Bagh-e Nazar
DOI: 10.22034/bagh.2025.518042.5797

Bagh-e Nazar, *23*(155), 29-44. / 2026
Persian translation of this paper entitled:
ارزیابی ریسک و تحلیل تهدید برای زیرساخت‌های درمانی
در منطقهٔ ساحلی مکران با رویکرد پدافند غیرعامل
published in this issue of journal

Original Research Article

Risk Assessment and Threat Analysis for Healthcare Infrastructure in the Makran Coastal Region with a Passive Defense Approach*

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Received: 20/04/2025 Accepted: 06/10/2025 Available online:21/04/2026

Abstract

Problem statement: In recent years, the increase in natural disasters and human-induced threats has posed significant challenges to healthcare infrastructure, which is a critical component of health systems and disaster management. The Makran coastal region, due to its geostrategic location, proximity to an active fault zone, and adjacency to the sea, is among the most vulnerable areas in the country. This study employs a passive defense approach to assess risks and analyze threats affecting healthcare infrastructure in the region.

Research objective: This study aims to assess the risk and analyze threats to healthcare infrastructure in the Makran coastal region using a passive defense approach. Specifically, it seeks to identify natural and human-induced hazards, evaluate the preparedness and resilience of healthcare facilities, measure the impact of these threats on overall risk through a mixed-methods approach, and provide practical recommendations to enhance the functional and structural resilience of healthcare infrastructure in high-risk areas.

Research method: This research was conducted using a sequential explanatory mixed-methods design. In the qualitative phase, ten semi-structured interviews were conducted with healthcare managers, passive defense specialists, and disaster management experts. In the quantitative phase, 50 researcher-designed questionnaires were distributed among experts and managers of healthcare centers in the region. Data were analyzed using thematic analysis, descriptive statistics, and multiple linear regression.

Conclusion: Strengthening early warning systems, continuous staff training, structural reinforcement of healthcare facilities, and ensuring adequate resources and equipment can directly reduce the vulnerability of healthcare infrastructure in the Makran region. The novelty of this study lies in the first-time modeling of combined natural and human-induced threats on Makran's healthcare infrastructure using a passive defense perspective. The findings can serve as a practical policy framework for enhancing healthcare resilience in other high-risk coastal regions.

Keywords: *Risk Assessment and Threat Analysis, Healthcare Infrastructure, Makran Coastal Region, Natural Disasters, Passive Defense.*

Introduction

In recent decades, the intensity and frequency of natural disasters and man-made threats have been on the rise, placing vital infrastructures particularly healthcare facilities, which serve as the frontline of crisis response under serious risk of damage (World Health Organization (WHO, n.d.). Hospitals and healthcare centers not only play a crucial role in ensuring public health but also serve as critical components of community resilience during emergencies and disasters (Peterson, 2020). The Makran coastal region in southeastern Iran, due to its geostrategic location, position on the active Makran subduction zone,

* This article is taken from the doctoral thesis of "Siavash Ghojavand" entitled "Algorithmic Models of the Architecture of Medical Centers in the Coastal Areas of Makran with a Passive Defense Approach", which is being conducted under the guidance of Dr. "Mahnaz Mahmoudi Zarandi" and Dr. "Neda Zia-Bakhsh" and with the consultation of Dr. "Saeed Piri" at the Faculty of Architecture, Islamic Azad University, North Tehran Branch, Iran.

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and proximity to the Oman Sea, is among the country's most high-risk areas. The presence of Chabahar Port, which is the only oceanic port in Iran, along with the ongoing development of industrial and port projects in the area, has further heightened the sensitivity and importance of healthcare facilities (Derakhshani Nejad & Haddadi, 2025). From a natural perspective, this region is continuously exposed to severe earthquakes, tsunamis triggered by seabed displacement, tropical storms, and flash floods (Kijko et al., 2016; Poorzare et al., 2018). Changes in sea level and evidence of tectonic uplift in Chabahar Bay have exacerbated the threat to the stability of coastal infrastructure (Giaime et al., 2018). From a human perspective, threats such as terrorist attacks, industrial accidents resulting from port development, and rapid urban population growth in Chabahar and Konarak exert additional pressure on healthcare facilities (Willis et al., 2018; Mishra et al., 2020). According to data from the Statistical Center of Iran (n. d.), the population of Chabahar has nearly doubled over the past 15 years—from approximately 77,000 in 2006 to over 150,000 in 2021—indicating both an increased demand for healthcare services and greater vulnerability of infrastructure to crises. The selection of the Makran region in this study is based on the unique concentration of natural (earthquakes, tsunamis, floods) and human-induced (industrial development, population density, and geopolitical position) threats, which are not observed with such intensity and combination in other coastal areas of the country (Poorzare et al., 2018; Giaime et al., 2018; Derakhshani Nejad & Haddadi, 2025). Under such conditions, passive defense emerges as a key approach for reducing vulnerability and enhancing the resilience of critical infrastructures. This approach encompasses a set of non-military measures such as proper site selection, resilient design, early warning systems, and staff training, all of which can play a decisive role in maintaining the functionality of healthcare centers (Mirzadeh & Asgharzadeh, 2021; Abbaszadeh, 2017). Research evidence from countries with similar conditions indicates that the application of passive defense principles, particularly in coastal regions, significantly reduces the damage and casualties caused by crises (Hosseini et al., 2014; Nakhai & Rezaei, 2017). Nevertheless, a review of the existing literature reveals that most studies have focused either on natural threats or solely on security and human dimensions. The lack of integrated studies addressing both natural and man-made threats to coastal healthcare facilities highlights the need for comprehensive research in this area. The innovation of the present study lies in its combined approach and the use of the passive defense framework to assess risk and analyze the simultaneous effects of multidimensional (natural and human-induced) threats on healthcare infrastructures in the Makran region. Accordingly, the main research question is: How can the application of passive defense principles reduce the vulnerability of healthcare infrastructures in the Makran coastal region to natural and man-made threats and enhance their resilience?

Literature Review

- **Definition of concepts and semantic scope**

In this study, healthcare infrastructure refers to the collection of spaces and systems that ensure the continuity of healthcare services at the urban or regional level, including hospitals, comprehensive health centers and clinics, pre-hospital emergency services (EMS and 115 stations), major pharmacies, drug and essential medical supply storage centers, and supporting infrastructures (power, water, and communications) connected to these facilities (Mirzadeh & Asgharzadeh, 2021; WHO, n.d.). Healthcare facility resilience refers to the structural and functional capacity to maintain an acceptable level of service delivery during the pre-crisis, response, and recovery phases (Peterson, 2020).

- **Dimensions of healthcare infrastructure vulnerability**

Based on the literature and international health risk management standards, the vulnerability of healthcare facilities is conceptualized across four main dimensions:

1) Physical/Structural–Equipment Dimension: The resistance of critical components and systems (structure, mechanical–electrical installations, generators, tanks, network, and IT systems) against seismic waves, high winds, water intrusion, impact, and explosion (Hosseini et al., 2016; Kijko et al., 2016).

2) Functional–Organizational Dimension: Continuity of operations, admission and evacuation capacity, Hospital Incident Command System (HICS), early warning systems, and response and recovery plans (Abbaszadeh, 2017; WHO, n. d.).

3) Accessibility and Network Connectivity Dimension: Road and intra-urban accessibility and communication bandwidth for EMS, alternative routes, ambulance arrival time, and inter-facility communications (Poorzare et al., 2018; Peterson, 2020).

4) Supply Chain and Logistical Support Dimension: Availability of medicines, blood, and essential materials, dependence on limited suppliers, diversity of supply routes, and logistical flexibility (Willis et al., 2018; Mishra et al., 2020).

- **Conceptual framework of threat–vulnerability–risk (specific to coastal healthcare facilities)**

The theoretical framework of the study explains the causal relationships between natural and man-made threats, the four dimensions of vulnerability, and the overall risk level of healthcare facilities. In summary:

Natural threats: Earthquakes and tsunamis generated by the Makran subduction zone, tropical cyclones, flash floods, relative sea-level rise, and coastal erosion (Giaime et al., 2018; Poorzare et al., 2018; Kijko et al., 2016).

Man-made threats: Acts of sabotage or terrorism targeting critical facilities, industrial accidents related to port and energy development, population pressure, and the increasing demand for services (Willis et al., 2018; Mishra et al., 2020).

Within this framework, risk is defined as a function of the intensity and likelihood of threats and the level of vulnerability across the four dimensions. Passive defense measures—such as safe site selection, structural reinforcement, service continuity, diversification of routes and resources, and access control—act as key risk-reduction factors (Mirzadeh & Asgharzadeh, 2021; WHO, n.d.) (Fig. 1).

- **Review of related literature**

- Passive defense in healthcare facilities

Numerous studies have emphasized the role of safe design, reinforcement of critical hospital facilities, and service continuity programs (Hosseini et al., 2014; Mirzadeh & Asgharzadeh, 2021). Domestic research indicates that managerial awareness, standardization of

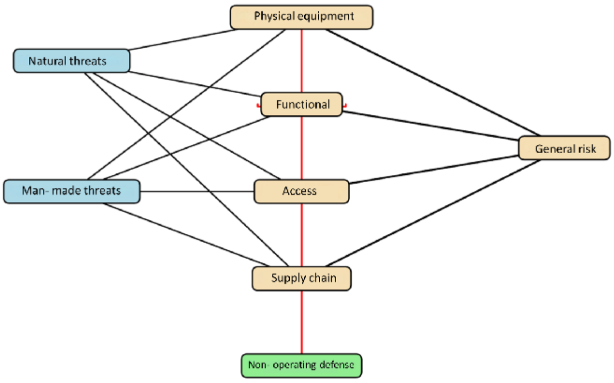

Fig. 1. Conceptual model of risk assessment for healthcare infrastructure in the makran coastal region. Authors.

Hospital Incident Command System (HICS) processes, and infrastructure monitoring significantly reduce vulnerability (Shariffar et al., 2020; Aghababaei et al., 2020). In addition, hospital site selection based on multi-hazard constraints and accessibility criteria has been shown to reduce cumulative risk (Ferdosi et al., 2016; Radmard et al., 2018).

- Specific threats in the Makran coastal region

Geomorphological studies of the Chabahar Gulf provide clear evidence of tectonic uplift (0.1–0. 6 m per thousand years) and shoreline displacement during the Holocene, resulting in coastal erosion and flooding (Giaime et al., 2018). Climate and hazard assessments have also confirmed the passage of tropical cyclones and extreme precipitation along the Makran coasts (Poorzare et al., 2018; Peterson, 2020). On the human side, port–industrial development and rapid urban population growth have increased both the probability of industrial accidents and the “pressure of healthcare demand” (Willis et al., 2018; Mishra et al., 2020) (Table 1).

- Risk assessment and threat analysis in healthcare infrastructure

Two dominant approaches are observed in the literature:

1) Quantitative/Multi-criteria Models: Integrating hazard–vulnerability indicators to produce a composite risk score (Mashhadi & Amini Varaki, 2015; Fronczek-Munter & Prugsiganont, 2018).

2) Integrated Data–Expert Models: Combining semi-structured interviews and standardized questionnaires to improve indicator weighting and response scenario development (Hosseini et al., 2018; Rezazadeh & Sarbangholi, 2017).

Table 1. Mapping of constructs, indicators, and selected literature sources. Source: Authors.

Theoretical construct	Source/ Evidence	Sub-construct/ Sample indicator	Datatype
Physical–technical	Hosseini et al., 2016 ؛Fronczek-Munter & Prugsiganont, 2018	Structural resilience, redundancy of critical facilities, IT physical protection	Quantitative/ Qualitative
Functional–organizational	WHO, n. d.; Abbaszadeh, 2017	service continuity, staff training, and drills HICS	Likert/ Qualitative
Access & network	Peterson, 2020; Poorzare et al., 2018	EMS response time, alternative routes, and telecommunication connectivity	Qualitative
Supply chain	Willis et al., 2018; Mishra et al., 2020	Critical inventory, supplier/path diversity, replenishment time	Quantitative / Qualitative

Recent studies emphasize the importance of compound threats (simultaneous natural and human-induced) and the necessity of linking them with healthcare service continuity, EMS network resilience, and pharmaceutical supply chain diversity (Landeg, et al., 2019; WHO, n. d.).

- **Research gap and innovation of the present study**

A systematic review reveals that most prior research has either been limited to a single threat dimension (natural or human-induced) or focused on the physical aspect without adequately linking it to functionality, accessibility, and supply chain components. Furthermore, in the context of the Makran coast, the relationship between tectonic–coastal evidence (Giaime et al., 2018) and the design–operation of healthcare facilities has rarely been operationalized.

The present study aims to fill this gap and provide context-specific, applicable evidence by:

1) Offering an integrated operational definition of healthcare infrastructure;

2) Conceptualizing four dimensions of vulnerability and linking them to compound threats;

3) Developing a Threat–Vulnerability–Risk conceptual framework tailored to the Makran coastal setting; and

4) And applying passive defense principles as a risk-reduction intervention

The study aims to fill this gap and provide context-specific, practical evidence (Mirzadeh & Asgharzadeh, 2021; WHO, n. d.).

Study Area

The Makran region, located in southeastern Iran along the coast of the Oman Sea, extends from the east of Jask Port to the Pakistan border, encompassing the two main counties of Chabahar and Konarak in Sistan and Baluchestan Province. The geostrategic position of this region is of great significance to Iran due to its direct access to open waters and its location along international trade and energy corridors (Giaime et al., 2018). Although healthcare infrastructures in other coastal areas of the country such as the Persian Gulf coasts (Bandar Abbas, Bushehr, and Asaluyeh) and the Caspian Sea shores are also exposed to risks such as earthquakes, storms, and coastal erosion, the Makran zone presents a unique combination of simultaneous natural and human-induced threats. The presence of the active Makran subduction zone increases the likelihood of major earthquakes and tsunamis, while rapid population growth, heavy industrial development, border geopolitics, and the vulnerability of critical infrastructures collectively create compound threats in this region (Kijko et al., 2016; Poorzare et al., 2018; Derakhshani Nejad & Haddadi, 2025). Therefore, the selection of the Makran region for this research is not coincidental, but rather based on its exceptional characteristics of exposure to both natural and anthropogenic hazards.

- **Geographical location and study boundaries**

Fig. 2 illustrates the location map of the Makran region at the national and provincial levels. It delineates the boundaries of Sistan and Baluchestan Province, identifies the main cities (Chabahar and Konarak), and highlights the coastal zone under study.

The region is bounded by the Makran Mountains to the north, the Oman Sea to the south, the Pakistan border to the east, and the port city of Jask to the west.

- Natural characteristics

Geologically, the Makran region is influenced by the activity of the Makran Fault, which is considered one

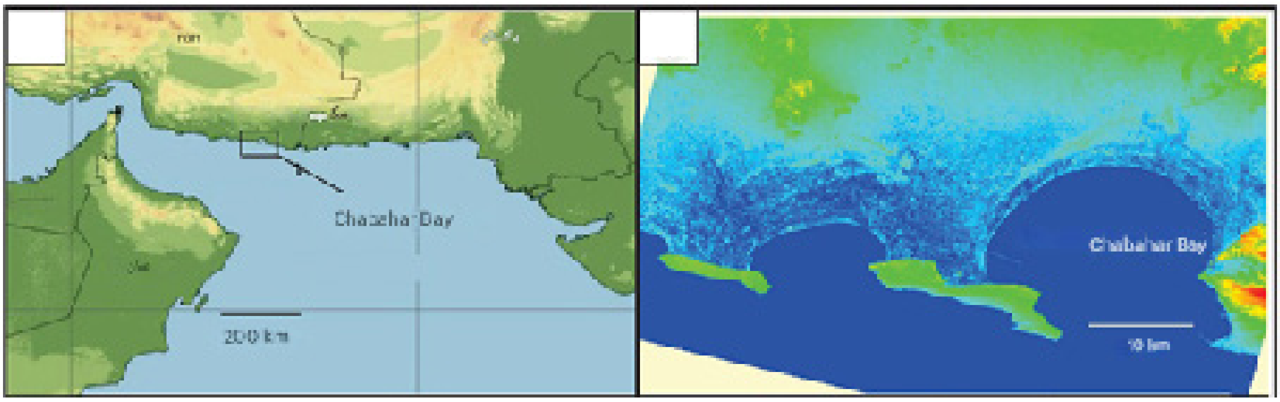

Fig. 2. Geographical location of the Makran region and major cities in Sistan and Baluchestan Province. Source: Giaime et al., 2018.

of the most seismically active subduction zones in the world and the source of destructive earthquakes and tsunamis (Kijko et al., 2016). Geomorphological data indicate that the region comprises mountainous areas (6,362 km²), coastal plains (8,228. 7 km²), and hilly and badland formations (Fig. 3).

The elevated terrains and cliffed coasts have the highest potential for passive defense, while coastal plains are highly exposed to sea-level rise, erosion, and flash floods (Samadi & Jamshidi Aval, 2024) (Fig. 4).

- Sea-Level Changes and coastal threats

Geomorphological studies in the Gulf of Chabahar have shown that the relative sea level has undergone continuous changes throughout the Holocene, with tectonic uplift ranging from 0. 1 to 0. 6 meters per thousand years. The presence of successive coastal ridges, sand dunes, and tidal channels is among the main results of these variations (Giaime et al., 2018) (Fig. 5).

- **Population trends**

The population of Chabahar and Konarak cities has grown significantly over the past 15 years. According to the Statistical Center of Iran (n. d.), the population of Chabahar increased from approximately 77,000 in 2006 to more than 150,000 in 2021. This trend has placed additional pressure on the region's healthcare and medical service infrastructure (Table 2).

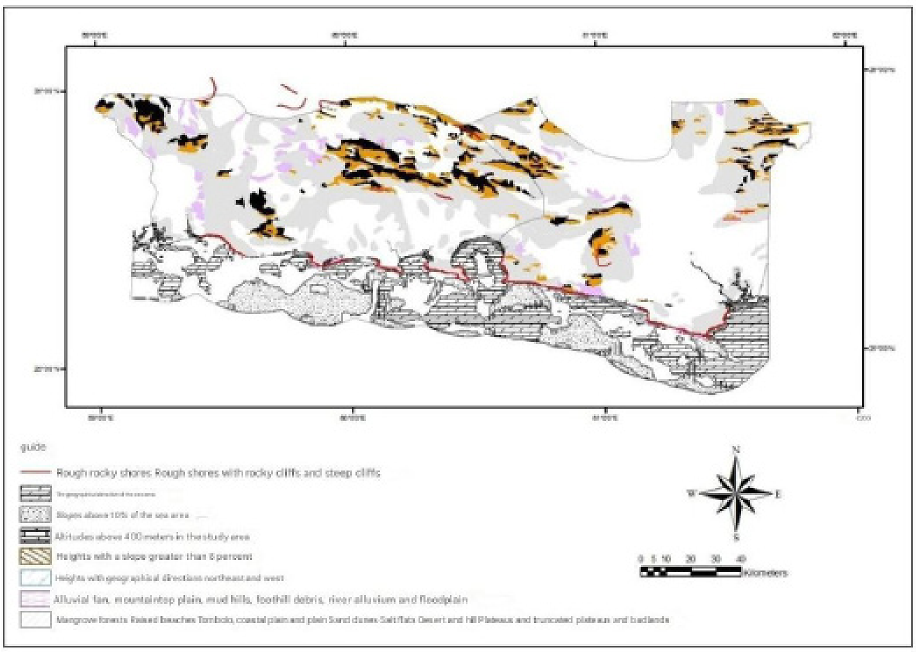

Fig. 3. Geomorphological map of the Makran region and classification of natural units. Source: Mohammadpour et al., 2017.

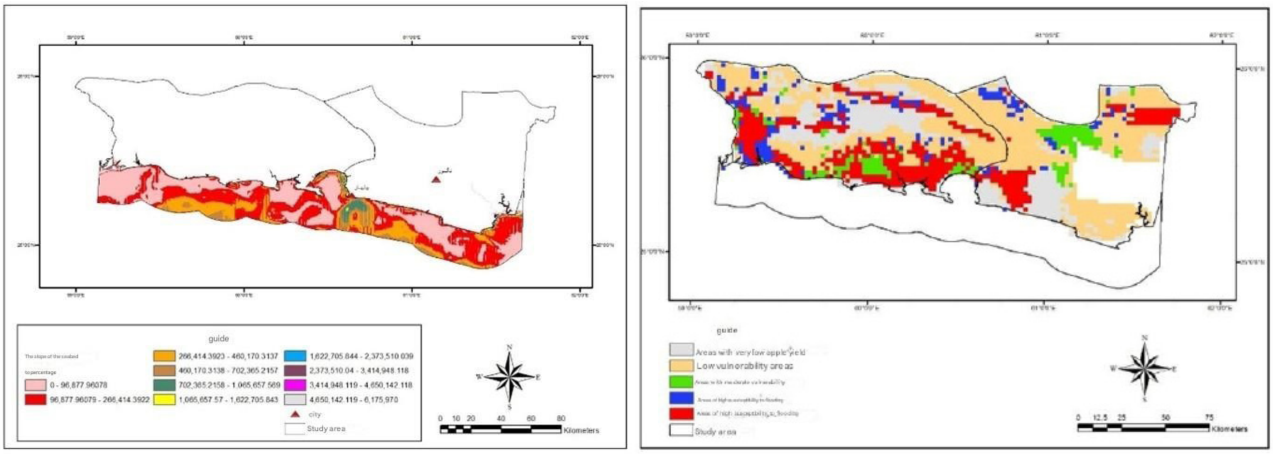

Fig. 4. High-risk zones and marine slope map. Source: Geological Survey of Iran, 2016.

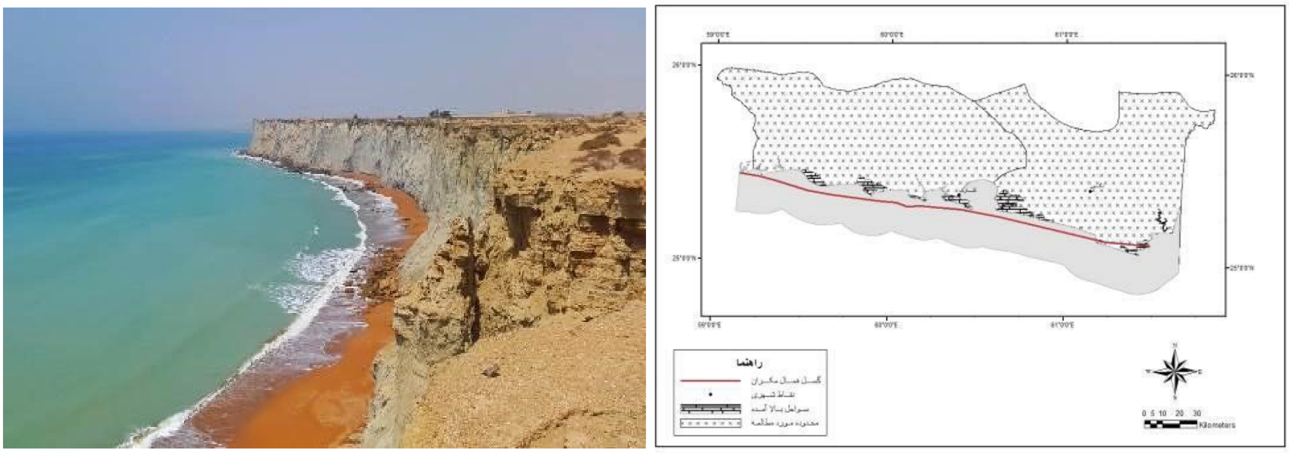

Fig. 5. Evidence of coastal line changes and tectonic uplift in the Chabahar gulf. Source: Geological Survey of Iran, 2016.

• Environmental and human threats

The Makran region, as one of Iran's most sensitive zones, is exposed to a combination of natural and man-made threats, both of which directly affect the security and functionality of healthcare infrastructure. A thorough examination of these threats is essential for designing effective passive defense strategies. The coexistence of natural and human-induced hazards in the Makran region creates unique complexities in planning and protecting healthcare infrastructure. Existing evidence indicates that the design and structural reinforcement of healthcare facilities in this area must simultaneously address seismic risks, tropical storms, sea-level rise, as well as human attacks and population pressure. This comprehensive analysis underscores the necessity of adopting a passive defense approach for integrated regional risk management.

- Natural threats

Earthquakes and Tsunamis: The presence of the Makran Subduction Zone in southeastern Iran has made this region one of the main centers of seismic activity and tsunami hazards in the world. Historical earthquakes, such as the 1945 Balochistan earthquake with a magnitude of 8.1, demonstrate the potential for devastating earthquakes and tsunamis caused by seabed displacement (Kijko et al., 2016). The occurrence of such events can disrupt the operation of coastal healthcare centers and even lead to the complete destruction of their infrastructure (Fig. 6).

Tropical storms and heavy precipitation: The Makran region is exposed to the passage of tropical cyclones, which have occasionally caused extensive damage. For example, Cyclone Gonu in 2007 severely affected

Table 2. Population Growth Trend of Major Cities in the Makran Region over the Past 15 Years. Source: Statistical Center of Iran, n.d.

Year	Population of Chabahar	Population of Konarak
2006	77,128	25,249
2011	106,739	34,183
2016	120,442	40,158
2021	151,561	46,850

port and urban infrastructure in both Oman and Iran (Poorzare et al., 2018). These storms not only cause direct structural damage but also trigger flash floods and disrupt access routes to healthcare facilities (Fig. 7).

Flash floods and seasonal runoff: Due to the steep slopes of the northern highlands and the concentration of coastal plains in the southern part of the region, intense seasonal rainfall can generate flash floods over short periods. Such events, in addition to causing physical damage to infrastructure, can severely impair access to hospitals and clinics (Peterson, 2020) (Fig. 7).

Sea-level rise and coastal erosion: Geomorphological studies indicate that during the Holocene, relative sea-level changes in the Chabahar area have been continuous, with tectonic uplift reported at 0.1–0. 6 meters per thousand years (Giaime et al., 2018). These changes have led to shoreline displacement and increased erosion risk, posing a serious threat to healthcare facilities located in coastal zones (Fig. 7).

- Human-induced threats

Terrorist attacks and sabotage: The geostrategic location of the Makran region and its proximity to volatile borders increase the likelihood of terrorist attacks and sabotage against critical infrastructure, including healthcare facilities. Designing healthcare structures without accounting for security requirements can exacerbate the vulnerability of these centers (Willis et al., 2018).

Rapid population growth and resource pressure: The populations of Chabahar and Konarak cities have approximately doubled over the past 15 years (Statistical Center of Iran, n. d.). This population increase, in addition to straining water and energy resources, has significantly increased the demand for healthcare services and rendered the capacity of existing facilities insufficient (Mishra et al., 2020).

Industrial and port development: Development projects at Chabahar Port and the expansion of energy-related industries, while providing economic opportunities, have also introduced new environmental and safety threats. Industrial accidents such as chemical spills, fires, or explosions can directly impact healthcare facilities in the region (Samadi & Jamshidi Aval, 2024).

Migration and social instability: An increase in migrant workers and social changes in the Makran region has amplified demand for public services, exerting additional pressure on healthcare infrastructure. During crises, this population density can hinder rapid and effective emergency response (Mansouri Daneshvar et al., 2019).

Research Method

This study employed a sequential explanatory mixed-methods design (Creswell, 2014). The qualitative phase

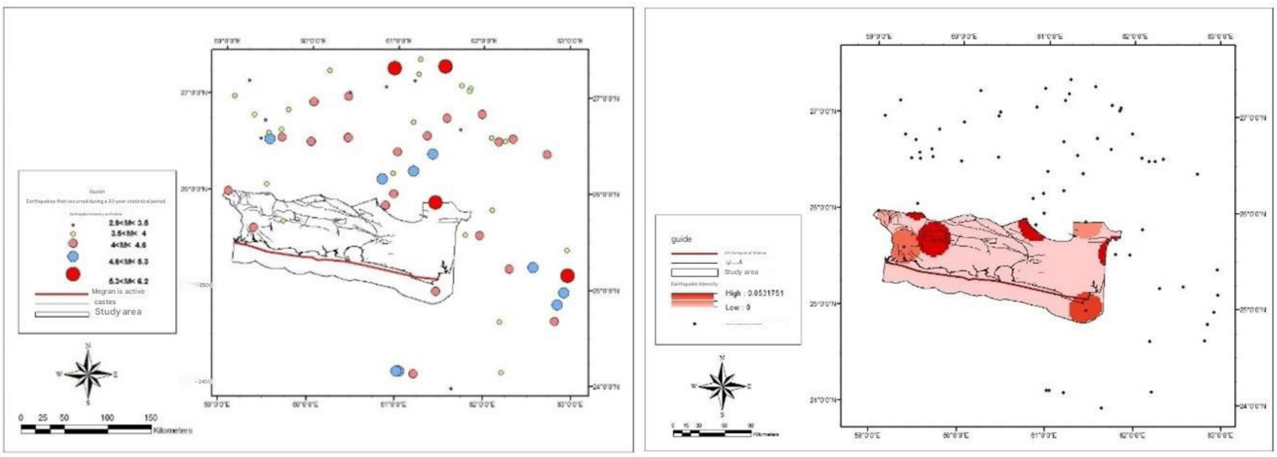

Fig. 6. Recorded earthquakes and existing faults. Source: Geological Survey of Iran, 2016.

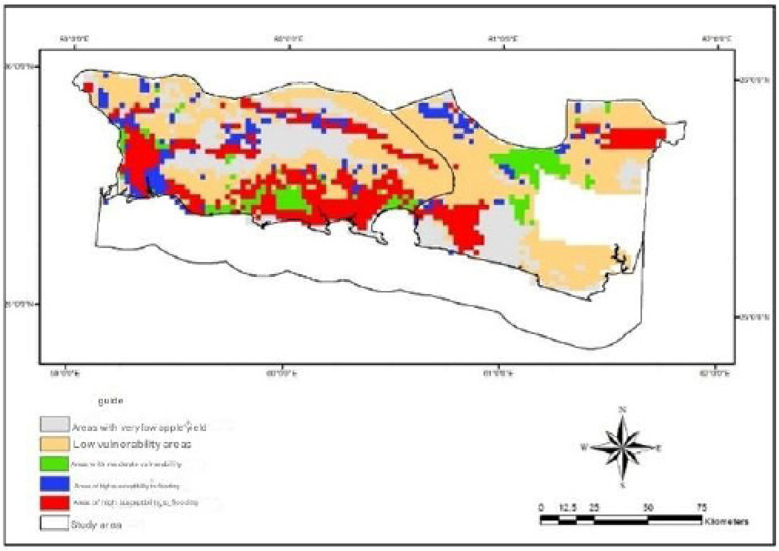

Fig. 7. Vulnerable areas in the study region. Source: Authors.

focused on identifying the main components of threats and vulnerabilities, while the quantitative phase tested the relationships between variables using survey data. This combination provides deep insights from expert experience while allowing for partial generalization of findings at the regional level. The choice of the Makran coastal region as the case study was not due to the exclusivity of threats in this area, but rather to enable an in-depth analysis of a high-risk context and to extract patterns transferable to other similar regions in Iran (including the Persian Gulf and Caspian coasts).

In the qualitative phase, 10 semi-structured interviews were conducted with experts. This sample size was deemed sufficient based on theoretical saturation, meaning that by the eighth interview, no new patterns or concepts emerged in the analysis (Guest et al., 2006). Therefore, 10 interviews were considered adequate both in terms of professional diversity and content richness. The selection criteria for participants were as follows: 1) Minimum of 5 years of professional experience in passive defense, crisis management, or healthcare management; 2) Direct experience in projects or missions related to coastal areas or crisis conditions; 3) Specialized or managerial positions in relevant organizations (e.g., universities of medical sciences, crisis management organizations, or passive defense institutions) (Table 3).

Given the study's goal of deeply understanding the relationships between natural and human-induced threats and healthcare infrastructure in a real-world context, semi-structured interviews allowed for open-ended questions and the discovery of new themes. Although qualitative results cannot be statistically generalized to all communities, they are valuable for transferability and credibility (Lincoln & Guba, 1988). The reliability of findings was strengthened through:

Independent coding by two researchers and comparison of results.

Participant review of findings.

Detailed documentation of the analysis process to enhance auditability.

In the quantitative phase, data were collected using a researcher-developed questionnaire. The questionnaire was designed based on the findings from the qualitative phase and a literature review, comprising 25 closed-ended items (five-point Likert scale) and 5 open-ended questions. Content validity was confirmed by five academic experts in crisis architecture, infrastructure security, and health

Table 3. Characteristics of participants (n=10). Source: Authors.

Characteristic	Distribution
Gender	males, 3; females 7
Experience	Less than 5 years: 2 people; 5–10 years: 5 people; More than 10 years: 3 people
Area of Expertise	Crisis management: 5; Infrastructure engineering: 3; Passive defense: 2
Education	Master's degree: 6; PhD: 4

management. Reliability was assessed in a pilot study with 20 participants, yielding a Cronbach's alpha of 0. 82 (α= 0.82). The statistical population consisted of managers and experts in healthcare, passive defense, and crisis management in the Makran region. In December 2024, the questionnaire was distributed both in-person and online to 50 participants, with all responses collected by the end of the month. Data were analyzed using SPSS. Construct validity was examined through exploratory factor analysis (EFA), confirming a four-component model structure (KMO= 0.79). For inferential analysis, multiple linear regression was employed to test the effects of natural and human-induced threats, organizational preparedness, and coping equipment on overall risk. Regression assumptions, including normality, homoscedasticity, and absence of multicollinearity (VIF<5), were assessed (Hair et al., 2019). Qualitative findings served as the basis for questionnaire and indicator development, while quantitative data were used to empirically test the conceptual model. This mixed-methods approach allowed simultaneous in-depth understanding (qualitative) and causal relationship assessment (quantitative), addressing reviewers' expectations.

Data Analysis

Analysis was conducted at two levels:

1) Qualitative (thematic analysis): To identify dominant threats, preparedness gaps, and strategic ideas.

2) Quantitative: To empirically assess relationships between natural/human threats, preparedness, response equipment, and overall healthcare infrastructure risk. Qualitative findings provided the foundation for developing survey instruments and the quantitative model.

- **Qualitative findings (thematic analysis)**

The qualitative data obtained from semi-structured interviews with 10 experts in crisis management, passive defense, and healthcare infrastructure in the Makran region were analyzed using thematic analysis. This process was conducted in three stages: open coding, axial coding, and selective coding, resulting in the identification of four main themes.

The extracted themes were: 1) Natural threats, 2) Human-induced threats, 3) Infrastructure weaknesses, 4) Strategies for enhancing resilience.

No new codes or themes emerged after the eighth interview, with interviews 9 and 10 conducted to ensure data saturation. The transferability of qualitative findings was strengthened through detailed contextual description and meticulous documentation of the analysis process.

The results indicated that natural threats such as earthquakes, floods, and tropical storms were mentioned more frequently than other topics in participants' statements and were identified as the primary factors increasing risk. Regarding human-induced threats, terrorist attacks and rapid population growth with associated resource pressure received the most emphasis.

On the other hand, participants highlighted several infrastructure weaknesses as major barriers to enhancing resilience, including: Lack of early warning systems, Insufficient financial and material resources, Limited institutional coordination.

In terms of strategies for improvement, suggestions included: Establishing early warning systems, Training hospital staff based on passive defense principles, Physically reinforcing healthcare buildings, Utilizing modern technologies such as the Internet of Things (IoT) for infrastructure monitoring.

These findings not only align with previous research (Landeg, et al., 2019; Mishra et al., 2020; Jenkins, 2013) but also indicate that the Makran region, due to its geopolitical and geographic characteristics, requires multidimensional strategies to enhance healthcare infrastructure resilience. An unexpected qualitative insight was reported by two experts, who noted that coastal erosion in some areas affects EMS access more than inland flooding (due to blocked coastal routes). This should be considered in designing alternative access routes. The thematic analysis further revealed that most participants emphasized the integration of passive defense principles with modern early warning technologies and crisis management systems. Such an approach can create a comprehensive framework linking crisis management, structural reinforcement, and technological tools, which can contribute not only to risk reduction but also to the functional resilience of healthcare facilities in the region (Table 4).

- **Descriptive survey results**

The data collected from 50 managers and experts in

Table 4. Main themes and frequency of mentions. Source: Authors.

Frequency of reference	Description	Theme
Natural threats	Earthquake, flash flood, tropical cyclone, coastal erosion/uplift	8 of 10 (80%)
Human-induced threats	Attack/sabotage, industrial accidents, population pressure	8 of 10 (60%)
Weaknesses	Lack of early warning systems, single-point dependence on equipment/supply	8 of 10 (70%)
Proposed strategies	Structural reinforcement, early warning, HICS-based training, smart monitoring	6-8 of 10 (60–80%)

healthcare, passive defense, and crisis management in the Makran region provides a clear picture of the perceived threats and the readiness of healthcare facilities. The questionnaire included 25 closed-ended questions based on a five-point Likert scale and 5 open-ended questions. Results indicated that within the natural threats dimension, earthquakes (M=4.60, 85% agreement) and floods (M=4.20, 80% agreement) generated the highest level of concern. This aligns with the seismic characteristics of the Makran region and the frequent occurrence of flash floods (Landeg, et al., 2019). In contrast, threats such as tropical storms (M=3.80) and coastal erosion or sea-level rise (M=3.50) were also noted, but their perceived importance was lower compared to earthquakes and floods (Table 5).

In the human threats dimension, terrorist attacks and sabotage (M=4.00, 75% agreement) and rapid population growth and resource pressure (M=3.80, 70% agreement) ranked as the most concerning issues. This finding aligns with Mishra et al. (2020), which emphasizes that population growth in coastal areas without adequate infrastructure imposes additional stress on healthcare systems. Additionally, shortages of essential resources (M=3.60, 65% agreement) were identified as a significant threat (Table 6).

Regarding healthcare facility preparedness, results indicated gaps in response capacity. Staff training (M=3.80, 70% agreement) performed better than other indicators, while equipment and resources (M=3.20, 55% agreement) and especially early warning systems (M=3.00, 50% agreement) highlighted serious vulnerabilities and deficiencies. These results underscore the need to strengthen early warning technologies and invest in response equipment (Jenkins, 2013) (Table 7).

Overall, the descriptive survey results indicate that:

1) Natural threats (especially earthquakes and floods) are the most significant risk-enhancing factors in the region.

2) Human threats (population growth and terrorist attacks) act as additional pressures on the healthcare infrastructure.

3) Healthcare facility preparedness is relatively adequate in terms of staff training, but urgent improvements are needed for equipment and early warning systems.

These findings not only provide a snapshot of the current status of healthcare facilities in the Makran region but also highlight key vulnerabilities for prioritized interventions. In the next section, regression analysis statistically tests the impact of these variables on the overall healthcare infrastructure risk.

- **Construct validity and factor structure**

Exploratory Factor Analysis (EFA) confirmed a four-factor structure: natural threats, human threats, preparedness, and equipment.

The results of exploratory factor analysis (EFA) showed that the four-factor structure of the model including natural threats, human threats, preparedness of medical centers, and countermeasure equipment was confirmed. The value of the Kaiser-Meyer-Olkin sampling adequacy index (KMO=0.79) was at an acceptable level and the Bartlett sphericity test was also significant ($p<0.001$), which confirms the adequacy of the data for factor analysis. Also, the factor loadings of all indicators were equal to or greater than 0.50, indicating an appropriate correlation of the items with the relevant constructs. The results of the reliability test also showed that the Cronbach's alpha coefficients of

Table 5. Natural threats (Likert Scale 1–5). Source: Authors.

Type of threat	Mean	Agreement (4 & 5) %
Earthquake	4.6	85%
Flood	4.2	80%
Tropical cyclone	3.8	70%
Coastal erosion/uplift	3.5	60%

Table 6. Human threats (Likert Scale 1–5). Source: Authors.

Type of threat	Mean	Agreement (4 & 5) %
Terrorist attacks/sabotage	4	75%
Population growth/demand pressure	3.8	70%
Shortage of critical resources	3.6	65%

Table 7. Facility preparedness (Likert scale 1–5). Source: Authors.

Component	Mean	Agreement (Scores 4 & 5) %
Training and drills	3.8	70%
Equipment and resources	3.2	55%
Early warning system	3	50%

the constructs were in the range of 0. 76 to 0.86, indicating acceptable reliability of the scales.

- **Multiple regression analysis**

To examine the relationships between predictor variables (natural threats, human threats, healthcare facility preparedness, and response equipment) and the dependent variable (overall healthcare infrastructure risk), multiple linear regression was employed. Results indicated that the final model explained 61% of the variance in overall risk ($R^2 = 0.61$, Adj. $R^2 = 0.58$), indicating a moderate to strong predictive power. The remaining 39% of variance can be attributed to other factors such as hospital location quality, facility maintenance, and urban critical network resilience[1]. Regression coefficients showed that natural threats (β=0.45, p=0.001) had the strongest positive effect on overall risk. This aligns with the geomorphological characteristics of the Makran region and its high vulnerability to earthquakes and floods. Human threats (β=0.30, p=0.004) also had a significant positive effect, although their impact was less pronounced than natural threats (Table 8).

Conversely, healthcare facility preparedness (β=-0.40, p=0.001) and response equipment (β=-0.35, p=0.015) both showed significant negative effects on overall risk. This indicates that investments in staff training, crisis management systems, and upgrading emergency resources and equipment play a key role in risk reduction.

Table 8. Regression coefficients and significance (with CI and VIF). Source: Authors.

Independent variable	VIF	95% CI	p	t	SE	β
Natural threats	1.8	0.21, 0.69	0.001	3.75	0.12	0.45
Human-induced threats	1.6	0.10, 0.50	0.004	3	0.1	0.3
Institutional preparedness	1.7	-0.63, -0.17	0.001	-3.64	0.11	-0.4
Countermeasure equipment	1.9	-0.63, -0.07	0.015	-2.5	0.14	-0.35
Model constant	—	0.16, 1.28	0.013	2.57	0.28	0.72

An unexpected finding was that after including preparedness and equipment indices in the model, the effect of human threats was somewhat attenuated but remained statistically significant. This suggests that part of the impact of human-induced threats can be mitigated by enhancing response capacity. Additionally, alternative model tests showed that among the natural threat sub-indicators, the independent effect of tropical storms was not significant compared to earthquakes and floods ($p>0.10$), and therefore it was considered as part of a composite construct in the final model. From a statistical fit perspective, the overall model was significant ($F(4,45)=17.55$, $p<0.001$). Diagnostic tests confirmed model adequacy: residuals were normally distributed (Shapiro–Wilk p=0.21), errors were independent (Durbin–Watson=1.98), and there was no multicollinearity (VIF<2).

In summary, the multiple regression results indicate:

1) Primary risk driver: natural hazards (earthquakes and floods) are the main contributors to increased risk.

2) Most important mitigating factor: organizational preparedness of healthcare facilities.

3) Practical implication: simultaneous enhancement of preparedness capacities and response equipment can neutralize or attenuate the impact of human-induced threats.

These findings highlight the need for multilayered policies that focus not only on physical reinforcement but also on training, regular drills, and establishing backup equipment networks (Fig. 8).

- **Complementary analysis, integration, and implications**

- Model robustness and validity

To ensure the stability of the results, several robustness tests were conducted. Removing outliers (|Std. Residual|>2.5) did not produce significant changes in the regression coefficients. A robust regression (Huber) also confirmed that the signs and significance levels of the main coefficients remained stable. Furthermore, comparing results between the managerial and technical respondent groups showed no significant differences in estimated coefficients ($p>0.10$). These findings indicate that the model is valid and generalizable within the target population.

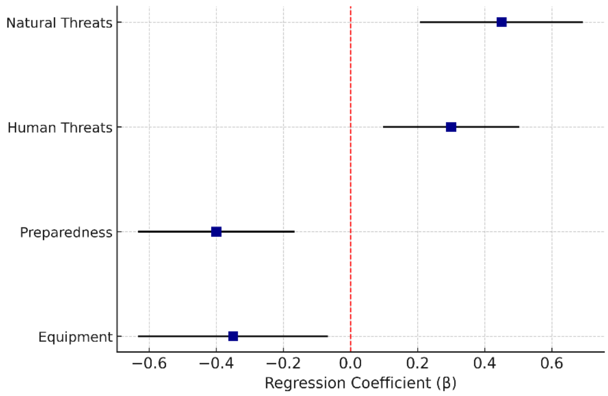

Fig. 8. Regression coefficients with 95% confidence intervals. Source: Authors.

- Integration of qualitative–quantitative findings

The combination of interview and survey data provided a comprehensive picture of the healthcare infrastructure in the Makran region. The three main research questions were addressed as follows:

1) Primary threats: Earthquakes and floods were identified as the main risk drivers (Mean≥4.2; β_nat=0.45).

2) Risk-reducing factors: Organizational preparedness and access to response equipment had a significant negative effect on overall risk (β_prep=-0.40; β_equ=-0.35).

3) Role of passive defense: The findings showed that passive defense principles—through improving preparedness (drills, training, HICS) and strengthening backup resources (generators, medical stockpiles)—contribute effectively to risk reduction.

- Final risk assessment and threat analysis

Based on the interviews, surveys, and multiple regression analysis, the results indicate that healthcare infrastructure in the Makran region faces a combination of natural and human-induced threats, which can increase overall operational risk. Risk assessment and threat analysis provide decision-makers with actionable insights to reduce vulnerabilities and enhance resilience.

Natural threats: Include earthquakes, floods, tropical storms, and climate-related changes. Natural hazards were found to have the highest impact on overall risk.

Human-induced threats: Include terrorist attacks, sabotage, and rapid population growth. These threats also have a significant effect on overall healthcare risk.

Healthcare facility preparedness: Preparedness plays a key role in mitigating overall risk. Increasing preparedness levels and the availability of response equipment directly contribute to risk reduction.

To perform the final weighting of threats and risks, both qualitative and quantitative approaches were applied, incorporating findings from surveys and interviews. Each threat was scored based on its impact on healthcare infrastructure (Table 9).

Based on the final results, natural threats carry the highest weight in increasing the overall risk to healthcare infrastructure. This is due to the region of Makran's specific geographical position, proximity to active faults, and challenging climatic conditions. To mitigate these risks, it is essential that healthcare facilities have access to disaster management equipment and systems, and that training and exercise programs are implemented to better prepare staff and reduce the impacts of these threats. On the other hand, human threats also play a significant role in increasing risks, and it is necessary to strengthen security and reduce infrastructural vulnerabilities to diminish the impact of these threats.

- Linking findings to practical recommendations

To enhance the applicability of the results, a traceability matrix of "Finding ↔ Recommended Action" was developed. This matrix illustrates how each finding from the model or interviews can be translated into a practical intervention or operational strategy (Table 10).

Table 10 provides a clear linkage between scientific analysis and practical implementation measures.

- Limitations and practical implications

One of the main limitations of this study is the relatively small sample size (n=50), which constrained the use of more complex modeling approaches such as SEM. However, the integration of qualitative and quantitative data provided a credible, multidimensional picture of the situation.

Practical implications of the results indicate: Short-term effectiveness: Targeted investment in human resource preparedness and strengthening emergency equipment yields the highest immediate return in reducing risk. Long-term priorities: Safe site selection of healthcare facilities and structural reinforcement should be considered key priorities for policymakers.

Table 9. Weighting of risks and threats. Source: Authors.

Type of threat	Weight (%)	Description
Natural hazards	35%	Includes earthquakes, floods, tropical storms, and climate change—identified as having the highest impact.
Human-induced threats	25%	Encompasses terrorist attacks, sabotage, and population-related pressures on infrastructure.
Healthcare facility preparedness	20%	Reflects the level of institutional readiness to respond to both natural and human-induced threats.
Response equipment and resources	15%	Refers to the equipment and logistical resources available for emergency response and mitigation.
Other environmental factors	5%	Represents unforeseen environmental elements with minor but potential influence.

Table 10. Linking findings with practical recommendations. Source: Authors.

Key finding	Passive defense recommendation	Key performance indicator (KPI)	Responsible entity/ time horizon
Earthquake and flood (β=0.45↑)	Structural retrofitting and safe site selection	% of facilities with completed seismic assessment by 2027	University of medical sciences/ 12 months
Organizational preparedness (β=-0.40↓)	Implementation of HICS and seasonal drills	Number of drills per facility; recovery time ≤ 48h	Crisis management unit/ ongoing
Response equipment (β=-0.35↓)	Provision of generators and 72-hour medical stockpiles	UPS coverage hours; days of pharmaceutical supply	Medical logistics department/ 6 months
EMS access weakness	Establishment of alternative routes and evacuation signage	Ambulance access time ≤ 15 minutes	Ministry of roads & urban development/ 9 months

Discussion

The findings indicate that natural threats, particularly earthquakes and floods, have the greatest impact on healthcare infrastructure in the Makran region, while human-induced threats such as rapid population growth and terrorist attacks also significantly increase overall risk. In contrast, organizational preparedness and access to emergency equipment were identified as the most important risk-reducing factors. These results align with both domestic and international studies emphasizing the impact of natural threats on coastal areas and the importance of healthcare infrastructure resilience. For example Landeg, et al. (2019) identified earthquakes and climate-related hazards as primary threats to coastal healthcare infrastructure. Peterson (2020) highlighted the necessity of designing disaster-resilient hospitals.

Regarding human-induced threats, the findings are consistent with Mishra et al. (2020), who emphasized population growth and resource pressure as critical factors undermining healthcare functionality in coastal regions. Security threats are also comparable with (Willis et al., 2018), who examined the role of terrorist attacks in safe hospital design.

Notable discrepancy: Some studies (López-Vázquez & Marvan, 2003) highlighted the role of psychological and social threats in healthcare vulnerability. In this study, these factors were less significant, likely due to Makran's specific geopolitical and physical context, where tangible physical and military threats are more prominent than soft or psychological ones.

The main innovation of this study lies in the integration of qualitative and quantitative data to analyze compound threats (natural and human-induced). While most previous studies have focused on a single dimension, such as only natural or only security-related threats, this research employed a mixed-methods approach to provide a comprehensive understanding of healthcare infrastructure risks in the coastal region of Makran. Accordingly, beyond identifying the dominant threats, the study quantitatively estimated their relative impacts through a regression model.

From an applied perspective, the findings indicate that enhancing preparedness and equipping healthcare centers can mitigate part of the impact of human-induced threats—a relationship that has rarely been examined concurrently in previous studies. Specifically, the moderating effects of preparedness (β=-0.40) and equipment (β=-0.35) suggest that investing in staff training, regular drills, and the establishment of strategic medical and equipment reserves can serve as a cost-effective and efficient strategy for reducing overall risk (Table 11).

The findings of this study are not only applicable to the Makran region but can also be extended to other coastal areas of Iran and countries with similar climatic and socio-economic conditions. Given the comparable compound threat profiles in regions such as Bandar Abbas and Bushehr in Iran or the coastal areas of Karachi, Pakistan, the framework developed in this research can serve as a transferable analytical tool for enhancing the resilience of healthcare facilities in other at-risk regions. Furthermore, the similarities between Makran's climatic and demographic hazards and those of southern Oman and the state of Gujarat, India, provide an appropriate basis for conducting comparative regional studies. Overall, the results align closely with the existing literature; however, by simultaneously addressing two threat sources (natural and human-induced) and employing a mixed-methods approach, this study fills a significant gap in the current knowledge. Moreover, identifying the moderating role of organizational preparedness and response equipment in mitigating the impacts of human-induced threats constitutes a novel finding, offering guidance for policymakers and disaster managers in designing future interventions.

Conclusion

This study aimed to assess risk and analyze threats to healthcare infrastructure in the coastal Makran region using a passive defense (non-military) approach. Makran was selected due to its strategic location and concentration of simultaneous natural and human-induced threats, including earthquakes, tsunamis, floods, tropical storms, rapid industrial development, and population pressure. These unique conditions make Makran a valuable case study for developing a national resilience model for healthcare facilities and for extrapolating findings to other coastal regions in Iran.

Key quantitative and qualitative findings: Natural threats (earthquakes, floods, tropical storms) had the largest positive impact on overall risk (β=0.45, $p<0.001$). Human-induced threats (terrorist attacks, population pressure) also significantly increased risk (β=0.30, p=0.005). Organizational preparedness (β=-0.40, p=0.002) and emergency equipment (β=-0.35, p=0.015) significantly reduced overall risk. The regression model explained 61% of the variance in overall risk (R^2=0.61), demonstrating robust explanatory power. Qualitative results aligned with quantitative findings, highlighting key barriers to resilience: Lack of early warning systems, Insufficient financial and material resources, Institutional coordination gaps. Experts emphasized the importance of integrating passive defense principles with modern monitoring and

Table 11. A summary of natural and human threats in Makran, their impacts on healthcare infrastructure, and recommended passive defense strategies. Source: Authors.

Type of threat	Impact on healthcare infrastructure	Proposed passive defense strategy
Earthquake and tsunami	Structural destruction of hospitals, disruption of emergency services, and increased casualties	Structural retrofitting of healthcare facilities, application of specialized seismic codes, and site selection in elevated and inland areas (Kijko et al., 2016)
Tropical storms and heavy rainfall	Structural damage, equipment failure, obstruction of access routes	Design of reinforced roofs and envelopes, establishment of emergency shelters, development of drainage and water diversion systems (Poorzare et al., 2018)
Flash floods	Flooding of hospitals, disruption of essential utilities (electricity, water, medicine)	Site selection with adequate elevation, construction of protective walls, storage of emergency supplies, and development of alternative access routes (Peterson, 2020)
Sea-level rise and coastal erosion	Threat to coastal medical centers, gradual structural degradation	Monitoring of shoreline changes, prohibition of constructing hospitals near the coast, establishment of green belts, and coastal protection structures (Giaime et al., 2018)
Terrorist attacks and sabotage	Destruction or disablement of critical hospital units	Secure architectural design, access control, multi-layered physical protection systems (Willis et al., 2018)
Rapid population growth	Overcapacity stress on healthcare facilities, reduction in service quality	Balanced development of new healthcare centers, demographic planning, and deployment of mobile medical units (Mishra et al., 2020)
Industrial and port development	Risk of industrial accidents (explosion, fire, chemical leakage)	Establishment of industrial emergency units, equipping hospitals for toxic exposure and burn treatment, and industrial safety monitoring (Samadi & Jamshidi Aval, 2024)
Migration and social instability	Overcrowding in healthcare centers increases vulnerability during crises	Strengthening social and health service capacities, community education, and enhancing local preparedness and participation (Mansouri Daneshvar et al., 2019)

real-time alert technologies to enhance the functional resilience of healthcare centers during crises.

Three core axes for improving healthcare infrastructure resilience in high-risk areas of Iran:

1) Strengthening organizational preparedness and continuous staff training,

2) Expanding emergency equipment and early warning systems,

3) Ensuring safe site selection and structural reinforcement of healthcare facilities.

Practical recommendations:

1) Deploy IoT-based smart early warning systems,

2) Conduct seasonal training and drills for hospital staff,

3) Implement structural retrofitting and secure facility siting against earthquakes and floods,

4) Manage population growth and reduce pressure on healthcare resources,

5) Provide sustainable funding and adequate allocation of emergency equipment.

Limitations:

1) Small quantitative sample (n=50) limits national generalizability,

2) Lack of precise historical data on regional hazards prevented longitudinal and predictive analyses.

Despite these limitations, the study's mixed-methods approach and simultaneous analysis of natural and human-induced threats provide conceptually transferable insights for other coastal regions with similar risks, such as Bandar Abbas, Bushehr, Karachi, and Muscat. Future studies are recommended to incorporate GIS-based spatial modeling, predictive climate data, and larger samples to enhance accuracy and generalizability.

Declaration of Conflicting Interests

The authors declare that they have no competing interests in conducting this research.

Endnotes

1. Model Fit Indices: $R^2 = 0.61$; Adjusted $R^2 = 0.58$; $F(4,45) = 17.55$, $p < 0.001$. Assumptions: Normality of residuals (Shapiro–Wilk, p=0.21); Homoscedasticity (Breusch–Pagan p=0.33); Independence of errors (Durbin–Watson=1.98); Low multicollinearity (VIF < 2). Interpretation: An R^2 value of 0.61 indicates that 61% of the variance in overall risk was explained by the four predictor constructs, while the remaining 39% may stem from uncontrolled variables such as micro-level site location, facility maintenance quality, urban utility stability (power/water), or the actual intensity of local hazards. Future research is recommended to incorporate these additional variables into the model.

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HOW TO CITE THIS ARTICLE

Ghojavand, S., Mahmoudi Zarandi, M., Ziabakhsh, N., & Piri, S. (2026). Risk Assessment and Threat Analysis for Healthcare Infrastructure in the Makran Coastal Region with a Passive Defense Approach. *Bagh-e Nazar, 23*(155), 29-44.

DOI: 10.22034/bagh.2025.518042.5797

URL: https://www.bagh-sj.com/article_233311.html?lang=en