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Comparative Review of Intelligent Flood Monitoring and Risk Assessment Systems: An IoT–Random Forest Perspective

***Idayana Alabere and Epelle Bright Curthbert**

Department of Department of Computer Science and Informatics, Federal University Otuoke, Otuoke, Bayelsa State, Nigeria.

*Corresponding authors' email: alabereii@fuotuke.edu.ng

ABSTRACT

Flooding remains one of the most destructive natural hazards worldwide, causing significant loss of life, damage to infrastructure, and socioeconomic disruption. Recent advances in the Internet of Things (IoT), wireless communication, and machine learning have enabled the development of intelligent flood monitoring systems capable of supporting real-time environmental monitoring and timely decision-making. This study presents a comparative review of recent intelligent flood monitoring systems with the objective of evaluating current technological approaches and identifying effective design strategies for flood risk assessment. The review systematically compares existing studies based on key criteria, including environmental sensing parameters, IoT architectures, wireless communication technologies, machine learning techniques, flood prediction capabilities, web-based monitoring platforms, and automated early warning mechanisms. Particular attention is given to an integrated framework that combines IoT-based environmental sensing with the Random Forest machine learning algorithm and its relative strengths when compared with other reported approaches. The comparative review indicates that integrating multiple environmental sensors with Random Forest models generally provide improved predictive reliability, greater robustness to heterogeneous environmental data, reduced susceptibility to overfitting, and enhanced support for real-time flood risk classification. The findings provide a comprehensive overview of recent technological developments and highlight the value of integrating IoT sensing and Random Forest-based analytics as a practical direction for developing reliable, scalable, and intelligent flood monitoring and risk assessment systems.

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INTRODUCTION

Flooding is one of the most destructive and recurrent natural hazards, posing significant threats to human lives, infrastructure, ecosystems, and economic development worldwide. The increasing frequency and severity of flood events have been linked to climate change, rapid urbanization, environmental degradation, deforestation, and inadequate drainage infrastructure. Rising global temperatures have intensified extreme precipitation, while expanding impermeable urban surfaces have reduced natural infiltration and increased surface runoff, heightening the vulnerability of both urban and rural communities to riverine, coastal, and flash flooding (Intergovernmental Panel on Climate Change [IPCC], 2023; World Meteorological Organization [WMO], 2023).

Flood disasters result in loss of lives, population displacement, destruction of residential and commercial properties, damage to critical infrastructure, disruption of agricultural activities, contamination of water resources, environmental degradation, and substantial economic losses. These widespread impacts have increased the demand for advanced flood monitoring systems capable of providing timely and accurate information for disaster preparedness, emergency response, and risk reduction (United Nations Office for Disaster Risk Reduction [UNDRR], 2022; WMO, 2023).

Conventional flood monitoring has relied on manual observations, hydrological gauges, weather stations, and periodic field inspections. Although effective, these approaches are limited by restricted spatial coverage, delayed data acquisition, high operational costs, and inadequate support for continuous real-time monitoring. Advances in digital technologies have transformed flood monitoring through Internet of Things (IoT)-enabled systems that continuously collect, transmit, process, and analyse environmental data using interconnected sensors for monitoring rainfall intensity, river water level, soil moisture, temperature, humidity, atmospheric pressure, and water flow (Yaseen et al., 2022).

Wireless Sensor Networks (WSNs) enable communication among distributed sensor nodes, while technologies such as LoRaWAN, GSM, NB-IoT, ZigBee, Wi-Fi, and cellular networks facilitate real-time data transmission to cloud-based platforms. Cloud computing provides scalable storage, remote accessibility, real-time analytics, and visualization capabilities that enhance environmental monitoring and support informed decision-making during flood emergencies (Abdulridha et al., 2022; Yaseen et al., 2022).

Artificial Intelligence (AI) and Machine Learning (ML) have further enhanced IoT-enabled flood monitoring by enabling predictive modelling and automated flood risk assessment using multidimensional environmental data. Unlike conventional threshold-based methods, machine learning algorithms can identify complex relationships among environmental variables to improve prediction accuracy. Techniques such as Artificial Neural Networks, Support Vector Machines, Decision Trees, Gradient Boosting, Extreme Gradient Boosting, Long Short-Term Memory networks, and Random Forest have demonstrated strong performance in flood prediction (Arabameri et al., 2023). Among these, Random Forest is widely adopted because of its robustness, ability to handle high-dimensional and heterogeneous datasets, resistance to overfitting, and stable predictive performance under uncertain environmental conditions.

Despite significant advances, existing IoT-based flood monitoring systems employ diverse sensing technologies, communication protocols, machine learning algorithms, visualization platforms, and early warning mechanisms, making it difficult to identify the most effective approaches for different deployment scenarios. This study therefore provides a comparative evaluation of existing IoT-enabled flood monitoring systems by examining their sensing technologies, wireless communication mechanisms, machine learning algorithms, flood prediction approaches, web-based monitoring platforms, and automated early warning capabilities. It further examines the use of IoT and Random Forest-based approaches, highlighting how their integration can address limitations identified in previous studies and contribute to more reliable, scalable, and intelligent flood monitoring and risk assessment systems. Figure 1 illustrates the evolution of flood monitoring technologies from conventional approaches to intelligent IoT-enabled flood prediction frameworks.

Figure 1: Evolution of Intelligent Flood Monitoring Technologies

This study adopted a comparative literature review methodology to examine recent developments in intelligent flood monitoring systems and assess the technological approaches used for flood prediction, risk assessment, and early warning. Relevant studies were identified through searches of major academic databases and scholarly repositories, including IEEE Xplore, ScienceDirect, SpringerLink, Web of Science, Scopus, and Google Scholar. Search terms included “IoT flood monitoring,” “Internet of Things flood prediction,” “intelligent flood monitoring system,” “machine learning flood prediction,” “Random Forest flood prediction,” “wireless sensor network flood monitoring,” and “IoT flood early warning.” The retrieved studies were screened based on their relevance to intelligent flood monitoring and the availability of sufficient technical information for comparative analysis. Studies that were unrelated to flood monitoring, lacked relevant technological components, or focused exclusively on conventional flood management were excluded. Information extracted from the selected studies included environmental sensing parameters, sensor technologies, IoT architectures, embedded platforms, wireless communication technologies, machine learning algorithms, data processing approaches, visualization platforms, and automated early warning mechanisms. The selected studies were comparatively evaluated based on environmental sensing capability, communication technology, prediction approach, monitoring and visualization capabilities, early warning mechanisms, scalability, computational requirements, strengths, and limitations. Particular attention was given to Random Forest and its characteristics in handling heterogeneous environmental datasets, modelling nonlinear relationships, reducing overfitting, and providing feature importance information. The review findings were synthesized descriptively to identify technological trends, limitations, and research gaps. The identified characteristics were subsequently used to assess the suitability of integrating multisensor IoT monitoring with Random Forest-based flood prediction, web-based visualization, and automated early warning as a practical approach for reliable and intelligent flood risk assessment.

RESULTS AND DISCUSSION

Results

The comparative review of existing intelligent flood monitoring systems revealed a clear shift from conventional flood monitoring approaches toward IoT-enabled systems that integrate environmental sensing, wireless communication, machine learning, web-based monitoring, and automated early warning mechanisms. The reviewed studies demonstrated differences in the number and types of environmental parameters monitored, with earlier approaches mainly relying on rainfall and water-level measurements, while more recent systems incorporated additional variables such as soil moisture, temperature, humidity, atmospheric pressure, and water flow. The use of multiple environmental parameters provides more comprehensive information for flood risk assessment and supports the application of data-driven prediction techniques.

The results further showed that different wireless communication technologies are adopted according to deployment requirements. Wi-Fi, GSM, LoRaWAN, NB-IoT, ZigBee, and cellular technologies were identified across the reviewed approaches. The comparison indicates that Wi-

Fi is suitable for environments with available internet infrastructure, while LoRaWAN, NB-IoT, and GSM provide alternatives for applications requiring wider coverage or deployment in locations with limited conventional connectivity. The reviewed systems also demonstrated increasing use of cloud-based and web-based platforms for remote data access, visualization, and monitoring.

Machine learning emerged as an important component of recent intelligent flood monitoring systems. The reviewed studies employed different algorithms, including Artificial Neural Networks, Support Vector Machines, Decision Trees, Gradient Boosting, Extreme Gradient Boosting, Long Short-Term Memory networks, and Random Forest. Among the approaches examined, Random Forest demonstrated important practical characteristics, including the ability to handle heterogeneous environmental variables, model nonlinear relationships, reduce overfitting, and provide feature importance information. These characteristics support its application in flood susceptibility assessment and risk classification.

The comparison also revealed that systems combining predictive analytics with automated warning mechanisms provide broader functionality than systems based solely on threshold-based monitoring. Web dashboards, alarms, SMS, mobile applications, email, and other notification mechanisms were identified as approaches for communicating flood risks. Overall, the results indicate that integrating multisensor IoT monitoring with Random Forest-based prediction, web-based visualization, and automated early warning provides a comprehensive approach for intelligent flood risk monitoring. However, the reviewed studies also revealed persistent limitations related to sensor reliability, communication stability, geographical validation, scalability, interoperability, and dependence on specific environmental conditions.

Comparative Review of Existing Intelligent Flood Monitoring Systems

Recent advances in intelligent flood monitoring have been driven by the convergence of the Internet of Things (IoT), Wireless Sensor Networks (WSNs), cloud computing, edge computing, and machine learning. Together, these technologies have transformed conventional flood monitoring from isolated hydrological measurements into interconnected systems capable of continuous environmental sensing, real-time data transmission, predictive analytics, and automated decision support. Although existing studies share the common objective of improving flood preparedness and minimizing disaster impacts, they differ in sensing architectures, communication technologies, computational platforms, prediction algorithms, visualization approaches, and early warning mechanisms, influencing system scalability, prediction reliability, computational efficiency, and deployment suitability.

A common characteristic of contemporary flood monitoring systems is the use of multiple environmental sensors to monitor hydrological and meteorological variables associated with flooding. While earlier systems relied primarily on rainfall intensity and river water level, recent approaches integrate soil moisture, water flow velocity, atmospheric pressure, temperature, humidity, and river discharge to improve prediction accuracy. Multisensor configurations provide a more comprehensive environmental representation by enabling machine learning algorithms to exploit relationships among multiple variables, although they increase deployment costs, calibration requirements, and maintenance complexity (Arabameri et al., 2023). Most intelligent flood monitoring systems employ embedded platforms such as ESP32, Arduino, or Raspberry Pi integrated with ultrasonic, pressure, rainfall, and soil moisture sensors. Compared with conventional hydrological stations, these distributed IoT architectures provide greater spatial coverage, lower deployment costs, and improved flexibility for monitoring remote and flood-prone areas (Yaseen et al., 2022).

Wireless communication technologies also vary considerably across existing systems. Wi-Fi is widely adopted because of its simplicity, high data transmission rate, and ease of integration in urban environments. In contrast, LoRaWAN and NB-IoT provide longer communication ranges and lower power consumption, making them suitable for geographically dispersed monitoring stations. GSM and cellular networks remain practical where internet infrastructure is limited, although they incur higher operational costs and depend on network availability during extreme weather events. ZigBee supports efficient short-range communication but is less suitable for large-scale deployments because of its limited transmission range. Consequently, communication protocol selection depends on deployment distance, energy requirements, reliability, and available infrastructure (Abdulridha et al., 2022).

Machine learning has become a defining feature of modern flood monitoring systems, although prediction algorithms differ considerably. Artificial Neural Networks (ANNs) effectively model nonlinear relationships but generally require substantial training data and computational resources. Support Vector Machines (SVMs) achieve high classification accuracy for smaller datasets but require careful parameter optimization and become computationally expensive with larger datasets. Long Short-Term Memory (LSTM) networks effectively capture temporal dependencies in hydrological time-series data but involve greater computational complexity. In comparison, ensemble methods, particularly Random Forest, provide a balance of predictive accuracy, computational efficiency, robustness to noisy environmental data, and resistance to overfitting, resulting in stable performance across heterogeneous datasets (Arabameri et al., 2023), Consequently, Random Forest has become one of the most widely adopted algorithms for flood susceptibility assessment and flood risk classification.

Visualization platforms and early warning mechanisms have also evolved considerably. Web-based dashboards now provide interactive visualization of sensor readings, predicted flood risks, geographical information, and historical environmental trends. Systems integrating machine learning with automated notifications generally outperform threshold-based warning systems, which are simpler to implement but may generate false alarms or fail to detect complex environmental interactions. Predictive warning mechanisms deliver risk-based notifications through SMS, mobile applications, email, alarms, or web platforms, improving emergency preparedness and supporting proactive disaster response.

Despite these advances, several challenges remain. Many systems are validated only within limited geographical regions, reducing their applicability under different hydrological and climatic conditions. Sensor calibration, communication reliability, energy efficiency, missing observations, and network interruptions continue to affect system performance, while comparatively few studies investigate model interpretability, interoperability, long-term scalability, or integration with emergency management frameworks. These limitations highlight the need for intelligent flood monitoring systems that integrate comprehensive multisensor monitoring, adaptive communication technologies, scalable computing architectures, interpretable machine learning models, and robust automated early warning mechanisms. Accordingly, this review evaluates representative intelligent flood monitoring systems using the technological framework presented in Figure 2, which identifies the principal comparison criteria adopted throughout the review.

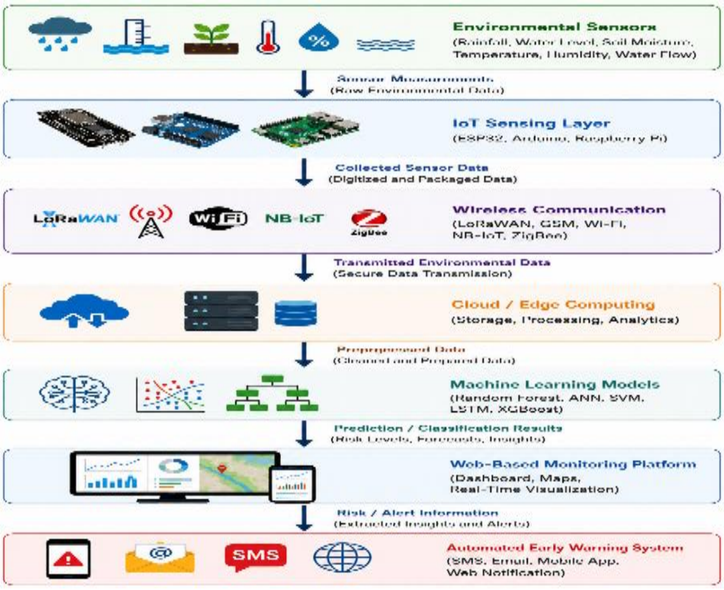

Figure 2: Comparative Framework for Evaluating Intelligent Flood Monitoring Systems

Table 1: Comparative Summary of Selected Intelligent Flood Monitoring Studies

Study	Environmental Sensors	ML/Prediction Algorithm	Key Contribution
Cloud-based IoT Flood Monitoring System	Water level, rainfall sensors	Threshold-based analytics	Developed a cloud-enabled IoT system for real-time flood monitoring using sensor data and threshold-based alerts.
AI-enabled IoT Smart Environmental Monitoring Framework	Distributed environmental sensors (WSNs)	AI-enabled analytical framework	Proposed an intelligent IoT architecture integrating WSNs and AI for environmental monitoring and event notification
Random Forest-based Flood Susceptibility Assessment Model	Environmental and GIS-derived variables	Random Forest and other ensemble learning algorithms	Applied ensemble machine learning techniques for accurate flood susceptibility mapping and nonlinear environmental modelling.
Artificial Neural Network-based Flood Prediction System	Hydrological and meteorological variables	Artificial Neural Network (ANN)	Developed an ANN-based model for predicting flood risk from hydrological and meteorological data.
IoT-enabled Machine Learning Flood Prediction Framework	IoT-enabled multisensory hydrological datasets	Comparative machine learning models including Random Forest	Compared multiple machine learning algorithms within an IoT framework for automated flood prediction and early warning.

Table 1 shows that recent intelligent flood monitoring studies share the common objective of improving flood prediction through environmental sensing and data-driven analytical techniques. Although all the reviewed systems utilize environmental data for flood assessment, they differ in the types of sensors employed, the prediction algorithms adopted, and their overall contributions to flood monitoring. Earlier studies primarily relied on rainfall and water level measurements with threshold-based approaches, whereas more recent systems integrate multisensor environmental data with machine learning algorithms to improve prediction accuracy. Among the reviewed approaches, Random Forest has demonstrated strong performance in modelling complex environmental relationships and handling heterogeneous datasets, making it one of the most effective techniques for flood susceptibility assessment and risk prediction. Despite these advances, no single study provides a comprehensive solution capable of addressing all flood monitoring challenges, indicating the need for integrated frameworks that combine multi-sensor environmental sensing with robust machine learning techniques for reliable and intelligent flood risk assessment.

Comparative Analysis of the Proposed IoT–Random Forest Framework

Recent advances in intelligent flood monitoring have demonstrated that effective flood risk assessment depends not only on the availability of environmental data but also on the integration of sensing technologies, communication infrastructure, data analytics, and decision-support mechanisms. Existing intelligent flood monitoring systems employ different combinations of IoT devices, wireless communication protocols, and machine learning techniques, resulting in variations in prediction accuracy, scalability, computational requirements, and operational efficiency. Against this background, the integrated IoT–Random Forest framework represents a practical architecture that combines real-time environmental sensing with ensemble machine learning to support reliable flood monitoring and early warning. A distinguishing characteristic of the proposed framework is its emphasis on multisource environmental sensing. Rather than relying solely on river water level or rainfall measurements, the framework integrates rainfall intensity, river water level, soil moisture, temperature, humidity, atmospheric pressure, and water flow. Monitoring diverse environmental parameters enables the predictive model to capture interactions among factors that collectively influence flood occurrence, providing richer input data than systems based on single-variable threshold detection (Arabameri et al., 2023).

The IoT architecture further enhances system performance by employing distributed sensor nodes connected through Wireless Sensor Networks (WSNs). Sensor data are transmitted using communication technologies such as LoRaWAN, NB-IoT, GSM, Wi-Fi, or other suitable wireless protocols, depending on deployment requirements and available infrastructure. Compared with conventional monitoring stations, distributed IoT architectures improve spatial coverage, support continuous real-time monitoring, and simplify deployment across geographically dispersed flood-prone locations (Yaseen et al., 2022). Effective predictive modelling also depends on appropriate data preprocessing. Environmental sensor data frequently contain missing values, measurement noise, duplicate observations, and inconsistencies arising from communication interruptions or sensor malfunction. Consequently, data cleaning, normalization, feature selection, and handling of missing observations improve model reliability and contribute to more consistent prediction outcomes.

Among the machine learning techniques applied to flood prediction, previous studies indicate that Random Forest offers several practical characteristics that make it well suited for environmental risk assessment. The algorithm constructs multiple decision trees using randomly selected subsets of observations and predictor variables before aggregating their outputs through ensemble voting. This enables Random Forest to model complex nonlinear relationships while reducing overfitting and maintaining stable classification performance across heterogeneous environmental datasets. It also provides measures of feature importance, enabling researchers and decision-makers to identify the variables contributing most significantly to flood prediction (Breiman, 2001; Arabameri et al., 2023). Compared with other machine learning techniques, Random Forest provides a balance of predictive accuracy, computational efficiency, robustness to noisy environmental data, and resistance to overfitting across heterogeneous datasets (Arabameri et al., 2023; Géron, 2023) The integration of Random Forest with web-based monitoring further strengthens decision support by transforming sensor measurements into actionable information. Interactive dashboards enable continuous visualization of environmental parameters, predicted flood risk levels, historical trends, and system status. Automated alert mechanisms generate SMS notifications, email messages, mobile application alerts, or web notifications whenever predicted flood risk exceeds predefined thresholds. By combining predictive analytics with automated warning dissemination, the framework supports earlier intervention and more informed emergency response than systems relying solely on manual monitoring or fixed threshold alarms. From a deployment perspective, the integrated framework offers a modular IoT architecture that allows additional sensors to be incorporated without major system redesign, improving scalability for larger geographical regions. Random Forest also provides efficient model training and inference while maintaining reliable classification performance, making the framework suitable for deployment in resource-constrained environments where processing capability, communication bandwidth, and energy availability are limited.

Table 2: Comparative Analysis of the Integrated IoT–Random Forest Framework

Study	Prediction Algorithm	Strength	Limitations	Improvements Offered by the Integrated IoT–Random Forest Framework
Cloud-based IoT Flood Monitoring System	Threshold-based analysis	Real-time environmental monitoring	Limited predictive capability	Incorporates Random Forest-based prediction and automated flood risk classification.
AI-enabled IoT Environmental Monitoring Framework	AI-enabled monitoring framework	Scalable IoT architecture	Limited emphasis on flood-specific prediction	Integrates multisensor flood monitoring with Random Forest for intelligent prediction and risk assessment.
Random Forest-based Flood Susceptibility Assessment Model	Random Forest	High prediction accuracy for flood susceptibility	Primarily supports offline susceptibility assessment	Extends Random Forest to real-time IoT monitoring and automated early warning.
Artificial Neural Network-based Flood Prediction System	Artificial Neural Network (ANN)	Strong nonlinear modelling capability	High computational complexity and limited interpretability	Provides comparable predictive performance with improved interpretability and lower computational demand.
IoT-enabled Machine Learning Flood Prediction Framework	Comparative machine learning models	Comprehensive evaluation of prediction models	Performance depends on geographical and environmental conditions	Integrates multisensor IoT monitoring, Random Forest prediction, web-based visualization, and automated alert generation in a unified framework.

Table 2 demonstrates that recent intelligent flood monitoring systems have adopted different prediction approaches, each offering distinct strengths and limitations. While threshold-based methods provide simple real-time monitoring, machine learning techniques improve flood prediction by modelling complex environmental relationships. Random Forest, Artificial Neural Networks, and other machine learning models have enhanced prediction accuracy, although challenges such as limited interpretability, computational complexity, offline analysis, and dependence on specific environmental conditions remain. The integrated IoT–Random Forest framework addresses these limitations by combining real-time multisensor monitoring with Random Forest-based prediction, automated flood risk classification, web-based visualization, and early warning within a unified architecture. This integrated approach provides a practical balance between predictive accuracy, computational efficiency, robustness, and interpretability, making it suitable for intelligent flood monitoring and risk assessment applications.

Discussion

The findings of this review indicate that the effectiveness of intelligent flood monitoring systems depends largely on the integration of environmental sensing, predictive analytics, and early warning mechanisms. The reviewed studies demonstrate a gradual transition from conventional and threshold-based monitoring toward multisensor IoT systems supported by machine learning. Systems that rely mainly on rainfall or water-level measurements provide relatively simple and cost-effective monitoring; however, their ability to represent the complex environmental conditions associated with flood occurrence is limited. In contrast, multisensor systems provide more comprehensive environmental information by combining variables such as rainfall, water level, soil moisture, temperature, humidity, and water flow, thereby providing richer input for predictive models.

The analysis further indicates that machine learning provides advantages over fixed threshold-based flood detection because it can identify relationships among multiple environmental variables. Although ANN, SVM, LSTM, and other algorithms provide useful predictive capabilities, Random Forest demonstrates a practical balance between predictive capability, robustness, computational efficiency, and resistance to overfitting. Its suitability for heterogeneous environmental data and its ability to provide feature importance information make it particularly relevant to IoT-based flood risk assessment. However, the findings do not suggest that Random Forest is universally superior, as model performance can vary according to datasets, geographical conditions, feature selection, and experimental settings.

The integration of multisensor IoT monitoring with Random Forest-based prediction therefore represents a promising approach for intelligent flood monitoring. Combining real-time sensing, predictive analysis, web-based visualization, and automated warning mechanisms can reduce dependence on manual observation and fixed threshold alerts while improving the availability of timely flood risk information. Nevertheless, challenges related to sensor reliability, data quality, communication interruptions, scalability, interoperability, and geographical validation remain important considerations. Future systems should therefore focus not only on prediction accuracy but also on reliability, adaptability, energy efficiency, interpretability, and practical deployment across different environmental conditions.

CONCLUSION

The comparative review demonstrates that the increasing frequency and severity of flood events have accelerated the adoption of intelligent flood monitoring technologies capable of supporting proactive flood risk management and early warning. As conventional monitoring approaches are constrained by limited spatial coverage and delayed information delivery, recent technological developments have increasingly focused on integrating Internet of Things (IoT) technologies, wireless communication networks, cloud computing, and machine learning to enable continuous environmental monitoring and informed decision-making.

This comparative review examined contemporary intelligent flood monitoring systems by evaluating their environmental sensing capabilities, IoT architectures, communication technologies, prediction algorithms, visualization platforms, and automated early warning mechanisms. The analysis demonstrates a clear transition from single-parameter monitoring toward multisensor IoT-based systems that capture diverse hydrological and meteorological variables in real time. It also reveals growing adoption of low-power wireless communication technologies and cloud-supported monitoring platforms that improve data accessibility, system scalability, and remote situational awareness. These developments collectively reflect an increasing emphasis on integrated and intelligent flood monitoring architectures capable of supporting proactive disaster management.

The review further highlights the important role of machine learning in enhancing flood prediction by identifying complex relationships among multiple environmental variables. Although various algorithms have been successfully applied in flood monitoring, the analysis indicates that the Random Forest algorithm offers several practical advantages for environmental prediction. Its ability to model nonlinear relationships, resist overfitting, handle heterogeneous and noisy environmental datasets, maintain stable classification performance, and provide measures of feature importance makes it a suitable analytical approach for many IoT-enabled flood monitoring applications. Rather than representing a universal solution, Random Forest provides a balanced combination of predictive capability, computational efficiency, and interpretability that aligns well with the operational requirements of intelligent environmental monitoring systems.

Despite these advances, the literature continues to reveal several limitations, including variations in sensing configurations, communication infrastructures, prediction methodologies, visualization strategies, and early warning mechanisms. Many studies also remain constrained by limited deployment environments, challenges associated with sensor reliability and communication stability, and insufficient emphasis on system scalability and interoperability. These differences underscore the importance of comparative evaluations for identifying effective technological combinations and guiding future system development.

Future research should focus on developing standardized evaluation frameworks, improving interoperability among heterogeneous IoT devices, strengthening the integration of edge and cloud computing, enhancing model interpretability, and designing scalable, energy-efficient intelligent flood monitoring systems that can support reliable deployment across diverse environmental and geographical conditions. Such advances will contribute to more resilient, adaptive, and effective flood risk management strategies capable of addressing the growing challenges posed by extreme hydrological events.

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