |
| 9  | Lushan        | 15,193     | 20                           | 4               |
| 10 | Rezvanshahr   | 27,535     | 35                           | 8               |
| 11 | Anzali        | 118,564    | 50                           | 4               |
| 12 | Siahkhal—Lahijan | 21,653 | 170                          | 10              |
| 13 | Talesh        | 780,360    | 60                           | 8               |
| 14 | Amlash        | 17,598     | 20                           | 1               |
| 15 | Rudbar        | 58,354     | 20                           | 1               |
| 16 | Lissar        | 3262       | 8                            | 1               |
| 17 | Havigh        | 4194       | 7                            | 1               |
| 18 | Rudsar        | 73,709     | 80                           | 2               |
| 19 | Klachai       | 36,366     | 15                           | 2               |
| 20 | Wajargah      | 4522       | 8                            | 1               |
| 21 | Chaboksar     | 25,004     | 10                           | 5               |
| 22 | Pareh Sar     | 7626       | 6                            | 3               |
| 23 | Rostamabad    | 13,749     | 8                            | 5               |

Table 1 Amount and characteristics of landfills and population centers in Gilan
Fig. 2 Distribution of municipal waste disposal and access roads to burial centers in Gilan province

Geometric mean, $n$ is the number of people who made a pairwise judgment, and $k$ represents the personal code that caused the comparison.

$$A_{ij} = \prod_{k=1}^{n} (a_{ij}^{k})^{1/n}$$  \hspace{1cm} (3)

In the next step, using Eq. (4), the normalization for the criteria, options, and weight vector was calculated. Then, the normalized weight was obtained by taking the arithmetic mean of each row of the group matrix. In this relation, $r_{ij}$ represents the normalized element corresponding to a pairwise comparison matrix row.

$$r_{ij} = \frac{a_{ij}}{\sum_{i=0}^{m} a_{ij}}$$  \hspace{1cm} (4)

Formation of an unweighted supermatrix: super matrix represents the relationships between network components.
based on the weight vectors obtained from the previous step following Eq. (5),

$w = \begin{bmatrix} \text{Goal} & \text{Criteria} & \text{Alternative} \\ 0 & 0 & 0 \\ w_{21} & w_{22} & w_{23} \\ 0 & w_{32} & 1 \end{bmatrix}$

(5)

Table 2 Nine-point spectrum of degree of criteria preference in pairwise comparisons (Saaty, 1990)

| Verbal expressions           | Degree of importance |
|-----------------------------|----------------------|
| Equal importance            | 1                    |
| Poor importance             | 3                    |
| Strong importance           | 5                    |
| Extreme importance          | 7                    |
| Absolute importance         | 9                    |
| The degree of importance    | 2, 4, 6, 8           |
| between the two preferences |                      |

where $w_{21}$ represents the vector that determines the effect of the target on each of the criteria, the $w_{22}$ vector represents the internal relationship of the criteria, and the $w_{32}$ weight vector indicates the impact of each criterion on the options. Since factors can be affected by each other on the same level, the sum of the weights in the columns will not be equal to one. To solve this problem, the matrix is obtained in a weighted way according to the step.

Calculation of weighted supermatrix: a weighted supermatrix has been obtained by the product of each parameter of the column clusters of an unweighted supermatrix by the relative weight vector of that cluster.

Limited supermatrix calculation: by powering all the elements of the supermatrix, a weighted supermatrix is obtained. This operation is repeated until all the elements of the supermatrix are the same, the elements of the matrix converge, and their row values are equal. The final weights of the three parameters of

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Fig. 3 Implementation of the risk assessment process comparative analysis of urban landfills

Table 2

| Verbal expressions        | Degree of importance |
|---------------------------|----------------------|
| Equal importance          | 1                    |
| Poor importance           | 3                    |
| Strong importance         | 5                    |
| Extreme importance        | 7                    |
| Absolute importance       | 9                    |
| The degree of importance  | 2, 4, 6, 8           |

The degree of importance between the two preferences.
consequence intensity (C), exposure rate (E), and probability of occurrence (P) were calculated. The final weights were considered to obtain the risk score (R) of each of the hazardous sources (units or activities under consideration at landfills that are risky) to obtain a rating; the Risk score was calculated using Eq. (6).

\[ R = W_C \times C \times W_E \times E \times W_P \times P \]  (6)

Prioritization risks using the TOPSIS technique

Data matrix formation based on m option by n index:

\[ A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix} \]  (7)

Descaling the decision matrix (N) in Eq. (8): normal distribution is used for descaling. The probability distribution of each element \((n_{ij})\) is calculated from the decision matrix.

\[ n_{ij} = \frac{a_{ij}}{\sqrt{\sum_{j=1}^{n} a_{ij}^2}} \]  (8)

Weighted descaled matrix \((V)\), Eq. (9): the descaled matrix is multiplied by a square matrix \((w \times n)\) whose principal diameter elements are the weights of the indices, and the other elements are zero.

\[ V = N \times w_{n \times n} \]  (9)

Determining the ideal positive and negative solution: in this study, for the positive ideal, the maximum numerical value of each column, and for the negative ideal, the minimum numerical value of each column was considered in the weighted descaled matrix.

The distance between each option and the positive and negative ideals

The Euclidean distance of each positive ideal choice \((d_i^+)\) and the distance of each option to the negative ideal \((d_i^-)\) is calculated based on Eq. (10).

\[ d_i^+ = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_{i+})^2} \ , \quad i = 1, 2, \ldots d_i^- \]

\[ d_i^- = \sqrt{\sum_{j=1}^{n} (V_{ij} - V_{i-})^2} \ , \quad i = 1, 2, \ldots m \]  (10)

Determining the relative proximity \((CL_i)\) of each option (risk) to the ideal solution: the relative proximity of \(A_i\) to the ideal solution was calculated using Eq. (11). Ranking options (risks): any option with a larger CL is better.

\[ CL_i = \frac{d_i^- + d_i^+}{d_i^- + d_i^+} \quad (i = 1, 2, \ldots, n) \]  (11)

If \(A_i = A_i^+\), then \(d_i^- = 0\), and \(CL_i^+ = 1\), and if \(A_i = A_i^-\), then \(d_i^- = 0\) and \(CL_i^- = 0\). Therefore, the closer the \(A_i\) risk is to the ideal solution, the closer its value \(CL_i\) will be to one.

Implementation of bowtie process

**Identification of the study area (landfills)**

At this stage, all the information on the landfills was collected to identify and assess health, safety, and environmental risks.

**Risk identification**

At this stage, observation, face-to-face interviews, and reports of personal incidents that occurred in landfills were conducted and reviewed. Using the proposed bowtie risk matrix, the identified risks were analyzed, ranked, and their risk levels were determined. The importance of this stage should not be overlooked, because not identifying potential risks means ignoring the consequences and effects.

**Determining the main event**

At this stage, considering the necessity of landfills and the range of consequences of occurrence in terms of safety, health, environment, socio-economic, and cultural risks among the high-risk levels, five hazards were considered the main event in high-risk areas in landfill bowtie method. After determining the main
events as software input, bowtie for each event, the following steps were performed in order:

1. Identification of threats: this process continued until all main event threats were identified. For each event, one or more threats have been identified that cause the main hazard.
2. Identification of controls: this step identified all the controls that existed for each threat and consequence.
3. Identification of aggravating factors in the failure of controls: each of the controls may fail for various reasons. In this part, all the failure factors of the controls were identified, and there may be one or more failure factors for each control. Aggravating factors increase the level of risk by failing controls.
4. Identification of the consequences: in this step, all the related consequences or the main event caused by any threat were identified. Each threat may have one or more consequences.
5. Identification of recovery measures: at this stage, recovery measures were identified to reduce the effects of each consequence. Each result was determined by one or more recovery actions, and the individual or group responsible for performing or following them was identified.
6. Identification of the failure of recovery measures: each of the identified recovery measures may fail for various reasons, at which point all the failure causes were identified. Each recovery measure may have one or more failure factors.
7. Identification of the failure control of recovery measures: in this step, one or more controls were identified for each failure factor.
8. All of the above were entered in the BowTie ProTM software, and the relevant diagrams were drawn. Figure 4 illustrates the structure of the bowtie model.

Correction: action is taken to eliminate non-conformity risk in the construction phase and operation in waste landfills.

Action: action is taken to eliminate the cause of non-compliance in adverse conditions. Action solves the problem more profoundly.

Improvement: a way to fight is to not repeat mistakes. It is continuous identification, analysis of changes, and modification of existing risks in landfills. By improving

![Fig. 4 Bowtie model structure](image.png)
### Table 3  Final results of identification of landfill risks by Delphi method

| Construction phase risk identification | Identification of operational phase risk |
|----------------------------------------|----------------------------------------|
| Machinery colliding with equipment     | Staff fall into leachate recirculation pool |
| Overturning machines from the walls    | Blockage of leachate collection and conduction channels |
| Falling from a height                  | Occurrence of fire |
| Occurrence of fires in landfills, workshops, machinery, and equipment | Collision of waste handling machines with leachate system pipes |
| Machinery collision with workforce     | Disease prevalence |
| Collision of construction machinery with leachate system pipes | Occurrence of road accidents |
| Incidence of various diseases          | Bites of reptiles and rodents |
| Cutting the cables and crane restraint belts | Malfunction of recirculation pumps |
| Falling of concrete pipes, electric poles, concrete walls during handling and installation | Respiratory injuries and skin complications |
| Occurrence of road accidents           | Blockage of the aeration ducts |
| Incidence of skin complications and respiratory injuries stress for the seasonal habitat of migratory birds | Machinery collision with equipment, workers, and employees |
| Disease transmission                   | Leakage of oil and petroleum products (fuel) |
| Increased suspended particles in the air | Leakage from the floor of the landfill |
| Decreased biodiversity                 | Stress for the seasonal habitat of migratory birds |
| Noise pollution                        | Disease transmission |
| Creating tension for livestock         | Dissolution, suspension of materials and products resulting from biological changes in leachate |
| Corrosion caused by the acidic environment | Evaporation of chemical compounds and water in gases from municipal waste |
| Soil corrosion                         | Environmental |
| Geographical events (floods, earthquakes, and landslides) | Blockage of leachate collection and conduction system |
| Leakage of oil and petroleum products (fuel) from machinery and fuel storage tanks | Subsidence of landfills that cause cracks and tears in the surface and cover |
| High costs of the landfill project     | Breakage and disruption of facilities and equipment settings |
| Failure of landfilling                  | Blockage of the aeration ducts |
| Psychological tensions between human resources | Improper operation of the leachate recirculation system |
| Occurrence of local conflicts          | High costs of control and development of engineering-sanitary landfill |
| High health costs due to burial operations accidents | Lack of proper coverage of management changes, difficulties, and consequences of replacement |
|                                        | Economic, social, and cultural |
|                                        | Reduction of spatial restrictions |
|                                        | Occurrence of local conflicts |
|                                        | Plan failure |
|                                        | Psychological tensions between workers and employees |
the risks, it is possible to make sure that the conditions of the waste disposal site are at an acceptable and desirable level. The importance of process improvement is to the extent that it reduces the wastage of resources and facilities in organizations, increases efficiency, increases the sharing of ideas, and makes more effective use of existing resources.

**Result and discussion**

Using the Delphi questionnaire to identify the factors and classify the risks of landfilling in Gilan province during construction and operation, we have identified critical risks separately.

The final results of the Delphi technique

Sixty-one risks were identified in the construction and operation phase of landfills. Several indicators were simplified. Related indices were obtained using the Delphi method. Among these identified risks, two risks were identified: the accumulation of sanitary and industrial wastes in the place and the creation of road traffic without a significant impact. Table 3 shows the final results of the Delphi questionnaire.

Considering the spatial characteristics of the landfill, the affected environment, and the types of risks arising from the network structure project were drawn based on the purpose of the research, as shown in Fig. 5.

According to the purpose of the research, the relationship within the sub-criteria was determined. The weight of the criteria and sub-criteria obtained in the construction and operation phases are shown in Tables 4 and 5.

The results of the Analytic Network Process (ANP) show that in the construction phase, the safety and

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**Fig. 5** Construction of a model related to effective indicators in assessing the risk of landfilling in the construction phase
health factor of fire in landfills, and workplaces, with a weight of 0.0556, is the priority, and the incidence of various diseases with a weight of 0.0459 is the second priority. Also, prioritizing the risks in the construction phase of the corrosive environmental factor caused by the acidic environment weighing 0.0573 is the priority, and creating stress for the seasonal habitat of migratory birds weighing 0.0543 is the second priority. The results of prioritization in the construction phase of economic, social, and cultural factors show that the high costs of implementing the landfill project with a weight of 0.0354 are the priority, and the landfill failure with a weight of 0.0336 is the second priority.

According to the operation factor results, the occurrence of fire and arson with a weight of 0.0391 is the priority. The second priority is the blockage of collection and conduction of leachate with a weight of 0.0325. According to the prioritization of risks in the operation phase of the environmental factor, leakage from the landfill floor weighing 0.0473 is the priority, and improper operation of the leachate recirculation system weighing 0.0465 is the second priority. In the operation phase, it was found that high costs of control

| Weight and rank of the principal factors | Sub-risk factors                                                                 | Relative weight | Final weight |
|----------------------------------------|---------------------------------------------------------------------------------|----------------|--------------|
| Health-safety                          | Collision of metal parts with workforce                                       | 0.0984710      | 0.032444     |
|                                        | Machinery colliding with equipment                                             | 0.1098005      | 0.036177     |
|                                        | Overturning machines from the walls                                            | 0.0811840      | 0.026748     |
|                                        | Falling from a height                                                         | 0.1048410      | 0.035611     |
|                                        | Occurrence of fires in landfills, workshops, machinery, and equipment          | 0.1689201      | 0.055656     |
|                                        | Machinery collision with workforce                                            | 0.1096259      | 0.036119     |
|                                        | Collision of construction machinery with leachate system pipes                 | 0.1298495      | 0.042783     |
|                                        | Incidence of various diseases                                                  | 0.1395012      | 0.045963     |
|                                        | Cutting the cables and crane restraint belts                                   | 0.1084312      | 0.035726     |
|                                        | Falling of concrete pipes, electric poles, concrete walls during handling and installation | 0.0898705 | 0.029610     |
|                                        | Occurrence of road accidents                                                   | 0.1106588      | 0.036460     |
|                                        | Incidence of skin complications and respiratory injuries                       | 0.1068450      | 0.035203     |
| Environmental                         | stress for the seasonal habitat of migratory birds                            | 0/140867       | 0.054323     |
| stress for the seasonal habitat of migratory birds | Disease transmission               | 0/107854       | 0.0415592    |
|                                        | Increased suspended particles in the air                                       | 0/109574       | 0.042255     |
|                                        | Decreased biodiversity                                                        | 0/097118       | 0.037452     |
|                                        | Noise pollution                                                               | 0/098641       | 0.038039     |
|                                        | Creating tension for livestock                                                 | 0/095005       | 0.036637     |
|                                        | Corrosion caused by the acidic environment                                     | 0/148752       | 0.057363     |
|                                        | Soil corrosion                                                                | 0/110897       | 0.042765     |
|                                        | Geographical events (floods, earthquakes, and landslides)                     | 0/134582       | 0.051899     |
|                                        | Leakage of oil and petroleum products (fuel) from machinery and fuel storage tanks | 0/102757 | 0.039626     |
| Economic, social, and cultural         | High costs of the landfill project                                            | 0/124312       | 0.0354144    |
| cultural                               | Failure of landfilling                                                        | 0/118132       | 0.0336538    |
|                                        | Psychological tensions between human resources                                | 0/083212       | 0.0237056    |
|                                        | Occurrence of local conflicts                                                  | 0/078241       | 0.0222895    |
|                                        | High health costs due to burial operations accidents                           | 0/09377        | 0.0267125    |
and development of engineering-health landfill with a weight of 0.0275 are the priority, and lack of proper management coverage (management changes, difficulties, and consequences of replacement) with a weight of 0.250 is the second priority. Figure 6 shows the prioritization of risks in the construction and operation stages according to the purpose of the research. These four factors are the leading risk indicators that are of equal importance. (Environmental risk = affected area × consequence × probability rate). (Health safety risk = exposure rate × consequence × probability). So, all four indicators receive priority one and a weight of 0.25.

Table 6 shows the geometric matrix of the comparison of risk indicators in terms of goals. The first
line compares the amount of contact, the amount of probability, the amount of consequence, and the range under the effect compared to the target, which is the risk assessment of the burial place.

Prioritization of construction phase indicators over risk and consequence

In the landfill of Gilan province, most of the risks are environmental risks. Table 7 results have higher consequences and risk probability in the operation phase than in the construction phase. The consequence rate of the environmental index weighing 0.508 is higher than the safety and health index weighing 0.353. The risk probability in the ecological index weighing 0.721 is higher than the security and health index weighing 0.163.

Prioritization of health and safety risks of the construction phase in terms of consequences, risk, exposure, and affected area

Fires in workshop landfills, machinery, and equipment during work and consequences such as inhalation of harmful substances may cause acute and chronic illness or poisoning in workers. These fires in landfills can be allergenic and carcinogenic (Herrero et al., 2020). Since 75% of landfills in Gilan province are located in forests, this causes deforestation, which can be very dangerous to health. Cadmium (Ishchenko & Vasylkivskyi, 2020; Lakhouit & Alsulami, 2020), lead, asbestos in waste, and hardwood dust can cause skin inflammation, eczema, asthma, or other chronic diseases. Smoke from fires in large quantities causes lung irritation. Among the safety-health risks in Table 10, the construction phase is prioritized in terms of fire risk consequences in landfills, workshops, machines, and equipment with a weight of 0.121, with a more destructive effect than other risks. In the matrix of comparing health safety risks to the probability index, the risk of construction machinery colliding with leachate conduction system pipes weighing 0.210 is given priority in the first place, and the rest are placed in the following priorities. One of the biggest problems in the landfill is the collision of machines with leachate pipes, which will have various consequences, and there is no control in the factory. In health safety factors, the risk of road accidents is the priority in exposure with a weight of 0.212.

| Table 6 | Geometric matrix of the comparison of the indicators of the risks of the waste landfill in terms of the target |
|---------|----------------------------------------------------------------------------------------------------------------|
| Risks of the landfill | Affected range | The amount of contact | Risk probability | Consequence |
| Affected range | | | | |
| The amount of contact | 1 | | | |
| Risk probability | 1 | 1 | | |
| Consequence | 1 | 1 | 1 | |
In Table 8 matrix comparing health and safety risks concerning the consequence rate, the risk of fire and arson with a weight of 0.272 is the priority, and the rest are the following priorities. Health and safety risks of the operation phase and the risk of fires and arson occurring every day are given the highest

| Exposure rate | Risk probability | Consequence | Health-safety risks                                                                 | Phase          |
|---------------|------------------|-------------|-------------------------------------------------------------------------------------|----------------|
| 0/0731        | 0/1221           | 0/1213      | Occurrence of fires in landfills, workshops, machinery, and equipment                | Construction   |
| 0/1211        | 0/2101           | 0/1130      | Collision of construction machinery with leachate system pipes                      | Construction   |
| 0/0625        | 0/1522           | 0/1109      | Incidence of various diseases                                                       | Construction   |
| 0/1221        | 0/1113           | 0/1052      | Occurrence of road accidents                                                        | Construction   |
| 0/2021        | 0/081            | 0/1011      | Machinery colliding with equipment                                                  | Construction   |
| 0/0232        | 0/0721           | 0/0947      | Machinery collision with workforce                                                  | Construction   |
| 0/0601        | 0/0625           | 0/0824      | Cutting the cables and crane restraint belts                                        | Construction   |
| 0/0725        | 0/0531           | 0/0812      | Incidence of skin complications and respiratory injuries                            | Construction   |
| 0/0531        | 0/0423           | 0/0620      | Falling from a height                                                              | Construction   |
| 0/0323        | 0/0345           | 0/0523      | Falling of concrete pipes, electric poles, concrete walls during handling and installation | Construction   |
| 0/0645        | 0/0335           | 0/0395      | Collision of metal parts with workforce                                             | Construction   |
| 0/0234        | 0/0253           | 0/0353      | Overturning machines from the walls                                                 | Construction   |
| 0/036         | 0/178            | 0/272       | Occurrence of fire                                                                  | Construction   |
| 0/249         | 0/085            | 0/149       | Blockage of leachate collection and conduction channels                             | Construction   |
| 0/112         | 0/058            | 0/112       | Blockage of the aeration ducts                                                      | Construction   |
| 0/175         | 0/067            | 0/091       | Disease prevalence                                                                  | Construction   |
| 0/117         | 0/094            | 0/074       | Collision of waste handling machines with leachate system pipes                     | Construction   |
| 0/022         | 0/076            | 0/065       | Occurrence of road accidents                                                        | Construction   |
| 0/031         | 0/058            | 0/057       | Overturning machines from the walls                                                 | Construction   |
| 0/123         | 0/158            | 0/047       | Malfunction of recirculation pumps                                                  | Construction   |
| 0/057         | 0/059            | 0/043       | Respiratory injuries and skin complications                                         | Construction   |
| 0/028         | 0/075            | 0/016       | Staff fall into leachate recirculation pool                                         | Construction   |
| 0/027         | 0/055            | 0/053       | Machinery collision with equipment, workers, and employees                           | Construction   |
Table 9  Prioritization of environmental risks in the construction and operation phases

| Affected range | Risk probability | Consequence | Environmental risks                                                                 | Phase          |
|----------------|------------------|-------------|--------------------------------------------------------------------------------------|----------------|
| 0/0426         | 0/1343           | 0/1533      | Geographical events (floods, earthquakes, and landslides)                           | Construction   |
| 0/0864         | 0/2452           | 0/1331      | Leakage of oil and petroleum products (fuel) from machinery and fuel storage tanks   |                |
| 0/1225         | 0/1372           | 0/1132      | Soil corrosion                                                                      |                |
| 0/0864         | 0/1157           | 0/1051      | Decreased biodiversity                                                              |                |
| 0/0947         | 0/0724           | 0/1020      | stress for the seasonal habitat of migratory birds                                  |                |
| 0/2406         | 0/0941           | 0/0952      | Increased suspended particles in the air                                             |                |
| 0/0651         | 0/0625           | 0/0752      | Noise pollution                                                                      |                |
| 0/1132         | 0/0531           | 0/0863      | Disease transmission                                                                 |                |
| 0/0802         | 0/0623           | 0/0634      | Corrosion caused by the acidic environment                                           |                |
| 0/0683         | 0/0232           | 0/0732      | Creating tension for livestock                                                       |                |
| 0/155          | 0/084            | 0/193       | Dissolution, suspension of materials and products resulting from biological changes in leachate | Operation      |
| 0/076          | 0/052            | 0/152       | Leakage from the floor of the landfill                                              |                |
| 0/081          | 0/055            | 0/075       | evaporation of chemical compounds and water in gases from municipal waste            |                |
| 0/122          | 0/078            | 0/065       | Disease transmission                                                                 |                |
| 0/064          | 0/042            | 0/053       | Leakage of oil and petroleum products (fuel)                                        |                |
| 0/065          | 0/148            | 0/063       | Improper operation of the leachate recirculation system                              |                |
| 0/057          | 0/057            | 0/027       | Adsorption of volatile and semi-volatile organic compounds into wastes              |                |
| 0/047          | 0/047            | 0/029       | Halogen release and decomposition of organic matter and redox reactions on metals and metal salts |                |
| 0/043          | 0/013            | 0/019       | Blockage of leachate collection and conduction system                               |                |
| 0/016          | 0/037            | 0/083       | Subsidence of landfills that cause cracks and tears in the surface and cover         |                |
| 0/053          | 0/028            | 0/023       | Breakage and disruption of facilities and equipment settings                        |                |
| 0/021          | 0/015            | 0/025       | Blockage of the aeration ducts                                                      |                |

Table 10  Prioritization of economic, social, and cultural risks of the construction and operation phases

| Risk probability | Consequence | Economic, social, and cultural risks | Phase          |
|------------------|-------------|--------------------------------------|----------------|
| 0/4675           | 0/1542      | High costs of the landfill project   | Construction   |
| 0/2432           | 0/1762      | High health costs due to burial operations accidents |                |
| 0/1356           | 0/0773      | Failure of landfilling               |                |
| 0/0889           | 0/1961      | Psychological tensions between human resources |                |
| 0/0648           | 0/3962      | Occurrence of local conflicts        |                |
| 0/476            | 0/084       | High costs of control and development -sanitary landfill | Operation      |
| 0/075            | 0/075       | Lack of proper coverage of management changes, difficulties, and consequences of replacement |                |
| 0/184            | 0/242       | Reduction of spatial restrictions    |                |
| 0/125            | 0/072       | Occurrence of local conflicts        |                |
| 0/075            | 0/472       | Plan failure                         |                |
| 0/065            | 0/055       | Psychological tensions between workers and employees |                |
priority according to the risk index weighing 0.178. Health and safety risks are in focus compared to the exposure rate index, blockage of collection channels, and leachate conduction with a weight of 0.249. The rest are in the following priorities. Health and safety risks are the priority compared to the affected area index, blockage of collection channels, and leachate conduction with a weight of 0.157. The rest are the following priorities.

Table 9 shows that the destructive intensity of the risk of geographical events (floods, earthquakes, and landslides) is higher than other factors, with a weight of 0.153; they are the priority. The other factors are in the following: priorities, respectively. Since the transmission pipes have little flexibility in the design index, the factors that cause landslides (landslides, subsidence, liquefaction, earthquakes, etc.) should be considered. It is vital to view items that reduce the potential for displacement. The risk of oil and material leakage at landfill sites in the construction phase with a weight of 0.245 is the priority, and soil corrosion with a weight of 0.434 is the second priority. Pollution in the region has been widespread due to increased suspended particles during the construction phase. The corrosion index is affected by internal and external factors. The transmission pipes’ corrosion

Table 11 The distance of each option to the ideal positive and negative solution and the proximity coefficient of each option in the construction phase

| Rank | (CL*) | (d−i) | (d+i) | Risks of municipal landfill                                      |
|------|-------|-------|-------|-----------------------------------------------------------------|
| Safety and health | | | | | | |
| 1 | 1 | 0/1938 | 0/000 | Occurrence of fires in landfills, workshops, machinery, and equipment |
| 2 | 0/6258 | 0/1309 | 0/0783 | Occurrence of road accidents |
| 3 | 0/5273 | 0/1250 | 0/1112 | Overturning machines from the walls |
| 4 | 0/4792 | 0/1230 | 0/1337 | Falling from a height |
| 5 | 0/4596 | 0/1009 | 0/1186 | Collision of metal parts with workforce |
| 6 | 0/4189 | 0/0653 | 0/1575 | Machinery collision with workforce |
| 7 | 0/4050 | 0/0755 | 0/1306 | Incidence of various diseases |
| 8 | 0/3606 | 0/0736 | 0/1306 | Cutting the cables and crane restraint belts |
| 9 | 0/3306 | 0/0689 | 0/1396 | Falling of concrete pipes, electric poles, concrete walls during handling and installation |
| 10 | 0/2932 | 0/0917 | 0/1372 | Machinery colliding with equipment |
| 11 | 0/2440 | 0/0489 | 0/1513 | Incidence of skin complications and respiratory injuries |
| Environmental | | | | | | |
| 1 | 0/7545 | 0/1584 | 0/0515 | Geographical events (floods, earthquakes, and landslides) |
| 2 | 0/5161 | 0/1215 | 0/1139 | Leakage of oil and petroleum products (fuel) from machinery and fuel storage tanks |
| 3 | 0/5090 | 0/0988 | 0/3478 | Soil corrosion |
| 4 | 0/4690 | 0/8237 | 0/4081 | Decreased biodiversity |
| 5 | 0/4590 | 0/0958 | 0/1471 | stress for the seasonal habitat of migratory birds |
| 6 | 0/4379 | 0/0748 | 0/3482 | Increased suspended particles in the air |
| 7 | 0/4315 | 0/6387 | 0/6281 | Noise pollution |
| 8 | 0/3878 | 0/9172 | 0/4606 | Disease transmission |
| 9 | 0/3840 | 0/0902 | 0/0157 | Corrosion caused by the acidic environment |
| 10 | 0/2779 | 0/0555 | 0/1442 | Creating tension for livestock |
| Economic, social, and cultural risks | | | | | | |
| 1 | 0/7657 | 0/2407 | 0/0738 | High costs of the landfill project |
| 2 | 0/2768 | 0/0707 | 0/1844 | High health costs due to burial operations accidents |
| 3 | 0/2371 | 0/0606 | 0/1947 | Failure of landflling |
| 4 | 0/2345 | 0/0738 | 0/2409 | Psychological tensions between human resources |
| 6 | 0/2344 | 0/0737 | 0/2407 | Occurrence of local conflicts |
rate is influenced by internal (based on the type of fluid and pipe material) and external factors (soil type, moisture content, and atmospheric elements).

Environmental risks in the operation phase, weighing 0.193, are the priority compared to the consequence rate, the risk of increased dissolution, suspension of materials and products resulting from biological changes in leachate, and leachate leakage from the landfill floor weighing 0.152 being the second priority. Since landfills cause stress and pollution for livestock and seasonal habitats of migratory birds, this factor with a weight of 0.241 has been the priority among other risks in terms

| Rank | \((CL^*\) | \((d^-_i\) | \((d^+_i\) | Risks of municipal landfill |
|------|---------|---------|---------|---------------------------|
| Safety and health | | | | |
| 1 | 0/860 | 0/163 | 0/021 | Occurrence of fire |
| 2 | 0/594 | 0/1307 | 0/0892 | Blockage of leachate collection and conduction channels |
| 3 | 0/557 | 0/1051 | 0/0836 | Blockage of the aeration ducts |
| 4 | 0/4932 | 0/1062 | 0/1091 | Disease prevalence |
| 5 | 0/4601 | 0/0865 | 0/1015 | Collision of waste handling machines with leachate system pipes |
| 6 | 0/4457 | 0/0913 | 0/1136 | Occurrence of road accidents |
| 7 | 0/4253 | 0/0963 | 0/1301 | Overturning machines from the walls |
| 8 | 0/4223 | 0/0890 | 0/1218 | Malfunction of recirculation pumps |
| 9 | 0/3866 | 0/0837 | 0/1328 | Respiratory injuries and skin complications |
| 10 | 0/3663 | 0/0755 | 0/1306 | Staff fall into leachate recirculation pool |
| 11 | 0/3068 | 0/0641 | 0/1449 | Machinery collision with equipment, workers, and employees |
| 12 | 0/2659 | 0/0560 | 0/1547 | Bites of reptiles and rodents |
| Environmental | | | | |
| 1 | 0/5814 | 0/1741 | 0/1254 | Dissolution, suspension of materials and products resulting from biological changes in leachate |
| 2 | 0/5414 | 0/1750 | 0/1482 | Leakage from the floor of the landfill |
| 3 | 0/4585 | 0/1460 | 0/1528 | Evaporation of chemical compounds and water in gases from municipal waste |
| 4 | 0/4428 | 0/1443 | 0/1816 | Disease transmission |
| 5 | 0/4134 | 0/1293 | 0/1835 | Leakage of oil and petroleum products (fuel) |
| 6 | 0/3865 | 0/0953 | 0/1511 | Improper operation of the leachate recirculation system |
| 7 | 0/3497 | 0/0963 | 0/1791 | Adsorption of volatile and semi-volatile organic compounds into wastes |
| 8 | 0/3109 | 0/0832 | 0/1845 | Halogen release and decomposition of organic matter and redox reactions on metals and metal salts |
| 9 | 0/2704 | 0/0732 | 0/1975 | Blockage of leachate collection and conduction system |
| 10 | 0/2491 | 0/0440 | 0/2175 | Subsidence of landfills that cause cracks and tears in the surface and cover |
| 11 | 0/2261 | 0/0659 | 0/1997 | Breakage and disruption of facilities and equipment settings |
| 12 | 0/1952 | 0/0815 | 0/1565 | Blockage of the aeration ducts |
| 13 | 0/1684 | 0/0479 | 0/1443 | Increased suspended particles in the air |
| 14 | 0/0973 | 0/0189 | 0/1756 | Creating stress for livestock and seasonal habitats of migratory birds |
| Economic, social, and cultural risks | | | | |
| 1 | 0/7517 | 0/1562 | 0/0517 | High costs of control and development of engineering-sanitary landfill |
| 2 | 0/5684 | 0/1548 | 0/1176 | Lack of proper coverage of management changes, difficulties, and consequences of replacement |
| 3 | 0/3562 | 0/0776 | 0/1404 | Reduction of spatial restrictions |
| 4 | 0/3293 | 0/0785 | 0/1595 | Occurrence of local conflicts |
| 5 | 0/2491 | 0/0479 | 0/1443 | Plan failure |
| 6 | 0/0973 | 0/0178 | 0/1655 | Psychological tensions between workers and employees |
of probability. The increase of suspended particles weighing 0.165, among other risks, is the priority of the affected area.

Among the five socio-economic and cultural risks in the construction phase (Table 10), the risk of local conflicts, with a weight of 0.396, has a higher destructive rate, so it is the priority risk over the consequences. In the matrix of comparing economic-social and cultural risks concerning the probability index, the risk of incurring high costs of landfill projects with a weight of 0.467 is the priority; the rest are in the following priorities.

As can be seen from the six socio-economic and cultural risks in the operation phase, the risk of plan failure with a weight of 0.472 has a higher destructive rate, so it is the priority in terms of the consequence. Socio-economic and cultural risks rank first in the probability index, which increases the costs associated with the control and development of landfills which weighs 0.476.

Results of analysis and prioritization of landfills risks based on importance using the TOPSIS method

In Tables 11 and 12, the proximity coefficient of each option in the construction and operation phases is calculated. Each choice that has a closer coefficient has a higher priority.

Results of landfills risk analysis and presentation of management solution, using the bowtie method

A bowtie diagram of landfill operations is presented in Figs. 7, 8, and 9. As seen in these diagrams, the red circle is the source of risk (environmental, safety-health, and economic-social and cultural).

Significant environmental damages in the process of this project can be disrupting the landscape, increasing pollution and suspended particles, evaporation of chemical compounds and water in gases.

Fig. 7 Environmental risks of landfills in Gilan province in BowTie software
from municipal waste, oil, and petroleum (fuel) leakage, absorption of volatile and semi-volatile organic compounds into wastes (Lakhouit & Alsulami, 2020; Nair et al., 2019), obstruction of leachate collection and conduction system (Liu et al., 2018), blockage of aeration ducts, problems in feeding local livestock, concerns for the seasonal habitat of migratory and native birds, soil and water pollution (Madon et al., 2020), and destruction of buildings and soil texture, etc. In addition, the conditions of the landfill, which are hygienic and semi-aerobic, and the conditions of the ecological and biological system of Gilan province will cause the most damage. Enclosing landfills dramatically reduces the appearance of the environment. The use of clay on the landfill floor prevents leachate leakage to the underlying layers and prevents soil and groundwater contamination. Factors considered in determining the effect of the unsaturated area in the basin are soil permeability and groundwater depth. In Gilan province, the groundwater level is very high and will have the most significant impact in the present study (Monavari et al., 2013). According to Si et al. (2012) research, residents have reported a high degree of risk of poisoning in material leaks. In the present study, the risk of leakage of leachate infiltration into groundwater (Negi et al., 2020), oil, and petroleum products (fuel) was high. To some extent, the failure of leachate collection and management systems and facilities was effective in increasing the level of this risk. Studies on risk assessment show that individuals can be very effective in risk consequences; as Aminbakhsh et al. (2013) and Linkov et al. (2006) point out in their paper, one of the most critical problems in risk assessments is the impact of assessment judgments. In comparing the results obtained by TOPSIS and ANP methods, it can be concluded that in the case of determining the weight of risk parameters and their non-uniform importance for different types of indicators, the obtained priorities are better. Not including the same weight in the risk parameters can lead to a more realistic risk assessment. According to this issue, environmental damage is maximized

![Diagram](image-url)

**Fig. 8** Health and safety risks of landfills in Gilan province in BowTie software
in water, soil (Kazemi et al., 2021), and air landfills. Therefore, more damage is done to the environment. One of the most important risk assessment factors in the construction phase is the presence of geographical events (floods, earthquakes, and landslides) (Torresan et al., 2016). Governments are target groups for developing and implementing natural and geographic disaster risk reduction strategies. Natural risk mitigation programs are important, especially in times of crisis such as floods and landslides, which can disrupt regular waste management services in cities (Phonphoton & Pharino, 2019).

Using the results of the identified risks during this study, it was shown that in the field of safety and health in the construction phase, 12 safety and health risks are compared to 12 environmental risks. In the operation phase, ten safety and health risks were exposed to 14 environmental conditions. Considering that based on the results of pairwise comparison tables, the probability of safety and health accidents compared to environmental accidents by the expert group in the construction phase has a weight of 0.313 to 0.511 and the operation phase has a weight of 0.163 to 0.721, it should be concluded that the hypothesis of this research that the highest risks in landfills are related to environmental risks is confirmed. The findings of this study are inconsistent with the results of researchers such as Vinti et al. (2021), in which the highest probability of risk in the construction and operation phase is related to safety and health and following the findings of Saleh et al. (2020), That the effects are less in the operation phase. The results of this study show that anthropogenic activities related to sanitary landfilling in recent years have had a great impact on Gilan province (Bejai Bisht et al., 2020; Rasool et al., 2016). Safety, health, and economic and environmental (Monavari et al., 2013) constraints, as well as shortcomings in urban solid waste management, are the main causes of environmental pollution and destruction of natural resources in Gilan province.

**Conclusion**

Conducting such studies is necessary because of the hygienic disposal of waste, which is associated with placing waste in dense layers on top of each other. This issue can potentially cause the destruction of existing habitats. In landfills, as a result of the biological decomposition of organic materials in the waste, different materials such as leachate, gas, chemicals, and organic and inorganic materials are produced. These materials are among the sources of environmental pollution.
pollution due to their harmful effects. In addition, the effects of various activities resulting from the implementation of the project on the environment are numerous and significant. It is necessary to carry out environmental risk assessment studies to better understand the destructive factors and their effects on the environment and to provide useful solutions for proper control and management. The occurrence of fire and arson are two of the most apparent and fundamental factors that cause irreparable damage both in the construction and during the operation phases. Besides occurring naturally, fires in forests are also amplified by human factors. This has a history in the northern forests and should be considered in any planning. Other notable health-related damages include skin complications, disruption of daily life, high healthcare costs, road accidents, falls from heights, livelihood problems, and in some cases, death.

Considering the high species diversity and abundance of population, the damage to local livestock and the habitat of migratory and native birds will also be significant (many migratory and native birds overwinter or live in Gilan province). In terms of environmental characteristics, Gilan province has rare plants, forest trees, and wildlife. Approximately 50,000 hectares of forests are being deforested every year in this area, according to studies. In this process, the rangeland ecosystems of the region (forest rangelands, coastal rangelands, summer rangelands, and lowland rangelands) have also been exposed to severe damage; however, regarding the destruction of buildings and soil texture due to improper harvesting, the use of soil as a daily cover and construction of cell walls is inevitable in the implementation of the project, which due to soil shortages, erosion, and corrosion have caused many problems. Exhaust gas from landfills is one of the most important environmental parameters of landfills. Soil type has a significant effect on chemical processes in landfills.

The presence of fine-grained materials such as silt and clay reduces the relative permeability of soils and limits the migration and movement of contaminants. The high level of microbial activity at landfill sites, the organic matter present, and the root system of the plants give the layer greater damping capacity compared to a lower part of an unsaturated area. In addition, the damping processes of infiltration, adsorption, and escape of gases are fundamental where the soil horizon is thick. The visible effect of the saturation zone on the environmental risks of landfilling is not hidden from anyone. Because of the unsaturated area with the retention, absorption, and removal of pathogenic viruses and bacteria, Absorption and reduction of many chemicals and organic and synthetic, diluting the concentration of heavy metals and other inorganic substances by adsorption and reaction with the surface of minerals, plays an essential role in preventing groundwater contamination. It is in the risk outcomes that it is necessary to minimize this problem. Budget control is a factor that automatically controls costs. If the landfill project is short of human resources, financial resources, and equipment, the probability of project failure increases. In the TOPSIS method, no comparison is made between the options, and the weight of the options is calculated without comparison with other options. In contrast, as the weight of each criterion is calculated separately, without pairwise comparison with other criteria, the results of the ANP method seem more accurate and reliable as each criterion’s weight and importance for each issue are assessed concerning the others.

The bowtie model was used as a complementary management method in the present study to provide solutions to reduce or eliminate significant risks. The structure of the bowtie method in landfill risk assessment is most reliable when several obstacles are used to prevent each risk. Several compensatory factors are used to compensate for any consequences of an accident, including environmental, socio-economic, health, safety, and culture. The use of an obstacle or a compensatory factor alone can not provide the necessary reassurance in landfills. The results of this study showed that risk management in the bowtie method is a very suitable tool for risk identification in metropolitan areas. This tool is effective for risk identification and qualitative analysis. All the causes and consequences of the accident are clearly defined in the diagrams. The bowtie method is one of the methods that completely shows how different potential factors in landfills turn into the initial incident and the final events. In the meantime, the various protections that exist to control and limit are analyzed. The bowtie method focuses more on obstacles. In the landfill of Gilan province, most of the risks are environmental risks. Initially, it was thought that health-safety risks outweighed other risks, both in number and severity. However, this study has shown that all ecological, biological, and physical factors in Gilan
province have a special environmental value. In the bowtie method, the threat is depicted by important environmental issues (threat perception) that one or more aspects can be the cause of its occurrence. Barriers are also created to protect against these threats. Solutions were presented to control the threatening factors and to reduce or eliminate the environmental risks of the burial place of Gilan province using the bowtie management method. Combining bowtie methods with ANP and TOPSIS can be very effective. According to the results of risk prioritization methods, management priorities can be planned to control risks.

**Data availability**  The data that support the findings of this study are not openly available due to institutional sensitivities and are available from the corresponding author upon reasonable requests.

**Declarations**

**Conflict of interest**  The authors declare no competing interests.

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