An ITIL-Aligned Resilience Evaluation Framework for IoT Flood Prediction Systems in Resource-Constrained Environments

Muwanga Erasto Kosea[1], Dr. Daniel Otanga[2], Dr. Satwinder Singh Rupra[3]

[123]*School of Computing and Informatics, Masinde Muliro University of Science and Technology, Kakamega, Kenya*

---***---

Abstract-*Flood prediction systems based on Internet of Things (IoT) technologies are increasingly used to support early warning and disaster risk reduction. However, their effectiveness in resource-constrained environments remains limited by unreliable sensor data, fragmented environmental datasets, and weak operational governance. Many existing frameworks emphasize sensor deployment and predictive analytics while underemphasizing mechanisms for data reliability, incident management, and service continuity. This study introduces an ITIL-aligned resilience evaluation framework for assessing the operational readiness of IoT flood prediction systems under degraded conditions. Grounded in Pragmatism and Design Science Research Methodology, the study evaluates eight representative IoT flood prediction frameworks across five resilience dimensions: data handling and validation, incident management, service continuity, fault tolerance, and system adaptability. The findings reveal systematic weaknesses in incident response, resilience planning, and management of unreliable sensor inputs. Guided by these results, the study derives resilience-oriented design principles for improved IoT flood prediction architectures and validates them through simulation using CHIRPS rainfall data (2010–2024) for flood-prone locations in Uganda. Results indicate that resilience-oriented design improves predictive stability and maintains acceptable performance under incomplete and unreliable data conditions. Although evaluated in an East African context, the framework offers a generalized diagnostic approach for assessing IoT-based flood prediction systems in resource-constrained environments more broadly.*

Keywords: Internet of Things; Flood prediction; Data reliability; Sensor fault tolerance; Design science research; East Africa

1. INTRODUCTION

Flooding remains one of the most destructive natural hazards affecting East Africa, particularly in rapidly urbanizing environments characterized by inadequate drainage infrastructure and growing population densities. Countries such as Uganda, Kenya, and Tanzania experience recurrent flood events that lead to loss of life, infrastructure damage, and economic disruption (World Bank, 2021; UNEP, 2020). Flood early warning frameworks are therefore critical components of disaster risk reduction strategies in the region. Recent advances in Internet of Things (IoT) technologies have enabled continuous environmental monitoring through distributed sensors, automated data transmission, and predictive analytics (Atzori et al., 2010; Gubbi et al., 2013). IoT-based flood prediction frameworks typically integrate rainfall sensors, water-level monitoring devices, and machine learning algorithms to support automated early warning dissemination (Zhou et al., 2020; Kumar & Singh, 2022). These frameworks have shown considerable promise in enhancing situational awareness and reducing disaster response time.

Despite these advances, the reliability of IoT flood prediction frameworks remains constrained in developing regions. Sensor failures, power instability, network interruptions, and fragmented environmental datasets frequently introduce noise and missing values into data streams (Mishra et al., 2020; Deng et al., 2020). Such disruptions degrade predictive accuracy and undermine the credibility of automated warning frameworks. Existing IoT flood prediction frameworks often prioritize sensor deployment and algorithmic sophistication while overlooking operational governance mechanisms that ensure system reliability. In resource-constrained environments, the absence of structured processes for data validation, incident handling, and service continuity frequently leads to unreliable warning frameworks. This study addresses this gap by applying an ITIL-aligned design evaluation to existing IoT flood prediction frameworks and developing a resilience-oriented architecture capable of maintaining operational stability under degraded conditions.

This study contributes to the literature in three ways. First, it introduces an ITIL-aligned resilience evaluation framework that translates service management principles into five measurable dimensions for assessing IoT flood prediction systems. Second, it provides a structured comparative evaluation of existing IoT flood prediction frameworks using governance-oriented criteria that are rarely incorporated into flood prediction research. Third, it derives and validates resilience-oriented design principles showing how data reliability mechanisms, fault tolerance, and service continuity features can improve early warning performance under degraded infrastructure conditions. Together, these contributions extend existing work beyond algorithmic performance by offering a more generalizable framework for evaluating and improving IoT-based flood prediction systems in resource-constrained environments.

1.1 Problem Statement

Despite the increasing adoption of Internet of Things (IoT) technologies in environmental monitoring and flood early warning frameworks, reliable flood prediction in East Africa remains difficult to achieve. Many IoT-based frameworks rely on continuous sensor data and stable communication infrastructure; however, these assumptions rarely hold in resource-constrained environments. Sensors deployed in flood-prone areas often experience calibration drift, environmental interference, power instability, and intermittent connectivity, resulting in noisy readings, missing values, and inconsistent data streams. These disruptions compromise the reliability of real-time observations and reduce the accuracy of predictive models used for early warning. In addition, many flood prediction frameworks depend on generalized or externally sourced datasets that do not adequately represent the unique hydrological and climatic characteristics of East African environments. The absence of localized datasets limits model adaptability and weakens the credibility of prediction outputs among communities and decision makers. Furthermore, existing IoT flood prediction research frequently emphasizes algorithmic sophistication and real-time sensing while underemphasizing operational governance mechanisms such as data validation, incident management, and service continuity. Consequently, many frameworks remain vulnerable to sensor failure and data disruptions during extreme events. This study addresses this gap through an ITIL-aligned evaluation of IoT flood prediction frameworks to support resilience-oriented system design for resource-constrained environments.

2. RELATED WORK AND THEORETICAL FOUNDATION

2.1 Related Work

Recent advances in Internet of Things (IoT) technologies have significantly transformed flood monitoring and early warning frameworks by enabling continuous environmental sensing, real-time data transmission, and automated alert generation. IoT-based flood prediction frameworks typically integrate rainfall sensors, water-level monitoring devices, and meteorological data streams with predictive analytics to detect flood risk and disseminate warnings to decision makers and affected communities. Empirical studies show that such frameworks enhance situational awareness and improve response time during extreme weather events (Zhou et al., 2020; Kumar & Singh, 2022). In regions with stable infrastructure and well-established data governance frameworks, IoT-enabled monitoring frameworks have demonstrated strong potential for improving disaster preparedness and flood risk management.

However, many existing IoT flood prediction frameworks implicitly assume the availability of reliable infrastructure, continuous connectivity, and well-maintained sensor networks. These assumptions are rarely valid in developing regions, particularly in East Africa, where power instability, limited network coverage, and constrained maintenance capacity frequently disrupt sensor operations. Field-based studies indicate that sensor failures often occur during extreme weather events due to power outages, flooding of sensor installations, environmental interference, and communication breakdowns (Ahn & Kim, 2022; Nabirye et al., 2023). Ironically, these failures tend to occur precisely when reliable data are most critical for early warning and emergency response.

Sensor unreliability represents one of the most persistent technical challenges in IoT-based environmental monitoring frameworks. Calibration drift, exposure to harsh environmental conditions, heterogeneous sensor configurations, and unstable power supply introduce noise, missing values, and inconsistencies into environmental data streams (Bashir et al., 2021; Deng et al., 2020). In flood prediction frameworks, such data quality issues propagate through analytical models, potentially generating false alarms, delayed warnings, or unstable predictions. These challenges highlight the importance of incorporating data validation, fault tolerance, and error-handling mechanisms within IoT-based monitoring architectures.

Beyond sensor-level challenges, data reliability issues also arise at the dataset level. Hydrological and meteorological datasets in East Africa are often fragmented across institutions, outdated, sparsely distributed, and poorly standardized (Ouma & Tateishi, 2022). These limitations reduce their suitability for predictive modeling and real-time decision-making.

Consequently, many flood prediction frameworks rely on generalized global datasets that fail to adequately capture local hydrological behavior, urban drainage characteristics, and microclimatic variations typical of flood-prone areas in the region.

Recent studies emphasize the importance of locally calibrated and context-specific datasets for improving flood prediction accuracy. For example, Asare and Boateng (2023) demonstrate that flood models trained using localized hydrological datasets outperform those relying solely on global environmental datasets, particularly in regions characterized by complex topography and informal urban development. These findings suggest that improving flood prediction accuracy requires not only advanced analytical techniques but also reliable and contextually appropriate data sources.

Despite the growing body of research on IoT-enabled flood monitoring frameworks, a significant gap remains in the design of frameworks capable of operating reliably under degraded infrastructure conditions. Many studies focus primarily on enhancing predictive algorithms or expanding sensor networks while giving limited attention to operational resilience and data reliability management. As a result, existing frameworks often struggle to sustain reliable early warning services when sensor networks fail or data streams become incomplete. Addressing these limitations requires a shift from infrastructure-agnostic system designs toward resilience-oriented and data-centric IoT architectures that explicitly account for uncertainty and system failure in resource-constrained environments.

2.2 Theoretical Foundation

This study adopts General Systems Theory (GST) as its primary theoretical foundation for conceptualizing IoT-based flood prediction frameworks. Originally proposed by Bertalanffy (1968), GST views complex phenomena as frameworks composed of interrelated and interdependent components whose behavior cannot be fully understood in isolation. Instead, system performance emerges from interactions among components and the feedback processes that regulate these interactions. This perspective provides a holistic framework for analyzing complex socio-technical frameworks such as IoT-based environmental monitoring networks.

In the context of flood prediction, GST enables the conceptualization of IoT monitoring frameworks as integrated structures consisting of sensing devices, communication infrastructure, data processing components, governance mechanisms, and end users. Each of these elements functions as a subsystem that contributes to overall system performance. Disruptions within any subsystem such as sensor malfunction, communication failure, or incomplete datasets can propagate across the system and degrade prediction accuracy unless appropriate feedback and control mechanisms are implemented (Skyttner, 2005).

The systemic perspective provided by GST is particularly relevant in the context of East Africa, where environmental monitoring frameworks operate under conditions of infrastructural fragility, environmental variability, and institutional constraints. In such environments, system reliability depends not only on predictive algorithms but also on the ability of the broader system architecture to adapt to uncertainty, manage incomplete data, and sustain operational continuity during disruptions. By emphasizing interdependence, feedback, and adaptation, GST supports the design of IoT flood prediction frameworks that prioritize resilience, fault tolerance, and continuous system improvement. This theoretical perspective therefore underpins the study's focus on developing resilience-oriented IoT architectures capable of maintaining functional stability under degraded operating conditions typical of resource-constrained environments.

3. ITIL-ALIGNED DESIGN EVALUATION OF EXISTING FRAMEWORKS

Table 1. Positioning of the Proposed Evaluation Framework against Prior IoT Flood Prediction Studies

Study	Primary Focus	Predictive/Analytical Focus	Governance-Oriented Evaluation	Explicit Resilience Dimensions
Zhou et al. (2020)	IoT flood monitoring	Yes	No	No
Kumar and Singh (2022)	IoT early warning analytics	Yes	No	No
Deng et al. (2020)	Reliability challenges review	Partial	No	Partial

Mishra et al. (2020)	Sensor data quality	Partial	No	Partial
This study	ITIL-aligned resilience evaluation	Yes	**Yes**	**Yes**

This study introduces an ITIL-aligned resilience evaluation framework to assess the operational readiness of IoT flood prediction systems deployed in resource-constrained environments. Rather than using ITIL only as a general governance reference, the study operationalizes it into five evaluation dimensions: data handling and validation, incident management, service continuity, fault tolerance and redundancy, and adaptability and scalability. These dimensions provide a structured basis for comparing heterogeneous IoT flood prediction systems according to their ability to sustain reliable operation under degraded conditions. In this way, the study contributes a governance-informed methodological framework for resilience evaluation rather than a purely descriptive review of existing systems.

The framework evaluates systems across five operational dimensions to identify resilience weaknesses and derive design recommendations.

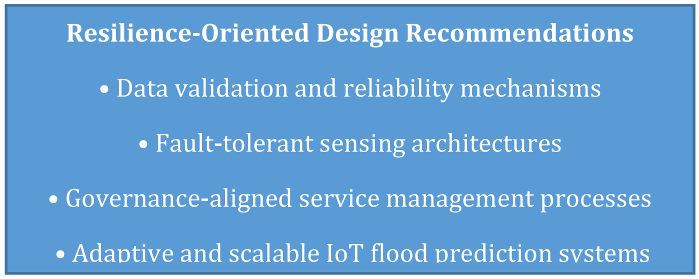

Fig. 1. ITIL-aligned resilience evaluation framework for assessing IoT flood prediction systems in resource-constrained environments.

The proposed evaluation framework was designed to reflect operational realities affecting IoT flood prediction deployments in developing regions, including unreliable sensor data streams, intermittent connectivity, power instability, and limited technical maintenance capacity. Consequently, the evaluation assessed frameworks according to their ability to manage sensor failure, maintain service continuity, handle incomplete data streams, and sustain operational functionality under degraded infrastructure conditions. This structured evaluation approach aligns with Design Science Research principles, which emphasize systematic assessment of technological artifacts based on their utility, robustness, and practical applicability (Hevner, 2007).

The frameworks assessed in this study represent a diverse set of IoT-based flood monitoring and prediction frameworks reported in the literature. Several of these frameworks demonstrate strong potential for urban flood monitoring through IoT-enabled sensing and automated alert dissemination. For example, floodwater detection and early warning frameworks designed for cities such as Arusha and Dar es Salaam support real-time data acquisition and timely warning delivery. However, these frameworks often provide limited safeguards for service continuity when power instability, sensor damage, or communication failures occur. Similarly, impact-based flood forecasting approaches implemented in the Greater Horn of Africa improve disaster preparedness by linking hazard forecasts with potential socio-economic impacts. Despite these advantages, such approaches frequently depend on centralized infrastructure and externally sourced datasets that may be difficult to sustain locally. These limitations highlight the importance of stable data pipelines, contextual deployment feasibility, and governance mechanisms that preserve operational continuity in resource-constrained environments (Deng et al., 2020; Ouma & Tateishi, 2022).

Other frameworks emphasize continuous hydrological sensing combined with automated analytics but remain vulnerable to sensor unreliability and inadequate fault-handling processes. IoT-based river monitoring and alerting frameworks, for instance, enable early detection through water-level sensing and automated trigger mechanisms. Nevertheless, many implementations lack redundancy mechanisms and structured incident escalation procedures, reducing reliability when sensors malfunction during extreme weather events. Similarly, low-cost and low-power IoT monitoring frameworks incorporating machine learning offer affordability and ease of deployment but often sacrifice resilience features such as redundancy, validation routines, and recovery workflows. In these frameworks, data drift, missing values, and sensor noise can rapidly degrade analytical reliability and reduce trust in automated prediction outputs. These observations emphasize the importance of integrating fault detection, sensor calibration mechanisms, and operational monitoring capabilities within IoT flood monitoring architectures (Ahn & Kim, 2022; Mishra et al., 2020).

A third category of frameworks focuses on advanced analytics and automated flood risk classification using deep learning and machine learning techniques. For example, LSTM-based rainfall and water-level monitoring frameworks demonstrate strong forecasting capability when operating under stable input conditions. However, their performance depends heavily on consistent data streams and robust preprocessing workflows conditions that are rarely guaranteed in developing regions. Similarly, machine learning-based flood monitoring frameworks improve automated prediction efficiency but often lack mechanisms for managing noisy sensor inputs or maintaining service continuity under network disruptions. Trigger-based flood detection and avoidance frameworks may provide interpretable alerting mechanisms, yet the absence of structured service management processes increases vulnerability to prolonged system downtime. Collectively, these observations indicate that while many existing IoT flood prediction frameworks demonstrate analytical sophistication, they frequently lack resilience-oriented design features necessary for stable operation under real-world uncertainty (Li et al., 2023; Uwayisenga et al., 2021).

Overall, the evaluation highlights a recurring pattern across existing IoT flood prediction frameworks: strong emphasis on sensing technologies and predictive algorithms, but comparatively limited attention to operational resilience, incident management, and service continuity. These weaknesses are particularly critical in developing regions where infrastructure limitations and environmental uncertainties frequently disrupt sensor networks and data pipelines. The findings therefore underscore the need for resilience-oriented IoT architectures that integrate governance-aligned mechanisms for managing data reliability, sensor failures, and service disruptions in flood early warning frameworks.

4. EVALUATION FINDINGS AND DISCUSSION

This section presents the comparative evaluation results of the selected IoT flood prediction frameworks using the ITIL-aligned diagnostic tool. The objective of the evaluation was to determine the extent to which existing frameworks demonstrate operational resilience and service continuity readiness under degraded operating conditions typical of resource-constrained environments. Five evaluation dimensions were used: (i) data handling and validation, (ii) incident management, (iii) service continuity, (iv)fault tolerance and redundancy, and (v) adaptability and scalability. These dimensions reflect critical governance and operational capabilities required for maintaining reliable flood early warning services in environments characterized by unreliable sensors, fragmented datasets, and unstable communication infrastructure.

Table 2. ITIL-Aligned Resilience Evaluation Framework and Scores for Selected IoT Flood Prediction Systems (1–5 Scale) (1 = Weak/Absent, 2 = Low, 3 = Moderate, 4 = Strong, 5 = Very Strong)

Framework Evaluated (4.1.1–4.1.8)	Data Handling & Validation	Incident Management	Service Continuity	Fault Tolerance / Redundancy	Adaptability & Scalability
4.1.1 Floodwater Detection & Early Warning (Arusha/Dar)	3	2	2	2	3
4.1.2 Impact-Based Forecasting (GHoA)	3	2	2	2	3
4.1.3 IoT River Monitoring & Alerting	3	2	2	3	3
4.1.4 Low-Cost IoT + ML Groundwater	2	2	2	2	3
4.1.5 LSTM Rainfall/Water-Level Monitoring	3	2	2	2	3
4.1.6 Early Flood Detection & Avoidance	2	2	2	2	3
4.1.7 IoT Water Monitoring Forecasting	3	2	2	2	3
4.1.8 IoT ML Flood Monitoring	3	2	2	2	3

Table 2 summarizes the ITIL-aligned evaluation scores for the eight selected frameworks on a five-point scale. The results reveal a consistent pattern across the evaluated systems. Most frameworks demonstrate moderate capability in data acquisition and scalability, indicating that considerable attention has been devoted to real-time sensing technologies and predictive analytics. However, the results also reveal systematic weaknesses in incident management, service continuity, and fault tolerance, which are essential for sustaining reliable system operation during infrastructure disruptions.

The relatively higher scores in the data handling and adaptability dimensions reflect the strong emphasis placed by researchers on sensor integration and algorithmic performance. Many frameworks incorporate advanced analytical methods, including machine learning and deep learning approaches, which enhance predictive accuracy under stable input conditions. Nevertheless, the evaluation indicates that such analytical sophistication is rarely accompanied by governance-aligned mechanisms that manage operational failures or degraded data conditions. Consequently, these systems remain vulnerable to sensor malfunctions, communication breakdowns, and incomplete data streams conditions that frequently occur during extreme weather events when reliable flood prediction is most critical (Deng et al., 2020; Mishra et al., 2020).

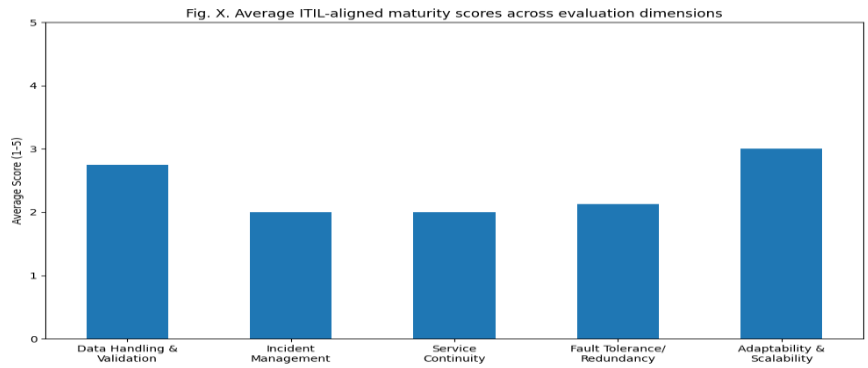

Fig. 2. Average ITIL-aligned maturity scores across the five evaluation dimensions for the eight IoT flood prediction frameworks.

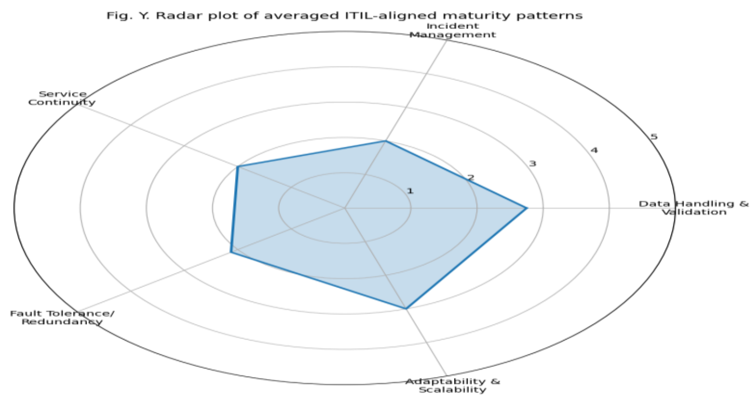

Fig. 3. Radar plot showing ITIL-aligned maturity score patterns averaged across assessed IoT flood prediction frameworks.

Figures 2 and 3 further illustrate this maturity imbalance. While data handling and scalability dimensions achieve moderate maturity levels across frameworks, incident management and service continuity consistently exhibit low scores. This imbalance highlights a structural limitation in current IoT flood prediction research, where system design tends to prioritize sensing infrastructure and predictive algorithms while overlooking the operational processes necessary to maintain service reliability. Such weaknesses become particularly problematic in developing regions such as East Africa, where network coverage is inconsistent, electrical power is unstable, and sensor maintenance resources are limited.

Table 3. Ranked ITIL-Aligned Maturity Scores of Evaluated IoT Flood Prediction Frameworks

Rank	Framework	Total Score (out of 25)	Average Score (1–5)
1	IoT River Monitoring & Alerting System	13	2.60
2	Floodwater Detection & Early Warning (Arusha/Dar)	12	2.40
3	Impact-Based Flood Forecasting (GHoA)	12	2.40
4	IoT LSTM Rainfall/Water-Level Monitoring	12	2.40
5	IoT Water Monitoring-Based Flood Forecasting	12	2.40
6	IoT ML Flood Monitoring	12	2.40
7	Low-Cost IoT + ML Groundwater Prediction	11	2.20
8	IoT Early Flood Detection & Avoidance System	11	2.20

The ranking analysis presented in Table 3 reinforces this observation. Although minor differences exist among the evaluated frameworks, the total scores remain clustered within a narrow range between 11 and 13 out of a possible 25 points, indicating that resilience limitations are widespread across the domain. Even the highest-ranked framework the IoT River Monitoring and Alerting System achieves only moderate maturity levels overall. This suggests that the identified weaknesses are not isolated to individual system implementations but rather reflect systematic design limitations in current IoT flood prediction architectures. From a design science perspective, these findings highlight the need to shift the focus of IoT flood prediction research from purely analytical performance toward resilience-oriented system design. In particular, the evaluation demonstrates that reliable early warning systems require explicit mechanisms for data validation, sensor redundancy, incident response workflows, and service continuity planning. Without these mechanisms, predictive models regardless of their analytical sophistication remain vulnerable to degraded inputs and operational failures.

The evaluation results therefore motivate the development of an enhanced framework that treats data reliability and operational continuity as foundational system properties rather than optional implementation features. Such an approach aligns with the principles of General Systems Theory, which emphasize the importance of feedback, interdependence, and adaptive control in maintaining system stability under uncertain environmental conditions (Bertalanffy, 1968; Skyttner, 2005). By integrating resilience mechanisms at multiple system layers, future IoT flood prediction frameworks can maintain functional stability even when sensor networks or communication infrastructure experience disruption.

Although the evaluation is grounded in flood prediction frameworks relevant to East African deployment conditions, the resilience gaps identified in this study are not unique to the region. Similar challenges related to unreliable sensors, incomplete environmental datasets, intermittent connectivity, and constrained maintenance capacity are widely reported in other low-resource settings. The proposed ITIL-aligned resilience evaluation framework therefore has broader applicability as a diagnostic tool for assessing IoT-based flood prediction systems in resource-constrained environments beyond East Africa. In this sense, the study provides not only regionally grounded findings but also a generalized methodological basis for resilience evaluation in disaster monitoring systems.

4.1 Implications for IoT Disaster Risk Management Frameworks

The findings of this study have several important implications for the design and deployment of IoT-based disaster risk management systems, particularly in resource-constrained environments. First, the evaluation results demonstrate that improving predictive algorithms alone is insufficient to ensure reliable flood early warning services. While many existing frameworks emphasize sensor networks and advanced analytical models, the absence of structured governance mechanisms such as incident management, monitoring, and service continuity planning significantly undermines system reliability. This suggests that IoT disaster management frameworks must be designed as operational services rather than purely analytical systems, integrating governance-driven mechanisms that ensure continuous functionality under degraded infrastructure conditions.

Second, the study highlights the central role of data reliability as a mediating system property in flood prediction architectures. In environments where sensor networks frequently experience data gaps, noise, and transmission failures, system design must explicitly incorporate mechanisms for data validation, redundancy, and fault-tolerant data processing. Rather than assuming the availability of complete and accurate data streams, future IoT frameworks should anticipate unreliable inputs and incorporate adaptive data-handling processes capable of stabilizing analytics pipelines. This approach aligns with resilience-oriented system design principles, which emphasize maintaining functional performance despite uncertainty and environmental disruptions.

Third, the findings underscore the importance of integrating service management frameworks such as ITIL into the design of environmental monitoring systems. Although ITIL does not directly influence predictive accuracy, it provides structured processes for managing operational incidents, maintaining service continuity, and supporting continual system improvement. Incorporating governance-oriented mechanisms into IoT disaster monitoring frameworks therefore enhances system stability and ensures that early warning services remain operational during extreme events when they are most critically needed.

Finally, the results highlight the importance of context-sensitive system design for developing regions. Flood prediction systems developed for high-infrastructure environments often assume reliable communication networks, stable electrical power, and well-maintained sensor installations. However, these assumptions rarely hold in many parts of East Africa. IoT disaster risk management frameworks intended for such contexts must therefore prioritize robustness, modularity, and graceful degradation, ensuring that systems continue to function even when components fail or data availability declines.

Overall, these implications suggest that the future of IoT-based flood prediction research should move toward resilience-oriented, governance-informed system architectures that integrate reliable sensing, adaptive analytics, and structured service management processes. Such approaches are essential for improving the credibility and operational effectiveness of flood early warning systems in data-scarce and infrastructure-constrained environments.

4.2 Limitations and Future Research

Although this study provides important insights into the operational resilience of IoT-based flood prediction frameworks, several limitations should be acknowledged. First, the evaluation relied primarily on framework-level design analysis and simulation-based validation rather than full-scale field deployment. While simulation environments enable controlled experimentation under various data-loss and network instability scenarios, they cannot fully capture the complexity of real-world operational conditions, including sensor degradation, environmental interference, and human interaction with early warning systems. Future research should therefore include long-term field deployments of resilience-oriented IoT flood prediction systems to validate their operational performance in real disaster-prone environments.

Second, the evaluation focused on eight representative IoT flood prediction frameworks identified in the literature, which may not capture the full diversity of system architectures currently being developed globally. Although the selected frameworks represent widely reported approaches including sensor-based monitoring systems, machine learning–driven prediction models, and hybrid analytics frameworks; future studies could expand the evaluation dataset to include additional systems developed across different geographic regions and environmental contexts.

Third, while the study incorporated CHIRPS rainfall data to simulate realistic environmental conditions for East African flood-prone regions, additional datasets such as river discharge measurements, soil moisture indicators, and high-resolution hydrological models could further enhance predictive accuracy and contextual understanding. Integrating multiple environmental data sources may improve the robustness of flood prediction systems and enable more comprehensive modeling of complex hydrological processes.

Future research should also explore advanced resilience mechanisms for IoT-based environmental monitoring systems. These may include adaptive sensor calibration techniques, edge-computing–based data validation, federated learning approaches for distributed flood prediction models, and blockchain-enabled data integrity mechanisms. Additionally, future studies should investigate the social and institutional dimensions of IoT-based flood early warning systems, including community trust, governance frameworks, and policy integration for disaster preparedness. Overall, addressing these limitations will contribute to the development of more robust, scalable, and context-sensitive IoT flood prediction systems, strengthening the reliability of early warning services in developing regions characterized by data scarcity and infrastructural constraints.

5. CONCLUSION

This study introduced and applied an ITIL-aligned resilience evaluation framework for assessing IoT flood prediction systems in resource-constrained environments. The evaluation focused on five critical service management dimensions: data handling and validation, incident management, service continuity, fault tolerance, and system adaptability. The results reveal a consistent pattern across the evaluated frameworks. While many systems demonstrate progress in real-time sensing and predictive analytics, they frequently lack governance-aligned mechanisms for managing operational failures, maintaining service continuity, and ensuring reliable performance under degraded conditions.

The analysis highlights a significant maturity imbalance within current IoT flood prediction research. Most frameworks prioritize sensor deployment and algorithmic sophistication while underemphasizing mechanisms for incident response, redundancy management, and recovery planning. As a result, many systems remain vulnerable to sensor failures, data gaps, and communication disruptions conditions that frequently occur in developing regions during extreme weather events. These limitations reduce the reliability of early warning services and undermine trust in automated flood prediction systems.

By applying an ITIL-aligned evaluation framework, this study provides structured evidence of the operational resilience gaps present in existing IoT flood prediction architectures. The findings demonstrate that improving predictive accuracy alone is insufficient for reliable flood early warning systems. Instead, resilience-oriented system design must integrate data reliability mechanisms, fault tolerance strategies, and governance-guided service management processes to sustain operational functionality under uncertain and degraded infrastructure conditions.

Beyond the specific East African context examined, the study offers a generalized methodological approach for diagnosing resilience weaknesses in IoT-based disaster monitoring systems. By showing that reliable flood early warning depends not only on predictive analytics but also on governance-aligned mechanisms for data validation, fault tolerance, and service continuity, the study extends current flood prediction research toward a more operationally grounded understanding of resilience. The evaluation framework and derived design implications can therefore support future research and system development in a wider range of resource-constrained environments.

6. DECLARATIONS

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The authors declare that they have no conflict of interest.

Ethics Approval

This study did not involve human participants or animals and therefore did not require ethical approval.

Data Availability

The rainfall datasets used in this study are publicly available from the Climate Hazards Group (CHIRPS).

Author Contributions

I. Muwanga Erasto Kosea: Conceptualization, Methodology, Software, Analysis, Writing original draft.
II. Dr. Daniel Otanga: Supervision, Writing review & editing.
III. Dr. Satwinder Singh Rupra: Supervision, Methodological validation, Writing review & editing.

REFERENCES:

1) Ahn, S., & Kim, J. (2022). IoT-based river monitoring and flood alert system using wireless sensor networks. Sensors, 22(3), 1045. https://doi.org/10.3390/s22031045
2) Asare, K., & Boateng, A. (2023). Localized hydrological datasets and flood prediction accuracy in West African urban basins. Hydrology Research, 54(2), 311–327. https://doi.org/10.2166/nh.2023.145
3) Atzori, L., Iera, A., & Morabito, G. (2010). The Internet of Things: A survey. Computer Networks, 54(15), 2787–2805. https://doi.org/10.1016/j.comnet.2010.05.010
4) Bashir, A. K., Hassan, R., & Mohamad, H. (2021). Sensor data reliability challenges in IoT-based environmental monitoring systems. IEEE Access, 9, 106210–106223. https://doi.org/10.1109/ACCESS.2021.3098987
5) Bertalanffy, L. von. (1968). General system theory: Foundations, development, applications. George Braziller.
6) Deng, Y., Li, Y., & Zhang, X. (2020). IoT-based flood monitoring and early warning systems: A review of architectures and reliability challenges. Environmental Modelling & Software, 124, 104585. https://doi.org/10.1016/j.envsoft.2019.104585
7) Gregor, S., & Hevner, A. (2013). Positioning and presenting design science research for maximum impact. MIS Quarterly, 37(2), 337–355.

8) Gubbi, J., Buyya, R., Marusic, S., & Palaniswami, M. (2013). Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Computer Systems, 29(7), 1645–1660. https://doi.org/10.1016/j.future.2013.01.010
9) Hevner, A. R. (2007). A three cycle view of design science research. Scandinavian Journal of Information Systems, 19(2), 87–92.
10) Kumar, R., & Singh, P. (2022). IoT-enabled flood prediction and monitoring system using machine learning algorithms. Journal of Hydrology, 604, 127250. https://doi.org/10.1016/j.jhydrol.2021.127250
11) Li, X., Wang, Y., & Chen, Z. (2023). LSTM-based rainfall and flood prediction using IoT-enabled hydrological monitoring systems. Water, 15(2), 341. https://doi.org/10.3390/w15020341
12) March, S. T., & Smith, G. F. (1995). Design and natural science research on information technology. Decision Support Systems, 15(4), 251–266.
13) Mishra, A., Rai, S., & Singh, V. (2020). Low-cost IoT-based environmental monitoring systems for flood detection using machine learning. Sensors, 20(21), 6208. https://doi.org/10.3390/s20216208
14) Nabirye, R., Ouma, Y., & Tateishi, R. (2023). Flood risk mapping and monitoring in East Africa using integrated geospatial datasets. Natural Hazards, 116, 1947–1965.
15) Ouma, Y., & Tateishi, R. (2022). Remote sensing-based flood monitoring and hydrological data integration in East Africa. Remote Sensing, 14(4), 912. https://doi.org/10.3390/rs14040912
16) Skyttner, L. (2005). General systems theory: Problems, perspectives, practice (2nd ed.). World Scientific.
17) Uwayisenga, J., Mutabazi, A., & Hakizimana, P. (2021). Machine learning-based flood monitoring and early warning system using IoT sensors. Environmental Monitoring and Assessment, 193(6), 342. https://doi.org/10.1007/s10661-021-09042-8
18) UNEP. (2020). Flood risk and climate vulnerability in East Africa. United Nations Environment Programme.
19) World Bank. (2021). East Africa climate risk and flood vulnerability assessment. World Bank Publications.
20) Zhou, H., Li, Z., & Wang, Y. (2020). IoT-based real-time flood monitoring system using wireless sensor networks. IEEE Internet of Things Journal, 7(5), 4072–4083. https://doi.org/10.1109/JIOT.2019.2963145