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A Multi-Source Data-Driven Natural Disaster Emergency Management System: Risk Early Warning Framework, Social Media Opinion Mining, and Monitoring System Development

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ABSTRACT

In response to the systemic lag and reactive difficulties present in traditional natural disaster management models regarding the timeliness of risk perception, the accuracy of decision-making, and the coordination of emergency responses, this paper constructs a natural disaster risk early warning system framework that spans the entire cycle of pre-disaster prevention, mid-disaster emergency response, and post-disaster recovery, forming a closed-loop governance chain of "monitoring–assessment–release–response–feedback–optimization." On this basis, taking the "8·21" wildfire in Beibei, Chongqing, China, in 2022 as a typical case, a social media public opinion visualization analysis was conducted based on 5,507 text posts from the Weibo platform. Through word frequency statistics, temporal comment volume analysis, and word cloud visualization, the study reveals the spatially structured characteristics of public attention and the temporal evolution pattern of sentiment tendencies. Finally, from four dimensions—improving classified monitoring and graded early warning systems, establishing information sharing and hierarchical reporting systems, perfecting early warning release and graded response mechanisms, and advancing the informatization of monitoring, forecasting, and early warning efforts—the paper proposes a development path for a comprehensive natural disaster monitoring and early warning system, aiming to provide theoretical references and practical guidance for advancing the modernization of natural disaster prevention and emergency management capabilities.

1. Introduction

Natural disasters, due to their sudden onset, strong destructive power, and wide range of impacts, are one of the most severe challenges faced by human society today [1, 2]. On a global scale, disasters such as land subsidence, landslides, debris flows, and floods occur frequently, seriously threatening people's lives and property as well as the sustainable development of the economy and society. China is located at the intersection of the Pacific Ring of Fire and the Mediterranean–

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Himalayan seismic belt, and with its complex terrain and diverse climate types, it is one of the countries most severely affected by natural disasters in the world [3, 4]. The wide variety of disasters, extensive geographic distribution, high frequency of occurrence, and severe losses have become an important part of China's basic national conditions. To align with the imperatives of modernizing China's national governance system and governance capacity in the new era, the Ministry of Emergency Management was formally inaugurated in 2018, ushering in a distinct historical phase in the country's natural disaster emergency management. The establishment of the Ministry of Emergency Management has broken the previous fragmented management pattern of “nine dragons controlling the water” and segmented authority, achieving a profound shift from post–disaster relief to pre–disaster prevention, from single–disaster management to comprehensive disaster reduction, and from loss mitigation to risk reduction. It has significantly enhanced the country's overall capacity to respond to natural disasters and elevated natural disaster emergency management to a new level (Figure 1).

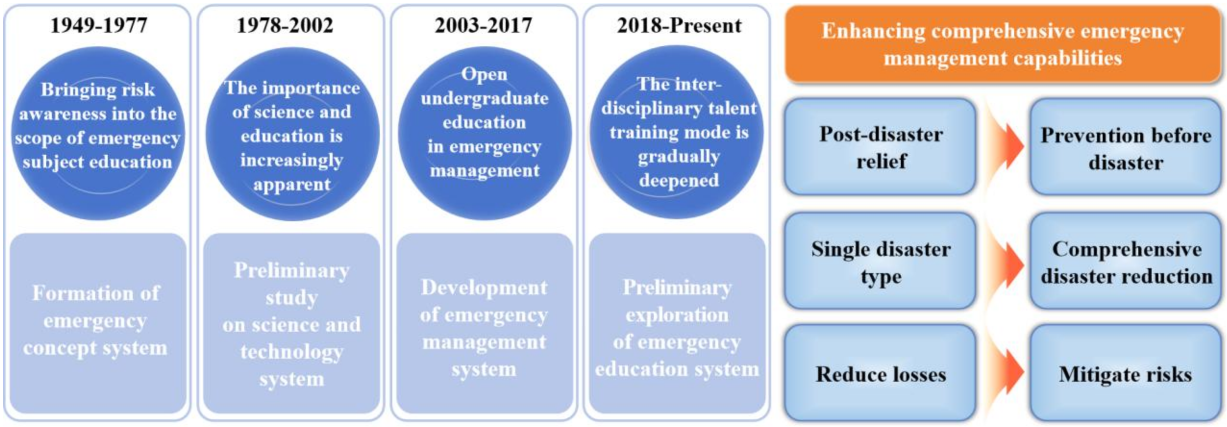


Fig. 1. Development of China's emergency management

However, for a long time, traditional natural disaster management models have primarily focused on post–disaster monitoring, on–site inspections, and experience–based decision–making, exhibiting obvious lagging and passive characteristics. Traditional monitoring methods often rely on manual patrols and single–point monitoring devices, with long data acquisition cycles and limited coverage. Early warnings are usually issued only when a disaster occurs or is imminent, and due to geographical constraints, there are many monitoring blind spots, making it difficult to achieve real–time perception and dynamic tracking of disaster risks. Moreover, at the emergency management level, issues such as long information transmission chains, low inter–departmental coordination efficiency, and imperfect early warning response mechanisms remain prominent, often causing the best window for disaster emergency response to be missed. This passive approach, which places more emphasis on disaster relief than on prevention, has become increasingly inadequate to meet the urgent demands of modern disaster prevention, mitigation, and relief work.

In recent years, the cross–application of next–generation information technologies represented by big data, large–scale artificial intelligence models, the Internet of Things, remote sensing technology, and social media mining has provided an entirely new technological pathway for overcoming the difficulties of traditional disaster warning systems. Scholars at home and abroad have carried out systematic research on disaster risk intelligent perception and forecasting and warning, focusing on the theoretical frontiers, including disaster mechanism analysis, data–driven risk assessment, and intelligent forecasting of extreme weather. Yang *et al.,* [5] used an analytical method that integrates the Decision–Making Trial and Evaluation Laboratory with Adversarial Hasse Diagram

Technique to systematically analyze the key disaster–inducing factors and their mechanisms underlying urban subway vulnerabilities under extreme heavy rainfall conditions; Bi *et al.,* [6] constructed the Pangu–Weather forecasting system based on 3D Earth–specific Transformer and a hierarchical temporal aggregation strategy, using 39 years of ERA5 reanalysis data, significantly reducing cumulative errors in iterative forecasts and demonstrating excellent predictive performance in extreme weather applications such as tropical cyclone path tracking and ensemble forecasting; Ming *et al.,* [7] utilized GPU–based heterogeneous parallel efficient algorithms to predict the highly transient flood processes caused by heavy rainfall, enabling high–resolution long–term scenario simulations for large river sections and even entire rivers, with a complete two–dimensional hydrodynamic model applied to predict extreme flood events at a resolution of 10 meters within a 2,500 square kilometer watershed. Furthermore, social media platforms, as the “first scene” for the dissemination of sudden disaster information, contain text, images, and geolocation information, which can compensate for the timeliness shortcomings of traditional monitoring networks and serve as an important bridge between public disaster perception and government emergency decision–making. The integrated application of these technologies is driving a fundamental transformation in natural disaster management, from traditional passive response to proactive prevention, from empirical judgment to data–driven decision–making, and from single monitoring to comprehensive early warning, providing a solid technological foundation for building an intelligent and precise natural disaster emergency management system.

2. Framework of Natural Disaster Risk Early Warning System

In recent years, the Chinese government has attached great importance to the prevention and mitigation of natural disasters and risk warning work. It has established a multi-level disaster warning system from the national to local levels and implemented a series of key projects in critical areas and weak links, thereby setting an action program for natural disaster prevention and mitigation in the new era [8]. On this basis, in order to transform the top-level design for enhancing natural disaster prevention and mitigation capabilities into systematic and operable governance practices, it is urgently necessary to build a risk warning technology framework that covers the entire disaster lifecycle. Accordingly, the system framework for natural disaster risk early warning constructed in this paper mainly comprises the following four core components: risk identification, analysis and judgment, early warning issuance, and risk management and emergency response (Figure 2).

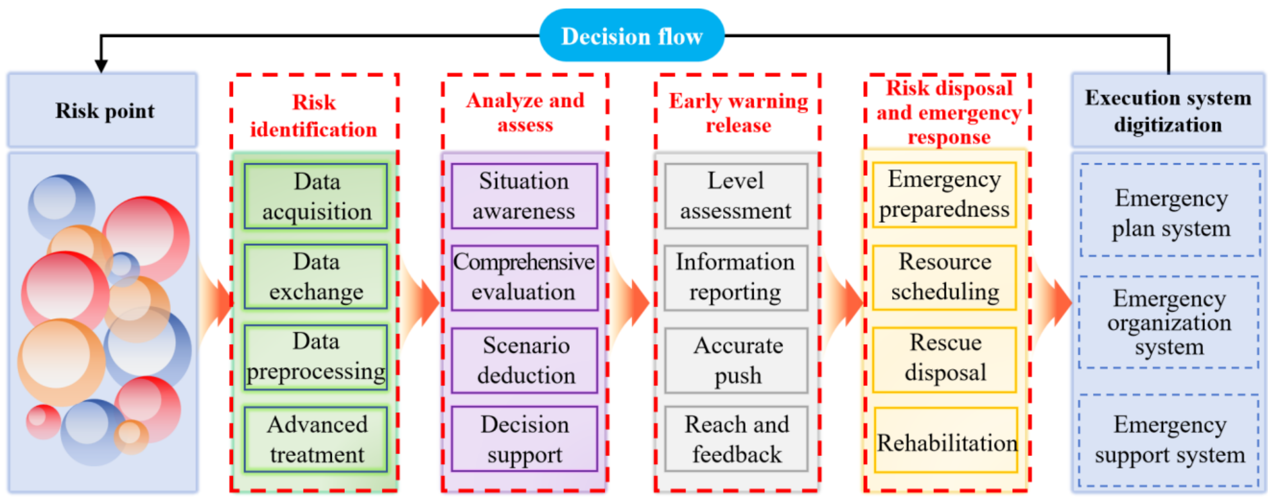


Fig. 2. Design of natural disaster risk early warning processes

These components are interconnected through information flows and decision flows, forming a full–cycle closed–loop governance chain that spans pre-disaster prevention, emergency response during disasters, and post-disaster recovery. This establishes a full-chain operational system of "monitoring–assessment–release–response–feedback–optimization", enabling dynamic perception of disaster risk conditions, trend analysis, graded warnings, and cross–departmental coordinated actions. Relying on multi–source data integration and intelligent model simulations, it significantly improves the timeliness of early warnings and the accuracy of decision–making, which holds important theoretical value and practical significance for advancing the modernization of natural disaster prevention systems and emergency management capabilities [9–11].

2.1 Risk Identification

Risk identification is the perceptual front end and data foundation of the natural disaster risk warning system. Its core task is to achieve the comprehensive, continuous, and all–element capture and structured analysis of disaster risk factors (Figure 3). This stage encompasses four progressive links: Data collection relies on satellite remote sensing, ground sensor networks, drone inspections, social media, and government data platforms to construct an integrated monitoring system across space, air, and ground, enabling the real–time capture of multidimensional disaster-inducing factors such as meteorology, hydrology, geology, and oceanography; Data exchange establishes cross–departmental, cross–regional, and cross–level data sharing mechanisms and standard interfaces, breaking down information barriers among emergency management, meteorology, water resources, and natural resources departments to form an interconnected data resource pool; Data preprocessing conducts quality verification, anomaly removal, and format standardization of raw monitoring data to ensure data consistency; Deep processing employs data mining, knowledge graphs, and feature engineering technologies to extract key indicators of disaster evolution and implicit association rules, providing effective information input for subsequent analysis.

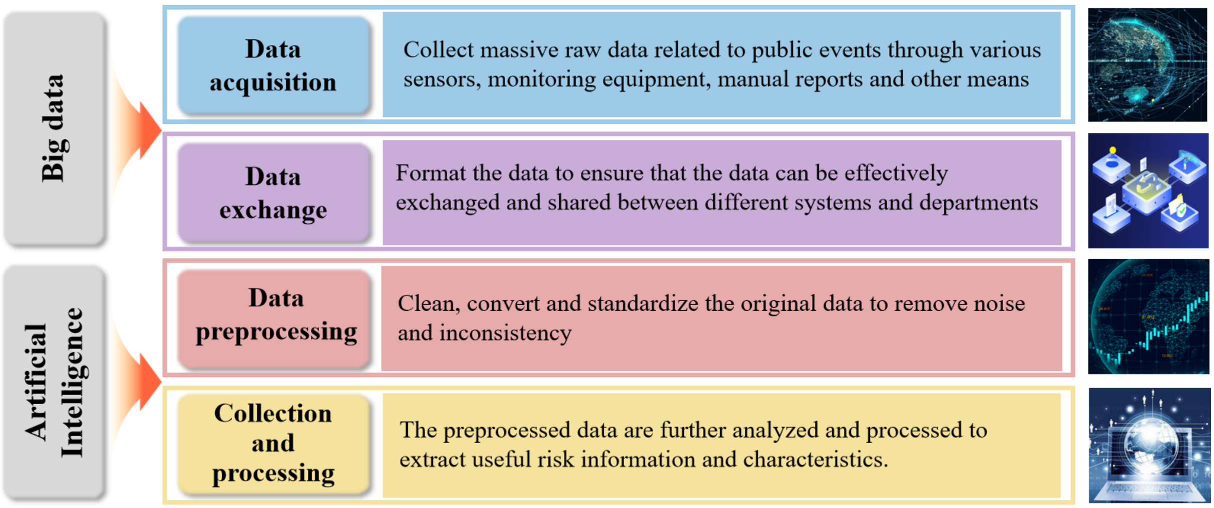


Fig. 3. Risk identification process

2.2 Analysis and Judgment

Analysis and judgment serve as the core hub connecting risk perception and early warning decision–making, shouldering the function of transforming massive monitoring data into understandable, quantifiable, and actionable disaster risk cognition products [12]. This stage consists of four dimensions: Situational awareness constructs a dynamic portrait of disaster risk through multi–source data integration and visualization technology, achieving a macro–level understanding of risk field distribution, intensity changes, and evolution trends; Comprehensive assessment relies on risk assessment models, vulnerability indicator systems, and exposure analysis methods to quantitatively determine risk levels, impact ranges, and potential losses, clarifying the focus and priority of prevention and control; Scenario simulation, based on historical disaster case databases and real–time data–driven approaches, uses artificial intelligence algorithms to model the disaster chain development process and secondary disaster derivative risks under different hazard scenarios, predicting potential consequences under extreme conditions; Decision support integrates the assessment results and simulation conclusions, generating specialized reports that include risk judgment, response strategies, and resource requirements, providing a scientific basis for determining early warning levels and emergency command.

2.3 Risk Warning

The issuance of early warnings is a crucial hub for transmitting risk information to threatened entities and directly determines the timeliness and coverage of disaster prevention and mitigation measures [13, 14]. This stage includes four key steps: determining the level involves analyzing and assessing the basis of conclusions, comparing them with national standards for issuing emergency warning information, determining the warning level (blue, yellow, orange, red) and corresponding activation thresholds, and clarifying the timeliness of the warning and the spatial extent of its impact; compiling information follows the principle of the "publisher responsibility system," producing warning information products that are standardized, semantically clear, and clearly directed, including the type of disaster, risk level, affected area, start time, defense guidelines, and evacuation requirements; precise dissemination integrates broadcasting, television, SMS, new media, emergency broadcast systems, dedicated alarm terminals, and IoT sensing devices to build a three–dimensional distribution network that is "horizontal to the edges and vertical to the ground," achieving targeted communication to specific areas and populations; reach and feedback establish a mechanism for monitoring and reporting the effectiveness of warning information dissemination, assessing information coverage, receipt rate, and public behavioral response, providing closed–loop feedback for optimizing dissemination strategies.

2.4 Risk Management and Emergency Response

Risk management and emergency response are the final stages for the effective implementation of the early warning system, aiming to transform warning information into substantial disaster reduction actions and rescue outcomes [15]. This phase encompasses four levels of action: Activation of response immediately triggers the corresponding level of emergency plan based on the warning level, clarifying the command structure, division of responsibilities, and operational procedures, achieving a rapid transition from normal management to emergency status; Resource deployment coordinates emergency rescue teams, professional equipment, disaster relief materials, transportation, communication support, and medical resources, carrying out pre–positioning and dynamic allocation based on risk conditions to ensure key resources are directed to critical areas at critical times; On–site handling orderly conducts the substantive rescue actions such as personnel evacuation, engineering hazard prevention and mitigation, life rescue, medical care, epidemic prevention and hygiene, and infrastructure repair, minimizing casualties and property losses; Assessment and adjustment dynamically track disaster development and the progress of response, evaluate the effectiveness of emergency response and resource gaps in real time, adjust the response level and optimize handling plans according to changing disaster conditions, and feed handling experiences back into the risk identification and analysis stage, achieving continuous iteration and capacity enhancement of the early warning system.

3. Analysis of Natural Disaster Events

To deepen practical research on natural disaster emergency responses from the perspectives of data retrieval and public opinion analysis, this paper conducts a visualization analysis using the “8·21” wildfire in Beibei, Chongqing, in 2022 as a typical case. In August 2022, Chongqing experienced the most severe extreme continuous high–temperature weather since 1961. Coupled with the ongoing drought that resulted in extremely low vegetation moisture content, the risk of wildfires rose sharply. At around 22:30 on August 21, a wildfire suddenly broke out in Hutou Village, Xiema Subdistrict, Beibei District. The fire spread rapidly under high temperatures and strong winds, exhibiting simultaneous multi–point occurrences, and posed a serious threat to the Jinyun Mountain National Nature Reserve and the urban areas at the foot of the mountain.

This article uses “Chongqing wildfires” as a keyword and employs web crawler technology to collect relevant text data from the Weibo platform between August 21 and 25, 2022, obtaining a total of 5,507 valid posts. After cleaning and segmenting this dataset, word clouds are used for visualization, revealing public focus points and emotional tendencies from the perspective of social media public opinion, thereby providing data support and reference for disaster prevention and emergency management decision–making.

3.1 Data Collection and Data Preprocessing

This study utilized web crawler technology, using “Chongqing wildfires” as the search keyword to collect relevant data from the Sina Weibo platform, and organized the collected results in order based on their publication time. The focus period was from August 21 to 25, 2022, covering the critical phase from the outbreak of the wildfire to the complete extinguishment of visible flames. Since data related to natural disasters often come from multiple information sources, which may vary in quality and contain contradictory content, the original dataset was cleaned to remove erroneous and false information, thereby enhancing the accuracy and usability of the data (Figure 4).

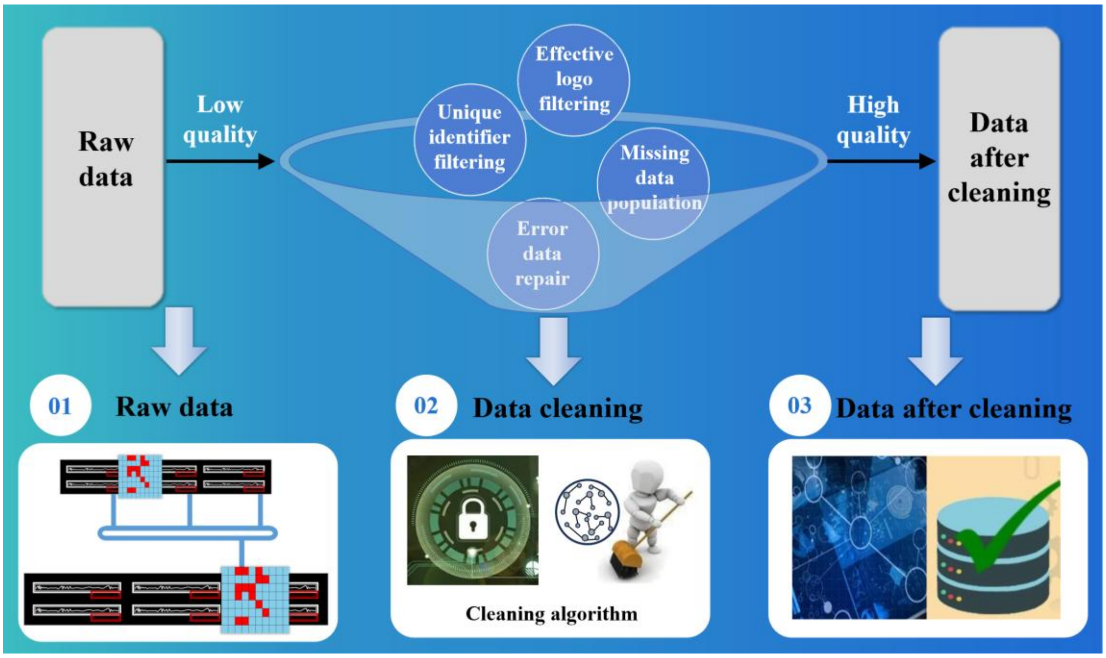
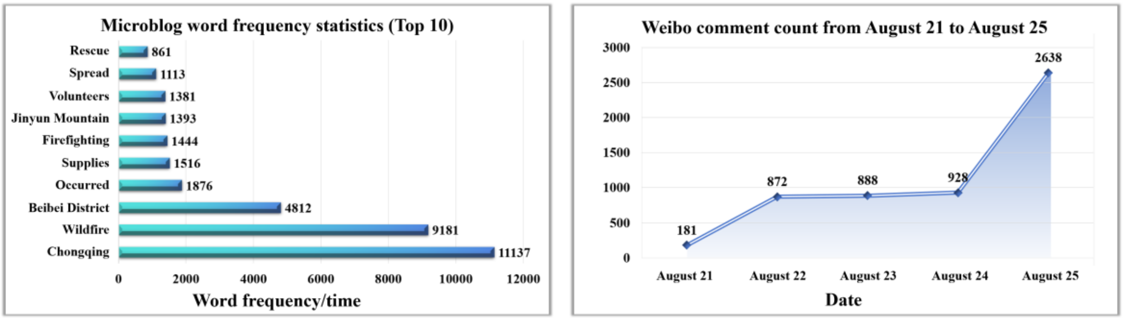


Fig. 4. Risk identification process

3.2 Data Statistics and Processing Analysis

A word frequency table was generated based on the preprocessed text data (Figure 5(a)). As shown in the figure, “Chongqing” accounts for 32.08% of the word frequency, “Wildfire” accounts for 26.45%, and “Beibei District” accounts for 13.86%. These three terms have relatively high proportions, revealing the location of the disaster, the type of incident, and the specific district, respectively, forming a three–level semantic anchor of “location–disaster type–area,” reflecting the structured characteristics of public opinion in terms of spatial positioning and thematic focus. In addition, further time series statistics of the daily number of comments were conducted (Figure 5(b)). From August 21 to 25, the number of comments showed a staged increase of “initial low–level emergence (181 comments) – platform fermentation (872–923 comments) – peak outbreak (2,638 comments),” corresponding to the initial, sustained, and peak phases of public opinion response. The above results indicate that the Chongqing wildfire–related public opinion formed a precise spatial focus structure and exhibited a pattern of emotional mobilization over time that lagged behind the development of the disaster and was triggered alongside rescue narratives. This provides a data reference for analyzing the spatiotemporal patterns and key points of public attention during sudden natural disasters.



(a) High-frequency word statistics of Weibo comments (b) Comment count statistics

Fig. 5. Weibo data statistics on the “Chongqing Wildfire” (a) High-frequency word statistics of Weibo comments (b) Comment count statistics

In order to gain a more comprehensive understanding of the disaster information contained in the Weibo text data of the Chongqing Beibei “8·21” wildfire, this study conducts a visual analysis of the collected Weibo data. A word cloud is used to intuitively display the key elements of the Chongqing Beibei “8·21” wildfire (Figure 6), and the temporal evolution of public attention and sentiment tendencies is divided into the following five stages:

(1) August 21 (Initial outbreak of the wildfire): As shown in Figure 6(a), words such as “Chongqing,” “Beibei,” “Wildfire,” “Rain,” “Worrying,” and “Hope” appeared frequently, reflecting the location of the disaster, the type of disaster, and the public’s high level of attention and anxiety regarding the wildfire on the night it broke out. Public concern focused on the spread of the fire, weather conditions, and personal safety. The emotional tendency was primarily worry and anxiety, mixed with an urgent anticipation of rainfall and temperature drop, reflecting the public’s uncertainty about the progression of the disaster in its early stage and their close attention to the progress of the rescue efforts.

(2) August 22 (Period of fire spread): As shown in Figure 6(b), words such as “Chongqing,” “Jinyun,” “Smoke,” “Fire,” “Rain,” and “Wind” are prominent in the word cloud, indicating that as the fire spread toward the Jinyunshan Nature Reserve, public attention surged sharply. At this stage, the public's focus expanded in multiple dimensions: first, the fire situation (“Occurs,” “Spread,” “Burned”); second, rescue actions (“Rescue,” “Firefighters,” “Volunteers”); third, environmental impact (“Smoke,” “Air”); and fourth, weather changes (“Rain,” “Wind,” “Temperature”). Regarding emotional tendencies, words like “Hope,” “Wishing,” and “Ensure” show that the public, despite their

anxiety, still maintain trust in the rescue forces and hope for control over the disaster, while “God” reveals that some people feel powerless and express a sense of prayer when facing natural disasters.

(3) August 23 (Period of sustained emergency): As shown in Figure 6(c), besides information on the type and location of the disaster, words such as “Still,” “Supplies,” and “Prevention” stand out in the word cloud. The high frequency of the term “Still” indicates that public anxiety over the fire's persistence had significantly intensified. At this stage, the public’s focus shifted to the progress of fire control (“Still,” “Now,” “Spreading”), provision of supplies (“Supplies,” “Support,” “Vehicles”), and fire prevention and isolation measures (“Prevention,” “Site”). Emotional tendencies displayed characteristics of “resilience amid anxiety,” with the continued appearance of “Hope” indicating that the public had not yet given up expectations, “Safe” reflecting concern for the safety of rescue personnel and affected residents, and words such as “Can” and “Will” demonstrating the public’s belief in overcoming the disaster.

(4) August 24 (Decisive battle period): As shown in Figure 6(d), beyond information about the type and location of the disaster, words such as “Rescue,” “Firefighters,” “Support,” “Army,” and “Young” dominate the word cloud, indicating a structural shift in public attention from merely focusing on the disaster to focusing on rescue forces and voluntary actions. The prominence of "Rescue" reflects the public’s significant attention to civilian heroes spontaneously participating in the rescue, particularly motorcycle volunteers; words like “Firefighters,” “Support,” and “Army” demonstrate respect for professional rescue forces; the appearance of “Young” indicates that young volunteers born after 2000 stepping forward against the danger have become a focus of public opinion. The emotional tendency is mainly feelings of being moved, admiration, and pride, while words such as “Help,” “Please,” and “Will” convey a unified atmosphere of nationwide participation and solidarity in overcoming the crisis.

(5) August 25 (Period when victory is in sight): As shown in Figure 6(e), terms such as “Firefighting,” “Volunteers,” “People,” “Supplies,” and “Motorcycle” appeared densely, indicating that wildfire suppression had entered a critical stage and public sentiment reached an emotional peak. During this stage, the public's attention was highly focused on volunteer forces (“Volunteers,” “Motorcycle,” “Relay”), material transportation (“Supplies,” “Transport”), and firefighting effectiveness (“Firefighting,” “Off,” “Efforts”). The prominent appearance of “Motorcycle” and “Relay” confirms that the “motorcycle brigade” played a key role in wildfire rescue, becoming an iconic image widely discussed online; terms such as “All,” “People,” and “Together” highlight the spirit of the “human chain” and collectivist values. Emotional tendencies were dominated by excitement, being moved, and gratitude; words like “Salute,” “Support,” and “Well” conveyed high respect for those confronting the fire, while terms such as “Video” and “CCTV” indicated that mainstream media coverage of the rescue efforts further amplified the spread of positive energy.

Overall, this study intuitively demonstrates the evolution of public sentiment during the Chongqing wildfire natural disaster, from “disaster anxiety” to “rescue focus” and then to “emotional resonance,” profoundly revealing the emotional elevation mechanism in social media discourse, where individual anxiety transforms into collective identification and passive attention evolves into active participation. It provides a typical example for understanding social mobilization and emotional resonance in sudden public emergencies.

4. Development of the Comprehensive Monitoring and Early Warning System for Natural Disasters

Against the backdrop of intensified global climate change coupled with high–intensity human activities, natural disasters are exhibiting a trend of increasing frequency, rising intensity, and significantly heightened uncertainty, with the nonlinear interactions between disaster–causing factors and disaster–bearing entities becoming increasingly complex. Traditional monitoring and early warning models have revealed systemic limitations in terms of spatiotemporal resolution, multi–source information integration capabilities, and dynamic risk assessment accuracy, making them difficult to adapt to the refined requirements of current disaster risk governance. In view of this, there is an urgent need to break through departmental divisions and data barriers, and to establish a comprehensive monitoring and early warning system, to achieve a paradigm shift from passive response to proactive prevention and control, from empirical judgment to data–driven approaches, and from single–disaster management to comprehensive risk governance.

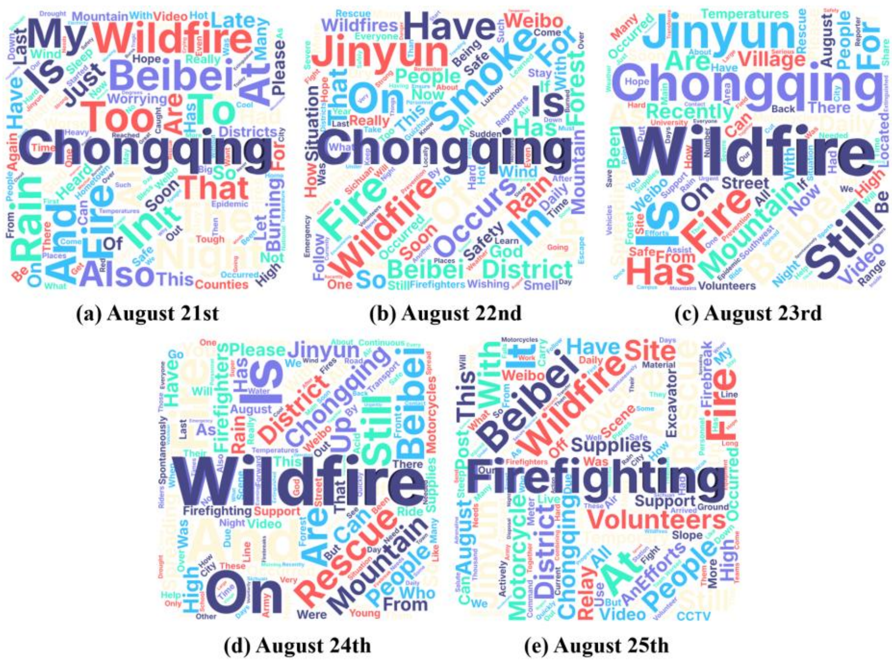


Fig. 6. “Chongqing Wildfire” word cloud

4.1 Classification, Monitoring, and Graded Early Warning System for Natural Disasters

Promoting a sound system for the classification, monitoring, and graded early warning of natural disasters is a fundamental project for enhancing disaster risk governance capabilities [16], Figure 7.

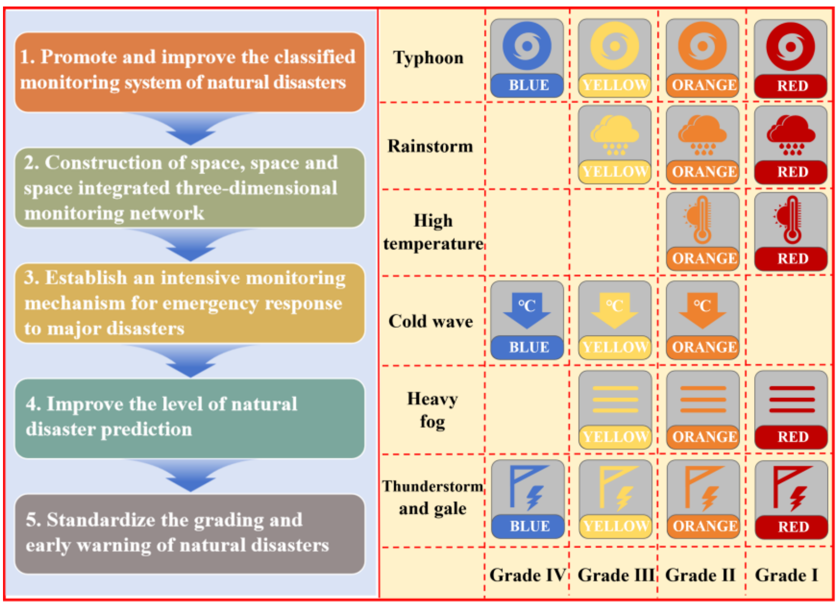


Fig. 7. Classification, monitoring, and graded early warning of natural disasters

In terms of classification and monitoring, satellite remote sensing, aerial remote sensing, ground observation networks, and IoT sensing devices should be integrated to develop multi–hazard monitoring capabilities for meteorological and hydrological disasters, geological disasters, marine disasters, and others. At the same time, an emergency encrypted monitoring mechanism for major disasters should be established to dynamically increase monitoring frequency and spatial resolution during high–risk periods or critical conditions, ensuring real–time tracking of disaster–causing factors and anomaly detection. Regarding graded early warning, it is necessary to strictly adhere to national standards for the release of sudden disaster warning information. Based on disaster type, intensity, and impact range, scientific thresholds for four warning levels—blue (Level IV), yellow (Level III), orange (Level II), and red (Level I)—should be defined, clarifying the timeliness requirements and spatial coverage for each level. Additionally, differentiated warning rules should be established according to the characteristics of different types of disasters. For instance, meteorological disasters such as typhoons, heavy rain, cold waves, dense fog, and thunderstorms with strong winds should each have a graded determination model based on meteorological element thresholds, affected areas, and duration, to achieve the standardization of graded early warning for natural disasters.

4.2 System for Sharing and Reporting Natural Disaster Monitoring and Early Warning Information

Establish a system for sharing and reporting natural disaster monitoring and early warning information, focusing on breaking down information barriers between departments and hierarchical levels, and constructing a systematic architecture with horizontal coordination and vertical linkage [17], Figure 8.

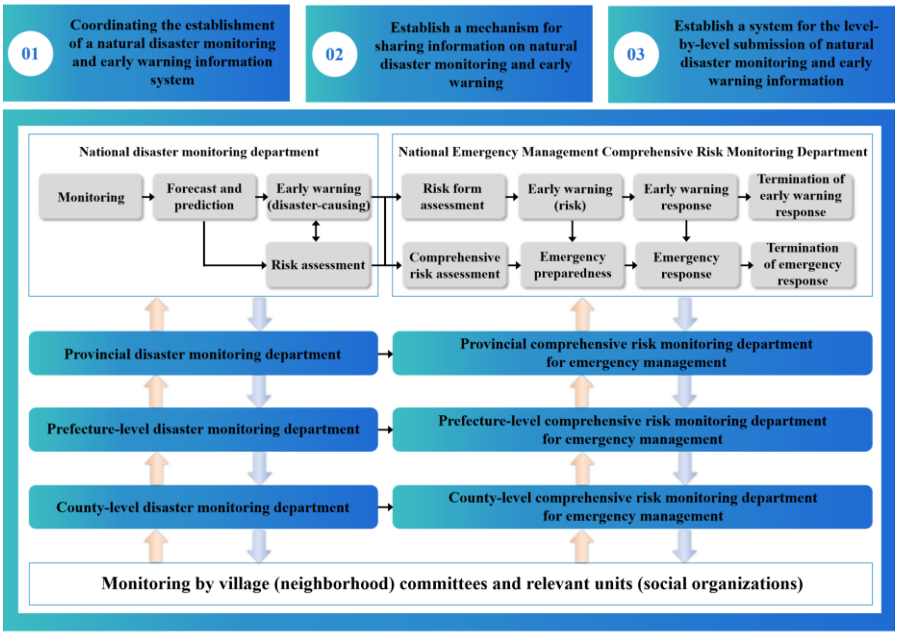


Fig. 8. Monitoring and early warning information sharing and reporting system

In terms of information sharing, it is necessary to integrate the resources of disaster–causing monitoring departments at all levels and comprehensive risk monitoring departments of emergency management, promote real–time interconnection of information such as monitoring data, forecasts and predictions, risk situation assessments, hazard evaluations, and comprehensive risk assessments, achieve effective linkage between disaster–causing warnings and emergency warnings, and ensure that information is synchronized across all stages of warning response, emergency preparedness, and emergency response [18]. Regarding hierarchical reporting, establish a bottom–up information reporting chain starting from village (residential) committees and social organization monitoring points, through county, municipal, and provincial levels, up to the national level, while also improving the top–down mechanisms for early warning releases and command transmission, forming a bidirectional and smooth closed–loop management system. Disaster–causing monitoring departments and emergency management departments at all levels should coordinate simultaneously to ensure that disaster information is collected promptly, assessed accurately, and responded to rapidly, comprehensively enhancing the overall effectiveness of monitoring and early warning.

4.3 Natural Disaster Early Warning Information Release and Response System

To improve the system for the release of natural disaster warning information and emergency response, it is necessary to establish a differentiated and precise hierarchical and categorized dissemination system to achieve efficient reach and targeted responses to warning information [19], Figure 9. At the level of the release mechanism, a hierarchical dissemination framework should be established for government leaders, emergency coordination departments, responsible persons for emergencies, social media, and urban and rural public. For government leaders and emergency coordination departments, mobile text messages, telephone calls, and government intranet should serve as the primary channels, supplemented by fax and email to ensure full coverage of information transmission and direct delivery of instructions; for responsible persons for emergencies, precise pushes should be implemented via mobile text messages, while coordinating with broadcasting, television, and internet channels to expand coverage; for social media, the internet should be the main channel, supplemented by email, to ensure rapid information dissemination; for urban and rural public, a combination of broadcasting, television, internet, and text messages should be used as diverse media, supplemented by display screens, the “Village–to–Village” broadcast system, marine radio, and other terminal facilities to ensure effective communication of information to both urban and rural populations. At the level of warning response, based on the warning level and audience hierarchy, differentiated response measures should be synchronously launched, including emergency coordination, responsibility implementation, social mobilization, and public risk avoidance, to ensure that warning information is converted into timely and effective disaster prevention and mitigation actions, comprehensively enhancing the end–level execution capability and overall effectiveness of the warning system.

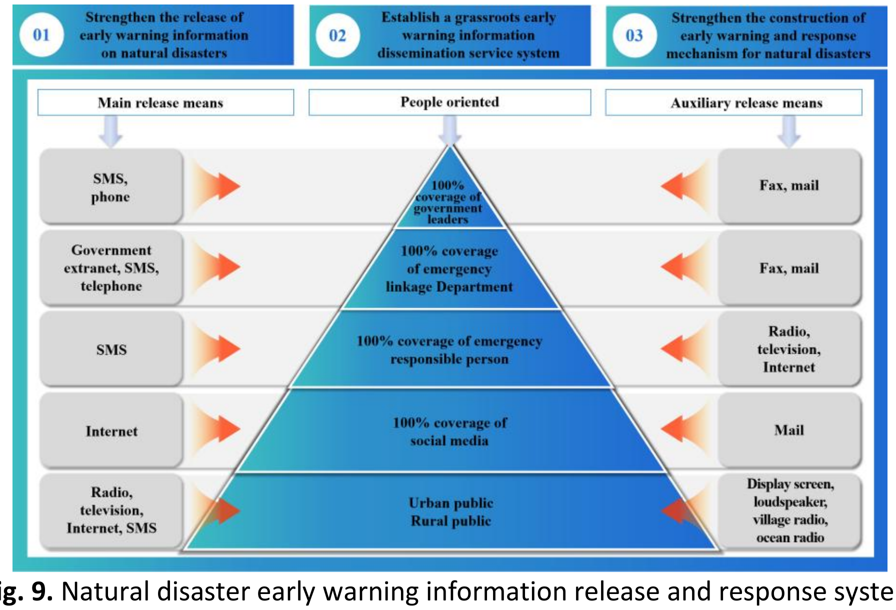


Fig. 9. Natural disaster early warning information release and response system

4.4 Informationization Project for Natural Disasters

To advance the informatization project for natural disaster monitoring and early warning, it is necessary to construct a full–chain technical architecture covering data collection and compilation [20], intelligent analysis, and business applications, achieving intelligent monitoring and precise early warning driven by data (Figure 10). At the level of information collection and acquisition, a multi–source heterogeneous data aggregation mechanism should be established. Data on meteorology, water resources, earthquakes, geology, as well as information on populations, socioeconomics, and housing, should be obtained through inter–departmental sharing; grassroots survey statistics and Internet of Things sensing data should be obtained through independent collection; satellite and aerial (drone) remote sensing data should be obtained through integrated application of remote sensing resources; social data and media public opinion information collected from various social sources should be aggregated to form a three–dimensional data supply system. At the level of data management, heterogeneous data should be standardized and governed, constructing four comprehensive databases covering real–time data, forecasts and warnings, historical records, and basic data to support the integrated application of data products. At the level of risk monitoring, assessment, and early warning, by combining dynamic monitoring with medium– and long–term analysis and judgment, risk monitoring, risk assessment, and disaster early warning can be organically integrated through comprehensive consultation and judgment, and hazardous area predictions can be conducted. Ultimately, the monitoring, assessment, and early warning system should be applied across all stages of disaster prevention, mitigation, and relief—including comprehensive disaster reduction, emergency preparedness, emergency response, post–disaster assistance, and recovery and reconstruction—to enhance the digitalization and intelligence of natural disaster governance.

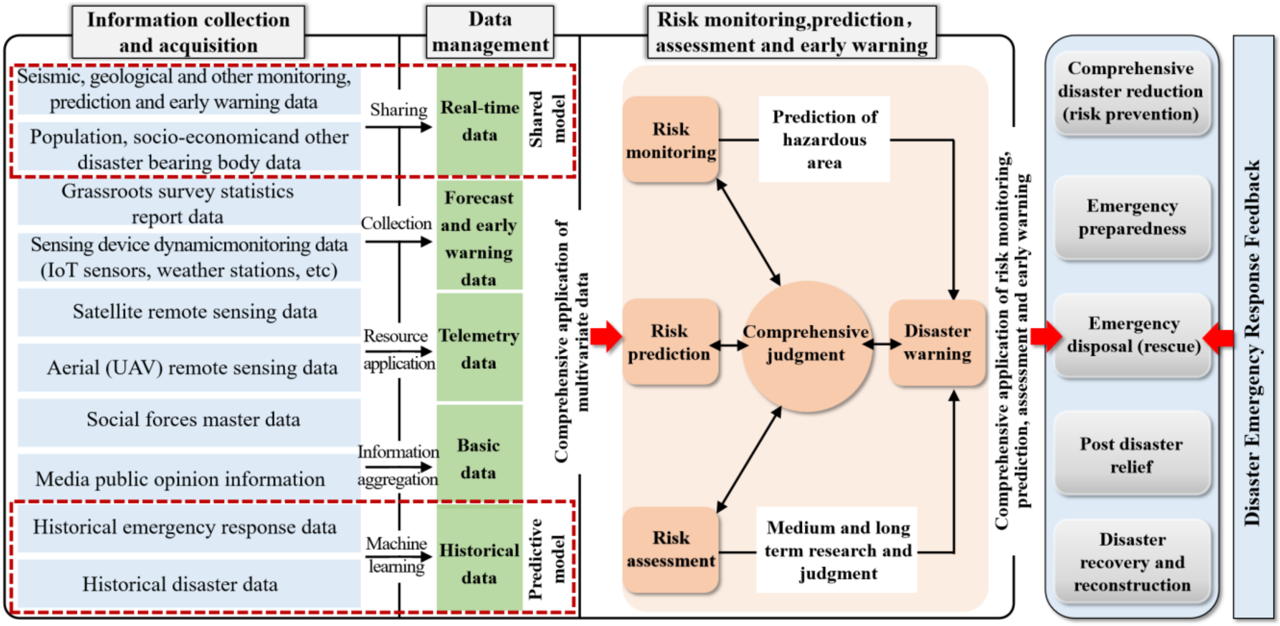


Fig.10. Disaster early warning information system architecture

5. Conclusions

Based on the above research content, this paper draws the following main conclusions from the three levels of theoretical framework construction, empirical analysis of typical cases, and development of the institutional system:

(1) A full–cycle natural disaster risk early warning system framework has been constructed. To address the lag and passivity of traditional disaster management models, a risk early warning system

framework connecting pre-disaster prevention, emergency response during disasters, and post-disaster recovery has been designed, forming a closed–loop governance chain of "monitoring–assessment–release–response–feedback–optimization."

(2) The spatiotemporal evolution patterns of social media public opinion during sudden disasters have been revealed. Taking the "8·21" wildfire in Beibei, Chongqing in 2022 as a typical case, a visualization analysis was conducted based on 5,507 Weibo text data entries, finding that public attention gradually shifted spatially from the disaster itself to rescue actions and volunteer spirit, with emotional tendencies evolving from anxiety and worry to feelings of being touched and pride.

(3) A development path for a comprehensive monitoring and early warning institutional system for natural disasters has been proposed. By systematically promoting institutional innovation in four dimensions—improving the classified monitoring and graded early warning system, establishing an information–sharing and hierarchical reporting system, perfecting the graded response mechanism for warning releases, and advancing the informatization of monitoring, forecasting, and early warning—this approach aims to achieve a paradigm shift from passive response to proactive prevention, from experience–based judgment to data–driven decision–making, and from single–disaster management to comprehensive risk governance.

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Conflicts of Interest

The authors declare no conflicts of interest.

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