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NATURAL DISASTER EARLY WARNING SYSTEMS IN VIETNAM IN THE DIGITAL ERA: CHALLENGES AND RISK MANAGEMENT IMPLICATIONS FOR COMMERCIAL BANKS

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ABSTRACT

Climate change has increased the frequency and severity of natural disasters, posing significant challenges to sustainable development, disaster resilience, and financial stability in Vietnam. In this context, digital-enabled early warning systems have become an essential component of disaster risk reduction by supporting timely decision-making, enhancing preparedness, and reducing potential socio-economic losses. This study examines the current state of natural disaster early warning systems in Vietnam, identifies key challenges to their effectiveness, and explores their implications for risk management in commercial banks. The study adopts an integrated qualitative approach combining literature review, comparative analysis, and policy-oriented assessment based on theoretical perspectives, international experience, and official reports. The findings indicate that although Vietnam has made considerable progress in hydro-meteorological forecasting and disaster monitoring, significant limitations remain in forecast model resolution, observation network coverage, data infrastructure, institutional coordination, and decision-support capacity. Furthermore, the adoption of digital technologies-including artificial intelligence (AI), big data, the Internet of Things (IoT), and Digital Twin-remains fragmented and insufficiently integrated across the early warning system. The study further demonstrates that weaknesses in disaster early warning systems have important implications for commercial banks by increasing credit risk, operational risk, and geographic concentration risk associated with climate-related disasters. To strengthen both disaster resilience and financial stability, the paper recommends enhancing multi-source data integration, expanding AI-driven decision-support systems, improving institutional coordination, and promoting a transition from reactive disaster response to proactive, risk-informed disaster management. These measures would contribute to more resilient early warning systems while strengthening the climate risk management capacity of Vietnam's commercial banking sector.

Keywords: *early warning systems; natural disasters; digital transformation; climate resilience; commercial banks; risk management.*

Introduction

According to the Vietnam National Center for Hydro-Meteorological Forecasting (2025), Vietnam has been identified as one of the countries most severely affected by natural disasters due to its geographic location, tropical monsoon climate, and complex topography. Hazardous events such as typhoons, heavy rainfall, floods, flash floods, and landslides have been observed to increase in both frequency and intensity in the context of climate change. These phenomena have caused severe human and material losses, damaged infrastructure, and adversely affected socio-economic development. In this context, early warning systems are considered to play a critical role in reducing disaster risks and enhancing the proactive preparedness and response capacity of governments, communities, and economic actors.

Beyond direct impacts on production and social welfare, natural disasters have increasingly been recognized as a significant source of risk for the financial and banking sector. Disaster-related losses are found to weaken borrowers' repayment capacity, increase non-performing loans, reduce the value of collateral assets, and disrupt business operations. Consequently, credit risk, operational risk, and geographical concentration risk in commercial banks are substantially affected. Therefore, early warning systems are not only utilized for disaster prevention and control purposes but are also regarded as an important data source for risk identification, measurement, and monitoring in banking activities.

In recent years, Vietnam has made considerable efforts to improve forecasting and early warning capabilities, particularly in hydro-meteorology and disaster management. However, limitations are still observed in forecast model resolution, data infrastructure, observation networks, and governance and decision-making mechanisms. Meanwhile, rapid advances in digital technologies such as artificial intelligence, big data, the Internet of Things (IoT), and Digital Twin simulation have been creating new approaches that enable multi-source data integration, improved short-term forecasting, and scenario-based decision support (UNDRR, 2023).

From the perspective of modern banking risk management, the integration of early warning disaster data into management information systems is expected to support commercial banks in assessing risk exposure across sectors, regions, and credit portfolios. It also enhances internal warning systems, stress testing, and the development of response strategies to climate-related shocks. This aligns with the growing requirements for integrated risk management, ESG risk governance, and sustainable development in the banking sector.

Based on this context, the study adopts a systematic analytical approach combining theoretical foundations, international experience, and empirical assessment in Vietnam. Appropriate research methods are employed to clarify key limitations of the current early warning system and to provide a scientific basis for proposing digital transformation-oriented solutions aimed at strengthening risk management capacity in commercial banks in the near future.

1. Theoretical Framework and Research Methodology

Theoretical Framework

The Early Warning System (EWS) is considered a critical component of modern disaster risk management, which is designed to provide timely information on the likelihood, severity, and spatial extent of hazardous events in order to support preventive and response decision-making. According to the World Meteorological Organization, an effective early warning system is required to ensure four key components, including risk knowledge, monitoring and forecasting, warning dissemination, and response capability. In the context of climate change, such systems have increasingly been developed toward multi-source data integration, real-time operation, and digital technology-based decision support.

From a risk management perspective, natural disasters are regarded as an exogenous risk source that can propagate across multiple economic sectors, including the financial and banking system. For commercial banks, natural disasters are found to increase credit risk through reduced repayment capacity of borrowers, declining collateral values, disruption of production and business chains, and increased geographical concentration risk. At the same time, operational risk is also affected due to disruptions in transaction systems, information technology infrastructure, and branch operations in disaster-affected areas.

In this context, data generated from early warning systems is recognized as an important input for modern banking risk management systems. The integration of disaster warning data into risk assessment tools, Decision Support Systems (DSS), stress testing models, and spatial scenario analysis enables banks to improve early risk identification, proactively adjust credit portfolios, and enhance resilience against climate-related shocks. This approach is consistent with the trends of integrated risk management, ESG risk governance, and sustainable banking development.

Furthermore, the development of technologies such as artificial intelligence, big data, the Internet of Things (IoT), and Digital Twin simulation has expanded the linkage between disaster early warning systems and financial risk management. These technologies enable multi-scenario impact simulation and real-time decision support.

Research Methodology

This study adopts an interdisciplinary approach combining hydro-meteorology, information technology, data science, and risk management. The primary research methods include literature synthesis, comparative analysis, and empirical assessment of current practices in Vietnam.

First, relevant scientific literature, technical reports, international standards, and research studies on early warning systems, digital technologies in disaster forecasting, and banking risk management are collected and analyzed. Based on this review, key technological groups, including traditional physical models, AI/ML approaches, IoT sensor networks, satellite data, Big Data analytics, Digital Twin, and Decision Support Systems, are classified and evaluated in terms of applicability in the Vietnamese context.

Second, a comparative method is employed to examine international experiences from countries such as Japan, the Netherlands, Singapore, and the United States. The analysis focuses on multi-source data integration, multi-level operational structures, and the application of DSS and Digital Twin technologies in disaster risk reduction. These experiences are selected based on their relevance to Vietnam's geographic, climatic, data infrastructure, and governance conditions.

Finally, based on the synthesis of theoretical foundations, empirical assessment, and international benchmarking, a deductive approach is applied to propose improvement pathways for the early warning system. These proposals are structured in short-, medium-, and long-term orientations, while also clarifying the potential integration of early warning data into commercial banks' risk management systems to enhance forecasting, monitoring, and response capacity to climate-related risks.

2. Analysis of The Current State of The Early Warning System for Natural Disasters in VietNam

Current Status of Disaster Forecasting and Early Warning Systems

According to specialized reports and international studies (Khan et al., 2020; Vietnam National Center for Hydro-Meteorological Forecasting, 2025), disaster forecasting and early warning systems in Vietnam have been predominantly based on traditional physical models in the field of hydro-meteorology, including Numerical Weather Prediction (NWP) models as well as hydrological and hydraulic simulation models. At the national level, these models have been relatively systematically implemented, enabling the prediction of typhoon trajectories and intensities approximately 3-5 days in advance with improving reliability. They also support flood forecasting in major river basins such as the Red-Thai Binh River system, the Ma River, the Ca River, and the Mekong Delta basin.

A major challenge currently observed is that the spatial resolution of many forecasting models remains at approximately 3-10 km. This level of resolution is insufficient for capturing extreme precipitation events in mountainous areas and small catchments, where hydrometeorological processes occur at much finer spatial scales and evolve rapidly. In addition, data update cycles remain relatively long, typically ranging from 1 to 6 hours, which reduces the effectiveness of early warning in fast-evolving disaster situations. The lack of high-resolution real-time data from weather radar systems, in-situ sensors, and IoT-based monitoring networks further limits the effectiveness of short-term forecasting (nowcasting).

Table 1. Comparison between technical requirements and the current status of disaster forecasting and early warning systems in Vietnam

Content	Requirement for an effective EWS	Current situation in Vietnam	Assessment
Dominant modeling approach	Hybrid models (physical + AI/ML), real-time and short-term forecasting	Mainly traditional physical models (NWP, hydrological-hydraulic models)	Insufficient exploitation of data-driven and extreme-event learning approaches
Spatial resolution	≤ 1 km for small catchments and complex terrain	Typically 3-10 km for NWP; coarser in mountainous regions	Inadequate for localized rainfall and flash floods

Temporal update frequency	5-15 minutes (nowcasting)	1-6 hours	High latency in rapidly evolving rainfall events
Rainfall/hydrological station density	1-2 km² per station in high-risk areas	Approximately 10-20 km² per station; uneven distribution	Insufficient spatial coverage for small basins
Real-time data availability	High-resolution radar, IoT sensors, continuous satellite updates	Partial radar and automatic stations; limited integration	Lack of unified real-time data pipeline
Flash flood/landslide warning capability	30-120 minutes lead time	Typically ≤ 30 minutes	Limited response time
Decision Support System (DSS) integration	DSS + Digital Twin, scenario simulation	Mainly based on procedures and expert experience	Decision-making is not fully data-driven

(Source: Author's synthesis based on meteorological and disaster risk management reports)

The synthesis presented in Table 1 indicates that, from an economic perspective, these limitations increase uncertainty in disaster risk assessment across production and business activities, particularly in agriculture, aquaculture, logistics, and local infrastructure systems. For commercial banks, such limitations reduce the ability to identify early credit risk exposure at the geographical level. When disaster warnings are not sufficiently detailed or timely, it becomes difficult for banks to accurately assess impacts on cash flows, collateral values, and borrowers' repayment capacity.

The main causes of this situation are identified as follows: (i) continued reliance on traditional forecasting models; (ii) limited application of artificial intelligence and machine learning techniques; and (iii) uneven investment in short-term forecasting systems and hybrid modeling approaches across different regions.

Status of Data Infrastructure and Observation Networks

According to La, T.-V., Nguyen, T. H., Matgen, P., & Chini, M. (2024), in recent years, meteorological, hydrological, and automatic rainfall monitoring networks in Vietnam have been significantly expanded, contributing to improved national capacity for tracking typhoons, rainfall, and flood events. However, the spatial distribution of observation stations remains uneven, with a concentration in lowland areas, urban centers, and major river basins, while mountainous, midland regions, and high-risk zones for flash floods and landslides remain insufficiently covered. In many small mountainous catchments, the distance between rainfall and hydrological monitoring stations remains relatively large, which limits the ability to detect localized extreme events in a timely manner.

The limited density of monitoring stations in mountainous micro-basins further constrains early detection of localized heavy rainfall events. Meanwhile, modern observation technologies such as IoT-based sensor networks, high-resolution satellite data, and UAV/drone systems have mostly been implemented at pilot scale only, and have not yet formed an integrated and interoperable data ecosystem.

Table 2. Current status of data infrastructure and observation networks for early warning systems in Vietnam

Item	Requirement for modern systems	Current status in Vietnam	Impact
Meteorological-hydrological station network	Even distribution based on risk, higher density in mountainous areas	Concentrated in lowlands and major basins	Insufficient data for flash floods and landslides

Automatic rainfall stations	High density (1-2 km² per station in high-risk areas)	Low and uneven density	Limited detection of localized extreme rainfall
IoT sensor networks	Regional-scale deployment with real-time integration	Mostly pilot-scale implementation	Limited support for early warning effectiveness
Satellite and UAV data	Regular integration into analytical systems	Fragmented, project-based use	Underutilization of monitoring potential
Data standardization and integration	Unified data standards and interoperable APIs	Fragmented datasets, lack of standards	Reduced efficiency of DSS and forecasting models
Inter-agency data sharing	Real-time sharing across institutions	Limited, manual sharing mechanisms	Delays in decision-making processes

(Source: Author's synthesis based on specialized reports and practical implementation of monitoring systems)

As shown in Table 2, a notable challenge is that data remain fragmented across multiple managing agencies, lacking unified standards, real-time APIs, and inter-agency synchronization mechanisms. This results in delays in data utilization for forecasting, decision support, and early warning dissemination.

For commercial banks, these data limitations reduce the ability to develop geographically based credit risk maps. In the absence of standardized disaster-related data, it becomes difficult to integrate physical risk information into credit scoring systems, stress testing frameworks, and portfolio concentration risk monitoring. This issue is particularly critical for lending activities in agriculture, real estate, aquaculture, and small and medium-sized enterprises.

The main causes of these limitations include: (i) fragmented investment in data infrastructure; (ii) lack of inter-agency data-sharing mechanisms; and (iii) absence of an open data platform supporting cross-sector integration.

Status of Management, Operation, and Emergency Response

Studies on digital-based early warning systems (Akanbi, 2023) indicate that disaster management and response activities in Vietnam have undergone significant improvements in recent years, particularly in the strengthening of the legal framework, the enhanced coordination role of central authorities, and increased involvement of local governments. However, the current disaster risk management approach is still predominantly reactive in nature, with a strong emphasis placed on post-disaster response and recovery, while capabilities in early forecasting and data-driven decision-making remain limited.

The application of Decision Support Systems (DSS) and Digital Twin simulation is currently still at a pilot or experimental stage and has not yet been widely adopted as a routine operational tool in disaster management. Most response decisions are still made based on administrative procedures, practical experience, and manually aggregated information, which leads to delays in emergency response.

At the local level, capacities in data management, GIS application, and modeling remain uneven. Many local authorities lack specialized personnel capable of effectively utilizing real-time data. In addition, inter-agency coordination mechanisms for data sharing and decision-making remain fragmented and insufficiently integrated.

Table 3. Current status of disaster management, operation, and response in Vietnam

Content	**Requirement for modern management**	**Current status in Vietnam**	**Consequence**
Risk management approach	Proactive, based on forecasting and data	Mainly reactive after disasters	Short preparedness and warning time

DSS application	Regular use supporting scenario-based decisions	Limited and not widely implemented	Suboptimal decision-making
Digital Twin application	Multi-scenario simulation for evacuation and resource allocation	Almost not implemented	Limited pre-disaster impact assessment
Local data analytics capacity	Dedicated teams for data, GIS, and modeling	Uneven and insufficient capacity	High dependence on central authorities
Inter-agency coordination	Real-time data sharing and flexible processes	Fragmented and manual coordination	Delays in emergency response
Standardized operating procedures	Data-driven and scenario-based SOPs	Traditional SOPs, rarely updated	Lower response effectiveness

(Source: Author's synthesis based on disaster management practices and specialized reports)

As shown in Table 3, from the perspective of the banking system, this represents a critical challenge. When early warning systems are not closely integrated with local risk governance mechanisms, commercial banks face difficulties in developing early credit risk warning scenarios for disaster-affected customers. As a result, loan restructuring, credit limit adjustments, and portfolio risk controls are often implemented only after risks have already materialized.

Furthermore, under increasing international requirements for risk governance standards, the lack of integration between disaster data and internal banking risk management systems prevents many commercial banks from fully incorporating climate-related risks into their credit and operational risk frameworks.

The main causes of these limitations include: (i) a disaster management model that remains heavily administrative in nature; (ii) limited adoption of DSS and Digital Twin technologies; and (iii) the absence of effective data linkage mechanisms between disaster management agencies and the financial-banking sector.

Implications of the Early Warning System for Natural Disasters in Relation to Risk 3. Management in Vietnamese Commercial Banks

From the analytical results, it can be observed that the current early warning system for natural disasters in Vietnam still exhibits structural limitations arising simultaneously from forecasting capacity, data infrastructure, and operational governance models. These constraints not only reduce the effectiveness of disaster risk prevention and response but also generate spillover effects on local economic stability, production and business activities, and particularly credit risk management within the commercial banking system.

First, from the perspective of forecasting and early warning capacity, the continued reliance on traditional physical models with insufficient spatial resolution for small catchments and complex terrain indicates an urgent need to transition toward hybrid forecasting models that integrate physical models with artificial intelligence and machine learning techniques. In Vietnam, extreme rainfall events, flash floods, and landslides are increasingly characterized by localized and rapidly evolving patterns, while relatively long data update cycles reduce the effectiveness of real-time early warning. This implies that priority should be given to investments in nowcasting technologies, ultra-short-term forecasting models, high-resolution radar systems, and data-driven learning algorithms based on historical events. For the banking sector, this is particularly important, as geographically precise warnings form the basis for early identification of borrowers exposed to declining cash flows, reduced collateral values, and increased probability of non-performing loans.

Second, from the perspective of data

infrastructure and observation networks, the fragmentation of data across multiple agencies, the lack of standardization, and the absence of real-time connectivity indicate that Vietnam has not yet developed a sufficiently integrated disaster data platform to support forecasting, warning, and decision-making simultaneously. Uneven investment in monitoring infrastructure, especially in mountainous and small catchment areas, has created significant data gaps in the most vulnerable regions. This implies the need to develop an open national data architecture with interoperable APIs connecting meteorology, environment, agriculture, transport, and local authorities, while also promoting the integration of IoT, satellite, and UAV data into routine operational systems rather than limiting them to pilot projects. For the banking sector, a standardized disaster data ecosystem would enable the development of geographically based credit risk maps, integration of physical risk into credit rating systems, stress testing of credit portfolios, and monitoring of sectoral concentration risk in agriculture, aquaculture, logistics, and real estate.

Third, from the perspective of management, operation, and response, the predominance of administrative and reactive disaster management approaches highlights a significant gap between modern risk governance requirements and current operational practices. As Decision Support Systems (DSS) and Digital Twin technologies remain underutilized, many response decisions are still based on experience and manual procedures, leading to delayed responses and suboptimal resource allocation. This implies a necessary transition toward a data-driven risk governance model, in which decision support systems become an integral part of routine operations at both central and local levels. In parallel, local capacity in GIS, data analytics, and modeling must be strengthened to ensure the effective and uniform deployment of advanced technologies across regions. For the banking sector, improved integration between early warning systems and internal risk monitoring systems would enable more proactive loan restructuring, credit limit adjustments, portfolio concentration control, and the incorporation of climate risk into internationally aligned risk management frameworks.

Taken together, these three groups of issues indicate that the current limitations are not merely due to the absence of individual technologies but stem from a lack of an integrated mechanism linking technology, data, governance, and finance. Therefore, the overall implication is that the improvement of Vietnam's early warning system should be approached as part of a national risk governance strategy, in which strong institutional linkages between disaster management agencies, national data infrastructure, and the financial-banking sector are regarded as a foundational condition for enhancing resilience to increasingly severe climate-related risks.

Conclusion

This study has systematically analyzed the current status of the early warning system for natural disasters in Vietnam in the context of increasingly complex and less predictable hazards driven by climate change. The findings indicate that, although Vietnam has achieved significant progress in disaster forecasting and early warning, particularly in the field of hydro-meteorology, the current system still presents several important limitations. These limitations are clearly reflected in the spatial resolution of forecasting models, data infrastructure and observation networks, as well as governance, operational mechanisms, and decision-support capabilities. As a result, the effectiveness of early warning for highly localized extreme events such as flash floods and landslides has not yet fully met practical requirements.

Based on the analysis of the current situation and synthesized data tables, it is emphasized that the improvement of early warning systems is not solely a technological issue but also a matter of governance and inter-agency coordination. The application of digital technologies such as artificial intelligence, big data, the Internet of Things (IoT), and Digital Twin simulation is considered to offer significant opportunities for multi-source data integration, enhanced short-term forecasting, and scenario-based decision support. However, in order for these technologies to be effectively utilized, appropriate implementation roadmaps must be established in line with practical conditions, accompanied by investments in data infrastructure, standardized procedures, and human resource capacity building, particularly at the local level.

From a policy perspective, it is argued that Vietnam should gradually transition from a reactive disaster response approach toward a proactive, data-driven, and digitally enabled disaster risk management model. This transition is considered essential for improving early warning effectiveness, minimizing disaster-related losses, and contributing to long-term sustainable development.

From a financial sector perspective, a fully developed and digitized early warning system is not only expected to reduce socio-economic losses but also to serve as a critical input for risk management, geographically based credit assessment, and enhancing the resilience of commercial banks against climate-related shocks.

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