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Highlights:

- Prevention and defense constitute the core framework of disaster preparation.
- prediction, early warning, and forecasting are crucial technical means for natural disaster prevention.
- "Defense" encompassing both personnel-led and facility-led defensive approaches.

Keywords:

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Warning
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Prevention and Defense Technologies for Natural Disasters: A Review

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Abstract Based on the theoretical framework of natural disaster prevention and emergency response systems, this study analyzes the core connotations of "prevention" and "defense" within the pre-disaster prevention and control system for natural disasters, along with their synergistic mechanisms, uncovering their foundational roles in enhancing emergency response effectiveness and reducing disaster losses. The theoretical research results and practical models related to prevention and defense of natural disasters both domestically and internationally, are systematically reviewed in this paper, with a focus on analyzing the performance and existing issues in typical disaster cases, as well as analyzing successful cases and the shortcomings in actual emergency situations, by using literature review and case analysis. Through comparative case analysis, we propose three major research areas for future natural disaster prevention and defense: 1) advancing research on disaster mechanisms and innovating comprehensive prevention and control theories, 2) optimizing emergency management coordination systems and resilient resource allocation, and 3) strengthening technological support and enhancing social collaboration capabilities.

1. Introduction

The evolution of natural disaster management system began in the late 1980s, with the gradual formation of a global framework for disaster reduction collaboration led by the United Nations. The Sendai Framework for Disaster Risk Reduction, adopted in 2015, further promoted the upgrading of disaster prevention and mitigation mechanism, and established the United Nations Office for Disaster Risk Reduction (UNDRR) as the core institution for global disaster reduction policy coordination (Rokhideh et al., 2025; Wu, 2023). During this stage, a multi-level coordination mechanism was developed, including UNDRR's overall responsibility for formulating global disaster reduction strategies and coordinating countries and regions in implementing risk monitoring and assessment. Through the regularly updated Global Assessment Report on Disaster Risk Reduction and digital risk management platforms, a full-cycle governance model for natural disasters covering pre-disaster prevention, emergency response, and recovery and reconstruction has been established. With the continuous deepening of reforms in the emergency management system and mechanisms, countries such as the United States, Germany, Japan, and China have taken the lead in systematically standardizing and improving national-level preparations for natural disaster relief, emergency response, and safeguarding measures (He et al., 2021; Liu et al., 2024; Zhu, 2005; Kong et al., 2024; Li et al., 2004).

In recent years, with global climate change and intensified human activities, extreme weather events have occurred frequently, and the frequency, intensity, extremity, and disaster chain characteristics of global natural disasters have increased significantly (Figure 1) (Newman et al., 2023; Nohrstedt et al., 2022; Xue et al., 2024; Cui et al., 2021; Liu et al., 2024; Yin et al., 2021). As an important tool for addressing natural disasters, the formulation and implementation of natural disaster relief emergency plans hold immense value for effectively coping with natural disasters, mitigating disaster losses, safeguarding people's lives, maintaining social stability, and promoting sustainable economic and social development (Xue et al., 2024; Zhang et al., 2016). The core idea of natural disaster relief emergency plans lies in establishing a natural disaster prevention and control system, preparing early, and responding quickly. The essential elements include delineating the responsibilities and duties of departments at all levels during natural disaster emergencies, the procedural frameworks and coordination strategies for emergency response, and guaranteeing that a swift initiation and response can be mobilized to organize and coordinate diverse emergency rescue resources, thus ensuring that emergency relief operations are conducted in an orderly and efficient manner.

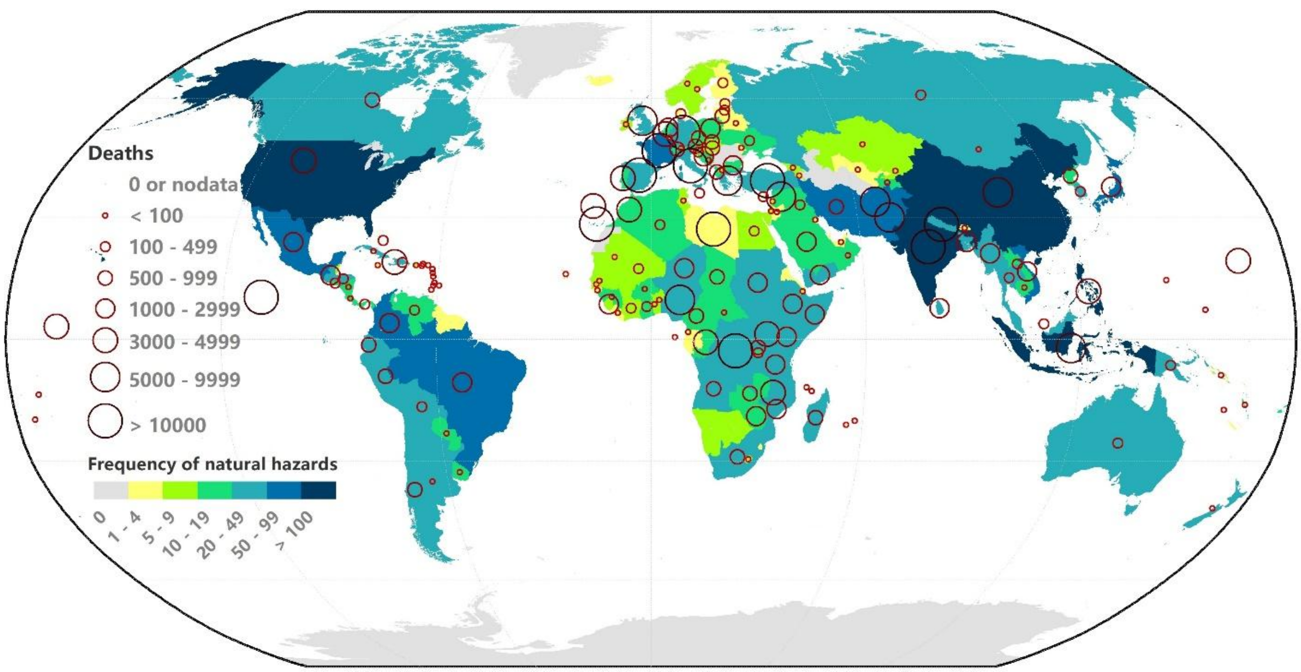

Fig. 1 The frequency and death toll of natural disasters causing serious losses worldwide in the past decade (2015-2024). The data is derived from EM-DAT (https://www.emdat.be/)

Prevention and defense constitute the core framework of disaster preparation within the natural disaster prevention and control system (Xu et al., 2016; Tang, 2022; Zhao et al., 2022; Feng, 2024; Peng et al., 2024). “Prevention” refers to risk anticipation, which involves using scientific and technological means to conduct risk assessment, early warning, and prediction. Through scientific anticipation of the temporal and spatial distribution, intensity levels, and impact scope of disasters, it provides support for emergency response decision-making (Tang, 2022; Zhang, 2020; Hu et al., 2021; Peng et al., 2022). This process demands high standards for data quality, scientific rigor, and advanced technological methods to ensure the accuracy and timeliness of early warning outcomes, thereby gaining a critical emergency window period for subsequent response efforts. “Defense” entails systematic protection based on the outcomes of risk anticipation, encompassing engineering and non-engineering protective measures such as enhancing the disaster resilience of infrastructure, improving emergency response mechanisms, and strengthening civil and material defenses (Lu et al., 2020; Feng, 2024; Peng et al., 2024). Its essence lies in constructing a multi-dimensional disaster defense system to achieve closed-loop management of proactive pre-disaster defense, efficient in-disaster response, and rapid post-disaster recovery, thereby effectively ensuring social operational safety and stability of people's livelihoods.

Therefore, in the face of the severe situation of current global climate change and frequent extreme weather events, prevention and defense, as important components of the natural disaster prevention and control system, require systematic review and analysis of their connotations and current development status. However, existing research has primarily focused on individual technological or policy domains, lacking a dynamic analysis of the synergistic mechanisms between "prevention" and "defense", and insufficiently assessing the cumulative effects of the application of preventive technologies and the establishment of defense systems. Therefore, this paper aims to explore the significant role of pre-disaster prevention in the entire process of natural disaster emergency rescue, its current implementation status, and the challenges ahead. Through literature review, case analysis, and other multi-level and multi-dimensional analysis methods, it systematically sorts out the theoretical research results and practical experiences regarding prevention and defense of natural disasters both domestically and internationally. The paper conducts an in-depth analysis of successful cases and shortcomings in the practical application of "prevention" and "defense" and proposes future development directions and priorities, as well as strategies and suggestions for enhancing disaster response capabilities. It could provide theoretical support and practical basis for further improving the disaster prevention and mitigation system.

2. Natural disaster prediction, early warning, and forecasting

2.1. The meaning and definition of prediction, warning, and forecasting

In the current scientific and technological framework for natural disaster prevention and mitigation, prediction, early warning, and forecasting are crucial technical means for natural disaster prevention. Natural disaster prediction involves the scientific deduction of factors such as the occurrence probability, intensity parameters, and impact scope of disasters through the integration of diverse technical approaches, including historical data, real-time observations, expert experience, and mathematical models (Guo et al., 2022; Hu et al., 2021; Xu et al., 2016; Ma et al., 2019; Tang, 2022). The natural disaster prediction requires comprehensive consideration of multiple environmental elements and is constrained by the complexity of disaster-causing mechanisms, resulting in probabilistic characteristics and uncertainties in prediction outcomes. Early warning denotes the emergency response procedure wherein specialized agencies or departments disseminate danger avoidance action directives or plans based on a dynamic monitoring system to possibly affected entities when a natural disaster attains its critical phase (Fan et al., 2019; Kuglitsch et al., 2024; Naidu et al., 2018; Rasheed et al., 2022; Li et al., 2013). However, natural disasters with strong suddenness such as flash floods and debris flow commonly face technical bottlenecks with high false alarm rates (Feng et al., 2016; Ren et al., 2023). Although forecasting technology falls broadly under the category of anticipation, it is currently mainly applied in the field of meteorological disasters (Qian et al., 2024; Zhao et al., 2022). Prediction, early warning, and forecasting of natural disaster constitute a progressive technological chain in natural disaster risk prevention. The essential difference among these three concepts lies in the need for early warning to simultaneously provide evasive action guidelines. When prediction and forecasting technologies exceed confidence thresholds and meet the conditions for issuing emergency instructions, they can be transformed into early warning functions. This progressive relationship at the technical level constitutes the technical chain for natural disaster risk prevention. This chained relationship reflects the technical logic of the natural disaster risk prevention system (Table 1).

Table 1. Comparison of differences between natural disaster prediction, early warning, and forecasting

	Prediction	*Early warning*	*Forecasting*
Technical means	Mathematical models, expert experience, or multi-source data fusion	Dynamic monitoring network, and threshold determination method	Numerical simulation, and real-time monitoring data assimilation
Main applications	Earthquakes, landslides, floods, droughts, etc. affected by multiple environmental factors	Natural disasters with strong suddenness	Meteorological disasters such as rainstorms and cold waves
Output form	Probability map, or risk zoning	Warning level	Time series intensity evolution and impact range simulation
Uncertainty characteristics	Probabilistic conclusions with errors caused by complex mechanisms	High false warning rate	Controllable meteorological errors (such as high accuracy in 24-hour forecasts)
Core functions	Supporting medium and long-term disaster prevention planning	Trigger emergency response and personnel avoidance	Priority guidance for defense measures and resource allocation
Technology conversion relationship	It can be converted into an early warning basis when the confidence threshold is reached	Integrate prediction and forecast results to achieve an action directive	Meteorological forecasts can facilitate early warning; nonetheless, conversion rates for other disaster categories remain low.

2.2. Evolution of Prediction, Early Warning, and Forecasting

As early as the 1950s and 1960s, countries like the Soviet Union and the United States began applying satellite technology to the monitoring and early warning of natural disasters, initiating plans such as “Space Technology for the Protection of the Earth” and “Cosmic Observation Experimental Satellites”. During the same period, China established a field observation-based natural disaster prediction and forecasting system, forming empirical judgment-based predictions and forecasts grounded in natural observation data (Xu et al., 2004; Yang et al., 2004). In the 1980s, international disaster prevention technology entered a period of explosive growth in remote sensing applications, with the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) deploying the METEOSAT series of satellites and the United States Geological Survey (USGS) constructing disaster warning models based on Landsat imagery. Technologies utilizing satellite technology for monitoring natural disasters were widely applied, and remote sensing-based prediction and early warning technologies for earthquakes, volcanoes, meteorological disasters, and other hazards developed rapidly (Fan et al., 1988; Liu et al., 2004; Zhang, 1990; Iglseder et al., 1995). During the 1990s, the computing revolution catalyzed advancements in natural disaster prevention technology, leading to the consecutive proposal of artificial intelligence algorithms. Scientists attempted to use computer technology and artificial neural networks for disaster prediction for earthquakes, oceans, and meteorology (Foody et al., 1997; Li et al., 1995). Since the onset of the 21st century, advancements in natural disaster early warning, prediction, and forecasting have accelerated, facilitated by remote sensing, earth observation, and computer technology, particularly through the application of 3S technologies (GIS, RS, and GPS) and mathematical models. Prediction or forecasting models for various disaster types have been developed utilizing historical disaster case data through statistical analysis; nevertheless, most are semi-empirical and semi-theoretical, exhibiting considerable limits (Gassner et al., 2002; Xu et al., 2009; Zhang, 2020). Although current mainstream international prediction models have surpassed the constraints of empirical formulas, they are still subject to significant uncertainties due to the complexity of the Earth system.

2.3. Current Developments in Prediction, Early Warning, and Forecasting Technologies

Against the backdrop of intensifying global climate change, extreme weather events are characterized by increased frequency and intensity. The evolving landscape of new disaster risks and advancements in disaster prevention concepts necessitate higher precision in disaster prediction and early warning technologies. With continuous technological innovation, big data and artificial intelligence (AI) provide new impetus for disaster prevention (Xue et al., 2023; Zhang et al., 2023; Liu et al., 2020; Peng et al., 2022; Xu, 2012; Zhao et al., 2022). Currently, the methodology system for natural disaster prediction, early warning, and forecasting has gradually shifted from traditional empirical and monitoring data-based statistical methods to intelligent methods grounded in big data on natural disaster backgrounds, ubiquitous sensing data, and AI frameworks. The application forms of prediction, early warning, and forecasting technologies have also transitioned from traditional standalone environments to informatized, integrated, and automated cross-domain and cross-modal network application environments (Ahmed et al., 2018; Wu et al., 2022; Yang et al., 2024). The current technological system has undergone transformations at three levels: methodological, application, and technical architecture. Methodologically, it has surpassed the limitations of traditional statistical models, establishing an intelligent analysis framework that integrates disaster background databases, ubiquitous sensing networks, and deep learning. At the application level, it has transformed from a standalone mode to a cross-domain collaborative system, forming an integrated and automated multi-modal early warning network. Technically, it encompasses six core modules, including satellite remote sensing monitoring, unmanned aerial vehicle (UAV) intelligent inspection, and digital twin simulation, achieving full-chain coverage for disaster identification, assessment, and early warning. The characteristics of prediction, forecasting, and early warning technologies have continuously evolved from single-hazard, point-specific, coarse-resolution, slow response, and high error rates to multi-hazard, disaster chain-oriented, high-resolution, rapid response, and high accuracy (Figure 2).

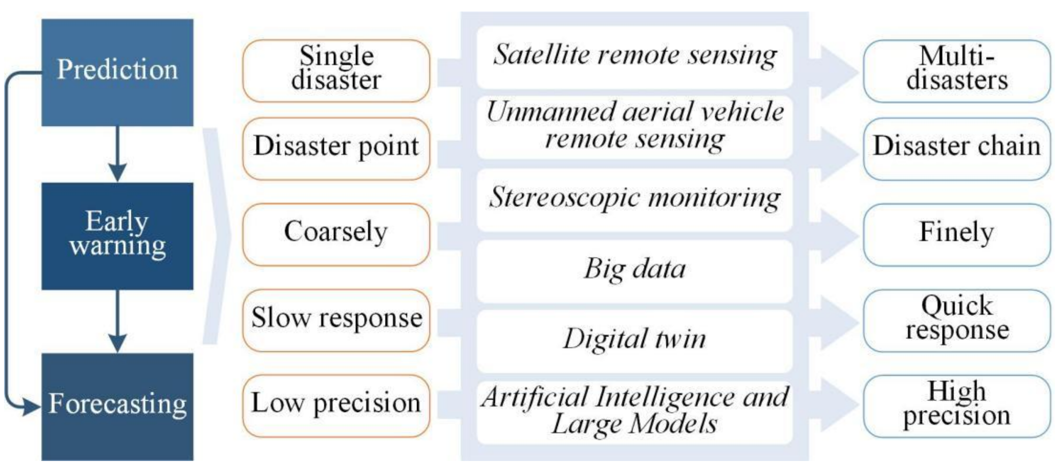

Fig. 2 The logical relationship and development status of natural disaster prediction, early warning, and forecasting

3. Natural disaster defense measures

3.1. The basic types and significance of defense

Disaster prevention of natural hazards falls under non-routine defensive measures. “Defense” constitutes a systematic project encompassing both personnel-led and facility-led defensive approaches (Figure 3) (Xue et al., 2024; Guo, 2025; Ibrahim et al., 2023). Personnel-led defense involves utilizing individuals' experiential knowledge, perception abilities, and action capabilities to patrol, detect, and identify hazards, followed by adopting corresponding measures for prevention and response (Marchezini et al., 2025). Its core lies in leveraging personnel's subjective initiative and on-site disposal efficiency. Functionally, the tasks of personnel-led defense encompass organizational structure and responsibility allocation, rescue team building, workgroup guidance and inspection, duty shifts and hazard monitoring, team drills and training, publicity, and public education. Facility-led defense focuses on physical protective functions, utilizing physical means to prevent and mitigate losses caused by natural disasters, emphasizing the role of physical facilities, resources, and materials. In pre-disaster preparations for natural hazards, this includes both engineering and non-engineering physical defense measures (Xu et al., 2025). Engineering measures encompass structural reinforcement for resistance, emergency shelters, resilient protective engineering, among others. Non-engineering measures include emergency relief supplies and rescue equipment and devices. These two defensive approaches are interconnected, maintain a dynamic balance, and support each other.

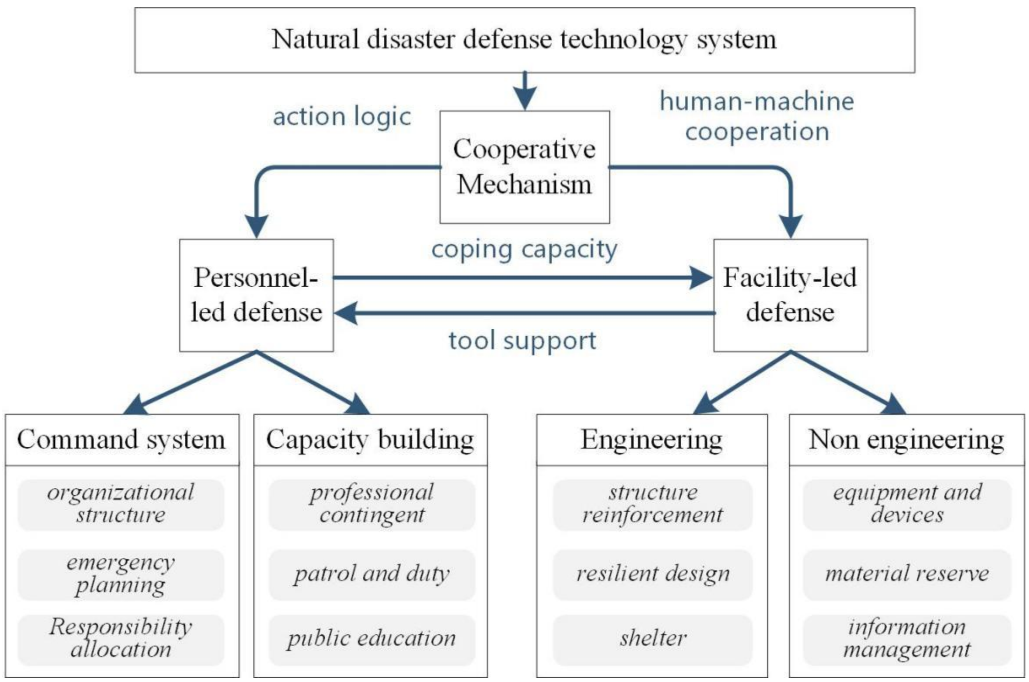

Fig. 3 Functional framework of natural disaster defense measures

3.2. Current development of personnel-led defense technologies

In the domain of pre-disaster planning for natural hazards, personnel-led defense traditionally involved monitoring, risk assessment, early warning, and response carried out by specialized individuals in relation to natural catastrophes. However, the significance of personnel-led defense extends far beyond this, embodying a comprehensive and multi-layered protection system centered on human beings, enriched with technological empowerment and social co-governance. For instance, in terms of organizational structure and responsibility division for natural disaster response, a well-established framework and clear division of labor are necessary, encompassing cross-departmental collaboration and a well-defined coordination and joint mechanism for functions and responsibilities. To establish rescue teams, it is essential to integrate emergency response, firefighting, armed police, public security, medical, publicity, and specialized rescue teams from diverse sectors, thereby creating a government-led and socially engaged emergency rescue system. High-level professional teams are necessary to support workgroup guidance and inspection, with governments and relevant departments at all levels forming expert teams in diverse fields to offer timely guidance, coordination, inspection, and evaluation of the execution of prevention and control measures. In duty shifts and hazard monitoring, similar to traditional defense concepts, modern technological means are used in combination with real-time monitoring and early warning systems to provide a scientific basis for disaster prevention. In team drills and training, emphasis is placed on skill enhancement of professional teams, strengthening team support for disaster emergency response and relief by continuously improving their emergency response and collaborative combat capabilities. In public relations and education, initiatives aim to promote self-rescue, mutual rescue, and social co-governance by utilizing diverse channels and methods to disseminate information on natural disaster prevention and management, thereby improving public awareness of disaster prevention and enhancing self-rescue and mutual rescue competencies. With the development of technology and the deepening of the personnel-led defense concept, personnel-led defense is gradually integrating into digitalization and intelligence, utilizing advanced technological means to improve the rationality of resource allocation and enhance the accuracy and timeliness of monitoring and early warning (Jing et al., 2024; Liu et al., 2018; Zhang et al., 2019; Dikshit et al., 2024; Mondini et al., 2023).

3.3. Current development of facility-led defense technologies

In the context of pre-disaster preparation for natural hazards, facility-led defense methods serve as crucial lines of defense against disaster impacts and losses, with their technological levels continuously evolving and innovating in response to technological advancements and societal needs. In terms of engineering-based defense, significant progress has been made in recent years in the reinforcement of buildings and their resistance to natural disaster impacts. From traditional concrete reinforcement to modern high-performance composite material reinforcement techniques, these advancements have not only enhanced buildings' capabilities to withstand earthquakes, floods, winds, and other hazards but have also achieved high efficiency, environmental protection, and cost-effectiveness (Lu et al., 2020; Yu, 2021). Technical optimizations and updates in areas such as planning and construction of comprehensive emergency shelters and evacuation routes, as well as the development of intelligent resilient protection engineering systems, have further strengthened the overall disaster prevention effectiveness of engineering works and sustainable protection systems. On the non-engineering side of defense, on the one hand, the emergency relief material reserve system has become increasingly sophisticated, establishing a multi-level reserve network from national to local levels. Some regions have integrated informatization and intelligent management methods, enabling real-time updates and rapid responses to information on the types, quantities, and storage locations of reserve materials, gradually achieving precise allocation and efficient utilization of emergency relief materials. On the other hand, the technological sophistication of emergency rescue equipment has been increasing, evolving from traditional simple tools to today's intelligent or large-scale equipment such as drones, robots, and life detectors, providing stronger technical support and more precise and efficient solutions for emergency rescue operations in actual combat scenarios (Feng, 2024; Zhu et al., 2024).

4. Case study on preparation for natural disasters

Natural disasters such as earthquakes, geological hazards, typhoons, floods, and droughts not only pose direct threats to people's lives and properties but also pose severe challenges to social stability and economic development (Figure 4) (Dowling et al., 2014; Paprotny et al., 2018; Wyss et al., 2022; Xu et al., 2021; Xu, 2018; Zhang et al., 2024; Zhou et al., 2019).

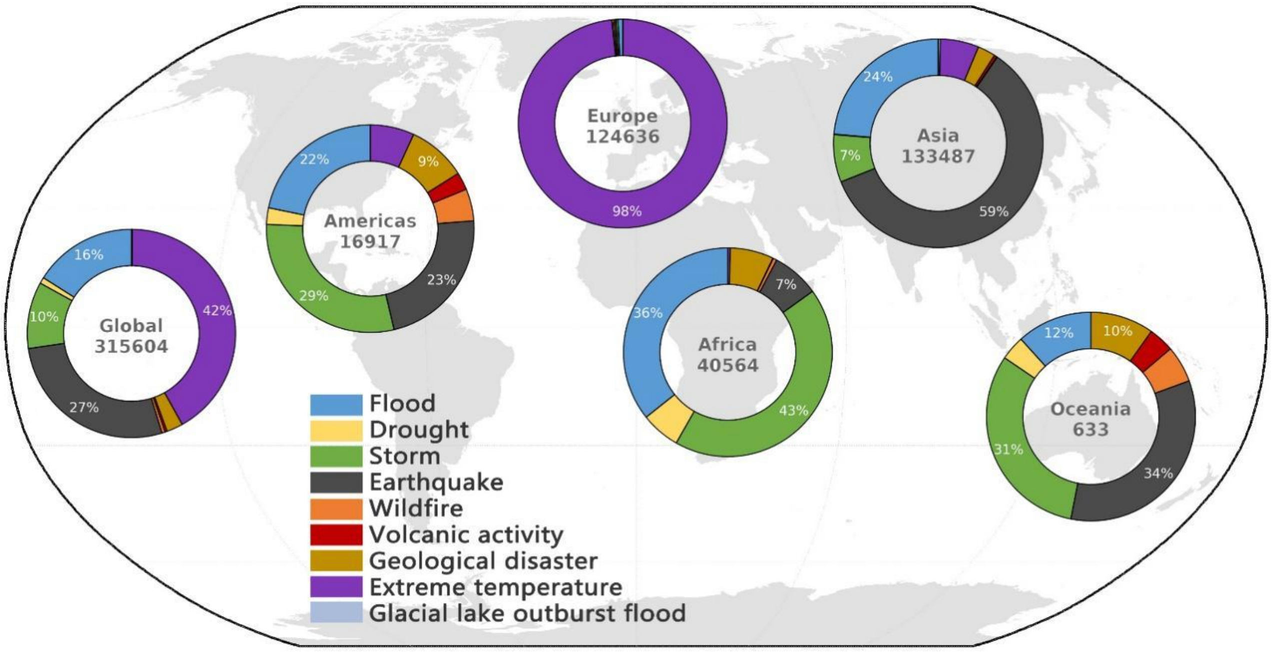

Fig. 4 Human casualties caused by major natural disasters all over the world in the past decade. The data is derived from EM-DAT (https://www.emdat.be/)

4.1. Earthquake

Earthquakes cannot be predicted with certainty, but they can be warned about and defended against. Following the 1976 Ms7.8 Tangshan earthquake, China gradually established the principle of "prioritizing prevention and combining prevention with relief" for earthquake disaster prevention and mitigation, and formulated relevant laws on this topic (Yimingbahai, 2018). The devastating "5.12" Wenchuan earthquake in 2008 caused significant damage to high-intensity areas. During the disaster, the destruction was caused partly by ground motions exceeding the design earthquake level, surface deformation, and widespread landslides and collapses, and partly by a considerable number of poorly earthquake-resistant buildings in urban areas and extremely poor earthquake resistance of rural houses, which led to higher casualties (Gao et al., 2008). On February 6, 2023, Turkey was hit by two consecutive Ms7.8 earthquakes. Investigations revealed that the poor quality of building materials such as concrete, lack of seismic reinforcement in steel structures, failure to comply with seismic design standards, and weak foundations were the main reasons for the severe damage to buildings (Wang, 2023). More than 80% of the deaths and missings during the 2022 Ms6.8 Luding earthquake were caused by geological disasters triggered by the earthquake. Moxi Town, located in the epicenter, had a design earthquake intensity of IX level. Although many severely damaged residential buildings were observed, the reinforcement and retrofitting works conducted on old urban communities undoubtedly greatly reduced casualties caused by building collapses and burials (Peng et al., 2024). Therefore, in earthquake disaster prevention, besides "post-earthquake warning", physical protection remains a primary means of disaster prevention and mitigation. China should improve the earthquake resistance of buildings such as houses based on earthquake hazard assessment and zoning. Especially in rural areas with weak earthquake disaster prevention and mitigation capabilities and poorly earthquake-resistant houses, seismic reinforcement and retrofitting should be carried out. Additionally, robust and well-equipped shelters, enhanced life search capabilities in complex environments, and standardized strategies for grassroots disaster relief material reserves are also important ways to improve earthquake disaster response capabilities (Liu et al., 2024).

4.2. Meteorological disaster

Meteorological disasters come in various forms and exhibit complex chain effects, causing immense losses to lives and properties worldwide. The prevention and response to meteorological disasters have become the focus of attention across all sectors of society. Taking torrential rain and typhoons as examples, the “7.20” extreme torrential rain disaster in Zhengzhou, China, in 2021, and the “23.7” extreme torrential rain and flood disaster in the Haihe River Basin, China, in 2023, both reflect numerous issues in disaster prevention and mitigation as well as emergency responses (Gao et al., 2024; Xiao, 2023). Before the heavy rainfall commenced, substantial losses were incurred despite forecasts and early warnings from meteorological agencies, attributed to insufficient reforms and emergency management system deployments in certain regions, flawed emergency response protocols, and inadequate civil defense measures, including poor preparation and deployment for disaster relief efforts. During the severe flooding in the Rhine River basin in Germany in July 2021, despite the European Flood Awareness System (EFAS) issuing heavy rainfall forecasts several days in advance, inadequate interpretation of the warning information by local governments and the absence of community-level emergency evacuation plans ultimately resulted in at least 184 deaths and billions of euros in economic losses. It underscores the critical challenge of translating precise warnings into grassroots emergency response actions (Zander et al., 2023). Typhoon “Doksuri” in 2023 was the strongest typhoon to make landfall in Southeast Asia in recent years, triggering disaster chains such as “typhoon-torrential rain-waterlogging” and “typhoon-torrential rain-flash floods-landslides” in coastal and mountainous regions. Due to the predictability of the typhoon's path and disaster intensity, affected areas such as Fujian, China, conducted advance preparations for disaster emergency response and relief, deploying arrangements according to unconventional emergency response plans. These included patrols and hidden danger investigations in densely populated and key areas, comprehensive investigations of secondary disaster sites, and 24/7 standby operations by troops, armed police, militias, fire and rescue teams, and professional technicians for danger removal and emergency rescue work (Zhang, 2024). The disaster response and emergency process fully demonstrated the important value of collaboration and linkage among various aspects of natural disaster preparedness, including disaster prediction, forecasting, and early warning, the construction of supporting mechanisms, personnel-led defense, and facility-led defense, thereby minimizing the losses caused by the disaster.

4.3. Geological disaster

In the late 1990s, China initiated the construction of a community-based geological disaster monitoring and prevention system. By 2003, China had commenced meteorological risk warning for geological disasters in several regions and gradually promoted meteorological warning response measures for geological disasters (Liu et al., 2015). Earthquake-induced geological disasters have always garnered extensive attention due to their wide disaster scope and significant losses (Keefer, 1984, Xu et al., 2010, Mercurio et al., 2023, Dai et al., 2023). With the introduction of the concept of landslide earthquake geology, research on the assessment, warning, and emergency disaster reduction of secondary geological disasters such as earthquake-induced landslides has rapidly developed, forming a series of scientific theories, methodologies, and technologies (Xu, 2018). In recent decades, numerous catastrophic geological disasters have occurred globally, causing significant casualties and economic losses. Examples include the devastating debris flow disaster in Zhouqu County, Gansu Province, China, on August 7, 2010, two landslides in Zhenxiong, Yunnan Province, China, on January 11, 2023, and January 22, 2024, the landslide in Papua New Guinea on May 24, 2024, and the massive landslide in Kerala, India, on July 30, 2024, all resulting in severe losses (Li et al., 2025). Post-disaster reviews and analyses have revealed that, apart from natural factors triggering debris flow disasters, human factors such as inadequate disaster monitoring and warning mechanisms, post-disaster reconstruction mechanisms, insufficient attention to post-disaster assessment and reconstruction site selection, and inadequate engineering measures for the prevention and control of landslides and debris flows are prominent (Xie, 2010). In recent years, key geological disaster prevention areas in China have promoted the integration of “technical prevention” and “human prevention” for geological disasters, significantly enhancing the intelligence and automation levels of geological disaster monitoring, warning, and emergency rescue. Through increasingly innovative advanced technologies and devices for geological disaster assessment, prediction, and warning, increasingly improved emergency management systems and mechanisms, and rapid warning-response human defense measures, cases of early preparation, rapid response, and successful avoidance of geological disasters have emerged continuously (Liu et al., 2022).

5. Thoughts on the development directions of prevention and defense for natural disaster

The earth's spheres constitute an interconnected and mutually feedback-driven holistic system. The ongoing global climate change has led to an increase in extreme weather events, exacerbating the threats and risks posed by a series of natural disasters. Given the current emergency management system framework and technological development level, natural disaster prevention faces challenges such as the intensification of extreme natural disasters, the complexity of disaster-inducing environments and the diversification of disaster-inducing factors, the expansion of human activities and exposure of disaster-bearing bodies, and the increasing public attention and safety demands. At the current stage of socio-economic and scientific-technological development, facing the complex and ever-changing natural disaster situation and the severe challenges it poses, and in response to the strategic deployment and needs for natural disaster emergency response and mitigation, it is necessary to deeply analyze the internal logic and correlations of natural disaster prediction and prevention, and to clarify the key development directions in various fields.

(1) Focusing on the response of the disaster environment to climate change, and revealing the disaster-inducing mechanism of extreme events. The formation and evolution mechanisms of extreme events are fundamental to uncovering their disaster-inducing mechanisms. It is necessary to conduct in-depth research on basic scientific issues such as the response of Earth's spherical systems to climate change, revealing the full range of factors and processes from the inception to occurrence of extreme events, and providing theoretical support for natural disaster prediction, warning, and effective prevention.

(2) Establishing a chain-based thinking for natural disasters, and implementing a comprehensive prevention strategy focusing on points, chains, and clusters. It is crucial to recognize that natural disasters are often not isolated events but complex processes of interconnected and chained reactions. A comprehensive prevention framework needs to be constructed, extending from individual disaster types to disaster chains and even disaster clusters, strengthening cross-disaster and cross-sector collaborative prevention and control to reduce losses and impacts from secondary and derivative disasters.

(3) Clarifying guidelines for disaster prevention and emergency response actions at the grassroots level and enhancing the coordination and linkage of emergency responses. Detailed and operable emergency response plans should be formulated based on the characteristics of different regions and disaster types, with particular emphasis on enhancing the pertinence and practicality of grassroots emergency response plans. Establishing efficient cross-departmental information sharing and coordination mechanisms, and particularly strengthening communication and cooperation among governments, enterprises, and social organizations to achieve resource sharing and complementary advantages. During disaster emergency preparation, various forces can be quickly assembled to form a joint force, improving the efficiency and effectiveness of emergency responses.

(4) Improving the natural disaster risk assessment and zoning system, and optimizing emergency resource allocation. Based on historical disaster big data, disaster-inducing environmental factors, and socio-economic conditions, advanced technologies should be utilized to construct scientific natural disaster evaluation and risk assessment models, clarifying the basic requirements for natural disaster prevention by region, category, and level. Emergency resources should be allocated reasonably based on risk assessment results. Establish a dynamic risk assessment mechanism to ensure efficient resource utilization.

(5) Strengthening the scientific and technological empowerment of natural disaster prevention, enhancing accuracy and reliability. Utilizing advanced technologies such as artificial intelligence, big data, digital twin, and AI large models to

improve the accuracy and timeliness of disaster prediction and warning. Developing high-precision, high-reliability prediction and warning technologies and equipment, promoting technological innovation in emergency equipment and rescue devices, enhancing the technological level and practical application capabilities of “technical prevention” and “physical prevention”, and improving the efficiency and effectiveness of emergency relief.

(6) Establishing a resilient prevention and control technology system to enhance natural disaster defense capabilities. Developing high-energy-level shock-resistant and resilient energy dissipation prevention and control theories and technology systems, focusing on the research and development of new materials for rapid repair and reinforcement, new technologies for resilient energy dissipation protection, etc., to improve the disaster resistance and recovery capabilities of infrastructure and buildings, providing support for disaster engineering-based defensive measures in high-risk areas.

(7) Improving the scientific and technological business support mechanism to ensure the involvement of research institutions in emergency response operations. Establishing a close cooperation mechanism between scientific research institutions and emergency management departments, and establishing corresponding systems or mechanisms to encourage and support the participation of scientific research institutions in emergency response drills and disaster rescue fieldwork. Strengthening the professionalization of emergency rescue teams and improving the overall quality and professional skills of team members.

(8) Promoting public education and participation to enhance emergency self-rescue and overall social resilience. Extensively carrying out disaster prevention and mitigation publicity and education activities to improve public awareness of disaster prevention and mitigation, self-rescue and mutual rescue capabilities. Enhancing public emergency self-rescue capabilities and overall social resilience, and forming a disaster prevention and mitigation pattern involving the whole society by encouraging and supporting the participation of social organizations, enterprises, and individuals in disaster prevention and mitigation works.

6. Conclusion

This paper systematically analyzes the theoretical framework and practical values of prevention and defense measures for natural disasters, elucidating the dialectical relationship between "prevention" and "defense" and their pivotal roles in enhancing emergency response efficiency, reducing disaster losses, and ensuring public safety. In response to the complex risks and challenges faced by current natural disaster prevention and control efforts, the study proposes to strengthen the scientific and practical effectiveness of disaster prevention and relief measures by addressing the weaknesses in the existing system. It recommends advancing work in three areas based on refining the theoretical framework of natural disaster prevention and mitigation: 1) advancing research on disaster mechanisms and innovating comprehensive prevention and control theories, 2) optimizing emergency management coordination systems and resilient resource allocation, and 3) strengthening technological support and enhancing social collaboration capabilities. By embracing the concepts of mechanism improvement, technology empowerment, and social co-governance, we advocate for optimizing the trinity disaster defense system of "technical prevention, personnel allocation and material support" to achieve a systematic improvement in natural disaster prevention and defense capabilities.

Author Contribution

C. X. and H. G. conceived and designed the research; W. W., Z. X. and X. H. collected the literature and materials; H. G. wrote the manuscript.

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Conflict of Interests

The authors declare no conflicts of interest.

Data Availability

The data supporting the findings of this study are available upon request from the corresponding author.

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