Heliyon 9 (2023) e19827

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Assessing risk associated with recreational activities in coastal areas by using a bayesian network

Meng-Tsung Lee [a], Yang-Chi Chang [b], Han-Chung Yang [a,*], Yi-Jun Lin [a]

[a] Department of Marine Leisure Management, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan
[b] Department of Marine Environment and Engineering, National Sun Yat-sen University, Kaohsiung, Taiwan

ARTICLE INFO

Keywords:
Risk assessment
Marine recreational activities
Bayesian network

ABSTRACT

Taiwan is an island and therefore has a considerable amount of coastal land. Drowning or near-drowning incidents often occur in coastal recreational areas. To reduce the risk of drowning or near-drowning associated with marine recreational activities in Taiwan, this study collected data on the risk associated with marine recreational activities. It selected risk factors using a modified Delphi panel method, with an expert panel used to obtain probability values for each risk factor. A Bayesian network for risk assessment was then established. The results of this study can serve as a reference for stakeholders involved in marine recreational activities. Severe weather conditions increase wave height and current speed, resulting in an increased risk of drowning or near-drowning when coastal recreational activities occur under these conditions. Individuals who undertake marine recreational activities without safety awareness are more likely to exhibit risky behaviors. When self-rescue ability is insufficient to prevent possible danger, the probability of drowning or near-drowning is higher. Serious incidents may lead to death, and therefore, marine recreational activities should be avoided when weather conditions are poor. In addition, the safety awareness and self-rescue ability of individuals undertaking coastal recreational activities should be improved. This study did not explore emergency response measures or postincident policy management.

1. Introduction

Taiwan is a subtropical country, and the climate and environment are suitable for marine recreation [1]. In Taiwan, the convenience of transportation to and diversity of recreational activities in coastal areas have led to coastal recreational activities being popular in the country. In the summer, individuals often visit seaside areas to undertake various recreational activities in the sea. To meet the demand for recreational activities in coastal areas, the government has designated coastal areas as suitable for recreational activities and undertaken planning to improve the safety and quality of such activities in coastal regions [2].

Marine leisure activities are diverse and their management requires considerable professional marine knowledge and skills related to leisure facilities operations. Therefore, determining the conditions necessary to ensure safety and conducting safety management is crucial for planners, investors, and management personnel involved in marine recreational activities. Doing so would enable participants in recreational activities to enjoy the benefits of coastal leisure in a safe environment.

In coastal areas, changes in climate, currents, topography, and other factors often cause dangerous rip currents and other hazardous

* Corresponding author.No. 142, Haijhuan Rd., Nanzih Dist., Kaohsiung City 811213, Taiwan.
E-mail address: hanchung@nkust.edu.tw (H.-C. Yang).

https://doi.org/10.1016/j.heliyon.2023.e19827
Received 1 March 2023; Received in revised form 25 August 2023; Accepted 1 September 2023
Available online 4 September 2023

phenomena. Therefore, individuals engaging in marine leisure in such areas are vulnerable to drowning or near-drowning. More dangerous areas of water that lifeguards do not patrol are associated with higher risks of drowning or near-drowning. Rip currents often carry individuals undertaking marine recreational activities away from the shore, leading to severe injuries or casualties. Rip currents are the main cause of drowning among individuals engaged in marine recreational activities and are a major cause of drowning worldwide [3–5].

Taiwan is an island. Rip currents often form near shorelines; therefore, drowning or near-drowning occur frequently in coastal recreation areas. According to Taiwan's National Fire Agency, approximately 1200 cases of drowning or near-drowning occurred in coastal areas from 2014 to 2021. Of these, approximately 750 led to death [6]. To understand and reduce the risks of drowning and near-drowning associated with marine recreational activities, this study determined the risk factors associated with marine recreational activities, evaluated the risks of drowning and near-drowning under different conditions, and provided suggestions for improving the safety of marine recreational activities. The primary risk factors investigated in this study are natural environmental and human factors, which led to the scope of the research being somewhat limited. This study does not investigate risks associated with recreational activities in noncoastal bodies of water, such as rivers or lakes, or analyze risks related to intentional self-harm. Additionally, this study focuses on pre-event risk analysis and does not investigate emergency response measures or postincident policy management.

2. Literature

2.1. Dangers of marine recreational activities

Marine recreational activities are often undertaken in an outdoor environment close to the sea. All marine environments are influenced by environmental risk factors, including rip currents, tsunamis, storm surges, and other dangerous events because of their complex terrains and climates [7]. Therefore, careful assessment of the risks of marine recreational activities before these activities are undertaken is necessary [2].

The potential danger associated with coastal recreational activities is mainly caused by a lack of water safety equipment or knowledge, a lack of preparation for these activities, and other human factors [8]. Natural elements, such as waves, tides, and marine currents, can cause drowning or near-drowning among individuals lacking marine knowledge [9–11].

Haddon argued that generally, accidents can be prevented [12]. In the context of marine activities, the Haddon matrix can be used to conduct a risk assessment of open water drowning accidents. In research that has applied the Haddon matrix to drowning accidents, such accidents are divided into three stages (i.e., before the accident, during the accident, and after the accident). In each stage, the causes of drowning are divided into three elements: human, water, and environmental factors [13,14].

2.2. Risk assessment

Risk involves uncertain factors that may adversely affect the achievement of internal control objectives [15]. In risk assessment, various uncertain factors affecting the accomplishment of internal control objectives are analyzed and countermeasures are adopted [16]. In risk assessment, a target or event is identified, and an assessor uses their knowledge or experience to quantitatively determine the potential negative effects of this target or event and the likelihood that adverse events will occur. Risk assessment results can be used as a reference for risk management [17].

Risk assessment is the assessment and analysis of possible hazards or losses. When risk assessment is conducted, having sufficient sample data is crucial. The use of insufficient data can reduce the accuracy and certainty of assessment results [18,19]. Therefore, different risk assessment methods should be adopted according to the richness of available data; this is also true for marine risk assessment.

2.3. Bayesian network

Bayes' theorem is based on probability theory. It was proposed by British mathematician Tomas Bayes in 1763. It mainly focuses on changes in conditional probability in sample data [20,21]. A Bayesian network is a probabilistic expert model in which probabilistic inference is used to identify the cause of an outcome. This network can be used when data are incomplete [22,23]. Combining Bayesian methods with other models is an efficient and principled approach that can prevent data overfitting [24]. Bayesian networks can be used for making predictions with limited information. Therefore, Bayes' theorem has been used in numerous fields, including marine ecological observation, climate change analysis, industrial engineering system analysis, medical engineering, diagnosis, and financial risk prediction [25–29].

3. Research methods

Little data is available regarding the risks associated with marine recreational activities. When data are insufficient, they can be enhanced using a literature review or expert opinions and can be effectively used through, for example, a Bayesian network [30]. The current research used a Bayesian network for marine recreational activity risk assessment and used Graphical Network Interface 2.0 software (Decision Systems Laboratory, University of Pittsburgh, Pittsburgh, PA, USA) for risk assessment and analysis [31]. The software provides a development environment for constructing graph theory–based decision-making models. Its operation is based on

Visual C++ and Microsoft Foundation Class Library, and it can be applied on all operating platforms [32].

Bayesian networks mainly represent information and are developed using a combination Bayesian probability theory and graph modelling [33–35]. In such networks, three forms of data, namely nodes, links, and conditional probability, are used to present uncertainty and interaction as causal relationships [36]. The Bayesian network architecture is a directed acyclic graph built on the basis of conditional probability [37], as presented in Fig. 1. In Bayesian directed acyclic graphs, each node represents a random variable, and each connecting line represents the interaction between the two nodes. The degree of mutual influence is determined using conditional probability [23,33,38].

Bayes' theorem is used to determine the probability of one event occurring on the basis of known occurrences of another event [23,33,39]. For example, when event A is known to occur, Bayes' theorem can be used to calculate the probability of event B occurring and the probability of a correlation between these events; this is conditional probability and is represented as $P(B|A)$. In Bayes' theorem, the probability values obtained in the following two cases differ.

Case 1. The calculation of the probability of event B occurring in the case of the occurrence of known event A, namely $P(B|A)$.

Case 2. The calculation of the probability of event A occurring in the case of the occurrence of known event B, namely $P(A|B)$.

In Bayes' theorem, when event A is known to occur, the sample space of the entire probability problem is reduced to the range in which event A occurs, and the probability of event B occurring at this time can be written as:

$P(B|A)$ = (number of occurrences of both A and B)/(number of occurrences of A)

$$= (P(A\cap B)) / (\sum P(P(A|B_i)P(B_i)))$$

$$= (P(A\cap B)) / (P(A))$$

Where

$$P(A\cap B) = P(A|B) \times P(B)$$

$$P(B|A) = (P(A|B)P(B))/(P(A))$$

$P(B|A)$: Posterior probability, the inferred probability of event B occurring when event A is known to occur.

$P(B)$: Prior probability, the probability that event B occurs before the occurrence of event A is unknown; that is, the probability that event B itself occurs.

$P(A)$: In the case of a known occurrence of A, $P(A)$ is called a priori probability. If the occurrence of A is unknown, its probability can be obtained using the full probability formula; thus $P(A)$ can also be called total probability.

$P(A|B)$: Conditional probability, the conditional probability that event A occurs when event B is known to occur.

4. Research results

4.1. *Establishment of risk factors and their interrelationships*

The marine recreational activity risk factors in this study were human and environmental. Few studies have investigated both of

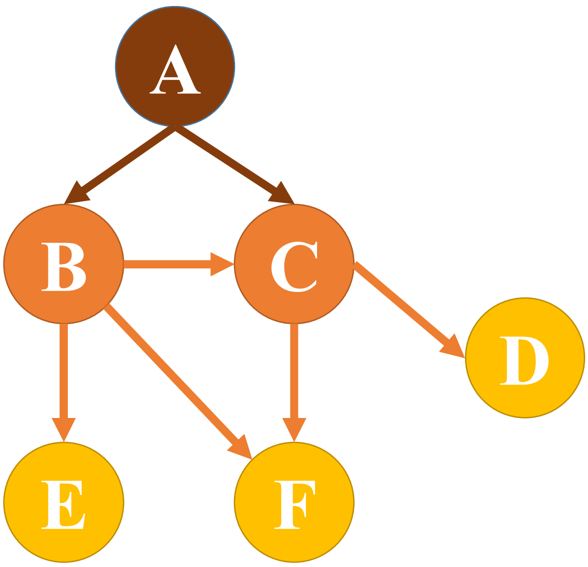

Fig. 1. Directed Acyclic Graph (produced by the authors).

these factors in this context, and further information regarding the risks associated with marine recreational activities in Taiwan must be obtained. Therefore, in the present study, an expert panel was assembled that assisted in the identification of risk factors, determination of the Bayesian network architecture, and completion of conditional probability tables. The expert panel had nine members, each with more than 15 years of experience in water rescue or drowning prevention, and included scholars, water rescue personnel, and coast guard personnel. The extensive experience and expertise of these individuals provided valuable insight for establishment of the model. The fields of the experts are listed in Table 1.

In accordance with the research objectives, relevant literature and research data were collected to enable the compilation of risk factors of marine recreational activities for risk assessment with the Haddon matrix. Pre-event, event, and postevent risk factors were included. The final set of risk factors was obtained from the feedback of the expert panel by using a modified Delphi panel method in which factors with an importance rating of ≥4 on a 5-point Likert scale were selected. The risk factor architecture is presented in Fig. 2. The influencing factors were divided into the following main categories: natural environmental factors, including beach type, wave height, rip current, and weather conditions [40–45]; participant factors, including the sex, age, alcohol consumption, self-rescue ability, physiological state, safety awareness, and level of panic of activity participants [43,46–51]; activity safety management factors, including activity equipment, safety commitment, safety procedure rehearsals, and real-time marine weather information [46,47,52–54]; and lifesaving resource factors, including patrols and lifeguards, emergency rescue facilities, and warning signs [43,52,55–57].

After the marine recreational activity risk factors were selected, the expert panel discussed the relationships between the factors. The interrelationships of the risk factors that they proposed are listed in Table 2. The symbol "←" indicates that the factor on the right side influences that on the left side, whereas "→" indicates that the factor on the left side influences that on the right side. For example, (F)←(G) indicates that (F) is influenced by (G), and (H)→(P) indicates that (H) influences (P). Using the relationships presented in Table 2, a Bayesian network was constructed to illustrate the interdependencies among the risk factors (Fig. 3).

4.2. Bayesian network model results

A conditional probability table was created to quantify the influences of the risk factors. The prior probability of each node in a Bayesian network can be calculated using data from the literature, possibly in combination with the judgment of experts and scholars [33]. The main sources of data for this study were experts and scholars (Table 1) with practical experience in areas related to marine recreational activities; they assisted in completing the conditional probability table. The Bayesian network was employed to multiply the conditional probability values of each risk factor in a basic model by using Graphical Network Interface, which was used to obtain numerical results for the risk of drowning or near-drowning associated with marine recreational activities.

In the basic model, the probability of substantial risk associated with marine recreational activities occurring was 64%. The probability values for each risk factor are listed in Table 3. The probability of risk factors being unfavorable were as follows: natural environment, 67%; participant factors, 56%; activity safety management, 54%; lifesaving resources, 59%; panic (yes), 67%; patrols and lifeguards (no), 73%; safety awareness, and 51%; safety procedure rehearsals (no), 36%.

This study simulated changes in the probability of each risk factor being unfavorable under conditions of 100% and 0% overall risk of unfavorable conditions. The changes in the probability values of each risk factor from the basic model are listed in Table 3. The factors that exerted the greatest effects were the four main factors, lifesaving resources, activity safety management, participant factors, and natural environment (listed from greatest to weakest effect). The effect of the natural environment was smaller than that of human factors. In addition, the results indicate that if lifesaving resources can be improved, safety management of activities can be effectively implemented, and participant-associated risks can be reduced, the risk of drowning or near-drowning associated with marine recreational activities will be considerably reduced. The five most influential secondary factors were panic, patrols and lifeguards, safety awareness, safety procedure rehearsals, and weather conditions. Emergency rescue facilities and warning signs, beach type, sex, and age did not significantly affect the risk of drowning or near-drowning associated with marine recreational activities.

The study also simulated a single scenario with an overall probability of unfavorable conditions of 100% by using secondary factors alone. The probability of other factors being unfavorable remained unchanged. The results of the analysis are listed in Table 4. The most influential secondary risk factor was patrols and lifeguards, followed by panic, weather conditions, safety awareness, safety procedure rehearsals, and wave height. The influence of these six factors changed by more than six percentage points, which is greater than the change in influence of the other factors. Rip current, beach type, age, and sex exhibited no notable change in probability.

Table 1
Expert datasheet.

Expert	Area of Expertise
A (scholar)	Coastal/ocean leisure and entertainment development, marine recreation management, leisure sports management
B (scholar)	Diving, water sports management, tourism management
C (scholar)	Diving, water sports management, leisure and recreation management
D (water rescue personnel)	Lifesaving, diving, river tracing, jet ski safety, fin swimming, sailing, surfing, inflatable rescue boats (IRBs), canoe instruction
E (water rescue personnel)	Swimming, diving, jet ski safety, surfing, IRBs, canoe instruction
F (water rescue personnel)	Swimming, lifesaving, diving, creek tracking, surfing, IRBs, canoe instruction
G (coastguard personnel)	Lifesaving, diving, maritime law enforcement
H (coastguard personnel)	Lifesaving, diving, maritime law enforcement
I (coastguard personnel)	Lifesaving, diving, maritime law enforcement

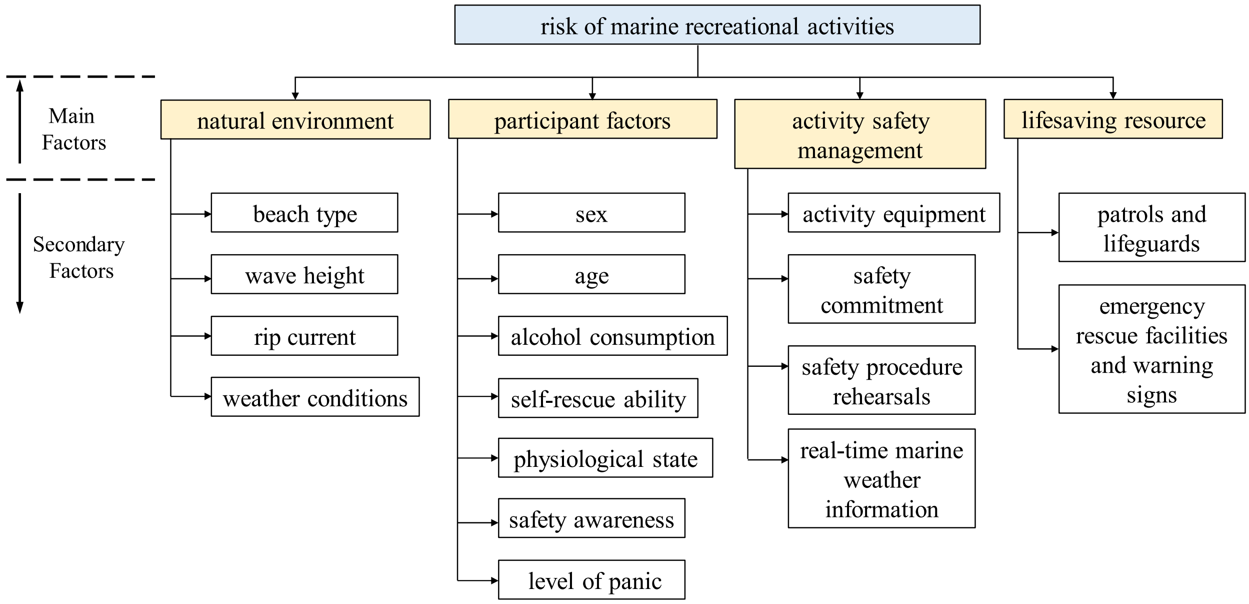

Fig. 2. Risk factor architecture.

Table 2
Relationships between assessment factors.

Left side	Direction of affect	Right side
(A)	←	(B), (C), (D), (E)
(B)	←	(G), (I), (K), (S)
(C)	←	(G), (H),(I), (M)
(D)	←	(F), (H), (L), (O)
(E)	←	(J), (N), (R)
(E)	→	(F)
(F)	←	(G)
(H)	←	(K), (Q)
(H)	→	(P)
(I)	←	(Q)
(J)	→	(N)
(M)	←	(Q)
(O)	←	(P), (U), (V)
(R)	←	(T)

The symbol "←" indicates that the factor on the right side influences that on the left side, whereas "→" indicates that the factor on the left side influences that on the right side.
(A) risk of drowning or near-drowning from marine recreational activities; (B) lifesaving resources; (C) activity safety management; (D) participant factors; (E) natural environment; (F) level of panic; (G) patrols and lifeguards; (H) safety awareness; (I) safety procedure rehearsals; (J) weather conditions; (K) real-time marine weather information; (L) self-rescue ability; (M) activity equipment; (N) wave height; (O) physiological state; (P) alcohol consumption; (Q) safety commitment; (R) rip current; (S) emergency rescue facilities and warning signs; (T) beach type; (U) sex; (V) age.

Using the aforementioned Bayesian model framework, this study simulated different risk conditions to understand the relationships between changes in risk associated with marine recreational activities. The conditions of each simulation are presented in Table 5.

In situation 1, the probability of a rip current being present (R2), the wave height exceeding 1 m (N2), the weather being sunny (J1), the participant's physiological state being good (O2), the participant's safety awareness being high (H2), the participant having self-rescue ability (L2), the activity equipment being good (M2), no patrol or lifeguard being present (G1), and emergency rescue facilities and warning signs being present is 100%, and the probability of other risk factors being unfavorable remains unchanged. When situation 1 conditions were applied, the risk of marine recreational activity conditions being unfavorable decreased by 11%, that is, decreased from 64% to 53%.

In situation 2, the probability of the wave height being <1 m (N1), the weather being sunny (J1), the participant's safety awareness being high (H2), the participant having self-rescue ability (L2), the activity equipment being good (M2), no patrols or lifeguards being present (G1), safety procedure rehearsals having occurred (I2), and the participant having real-time marine weather information (K2)

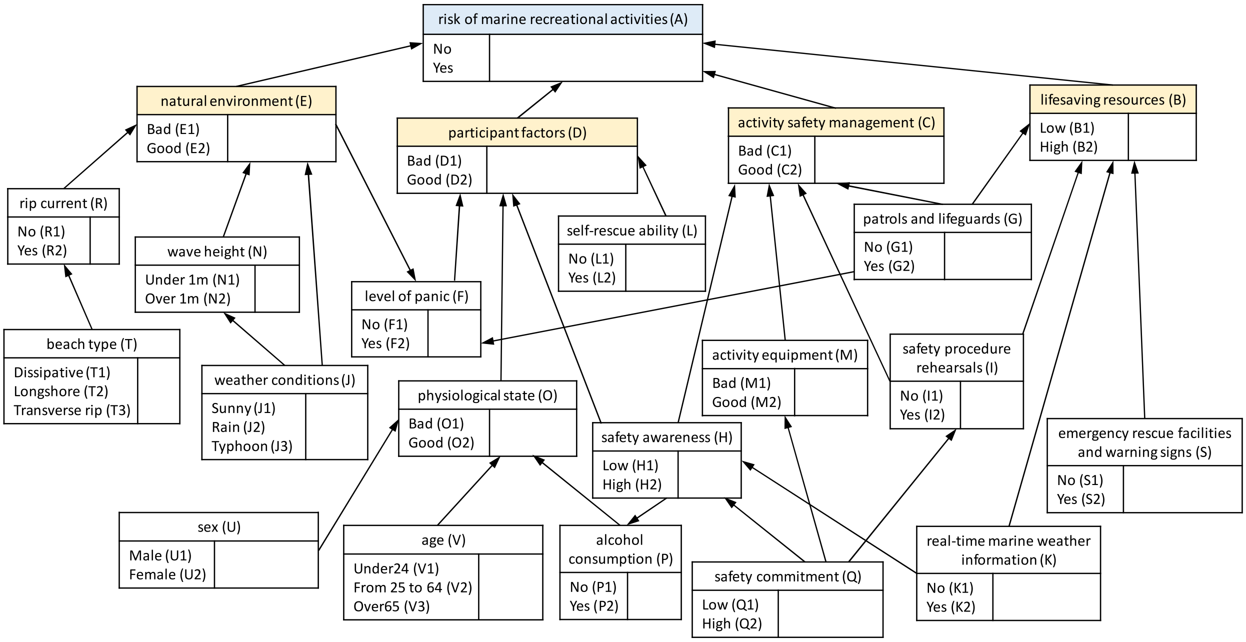

Fig. 3. Relationships between risk factors.

is 100%, and the probability of other risk factors being unfavorable remains unchanged. When situation 2 conditions were applied, the risk of marine recreational activity conditions being unfavorable decreased by 16%, that is, decreased from 64% to 48%.

In situation 3, the probability of the participant not having self-rescue ability (L1), safety commitment being low (Q1), safety procedure rehearsals not having occurred (I1), no patrol or lifeguard being present (G1), and emergency rescue facilities and warning signs being present (S2) is 100%, and the probability of other risk factors being unfavorable remains unchanged. When situation 3 conditions were applied, the risk of marine recreational activity conditions being unfavorable increased significantly by 12%, that is, increased from 64% to 76%. The conditions and analytical results for the other investigated situations are listed in Table 5.

4.3. Discussion

According to the simulated situations, establishment of patrols and the presence of lifeguards, reduction of panic, improvement of safety awareness, rehearsal of safety procedures, and avoidance of marine recreational activities when weather conditions are poor or wave height exceeds 1 m can effectively reduce the risk associated with these activities. According to Pereira [58], the presence of sufficient lifeguards and first aid safety equipment ensures the safety of beach recreational activities, particularly during the summer or other seasons suitable for water sports. Chen and Bau [59] stated that to create a safe beach recreation environment, different attributes of recreational activities should be managed in different areas, and attention should be given to whether sufficient lifeguards and lifesaving first aid equipment are present, particularly in areas with many tourists. Ahmad [60] concluded that although the most effective method for preventing drowning or near-drowning during participation in marine recreational activities is having a sufficient number of lifeguards present, hiring a sufficient number of lifeguards is costly.

Tourists who lack safety awareness are generally unaware of potential danger when engaging in coastal recreational activities. When no lifeguards are stationed in the area or no appropriate lifesaving equipment for rescue is available, the danger for such tourists is significantly higher. Therefore, on beaches where coastal recreational activities occur, if tourists' safety awareness and self-rescue ability is improved, the risk associated with coastal recreational activities is lower. Wilks et al. [61] stated that tourists who lack knowledge of marine safety are more likely to engage in dangerous behaviors, often endangering themselves and increasing the burden on lifeguards. Therefore, the danger of marine recreation can be effectively reduced by increasing the safety awareness of tourists and implementing safety education measures for marine activities.

5. Conclusions

On the basis of the risk factors and their interrelationships that were identified in this study and the results of risk simulations for different scenarios that were conducted using a Bayesian network, the present study obtained the following key findings: (1) Accidents are more likely to occur in sea areas without patrols and lifeguards. If no rehearsals of safety practices or inspections of activity equipment are conducted before a marine activity is made available, participants in the activity are more likely to panic if an incident occurs, and this significantly increases the risk of drowning or near-drowning. (2) Poor weather conditions lead to increased wave heights. When the wave height exceeds 1 m, the risk of drowning or near-drowning associated with marine recreational activities is

Table 3
Probability changes in factor unfavourability under 100% and 0% overall risk of unfavorable conditions.

Marine recreational activity risk factor		(1)	(2)	(3)	(4)	(5)	(6)
Lifesaving resources (B)	Low (B1)	59%	68%	+9%	43%	−16%	25%
	High (B2)	41%	32%	−9%	57%	+16%	
Activity safety management (C)	Bad (C1)	54%	61%	+7%	41%	−13%	20%
	Good (C2)	46%	39%	−7%	59%	+13%	
Participant factors (D)	Bad (D1)	56%	63%	+7%	44%	−12%	19%
	Good(D2)	44%	37%	−7%	56%	+12%	
Natural environment (E)	Bad (E1)	67%	72%	+5%	59%	−8%	13%
	Good (E2)	33%	28%	−5%	41%	+8%	
Panic (F)	No (F1)	33%	29%	−4%	40%	+7%	11%
	Yes (F2)	67%	71%	+4%	60%	−7%	
Patrols and lifeguards (G)	No (G1)	73%	77%	+4%	66%	−7%	11%
	Yes (G2)	27%	23%	−4%	34%	+7%	
Safety awareness (H)	Low (H1)	51%	54%	+3%	45%	−6%	9%
	High (H2)	49%	46%	−3%	55%	+6%	
Safety procedure rehearsals (I)	No (I1)	36%	39%	+3%	32%	−4%	7%
	Yes (I2)	64%	61%	−3%	68%	+4%	
Weather conditions (J)	Sunny (J1)	10%	9%	−1%	12%	+2%	3%
	Rain (J2)	25%	24%	−1%	27%	+2%	3%
	Typhoon (J3)	65%	67%	+2%	61%	−4%	6%
Real-time marine weather information (K)	No (K1)	60%	62%	+2%	56%	−4%	6%
	Yes (K2)	40%	38%	−2%	44%	+4%	
Self-rescue ability (L)	No (L1)	68%	70%	+2%	65%	−3%	5%
	Yes (L2)	32%	30%	−2%	35%	+3%	
Activity equipment (M)	Bad (M1)	44%	46%	+2%	41%	−3%	5%
	Good (M2)	56%	54%	−2%	59%	+3%	
Wave height (N)	Under 1 m (N1)	21%	19%	−2%	24%	+3%	5%
	Over 1 m (N2)	79%	81%	+2%	76%	−3%	
Physiological state (O)	Bad (O1)	43%	45%	+2%	41%	−2%	4%
	Good (O2)	57%	55%	−2%	59%	+2%	
Alcohol consumption (P)	No (P1)	57%	56%	−1%	60%	+3%	4%
	Yes (P2)	43%	44%	+1%	40%	−3%	
Safety commitment (Q)	Low (Q1)	65%	66%	+1%	63%	−2%	3%
	High (Q2)	35%	34%	−1%	37%	+2%	
Rip current (R)	No (R1)	77%	76%	−1%	78%	+1%	2%
	Yes (R2)	23%	24%	+1%	22%	−1%	
Emergency rescue facilities and warning signs (S)	No (S1)	85%	85%	0%	84%	−1%	1%
	Yes (S2)	15%	15%	0%	16%	+1%	
Beach type (T)	Dissipative (T1)	17%	16%	−1%	17%	0%	1%
	Longshore (T2)	28%	28%	0%	28%	0%	0%
	Transverse and rip (T3)	55%	56%	+1%	55%	0%	1%
Sex (U)	Male (U1)	60%	60%	0%	60%	0%	0%
	Female (U2)	40%	40%	0%	40%	0%	
Age (V)	≤24 years (V1)	50%	50%	0%	50%	0%	0%
	25–64 years (V2)	30%	30%	0%	30%	0%	
	≥65 years (V3)	20%	20%	0%	20%	0%	

(1) Bayesian network basic model with 64% overall chance of risk factor unfavourability in marine recreational activities; (2) Bayesian network model for 100% risk of unfavorable marine recreational activities conditions; (4) Bayesian network model for 0% risk of unfavorable marine recreational activity conditions; (3), (5), and (6) indicate probability variation: (3) = (2) − (1); (5) = (4) − (1); (6) = |(5) − (3)|.

greater. The results of Förster et al. [62] demonstrate that large waves that occur during typhoons are more likely to cause injury than those that occur during other weather conditions. This has led to most tourists visiting sightseeing areas outside of the typhoon season to reduce their risk of injury. (3) Tourists who engage in marine recreational activities who lack safety awareness are more likely to engage in dangerous behaviors. If their self-rescue ability is insufficient to escape potential danger, their risk of drowning or near-drowning is greater. (4) Future research should investigate regional variations in drowning and near-drowning events in coastal areas and whether certain areas are associated with higher risks than are others and should identify the underlying factors contributing to these differences. Such an analysis could include factors such as geography, local weather patterns, and tourist density.

Funding information

This research received no external funding.

Ethics statement

Informed consent was obtained from experts.

Table 4
Risk related to secondary risk factors under 100% overall risk of unfavorable conditions.

Risk factor		Risk of unfavorable factor (7)	Probability variation
Patrols and lifeguards (G)	No (G1)	67%	+3%
	Yes (G2)	54%	−10%
Panic (F)	No (F1)	56%	−9%
	Yes (F2)	67%	+3%
Weather conditions (J)	Sunny (J1)	56%	−8%
	Rain (J2)	61%	−3%
	Typhoon (J3)	66%	+2%
Safety awareness (H)	Low (H1)	68%	+4%
	High (H2)	59%	−5%
Safety procedure rehearsals (I)	No (I1)	68%	+4%
	Yes (I2)	61%	−3%
Wave height (N)	Under 1 m (N1)	59%	−5%
	Over 1 m (N2)	65%	+1%
Self-rescue ability (L)	No (L1)	65%	+1%
	Yes (L2)	60%	−4%
Safety commitment (Q)	Low (Q1)	65%	+1%
	High (Q2)	61%	−3%
Physiological state (O)	Bad (O1)	66%	+2%
	Good (O2)	62%	−2%
Activity equipment (M)	Bad (M1)	66%	+2%
	Good (M2)	62%	−2%
Alcohol consumption (P)	No (P1)	62%	−2%
	Yes (P2)	66%	+2%
Real-time marine weather information (K)	No (K1)	64%	0%
	Yes (K2)	61%	−3%
Emergency rescue facilities and warning signs (S)	No (S1)	64%	0%
	Yes (S2)	61%	−3%
Rip current (R)	No (R1)	63%	−1%
	Yes (R2)	65%	+1%
Beach type (T)	Dissipative (T1)	64%	0%
	Longshore (T2)	64%	0%
	Transverse and rip (T3)	63%	−1%
Age (V)	≤24 years (V1)	63%	−1%
	25–64 years (V2)	64%	0%
	≥65 years (V3)	64%	0%
Sex (U)	Male (U1)	63%	−1%
	Female (U2)	64%	0%

Table 5
Risk of unfavorable marine recreational activity conditions in different compound situations.

Situation	Situational conditions	Risk of unfavorable marine recreational activity conditions (9)	Probability variation (10) = (9) − 64%
Situation 1	G1, H2, J1, L2, M2, N2, O2, R2, S2	53%	−11%
Situation 2	G1, H2, I2, J1, K2, L2, M2, N1	48%	−16%
Situation 3	G1, I1, L1, Q1, S2	76%	+12%
Situation 4	F2, H1, N2, S2	70%	+6%
Situation 5	F2, H1, I1, G2	66%	+2%
Situation 6	F2, H1, N2	72%	+8%
Situation 7	F2, G1, R2	70%	+6%
Situation 8	G1, H1, N2	73%	+9%
Situation 9	L2, N2, O2	60%	−4%
Situation 10	F2, G2, H1, L1, O1, S2	63%	−1%
Situation 11	F2, G2, H1, L1, N2, S2	63%	−1%

Author contribution statement

Meng-Tsung Lee: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Yang-Chi Chang; Han-Chung Yang: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Yi-Jun Lin: Performed the experiments; Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1] C.L. Wu, H.M. Chang, Island marine tourism development critical success factors-case by wangan in taiwan, Journal of Global Business Management 9 (3) (2013) 126.
[2] J.G. Chen, Y.Z. Zhong, L.Z.H. Chuang, B. Koppe, H. Chien, Risk management of coastal water safety for recreational activities: the case of Taoyuan coast, Appl. Geogr. 117 (2020), 102173.
[3] B. Brighton, S. Sherker, R. Brander, M. Thompson, A. Bradstreet, Rip current related drowning deaths and rescues in Australia 2004–2011, Nat. Hazards Earth Syst. Sci. 13 (4) (2013) 1069–1075.
[4] B. Castelle, R. Brander, E. Tellier, B. Simonnet, T. Scott, J. McCarroll, P. Lechevrel, Surf zone hazards and injuries on beaches in SW France, Nat. Hazards 93 (3) (2018) 1317–1335.
[5] S.J. Pitman, K. Thompson, D.E. Hart, K. Moran, S.L. Gallop, R.W. Brander, A. Wooler, Beachgoers' ability to identify rip currents at a beach in situ, Nat. Hazards Earth Syst. Sci. 21 (1) (2021) 115–128.
[6] National fire agency, Overview of Water Accident Rescue Cases, NATIONAL FIRE AGENCY, 2023, July 7. MINISTRY OF THE INTERIOR, https://www.nfa.gov.tw/eng/index.php.
[7] C.W. Finkl (Ed.), Coastal Hazards, Springer, Dordrecht, 2013, p. 840.
[8] S. Fan, E. Blanco-Davis, Z. Yang, J. Zhang, X. Yan, Incorporation of human factors into maritime accident analysis using a data-driven Bayesian network, Reliab. Eng. Syst. Saf. 203 (2020), 107070.
[9] J.A. Stoop, Maritime accident investigation methodologies, Inj. Control Saf. Promot. 10 (4) (2003) 237–242.
[10] C.T. Blay, Drowning deaths in the nearshore marine waters of the island of kauai, Hawaii 1970-2009, Int. J. Aquat. Res. Educ. 5 (3) (2011) 7.
[11] J. García-Alba, J.F. Bárcena, L. Pedraz, F. Fernández, A. García, M. Mecías, D. Szpilman, SOSeas Web App: an assessment web-based decision support tool to predict dynamic risk of drowning on beaches using deep neural networks, Journal of operational oceanography (2021) 1–20.
[12] W. Haddon Jr., A note concerning accident theory and research with special reference to motor vehicle accidents, Ann. N. Y. Acad. Sci. 107 (2) (1963) 635–646.
[13] D. Morgan, Analyzing the risk of drowning at surf beaches, Tourism Rev. Int. 10 (1–2) (2006) 125–130.
[14] J.P. Guevarra, R.C. Franklin, J.A. Basilio, L.L. Orbillo, J.J.L. Go, Child drowning prevention in the Philippines: the beginning of a conversation, Int. J. Inj. Control Saf. Promot. 22 (3) (2015) 243–253.
[15] W. Ennouri, Risks management: new literature review, Polish journal of management studies 8 (2013) 288–297.
[16] Y. Wu, L. Li, Z. Song, X. Lin, Risk assessment on offshore photovoltaic power generation projects in China based on a fuzzy analysis framework, J. Clean. Prod. 215 (2019) 46–62.
[17] D. Ivanov, A. Dolgui, A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0, Prod. Plann. Control 32 (9) (2021) 775–788.
[18] V.T. Covello, M.W. Merkhoher, Risk Assessment Methods: Approaches for Assessing Health and Environmental Risks, Springer Science & Business Media, 1993.
[19] L. Gilsbach, P. Schütte, G. Franken, Applying water risk assessment methods in mining: current challenges and opportunities, Water Resour. Ind. 22 (2019), 100118.
[20] Bayes, T., & Price. (1763). An essay towards solving a problem in the doctrine of chances. Philosophical Transactions of the Royal Society, 53, 370–418..
[21] M. Păduraru, Theoretical and practical considerations regarding the use of conditional probability assessment algorithm in early warning tasks aimed to prevent acts of terrorism and violent extremism, J. Appl. Secur. Res. 17 (2) (2022) 208–240.
[22] M. Scanagatta, A. Salmerón, F. Stella, A survey on Bayesian network structure learning from data, Progress in Artificial Intelligence 8 (4) (2019) 425–439.
[23] S. Hosseini, D. Ivanov, Bayesian networks for supply chain risk, resilience and ripple effect analysis: a literature review, Expert Syst. Appl. 161 (2020), 113649.
[24] Y. Zheng, Y. Xie, X. Long, A comprehensive review of Bayesian statistics in natural hazards engineering, Nat. Hazards 108 (1) (2021) 63–91.
[25] M. Neil, D. Hager, L.B. Andersen, Modeling operational risk in financial institutions using hybrid dynamic Bayesian networks, Journal of Operational Risk 4 (1) (2009) 3–33.
[26] I. Paradinas, D. Conesa, M.G. Pennino, F. Muñoz, A.M. Fernández, A. López-Quílez, J.M. Bellido, Bayesian spatio-temporal approach to identifying fish nurseries by validating persistence areas, Mar. Ecol. Prog. Ser. 528 (2015) 245–255.
[27] A. Sperotto, J.L. Molina, S. Torresan, A. Critto, A. Marcomini, Reviewing Bayesian Networks potentials for climate change impacts assessment and management: a multi-risk perspective, J. Environ. Manag. 202 (2017) 320–331.
[28] M. Abimbola, F. Khan, Resilience modeling of engineering systems using dynamic object-oriented Bayesian network approach, Comput. Ind. Eng. 130 (2019) 108–118.
[29] S.M. Imaduddin, A. Fanelli, F.W. Vonberg, R.C. Tasker, T. Heldt, Pseudo-Bayesian model-based noninvasive intracranial pressure estimation and tracking, IEEE (Inst. Electr. Electron. Eng.) Trans. Biomed. Eng. 67 (6) (2019) 1604–1615.
[30] J.F. Balmat, F. Lafont, R. Maifret, N. Pessel, A decision-making system to maritime risk assessment, Ocean Eng. 38 (1) (2011) 171–176.
[31] Q. Zeng, L. Yang, Q. Zhang, Modeling the sailing risk of RoPax ships with bayesian network, Transport 32 (4) (2017) 340–347.
[32] Y. Ge, L. Zhou, S. Cui, M. Yang, July). Extending GeNIe for building graphical decision-theoretic models, in: 2013 10th International Conference on Fuzzy Systems and Knowledge Discovery (FSKD), IEEE, 2013, pp. 588–593.
[33] N. Fenton, M. Neil, Risk Assessment and Decision Analysis with Bayesian Networks, Crc Press, 2018.
[34] M. Neil, N. Fenton, L. Nielson, Building large-scale Bayesian networks, Knowl. Eng. Rev. 15 (3) (2000) 257–284.
[35] L. Wu, Student model construction of intelligent teaching system based on Bayesian network, Personal Ubiquitous Comput. 24 (3) (2020) 419–428.
[36] D. Heckerman, D. Geiger, D.M. Chickering, Learning Bayesian networks: the combination of knowledge and statistical data, Mach. Learn. 20 (3) (1995) 197–243.
[37] J. Sobieraj, D. Metelski, Private renting vs. Mortgage home buying: case of British housing market—a bayesian network and directed acyclic graphs approach, Buildings 12 (2) (2022) 189.
[38] Y.F. Li, H.Z. Huang, J. Mi, W. Peng, X. Han, Reliability analysis of multi-state systems with common cause failures based on Bayesian network and fuzzy probability, Ann. Oper. Res. (2019) 1–15.
[39] N. Khakzad, F. Khan, P. Amyotte, Safety analysis in process facilities: comparison of fault tree and Bayesian network approaches, Reliab. Eng. Syst. Saf. 96 (8) (2011) 925–932.
[40] E.J. Anthony, T. Aagaard, The lower shoreface: morphodynamics and sediment connectivity with the upper shoreface and beach, Earth Sci. Rev. 210 (2020), 103334.

[41] T.S. Feng, L.K. Chien, S.Y. Chiu, June). Establishment and application of coastal vulnerability index in taiwan nearshore area, in: The Twenty-First International Offshore and Polar Engineering Conference, OnePetro, 2011.
[42] A. McLachlan, O. Defeo, E. Jaramillo, A.D. Short, Sandy beach conservation and recreation: guidelines for optimising management strategies for multi-purpose use, Ocean Coast Manag. 71 (2013) 256–268.
[43] A. Attard, R.W. Brander, W.S. Shaw, Rescues conducted by surfers on Australian beaches, Accid. Anal. Prev. 82 (2015) 70–78.
[44] C.C. Wu, H.T. Jhan, K.H. Ting, H.C. Tsai, M.T. Lee, T.W. Hsu, W.H. Liu, Application of social vulnerability indicators to climate change for the southwest coastal areas of Taiwan, Sustainability 8 (12) (2016) 1270.
[45] A. Toimil, P. Díaz-Simal, I.J. Losada, P. Camus, Estimating the risk of loss of beach recreation value under climate change, Tourism Manag. 68 (2018) 387–400.
[46] P. Barss, O.M. Subait, M.H. Al Ali, M. Grivna, Drowning in a high-income developing country in the Middle East: newspapers as an essential resource for injury surveillance, J. Sci. Med. Sport 12 (1) (2009) 164–170.
[47] A. Turgut, T. Turgut, A study on rescuer drowning and multiple drowning incidents, J. Saf. Res. 43 (2) (2012) 129–132.
[48] C. Elrick-Barr, R. Kay, N. Farmer, Developing a road map for climate change adaptation: the experience of Surf Life Saving Australia, Ocean Coast Manag. 86 (2013) 75–79.
[49] D. Szpilman, Drowning, in: The Science of Beach Lifeguarding, CRC Press, 2018, pp. 143–160.
[50] L.R. Elliott, M.P. White, J. Grellier, S.E. Rees, R.D. Waters, L.E. Fleming, Recreational visits to marine and coastal environments in England: where, what, who, why, and when? Mar. Pol. 97 (2018) 305–314.
[51] J.R. Mallen, D.S. Roberts, SCUBA Medicine for otolaryngologists: Part I. Diving into SCUBA physiology and injury prevention, Laryngoscope 130 (1) (2020) 52–58.
[52] D.J. Barnett, R.D. Balicer, D. Blodgett, A.L. Fews, C.L. Parker, J.M. Links, The application of the Haddon matrix to public health readiness and response planning, Environ. Health Perspect. 113 (5) (2005) 561–566.
[53] J. Fang, W. Liu, S. Yang, S. Brown, R.J. Nicholls, J. Hinkel, P. Shi, Spatial-temporal changes of coastal and marine disasters risks and impacts in Mainland China, Ocean Coast Manag. 139 (2017) 125–140.
[54] G.A. Riddell, H. van Delden, H.R. Maier, A.C. Zecchin, Exploratory scenario analysis for disaster risk reduction: considering alternative pathways in disaster risk assessment, Int. J. Disaster Risk Reduc. 39 (2019), 101230.
[55] J. Wilks, Tourism and aquatic safety: No lifeguard on duty—swim at your own risk, Tourism Mar. Environ. 12 (3–4) (2017) 211–219.
[56] K. Moran, Beach safety education, in: The Science of Beach Lifeguarding, CRC Press, 2018, pp. 245–252.
[57] W. Zheng, F. Cai, S. Chen, J. Zhu, H. Qi, H. Cao, S. Zhao, Beach management strategy for small islands: case studies of China, Ocean Coast Manag. 184 (2020), 104908.
[58] L.C.C. Pereira, A. Vila-Concejo, R.M. da Costa, A.D. Short, Managing physical and anthropogenic hazards on macrotidal Amazon beaches, Ocean Coast Manag. 96 (2014) 149–162.
[59] C.L. Chen, Y.P. Bau, Establishing a multi-criteria evaluation structure for tourist beaches in Taiwan: a foundation for sustainable beach tourism, Ocean Coast Manag. 121 (2016) 88–96.
[60] S. Ahmad, Drowning prevention: introduction and recent developments, Res. J. Sci. Technol. 11 (2) (2019) 155–158.
[61] J. Wilks, P. Dawes, D. Pendergast, B. Williamson, Tourists and beach safety in Queensland, Australia, Tourism Mar. Environ. 1 (2) (2005) 121–128.
[62] J. Forster, P.W. Schuhmann, I.R. Lake, A.R. Watkinson, J.A. Gill, The influence of hurricane risk on tourist destination choice in the Caribbean, Climatic Change 114 (3) (2012) 745–768.