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Risk analysis under different mitigation strategies for potential threats in wastewater treatment systems

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Abstract

Wastewater treatment systems are among the most critical infrastructure for urban development, with a fundamental role in maintaining public health and hygiene. They are also considered as secondary sources for some specific uses. Any disruption in their performance due to any type of incident will have adverse environmental, economic, and health impacts. The aim of the study is to analyze the risk of different sections of a wastewater treatment system located in one of the regions of Iran and propose mitigation strategies to reduce the adverse effects of any threat. To achieve this goal, the types of potential threats are determined based on American Society of Civil Engineers (ASCE-2004) guidelines, and then calculated the Risk Priority Number (RPN) for each section of the plant using the Federal Emergency Management Agency's (FEMA-452) guidelines. Then, risk mitigation strategies for each section based on the study area's situation presented and prioritized using the Measurement Alternatives and Ranking according to Compromise Solution (MARCOS) method. In the last step, the percentage reduction of the RPN as well as its most important component will be analyzed under each of the strategies. The results showed that considering the proposed mitigation strategies for the most critical threats could reduce the RPN by 89% for the wastewater collection and transmission system under flood preparedness programs, 84% for the chlorination unit by improving personnel skills and training for gas leak control, and 90% for the sludge thickening and pumping section by replacing components ahead of schedule for their useful life.

Keywords Risk priority number · Wastewater treatment plant · Risk mitigation strategies · MARCOS multi-criteria decision-making method · Uncertainty reduction · Spherical fuzzy logic

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1 Introduction

An important part of water resource management includes the wastewater treatment systems management as one of the most essential infrastructure components for urban development, such that a malfunction in wastewater treatment plants can lead to the wastewater discharge into the environment without compliance with health guidelines, and consequently, the spread of health problems, contamination of soil, surface and groundwater resources. Considering the strategic importance of wastewater treatment plants for human and environmental well-being, protecting them from potential hazards along to minimizing risk and increasing readiness to tackle threats is necessary (Tuśer & Oulehlová, 2021). The level of capability and readiness of important and strategic systems such as sewage treatment systems in providing service in unusual situations during the operation time has particular importance since on the one hand, failure in their operation will cause severe crises in the society and on the other hand, being placed system in optimal service conditions again will minimize damages.

Therefore, it is necessary for managers to identify vulnerable parts in water and wastewater treatment systems, estimate the probability of various threats, with the aim of formulating comprehensive and practical risk management programs.

The most critical step in risk management is identifying different threats, since without identifying the threats, it is impossible to include them in risk analysis. Several studies are shown that various hazards, from natural events such as flood, severe storm, earthquake, cyber security gaps and terrorist attacks, to climate change, can disrupt the performance of wastewater treatment plants (ASCE, 2004).

The fundamental phase of risk management is assessment and calculation of risk, and then presentation the strategic decisions (Łój-Pilch & Zakrzewska, 2020). Risk assessment should be done systematic, continuous, based on the knowledge and perspectives of stakeholders (Corrao et al., 2012). One of the most widely used methods for assessing and calculating risk is the FEMA method, which has been widely used in various fields, some of which will be described below. Roozbahani et al. (2013) proposed a risk evaluation model to assess risks in a complex urban water supply system using a systematic approach including quantitative and qualitative water issues. McGrath et al. (2015) estimated the potential losses due to the flood risk using the the U.S. FEMA's standardized in the Fredericton city, Canada. The losses results indicated that flooded buildings number varied from 579 to 623 buildings, and the potential damage cost was more than \$21 million. Stults (2017) examined a framework for integration of climate change into FEMA regulations, with the goal of reducing the adverse effects of natural hazards through 30 local projects in the United States. The results showed a minimal level of compatibility between the integration of climate change and FEMA regulations. Qiang (2019) evaluated the exposure of important infrastructures in United States to flood risk based on spatial analyses using a combination of FEMA-flood maps and the United States Geological Survey (USGS) national structure database. The results showed that most of the important infrastructures in Louisiana and Florida was at risk of flooding. Wickham et al. (2019) assessed the risk of drought in the Platte River basin in Nebraska based on Threat and Hazard Identification and Risk Assessment (THIRA) and the FEMA risk assessment process. The results showed that current activities and plannings were insufficient to reduce vulnerability and increase effective preparedness and response to the worst drought. Abedzadeh et al. (2020) evaluated the risk of water resources projects under the sustainable development framework using the fuzzy fault tree analysis for the Makran coastal region and Bandar Abbas in Iran. The results indicated that failure probability of water resources projects in the best, current, and worst situations under the crisp and fuzzy approaches was 38, 90, and 50%, respectively. Yanilmaz et al. (2021) developed the FEMA and seriousness manageability urgency growth methods for analyzing the risk of disasters for the province of Tunceli in Turkey using the bayesian best–worst approach. First, the weight of risk parameters was calculated, and the priority of each risk was determined based on each parameter. The results showed that in the FEMA model, earthquake, mass movement, and flood were the highest priorities with final preference values of 0.192, 0.141, and 0.114, respectively. However, in the SMUG model, earthquake, flood, and pandemics were ranked as the top three priorities with final preferred values of 0.194, 0.129, and 0.120, respectively. Ribas et al. (2021) calculated the Risk Criticality Index (RCI) for the failure of a hydroelectric dam in Central Brazil and then extracted the risk priority number of the Fuzzy Inference System-Risk Priority Number (FIS-RPN) by combining RCI with detection. The results indicated that fuzzification process improved the accuracy of RPN calculation. Mazumder et al. (2022) investigated the impact of flood hazards on the vulnerability of people living in flood-prone areas of Tampa, Florida between 1996 and 2018 using the FEMA, Geographical Information System (GIS), and statistical analysis methods. The results showed that the distribution of the population in high-risk flood areas was disproportionate, and low-income populations were more vulnerable over time. Tabesh et al. (2022) assessed the risk of the Jalaliya water treatment plant in Tehran using the FFTA method. The results showed that improper reservoir design, equipment failure, transmission pipe failure, and inadequate pump maintenance were the most likely sources of risk. Neshenko et al. (2023) presented a unique method to support the risk management of cyber in critical water and sewage infrastructure. The results indicated that this method could facilitate the effective management of operational risk by providing rich context information.

After identifying threats, assessing and calculating risk, providing strategic solutions to reduce the destructive effects of any potential risks, the most important step is risk analysis and management. Since providing any kind of strategy requires evaluating all its dimensions, so that sustainable operation of the wastewater treatment system is achieved, the use of multi-criteria decision-making methods is one of the most common methods for selecting a desirable and optimal alternative among available alternatives. The basis of multi-criteria decision-making methods is constructive interaction between wide ranges of experts with different specializations, in a way that the most desirable alternative is chosen in terms of various dimensions of the issue. Several decision-making methods with different approaches have been developed for evaluating risk and also selecting the best alternative to reduce risk management measures in various areas, some of which are mentioned below. Joerin et al. (2010) evaluated the vulnerability of the drinking water system to microbiological pollution in Quebec, Canada and ranked various drinking water supply systems using the Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) approach. Li (2013) reduced the uncertainties of flood risk caused by flooding by Variable Fuzzy Sets (VFS) integration. Sepehri et al. (2019) used GIS and entropy weight method to prepare a flood risk map in the city of Hamedan, Iran. The results showed that 15.83, 31.72, 20.11, 16.02, and 16.32% of the study area were highly dangerous, dangerous, moderate, partial, and low-risk, respectively. Rahnamay-Bonab and Osgooei (2022) determined the possible failure modes of a wastewater treatment plant in Iran using the PFSWARA method. Opabola and Galasso (2022) ranked the best approach to collecting the required information for evaluating earthquake and tsunami risk in a residential area in a hypothetical city using three MCDM methods, including TOPSIS, EDAS, and WASPAS. Moradpanah et al. (2022) assessed the spatial-distribution of biotic vulnerability in the coastal area of Anzali based on 7-criterion and 13 sub-criteria. Initially, weights of sub-criteria and criteria were calculated using the Analytic Network Analysis method, and then the data layers were overlapped with the standard fuzzy membership function and the fuzzy gamma operator. Finally, 15 stress factors of Anzali wet-land were ranked based on VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR). The results showed that the input wastewater to the wetland had the maximum level of risk in terms of physico-chemical environment. Analouei et al. (2022) evaluated the wastewater treatment failure risk, and effective measures to reduce risk using a Dynamic Bayesian Network (DBN), and the results showed that with preventive measures implemented over eight years, the failure risk was reduced by 24%.

Abdel basset et al. (2022) developed a new framework to protect infrastructures of water systems against cyberattacks. The DEMATEL approach was integrated with Neutrosophic theory to assess the risks of Wastewater Treatment Technologies (WWTTs). Kumari et al. (2023) identified 24 potential failure modes of wastewater treatment plants at 5-industrial region of Delhi, India, with consensus among 5-expert. Then FAHP method was employed to calculate the risk factors weight and the Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS) method was used to rank the failure modes. Wu et al. (2023) used improved Best–Worst Method (BWM)—fuzzy comprehensive evaluation method to remove the municipal-sewage treatment safety hazards in Changchun City, China. The results indicated that safety status in the wastewater treatment-plant was safety level. Li et al. (2023) evaluated the reliability and operational functions of wastewater treatment facilities in China using a multilevel extension principle of matter-element analysis and Analytic Hierarchy Process (AHP).

The objectives of the present research include: (1) calculation the risk priority number for the important components of the wastewater treatment plant, (2) providing feasible strategies to reduce any possible risk by experts group, (3) prioritization the risk mitigation strategies through the MARCOS multi-criteria decision-making method, and (4) recalculation the risk priority number by considering the risk mitigation strategies based on the opinions of the expert group. To achieve the above goals, basic risks were identified based on FEMA-452 instruction for a wastewater treatment plant in one of the regions of Iran where risk identification and management programs have not been carried out. Then, the expert group was formed and after determining the most important risks, the solutions to reduce them were compiled and ranked using MARCOS MCDM method. Finally, the effectiveness of each of the solutions according to the experts, the risk priority numbers were recalculated again.

2 Materials and methods

This section describes the present research steps. Firstly, the study area is selected and the potential threats types in the system are classified including natural, technical, and intentional threats based on ASCE (2004). In the next step, the risk priority number for each part of the wastewater treatment system is calculated based on the FEMA-452 method, and risk mitigation strategies for each of them are proposed by experts. Then, sub-criteria and criteria sets are weighted using the SF-AHP method, and the risk mitigation strategies are prioritized using the MARCOS method. Finally, the RPN for each part of the wastewater treatment system is calculated based on the risk mitigation strategies, and the risk mitigation percentage is determined (Fig. 1).

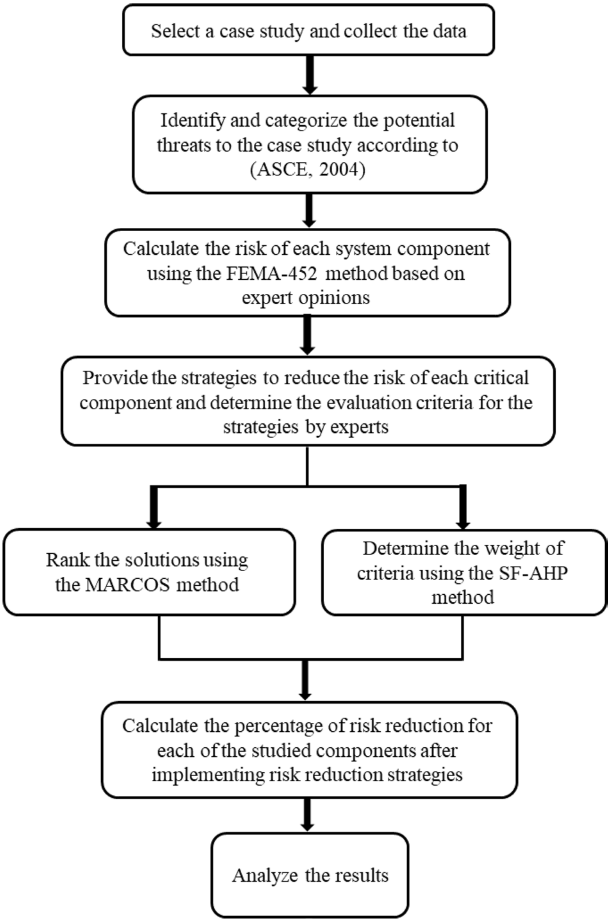


Fig. 1 Flowchart of this paper's methodology

2.1 Classification of threats types

In the present study, the potential threats types in the wastewater treatment system are classified according to the ASCE (2004) guidelines into three types including, natural, technological, and intentional threats, each of which will be explained in detail below.

(1) Natural threats: Natural threats are events that are beyond human control and their duration and severity cannot be predicted accurately, such as earthquak, flood, landslide, storm, and liquefaction, etc.
(2) Technical threats: Technical threats, which are unbiased and often occur directly or indirectly by system employees. These threats mostly include the lack of installation the monitoring and inspection systems, design problems especially incorrect calculation of the lifetime, chemical leakage caused by microorganism growth, and lack of awareness and knowledge of human resources due to inadequate training.
(3) Intentional threats: Those are biased and often created in order to disrupt and cause damage with specific goals. These threats mostly include cyber threats, physical threats

(e.g. bombing), and the releasing the unexpected pollution such as chemical and biological pollutants (Bailey, 2001). Figure 2 illustrates the classification of threat types.

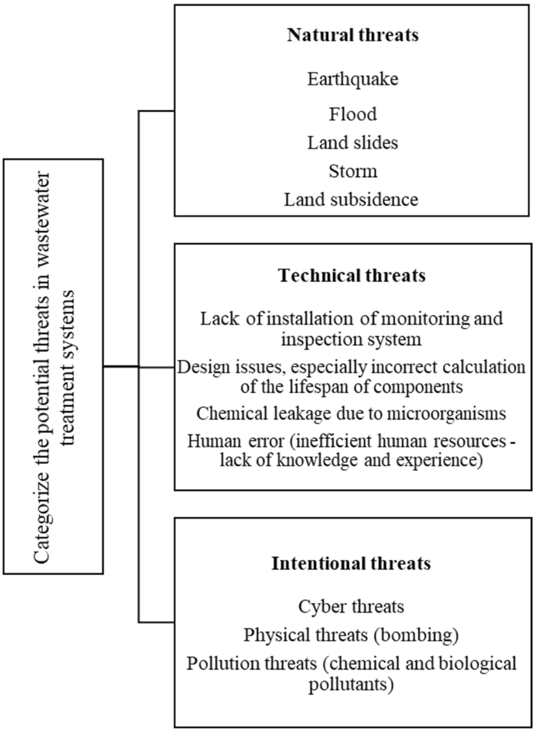
2.2 Calculating the RPN based on the FEMA-452 method

In this step, after identifying and classifying the potential threats types in different parts of the wastewater treatment system, the RPN is calculated based on the FEMA-452 (2005) guidelines. The FEMA-452 method is a comprehensive, explicit, flexible, and a function of three component: the threat probability, the effects of the threat or the severity of the damage, and the vulnerability of the system. In the following, each of these three components is briefly described:

(1) Threat probability: Threat probability represents the frequency of a threat or hazard occurring over time. For natural threats, various predictive models and recorded data from the past can be used to determine the probability of occurrence. However, determining the probability of occurrence of threats caused by human error or non-natural causes is challenging, complex, and often dependent on the opinions and experiences of experts.

(2) Asset value: The asset value or effects of the threat refer to the volume of financial losses, damages, and casualties in the facilities, equipment, and human resources in case of a threat and vulnerability in the examined section. The severity of the effects of the threat varies depending on the type of system.

Fig. 2 Categorizing types of potential threats in the studied wastewater treatment system



(3) Vulnerability: Vulnerability is the ability to face a threatening risk and is a function of the inherent nature of a system and the nature of each threat. In other words, depending on the preventive or predicted measures embedded in a system, this component can be variable.

The RPN is determined according to the FEMA-452 (2005) guidelines using Eq. (1):

$$RPN = T \times A \times V \tag{1}$$

in which RPN = the risk priority number; T = the threat probability; A = the asset value, and V = the vulnerability.

2.3 Multi-criteria decision-making methods

The MCDMs are powerful tools for selecting the best alternative based on various criteria and presence of different decision-maker and stakeholder groups with multiple goals in a system, as well as different definitions of alternative desirability. In the present study, two SF-AHP and MARCOS methods will be used to weighting the criteria and ranking the risk mitigation strategies, respectively, which will be described below.

2.3.1 Calculating the criteria and sub-criteria weights based on the SF-AHP method

Kutlu Gündoğdu and Kahraman (2020) introduced the SF-AHP method for the first time by combining the spherical fuzzy concept with the widely used analytic hierarchy process method. The inherent uncertainty in future plannings due to incomplete human knowledge about unforeseen changes in the future is inevitable. In the present research, Spherical Fuzzy Sets (SFS) have been used to do the pairwise comparisons matrixes in the SF-AHP weighting method. The most important specification of SFS is that three parameters including degree of membership, degree of non-membership and degree of hesitancy are used to express experts' opinions, which respectively indicate the degree of belonging, the degree of non-belonging and the degree of hesitancy of the decision-maker to the decision-making space. This allows the experts to be able to express their doubts about the subject of judgment in a more accurate quantitative manner, and thus the uncertainty caused by the lack of human knowledge regarding future events will be reduced.

The experts' participation in the evaluation process of the present research was as follows: In the first step, the experts group completed the questionnaire related to the risk priority number for the current condition of the sewage treatment plant. In the second step, according to the results of the first step and the field conditions, they proposed a set of possible solutions as well as a set of evaluation criteria. In the third step, experts completed the matrices of criteria pairwise comparisons using a 9 degree spectrum for SF-AHP method, and then the criteria weights were calculated using the SF-AHP method weighting method. In the fourth step, the experts first completed the decision-making matrix and then ranking of the alternatives were obtained base on the MARCOS method. In the last step, the experts completed the questionnaire related to the risk priority number regarding the best risk reduction strategy and new risk priority numbers were obtained. The SF-AHP method steps will be explained in more detail bellow.

2.3.1.1 Forming the spherical fuzzy pairwise comparison matrix by experts to compare criteria and sub-criteria In this step, the pairwise comparison matrix of the spherical fuzzy is formed by experts based on the descriptions in Table 1. In Table 1, $\alpha_{\tilde{A}}(u)$, $\beta_{\tilde{A}}(u)$, and $\gamma_{\tilde{A}}(u)$ represent the degree of membership, non-membership, and hesitation of the spherical fuzzy functions, respectively.

2.3.1.2 Calculating the score index based on aggregating the experts' opinions In this step, the score index is calculated based on aggregating the spherical fuzzy pairwise comparison matrices using Eq. (2).

$$\mathrm{SI} = \sqrt{\left|100 * \left[\left(\alpha_{\tilde{A}_S} - \gamma_{\tilde{A}_S}\right)^2 - \left(\beta_{\tilde{A}_S} - \gamma_{\tilde{A}_S}\right)^2\right]\right|} \tag{2}$$

in which SI = score index.

2.3.1.3 Calculating the consistency ratio of spherical fuzzy pairwise comparison matrices In this step, the consistency ratio is calculated based on the AHP method (Saaty, 1990) using Eq. (3).

$$CR = \frac{\frac{\lambda_{\max} - n}{(n-1)}}{RI} \tag{3}$$

in which CR = consistency ratio; n = the dimension of matrix; RI = the random inconsistency index based on different values of n (Saaty, 1977); and λ_{max} = the maximum eigenvalue.

The maximum value of CR is equal to 0.1, and otherwise, it is necessary to repeat the experts' scoring process.

2.3.1.4 Calculating the local weights of the criteria In this stage, the local weight of each criterion is obtained using Eq. (4):

$$SW_w = \left\langle \left[1 - \prod_{i=1}^{n}\left(1 - \alpha^2_{\tilde{A}_{Si}}\right)^{w_i}\right]^{1/2}, \prod_{i=1}^{n} \beta^{w_i}_{\tilde{A}_{Si}}, \left[\prod_{i=1}^{n}\left(1 - \alpha^2_{\tilde{A}_{Si}}\right)^{w_i} - \prod_{i=1}^{n}\left(1 - \alpha^2_{\tilde{A}_{Si}} - \gamma^2_{\tilde{A}_{Si}}\right)^{w_i}\right]^{1/2} \right\rangle \tag{4}$$

Table 1 Spherical fuzzy membership functions equivalent to Linguistic measures

Linguistic measures	(α, β, γ)			Score index (SI)
	$\gamma_{\tilde{A}}(u)$	$\beta_{\tilde{A}}(u)$	$\alpha_{\tilde{A}}(u)$	
Absolutely more importance (AMI)	0.0	0.1	0.9	9
Very high importance (VHI)	0.1	0.2	0.8	7
High importance (HI)	0.2	0.3	0.7	5
Slightly more importance (SMI)	0.3	0.4	0.6	3
Equally importance (EI)	0.4	0.4	0.5	1
Slightly low importance (SLI)	0.3	0.6	0.4	1.3
Low importance (LI)	0.2	0.7	0.3	1.5
Very low importance (VLI)	0.1	0.8	0.2	1.7
Absolutely low importance (ALI)	0.0	0.9	0.1	1.9

where SW_w = the arithmetic mean spherical fuzzy weight; and w_i = values between zero and 1 (such that their sum is equal to 1).

2.3.1.5 Defuzzification and calculating the final weights of the criteria In this step, the criteria defuzzified weights and the criteria final weights are calculated using Eqs. (5) and (6) respectively.

$$S\left(\tilde{\mathrm{w}}_{\mathrm{j}}^{s}\right) = \sqrt{\left|100 * \left[\left(3\alpha_{\tilde{\mathrm{A}}_{\mathrm{S}}} - \frac{\gamma_{\tilde{\mathrm{A}}_{\mathrm{S}}}}{2}\right)^{2} - \left(\frac{\beta_{\tilde{\mathrm{A}}_{\mathrm{S}}}}{2} - \gamma_{\tilde{\mathrm{A}}_{\mathrm{S}}}\right)^{2}\right]\right|} \tag{5}$$

$$\overline{w}_{j}^{s} = \frac{S\left(\tilde{w}_{j}^{s}\right)}{\sum_{J=1}^{n} S\left(\tilde{w}_{j}^{s}\right)} \tag{6}$$

where $S\left(\tilde{w}_{j}^{s}\right)$ = the criteria defuzzified weights; and $\overline{w}_{j}^{s}$ = the criteria final weights.

2.3.2 Ranking risk reduction strategies using the MARCOS method

The new multicriteria decision-making method, MARCOS, was introduced by Stević et al. (2020). Using this method, the best risk reduction strategy is selected with the least distance from the ideal solution and the maximum distance from the anti-ideal solution. The steps of the MARCOS approach are as the following:

Step 1. Forming the decision matrix

In this step, decision matrix is formed based on the experts' opinions.

Step 2. Forming the extended aggregated decision-making matrix

In this step, the extended aggregated decision-making matrix is formed, which includes the information matrix and the ideal and anti-ideal solutions according to Eq. (7):

$$\mathrm{X} = \begin{array}{c} \\ AAI \\ A_1 \\ A_2 \\ \cdots \\ A_m \\ AI \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \left[\begin{array}{cccc} x_{aa1} & x_{aa2} & \cdots & x_{aan} \\ x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ x_{m1} & x_{22} & \cdots & x_{mn} \\ x_{ai1} & x_{ai2} & \cdots & x_{ain} \end{array}\right] \end{array},$$

$$\left.AI = \max_{i} x_{ij} \quad if\ j \in B\ and\ \min_{i} x_{ij} \quad if\ j \in C\ \right\}$$

$$\left.AAI = \min_{i} x_{ij}\ \ if\ j \in B\ and\ \max_{i} x_{ij}\ \ if\ j \in C\ \right\} \tag{7}$$

where X = the extended aggregated decision-making matrix; n = the number of criteria; m = the number of alternatives; x_{mn} = the elements of the decision matrix; C_n = the set of criteria; A_m = the set of alternatives; AI = the ideal solution, and AAI = the anti-ideal solution (which are calculated based on the benefit and cost of criteria); B = the benefit criteria, and C = the cost criteria.

Benefit criteria are those that lead to an increase in benefit in the system, while cost criteria result in costs being incurred by the system. In the extended aggregated decision-making matrix, *AI* and *AAI* are normalized based on the type of criteria.

Step 3. Normalizing the extended aggregated decision-making matrix

In this step, the elements of the extended aggregated decision-making matrix are normalized for the benefit criteria using Eq. (8) and for the cost criteria using Eq. (9):

$$n_{ij} = \frac{x_{ij}}{x_{ai}} \quad if\, j \in B \tag{8}$$

$$n_{ij} = \frac{x_{ai}}{x_{ij}} \quad if\, j \in C \tag{9}$$

where x_{ij} = the element of the extended aggregated decision-making matrix; and x_{ai} = the maximum element of the extended aggregated decision-making matrix for each criterion.

Step 4. Calculating the weighted normalized matrix

In this step, the weighted normalized matrix is calculated by multiplying the elements of the normalized matrix by the weights of the criteria, using Eq. (10), and the sum of the elements of the weighted matrix is obtained using Eq. (11).

$$V = \left[v_{ij}\right]_{m \times n}, v_{ij} = n_{ij} \times w_j \tag{10}$$

$$S_i = \sum_{i=1}^{n} v_{ij},\ S_i(i = 1, 2, \ldots, m) \tag{11}$$

where V = the weighted normalized matrix; v_{ij} = the elements of the weighted normalized matrix; w_j = the weight of each criterion; and S_i = the sum of the elements of the weighted matrix.

Step 5. Calculating the utility degree of each alternative

In this step, the utility degree of each alternative is calculated with respect to the ideal and anti-ideal solutions, respectively, using Eqs. (12) and (13):

$$K_i^+ = \frac{\sum_{i=1}^{n} v_{ij}}{S_{ai}} \tag{12}$$

$$K_i^- = \frac{\sum_{i=1}^{n} v_{ij}}{S_{aai}} \tag{13}$$

where K_i^- = utility degree of each alternative compared to anti-ideal solution; K_i^+ = utility degree of each alternative relative to the ideal solution.

Step 6. Calculating the utility function of alternatives

In this step, the utility function of alternatives is calculated using Eq. (14):

$$f\left(K_i\right) = \frac{K_i^- + K_i^+}{1 + \frac{1 - \frac{K_i^+}{K_i^+ + K_i^-}}{\frac{K_i^+}{K_i^+ + K_i^-}} + \frac{1 - \frac{K_i^-}{K_i^- + K_i^+}}{\frac{K_i^-}{K_i^- + K_i^+}}} \tag{14}$$

where $f(K_i^+)$ = the utility function of the ideal solution; $f(K_i^-)$ = the utility function of the anti-ideal solution; and $f(K_i)$ = the utility of each alternative.

Ranking of alternatives is done based on the final values of the utility function, and the alternative with the maximum value of the utility function is the best alternative.

3 Case study

In this section, the characteristics of the case study, criteria, and strategies for mitigation the adverse effects of each threat on different parts of the wastewater treatment plant are introduced.

3.1 Introducing the study area

The case study in this research is the wastewater treatment plant No. 3 in the city of Qom, located in the northeast region of Qom province, Iran, and about 9 km away from the province's center. The aerial view of this treatment plant is shown in Fig. 3.

The volume of entering wastewater to the sewage treatment plant is 50,000 m^3 during one day and night. The maximum and minimum of BOD and COD is 300 mg/liter and 600 mg/liter (according to the standard of domestic wastewater parameters), and at least 280 mg/liter and 550 mg/liter, respectively. Also, the sludge from this system is classified in class B and its treatment type is activated sludge. The liquid part treatment process includes the entering the wastewater to the exit of the treated wastewater, and the solid part treatment process includes the treatment of the sludge resulting from the sedimentation of the wastewater, which is finally used as fertilizer in the form of compost. In general, the purification process in this system is defined in three types: physical (separation of grains), biological (purification by microorganisms) and chemical (injection of chlorine gas). The daily treatment capacity of this treatment plant is 51,000 cubic meters, equivalent to 250,000 people's domestic sewage which, in addition to providing water for the agricultural sector in the villages downstream of the treatment plant, plays an important role in preventing environmental pollution. The current various processes in the wastewater treatment system are shown in the flow diagram in Fig. 4.

Fig. 3 Aerial view of Qom wastewater treatment plant no. 3

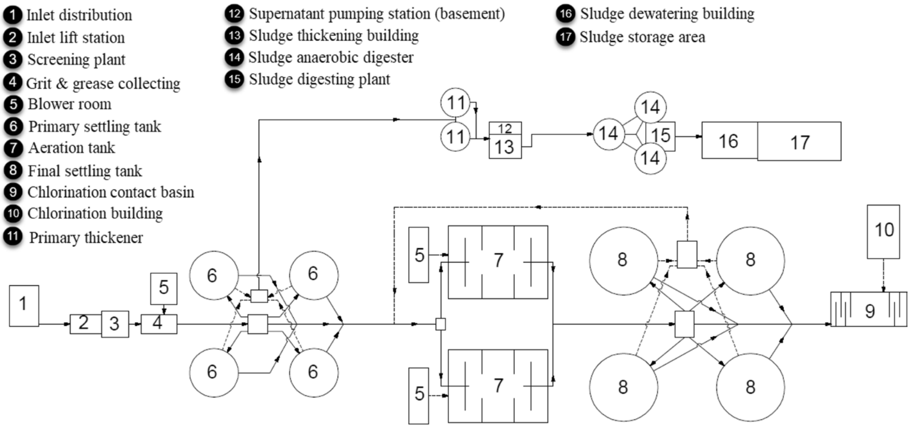


Fig. 4 Wastewater treatment plant's flow diagram

3.2 Different parts of the wastewater treatment system, determining the criteria set and mitigation strategies

In this study, the expert group consists of a resident supervisor (MSc in Mechanical Engineering), a control room operator (BSc in Electrical Engineering), and a HSE officer (BSc in Health, Safety and Environment). The different parts of the wastewater treatment system include: (a) sewage collection system and inlet structures (inlet distribution, inlet lift station, screening plant, grit and grease collecting), (b) primary and final settling tanks, aeration tanks, chlorination contact basin, sludge anaerobic digester with the boiler house and chlorination building, (c) sludge dewatering building, sludge Gravity Belt Thickener (GBT) and supernatant pumping station.

The main criteria include three main technical, economic, and cultural criteria, and nine sub-criteria for evaluating risk reduction strategies are identified. The criteria and sub-criteria are shown in Fig. 5. The risk reduction strategies for operation in groups (a), (b), and (c) at the wastewater treatment plant are presented in Table 2.

4 Results

In the first part, the most important threat in each section of the wastewater treatment system is identified, and its effects are analyzed. In the second part, the best solution for reducing the harmful effects of each threat in the event of its occurrence will be described using MARCOS. In the last part, the reduction in risk priority number in different sections of the wastewater treatment plant due to the implementation of the proposed strategies will be analyzed.

4.1 Identifying the most significant potential threat during the operation of the wastewater treatment plant

In this phase, after determining the score of each component of risk number based on the FEMA method for each of the different sections of the wastewater treatment system, the

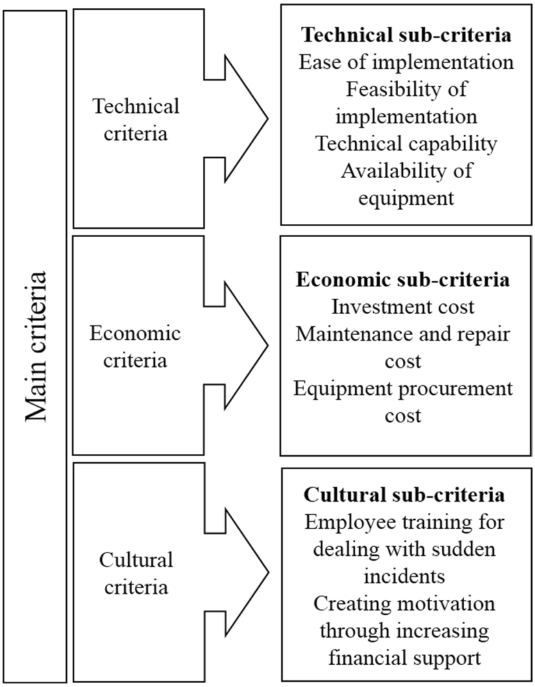


Fig. 5 Criteria and sub-criteria

risk priority number against natural, technical, and intentional threats was calculated by aggregating the opinions of experts. The results are presented in Table 3.

4.1.1 Risk analysis of group (a)

According to Table 3, the most significant natural threat to the sewage collection system is the risk of flooding. This is because the wastewater treatment system has been constructed at a lower elevation compared to the surrounding area to eliminate pumping equipment and reduce sewage transport costs, and therefore, heavy rainfall and flooding can disrupt the operation of the treatment plant.

The most significant technical threat to the sewage collection system is the possibility of incorrect calculation of the lifetime of components. The main reasons for this threat are the use of inadequate quality equipment in the wastewater treatment plant and non-compliance with existing standards.

The most significant intentional threat is the release of chemical and biological pollutants in the wastewater transport path to the treatment plant, which can be mainly caused by the discharge of industrial wastewater into the sewage collection system. Due to non-compliance with the concentration of pollutants in domestic wastewater standards, this can disrupt the operation of the wastewater treatment plant.

4.1.2 Risk analysis of group (b)

According to the calculations in Table 3, the most significant type of threat to the components of group (b), which includes tanks and wastewater treatment facilities, is the technical

Table 2 Risk mitigation strategies for operational risk for groups (a), (b), and (c) in the sewage treatment plant

Type of threat	Title of the threat with maximum risk value	Symbol	Risk reduction strategies
Group (a): Sewage collection system and inlet structures (inlet distribution, inlet lift station, screening plant, grit and grease collecting)			
Natural	Flood	A1	Creating a channel and directing the flood before the flood occurs
		A2	Constructing a flood barrier upstream of the wastewater treatment plant system
		A3	Using modern technologies in pipelines resistant to natural hazards
		A4	Reducing the impact of heavy rainfall through flood control methods
		A5	Designing preparedness plans for dealing with natural hazards
Technical	Design issues, especially incorrect calculation of the lifespan of components	B1	Procuring high-quality equipment
		B2	Replacing components ahead of the designated lifespan for their useful life
		B3	Controlling the necessary standards in designing sewage pipelines and fittings and equipping the inlet structures of the system, identifying and rectifying non-standard cases
		B4	Incorporating an appropriate location for repairs in the event of a design error
Intentional	Pollution (chemical and biological pollutants)	C1	Quality control of wastewater from facilities and industries in terms of chemical pollution (BOD)
		C2	Continuous monitoring of the system and controlling the flow of wastewater before entering the system
		C3	Providing locations for the discharge of wastewater from adjacent industries to the system or enabling municipal and urban policy intervention to prevent the discharge of wastewater from adjacent industries into the network path
Group (b): Primary and final settling tanks, aeration tanks, chlorination contact basin, sludge anaerobic digester with the boiler house and chlorination building			
Natural	Earthquake	A′1	Earthquake preparedness plans
		A′2	Using portable pumps to discharge sludge
		A′3	Identifying vulnerable points and strengthening them
		A′4	Using separators and dampers to increase the seismic response of structures
Technical	Human error	B′1	Operator training and use of auxiliary tools and personal protective equipment
		B′2	Using a harness belt by the operator
		B′3	Using a mask equipped with an oxygen capsule (related to anaerobic digestion)
		B′4	Procuring personal protective equipment specific to chlorine gas (related to the chlorine unit)
		B′5	Increasing the skills and training of personnel for chlorine gas leak extinguishing (related to the chlorine unit)

Table 2 (continued)

Type of threat	Title of the threat with maximum risk value	Symbol	Risk reduction strategies
Intentional	Pollution (chemical and biological pollutants)	C′1	Quality control of wastewater in terms of chemical pollution (BOD)
		C′2	Continuous monitoring of the system and control of wastewater flow
		C′3	Daily monitoring and sampling
		C′4	Monthly inspection of equipment
		C′5	Supervision and inspection of the system
		C′6	Ensuring the accuracy of the design
Group (c): Sludge dewatering building, sludge thickening building and supernatant pumping station			
Natural	Flood	A″1	Creating a channel and directing the flood before the flood occurs
		A″2	Constructing a flood barrier upstream of the wastewater treatment plant system
		A″3	Using modern technologies in pipelines resistant to natural hazards
		A″4	Reducing the impact of heavy rainfall through flood control methods
		A″5	Designing preparedness plans for dealing with natural hazards
Technical	Design issues, especially incorrect calculation of the lifespan of components	B″1	Procuring high-quality equipment
		B″2	Replacing components ahead of the designated lifespan for their useful life
Intentional	Physical (bombing)	C″1	Upgrading security systems and using CCTV cameras for continuous monitoring
		C″2	Predicting mobile pumps for sludge transfer in the event of structural failure and equipment damage due to bombing

Table 3 The priority risk number of each section of the wastewater treatment system based on the type of threat

Risk-taker components of the wastewater treatment system	Type of threat	Threat	Risk
Group (a): Sewage collection system and inlet structures (inlet distribution, inlet lift station, screening plant, grit and grease collecting)	**Natural**	**Flood**	**182.66**
	Technical	Design issues, especially incorrect calculation of the lifespan of components	154.5
	Intentional	Pollution (chemical and biological pollutants)	129.5
Group (b): Primary and final settling tanks, aeration tanks, chlorination contact basin, sludge anaerobic digester with the boiler house and chlorination building	Natural	Earthquake	78.11
	Technical	**Human error**	**135.44**
	Intentional	Pollution (chemical and biological pollutants)	134.11
Group (c): Sludge dewatering building, sludge thickening building and supernatant pumping station	**Natural**	**Flood**	**150.33**
	Technical	Design issues, especially incorrect calculation of the lifespan of components	132.66
	Intentional	Physical (bombing)	78.33

Bolded items represent the highest threat and risk threat. Tanks and wastewater treatment facilities are the most important and sensitive part of the wastewater treatment system, and even the slightest disruption in their performance can cause the entire wastewater treatment system to stop operating. Therefore, it is essential to minimize controllable human errors and provide necessary training to employees to comply with safety standards during work or in the event of an incident.

The second most threatening risk to group (b) components is the intentional threat of chemical and biological contaminants that may exceed the allowable concentration and disrupt the treatment process. This is especially important for wastewater treatment plants whose treated effluent is reused.

The occurrence of earthquakes is considered as the third threat to the group (b) components, which is due to the geographical location of Qom province and its classification in the high relative risk zone for earthquakes based on the Building Design Code against Earthquakes (Anonymous, 2014).

4.1.3 Risk analysis of group (c)

According to Table 3, the flood risk due to the construction of the system at a lower elevation compared to the surrounding area is the most significant natural threat to the components of group (c). Additionally, since group (c) components include sludge thickening buildings and effluent pumping stations, incorrect calculation of the lifetime of components can disrupt the performance of the sludge thickening building and the overall operation of the wastewater treatment plant. Also, the most significant intentional security threat to the wastewater treatment system is the risk of bombing.

4.2 Selecting the best solution based on the MARCOS decision-making method

After identifying the most probable threats in each section of the wastewater treatment system, multiple strategies were proposed. To evaluate the strategies, various criteria and subcriteria were first determined and weighted using the SF-AHP method.

4.2.1 Weighting of criteria using the SF-AHP method

The final weights of the criteria are shown in Fig. 6. According to Fig. 6, the sub-criterion of investment cost with a weight of 0.141 is ranked first. This indicates that the economic aspects of the proposed strategies are highly important to the experts and specialists, as the implementation of each strategy is directly dependent on creating economic infrastructure. The criterion of feasibility, with a weight of 0.139, is ranked second. The feasibility of each strategy in the study area, in terms of unique structural features and even climatic conditions, should be examined to maximize its efficiency. Additionally, the sub-criterion of availability of necessary equipment, with a final weight of 0.072, indicates the absence of significant obstacles in providing and procuring equipment for various sections of the wastewater treatment plant.

4.2.2 Ranking the risk mitigation strategies

The prioritization of risk reduction strategies against various potential threats for each group of the wastewater treatment system using the MARCOS method is presented in Table 4. According to Table 4, the most important risk reduction strategy for the

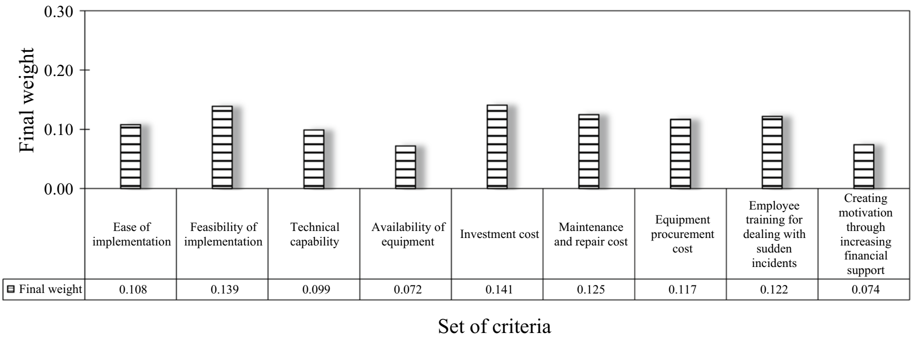


Fig. 6 Final weight of criteria

wastewater collection system and the inlet structures of the treatment plant against natural flooding threats is designing preparedness plans to deal with natural disasters. Against technical threats, the strategy is addressing design problems, especially incorrect calculation of component lifetimes, by incorporating appropriate repair locations in case of design errors. Against intentional threats, the strategy is to address pollution (chemical and biological pollutants) by providing discharge locations for nearby industrial wastewater or providing the possibility of municipal intervention and urban policies to prevent the discharge of industrial wastewater into the network route.

The most important risk reduction strategy for the ponds, anaerobic digesters, the boiler building, and the chlorination building against natural threats is earthquake preparedness, using portable pumps for sludge discharge. Against technical threats, the strategy is to address human errors by increasing the skills and training of staff to extinguish chlorine gas leaks (related to the chlorination unit). Against intentional threats, the strategy is to monitor and inspect the system to address pollution (chemical and biological pollutants).

Ultimately, the most important risk reduction strategy for the intake structure building, sludge thickener building, and wastewater pumping station against flooding is designing preparedness plans to deal with natural disasters. Against technical threats, the strategy is to address design problems, especially incorrect calculation of component lifetimes, by replacing components before their useful life expires. Against intentional physical threats (such as bombing), the strategy is to anticipate mobile pumps for sludge transfer in event of structural failure and equipment damage due to bombing.

4.3 Analysis of risk priority number for the set of risk reduction solutions

In this section, the effectiveness and risk reduction of preventive strategies in each section of the wastewater treatment system were analyzed by recalculating the risk priority number based on the opinions of experts, which will be described in detail below.

4.3.1 Analysis of risk reduction for group (a)

Comparison of risk priority number for group (a) with and without considering the set of strategies is shown in Fig. 7. According to Fig. 7, for group (a) components, risk priority number will decrease by 89% with the inclusion of designing preparedness plans to deal with flooding, and by 75 and 87% with the incorporation of appropriate repair locations in

Table 4 Prioritizing strategies for reducing risk

Group of critical components	Type of threat	Alternatives	$f(K_i)$	Rank
Critical components of group (a)	Natural	A1	0.6045	2
		A2	0.5774	4
		A3	0.5594	5
		A4	0.5779	3
		A5	**0.7512**	**1**
	Technical	B1	0.6208	3
		B2	0.698	2
		B3	0.5991	4
		B4	**0.7069**	**1**
	Intentional	C1	0.6601	2
		C2	0.6445	3
		C3	**0.6879**	**1**
Critical components of group (b)	Natural	A′1	0.6789	2
		A′2	**0.6819**	**1**
		A′3	0.6084	3
		A′4	0.595	4
	Technical	B′1	0.6589	3
		B′2	0.6612	2
		B′3	0.6325	5
		B′4	0.6342	4
		B′5	**0.7329**	**1**
	Intentional	C′1	0.6275	6
		C′2	0.6578	4
		C′3	0.684	3
		C′4	0.7013	2
		C′5	**0.7412**	**1**
		C′6	0.6325	5
Critical components of group (c)	Natural	A″1	0.6045	2
		A″2	0.5774	4
		A″3	0.5594	5
		A″4	0.5779	3
		A″5	**0.7512**	**1**
	Technical	B″1	0.6176	2
		B″2	**0.7084**	**1**
	Intentional	C″1	0.625	2
		C″2	**0.7066**	**1**

Bolded items indicate the highest priority of risk reduction strategies against various potential threats

case of design errors and providing discharge locations for nearby industrial wastewater or allowing for municipal intervention to prevent discharge of industrial wastewater into network route, respectively, against technical and intentional threats.

This indicates that, from the perspective of experts, the flood risk can disrupt the entire wastewater treatment system, and the necessity of designing and implementing

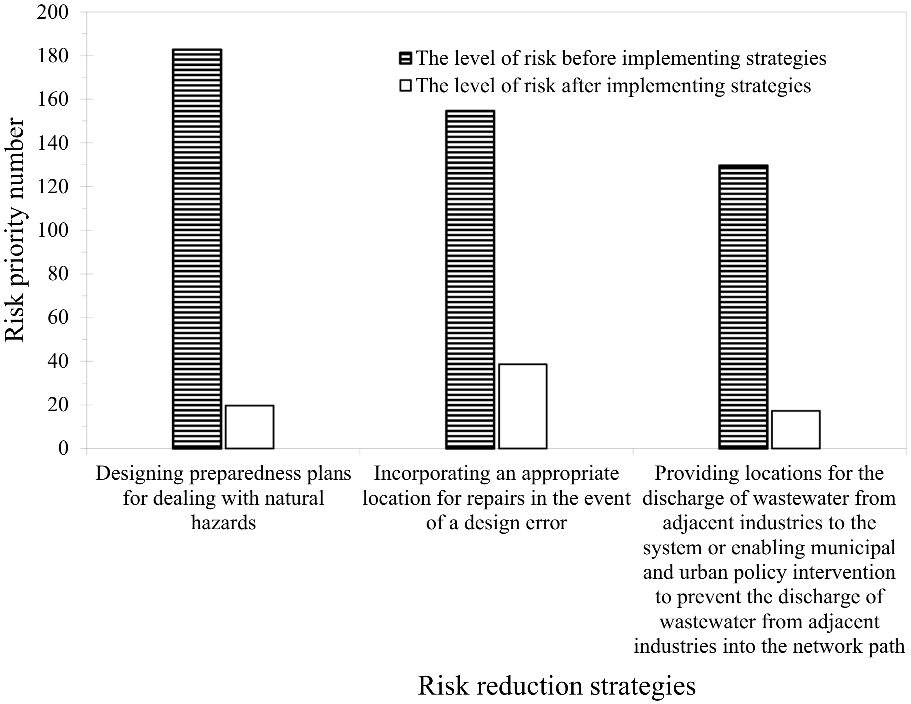


Fig. 7 Percentage of risk reduction with and without considering risk reduction strategies in the wastewater collection system and inlet section

preparedness plans against has great importance. Additionally, incorporating accessible locations for replacing or repairing components and parts during any type of threat or resulting damage can save time and increase the speed of repairing essential parts, which itself reduces disruptions in the treatment plant's performance. Preventing industrial wastewater discharge into the wastewater network path to the system, with the intervention of the municipality through the provision of separate locations for industrial wastewater discharge, reduces the risk of the entry of industrial pollutants into the municipal wastewater treatment. This is important because household wastewater treatment devices are designed to treat a specific concentration of pollutants, and the entry of pollutants with varying concentrations can damage the wastewater treatment plant equipment.

Among the components of risk priority number, the vulnerability component had the greatest reduction compared to other components. Vulnerability was reduced by 61% with the implementation of flood control plans prior to entering the wastewater treatment plant. Reducing the vulnerability component through the implementation of flood control plans prior to entering the wastewater treatment plant will reduce financial and human losses. The vulnerability component will be reduced by 61% through the solution of incorporating accessible locations for replacing or repairing components and parts, and by 60% through preventing industrial wastewater discharge into the wastewater collection and transfer system.

The feasibility of each of mitigation strategies for group (a) will be described below:

Mitigation strategies for flood:

(1) Implementation of rainwater ponds on the techometry plan map according to the slope of the area, population density and land use.
(2) Choosing the appropriate hydraulic cross section according to the volume of wastewater or surface water.

Mitigation strategies for design problem:

(1) Forming an expert team supervising for design of wastewater treatment plant parts and conducting standard tests
(2) Consider places for continuous monitoring of parts

Mitigation strategies for pollution:

(1) Considering specific places to discharge physical and chemical pollution
(2) Placing sensors sensitive to non-domestic pollutants in the sewage collection network

4.3.2 Analysis of risk reduction for group (b)

The comparison of risk priority number for group (b) with and without the set mitigation strategies is shown in Fig. 8. As shown in Fig. 8, risk priority number for group (b) related to increasing personnel skills and training to respond to chlorine gas leaks (related to the chlorination unit) decreased by 84%. Additionally, implementing strategies such as monitoring and inspection of the system in the face of intentional threats and using portable pumps for sludge discharge against natural threats reduced the risk priority number by 79 and 40%, respectively.

From the perspective of experts, the high sensitivity of the chlorination unit to fire and the possibility of its widespread spread to other parts of the wastewater treatment plant and its irreparable consequences highlight the importance of personnel and staff training and increasing their skills, particularly in terms of safety precautions.

According to experts, intentional threats are generally linked to individuals' lack of awareness and preparedness. In this case, continuous monitoring and inspection of various parts of the system are crucial in detecting threats such as the entry of pollutants into the system, which significantly reduces environmental and technical risks. Different structures in the system, including sedimentation tanks and aeration tanks, are designed to be earthquake-resistant and made of reinforced concrete. However, due to unpredictability of timing and earthquakes magnitude, measures such as predicting portable pumps can be useful in reducing economic and environmental damages by transferring sludge in the event of a structural break or damage due to an earthquake.

From the perspective of analyzing risk priority number components, the severity of damage in the event of using portable pumps for sludge discharge in the face of unpredictable threats such as earthquakes will be reduced by 27%. Using equipment such as portable pumps for sludge discharge in the event of an earthquake will reduce financial and environmental damages.

According to experts, the severity of damage caused by chlorine gas leaks will be reduced by 46% with an increase in personnel skills and training for responding to chlorine

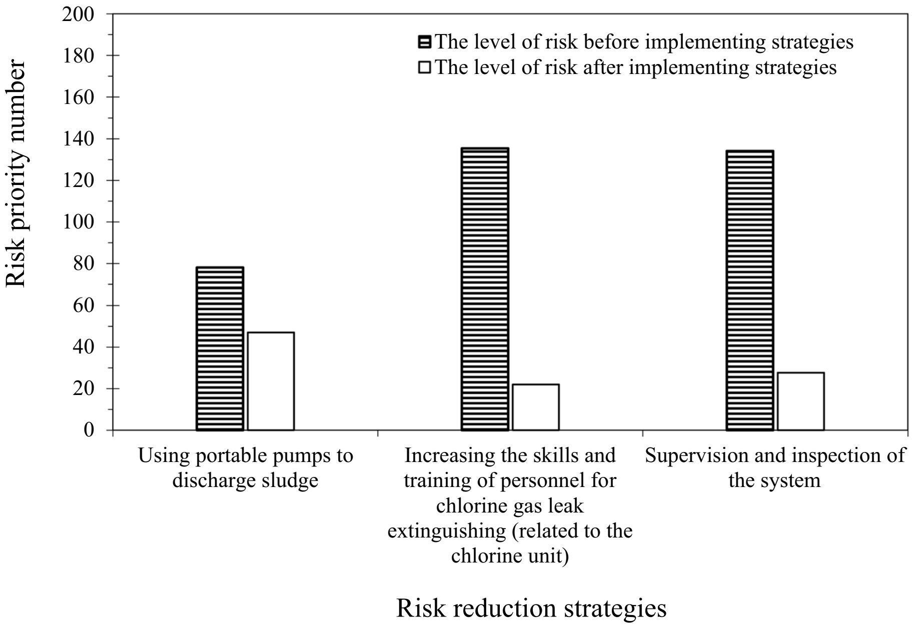


Fig. 8 Percentage of risk reduction with and without considering risk reduction strategies in the treatment tanks section and Chlorination building

gas leaks. This means that reducing fatalities and financial losses will significantly decrease with personnel's increased skills and speed in responding to chlorine gas leaks. Preventing the entry and spread of pollutants through continuous monitoring and inspection will also reduce the vulnerability component by 55% compared to other components.

The feasibility of each of mitigation strategies for group (b) will be described below:

Mitigation strategies for earthquake:

(1) Using the suitable and resistant materials in the design and construction of the wastewater treatment plant
(2) Placing floating pumps with the ability to quickly discharge sludge

Mitigation strategies for human error:

(1) Hiring specialized staff in sewage treatment plant
(2) Increasing human skills through professional training courses

Mitigation strategies for pollution:

(1) Continuous surveillance and monitoring of the system through security cameras
(2) Continuous sampling of tanks to measure the pollutants concentration

4.3.3 Analysis of risk reduction for group (c)

The comparison of risk priority number for group (c) with and without considering the set of strategies is shown in Fig. 9. According to Fig. 9, risk priority number for group (c) components will be reduced by 90% by replacing the parts before the end of their useful life. This means that implementing this strategy significantly reduces potential damages caused by component failure at the end of their useful life. Risk priority number is also reduced by 65 and 34%, respectively, by implementing preparedness plans for responding to natural disasters and predicting portable pumps for sludge transfer in the event of structural damage due to intentional threats such as bombings.

From the perspective of risk priority number analysis, implementing plans to control flood flow before entering the system has the greatest impact on reducing financial losses and equipment procurement and repair costs, with the severity component being reduced by 37%. To prevent equipment and component malfunctions, replacing parts before the end of their useful life will reduce the severity component by 59%. According to experts, predicting portable pumps in the event of any type of structural failure, such as bombings, reduces the vulnerability component as the most important component in reducing the risk priority number by 26%.

The feasibility of each of mitigation strategies for group (c) will be described below:

Mitigation strategies for flood:

(1) Determining the lines of the route of transfer and disposal of sewage by gravity or under pressure

(2) Hydraulic calculations for determining the dimensions and diameters of flood transmission lines and preparing the longitudinal plan and its calculation tables

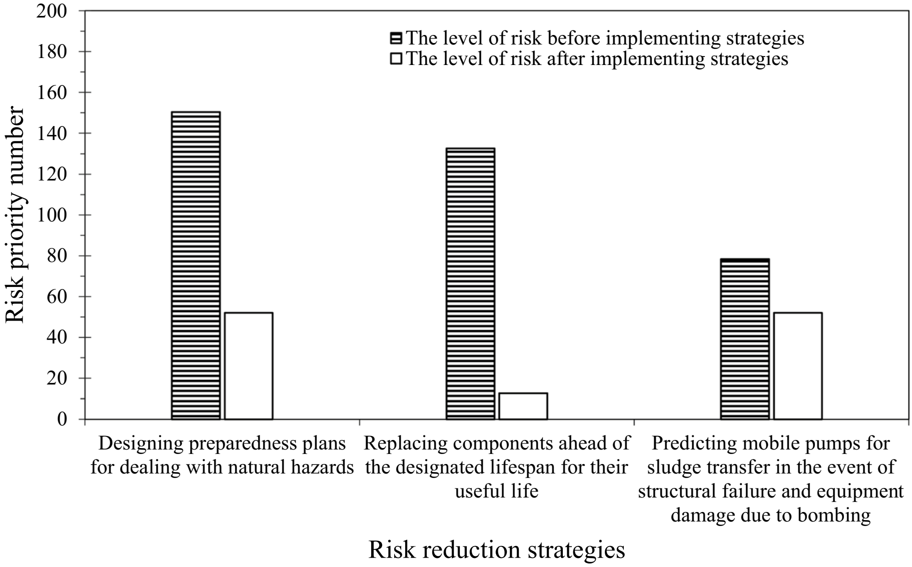


Fig. 9 Percentage of risk reduction with and without considering risk reduction strategies in the sludge dewatering building, sludge thickening, and wastewater pumping section

Mitigation strategies for design issues:

(1) Forming an expert team supervising for design of wastewater treatment plant parts and conducting standard tests
(2) Consider places for continuous monitoring of parts

Mitigation strategies for bombing:

(1) Intensification of care measures and physical protection and strengthening of structures
(2) Creation of multi-layer physical protection in depth around reservoir facilities

A comparison between the initial risk priority numbers and the revised risk priority numbers has been presented in Table 5.

5 Discussion

In order to improvise the results of the present study, results of several similar previous studies will be described.

Sadiq et al. (2004) used fuzzy risk in combination with the Analytical Hierarchy Process (AHP) method in order to analyze the aggregative risk of urban distribution network pollution. The results showed that the development of the concept of risk in the fuzzy environment reduced the uncertainty in the results of the ranking of different risks. Tidwell et al. (2005) investigated the security of water systems against terrorist attacks with the Markov Latent Effects (MLE) modeling and multi-criteria decision-making methods. The results showed that probability of an attack calculating was the most difficult part of threat assessment since lack of information. Taheriyoun and Moradinejad (2015) investigated the main factors that affect on performance of wastewater treatment using Fault Tree Analysis (FTA). The results indicated the human factors, climate, and sewer system had the highest effects. Fattahi and Khalilzadeh (2018) proposed the Fuzzy Weighted Risk Priority Number (FWRPN) in order to more accurately evaluate failure modes. For this purpose, the weight of 3-risk factors was calculated by AHP method and the weight of failure modes by fuzzy Multi-Objective Optimization on the basis of Ratio Analysis plus full multiplicative form (MULTIMOORA) method. The results indicated the weighted fuzzy risk priority number decreased by 56% with corrective measures. Alvand et al. (2021) used the SWARA and WASPAS methods under the fuzzy environment in order to cover shortcomings of

Table 5 A comparison between the initial risk priority numbers and the revised risk priority numbers

RPN for all type of risks						
Group type	Natural		Technical		Intentional	
	B.S	A.S	B.S	A.S	B.S	A.S
a	182.88	19.66	154.5	38.66	129.5	17.33
b	78.8	47	135.44	22	134.11	27.66
c	150.33	52	132.66	12.66	78.33	52

B.S before applying mitigation strategies

A.S after applying mitigation strategies

FMEA method in the risk assessment of construction projects in Iran. The results showed that the new model was more capable in prioritizing risk relative to conventional FMEA.

The results of some of the mentioned studies that are related to the subject of this research show that (1) using the fuzzy concept in combination with risk calculation methods reduces the uncertainty, (2) human error is one of the most important risk factors in wastewater treatment plants, (3) risk mitigation strategies reduce the risk priority number, (4) calculating the threat of an attack is very difficult due to the lack of sufficient information. Also, the theoretical contribution of the present study will be discussed.

(1) Most of the researches that have been carried out in field of risk analysis are about the environmental risk assessment such as chemical and biological risk, as well as the risk caused by the presence of harmful substances in municipal wastewater or reuse of treated wastewater (Cheng et al., 2022; Kiani et al., 2022; Liu et al., 2022; Yang et al., 2019). While less technological and operational risks, i.e. risks that cause disruption and failure in the overall performance of the wastewater treatment plant, have been investigated.
(2) Although several MCDM have been used in the ranking of risks or the ranking of solutions to reduce the adverse effects of each risk, in the present study, the spherical fuzzy logic has been used in the allocation of experts' opinions in the evaluation of the criteria set, which causes the selection of the best mitigation strategies will be more sustainable in the future time interval.
(3) The recalculation of risk priority number by considering the risk mitigation strategies from the experts shows the effectiveness of the proposed strategies.

The present study investigates the most important potential threats that expose a wastewater treatment plant to vulnerability. Although the probability of occurrence of these threats can never be accurately determined, but if they occur, irreparable damages will be inflicted on the performance of the sewage treatment plant and the entire region. Therefore, it is necessary to provide preventive solutions. The most important feature of the current research is to present a process to calculate and reduction the operational risk that can be generalized to other water and wastewater infrastructure, i.e. (1) Identifying the most important risk and risk calculation based on a standard guideline, (2) providing appropriate solutions using experts' opinions and reducing uncertainty in their opinions through a widely used theory (i.e. Fuzzy theory), and (3) finally measuring impact of each solution on the risk of operating different parts of the wastewater treatment plant. Calculating the operational risk has been done in other studies, but the effectiveness of risk mitigation strategies on RPN hasn't been conducted.

The general process of the present research including: calculation risk priority number base on the FEMA-425, calculation the criteria weight with the SF-AHP method, ranking the mitigation strategies by MARCOS MCDM method and recalculating the risk priority number can be generalized for other sewage treatment plants. It is possible that the final findings of SF-AHP and MARCOS methods be applicable to the other wastewater treatment plants with similar conditions from a technical point of view, type of equipment, type of treatment plant (urban or industrial), morphology and geological situation.

However, since MCDMs are constructed base on experts' opinions (for instance in this research, completing the paired comparison matrixes in SF-AHP method and the decision-making matrix in MARCOS MCDM method), it is possible to obtain different findings from the final findings of present research.

In General, the proposed mitigation strategies for a case study cannot be fully generalized for other regions. The proposed mitigation strategies in the present study are influenced are set by several factors such as the region conditions (in the present study, the sewage treatment plant is a city whose pollutants are not toxic or dangerous), the seismicity and flood occurrence and the morphological conditions of the region, the level of supervision and monitoring of the performance of the components, the current type of wastewater treatment equipment, the existence of enough space to implement the proposed mitigation strategies, the level of training and skills of employees and specialists, as well as their salaries.

These factors can limit the generalization the proposed strategies effectiveness to other wastewater treatment systems, but they may be generalizable if the type and components of treatment plant, earthquake susceptibility, natural disasters and employees and their education level are the same.

6 Concluding remarks

Sewage treatment systems are considered one of the most important urban development infrastructures in providing health, social well-being, and economic benefits. Maintaining the performance of its various components during any natural or man-made disasters and resulting damages is essential. The risk assessment process in sewage treatment plants, which includes identifying possible threats, calculating the risk priority number, and proposing strategies to reduce the adverse effects of any threat, is one of the key measures to prevent human and environmental crises. Given the extensive urban sewage treatment system and the internal relationship between its various components, as well as the various hazards that threaten its performance, determining the best strategies that ensures sustainable operation in any adverse conditions is challenging. The MCDMs are one of the most widely used tools for selecting the best alternative from among multiple proposed alternatives.

In this study, first, risk priority number for various components of the sewage treatment system was identified using the FEMA-452 method against the identified types of threats based on ASCE (2004). The results showed that the most significant threats to group (a), group (b), and group (c) components were flood risk, human error, and flood risk with a risk priority number of 183, 135, and 150, respectively.

In the second step, multiple strategies were proposed by experts to reduce the adverse effects of any potential threat to each section of the sewage treatment plant, and criteria were provided to evaluate them. To weight the criteria and reduce the uncertainty of expert opinions, the SF-AHP method was used, and the MARCOS method was employed to rank the strategies. The results of SF-AHP method showed that the investment cost criterion with a weight of 0.171 was the most important criterion according to the experts. Moreover, the results of the MARCOS method showed that the best strategy to reduce the risk priority number of group (a) and (c) components against flood risk was to design preparedness plans for responding to natural disasters with a desirability function of 0.7512 and 0.7512, respectively, and to increase the skills and training of personnel to extinguish chlorine gas leaks (related to the chlorination unit) to reduce the risk priority number of group (b) components against human error with a desirability function of 0.7329.

Finally, after identifying the best strategies, risk priority number and the effectiveness of the proposed strategies on the performance of the sewage treatment system were reanalyzed. The results showed that risk priority number, taking into account the proposed strategies related to the most significant threats in each section of the sewage treatment plant, decreased by 89% for group (a), which included designing readiness plans for responding to flood risk, 84% for group (b), which involved increasing the skills and training of personnel to extinguish chlorine gas leaks (related to the chlorination unit) in response to human error, and 90% for group (c), which entailed replacing parts before their scheduled end-of-life due to incorrect calculation of the parts' lifespan.

Identifying potential risks is the most important step that must be done very carefully, which requires a detailed investigation of the area condition (type of domestic or industrial treatment plant), wastewater collection network, type of equipment, and stages of the treatment plant.

Although the results of risk calculation in the wastewater treatment plant using the FEMA method are simple and understandable by experts, but because they are based on the opinions of experts, they may be accompanied by human error. Although the operational risk calculation in the wastewater treatment plant using the FEMA method is simple and understandable by experts, but because it is based on the opinions of experts, may be accompanied by errors caused by human knowledge, which can be done using methods such as Monte Carlo simulations reduced it to some extent.

Also, for a more detailed investigation of each of the risks, indicators can be defined for each of them so that the risk priority numbers can be calculated more accurately.

If the proposed strategies in the present study are implemented, the operating risk of the wastewater treatment plant will be reduced. Reducing the risk of operating wastewater treatment plant will increase the readiness of the whole system against the occurrence of natural, technical, and intentional threats in general, its main function will not be disturbed when any kind of threats occurs.

The proposed strategies in the present study have been suggested to the authors based on the field conditions of the study area, characteristics of the sewage treatment plant and interviews with experts working in the sewage treatment plant, and if funding is provided for the implementation of the strategies, it is possible to implement the scenarios in the real-world.

The assumptions considered in the research include the following:

(1) In this study, the most important components of sewage treatment plant were considered. The most important components include the parts in which the least disruption will cause the entire wastewater treatment plant faces a challenge.
(2) Natural hazards were regarded based on earthquake zoning and flood history in the past years.
(3) The population condition of the region and the development of industries in it will remain as it is.

Limitations in the present research include the following:

(1) Determining the economic costs of risk mitigation strategies has not been done due to the variability of costs and the difficulty of real quantitative estimation of strategies.
(2) If the wastewater treatment plant is expanded due to population growth, some of the current proposed mitigation strategies may be changed.
(3) One of the most challenging steps in calculating risk priority number is related to cyber threats because the information related to the history of threats, the weakness

and strength of the enemy, the ability to face attacks is usually not available, and its risk estimation has a lot of uncertainty.

Funding Not applicable.

Data availability Some or all data, models, or code that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethical approval The paper is not currently being considered for publication elsewhere. All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

Consent to participate Informed consent was obtained from all individual participants included in the study.

Consent to publish The participant has consented to the submission of the case report to the journal.

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