EnvironmentAsia
The international journal by the Thai Society of Higher Education Institutes on Environment

EnvironmentAsia 16(1) 2023 99-110
DOI 10.14456/ea.2023.9
ISSN 1906-1714; ONLINE ISSN: 2586-8861

Hazard Analysis of Environmental Incidents in Coastal Areas: A Case Study in the Southeastern Coastal Region of Vietnam

Cuong Le Tan[1,4*], Phuoc Nguyen Van[2], Quan Nguyen Hong[3,4], Huyen Do Thi Thu[1,4], and Loan Tran Thi Diem[1]

[1] *Institute for Environment and Resources*
[2] *Ho Chi Mink City Union of Science and Technology Associations*
[3] *Institute for Circular Economy Development*
[4] *Vietnam National University of Ho Chi Minh City*

*Corresponding author: tancuong@hcmier.edu.vn, letancuongmttn@gmail.com
Received: August 12, 2022; Revised: October 27, 2022; Accepted: November 2, 2022

Abstract

Coastal areas are facing many threats from the mainland, which can seriously affect the ecological environment and the livelihoods of coastal residents. Thus, the identification and estimation of environmental hazards to reduce the risk of environmental incidents due to the development process have drawn the keen attention of researchers. This study proposed a multiple-criteria decision-making (MCDM) approach based on the combination of the group best–worst method (GBWM) and geographic information system GIS to analyze the hazards of environmental incidents due to chemical spills from the mainland. A set of 6 criteria that focused on the potential occurrence of environmental incidents related to the chemical was proposed, including chemical types, chemical volume, chemical storage safety, potential incident location, chemical incident response plan, and chemical incident response capacity. The optimal weights of the criteria were determined by GBWM. In a case study of the southeastern coastal region in Vietnam, 65 fixed sources of potential environmental incidents related to hazardous chemical use, production, and trading were investigated and analyzed by the proposed approach, of which 15 sources were identified as the potential hazard sources of an environmental incident. These hazard sources were categorized into four levels: very high, high, medium, and low, accounting for 20.00%, 26.67%, 33.33%, and 20.00%, respectively. This study is expected to support the practitioners and policy enforcers in making decisions related to socioeconomic development, which can minimize the hazard of environmental incidents due to chemical spills from the mainland.

Keywords: Group best–worst method; Multiple-criteria decision-making; Hazard; Environmental incidents; Coastal areas

1. Introduction

Characterized by low terrain and resource-diverse settings and capable of providing many valuable services to humans by ecosystems (Domingues *et al.,* 2021), coastal regions have always been dynamic development areas and contribute significantly to the development of many regions and countries worldwide. The attractiveness of coastal areas to their hinterlands is that they are favorable for commercial activities, many services, high industrialization (Mohamed, 2020) and high population density. Despite the prospects for development, coastal areas always have a higher hazard of environmental incidents than other regions on the mainland (Mohd *et al.,* 2019). The coastal areas are facing many pressures and challenges for the development to ensure the creation of material products to serve the needs of coastal livelihoods and maintain the balance and stability of coastal ecosystems (Tian *et al.,* 2018). In the process of industrialization, the coastal region of Vietnam has experienced some serious environmental incidents. The most severe coastal environmental incident was the Formosa Steel plant's massive toxic chemical spill in 2016. The toxic discharges impacted the environmental quality of the central coastal region, leading to a deterioration of the water environment, seriously destroying marine life resources, and affecting the long-term livelihood of fishers. In 2008, an environmental incident caused by the wastewater discharge from the production of starches and monosodium glutamate by the Vedan company resulted in serious pollution of the Thivai river. Another environmental incident from the wastewater discharge of the Tanhai Concentrated Seafood Processing Zone in 2017 resulted in serious pollution of the water quality of the Chava river and over 90 tons of aquatic animal deaths.

Hazard is described as a source of danger (Kaplan *et al.,* 1981) and considered a potential threat that can cause human, social, economic, and environmental damage. It is classified into three main groups: natural, technological, and social disasters (Schneiderbauer *et al.,* 2004). As regards those caused through technology, hazards can occur due to explosions, toxic chemical spills, or accidents during production (Schneiderbauer and Ehrlich, 2004). Development activities in the mainland contain many hazards of environmental incidents affecting coastal areas that are primarily related to fixed sources of production and trading of toxic chemicals.

Three methods of analyzing environmental incident hazards in coastal areas that have been commonly reported in the literature are modeling (Al Shami *et al.,* 2017; Monteiro *et al.,* 2020), statistical (Gómez *et al.,* 2015; Neuparth et al., 2011) and criteria-based (Dong *et al.,* 2018; Peng *et al.,* 2013). Statistical and modeling methods can help visualize, explain, and predict environmental incident hazards; however, the major downside is the lack of input data or deficiency of the model structure. Thus criteria-based approaches tend to be more used. In this approach, the hazard value is usually estimated based on the criteria related to risk sources and safety aspects in risk prevention and control (Liu *et al.,* 2016; Zhao *et al.,* 2010).

According to Amendola (Amendola *et al.,* 1998), the criteria chosen to estimate the level of hazard of environmental incidents were dependent on the type of hazardous chemical, storage volume, tank safety, pipes, and risk source location. Moreover, in a study by Liu (Liu *et al.,* 2013), the hazard value was determined based on sub-criteria related to three main criteria: the state of risk sources, risk source control, and control of incident response process. In some other studies, the hazard factor was determined based on the ranking matrix, which was identified by the quotient of stock quantity to threshold quantity of hazardous substances and the level of management concerning the production process and risk control (Dong *et al.,* 2018; Liu *et al.,* 2016)

MCDM has been mentioned since the 1970s (Köksalan *et al.,* 2011). The highlight of MCDM methods is that they are based on many criteria that may have different dimensions, also may be both quantitative and qualitative (Mardani *et al.,* 2015) to support the decision-making of selection, ranking, or priority order related to research issues (Alvarez *et al.,* 2021). MCDM techniques are divided into four groups: full aggregation approach; outranking approach; goal, aspiration, or reference-level approach; and non-classical MCDM approach (Alvarez *et al.,* 2021). Many of these approaches are increasingly being used by scholars in different disciplines, such as the analytic hierarchy process (AHP) method (Miccoli *et al.,* 2016), the technique for order of preference by similarity to ideal solution (TOPSIS) (Zhang *et al.,* 2018); analytic network process (ANP) method (Mahmoudkelaye *et al.,* 2018), and preference ranking organization method for enrichment evaluation (PROMETHEE) (Makan *et al.,* 2019).

In 2015, a new technique was introduced by Rezaei (Rezaei, 2015), called the best–worst method (BWM). The best–worst method is also based on the principle of pairwise comparison of the AHP approach (Saaty, 1990), but instead of comparing each pair of all the selected criteria, only the best and worst criteria are determined and compared with the remaining criteria. Thus BWM is supposed to be more advanced than the traditional AHP method as it reduces the pairwise comparison (i.e. n) requirement that helps mitigate the anchoring bias and ensures consistent pairwise comparisons, with n(n – 1)/2 comparisons and (2n – 3) comparisons in AHP and BWM, respectively (Hoang *et al.,* 2021). Recently, the group best–worst method (GBWM) proposed by Safarzadeh (Safarzadeh *et al.,* 2018) was seen as an improvement over BWM to support decision-making when more stakeholders are involved. This advantage of GBWM that has been mentioned in some recent research works (Ahmad *et al.,* 2021; Hoang *et al.,* 2021).

Based on the results of this analysis, the main contributions of this study are as follows: (i) the application of GBWM based on the MCDM analysis tool, which combines GIS to build a model of analysis of the hazard of coastal environmental incidents caused by chemical spills from the mainland, with the appropriate criteria selected, combining optimal weighting determination of each criterion and (ii) an analysis of the hazard of environmental incidents caused by chemical spills from the mainland affecting the southeast coastal region, Vietnam.

2. Materials and Methods

2.1 Research area

The southeast coastal region is adjacent to the East Sea and is located in the southeast of Vietnam, with geographical coordinates in the range of 10°15’46”– 10°49’44” North latitude and 106°44’04”– 107°34’50” East longitude (Figure 1). The coastal area has a length of about 90 km. This area is considered the most developed economic region in Vietnam, with 21 industrial parks, industrial-scale aquaculture areas, a seaport, and famous tourist areas.

2.2 Methods

The MCDM methods are used in the analysis and evaluation related to hazards and environmental risks, the majority of research works apply the AHP method (Dong *et al.,* 2018; Liu *et al.,* 2016) and the ANP method (Celik *et al.,* 2009; Khalilzadeh *et al.,* 2021). It was found that there has not been any research work mentioning the application of GBWM in analyzing and assessing the hazards and environmental risks, particularly the hazards of coastal environmental incidents caused by chemical spills from the mainland. Studies that estimate the hazard value based on MCDM methods show that they are more amenable to collecting data and further analyzing the cause of the incident. However, the majority of the studies show that there has not been a full integration of specific criteria related to risk sources and management and

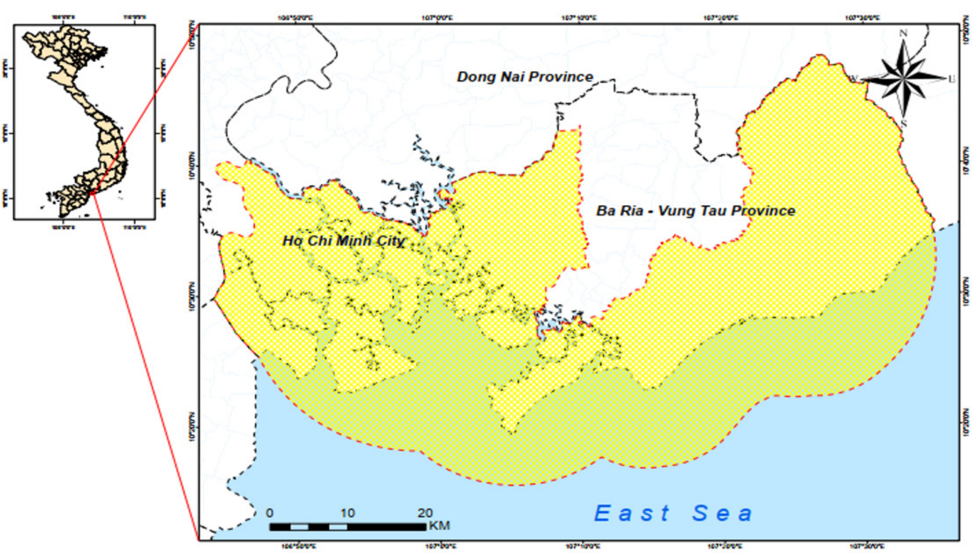

Figure 1. Research Area

control of weighted sources of risk identified by GBWM to demonstrate the importance of criteria in the integration process of estimating the level of hazard of environmental incidents affecting coastal areas due to chemical spills from the mainland.

In this study, a new approach based on the combination of GBWM and GIS is developed to analyze and assess the hazard of coastal environmental incidents from the mainland. The proposed approach is in four steps, as shown in Figure 2. These steps are described in detail in the appendage below.

2.2.1 Determining the selection criteria

(1) Establish a set of preliminary criteria: The selected preliminary criteria focus on criteria related to risk source characteristics and environmental risk control and management. Each selected preliminary criteria is of different importance and depends on five sub-criteria: simplicity and ease, alignment with the goal, available data, accuracy and transparency, and sensitivity (Afshari *et al.,* 2010);

(2) Conducting a questionnaire survey: 20 experts of different domains were invited to take the survey, 50% of them have scientific backgrounds related to the environment, and 50% have good knowledge of the study area. Seventeen out of 20 experts gave their feedback through email that can be used to determine the weighting of the sub-criteria (Saaty, 1990) as well as the evaluation scores of each criterion;

(3) Selecting suitable criteria: Apply the SAW method to calculate evaluation scores for each criterion in the initial set of criteria as the basis for screening and selecting suitable criteria. Evaluation scores for each criterion are made by the following formula (1) (Afshari *et al.,* 2010):

$$V(a_j) = \sum_{i=1}^{m} w_i \, v_{ij} \qquad (1)$$

Where $V(a_j)$ is the result of the evaluation score of the j^{th} criteria; w_i is the weight of the i^{th} sub-criteria; and v_{ij} is the score rated by sub-criteria i for the j^{th} criteria.

Through the abovementioned implementation steps, weighting of the sub-criteria, the evaluation scores of each criterion, and the selected appropriate criteria are described in detail in Table 1 and 2.

Table 1. Evaluation scores of each criterion

Criteria (Notation)	Scores for each sub-criterion					Total scores
	Simplicity and ease (0.15)	Alignment with the goal (0.26)	Available data (0.12)	Accuracy and transparency (0.25)	Sensitivity (0.22)	
Chemical types (C1)	0.54	1.06	0.48	1.03	0.80	3.91
Chemical volumes (C2)	0.63	1.12	0.42	1.03	0.88	4.08
Chemical storage safety (C3)	0.58	0.98	0.49	1.05	0.70	3.79
Chemical incident location (C4)	0.54	1.19	0.41	0.94	0.93	4.01
Chemical incident response plan (C5)	0.54	1.15	0.45	1.03	0.70	3.87
Chemical incident response capacity (C6)	0.47	1.09	0.39	0.82	0.78	3.55

Table 2. Selected criteria

Criteria	Description
C1	Demonstrating the characteristics and number of stored chemicals in the list of chemicals incident response of the fixed sources (Government, 2017; Liu *et al.*, 2013)
C2	The volume of chemicals stored at a time, compared to the storing chemical limit (Liu *et al.*, 2013; Peng *et al.*, 2013)
C3	Demonstrating safety in chemical storage (dam) that contains the volume of chemical spills (Government, 2017; Liu *et al.*, 2016)
C4	Showing the potential location of chemical spills affecting coastal areas (Dong *et al.*, 2018; Liu *et al.*, 2016)
C5	Demonstrating the level of compliance (approved plans, human resources, and incident response equipment) with the responsibility to prevent chemical spill incidents (Dong *et al.*, 2018; Government, 2017)
C6	Demonstrating the ability to respond to chemical spill incidents, rehearsal/assumptions frequency (Dong *et al.*, 2018; Government, 2017)

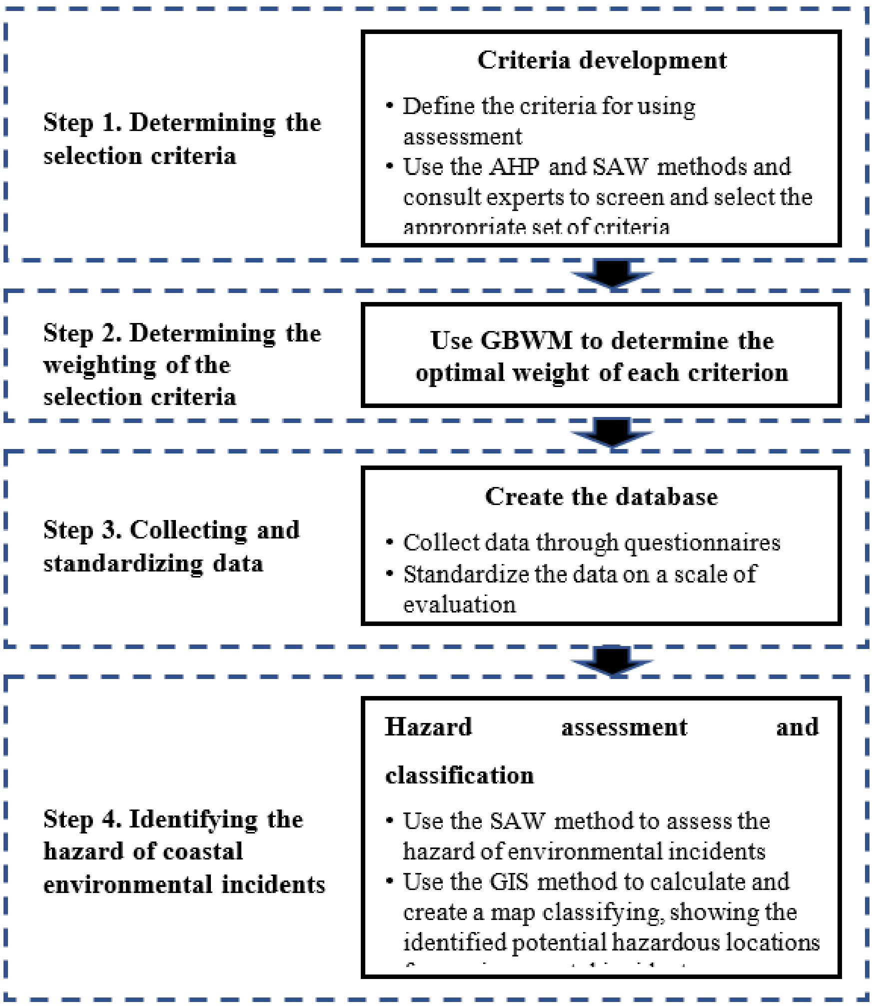

Figure 2. Research methodology framework

2.2.2 Determining the weighting of the selection criteria

The set of weighted criteria is denoted by C = {C_1, C_2, ..., C_n}, where n is the number of criteria selected. Optimal weighting and weighted variability range of criteria are determined using GBWM through the steps:

(1) Choose the best criterion (criterion B) and the worst criterion (criterion W): criterion B and W selected in the set of criteria C are the criteria most agreed upon by independent experts. Based on the results of consultations with independent experts to screen the criteria as presented in Table 1, criteria B and W are defined as criteria C2 and criteria C6, respectively.

(2) Determine the preference of criteria B over all other criteria and all the criteria over criteria W: We consulted the experts mentioned above in Step 1 using the questionnaire having a scale from 1 to 9. $A_B=(a_{B1}, a_{B2}, ..., a_{Bn})$ and $A_W = (a_{1W}, a_{2W}, \ldots, a_{nW})$ are the best-to-other and other-to-worst criteria sets, respectively, where a_{Bi} indicates the preference of criteria B over the criteria i and a_{iW} denotes the preference of criteria j over criteria W and $a_{BB} = a_{WW} = 1$.

(3) Calculate the optimal weightings and the weighted variation range of the criteria using the M2 mathematical model (Safarzadeh *et al.,* 2018):

$$Min\ Max_k w'_k \mu_k = Min\ (\mu)$$

In which:

$$\begin{aligned} &\mu \geq w'_k \mu_k \quad \forall k \in D \\ &\left|\frac{w_B}{w_i} - a_{Bi}\right| \leq \mu_k \ \forall i \in C, \forall k \in D \\ &\left|\frac{w_i}{w_w} - a_{iw}\right| \leq \mu_k \ \forall i \in C, \forall k \in D \qquad (2) \\ &\textstyle\sum_{i \in C} w_i = 1 \\ &w_i \geq 0\ \forall i \in C \end{aligned}$$

Where w'_k is the importance of k^{th} expert in the set of experts D, with w'_k [0,1] & $\sum_{k \in D} w'_k = 1$); w_B is the weight of B; w_w is the weight of W; w_i is the weight of criteria i; and μ_k is the dependent variable of consistency ratio (CR) for the k_{th} expert with $\mu_k = Max_i \left\{\left|\frac{w_B}{w_i} - a^k_{Bi}\right|, \left|\frac{w_i}{w_W} - a^k_{iW}\right|\right\}$.

Besides, from the results obtained using equation (2), the range of the optimal weight limited by the lower bound (w_{min}) and the upper bound (w_{max}) was determined (Rezaei, 2015).

As mentioned above, we assumed that the weights of the independent experts were equal. The optimal weights of the criteria and their range are calculated and exhibited in Table 3.

(4) Evaluate the reliability of the group decision-making: The specific consistency ratio of expert kth (CR_k) and the consistency ratios of the group of experts (CR^G) were calculated using equation (3):

$CR_k = w'_k \left(\frac{\mu_k}{CI^\theta}\right)$, θ shows the sensitivity of the model ($\theta \geq 0$), CI is the consistency index, $\forall k \in D$

$$CR^G = Max_k\ (CR_k) \qquad (3)$$

Assuming that $\theta = 1$, the individual consistency ratios (CR_k) and group consistency ratio (CR^G) are calculated:

$$CR^G = Max\ \{CR_1, CR_2, CR_3, CR_4, CR_5, CR_6, CR_7, CR_8, CR_9, CR_{10}, CR_{11}, CR_{12}, CR_{13}, CR_{14}, CR_{15}, CR_{16}, CR_{17}\} = 0.059 \times \frac{3.7250}{5.23} = 0.042$$

2.2.3 Collecting and standardizing data

Collection of information on fixed sources of production and trading of toxic chemicals in the research area is being done at the local Department of Natural Resources and Environment. The screening and identification of fixed sources of hazard for environmental incidents caused by chemical spills based on the volume of toxic chemicals at a time above the specified threshold are defined according to equation (4) (Peng *et al.,* 2013):

$$GNR = \sum_{i=1}^{n} \frac{q_i}{Q_i} \qquad (4)$$

Table 3. The optimal weights of the criteria and their range

Criteria	The optimal weights of the criteria and their range		
	W_{min}	W_i	W_{max}
C1	0.13	0.14	0.14
C2	0.45	0.46	0.47
C3	0.14	0.14	0.14
C4	0.14	0.14	0.14
C5	0.08	0.08	0.09
C6	0.04	0.04	0.04

Where GNR is the value of identifying hazard source; qi (tons) is the volume of toxic chemicals of the highest deposited fixed source at a time; Qi (tons) is the volume threshold as prescribed (Government, 2017).

Questionnaires were then developed and the subjects identified according to equation (4) with GNR values > 1 were interviewed to collect data related to the six criteria selected in Table 2.

Data collected were standardized according to the evaluation scale to calculate, analyze, and classify the level of hazard of coastal environmental incidents, as shown in Table 4.

2.2.4 Identifying the hazard of coastal environmental incidents

(1) Hazard score determination of environmental incident sources: Based on the set of criteria, their weights, and the data collected, the hazard value of each hazard source is determined using the equation (5) (Afshari *et al.,* 2010):

$$H_{(a_j)} = \sum_{i=1}^{m} w_i \, v_{ij} \qquad (5)$$

Where $H_{(aj)}$ is the hazard score of the j^{th} fixed source; w_i is the weight of the ith criteria; and v_{ij} is the score of the i^{th} criteria with respect to the j^{th} fixed source.

(2) Ranking the environmental incident hazard levels: Using equation (5) and the GIS approach (see also Figure 3), GIS was used to calculate the hazard value in which each criterion evaluation data would correspond to an attribute layer, similar to the criterion weighting defined by GBWM. The attribute and spatial data were combined to create a map of the spatial distribution of hazard sources in the study area according to four hazard levels: very high, high, medium, and low.

3. Results and Discussion

3.1 Identifying the fixed sources of hazard of environmental incidents

Based on the list of fixed sources collected, the study applied equation (4) for the preliminary screening and identification of 15 of the 65 fixed sources of production and trading of toxic chemicals that can cause the hazard of environmental incidents in the southeast coastal region, as shown in Table 5.

3.2 Assessing and classifying the hazard of environmental incidents

The data of the criteria collected through the results of the investigation of 15 of the 65 toxic chemical sources that can result in the hazard of environmental incidents is converted into values from 1 to 5 according to the scale of assessment established in Table 4. The hazard value of coastal environmental incidents was calculated according to the equation detailed in Table 6 and is divided

Table 4. Evaluation scale (Government, 2017; Ministry of Natural Resources and Environment, 2013)

Criteria	Evaluation scores				
	Very low	Low	Moderate	High	Very high
	(1)	(2)	(3)	(4)	(5)
C1	Only one	-	2–3	-	> 3
C2	Not exceed	Exceeds than two times	Exceeds 2–3 times	-	Exceeds than three times
C3	The dam contains enough	-	The dam contains close enough	-	No dam
C4	≥ 1 km to the river system, coastal waters	< 1 km to the level 2 sub-river systems	< 1 km to the level 1 sub-river systems	< 1 km to the main river	< 1 km to coastal waters
C5	All compliances	Except for incident response equipment	Only approved plans	Unapproved plans	No plan
C6	Annual	-	Random	-	Nope

into four ranges: 3.52 – 4.02, 3.00 – 3.51, 2.49 – 2.99, and 1.96 – 2.48, with a ranking from 1 to 4, respectively, of the levels of a hazard: very high, high, medium, and low. The degree of hazard of environmental incidents from fixed sources is distributed by space (Figure 4) and detailed in Table 6. The following can be observed from the results:

(1) A total of 7 of the 15 fixed sources, accounting for 46.67% of the total number of sources, represent very high and high levels of hazard of environmental incidents; this is followed by 5 of the 15 fixed sources, accounting for 33.33% of the total number of sources, posing an average level hazard of environmental incidents, which in turn is followed by 3 of the 15 fixed sources, accounting for 20.00% of the total number of sources, posing a low level of hazard of environmental incidents.

(2) Among the six criteria of the set of criteria, criterion C2 played the most important role, followed by C1, C3, C4, and finally, criteria C5 and C6. The calculation results showed that the criterion of chemical volumes stored at a time significantly increases the high- and high-ranking fixed sources score. Therefore, the proposed solutions should focus on the criteria in the same order.

3.3 Solutions to reduce the hazard of environmental incidents

Two primary solutions have been proposed to reduce the hazard of environmental incidents with high and very high levels of a hazard:

(1) Strengthen control and ensure appropriate storage of toxic chemicals: Review and adjust the permissible storage volume of the highest toxic chemicals at any given time, which is suitable with the approved chemical spill response plan. The authorities must also monitor the volume of toxic chemicals used for production in the year following the license issued by the competent authorities so that it can be adjusted according to need on a rolling basis.

(2) Strictly comply with the safety requirements in the use and production of toxic chemicals: Strengthen supervision requiring fixed source owners to comply with the safety requirements, ensuring the sources' ability to store the chemicals on site in the event of an unintended chemical spill. Simultaneously, review and adjust the plan and capacity to respond to environmental incidents, ensuring the annual organization of environmental incident response exercises due to chemical spills at least once a year.

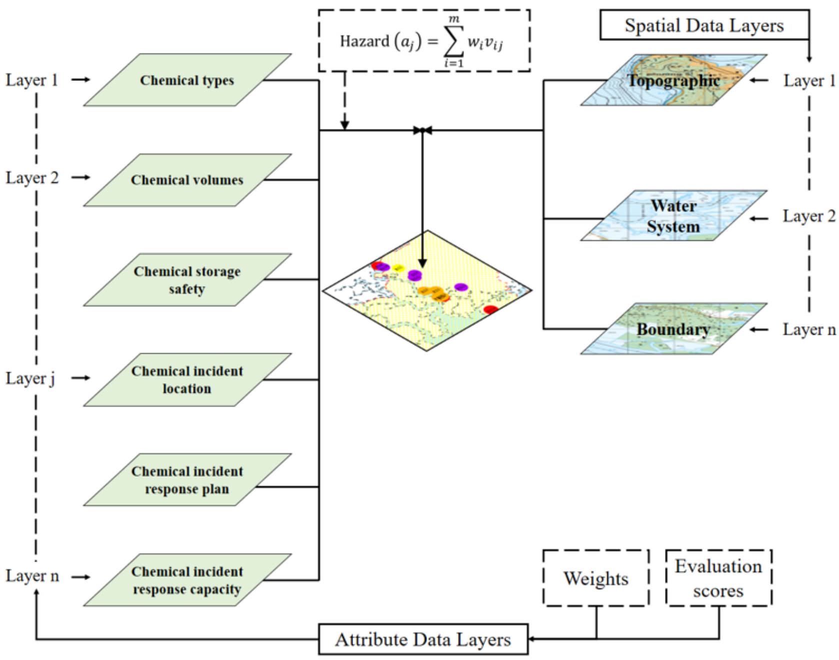

Figure 3. Hazard analysis model based on GIS

Table 5. Fixed sources are identified as hazards for environmental incidents

Shorten	Fields of operation description
RS1	Production of basic chemicals, with a capacity of about 160 tons per year
RS2	Production of stainless steel coil products, galvanized coil steel, and electromagnetic coil steel, with a capacity of about 1.2 million tons per year
RS3	Producing iron, steel, cast iron, and other products from rubber, with a capacity of about 1.2 million tons per year
RS4	The terminal contains liquefied petroleum gas (LPG) and condensate, with a capacity of 1.5 million tons per year
RS5	Production of galvanized steel roofing, aluminum zinc alloy, coating, galvanizing, and plating of other alloys, with a capacity of 1.2 million tons per year
RS6	Production of basic chemicals, with a capacity of 14,300 tons per year
RS7	Trade in services in chemicals, with a scale of 2,000 tons per year
RS8	Production of lubricants, lubricating greases, and petrochemical raw materials with a capacity of about 450,000 tons per year
RS9	Trade in services in chemicals, with a scale of 17,000 tons per year
RS10	Production of fertilizers and hydrochloric acid, with a capacity of about 45,000 tons per year
RS11	Production and trade in services in the field of chemicals
RS12	Fabric production and production of wooden furniture
RS13	Production of plastic powder products, with a capacity of about 100,000 tons per year
RS14	Production and consumption of basic chemicals, and other petrochemical products, with a capacity of about 37.1 million tons per year
RS15	Production of chemical products and storage of LPG

Table 6. Results of calculation and ranking of hazards of environmental incidents

Fixed source	Scores for each criterion						Value of hazards	Ranking
	C1	C2	C3	C4	C5	C6		
RS1	0.14	2.28	0.56	0.14	0.17	0.13	3.41	2
RS2	0.14	0.91	0.56	0.14	0.17	0.04	1.96	4
RS3	0.14	2.28	0.56	0.14	0.17	0.04	3.33	2
RS4	0.70	2.28	0.56	0.14	0.08	0.13	3.89	1
RS5	0.14	1.37	0.56	0.14	0.17	0.13	2.50	3
RS6	0.70	2.28	0.56	0.14	0.17	0.04	3.88	1
RS7	0.14	1.37	0.14	0.14	0.17	0.04	2.00	4
RS8	0.70	0.91	0.56	0.14	0.17	0.04	2.51	3
RS9	0.14	1.37	0.14	0.14	0.17	0.04	2.00	4
RS10	0.14	1.37	0.56	0.14	0.17	0.13	2.50	3
RS11	0.42	1.37	0.56	0.14	0.17	0.04	2.69	3
RS12	0.14	1.37	0.56	0.14	0.17	0.13	2.50	3
RS13	0.14	2.28	0.56	0.14	0.17	0.13	3.41	2
RS14	0.70	2.28	0.70	0.14	0.17	0.04	4.02	1
RS15	0.14	2.28	0.56	0.14	0.17	0.13	3.41	2

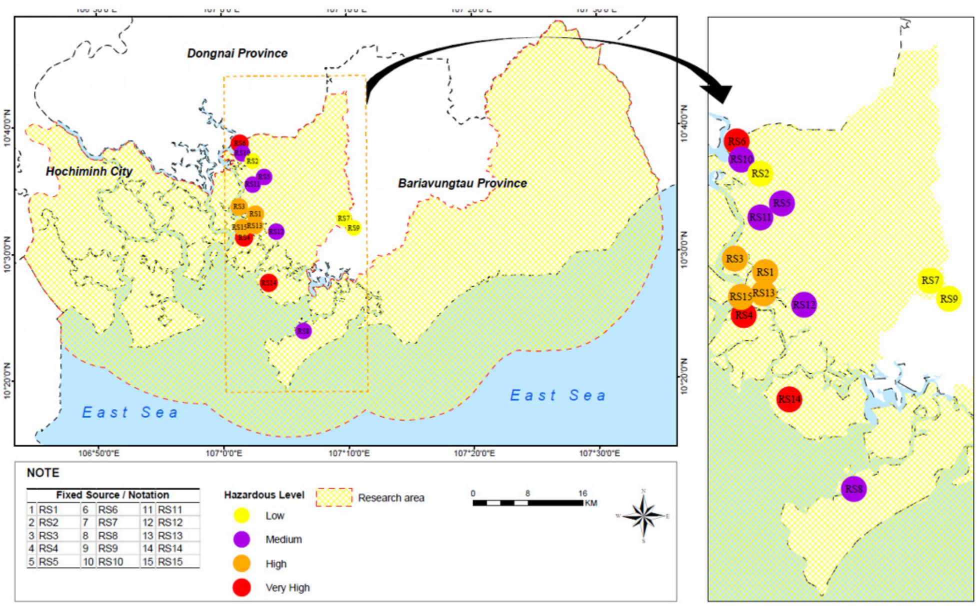

Figure 4. Map of the level of hazard of environmental incidents due to chemical spills from the mainland

4. Conclusion

The study has established a set of appropriate criteria to assess the risk of coastal environmental incidents caused by chemical spills from the mainland in Vietnam, with six suitable criteria selected: chemical types, chemical volumes, chemical storage safety, chemical incident location, chemical incident response plan, and chemical incident response capacity. At the same time, the study applied GBWM, a new approach to determining the weighting of criteria. In addition, the study screened the fixed sources of production and trading of toxic chemicals and constructed a map showing the extent of the hazard of environmental incidents for the southeastern coastal region based on a set of established criteria.

Moreover, the study has proposed solutions depending on the characteristics of the study area to reduce the hazard of environmental incidents from fixed sources with high and very high levels of hazard; and also contributes significantly to relevant research works.

Acknowledgment

This research is financially supported by Vietnam National University Ho Chi Minh City (VNU-HCM) under grant number C2021-24-25. The authors would like to thank the Institute for Environment and Resources for supporting and creating favorable conditions for us to complete this study.

Conflict of interest

The authors declare no conflict of interest.

References

Afshari A, Mojahed M, Yusuff RM. Simple additive weighting approach to personnel selection problem. International journal of innovation, management technology 2010; 1(5): 511.

Ahmad N, Hasan MG, Barbhuiya RK. Identification and prioritization of strategies to tackle COVID-19 outbreak: A group-BWM based MCDM approach. Applied soft computing 2021; 111: 107642.

Al Shami A, Harik G, Alameddine I, Bruschi D, Garcia DA, El-Fadel M. Risk assessment of oil spills along the Mediterranean coast: A sensitivity analysis of the choice of hazard quantification. Science of the Total Environment 2017; 574: 234-245.

Alvarez PA, Ishizaka A, Martinez L. Multiple-criteria decision-making sorting methods: A survey. Expert Systems With Applications 2021; 183: 115368.

Amendola A, Contini S. A methodology for risk analysis of industrial areas: the ARIPAR case study. Industrial Safety Series 1998; 6.

Celik M, Topcu YI. Use of an ANP to prioritize managerial responsibilities of maritime stakeholders in environmental incidents: An oil spill case. Transportation Research Part D: Transport Environment 2009; 14(7): 502-506.

Domingues RB, de Jesus SN, Ferreira Ó. Place attachment, risk perception, and preparedness in a population exposed to coastal hazards: A case study in Faro Beach, southern Portugal. International Journal of Disaster Risk Reduction 2021; 60: 102-288.

Dong L, Liu J, Du X, Dai C, Liu R. Simulation-based risk analysis of water pollution accidents combining multi-stressors and multi-receptors in a coastal watershed. Ecological Indicators 2018; 92: 161-170.

Gómez AG, Ondiviela B, Puente A, Juanes JA. Environmental risk assessment of water quality in harbor areas: a new methodology applied to European ports. Journal of environmental management 2015; 155 77-88.

Government. Guidelines for implementation of the law on chemicals. Vietnam. 2017.

Hoang TN, Ly TTB, Do HTT. A hybrid approach of wind farm site selection using Group Best-Worst Method and GIS-Based Fuzzy Logic Relations. A case study in Vietnam. Environmental Quality Management 2021.

Kaplan S, Garrick BJ. On The Quantitative Definition of Risk. Risk Analysis 1981; 1(1): 11-27.

Khalilzadeh M, Shakeri H, Zohrehvandi S. Risk identification and assessment with the fuzzy DEMATEL-ANP method in oil and gas projects under uncertainty. Procedia Computer Science 2021; 181: 277-284.

Köksalan MM, Wallenius J, Zionts S. Multiple criteria decision making: from early history to the 21st century. World Scientific, British Library. 2011.

Liu R, Borthwick AG, Lan D, Zeng W. Environmental risk mapping of accidental pollution and its zonal prevention in a city. Process Safety Environmental Protection 2013; 91(5): 397-404.

Liu R, Zhang K, Zhang Z, Borthwick AG. Watershed-scale environmental risk assessment of accidental water pollution: the case of Laoguan River, China. Environmental Informatics 2016; 31: 87-96.

Mahmoudkelaye S, Azari KT, Pourvaziri M, Asadian E. Sustainable material selection for building enclosure through ANP method. Case Studies in Construction Materials 2018; 9: e00200.

Makan A, Fadili A. Sustainability assessment of large-scale composting technologies using PROMETHEE method. Journal of Cleaner Production 2019; 261: 121244.

Mardani A, Jusoh A, Nor K, Khalifah Z, Zakwan N, Valipour A. Multiple criteria decision-making techniques and their applications–a review of the literature from 2000 to 2014. Economic research-Ekonomska istraživanja 2015; 28(1): 516-571.

Miccoli F, Ishizaka A. Sorting municipalities in Umbria according to the risk of wolf attacks with AHPSort II. Ecological Indicators 2016; 73: 741-755.

Ministry of Natural Resources and Environment. Technical guidlines for risk assessment of hazardous chemicals emissions in some industries. Vietnam. 2013.

Mohamed SA. Coastal vulnerability assessment using GIS-Based multicriteria analysis of Alexandria-northwestern Nile Delta, Egypt. Journal of African Earth Sciences 2020; 163: 103751.

Mohd FA, Maulud KNA, Karim OA, Begum RA, Awang NA, Ahmad A, Azhary WAHWM, Kamarudin MKA, Jaafar M, Mohtar WHMW. Comprehensive coastal vulnerability assessment and adaptation for Cherating-Pekan coast, Pahang, Malaysia. Ocean Coastal Management 2019; 182: 104948.

Monteiro CB, Oleinik PH, Leal TF, Marques WC, Nicolodi JL, Lopes BdCFL. Integrated environmental vulnerability to oil spills in sensitive areas. Environmental Pollution 2020; 267: 115238.

Neuparth T, Moreira S, Santos M, Reis-Henriques M. Hazardous and Noxious Substances (HNS) in the marine environment: Prioritizing HNS that pose major risk in a European context. Marine Pollution Bulletin 2011; 62(1): 21-28.

Peng J, Song Y, Yuan P, Xiao S, Han L. An novel identification method of the environmental risk sources for surface water pollution accidents in chemical industrial parks. Journal of Environmental sciences 2013; 25(7): 1441-1449.

Rezaei J. Best-worst multi-criteria decision-making method: Some properties and a linear model. Omega 2015; 64: 126-130.

Saaty TL. How to make a decision: the analytic hierarchy process. European journal of operational research 1990; 48(1): 9-26.

Safarzadeh S, Khansefid S, Rasti-Barzoki M. A group multi-criteria decision-making based on best-worst method. Computers Industrial Engineering 2018; 126: 111-121.

Schneiderbauer S, Ehrlich D. Risk, hazard and people's vulnerability to natural hazards. A review of definitions, concepts data European Commission Joint Research Centre EUR 2004; 21410: 40.

Tian H, Lindenmayer DB, Wong GT, Mao Z, Huang Y, Xue X. A methodological framework for coastal development assessment: A case study of Fujian Province, China. Science of the Total Environment 2018; 615: 572-580.

Zhang X, Zhang Q, Sun T, Zou Y, Chen H. Evaluation of urban public transport priority performance based on the improved TOPSIS method: A case study of Wuhan. Sustainable cities society 2018; 43: 357-365.

Zhao K, Quan D, Yang D, Yang J, Lin K. A system for identifying and analyzing environmental accident risk sources. Procedia Environmental Sciences 2010; 2: 1413-1421.