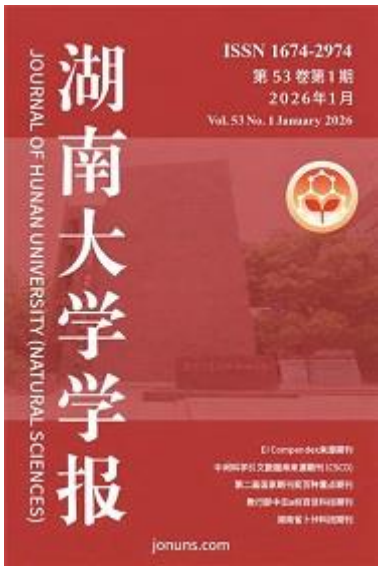

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Risk-Based Modeling Approach for Strengthening Hospital Preparedness Against CBRNE Threats to Enhance Public Health

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Abstract: Background: Indonesia's geographic position at the convergence of three major tectonic plates, its location along the Ring of Fire, tropical climate, and exposure to both natural and non-natural hazards demand robust and resilient disaster mitigation, response, and management capabilities.
Objectives: This study examines the current readiness of civilian and military hospitals in addressing CBRNE threats, analyzes regulatory fragmentation, and formulates evidence-based policy recommendations.
Methods: An exploratory mixed-methods design was employed using both primary and secondary data. Data were collected through interviews and structured questionnaires. Qualitative analysis was conducted with NVivo, while quantitative analysis employed SEM-PLS 4. The study was conducted in two hospitals—one civilian and one military - located in the Jakarta region.
Results: Qualitative findings reveal that CBRNE threats in Indonesia are real, recurrent, geographically dispersed, and primarily chemical, biological, radiological, and explosive in nature. These threats constitute a complex system, necessitating civil-military interoperability in management. The lack of permanent cooperation agreements represents a major barrier to effective mitigation, response, and management. Quantitative results show that hospital capacity, preparedness, and response capabilities significantly and negatively affect the effectiveness of CBRNE threat management, with a path coefficient of –0.622, T-statistics of 9.442, a p-value of 0.000, and an effect size (F^2) of 0.632. This negative relationship reflects empirical limitations in human resources, technology, and governance

that directly reduce response effectiveness.
Conclusion: Strengthening hospital preparedness requires integrated measures, including regulatory harmonization, permanent civil-military cooperation mechanisms, and improvements in human resources, technology, and governance.
Novelty: This study proposes a risk-based modeling framework that quantitatively integrates hospital capacity, emergency response readiness, and CBRNE hazard characteristics, providing a systematic approach to enhance hospital preparedness and public health resilience.

Keywords: CBRNE, Hospital Preparedness, Health Security, Indonesia, Civil-Military Interoperability.

基于风险的建模方法：增强医院应对化学、生物、放射、核与爆炸威胁的准备能力以提升公共卫生水平

摘要：背景：

尼地处三大主要板块交汇处，位于环太平洋火山带，气候为热带，并且面临自然与非自然灾害的威胁，这要求其具备强大且有弹性的灾害减缓、应对和管理能力。

目标：

本研究旨在评估民用和军用医院应对CBRNE威胁的现状，分析法规碎片化问题，并提出基于证据的政策建议。

方法：

本研究采用探索性混合方法设计，结合了原始数据和二手数据。数据通过访谈和结构化问卷收集。定性分析使用NVivo进行，定量分析采用SEM-PLS 4。研究在雅加达地区的两家医院进行——一家民用医院和一家军用医院。

结果：

定性结果显示，印尼的CBRNE威胁真实存在且反复发生，地理分布广泛，以化学、生物、放射和爆炸事件为主。这些威胁构成了一个复杂系统，需要民用与军用机构在管理中实现互操作性。缺乏长期合作协议是有效减缓、应对和管理的主要障碍。定量结果表明，医院能力、应急准备和响应能力对CBRNE威胁管理的有效性具有显著负向影响，其路径系数为–0.622，T统计量为9.442，p值为0.000，效应量（F^2）为0.632。此负向关系反映了人力资源、技术与治理方面的实际限制直接降低了响应效果。

结论：

提升医院应急准备能力需要综合措施，包括法规协调、建立长期民用与军用合作机制，以及在人力资源、技术和治理方面的改进。

创新点：

本研究提出了一种基于风险的建模框架，将医院能力、应急响应准备和CBRNE危险特性定量整合，为系统性增强医院准备能力和公共卫生韧性提供方法。

关键词：CBRNE、医院应急准备、健康安全、印尼、民用-军用互操作性

1. Introduction

Although CBRNE threats are widely recognized as strategic risks to public health security, a substantial gap persists between the expected level of hospital preparedness and actual practices on the ground[1], [2]. Hospital capacities remain limited, the implementation of theoretical preparedness frameworks is fragmented, and regulatory execution is not yet fully integrated with the national security system. Moreover, lessons learned from previous health crises have not been systematically institutionalized in a sustainable manner[3], [4], [5].

Indonesia is geographically located at the convergence of three major tectonic plates the Eurasian (Asian), Indo-Australian, and Pacific plates rendering the country highly vulnerable to earthquakes, tsunamis, and volcanic activity[6], [7], [8]. The southern and eastern regions of Indonesia lie along the volcanic belt known as the Ring of Fire, which significantly increases the risk of volcanic eruptions, earthquakes, landslides, and flooding[9]. In addition, Indonesia's tropical climate, characterized by distinct dry and rainy seasons, contributes to a high frequency of hydrometeorological disasters, as evidenced by the recent natural disasters in Sumatra[10], [11], [12], [12].

Beyond natural hazards, non-natural disasters such as Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) threats constitute multidimensional risks with direct implications for public health, social resilience, and national security. Exposure to CBRNE agents can result in high morbidity and mortality, long term health consequences, and environmental contamination that is difficult to remediate[13]. Effective management of such threats requires cross-sectoral coordination, resilient and technologically advanced health facilities, and integrated crisis management capabilities. High population density, persistent vulnerability to disasters, and the limited availability of specialized CBRNE referral hospitals further exacerbate risks to public health, social stability, and national security[14]. In this context, differences in functions, roles, and resources between civilian hospitals and TNI-affiliated hospitals become critical determinants of response effectiveness[8].

Hospitals play a strategic and fundamental role in responding to CBRNE threats, as they serve as the frontline of health services during mass-casualty incidents and extraordinary events. In the CBRNE context, hospitals are not limited to curative care but also function as centers for early detection, medical triage, decontamination, isolation, and specialized referral to prevent the escalation of health impacts[7]. Hospitals are responsible for ensuring the safety of patients, health workers, and the environment through strict infection control protocols, appropriate use of personal protective equipment, and safe management of hazardous and contaminated waste. Owing to these multidimensional functions, hospitals represent a key pillar in maintaining the resilience of the national health system against complex and high risk CBRNE threats[15].

At present, however, civilian hospitals and hospitals within the Ministry of Defense in Indonesia have not been fully positioned as the primary frontline in responding to CBRNE threats. This is reflected in uneven and suboptimal levels of capacity, preparedness, and response capability across regions. The implementation of early detection, triage, decontamination, isolation, and specialized referral functions remains constrained by limitations in infrastructure readiness, trained human resources, and adequate CBRNE-related technology. Furthermore, cross-sectoral collaboration in CBRNE management remains largely reactive and has yet to be integrated into a unified national system, thereby hindering the speed and effectiveness of response[16].

Civilian hospitals currently serve as the primary authority in managing CBRNE threats, as mandated by Law No. 17 of 2023 on National Health, in conjunction with Law No. 24 of 2007 on Disaster Management, Law No. 6 of 2018 on Health Quarantine, Law No. 10 of 1997 on Nuclear Energy, Law No. 5 of 2018 on the Eradication of Terrorism, and Law No. 32 of 2009 on Environmental Protection and Management. Within this framework, civilian hospitals hold the principal mandate for mitigation, response, and recovery from the health impacts of CBRNE threats. Conversely, Ministry of Defense-TNI hospitals provide defense health support through the function of Military Operations Other Than War (OMSP), as regulated under Law No. 3 of 2025 on the TNI, in conjunction with Law No. 3 of 2002 on National Defense and Ministry of Defense Regulation No. 32 of 2014. Nevertheless, effective collaboration between civilian and military hospitals remains constrained by differences in institutional roles and authorities, as well as the absence of permanent Cooperation Agreements as operational derivatives of these regulations. This condition has resulted in suboptimal integration of mitigation, response, and recovery efforts related to CBRNE threats in Indonesia[17].

Based on these conditions, the research gap lies in the absence of comprehensive and integrated studies that analyze the capacity, preparedness, and response capability of civilian hospitals and Ministry of Defense affiliated hospitals in addressing CBRNE threats in Indonesia. Previous studies have tended to examine disaster management or public health aspects in a fragmented manner, without simultaneously assessing legal mandates, infrastructure readiness, human resource competencies, technological support, and the effectiveness of civil-military collaboration within a unified operational framework. Moreover, empirical

assessments of the impact of regulatory fragmentation and the lack of permanent cooperation mechanisms on the effectiveness of CBRNE mitigation, response, and recovery remain limited, underscoring the need for this study as a scientific basis for strengthening CBRNE response governance in Indonesia[18].

Accordingly, this study aims to comprehensively and integratively analyze the capacity, preparedness, and response capability of civilian hospitals and Ministry of Defense affiliated hospitals in addressing CBRNE threats in Indonesia, by examining differences in legal mandates, infrastructure readiness, human resource competencies, technological support, and the effectiveness of civil-military collaboration. In addition, the study seeks to evaluate the implications of regulatory fragmentation and the absence of permanent cooperation mechanisms on the effectiveness of CBRNE mitigation, response, and recovery, in order to formulate more integrated and adaptive policy and governance recommendations to strengthen national CBRNE response resilience[19].

The novelty of this study lies in the application of a mixed-methods approach that simultaneously integrates qualitative and quantitative analyses to examine CBRNE threats as a unified and non-fragmented spectrum, while formulating a civil-military collaboration policy based on permanent Cooperation Agreements as an institutional and operational mechanism to address regulatory fragmentation, strengthen capacity and preparedness, enhance the effectiveness of national CBRNE response, and prevent reactive patterns of threat management[20].

2. Methods

2.1. Materials. Data Sources. Primary data were collected through in-depth interviews with 10 participants across two hospitals, focus group discussions with five CBRNE experts from the Defense Health and National Security Concentration at the Defense University, and direct field observations by the researcher. Secondary data were derived from a literature review and systematic screening of online mass media, supported by prior studies published in Scopus-indexed journals.

2.2. Methods. This study employed an exploratory mixed methods design to comprehensively examine hospital capacity, preparedness, and response capabilities in addressing CBRNE threats. The qualitative phase was conducted first to explore institutional capacity, governance arrangements, and patterns of civil-military collaboration through in-depth interviews, focus group discussions, and field observations. Findings from the qualitative phase informed the development of the quantitative research instrument. Subsequently, the quantitative phase utilized Structural Equation Modeling-Partial Least Squares (SEM-PLS 4) to empirically test the relationship between hospital capacity and the effectiveness of CBRNE threat management. Integration of qualitative and quantitative findings was carried out at the interpretation stage to ensure analytical convergence and to enhance the validity and robustness of the results(Open et al., 2021).

2.2.1.Study Sites and Period. The research was conducted at two hospitals: Fatmawati Hospital, South Jakarta, representing a Ministry of Health referral hospital, and the National Defense Central Hospital (RSPPN) Panglima Besar Soedirman, representing a defense/military hospital under the Ministry of Defense-TNI Health. The study was carried out from August to November 2025 in Jakarta.

2.2.2. Research Instruments. In the qualitative phase, eight medical professionals were selected purposively as key informants, with each in-depth interview lasting approximately 45 minutes. In the quantitative phase, a questionnaire was administered using purposive sampling to 100 respondents, comprising medical personnel, health workers, and administrative staff from both hospitals[23].

2.2.3. Data Analysis. Qualitative data were analyzed using NVivo 12 through thematic analysis, inter-theme relationship analysis, and thematic hierarchy mapping to identify patterns and dynamics in CBRNE response[24][25]. Quantitative analysis was conducted using Structural Equation Modeling-Partial Least Squares (SEM-PLS 4), including assessments of the outer model, inner model, and overall model fit[26][27].

2.2.4. Ethical Considerations and Data Validation. The study obtained ethical clearance and research authorization from the Defense University, as well as institutional approval from each participating hospital. Data validity was strengthened through source triangulation to enhance the credibility of the findings.

2.2.5. Proposition. Theoretically, civil-military collaboration based on permanent Cooperation Agreements, as operational derivatives of CBRNE-related regulations, is expected to enhance the capacity, preparedness, and response capability of civilian hospitals and Ministry of Defense-TNI Health hospitals in addressing CBRNE threats in Indonesia[28].

2.2.6. Data Validation. Source triangulation was employed[29].

2.2.7. Research Stages. The study commenced with an official research assignment from the Defense University, followed by the preparation and submission of research permits to the two target hospitals, the acquisition of institutional approvals, field data collection, data processing and analysis, presentation of findings to five CBRNE experts in Defense Health at the Defense University, discussion and refinement of results, and the preparation of a manuscript for publication of the research findings[30].

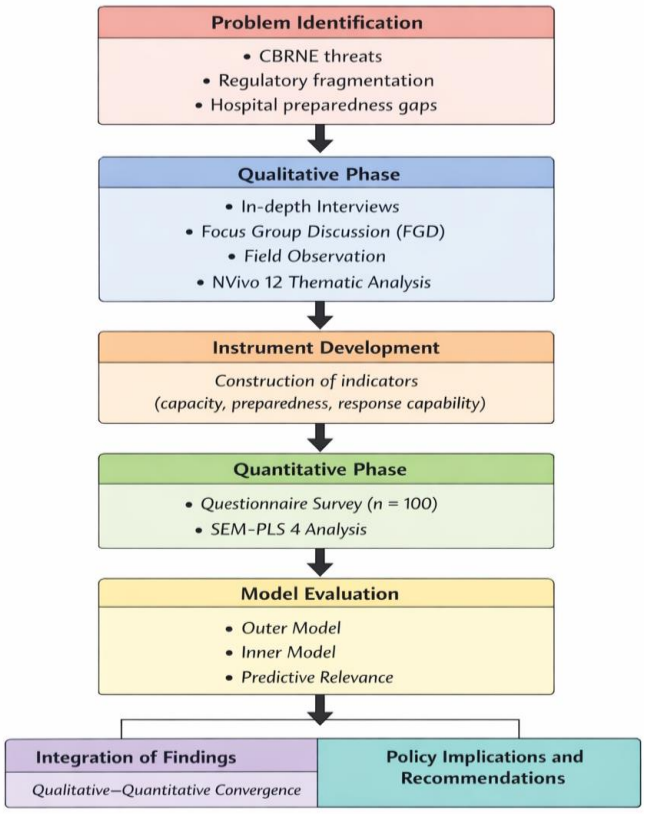

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Figure 1: Research Design and Analytical Framework

3. Results

3.1 Qualitative Results

3.1.1 Findings Based on Qualitative Analysis

Interview Excerpt from a Participant at the National Defense Central Hospital (RSPPN) Panglima Besar Soedirman:

> "Currently, the National Defense Central Hospital (RSPPN) Panglima Besar Soedirman does not yet have a dedicated decontamination facility, specialized personal protective equipment, or adequately trained personnel. Within the defense health system, the Indonesian National Armed Forces (TNI) possess Nuclear, Biological, and Chemical (NBC/Nubika) units within the Army, and the TNI demonstrated considerable experience and effectiveness in managing the COVID-19 pandemic. However, to the best of my knowledge, no hospital within the defense sector has been formally designated as a referral hospital for CBRNE threats, particularly hospitals located in regional areas"[31].

Interview Excerpt from a Participant at Fatmawati General Hospital:

> "Fatmawati General Hospital is indeed one of the three hospitals officially designated by the Indonesian Ministry of Health to handle CBRNE threats. The other two hospitals are the Infectious Disease Hospital (RSPI) Prof. Dr. Sulianti Saroso and Ali Sadikin Hospital. Fatmawati Hospital is equipped with a decontamination room and specialized personal protective equipment; however, it faces limitations in terms of trained personnel and critical technologies. These include the limited availability of multi-gas detectors, chemical agent monitors, ion mobility spectrometry, real-time PCR analyzers, bioaerosol detectors, Geiger Müller counters, gamma spectrometers, and personal dosimeters for early detection"[32], [33], [34].

> "For protection and decontamination, hospitals require comprehensive systems such as decontamination shower units, Level B-C hazmat suits, powered air-purifying respirators (PAPR), self-contained breathing apparatus (SCBA), HEPA filtration units, and radiation shielding equipment. From the perspective of medical and laboratory services, hospitals must be equipped with Class II/III biosafety cabinets, BSL-2 or BSL-3 laboratories, rapid CBRNE diagnostic tools, antidote kits such as atropine, pralidoxime, and cyanide kits, auto-injector antidotes, as well as ICU ventilators and extracorporeal membrane oxygenation (ECMO) systems"[35], [36].

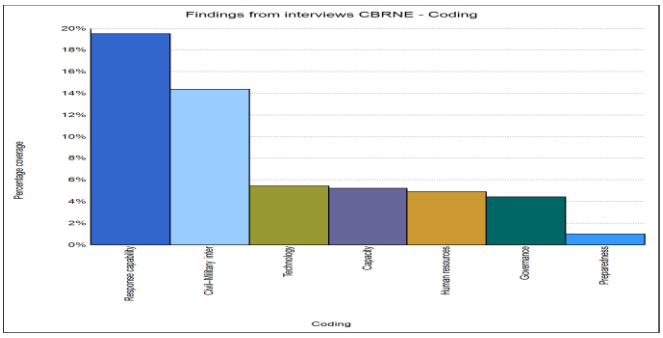
> "In addition, effective crisis management requires the establishment of a Hospital Incident Command System (HICS) and an Emergency Operations Center (EOC), integrated health information systems, GIS-based mapping systems, and secure communication platforms. From a security and training standpoint, hospitals also require X-ray scanners, explosive trace detectors, bomb-disposal robots, surveillance drones, and digital-based CBRNE simulation and training systems"[37].

3.1.2. Synthesis of Interview Findings, Field Observations, and Literature Review

Overall, the combined findings from interviews, field observations, and the literature indicate a significant disparity between policy designation and operational readiness in addressing CBRNE threats. While selected civilian hospitals have been formally appointed and partially equipped, substantial gaps persist in human resource capacity, advanced detection technology, integrated command systems, and intersectoral coordination. In contrast, defense sector hospitals remain institutionally underprepared, despite the existence of specialized military CBRNE units and prior operational experience in large scale health

emergencies. This condition underscores the urgent need for a nationally integrated CBRNE preparedness framework that aligns civilian and military health systems, strengthens infrastructure and workforce capacity, and ensures equitable readiness across both central and regional healthcare facilities[38].

3.1.2. Results of Interview, Observation, and Literature Review Analysis Using NVivo 12



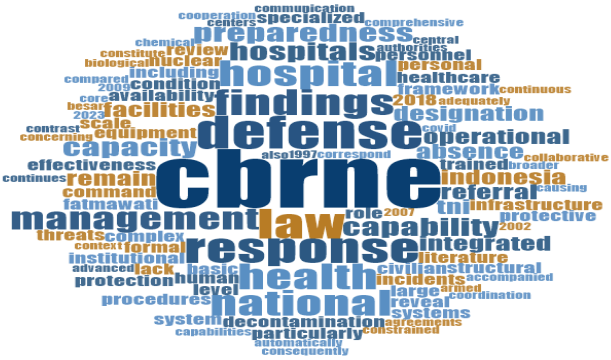
Data Source: Developed by the authors

Figure 2: Coding Coverage of Interview Themes (NVivo 12)

Figure 2 illustrates the percentage distribution of major thematic categories derived from the coding of interview data related to CBRNE response. The dominance of themes concerning response capability and civil-military interoperability indicates that participants primarily emphasized operational aspects during crisis situations, while preparedness and governance received comparatively less attention. This pattern reflects a discernible gap at the pre-crisis stage of CBRNE management[39].

Stakeholder orientation in addressing CBRNE threats remains largely reactive, with a predominant focus on response capacity and coordination once a crisis has already occurred. The relatively limited emphasis on preparedness and governance signifies structural weaknesses in the pre-crisis phase, particularly in strategic planning, system strengthening, and institutional arrangements that should serve as the foundation for prevention and mitigation. Such conditions suggest that Indonesia's CBRNE response system has not yet fully adopted a long term risk management perspective, thereby increasing systemic vulnerability when confronted with complex and large scale CBRNE incidents[40].

The implications of these findings underscore the necessity for a paradigm shift in CBRNE management, moving from a predominantly reactive approach toward the systematic strengthening of pre-crisis preparedness and governance. A planned, integrated, and sustainable framework is essential to reduce the vulnerability of the national response system and to enhance resilience against complex and large scale CBRNE incidents[41].



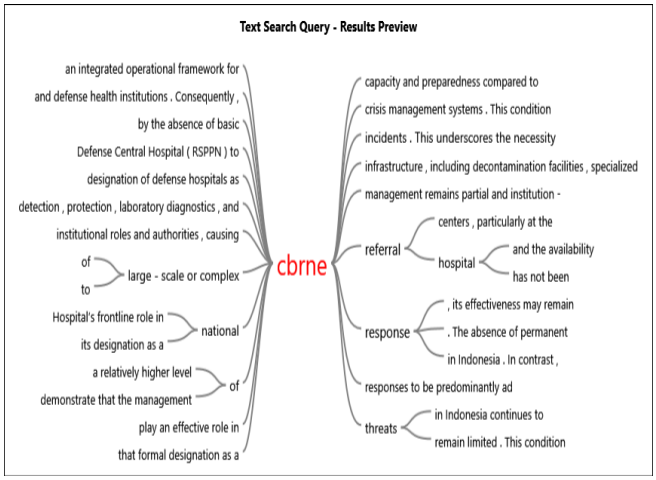
Data Source: Developed by the authors

Figure 3: Word Cloud Analysis of CBRNE Interview Data

Figure 3 presents a visualization of the most frequently occurring words in the interview data. The most prominent and dominant themes revolve around "CBRNE," "defense," and "hospital," indicating that the primary focus of the study lies in hospital responses within the defense context to CBRNE threats. Other key themes that emerge strongly include "capacity," "preparedness," and "response," which represent the three main dimensions of hospital preparedness analysis[42].

In addition, supporting themes such as "management," "governance," "law," and "designation" emphasize the importance of regulatory frameworks, governance structures, and institutional designation in responding to CBRNE threats. Operational aspects are also highly evident through the frequent appearance of themes such as "facilities," "infrastructure," "trained personnel," and "decontamination," reflecting the interconnection between physical readiness, technological capability, and human resources[38].

Overall, the dominance of these themes indicates that CBRNE is understood as a complex health defense issue that is highly dependent on the integration of institutional capacity, system preparedness, and hospitals operational response capabilities. The implications for strengthening CBRNE response should therefore be directed toward the development of hospital systems that are institutionally, operationally, and regulatorily integrated, by balancing the enhancement of technical capacity, pre-crisis preparedness, and civil-military collaborative governance, so that responses move beyond a reactive approach toward a long-term risk management orientation[20].



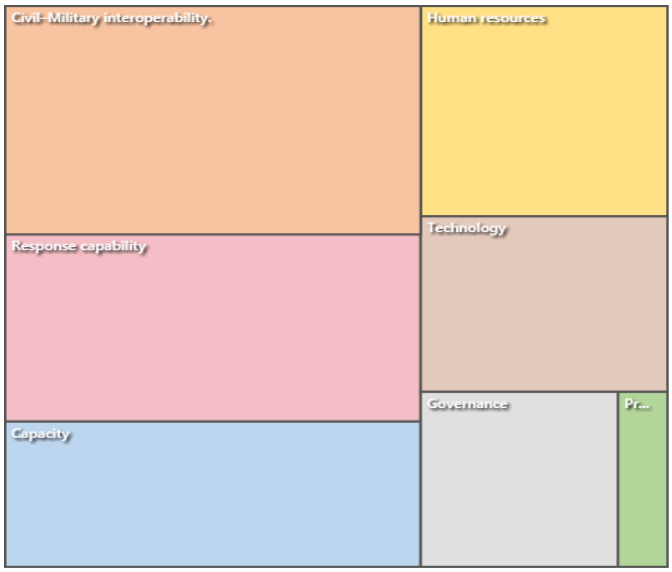
Data Source: Developed by the authors

Figure 4. Tex Search Query-Result NVivo 12

The thematic relationship map shows that "CBRNE" functions as the central node linking various institutional, operational, and policy dimensions within the defense health response. The theme of "capacity and preparedness" is directly associated with the availability of basic infrastructure, such as decontamination facilities, diagnostic laboratories, and crisis management centers, which determine the effectiveness of "hospital response" to large-scale or complex CBRNE incidents[43]. The absence of formal designation of defense hospitals as referral hospitals, along with the lack of an integrated operational framework, weakens the clarity of institutional roles and authority, resulting in responses that tend to be partial and ad hoc. This relationship is further reinforced by the themes of "governance" and "referral system," indicating that without permanent cooperation agreements and institutionalized coordination mechanisms, national response capacity to CBRNE threats will remain limited[44].

CBRNE threats thus serve as a unifying issue that demands cross-dimensional integration across institutional, operational, and policy frameworks within defense health. The close linkage between capacity and preparedness and the effectiveness of hospital response indicates that hospital readiness is largely determined by the availability of critical infrastructure and robust crisis management systems, particularly in addressing large-scale or complex CBRNE incidents. The lack of formal designation of defense hospitals as referral centers, combined with the absence of an integrated operational framework, reflects weak governance and fragmented authority, which in turn leads to uncoordinated and ad hoc responses. The themes of governance and referral system play a central role as structural connectors that determine the extent to which capacity and preparedness can be transformed into effective national response capabilities. Without clear institutionalization of cooperation and coordination, CBRNE response resilience will remain constrained[45].

Therefore, the strengthening of the national CBRNE response requires the institutionalization of governance arrangements through the formal designation of referral hospitals, the development of an integrated operational framework, and the establishment of permanent cooperation agreements. These measures are essential to ensure that hospital capacity and preparedness can be effectively converted into coordinated and sustainable response capabilities[46].



Data Source: Developed by the authors

Figure 5. Tree Map/Code Co-occurrence Analysis

Figure 5 illustrates the distribution and relative weighting of the main themes derived from the qualitative analysis. The themes of "civil-military interoperability" and "response capability" appear as the most dominant, underscoring that the effectiveness of CBRNE response is strongly influenced by the level of integration and coordination between civilian and military institutions, as well as by operational capacity in managing crises[47]. The themes of "human resources" and "technology" emerge as determining factors that either strengthen or constrain capacity and preparedness, particularly in relation to the availability of trained personnel and specialized CBRNE technological support. Meanwhile, the themes of "capacity" and "governance" reflect the structural and institutional dimensions that form the foundation of response sustainability, including policy frameworks, governance arrangements, and infrastructure availability. Overall, this visualization indicates that CBRNE response constitutes a complex system that is highly dependent on the interlinkages among civil–military interoperability, response capability, human resources, technology, and an integrated governance framework[48].

CBRNE response represents a complex and interdependent system across multiple key dimensions. The dominance of civil-military interoperability and response capability highlights that the effectiveness of CBRNE crisis management is largely determined by cross-sectoral integration and coordination, as well as by operational readiness during incidents. This finding reinforces the argument that hospital technical capacity alone cannot function optimally without clear and effective civil-military cooperation mechanisms. Furthermore, the emergence of human resources and technology as critical determinants indicates that limitations in trained health personnel and specialized CBRNE technologies constitute major barriers that directly weaken preparedness and response capacity. In addition, capacity and governance function as structural foundations that determine system sustainability, as without adequate policies, governance mechanisms, and infrastructure, integration and response capabilities cannot be maintained consistently[49].

The implications suggest that strengthening CBRNE response must be pursued through a holistic approach, encompassing the institutionalization of civil-military interoperability, the enhancement of human resource competencies and specialized technologies, and the reinforcement of governance and structural capacity. Such an approach is essential to ensure that hospital response capabilities operate effectively and sustainably in the face of CBRNE crises[50].

3.1.3. Findings from Online Mass Media Sources

Table 1. List of CBRNE Incidents in Indonesia

Threat Type	Incident	Year
Chemical	Ammonia leak at PIM Aceh, Ltd	2016
Radiological	Reactors (Bandung, Yogyakarta, Serpong) Cesium-137	2000
Chemical	Ammonia leak at KFI Cilegon, Ltd	2020
Chemical	Ammonia leak in Gresik	2022
Chemical	Pertamina Plumpang Depot explosion	2023
Biological	Anthrax outbreak in Kulon Progo-Yogyakarta	2019
Biological	Covid-19	2019-2022
Biological	Anthrax outbreak in Gunungkidul	2023
Biological	Anthrax cases in Papua	2022
Radiological	Cesium-137 exposure in Batan Indah Housing	2020
Radiological	Cikande Shrimp Case, Tangerang Banten	2025
Radiological	Clove Case, Lampung Selatan-Sumatra	2025
Radiological	Radioactive material found in Lampung	2018
Radiological	Loss of industrial radiography sources	2016-2022
Nuclear	Anomalies at BATAN nuclear research facility	2014-2020
Explosive	Tangerang fireworks factory explosion	2017
Explosive	Cimahi ammunition warehouse explosion	2023
Explosive	Series of terrorism related explosions in Indonesia	2016-2021
Explosive	Molotov bomb incidents in Indonesia	2025

Data Source: Developed by the authors

Table 1 demonstrates that CBRNE incidents in Indonesia are tangible, recurrent, and cross-sectoral in nature, with threat patterns predominantly characterized by chemical, biological, radiological, and explosive events occurring over extended periods and dispersed across diverse geographical regions. Incidents such as ammonia leaks, anthrax outbreaks, the COVID-19 pandemic, exposure to and loss of radioactive sources, as well as explosions at industrial facilities and ammunition depots, affirm that CBRNE threats are not hypothetical. Rather, they have occurred and continue to manifest within the contexts of industrial activity, public health, nuclear research, and national security. The persistence and diversity of these incidents indicate a high level of national vulnerability to non-conventional risks, while simultaneously highlighting the close interconnection between industrial safety, environmental health, and public security[51].

From a scientific perspective, these findings reinforce the argument that CBRNE preparedness must be positioned as a strategic priority within both health and defense domains. This necessitates the strengthening of early detection capabilities, the development of integrated medical response systems, and the establishment of sustained cross-sectoral coordination across all regions of Indonesia[52].

The implications of these quantitative findings suggest that Indonesia requires a

nationally coordinated, continuous, and cross-sectoral approach to CBRNE preparedness. Such an approach should focus on enhancing early warning and detection capacity, integrated medical response mechanisms, and institutionalized health defense coordination in order to mitigate the health, environmental, and security risks posed by recurrent and geographically dispersed CBRNE incidents[53].

Table 2. Indikator Variabel X -Capacity Preparedness and Response Capability of Hospitals

Indicator	X1- Infrastructure Readiness X2- Human Resource Competence X3- Technological Capability and Operational Procedures and SOPs X4-Training and Simulation Preparedness

Data Source: Developed by the authors

Table 2 conceptualizes Variable X (Hospital Capacity, Preparedness, and Response Capability) as a construct formed by four interrelated core indicators. Infrastructure readiness (X1) reflects the availability of physical facilities that support

CBRNE response; human resource competence (X2) represents the skills and expertise of healthcare personnel; technological capability together with operational procedures and standard operating procedures (X3) indicates the extent of technological support and the application of standardized work processes; while preparedness through training and simulation (X4) captures the level of hospitals' operational readiness in responding to emergency situations. Collectively, these four indicators determine the overall level of hospital preparedness and the effectiveness of response to CBRNE threats[54].

Enhancing the effectiveness of hospital responses to CBRNE threats can only be achieved when capacity strengthening is conducted simultaneously across infrastructure, human resource competence, technological and SOP support, and preparedness through continuous training and simulation. Deficiencies in any single indicator will undermine the overall readiness and resilience of the hospital response system[55].

Table 3. Indikator Variabel Y-Effectiveness of CBRNE Threat Management in Indonesia

Indicator	Y1-Response Timeliness,Coordination and Interoperability, and Casualty and Exposure Control. Y2-Service Continuity and System Resilience, Compliance with Safety and Regulatory Standards.

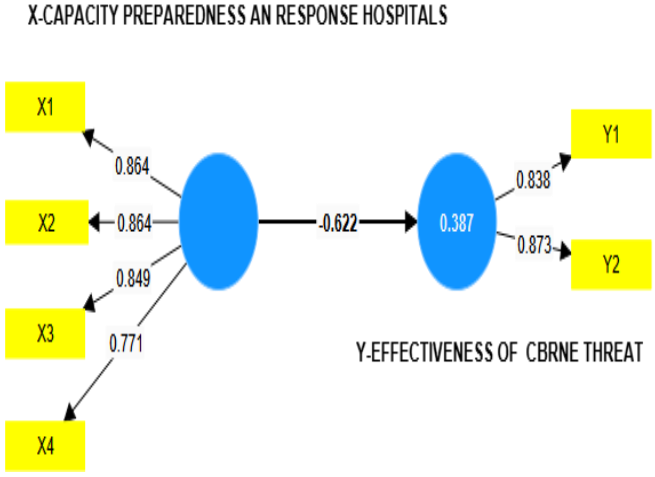
Data Source: Developed by the authors

Table 3 describes Variable Y (Effectiveness of CBRNE Threat Management in Indonesia), which is measured through two principal indicators. Timeliness of response, coordination and interoperability, and the control of casualties and exposure (Y1) reflect the system's capacity to respond to CBRNE incidents in a rapid, coordinated, and effective manner in order to minimize health impacts. Meanwhile, service continuity and system resilience, along with compliance with safety standards and regulatory requirements (Y2), illustrate the ability of the health and defense systems to maintain operations in a sustained and safe manner in accordance with established regulations. Together, these two indicators represent the overall level of effectiveness in national CBRNE threat management[56].

The effectiveness of CBRNE threat management in Indonesia is therefore strongly determined by the system's capacity to deliver timely and coordinated responses while simultaneously ensuring service continuity and adherence to safety standards. Accordingly, the strengthening of operational response capabilities must proceed in parallel with efforts to enhance system resilience and regulatory governance[57].

3.2 Quantitative Results

3.2.1.Outer Model



Data Source: Developed by the authors

Figure 6. Outer Loading Sem Pls-4

The figure represents a SEM-PLS structural model that explains the relationship between Variable X (Capacity, Preparedness, and Response Capability of Hospitals) and Variable Y (Effectiveness of CBRNE Threat Management in Indonesia), along with their respective indicators[58]. From the measurement model (outer model), the outer loading values for indicators X1-X4 (approximately 0.77-0.86) and Y1-Y2 (approximately 0.84-0.87) indicate that all indicators demonstrate strong convergent validity, as their values exceed the recommended threshold of 0.70. This confirms that each indicator consistently and reliably reflects its corresponding latent construct[59].

Within the structural model (inner model), the path coefficient from Variable X to Variable Y is –0.622, indicating a statistically significant but negative relationship. Substantively, this finding suggests that lower levels of hospital capacity, preparedness, and response capability are associated with reduced effectiveness in managing CBRNE threats. This relationship highlights the presence of structural and operational unpreparedness that exerts a systemic impact on national CBRNE management effectiveness. The R^2 value of 0.387 for Variable Y indicates that approximately 38.7% of the variance in the effectiveness of CBRNE threat management can be explained by hospital capacity, preparedness, and response capability, while the remaining variance is influenced by other factors not captured within the model[60]. The implications of these findings indicate that improving the effectiveness of CBRNE threat management in Indonesia requires systematic strengthening of hospital capacity, preparedness, and response capability as key explanatory factors. At the same time, it underscores the necessity of integrating additional determinants beyond the hospital sector into national policies and governance frameworks in order to mitigate the systemic consequences of structural unpreparedness[61].

Table 4. Construct Validity and Reability

Variable	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)
X-capacity preparedness an response hospitals	0.858	0.860	0.904	0.702
Y-effectiveness of cbrne threat	0.635	0.640	0.845	0.732

Data Source: Developed by the authors

Table 4 indicates that the research constructs have met acceptable criteria for validity and reliability. The Cronbach's alpha and composite reliability values (rho_a and rho_c) for Variable X exceed the minimum threshold of 0.70, demonstrating strong internal consistency, while Variable Y attains a level of reliability that remains acceptable for exploratory research. In addition, the Average Variance Extracted (AVE) values for both variables exceed 0.50, confirming adequate convergent validity and indicating that the indicators are able to represent their respective latent constructs in a robust and reliable manner[62].

The implications of these results indicate that the research instrument demonstrates both methodological robustness and empirical reliability in capturing the multidimensional nature of hospital capacity, preparedness, and response capability, as well as the effectiveness of CBRNE threat management. The satisfactory levels of validity and reliability confirm that the selected indicators accurately reflect the underlying constructs and are suitable for analyzing complex, high-risk health security contexts. Consequently, the structural relationships identified in the model can be interpreted with a high degree of confidence, as they are grounded in consistent and stable measurements. This provides a solid empirical basis for drawing meaningful conclusions regarding systemic strengths and weaknesses in hospital preparedness. Moreover, the credibility of the analytical framework supports its use as a reference for policy formulation, enabling decision-makers to design targeted, evidence-based interventions aimed at strengthening institutional capacity, improving intersectoral coordination, and enhancing national resilience against CBRNE threats[63].

Table 5. Discriminat Validity-HTMT

Variable	X-capacity preparedness an response hospitals	Y-effectiveness of CBRNE threat
X-capacity preparedness an response hospitals		
Y-effectiveness of cbrne threat	0.831	

Data Source: Developed by the authors

Table 5 demonstrates that discriminant validity between the constructs has been satisfactorily established, as indicated by the Heterotrait-Monotrait Ratio (HTMT) value of 0.831, which remains below the recommended threshold of 0.90. This finding confirms that Variable X (Capacity, Preparedness, and Response Capability of Hospitals) and Variable Y (Effectiveness of CBRNE Threat Management) are conceptually distinct constructs, while still maintaining an adequate level of association within the research model. Accordingly, each construct measures a different conceptual domain without evidence of measurement overlap[64]. The research model therefore exhibits strong conceptual clarity, as each construct is measured in a specific and non-overlapping manner. This ensures that the causal relationship between hospital capacity and the effectiveness of CBRNE threat management can be interpreted with greater accuracy and validity[65].

Tabel 6. Discriminat Validity-Fornell Lacrker-Criterion

Variable	X-Capacity preparedness an response hospitals	Y-Effectiveness of cbrne threat
X-capacity preparedness an response hospitals	0.838	
Y-effectiveness of cbrne threat	-0.622	0.856

Data Source: Developed by the authors

Table 6 indicates that discriminant validity based on the Fornell-Larcker criterion has been adequately established. The square root values of the Average Variance Extracted (AVE) for each construct (0.838 for Variable X and 0.856 for Variable Y) are higher than the inter-construct correlation (–0.622). This confirms that each construct explains its own indicators more strongly than it explains other constructs, thereby demonstrating that Variable X and Variable Y are conceptually and empirically distinct within the research model[66].

Accordingly, the measurement model exhibits strong conceptual and empirical precision, enabling the relationship between hospital capacity and the effectiveness of CBRNE threat management to be examined without bias arising from construct overlap[67].

3.2.2. Inner Model

Table 7. Hypothesis Testing Results

Variable	Original sample (O)	Sample mean (M)	Standard deviation (STDEV)	T -Statistics (|O/STDEV|)	P values
X-capacity preparedness an response hospitals -> Y-effectiveness of cbrne threat	-0.622	-0.631	0.066	9.442	0.000

Data Source: Developed by the authors

Table 7 presents the hypothesis testing results, confirming that hospital capacity, preparedness, and response capability have a significant effect on the effectiveness of CBRNE threat management in Indonesia. The path coefficient of –0.622, with a T-statistic of 9.442 and a p-value of 0.000 (< 0.05),

indicates that the relationship is statistically significant; therefore, the research hypothesis is accepted[68].

The negative direction of the relationship signifies that empirically low levels of hospital capacity, preparedness, and response capability are directly associated with lower effectiveness in managing CBRNE threats in Indonesia. This finding points to structural and operational weaknesses within the health and defense systems, particularly in relation to the limited availability of CBRNE-specific infrastructure, insufficient human resource competence, inadequate technological support, and the absence of institutionalized cross-sector coordination mechanisms. From an analytical perspective, when hospitals are not systemically prepared, responses to CBRNE incidents tend to be delayed, fragmented, and poorly coordinated, thereby increasing the risks of exposure, casualties, and disruptions to the continuity of healthcare services. Accordingly, the negative relationship reflects the urgent need to strengthen hospital capacity as a fundamental prerequisite for improving national CBRNE management effectiveness[69].

These findings underscore that improvements in the effectiveness of CBRNE management are highly dependent on the systematic and integrated strengthening of hospital capacity. This includes the development of dedicated CBRNE infrastructure, enhancement of human resource competencies, utilization of CBRNE detection and response technologies, and reinforcement of governance arrangements and cross-sector interoperability, enabling hospitals to respond to CBRNE threats in a rapid, coordinated, and sustainable manner[70].

The policy implications of this study indicate that strengthening hospital capacity, preparedness, and response capability must be positioned as a strategic priority within national CBRNE policy frameworks, as deficiencies in these areas have been shown to directly undermine response effectiveness. From a policy standpoint, the findings call for targeted investment in CBRNE-specific infrastructure, the development of a trained and specialized workforce, the adoption of detection and response technologies, and the establishment of institutionalized coordination and interoperability mechanisms across sectors. Without such systemic strengthening, CBRNE responses are likely to remain slow and fragmented, thereby exacerbating public health risks, disrupting healthcare services, and generating broader national security implications[71].

Table 8. R-square

Variable	R-Square	R-Square adjusted
Y-effectiveness of cbrne threat	0.387	0.381

Data Source: Developed by the authors

Table 8 indicates that the R-square value is 0.387 and the adjusted R-square is 0.381, meaning that 38.7% of the variance in the effectiveness of CBRNE threat management can be explained by hospital capacity, preparedness, and response capability within the proposed research model. This value reflects a moderate explanatory power, empirically confirming that hospital capacity plays a significant role, while also indicating the presence of other influential factors beyond the model, such as national governance structures, cross-sectoral policies, and institutional interoperability, which also affect the effectiveness of CBRNE threat management in Indonesia[72]. Accordingly, improving the effectiveness of CBRNE threat management requires not only the strengthening of hospital capacity but also the integration of external determinants, including national governance, cross-sector policy alignment, and institutional interoperability. Such integration is essential to ensure that CBRNE responses are implemented in a more comprehensive, coordinated, and effective manner[73].

Table 9. F-square

Variable	Y-Capacity preparedness an response hospitals	Y-Effectiveness of CBRNE threat
X-Capacity preparedness an response hospitals		0.632
Y-Effectiveness of cbrne threat		

Data Source: Developed by the authors

Table 9 shows an F-square value of 0.632, indicating that Variable X (Capacity, Preparedness, and Response Capability of Hospitals) exerts a strong influence (large effect size) on Variable Y (Effectiveness of CBRNE Threat Management). This value confirms that the contribution of hospital capacity to the effectiveness of CBRNE threat management is both substantively meaningful and practically significant. Accordingly, strengthening hospital capacity, preparedness, and response capability constitutes a key determinant in improving the overall effectiveness of CBRNE

management in Indonesia[74]. The strengthening of hospital capacity, preparedness, and response capability should therefore be prioritized as a central policy strategy, given that this factor has been empirically demonstrated to exert a substantial and decisive practical impact on the effectiveness of CBRNE threat management in Indonesia[75].

3.2.3.Model FIT

Table10. Model Fit

Model	Saturated model	Estimated model
SRMR	0.116	0.116

Data Source: Developed by the authors

Table 10 presents the results of the model fit assessment using the Standardized Root Mean Square Residual (SRMR) indicator. The SRMR value of 0.116 for both the saturated model and the estimated model indicates that the model demonstrates an acceptable level of fit for exploratory research, although it does not yet reach the category of a very good fit. This finding suggests that the structural relationships among variables are able to represent the empirical data in a reasonably adequate manner, while also indicating the presence of room for further model refinement through the inclusion of additional relevant variables to enhance overall model fit[76].

Accordingly, the research model is appropriate for use as an initial analytical framework. However, further model development by incorporating other strategic variables such as cross-sectoral governance and institutional interoperability is necessary to improve the precision and explanatory strength of future CBRNE studies[77].

Table 11. MV Prediction Summary-Overview

Variable	Q^2predict	PLS-SEM_RMSE	PLS-SEM_MAE	LM_RMSE	LM_MAE
Y1	0.228	0.424	0.347	0.423	0.338
Y2	0.298	0.412	0.339	0.377	0.286

Data Source: Developed by the authors

Table 9 presents the results of the evaluation of the model's predictive capability (MV Prediction Summary). The positive Q^2predict values for indicators Y1 (0.228) and Y2 (0.298) confirm that the model demonstrates adequate predictive relevance with respect to the effectiveness of CBRNE threat management. Furthermore, the comparison of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) between the PLS-SEM model and the Linear Model (LM) indicates that the prediction errors generated by PLS-SEM are relatively comparable and, for several indicators, superior to those of the linear model. These findings suggest that the proposed model possesses sufficient predictive accuracy, thereby affirming the relevance of hospital capacity, preparedness, and response capability constructs in predicting the effectiveness of CBRNE threat management in Indonesia[78].

Overall, the model is not only robust in its explanatory power but also demonstrates satisfactory predictive capability. Consequently, hospital capacity, preparedness, and response capability may be regarded as reliable determinants for forecasting and designing policy interventions aimed at enhancing the effectiveness of CBRNE threat management in Indonesia[79].

Table 12. CPAT-PLS SEM vs. Indicator Average (A1)

Y-Variable	PLS loss	IA loss	Average loss difference	t value	p value
Y-effectiveness of CBRNE threat	0.175	0.237	-0.063	3.450	0.001
overall	0.175	0.237	-0.063	3.450	0.001

Data Source: Developed by the authors

Table 12 presents the results of the Comparative Predictive Ability Test (CPAT), which compares the predictive performance of the PLS-SEM model with the Indicator Average (IA) approach in explaining the effectiveness of CBRNE threat management. The lower PLS loss value (0.175) compared to the IA loss (0.237), with a mean loss difference of –0.063, demonstrates the superior predictive performance of the PLS-SEM model. The statistical test results, indicated by a t-value of 3.450 and a p-value of 0.001 (< 0.05), confirm that this difference is statistically significant. These findings indicate that the developed PLS-SEM model predicts the effectiveness of CBRNE threat management more accurately than the indicator-average approach, thereby strengthening the model's

validity and practical utility in explaining the relationship between hospital capacity and the effectiveness of CBRNE management in Indonesia[80].

Accordingly, the proposed PLS-SEM model demonstrates significant predictive superiority and is suitable for use as a robust analytical framework to support evidence-based policy formulation aimed at improving the effectiveness of CBRNE threat management in Indonesia[81].

4. Discussion

4.1 Interpretation of Qualitative Findings

The qualitative findings of this study reveal that hospital responses to CBRNE threats in Indonesia are shaped by a complex interaction of institutional capacity, governance arrangements, technological readiness, human resource competence, and civil-military interoperability. Data derived from in-depth interviews, focus group discussions, field observations, and NVivo-based thematic analysis consistently indicate that existing CBRNE response mechanisms remain predominantly reactive rather than preventive. Hospitals tend to prioritize response actions once an incident occurs, while preparedness and governance dimensions receive comparatively limited institutional attention. This pattern reflects a systemic weakness at the pre-crisis stage, where strategic planning, risk anticipation, and institutional readiness should form the foundation of effective CBRNE management.

A critical qualitative insight concerns the disparity between formal policy designation and actual operational readiness. While several civilian hospitals have been officially appointed as CBRNE referral hospitals, this designation has not been fully translated into comprehensive readiness in terms of trained personnel, advanced detection technologies, and integrated command systems. NVivo coding results demonstrate that themes related to response capability and interoperability dominate stakeholder narratives, whereas preparedness, governance, and long-term capacity development appear less emphasized. This imbalance suggests that institutional readiness is often interpreted narrowly as the ability to respond during emergencies, rather than as a continuous process encompassing mitigation, preparedness, response, and recovery.

Qualitative evidence also highlights significant limitations within defense-affiliated hospitals. Despite the existence of specialized military CBRNE units within the Indonesian National Armed Forces (TNI) and prior operational experience during large-scale health emergencies such as the COVID-19 pandemic, defense hospitals have not been formally designated or institutionally prepared as CBRNE referral centers. This situation creates ambiguity in roles and responsibilities during CBRNE incidents and undermines the potential contribution of military medical infrastructure to national response efforts. The absence of permanent cooperation agreements between civilian and military health institutions emerges as a central governance gap, reinforcing fragmented and ad hoc coordination patterns.

Furthermore, the qualitative findings underscore the importance of human resources and technology as critical enabling factors of preparedness and response. Interviews reveal that shortages of trained CBRNE personnel, limited access to specialized detection and diagnostic equipment, and inadequate simulation-based training significantly constrain hospital readiness. NVivo word frequency and thematic relationship analyses demonstrate strong linkages between capacity, preparedness, and response effectiveness, indicating that deficiencies in any single component can have cascading effects across the entire response system. From an interpretative standpoint, these findings affirm that hospital preparedness for CBRNE threats must be understood as a systemic construct rather than a collection of isolated technical capabilities.

Overall, the qualitative interpretation indicates that CBRNE threats in Indonesia are perceived by stakeholders as real, recurrent, and geographically dispersed, requiring an integrated and sustained response framework. The dominance of reactive orientations, combined with fragmented governance and the lack of institutionalized civil-military collaboration, limits the effectiveness and sustainability of current response mechanisms. Consequently, strengthening CBRNE preparedness demands a paradigm shift from crisis-driven response toward proactive, integrated, and governance-based preparedness models that institutionalize cooperation, enhance capacity development, and align civilian and military health systems within a unified national framework.

4.2 Interpretation of Quantitative Findings

The quantitative findings of this study provide strong empirical evidence regarding the relationship between hospital capacity, preparedness, and response capability and the effectiveness of Chemical, Biological, Radiological, Nuclear, and Explosive (CBRNE) threat management in Indonesia. The Structural Equation Modeling–Partial Least Squares (SEM-PLS 4) analysis demonstrates that hospital capacity, preparedness, and response capability have a statistically significant effect on the effectiveness of CBRNE threat management, as indicated by a path coefficient of –0.622, a T-statistic of 9.442, and a p-value of 0.000. These results confirm that the tested relationship is statistically robust and not attributable to random variation.

The negative direction of the relationship should be interpreted substantively as a reflection of current empirical conditions. The negative coefficient indicates that lower levels of hospital capacity, preparedness, and response capability are directly associated with reduced effectiveness in managing CBRNE threats. In practical terms, limitations in infrastructure readiness, human resource competence, technological support, and operational preparedness through training and simulation significantly weaken hospitals' ability to respond effectively to CBRNE incidents. This finding underscores that insufficient institutional preparedness translates directly into diminished national response performance when facing high-risk and complex threats.

The assessment of the measurement model (outer model) shows that all indicators of hospital capacity, preparedness, and response capability—including infrastructure readiness, human resource competence, technological capability and standard operating procedures, and preparedness through training and simulation—exhibit strong outer loading values exceeding the recommended threshold. This confirms that the indicators reliably and consistently represent the underlying latent construct. Similarly, the indicators measuring the effectiveness of CBRNE threat management, such as response timeliness, coordination and interoperability, casualty and exposure control, service continuity, and compliance with safety and regulatory standards, demonstrate satisfactory validity and reliability.

In terms of explanatory power, the R-square value of 0.387 indicates that approximately 38.7% of the variance in the effectiveness of CBRNE threat management can be explained by hospital capacity, preparedness, and response capability. This represents a moderate level of explanatory strength, suggesting that while hospital capacity is a critical determinant, other factors beyond the hospital domain also influence CBRNE management effectiveness. These factors may include national governance arrangements, cross-sectoral policy coordination, crisis leadership, and the degree of institutional interoperability between civilian and military actors.

Furthermore, the effect size (F-square) value of 0.632 indicates a strong practical influence of hospital capacity, preparedness, and response capability on the effectiveness of CBRNE threat management. This finding highlights that strengthening hospital capacity is not merely supportive in nature but constitutes a key determinant with substantial practical implications for improving response outcomes. Investments in infrastructure, human resource development, advanced detection and protection technologies, and systematic training and simulation therefore have a direct and meaningful impact on enhancing national CBRNE response effectiveness.

Overall, the interpretation of the quantitative findings confirms that the effectiveness of CBRNE threat management in Indonesia is highly dependent on the level of institutional preparedness of hospitals as frontline actors within the health system. The significant negative relationship observed reflects the empirical reality that structural and operational limitations systematically undermine response effectiveness. Consequently, strengthening hospital capacity, preparedness, and response capability must be positioned as a strategic priority within national CBRNE policy frameworks, not only to improve emergency response performance but also to build a more resilient, adaptive, and sustainable health system capable of addressing complex and high-risk threats in the future.

4.3 Integration of Results and Policy Implications

Qualitative findings derived from in-depth interviews, focus group discussions, and field observations indicate that responses to CBRNE threats are understood as a complex system characterized by strong interdependencies among multiple key elements. Civil–military interoperability emerged as a critical prerequisite linking operational response capability with the availability of human resources and technological support. Limitations in any single component such as the shortage of trained personnel or the absence of specialized CBRNE technologies were found to directly undermine response effectiveness, even when policy frameworks were formally in place. Furthermore, the lack of integrated governance structures reinforces fragmented and reactive response patterns. Interpretatively, these findings suggest that strengthening CBRNE response cannot be pursued through sectoral approaches, but rather requires a holistic strategy that integrates institutional, operational, and policy dimensions to ensure effective and sustainable system performance[82].

Qualitative findings from secondary data based on the literature review further emphasize that the absence of permanent cooperation agreements constitutes a fundamental barrier to CBRNE mitigation, response, and management. This condition results in cross-sector collaboration being largely ad hoc, non-institutionalized, and highly dependent on crisis situations. Substantively, these findings demonstrate that without permanent and operational cooperation frameworks, inter-agency coordination remains weak, roles and authorities become ambiguous, and CBRNE responses risk being ineffective and unsustainable[83].

Qualitative analysis of secondary data from online mass media sources reveals that CBRNE threats in Indonesia are real, recurrent, and cross-sectoral, occurring over extended periods and dispersed across diverse geographical areas. The predominance of chemical, biological, radiological, and explosive incidents indicates that CBRNE threats are not incidental phenomena, but rather structural risks that continuously affect public health, the environment, and national security. Substantively, these findings underscore the urgency of strengthening an integrated national preparedness and response system, as recurrent and geographically dispersed threat patterns demand response capacities that are not merely reactive, but also sustainable and adaptive[84].

Quantitative findings reinforce and confirm the qualitative evidence by demonstrating that hospital capacity, preparedness, and response capability exert a strong and significant influence on the effectiveness of CBRNE threat management in Indonesia, as reflected by a path coefficient of –0.622, a T-statistic of 9.442, a p-value of 0.000, and an F-square value of 0.632. Interpretatively, the negative direction of this relationship reflects the current empirical reality in which limitations in hospital capacity across human resources, technology, and governance are directly associated with lower effectiveness of CBRNE response. These results are consistent with the qualitative findings, which emphasize that CBRNE response constitutes a complex system reliant on civil-military interoperability, technological support, and integrated governance frameworks, and is further weakened by the absence of permanent cooperation agreements and predominantly reactive collaboration patterns[85].

Taken together, the convergence of qualitative and quantitative evidence consistently demonstrates that strengthening CBRNE response requires a holistic and systemic approach rather than a sectoral one, in order to effectively address CBRNE threats that are real, recurrent, and geographically dispersed across Indonesia[86].

This study ultimately demonstrates that strengthening CBRNE response in Indonesia must be regarded as a cross-sectoral strategic agenda that demands comprehensive governance reform, rather than merely partial improvements in hospital technical capacity. The consistency between qualitative and quantitative findings confirms that without institutionalized civil-military interoperability, adequately trained human resources, specialized CBRNE technologies, and clearly defined permanent cooperation frameworks, response effectiveness will remain limited and reactive. Therefore, the key practical implication is the necessity of a policy paradigm shift from ad hoc emergency response toward the development of a holistic, adaptive, and sustainable national CBRNE preparedness system, in order to ensure more effective protection of public health, the environment, and national security[87].

5. Conclusions

The capacity, preparedness, and response capability of civilian hospitals and hospitals within the Ministry of Defense in addressing CBRNE threats remain insufficiently integrated. Both qualitative and quantitative analyses consistently confirm the existence of divergent legal mandates, limited infrastructure readiness, gaps in human resource competencies, inadequate availability of CBRNE-specific technologies, and weak effectiveness of civil–military collaboration. Furthermore, this study demonstrates that regulatory fragmentation and the absence of permanent cooperation mechanisms have a tangible impact on the low effectiveness of CBRNE mitigation, response, and recovery.

The findings provide a robust empirical foundation, supported by convergent qualitative and quantitative evidence identifying key determinants of CBRNE response effectiveness, including institutional hospital capacity, human resource readiness, technological support, and civil-military collaboration mechanisms. This empirical evidence indicates that weaknesses in CBRNE response are not merely technical in nature, but are rooted in fragmented governance and the absence of permanent cooperation frameworks that impede cross-sectoral integration. Accordingly, the study advocates the development of more integrated, adaptive, and sustainable governance arrangements to strengthen national CBRNE response resilience.

This research provides a multidisciplinary contribution to the field of applied natural sciences by examining hospital preparedness and response to CBRNE threats as biological, chemical, physical, and environmental phenomena with direct implications for human life. Contributions to biological and environmental sciences are reflected in the analysis of biological risks and environmental impacts on public health system resilience. Within the domains of chemical and material sciences, the study emphasizes the importance of detection, decontamination, and medical protection technologies in responding to chemical and radiological exposures, which must be supported by systematic training and capacity building for hospital medical personnel with expertise in nuclear medicine. Meanwhile, contributions to the physical sciences are realized through the assessment of radiological, nuclear, and explosive risks to healthcare facilities and critical infrastructure. Empirically, this study bridges natural sciences with their practical application in CBRNE risk management, thereby

supporting the strengthening of resilient public health systems, environmental protection, and the enhancement of Indonesia's national security and resilience in a sustainable manner.

This study is limited by its focus on only two hospitals located in the Jakarta region and a relatively restricted number of respondents, which may limit the generalizability of the findings to the broader national context of CBRNE preparedness and response in Indonesia.

Future studies are recommended to expand the geographical scope and sample of hospitals, incorporate more detailed national governance and cross-sector interoperability variables, and employ longitudinal or comparative designs to better capture the dynamics of CBRNE preparedness and response over time.

Author Contributions:

1.Faonaso Harefa: Conceptualization, research design, data collection, qualitative analysis (NVivo), quantitative analysis (SEM-PLS), manuscript drafting, and final revision.

2.Yahdiana Harahap: Methodological supervision, validation of quantitative analysis, interpretation of results, and manuscript review.

3.Dian Andriani Ratna Dewi: Literature review, qualitative data validation, policy analysis, and manuscript editing.

4. R.M. Tjahya Nurrobi: Conceptual validation, defense health and CBRNE expertise, interpretation of findings, and critical revision of the manuscript.

5.Cecilia F. Harsono: Translation of the manuscript into academic English, linguistic editing, consistency checking of terminology, and critical review of the manuscript to ensure clarity, coherence, and compliance with academic writing standards.

References:

[1] A. Malizia *et al.*, "Integrating the exposome framework in CBRNe risk assessment : a holistic approach to chemical , biological , radiological , nuclear , and explosive threats," vol. 123, 2025.

[2] L. Gorniak, N. Cichon, M. Stela, M. Niemcewicz, and M. Podogrocki, "A Practical Classification Approach for Chemical , Biological , Radiological and Nuclear (CBRN) Hazards Based on Toxicological and Situational Parameters," pp. 1–27, 2025.

[3] R. A. Sheikhi, M. Heidari, P. Doosti, and S. Nemati, "emergency medical service provider ' s preparedness against chemical , biological , radiological , and nuclear (cbrn) incidents : a systematic review," vol. 10, no. 3, pp. 140–151, 2025, doi: 10.5603/demj.103354.

[4] G. M. Ludovici, P. A. Tassi, A. Iannotti, C. Russo, R. Quaranta, and G. Manenti, "Ethics , Medicine and Public Health Bioterrorism and CBRNe threats : The role of Ebola in global security," *Ethics, Med. Public Heal.*, vol. 33, p. 101138, 2025, doi: 10.1016/j.jemep.2025.101138.

[5] E. S. Qzih and M. M. Ahmad, "Hospital-Based Preparedness Measures for CBRNE Disasters : A Systematic Review," 2024, doi: 10.1177/11786302241288859.

[6] A. Geophysics, "Tsunami Occurrence 1900 – 2020 : A Global Review , with Examples from Indonesia," vol. 180, pp. 1549–1571, 2023, doi: 10.1007/s00024-022-03057-1.

[7] P. Supendi *et al.*, "On the potential for megathrust earthquakes and tsunamis off the southern coast of West Java and southeast Sumatra ," *Nat. Hazards*, vol. 116, no. 1, pp. 1315–1328, 2023, doi: 10.1007/s11069-022-05696-y.

[8] E. U. Zorn, A. Orynbaikyzy, S. Plank, A. Babeyko, H. Darmawan, and I. F. Robbany, "Identification and ranking of subaerial volcanic tsunami hazard sources in Southeast Asia," pp. 3083–3104, 2022.

[9] M. N. Malawani, F. Lavigne, C. Gomez, B. W. Mutaqin, and D. S. Hadmoko, "Review of local and global impacts of volcanic eruptions and disaster management practices: The Indonesian example," *Geosci.*, vol. 11, no. 3, pp. 1–18, 2021, doi: 10.3390/geosciences11030109.

[10] Y. Yulizar and C. Asdak, "The joint variation of temperature and precipitation across Indonesia: A seasonal and regional analysis," *Theor. Appl. Climatol.*, vol. 156, no. 11, pp. 1–15, 2025.

[11] J. Susanto, X. Zheng, Y. Liu, and C. Wang, "The impacts of climate variables and climate-related extreme events on island country ' s tourism : Evidence from Indonesia," *J. Clean. Prod.*, vol. 276, p. 124204, 2020, doi: 10.1016/j.jclepro.2020.124204.

[12] R. Hidayat, Apip, A. P. Dasril, and M. Taufik, "Climate teleconnection triggers prolonged dry season in tropical maritime continent," *Theor. Appl. Climatol.*, vol. 156, no. 11, p. 626, 2025.

[13] B. P. Shreve, "The modern explosive threat: Improvised explosive devices," in *Operational and Medical Management of Explosive and Blast Incidents*, Springer, 2020, pp. 99–107.

[14] K. Benedict and K. Kaplan, “Nuclear Threats and the (F) Utility of Law,” pp. 71–86, 2025.
[15] A. Farahat, N. El-Kork, R. P. Singh, and F. Jing, “Possible Overestimation of Nitrogen Dioxide Outgassing during the Beirut 2020 Explosion,” *Remote Sens.*, vol. 14, no. 24, 2022, doi: 10.3390/rs14246377.
[16] C. Weiss *et al.*, “Toward Nanotechnology-Enabled Approaches against the COVID-19 Pandemic,” *ACS Nano*, vol. 14, no. 6, pp. 6383–6406, 2020, doi: 10.1021/acsnano.0c03697.
[17] K. Wu *et al.*, “Magnetic-nanosensor-based virus and pathogen detection strategies before and during covid-19,” *ACS Appl. Nano Mater.*, vol. 3, no. 10, pp. 9560–9580, 2020, doi: 10.1021/acsanm.0c02048.
[18] H. Müller and C. Wunderlich, “Nuclear disarmament without the nuclear-weapon states: The nuclear weapon ban treaty,” *Daedalus*, vol. 149, no. 2, pp. 171–189, 2020, doi: 10.1162/DAED_a_01796.
[19] I. F. Akyildiz, M. Ghovanloo, U. Guler, T. Ozkaya-Ahmadov, A. F. Sarioglu, and B. D. Unluturk, “PANACEA: An Internet of Bio-NanoThings Application for Early Detection and Mitigation of Infectious Diseases,” *IEEE Access*, vol. 8, pp. 140512–140523, 2020, doi: 10.1109/ACCESS.2020.3012139.
[20] X. Castañer and N. Oliveira, “Collaboration, Coordination, and Cooperation Among Organizations: Establishing the Distinctive Meanings of These Terms Through a Systematic Literature Review,” *J. Manage.*, vol. 46, no. 6, pp. 965–1001, 2020, doi: 10.1177/0149206320901565.
[21] O. Access, “Cardiff,” 2022.
[22] A. Open *et al.*, “Using an exploratory sequential mixed methods design to adapt an Illness Perception Questionnaire for African Americans with diabetes : the mixed data integration process Using an exploratory sequential mixed methods design to adapt an Illness Perception Questionnaire for African Americans with diabetes : the mixed data integration process,” vol. 2850, 2021, doi: 10.1080/21642850.2021.1976650.
[23] M. Tahmid, S. Dey, and S. R. Syeda, “Mapping human vulnerability and risk due to chemical accidents,” *J. Loss Prev. Process Ind.*, vol. 68, p. 104289, 2020, doi: 10.1016/j.jlp.2020.104289.
[24] K. Dhakal, “NVivo,” *J. Med. Libr. Assoc.*, vol. 110, no. 2, pp. 270–272, 2022, doi: 10.5195/jmla.2022.1271.
[25] E. D. La Cruz, “A Quantitative Study of Cybersecurity Data Analytics System Success Using Partial Least Squares Structural Equation Modeling,” *Αγαη*, vol. 15, no. 1, pp. 37–48, 2024, doi: 10.13140/RG.2.2.35552.70405.
[26] M. Vukovi´c, “CB-SEM vs PLS-SEM comparison in estimating the predictors of investment intention,” *Croat. Oper. Res. Rev.*, vol. 15, no. 2, pp. 131–144, 2024, doi: 10.17535/crorr.2024.0011.
[27] A. E. Legate, J. F. Hair, J. L. Chretien, and J. J. Risher, “PLS-SEM: Prediction-oriented solutions for HRD researchers,” *Hum. Resour. Dev. Q.*, vol. 34, no. 1, pp. 91–109, 2023, doi: 10.1002/hrdq.21466.
[28] W. C. W. Chan, “Nano Research for COVID-19,” *ACS Nano*, vol. 14, no. 4, pp. 3719–3720, 2020, doi: 10.1021/acsnano.0c02540.
[29] H. Baharum *et al.*, “Validating an Instrument for Measuring Newly Graduated Nurses’ Adaptation,” *Int. J. Environ. Res. Public Health*, vol. 20, no. 4, 2023, doi: 10.3390/ijerph20042860.
[30] P. Vounba, S. Loul, L. F. Tamadea, and J. F. D. Siawaya, “Microbiology laboratories involved in disease and antimicrobial resistance surveillance: Strengths and challenges of the central African states,” *Afr. J. Lab. Med.*, vol. 11, no. 1, pp. 1–10, 2022, doi: 10.4102/ajlm.v11i1.1570.
[31] S. Liu *et al.*, “sustainability A State-of-the-Art Review of Radioactive Decontamination Technologies : Facing the Upcoming Wave of Decommissioning and Dismantling of Nuclear Facilities,” no. Figure 1, 2022.
[32] Y. Guo, G. Francesco, B. Corica, and M. Proietti, “European Journal of Internal Medicine Mobile health-technology integrated care in atrial fibrillation patients with heart failure : A report from the mAFA-II randomized clinical trial,” vol. 107, no. July 2022, pp. 46–51, 2023, doi: 10.1016/j.ejim.2022.11.002.
[33] G. F. Romiti, Y. Guo, Ã. B. Corica, M. Proietti, and G. Y. H. Lip, “Mobile Health-Technology-Integrated Care for Atrial Fibrillation : A Win Ratio Analysis from the mAFA-II Randomized Clinical Trial,” pp. 1042–1048, 2023.
[34] Y. Guo *et al.*, “Observations from the

Huawei Heart Study and mAFA II randomized trial.".
[35] L. F. Probst *et al.*, "Mask decontamination methods (model N95) for respiratory protection : a rapid review," pp. 1–11, 2021.
[36] S. A. Bhatti, F. H. Memon, F. Rehman, Z. Bhatti, T. Naqvi, and K. H. Thebo, "Recent progress in decontamination system against chemical and biological materials : challenges and future perspectives," 2021.
[37] A. Asgary, M. Aarabi, S. Dixit, H. Wen, M. Ahmed, and J. Wu, "A Survey of the Use of Modeling , Simulation , Visualization , and Mapping in Public Health Emergency Operations Centers during the COVID-19 Pandemic," 2024.
[38] D. P. Melters and Y. Dalal, "Nano-Surveillance: Tracking Individual Molecules in a Sea of Chromatin," *J. Mol. Biol.*, vol. 433, no. 6, 2021, doi: 10.1016/j.jmb.2020.11.019.
[39] R. E. Caraka *et al.*, "Cluster around Latent Variable for Vulnerability towards Natural Hazards, Non-Natural Hazards, Social Hazards in West Papua," *IEEE Access*, vol. 9, pp. 1972–1986, 2021, doi: 10.1109/ACCESS.2020.3038883.
[40] J. F. Hassard and M. S. Nieuwenhuizen, "Chemical Threats," *Adv. Sci. Technol. Secur. Appl.*, pp. 17–46, 2022, doi: 10.1007/978-3-031-17374-5_2.
[41] N. F. Wendimagegn and M. C. Bezuidenhout, "Integrating promotive, preventive, and curative health care services at hospitals and health centers in Addis Ababa, Ethiopia," *J. Multidiscip. Healthc.*, vol. 12, pp. 243–255, 2019, doi: 10.2147/JMDH.S193370.
[42] A. Elnaiem *et al.*, "Global and regional governance of One Health and implications for global health security," *Lancet*, vol. 401, no. 10377, pp. 688–704, 2023, doi: 10.1016/S0140-6736(22)01597-5.
[43] C. Xu, C. Lei, S. Hosseinpour, S. Ivanovski, L. J. Walsh, and A. Khademhosseini, "Nanotechnology for the management of COVID-19 during the pandemic and in the post-pandemic era," *Natl. Sci. Rev.*, vol. 9, no. 10, 2022, doi: 10.1093/nsr/nwac124.
[44] G. M. Havârneanu, L. Petersen, A. Arnold, D. Carbon, and T. Görgen, "Preparing railway stakeholders against CBRNe threats through better cooperation with security practitioners," *Appl. Ergon.*, vol. 102, no. March, 2022, doi: 10.1016/j.apergo.2022.103752.
[45] T. H. Bhat, G. Jiawen, and H. Farzaneh, "Air pollution health risk assessment (Ap-hra), principles and applications," *Int. J. Environ. Res. Public Health*, vol. 18, no. 4, pp. 1–29, 2021, doi: 10.3390/ijerph18041935.
[46] E. M. Hassan and H. Mahmoud, "Healthcare and education networks interaction as an indicator of social services stability following natural disasters," *Sci. Rep.*, vol. 11, no. 1, pp. 1–15, 2021, doi: 10.1038/s41598-021-81130-w.
[47] S. Riadi and Erdiyansyah, "Collaborative governance in handling natural and non-natural disasters based on the perspective of public administration: Evidence from Indonesia," *Probl. Perspect. Manag.*, vol. 19, no. 2, pp. 468–479, 2021, doi: 10.21511/ppm.19(2).2021.37.
[48] J. Janse *et al.*, "Civil-military cooperation in the management of infectious disease outbreaks: A scoping review," *BMJ Glob. Heal.*, vol. 7, no. 6, pp. 1–13, 2022, doi: 10.1136/bmjgh-2022-009228.
[49] D. Settembre-Blundo, R. González-Sánchez, S. Medina-Salgado, and F. E. García-Muiña, "Flexibility and Resilience in Corporate Decision Making: A New Sustainability-Based Risk Management System in Uncertain Times," *Glob. J. Flex. Syst. Manag.*, vol. 22, no. December, pp. 107–132, 2021, doi: 10.1007/s40171-021-00277-7.
[50] D. G. Sami and S. Chun, "Strengthening Health Security at Ground Border Crossings: Key Components for Improved Emergency Preparedness and Response—A Scoping Review," *Healthc.*, vol. 12, no. 19, 2024, doi: 10.3390/healthcare12191968.
[51] A. Khorram-Manesh, L. J. Mortelmans, Y. Robinson, F. M. Burkle, and K. Goniewicz, "Civilian-Military Collaboration before and during COVID-19 Pandemic—A Systematic Review and a Pilot Survey among Practitioners," *Sustain.*, vol. 14, no. 2, 2022, doi: 10.3390/su14020624.
[52] E. R. Cui *et al.*, "Disparities in emergency medical services time intervals for patients with suspected acute coronary syndrome: Findings from the North Carolina prehospital medical information system," *J. Am. Heart Assoc.*, vol. 10, no. 15, pp. 1–12, 2021, doi: 10.1161/JAHA.120.019305.
[53] O. A. Ogunseitan, "One Health and the Environment: From Conceptual Framework to Implementation Science," *Environment*, vol. 64, no. 2, pp. 11–21, 2022, doi: 10.1080/00139157.2022.2021792.
[54] Y. Yu, J. Ding, Y. Zhou, H. Xiao, and G.

Wu, "Biosafety chemistry and biosafety materials: A new perspective to solve biosafety problems," *Biosaf. Heal.*, vol. 4, no. 1, pp. 15–22, 2022, doi: 10.1016/j.bsheal.2022.01.001.

[55] M. G. Dente *et al.*, "Strengthening preparedness against global health threats: A paradigm shift based on One Health approaches," *One Heal.*, vol. 14, no. February, p. 100396, 2022, doi: 10.1016/j.onehlt.2022.100396.

[56] M. Ku, A. Han, and K. H. Lee, "The dynamics of cross-sector collaboration in centralized disaster governance: a network study of interorganizational collaborations during the mers epidemic in south korea," *Int. J. Environ. Res. Public Health*, vol. 19, no. 1, 2022, doi: 10.3390/ijerph19010018.

[57] S. Nazari, S. Sharififar, M. Ahmadi Marzaleh, S. Zargar, S. Azarmi, and Y. Akbari Shahrestanaki, "Structural Elements and Requirements in Forming Prehospital Health Response Teams in Response to Chemical, Biological, Radiation, and Nuclear Incidents (CBRN), a Comparative Review Study," *Disaster Med. Public Health Prep.*, vol. 17, no. 9, 2023, doi: 10.1017/dmp.2022.259.

[58] F. Taveira-Pinto, P. Rosa-Santos, and T. Fazeres-Ferradosa, "Anthropogenic influences on integrated coastal zone management," *J. Integr. Coast. Zo. Manag.*, vol. 20, no. 4, pp. 215–217, 2020, doi: 10.5894/rgci-n428.

[59] M. Geretto *et al.*, "Occupational exposures and environmental health hazards of military personnel," *Int. J. Environ. Res. Public Health*, vol. 18, no. 10, 2021, doi: 10.3390/ijerph18105395.

[60] R. Rai, S. El-Zaemey, N. Dorji, B. D. Rai, and L. Fritschi, "Exposure to occupational hazards among health care workers in low-and middle-income countries: A scoping review," *Int. J. Environ. Res. Public Health*, vol. 18, no. 5, pp. 1–41, 2021, doi: 10.3390/ijerph18052603.

[61] S. H. Latonen, R. M. Suominen, A. M. Juppo, M. Airaksinen, and H. Seeck, "Organisation of cross-sector collaboration and its influence on crisis management effectiveness among pharmaceutical supply chain stakeholders during the COVID-19 pandemic," *Public Health*, vol. 222, pp. 196–204, 2023, doi: 10.1016/j.puhe.2023.06.042.

[62] J. L. Fallowfield *et al.*, "A whole system approach to promoting health and human performance in military settings as vital prerequisites for force readiness and operational capability," *Front. Physiol.*, vol. 16, no. April, pp. 1–8, 2025, doi: 10.3389/fphys.2025.1541256.

[63] M. P. Fitchett, P. M. Saffy, and C. M. Lewis, "Availability of antidotes for drug poisonings and doctors' perspectives thereof," *S. Afr. J. Sci.*, vol. 120, no. 7–8, pp. 1–10, 2024, doi: 10.17159/sajs.2024/16394.

[64] S. Kudłacik-Kramarczyk, W. Kieres, A. Przybyłowicz, C. Ziejewska, J. Marczyk, and M. Krzan, "Recent Advances in Micro- and Nano-Enhanced Intravascular Biosensors for Real-Time Monitoring, Early Disease Diagnosis, and Drug Therapy Monitoring," *Sensors*, vol. 25, no. 15, pp. 1–25, 2025, doi: 10.3390/s25154855.

[65] X. Hu, K. Naim, S. Jia, and Z. Zhengwei, "Disaster policy and emergency management reforms in China: From Wenchuan earthquake to Jiuzhaigou earthquake," *Int. J. Disaster Risk Reduct.*, vol. 52, no. June, 2021, doi: 10.1016/j.ijdrr.2020.101964.

[66] L. Ispas, C. Mironeasa, and A. Silvestri, "Risk-Based Approach in the Implementation of Integrated Management Systems: A Systematic Literature Review," *Sustain.*, vol. 15, no. 13, pp. 1–22, 2023, doi: 10.3390/su151310251.

[67] S. Gastaldi and M. Horlait, "Health Care Organizations' Interoperability during Multi-Organizational Disaster Management: A Scoping Review," *Prehosp. Disaster Med.*, vol. 37, no. 3, pp. 401–408, 2022, doi: 10.1017/S1049023X22000516.

[68] E. Emaliyawati *et al.*, "Enhancing Disaster Preparedness Through Tabletop Disaster Exercises: A Scoping Review of Benefits for Health Workers and Students," *Adv. Med. Educ. Pract.*, vol. 16, pp. 1–11, 2025, doi: 10.2147/AMEP.S504705.

[69] B. Lillywhite and G. Wolbring, "Risk Narrative of Emergency and Disaster Management, Preparedness, and Planning (EDMPP): The Importance of the 'Social,'" *Sustain.*, vol. 15, no. 1, pp. 1–36, 2023, doi: 10.3390/su15010387.

[70] R. Perz, "the Multidimensional Threats of Unmanned Aerial Systems: Exploring Biomechanical, Technical, Operational, and Legal Solutions for Ensuring Safety and Security," *Arch. Transp.*, vol. 69, no. 1, pp. 91–111, 2024, doi: 10.61089/aot2024.h7j32562.

[71] E. Medaa, A. A. Shirzadi Javid, H. Malekitabar, and S. Banihashemi, "The Synergy

and Accumulation Model for Analysis (SAMA): A Novel Approach to Transforming Risk Analysis in Construction with a Focus on the Deepwater Horizon Disaster Case," *Buildings*, vol. 15, no. 11, pp. 1–27, 2025, doi: 10.3390/buildings15111879.
[72] E. S. Qzih and M. M. Ahmad, "Hospital-Based Preparedness Measures for CBRNE Disasters: A Systematic Review," *Environ. Health Insights*, vol. 18, 2024, doi: 10.1177/11786302241288859.
[73] S. Bandyopadhyay *et al.*, "Infection and mortality of healthcare workers worldwide from COVID-19: A systematic review," *BMJ Glob. Heal.*, vol. 5, no. 12, 2020, doi: 10.1136/bmjgh-2020-003097.
[74] C. K. Zogg *et al.*, *In defense of Direct Care: Limiting access to military hospitals could worsen quality and safety*, vol. 57, no. 4. 2022. doi: 10.1111/1475-6773.13885.
[75] H. Sofyana, K. Ibrahim, I. Afriandi, and E. Herawati, "The implementation of disaster preparedness training integration model based on Public Health Nursing (ILATGANA-PHN) to increase community capacity in natural disaster-prone areas," *BMC Nurs.*, vol. 23, no. 1, pp. 1–18, 2024, doi: 10.1186/s12912-024-01755-w.
[76] V. Sandoval, M. Voss, V. Flörchinger, S. Lorenz, and P. Jafari, "Integrated Disaster Risk Management (IDRM): Elements to Advance Its Study and Assessment," *Int. J. Disaster Risk Sci.*, vol. 14, no. 3, pp. 343–356, 2023, doi: 10.1007/s13753-023-00490-1.
[77] J. Ranse *et al.*, "Strengthening emergency department response to chemical, biological, radiological, and nuclear disasters: A scoping review," *Australas. Emerg. Care*, vol. 28, no. 1, pp. 37–47, 2025, doi: 10.1016/j.auec.2024.09.003.
[78] C. Wankmüller and G. Reiner, *Coordination, cooperation and collaboration in relief supply chain management*, vol. 90, no. 2. Springer Berlin Heidelberg, 2020. doi: 10.1007/s11573-019-00945-2.
[79] H. Wyrębek, "National Security Challenges and Threats," *Wiedza Obron.*, vol. 279, no. 2, pp. 109–123, 2022, [Online]. Available: https://doi.org/10.34752/2022-e279
[80] H. Wang, J. Sun, Y. Shi, and T. Shen, "Driving the effectiveness of public health emergency management strategies through cross-departmental collaboration: Configuration analysis based on 15 cities in China," *Front. Public Heal.*, vol. 10, 2022, doi: 10.3389/fpubh.2022.1032576.
[81] T. R. Frieden, L. K. Cobb, R. C. Leidig, S. Mehta, and D. Kass, "Reducing Premature Mortality from Cardiovascular and Other Non-Communicable Diseases by One Third: Achieving Sustainable Development Goal Indicator 3.4.1," *Glob. Heart*, vol. 15, no. 1, pp. 1–10, 2020, doi: 10.5334/GH.531.
[82] J. Chikovore *et al.*, "Missing men with tuberculosis: The need to address structural influences and implement targeted and multidimensional interventions," *BMJ Glob. Heal.*, vol. 5, no. 5, 2020, doi: 10.1136/bmjgh-2019-002255.
[83] W. Jiang *et al.*, "Toward Interoperable Multi-hazard Modeling: A Disaster Management System for Disaster Model Service Chain," *Int. J. Disaster Risk Sci.*, vol. 13, no. 6, pp. 862–877, 2022, doi: 10.1007/s13753-022-00450-1.
[84] L. Yao *et al.*, "Detection of coronavirus in environmental surveillance and risk monitoring for pandemic control," *Chem. Soc. Rev.*, vol. 50, no. 6, pp. 3656–3676, 2021, doi: 10.1039/d0cs00595a.
[85] K. Sapountzaki, "Risk Mitigation, Vulnerability Management, and Resilience under Disasters," *Sustain.*, vol. 14, no. 6, 2022, doi: 10.3390/su14063589.
[86] K. Gooding, M. P. Bertone, G. Loffreda, and S. Witter, "How can we strengthen partnership and coordination for health system emergency preparedness and response? Findings from a synthesis of experience across countries facing shocks," *BMC Health Serv. Res.*, vol. 22, no. 1, pp. 1–19, 2022, doi: 10.1186/s12913-022-08859-6.
[87] A. M. Gavrila, A. Diacon, T. V. Iordache, T. Rotariu, M. Ionita, and G. Toader, "Hazardous Materials from Threats to Safety: Molecularly Imprinted Polymers as Versatile Safeguarding Platforms," *Polymers (Basel).*, vol. 16, no. 19, 2024, doi: 10.3390/polym16192699.

参考文:

[1] A. Malizia 等, "在 CBRNe 风险评估中整合外显组框架：针对化学、生物、放射、核与爆炸威胁的整体方法", 第123卷, 2025年。
[2] L. Gorniak, N. Cichon, M. Stela, M. Niemcewicz, 和 M. Podogrocki, "基于毒理学与情境参数的化学、

生物、放射与核（CBRN）危害实用分类方法”，第1–27页，2025年。
[3] R. A. Sheikhi, M. Heidari, P. Doosti, 和 S. Nemati，“急救医疗服务提供者应对化学、生物、放射和核（CBRN）事件的准备情况：系统综述”，第10卷，第3期，第140–151页，2025年，doi:10.5603/demj.103354。
[4] G. M. Ludovici, P. A. Tassi, A. Iannotti, C. Russo, R. Quaranta, 和 G. Manenti，“伦理学、医学与公共卫生：生物恐怖主义与 CBRNe 威胁——埃博拉在全球安全中的作用”，伦理学、医学与公共卫生，第33卷，第101138页，2025年，doi:10.1016/j.jemep.2025.101138。
[5] E. S. Qzih 和 M. M. Ahmad，“基于医院的 CBRNE 灾害应急准备措施：系统综述”，2024年，doi:10.1177/11786302241288859。
[6] A. Geophysics，“海啸发生 1900–2020：全球综述及印尼案例”，第180卷，第1549–1571页，2023年，doi:10.1007/s00024-022-03057-1。
[7] P. Supendi 等，“西爪哇南部海岸与苏门答腊东南部海域的巨型断层地震与海啸潜力”，自然灾害，第116卷，第1期，第1315–1328页，2023年，doi:10.1007/s11069-022-05696-y。
[8] E. U. Zorn, A. Orynbaikyzy, S. Plank, A. Babeyko, H. Darmawan, 和 I. F. Robbany，“东南亚陆上火山海啸危险源识别与排序”，第3083–3104页，2022年。
[9] M. N. Malawani, F. Lavigne, C. Gomez, B. W. Mutaqin, 和 D. S. Hadmoko，“火山喷发的地方与全球影响及灾害管理实践综述：以印尼为例”，地球科学，第11卷，第3期，第1–18页，2021年，doi:10.3390/geosciences11030109。
[10] Y. Yulizar 和 C. Asdak，“印尼气温与降水的联合变化：季节性与区域分析”，理论与应用气候学，第156卷，第11期，第1–15页，2025年。
[11] J. Susanto, X. Zheng, Y. Liu, 和 C. Wang，“气候变量及极端气候事件对岛国旅游的影响：印尼案例”，清洁生产杂志，第276卷，第124204页，2020年，doi:10.1016/j.jclepro.2020.124204。
[12] R. Hidayat, Apip, A. P. Dasril, 和 M. Taufik，“气候遥相关触发热带海洋大陆延长干季”，理论与应用气候学，第156卷，第11期，第626页，2025年。
[13] B. P. Shreve，“现代爆炸威胁：简易爆炸装置”，载于《爆炸与冲击事件的操作与医疗管理》，施普林格，2020年，第99–107页。
[14] K. Benedict 和 K. Kaplan，“核威胁与法律（F）效用”，第71–86页，2025年。
[15] A. Farahat, N. El-Kork, R. P. Singh, 和 F. Jing，“贝鲁特 2020 爆炸期间二氧化氮释放可能被高估”，遥感，第14卷，第24期，2022年，doi:10.3390/rs14246377。
[16] C. Weiss 等，“面向 COVID-19 疫情的纳米技术方法”，ACS Nano，第14卷，第6期，第6383–6406页，2020年，doi:10.1021/acsnano.0c03697。
[17] K. Wu 等，“基于磁纳米传感器的病毒与病原体检测策略：COVID-19 期间与之前”，ACS 应用纳米材料，第3卷，第10期，第9560–9580页，2020年，doi:10.1021/acsanm.0c02048。
[18] H. Müller 和 C. Wunderlich，“无核武国家的核裁军：核武器禁令条约”，Daedalus，第149卷，第2期，第171–189页，2020年，doi:10.1162/DAED_a_01796。
[19] I. F. Akyildiz, M. Ghovanloo, U. Guler, T. Ozkaya-Ahmadov, A. F. Sarioglu, 和 B. D. Unluturk，“PANACEA：用于早期检测与缓解传染病的生物-纳米物联网应用”，IEEE Access，第8卷，第140512–140523页，2020年，doi:10.1109/ACCESS.2020.3012139。
[20] X. Castañer 和 N. Oliveira，“组织间协作、协调与合作：通过系统文献综述确立术语的不同含义”，管理学杂志，第46卷，第6期，第965–1001页，2020年，doi:10.1177/01492063209015

65。
[21] O. Access，“加的夫”，2022年。
[22] A. Open 等，
“采用探索性序贯混合方法设计调整非裔美国糖尿病患者的疾病认知问卷：混合数据整合过程”，第2850卷，2021年，doi:10.1080/21642850.2021.1976650。
[23] M. Tahmid, S. Dey, 和 S. R. Syeda，“化学事故下的人类脆弱性与风险映射”，过程工业损失预防杂志，第68卷，第104289页，2020年，doi:10.1016/j.jlp.2020.104289。
[24] K. Dhakal，“NVivo”，
医学图书馆协会杂志，第110卷，第2期，第270–72页，2022年，doi:10.5195/jmla.2022.1271。
[25] E. D. La Cruz，
“使用偏最小二乘结构方程模型的网络安全数据分析系统成功的量化研究”，Αγαη，第15卷，第1期，第37–48页，2024年，
doi:10.13140/RG.2.2.35552.70405。
[26] M. Vuković，“CB-SEM 与 PLS-SEM 在投资意向预测中比较”，克罗地亚运筹学评论，第15卷，第2期，第131–144页，2024年，
doi:10.17535/crorr.2024.0011。
[27] A. E. Legate, J. F. Hair, J. L. Chretien, 和 J. J. Risher，“PLS-SEM：
面向预测的人力资源发展研究解决方案”，人力资源发展季刊，第34卷，第1期，第91–109页，2023年，doi:10.1002/hrdq.21466。
[28] W. C. W. Chan，“COVID-19 的纳米研究”，ACS Nano，第14卷，第4期，第3719–3720页，2020年，
doi:10.1021/acsnano.0c02540。
[29] H. Baharum 等，“验证新毕业护士适应能力测量
工具”，国际环境研究与公共卫生杂志，第20卷，第4期，2023年，doi:10.3390/ijerph20042860。
[30] P. Vounba, S. Loul, L. F. Tamadea, 和 J. F. D. Siawaya，“参与疾病与抗菌素耐药监测的微生物实验室：中非国家的优势与挑战”，非洲实验室医学杂志，第11卷，第1期，第1–10页，2022年，doi:10.4102/ajlm.v11i1.1570。
[31] S. Liu 等，“可持续性：放射性去污技术的前沿综述——
应对核设施退役与拆除的未来浪潮”，2022年。
[32] Y. Guo, G. Francesco, B. Corica, 和 M. Proietti，“欧洲内科杂志：心房颤动合并心力衰竭患者的移动健康技术整合护理——来自 mAFA-II
随机临床试验的报告”，第107卷，2023年7月，第46–51页，doi:10.1016/j.ejim.2022.11.002。
[33] G. F. Romiti, Y. Guo, A. B. Corica, M. Proietti, 和 G. Y. H. Lip，“心房颤动的移动健康技术整合护理：mAFA-II 随机临床试验的胜率分析”，第1042–1048页，2023年。
[34] Y. Guo 等，“来自华为心脏研究与 mAFA II 随机试验的观察”。
[35] L. F. Probst 等，“呼吸防护口罩（N95 型）去污方法：快速综述”，第1–11页，2021年。
[36] S. A. Bhatti, F. H. Memon, F. Rehman, Z. Bhatti, T. Naqvi, 和 K. H. Thebo，“针对化学与生物材料的去污系统最新进展：挑战与未来展望”，2021年。
[37] A. Asgary, M. Aarabi, S. Dixit, H. Wen, M. Ahmed, 和 J. Wu，“COVID-19 疫情期间公共卫生应急行动中心的建模、仿真、可视化与地图应用调查”，2024年。
[38] D. P. Melters 和 Y. Dalal，“纳米监控：在染色质海洋中跟踪单个分子”，分子生物学杂志，第433卷，第6期，2021年，doi:10.1016/j.jmb.2020.11.019。
[39] R. E. Caraka 等，“西巴布亚地区针对自然灾害、非自然灾害及社会灾害的脆弱性潜变量聚类分析”，IEEE Access，第9卷，第1972–1986页，2021年，doi:10.1109/ACCESS.2020.3038883。
[40] J. F. Hassard 和 M. S. Nieuwenhuizen，“化学威胁”，科学技术安全应用进展，第17–46页，2022年，doi:10.1007/978-3-031-17374-5_2。
[41] N. F. Wendimagegn 和 M. C. Bezuidenhout，“在埃塞俄比亚亚的斯亚贝巴医院与卫生中心整合促进性、预防性和治疗性医疗服务”，多学科医疗杂志，第12卷，第243–255页，2019年，doi:10.2147/JMDH.S193370。
[42] A. Elnaiem 等，“‘一体化健康’全球

与区域治理及其对全球卫生安全的影响”，柳叶刀，第401卷，第10377期，第688–704页，2023年，doi:10.1016/S0140-6736(22)01597-5。
[43] C. Xu, C. Lei, S. Hosseinpour, S. Ivanovski, L. J. Walsh, 和 A. Khademhosseini, “纳米技术在 COVID-19 疫情期间及后疫情时代的管理应用”，国家科学评论，第9卷，第10期，2022年，doi:10.1093/nsr/nwac124。
[44] G. M. Havârneanu, L. Petersen, A. Arnold, D. Carbon, 和 T. Görgen, “通过加强与安全从业者合作提高铁路利益相关者应对 CBRNe 威胁的能力”，应用人体工程学，第102卷，2022年3月，doi:10.1016/j.apergo.2022.103752。
[45] T. H. Bhat, G. Jiawen, 和 H. Farzaneh, “空气污染健康风险评估（Ap-HRA）原理与应用”，国际环境研究与公共卫生杂志，第18卷，第4期，第1–29页，2021年，doi:10.3390/ijerph18041935。
[46] E. M. Hassan 和 H. Mahmoud, “自然灾害后医疗与教育网络互动作为社会服务稳定性的指标”，科学报告，第11卷，第1期，第1–15页，2021年，doi:10.1038/s41598-021-81130-w。
[47] S. Riadi 和 Erdiyansyah, “基于公共管理视角的自然与非自然灾害协作治理：印尼案例”，管理问题与视角，第19卷，第2期，第468–479页，2021年，doi:10.21511/ppm.19(2).2021.37。
[48] J. Janse 等，“传染病暴发管理中的民用-军用合作：范围综述”，BMJ 全球健康，第7卷，第6期，第1-13页，2022年，doi:10.1136/bmjgh-2022-009228。
[49] D. Settembre-Blundo, R. González-Sánchez, S. Medina-Salgado, 和 F. E. García-Muiña, “企业决策中的灵活性与韧性：基于可持续性的风险管理新系统”，全球柔性系统管理杂志，第22卷，2021年12月，第107–132页，doi:10.1007/s40171-021-00277-7。
[50] D. G. Sami 和 S. Chun, “强化地面边境口岸的健康安全：改善应急准备与响应的关键要素——范围综述”，Healthcare，第12卷，第19期，2024年，doi:10.3390/healthcare12191968。
[51] A. Khorram-Manesh, L. J. Mortelmans, Y. Robinson, F. M. Burkle, 和 K. Goniewicz, “COVID-19 疫情前后民用-军用合作——系统综述及从业者试点调查”，可持续性，第14卷，第2期，2022年，doi:10.3390/su14020624。
[52] E. R. Cui 等，“急性冠状综合征疑似患者的急救医疗服务时间差异：来自北卡罗来纳州院前医疗信息系统的发现”，美国心脏协会杂志，第10卷，第15期，第1–12页，2021年，doi:10.1161/JAHA.120.019305。
[53] O. A. Ogunseitan, “一体化健康与环境：从概念框架到实施科学”，环境，第64卷，第2期，第11–21页，2022年，doi:10.1080/00139157.2022.2021792。
[54] Y. Yu, J. Ding, Y. Zhou, H. Xiao, 和 G. Wu, “生物安全化学与生物安全材料：解决生物安全问题的新视角”，生物安全与健康，第4卷，第1期，第15–22页，2022年，doi:10.1016/j.bsheal.2022.01.001。
[55] M. G. Dente 等，“增强全球健康威胁应对能力：基于一体化健康方法的范式转变”，One Health，第14卷，2022年2月，第100396页，doi:10.1016/j.onehlt.2022.100396。
[56] M. Ku, A. Han, 和 K. H. Lee, “集中式灾害治理中跨部门合作动态：韩国中东呼吸综合征疫情期间组织间协作网络研究”，国际环境研究与公共卫生杂志，第19卷，第1期，2022年，doi:10.3390/ijerph19010018。
[57] S. Nazari, S. Sharififar, M. Ahmadi Marzaleh, S. Zargar, S. Azarmi, 和 Y. Akbari Shahrestanaki, “院前卫生响应团队应对化学、生物、辐射及核事件（CBRN）的结构要素与要求：比较综述研究”，灾害医学与公共卫生准备，第17卷，第9期，2023年，doi:10.1017/dmp.2022.259。

[58] F. Taveira-Pinto, P. Rosa-Santos, 和 T. Fazeres-
Ferradosa, “人类活动对综合沿海区域管理的影响”, 综合沿海区域管理杂志，第20卷, 第4期, 第215–217页，2020年, doi:10.5894/rgci-n428。
[59] M. Geretto 等, “军人职业暴露与环境健康危害”, 国际环境研究与公共卫生杂志，第18卷, 第10期, 2021年, doi:10.3390/ijerph18105395。
[60] R. Rai, S. El-Zaemey, N. Dorji, B. D. Rai, 和 L. Fritschi, “低中收入国家医疗人员职业危害暴露：范围综述”, 国际环境研究与公共卫生杂志，第18卷, 第5期, 第1–41页，2021年, doi:10.3390/ijerph18052603。
[61] S. H. Latonen, R. M. Suominen, A. M. Juppo, M. Airaksinen, 和 H. Seeck, “COVID-19 疫情期间药品供应链利益相关者跨部门合作组织及其对危机管理有效性的影响”, 公共卫生，第222卷, 第196–204页，2023年, doi:10.1016/j.puhe.2023.06.042。
[62] J. L. Fallowfield 等, “在军事环境中促进健康与人体表现的整体系统方法：保障部队准备与作战能力的关键前提”, 生理学前沿, 第16卷, 2025年4月, 第1–8页，doi:10.3389/fphys.2025.1541256。
[63] M. P. Fitchett, P. M. Saffy, 和 C. M. Lewis, “药物中毒解毒剂的可用性及医生观点”, 南非科学杂志，第120卷, 第7–8期, 第1–10页，2024年, doi:10.17159/sajs.2024/16394。
[64] S. Kudłacik-Kramarczyk, W. Kieres, A. Przybyłowicz, C. Ziejewska, J. Marczyk, 和 M. Krzan, “用于实时监测、早期疾病诊断与药物疗法监控的微纳增强血管内生物传感器的最新进展”, 传感器，第25卷, 第15期, 第1–25页，2025年, doi:10.3390/s25154855。
[65] X. Hu, K. Naim, S. Jia, 和 Z. Zhengwei, “中国灾害政策与应急管理改革：从汶川地震到九寨沟地震”, 国际灾害风险减少杂志，第52卷, 2021年6月, doi:10.1016/j.ijdrr.2020.101964。
[66] L. Ispas, C. Mironeasa, 和 A. Silvestri, “综合管理体系实施中的基于风险方法：系统文献综述”, 可持续性，第15卷, 第13期, 第1–22页，2023年, doi:10.3390/su151310251。
[67] S. Gastaldi 和 M. Horlait, “多组织灾害管理中医疗机构互操作性：范围综述”, 院前灾害医学, 第37卷, 第3期, 第401–408页，2022年, doi:10.1017/S1049023X22000516。
[68] E. Emaliyawati 等, “通过桌面灾害演练增强灾害应急准备：对医务人员和学生的益处范围综述”, 医学教育实践进展，第16卷, 第1–11页，2025年, doi:10.2147/AMEP.S504705。
[69] B. Lillywhite 和 G. Wolbring, “应急与灾害管理、准备与规划的风险叙事（EDMPP）：‘社会’因素的重要性”, 可持续性，第15卷, 第1期, 第1–36页，2023年, doi:10.3390/su15010387。
[70] R. Perz, “无人机系统的多维威胁：探索生物力学、技术、操作与法律解决方案以保障安全”, 运输档案，第69卷, 第1期, 第91–111页，2024年, doi:10.61089/aot2024.h7j32562。
[71] E. Medaa, A. A. Shirzadi Javid, H. Malekitabar, 和 S. Banihashemi, “分析协同与累积模型（SAMA）：针对深水地平线灾难案例的建筑风险分析新方法”, 建筑, 第15卷, 第11期, 第1–27页，2025年, doi:10.3390/buildings15111879。
[72] E. S. Qzih 和 M. M. Ahmad, “基于医院的 CBRNE 灾害应急措施：系统综述”, 环境健康洞察，第18卷, 2024年, doi:10.1177/11786302241288859。
[73] S. Bandyopadhyay 等, “全球医疗工作者 COVID-19 感染与死亡：系统综述”, BMJ 全球健康, 第5卷, 第12期, 2020年, doi:10.1136/bmjgh-2020-003097。
[74] C. K. Zogg 等, “为直接护理辩护：限制进入军事医院可能恶化质量与安全”, 第57卷, 第4期, 2022年, doi:10.1111/1475-6773.13885。
[75] H. Sofyana, K. Ibrahim, I. Afriandi, 和 E. Herawati, “基于公共卫生护理的灾害准备培训

整合模型（ILATGANA-PHN）在自然灾害高发区提高社区能力的实施”，BMC 护理，第23卷，第1期，第1–18页，2024年，doi:10.1186/s12912-024-01755-w。

[76] V. Sandoval, M. Voss, V. Flörchinger, S. Lorenz, 和 P. Jafari，“综合灾害风险管理（IDRM）：推进研究与评估的要素”，国际灾害风险科学杂志，第14卷，第3期，第343–356页，2023年，doi:10.1007/s13753-023-00490-1。

[77] J. Ranse 等，“强化急诊科对化学、生物、辐射及核灾害的应对能力：范围综述”，澳大利亚急救护理，第28卷，第1期，第37–47页，2025年，doi:10.1016/j.auec.2024.09.003。

[78] C. Wankmüller 和 G. Reiner，“救援供应链管理中的协调、合作与协作”，第90卷，第2期，Springer Berlin Heidelberg，2020年，doi:10.1007/s11573-019-00945-2。

[79] H. Wyrębek，“国家安全挑战与威胁”，国防知识，第279卷，第2期，第109–123页，2022年，[在线]。可访问：https://doi.org/10.34752/2022-e279

[80] H. Wang, J. Sun, Y. Shi, 和 T. Shen，“通过跨部门协作提升公共卫生应急管理策略的有效性：基于中国15个城市的配置分析”，公共卫生前沿，第10卷，2022年，doi:10.3389/fpubh.2022.1032576。

[81] T. R. Frieden, L. K. Cobb, R. C. Leidig, S. Mehta, 和 D. Kass，“将心血管及其他非传染性疾病过早死亡率降低三分之一：实现可持续发展目标指标3.4.1”，全球心脏，第15卷，第1期，第1–10页，2020年，doi:10.5334/GH.531。

[82] J. Chikovore 等，“缺失的结核男性：需应对结构性影响并实施有针对性、多维干预”，BMJ 全球健康，第5卷，第5期，2020年，doi:10.1136/bmjgh-2019-002255。

[83] W. Jiang 等，“迈向互操作的多灾害建模：灾害模型服务链的灾害管理系统”，国际灾害风险科学杂志，第13卷，第6期，第862–877页，2022年，doi:10.1007/s13753-022-00450-1。

[84] L. Yao 等，“环境监测中冠状病毒检测及大流行控制风险监测”，化学学会评论，第50卷，第6期，第3656–3676页，2021年，doi:10.1039/d0cs00595a。

[85] K. Sapountzaki，“灾害下的风险缓解、脆弱性管理与韧性”，可持续性，第14卷，第6期，2022年，doi:10.3390/su14063589。

[86] K. Gooding, M. P. Bertone, G. Loffreda, 和 S. Witter，“如何加强卫生系统应急准备与响应的伙伴关系与协调？来自多国应对冲击经验的综合发现”，BMC 卫生服务研究，第22卷，第1期，第1–19页，2022年，doi:10.1186/s12913-022-08859-6。

[87] A. M. Gavrila, A. Diacon, T. V. Iordache, T. Rotariu, M. Ionita, 和 G. Toader，“危险材料威胁安全：分子印迹聚合物作为多功能防护平台”，聚合物（巴塞尔），第16卷，第19期，2024年，doi:10.3390/polym16192699。

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