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ORIGINAL RESEARCH ARTICLE

FloodIntel: Advancing flood disaster forecasting through comprehensive intelligent system approach

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ABSTRACT

Background: Every year, floods are the most devastating natural disaster that hits Malaysia, causing damage to people's livelihoods, destroying property and infrastructure, and taking lives. Flood disasters are becoming more frequent and severe, necessitating the development of sophisticated forecasting and early warning systems to mitigate their effects. This study presents the design and implementation of a sophisticated flood forecasting and early warning system, utilizing intelligent technologies to enable timely prediction and proactive measures in high-risk areas. **Methods:** The proposed system incorporates Internet of Things (IoT) technology to collect real-time data on the river's water level. The collected data are analyzed using an association rule technique to generate accurate forecasts of prospective flood occurrences. By using this intelligent flood disaster prediction system, users and authorities can receive early warnings and make informed decisions regarding evacuation, resource allocation, and infrastructure reinforcement. The system's capability to provide early flood forecasts in high-risk areas can substantially enhance flood preparedness and response and save more life. **Results:** The findings of the study highlight the potential of the system to improve flood risk management strategies and reduce flood-related devastation and human suffering in vulnerable regions. **Conclusions:** In conclusion, it is important to implement IoT and AI technologies to improve flood prediction systems and reduce the negative effects of flood disasters.

Keywords: flood disaster; flood forecasting; IoT; real-time data

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1. Introduction

Terengganu, located on the east peninsula, is especially susceptible to frequent flooding during the monsoon season, and floods significantly affect Malaysia. Because 70% of the region's land is low-lying, it is vulnerable to the devastating effects of flooding, including loss of life, destruction of infrastructure, and disruption of livelihoods. Residents face a greater risk of flooding from October to March due to excessive rainfall and rising sea levels. Large waves frequently strike coastal areas, and riverside residents must deal with high tides.

A flood is a type of natural catastrophe characterized by the overflow of water onto normally dry land. This can be caused by excessive precipitation, melting snow, the failure of a dam or levee, or a high tide along the coast. Flooding has been one of the most calamitous natural disasters in the past decade, causing economic losses, human deaths, and environmental devastation[1].

The most common type of flooding, overland flooding, typically occurs when rain causes adjacent areas to flood because rivers and streams overflow their banks. It can also happen when the capacity of streets and drains to remove floodwater from urban areas and underground pipelines is exceeded. Since decision-makers lack intelligent instruments to predict flood zones, the need for flood forecasting is increasing.

This study proposes using Internet of Things (IoT) technology to predict and mitigate flooding by monitoring river water levels to address these issues. The IoT enables incorporating sensors into diverse objects, thereby facilitating the collection and transmission of environmental data via communication networks. Monitoring water levels is a common method for flood prediction, as it permits the estimation of flood probabilities. This study analyzes historical data and identifies patterns between river water levels and flood occurrences by employing the association rule technique.

The key objective of this project is to create an intelligent flood disaster prediction system for Terengganu that can deliver accurate flood forecasts based on IoT-enabled measurements of river water levels in real-time. The system aims to address the persistent flood concerns faced by the residents. The system can identify patterns, trends, and critical thresholds by collecting and analyzing data from water level sensors, triggering warnings and alerts in potential flood scenarios. The method also makes it easier to develop models that, using information on past and present water levels, predict the severity and scope of floods based on the model developed by Harun et al.[2]. The model produces high prediction accuracy (over 80%) based on historical flood area, river water level, and rainfall data. The real-time water level is crucial for successful model prediction as input for crisis management, response planning, and evacuation decision-making.

The proposed system can establish predictive relationships between river water levels and flood events by applying association rules based on research outcomes from Harun et al.[2]. The study aimed to find the correlation between water level and flood area and propose a prediction model in the Terengganu area using Association Rules (AR). By mining historical data and identifying frequent patterns, the system can generate principles such as "If the water level is high, then there is a high probability of a flood event." These regulations aid in disseminating early warnings, alerting individuals in regions where riverbanks are at risk of overflowing. This intelligent flood prediction system will enhance Terengganu's flood resilience, risk management, and public safety. However, one of the biggest challenges to monitoring real-time data of rivers' water level. Therefore the research aims to integrate IoT to automatically monitor water level and help implement AR rules.

The remaining sections of this paper are structured as follows: Section 2 provides a comprehensive literature review on floods, the Internet of Things (IoT), and studies relevant to predicting floods using IoT. Section 3 describes the methodology used in the design and implementation processes. It describes the selection and deployment of Internet of Things sensors, data collection procedures, and the communication infrastructure used to transmit the collected data. The performance of the implemented system in precisely measuring and predicting river water levels is evaluated in Section 4, which presents the experimental results and evaluation metrics. Section 5 discusses this paper's findings, limitations, and future directions, concluding with the significance of IoT-based advanced flood prediction.

2. Related works

Machine learning plays a crucial role in flood prediction by harnessing historical weather and river flow data to build predictive models. These models utilize advanced algorithms to analyze patterns and relationships, enabling them to forecast potential flooding events with greater accuracy. By factoring in variables like rainfall intensity, topography, soil type, and land use, machine learning models can provide timely warnings and inform disaster management efforts. Additionally, real-time data from sensors and remote sensing technologies further enhance these predictions, allowing for proactive measures to mitigate the impact of floods, protect communities, and improve overall disaster preparedness and response. The major machine learning algorithms utilized in flood prediction encompass Artificial Neural Networks (ANNs)[3], neuro-fuzzy models[4], adaptive neuro-fuzzy inference systems (ANFIS)[5], support vector machines (SVM)[6], wavelet neural networks (WNN)[7], and multilayer perceptron (MLP)[8].

A work by Aziz et al.[1] proposed Association Rules (ARs) to predict flood area by determine the relationship between water level and flood area to construct a model to predict flooding. The association rules mining technique will extract the best rules from the dataset using the Apriori algorithm, which was used to identify the most frequent item sets. By using the candidate generation and trimming techniques, the Apriori algorithm determined the 10 best rules with a confidence level of 100% and minimal support of 40%. The results of this study demonstrated the applicability of data mining in the subject area and demonstrated how it can aid in providing early warning to potential victims and save time while preserving lives and property.

Bande et al.[9] presented "Smart flood disaster prediction system using IoT and neural networks." This study's objective is to monitor river water level, humidity, temperature, pressure, and precipitation and ascertain their temporal correlation data for flood prediction analysis. Each Raspberry Pi module utilizes three sensors: the LM35 temperature sensor, the BME280 atmospheric pressure sensor, and the FDC1004 water level sensor. Therefore, Artificial Neural Network (ANN) is used for prediction analysis.

A study by Smys et al.[10] presented a flood management system that used IoT sensors and cloud data, incorporating Convolutional Neural Network (CNN) to analyze the flood flow from dam valves. With upgraded sensors and gearbox modules, the system can be used in real-time dams to guarantee consistent water flow rates and effective flood management procedures. **Figure 1** illustrates the implemented architecture for the proposed model in the research.

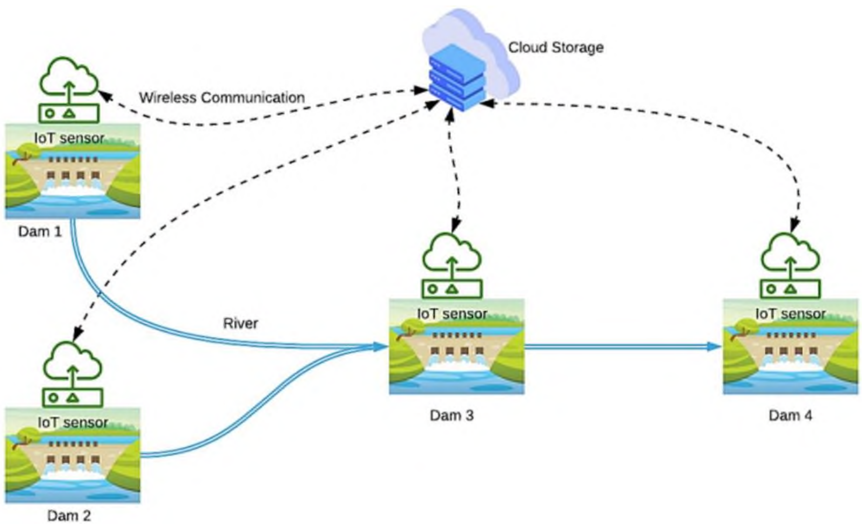

Figure 1. The architecture of the proposed model[3].

Four dams are connected via a cloud environment to share the collected data. Here, a network of sensors is connected to each dam to monitor the incoming and departing water flows and the status of the dam's current level. The climatic variations in the vicinity of the dam are constantly observed to determine the precipitation.

The Internet of Things (IoT) is a system of interconnected physical devices, vehicles, and home appliances that are embedded with electronics, software, sensors, and network connectivity, enabling them to collect and exchange data. This creates a network where objects can be remotely monitored and controlled, allowing for more direct integration of the physical world into computer-based systems and resulting in increased efficiency, precision, and economic benefit. Because IoT does not necessitate distance, it is simpler for individuals to control objects.

In the IoT, numerous objects that enclose humans will be connected to the network. As a result, IoT devices are used to collect data and identify threats following natural disasters. Even though IoT technologies cannot prevent the occurrence of a disaster, they may be extraordinarily useful tools for communicating disaster preparedness and countermeasure information, such as disaster prediction and early warning systems.

In a study conducted by Sarak[11], data was gathered from critical points across the terrain and analyzed to identify potential triggers for severe flooding downstream in the river basin. When automated by proficient services, this data aggregation process could facilitate the timely implementation of flood mitigation strategies. An early warning system was developed by integrating hardware components, sensors, microcontrollers, a web server, and custom software. This system can issue prompt alerts regarding the threat of river overflow and the emergence of intense streams or landslides. The system's foundation relies on a network of automatic meteorological stations (AMS), which transmit data at regular intervals to a central server. At this central server, the data undergoes further processing and is then presented to individuals with the appropriate authorization level to access the system.

The work by Aswad et al.[12] proposes an Internet of Things-based flood status prediction (IoT-FSP) model that is used to facilitate the prediction of the river's flood situation. This model employs the Internet of Things architecture to enhance the collection of flood-related data and incorporates three distinct machine learning (ML) algorithms to carry out the flood prediction process. Their study's outcomes demonstrate the IoT-FSP model's effectiveness in acquiring relevant data and making accurate flood predictions. The model achieves an impressive average accuracy rate of 85.72% based on results obtained through a three-fold cross-validation approach. Notably, the machine learning algorithms utilized in the model exhibit proficiency in handling multiple outputs, specifically encompassing 13 different textual descriptions of flood statuses. This proficiency highlights the potential of explainable Artificial Intelligence and empowers the IoT-FSP model to serve as a proactive early warning system and a comprehensive flood monitoring solution.

Based on previous works, the development of IoT integrated with ML algorithms helps produce early warning predictions for flood disasters. Thus, it is the motivation of the results to use IoT and apply AR to predict flood disasters in Terengganu areas.

3. Methods

The development method for this system is an iterative and incremental development approach, allowing for a flexible and adaptable technique to measure the river's water level and identify high-risk areas. As shown in **Figure 2**, the method entails breaking the development process down into smaller iterations, concentrating on specific tasks and goals, and incorporating feedback and adjustments into succeeding iterations.

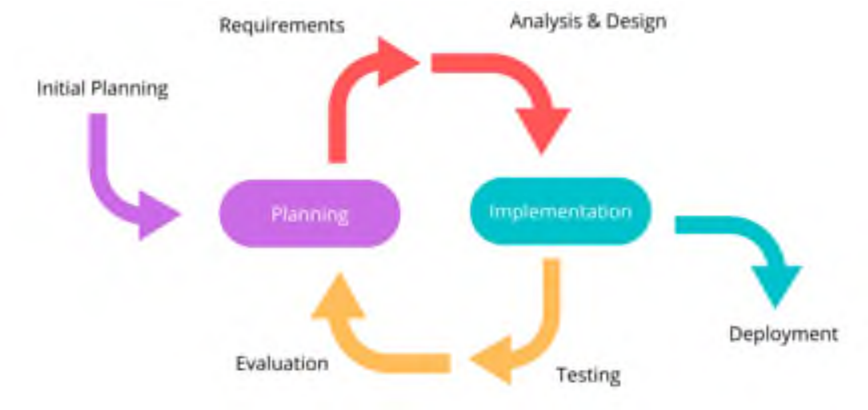

Figure 2. Iterative and incremental development model.

Following an incremental strategy, the system functionality is gradually built upon and expanded, ensuring validation and addressing potential challenges. The research team, stakeholders, and end users collaborate and communicate throughout the process to collect requirements, refine the design, and validate system performance. This gradual and iterative approach provides a well-organized and collaborative framework for developing a dependable and effective intelligent system for flood disaster prediction.

This framework provides a systematic and structured approach to designing and implementing an intelligent flood disaster prediction system, integrating IoT technologies and advanced data analysis techniques for accurate and timely forecasting. The system's architecture and associated system flows are depicted in **Figure 3**.

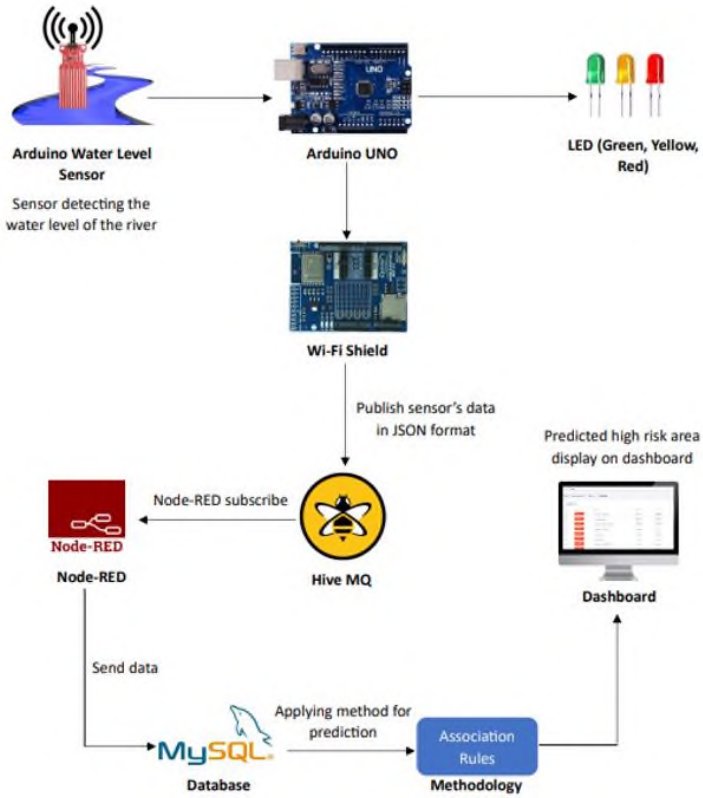

Figure 3. Framework of the system.

First, hardware components, including a Wi-Fi shield affixed to the Arduino UNO board, are connected to a power source. This setup enables the river's water level to be measured. Once the water level data is obtained, it is published in JSON format via the Wi-Fi shield to the Public MQTT Broker. LEDs will indicate the water level in green, yellow, and red. Green indicates a normal water level, yellow is a warning, and red is dangerous. The visual programming tool Node-RED subscribes to the topic published by the Wi-Fi shield. Every time data is published, Node-RED reads it and inserts it into a MySQL database for further analysis. Applying association rules to the collated data allows for identifying high-risk regions. These association rules facilitate the identification of patterns and relationships between the water level measurements and the occurrence of flooding. By leveraging this information, the system can predict prospective flood-prone high-risk areas.

However, one of the biggest challenges is in real situations the Wi-Fi connection can be problematic under certain circumstances. A study by Dobrojevic and Bacanin[13] suggested that communication between IoT devices can be solved using short-range networks such as Bluetooth, ZigBee, Z-Wave or Wi-Fi. Zigbee is a low-power, low-data-rate wireless communication protocol designed for short-range communication between devices. It operates in the 2.4 GHz frequency band and is commonly used for home automation, industrial automation, and sensor networks. Zigbee networks typically form a mesh topology, where devices can relay data for each other, creating a robust and scalable network. It's popular for smart home applications due to its low power consumption and support for a wide range of device types. Z-Wave is another wireless communication protocol designed for home automation. It operates in the sub-1 GHz frequency range, allowing for better penetration through walls and longer communication ranges compared to some other protocols. Z-Wave also uses mesh networking and offers a wide range of devices that can communicate with each other. One of its advantages is its ability to create a stable and reliable network. Another option is Arduino SMS Module, a module or component that allows Arduino microcontrollers to send and receive SMS (Short Message Service) messages over cellular networks. This can be useful when Internet connectivity is limited or unavailable, as it allows remote control or monitoring devices through text messages. It's often used for remote monitoring, security systems, and basic IoT communication applications.

The predicted high-risk areas are then displayed on the system's dashboard, enabling stakeholders and authorities to make informed decisions about evacuation, resource allocation, and infrastructure reinforcement. By following this methodology, the study aims to employ intelligent technologies such as the Internet of Things (IoT), data analysis, and association rule techniques to improve flood forecasting and early warning systems, ultimately contributing to enhanced flood risk management strategies and mitigating the effects of floods in vulnerable regions. **Figure 4** depicts the system's water level states, including the normal, warning, and danger states. There are three distinct danger levels: danger 1, danger 2, and danger 3. The value is for testing the device's functionality, while the actual threshold is set based on the previous works[2].

Figure 4. Water level states.

The normal state denotes an acceptable water level, signifying a safe condition. The warning state is characterized by an elevated water level that indicates a potential risk and functions as an early indicator of potential flooding or adverse conditions. The danger state, which consists of danger 1, danger 2, and danger 3, denotes water levels that indicate an imminent risk of inundation or other hazardous situations. By dividing the danger state into three categories, the system provides a more nuanced evaluation of the severity of the water level and enables stakeholders to respond appropriately based on the specific danger level. This categorization improves the system's ability to accurately predict and communicate flood risks, thereby facilitating effective decision-making and proactive actions to mitigate potential damage. The river model shown in **Figure 5**. Functions as a prototype for the sensor used to measure the river's water level.

Figure 5. River model.

The river model simulates real-world conditions and permits evaluating and validating the sensor's functionality and accuracy. This prototype plays a vital role in the development and calibration of the system, ensuring that it can accurately capture and measure the actual river environment's water level variations. Before the sensor is deployed in the field, the river model is a valuable tool for assessing its performance and making any necessary adjustments.

4. Results

This section presents the results and discussion of the conducted experiments and studies, focusing on evaluating the proposed intelligent flood disaster prediction system and its effectiveness in identifying high-risk areas and predicting potential flood occurrences. The data from the water level sensor on the serial monitor was successfully published into the Public MQTT Broker. MQTT is a standard messaging protocol for the IoT. It is designed as an extremely lightweight publish/subscribe messaging transport that is ideal for connecting remote devices with a small code footprint and minimal network bandwidth. Public MQTT Broker facilitates data transmission between the sensor and the database by acting as middleware. After the data has been published to the Public MQTT Broker, Node-RED subscribes to it and inserts the received values into the database. **Figure 6** below illustrates the workflow of this data insertion procedure.

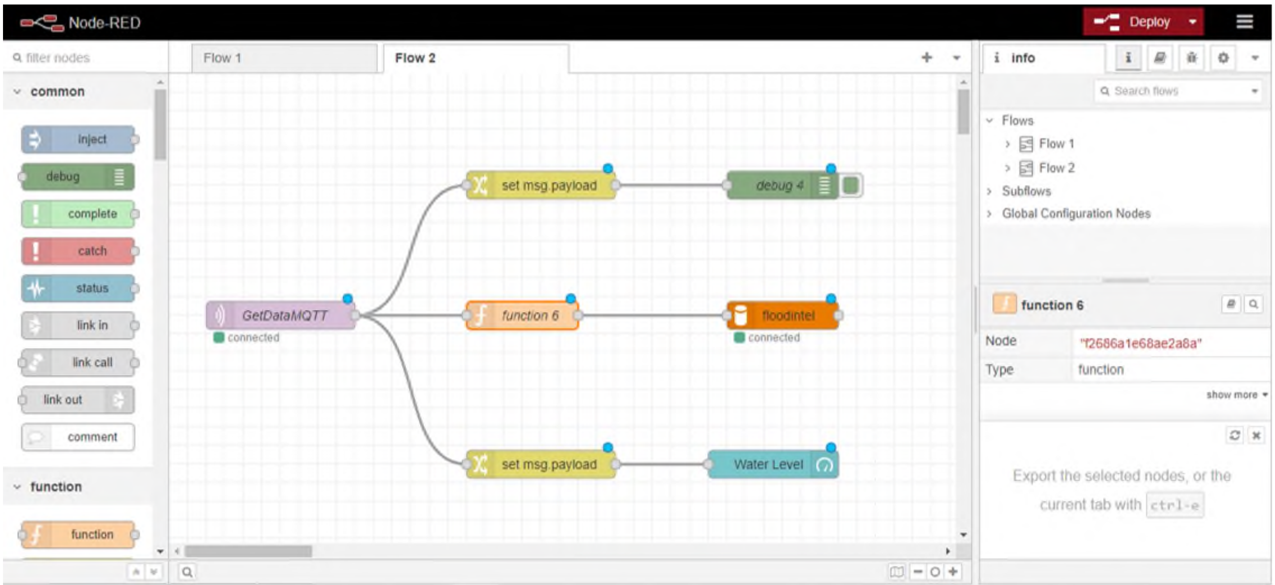

Figure 6. Node-RED workflow.

Node-RED is essential for receiving published data and inserting it into a MySQL database for later analysis. Each time a data publication event occurs, Node-RED collects the data and inserts it into the specified MySQL database. Data on water levels saved in MySQL forecasts the potential effect area. Based on the current timestamp, the system determines that the water level is 439, which is above the Danger 3 threshold. As a result of this critical situation, the system warns users and the public. The alarm warning ensures prompt communication and appropriate action to reduce risks from the high-water level. **Figure 7** depicts the water level status display, which is an integral component of the user interface for the system. It allows users to readily access and monitor the river's real-time water level data.

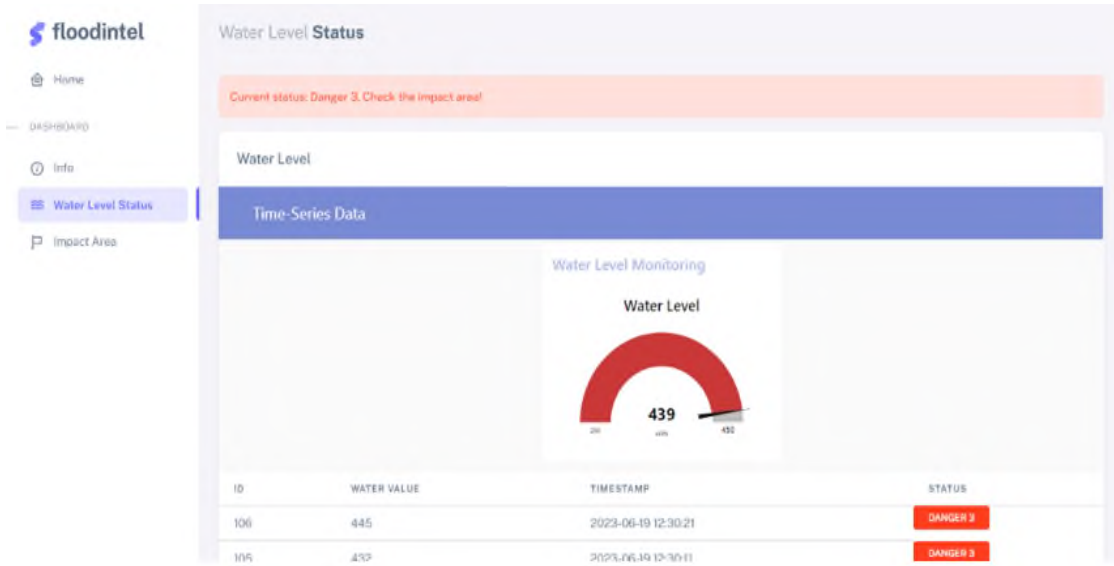

Figure 7. Water level status.

The system proactively warns users to monitor the impact area as the water level status is updated. The system can identify when the water level approaches or is above the danger level 3 threshold by continuously monitoring the water level. It then advises users to look for potential concerns in the affected region. **Figure 8** visually represents the predicted impact area, highlighting the areas that may be affected as the water level approaches the danger level 3 threshold. This allows users to stay informed and take necessary precautions to ensure their safety and minimize the potential impact of the flood disaster.

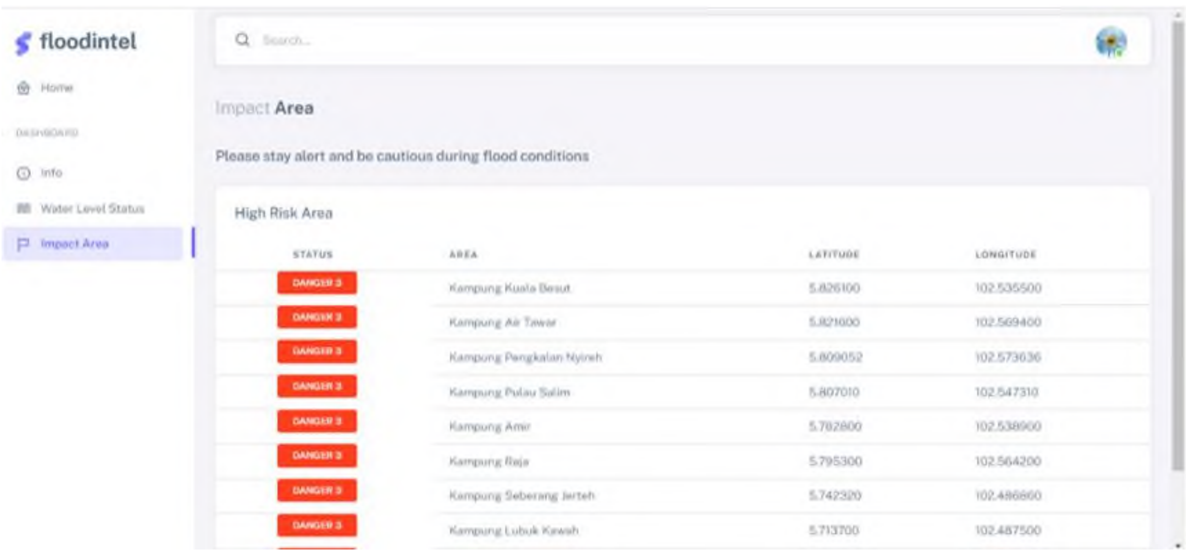

Figure 8. Impact area page.

Based on the study of the collected data and the application of association rules, this table identifies the regions that are anticipated to be most severely affected by the deluge. The impact area table is a valuable resource for stakeholders and authorities, allowing them to plan and allocate resources for disaster response and mitigation in a proactive manner. By identifying areas that are at higher risk, prompt evacuation measures and targeted relief efforts can be implemented to mitigate potential damage and protect the affected population. The impact area table plays a crucial role in enhancing flood preparedness and response strategies, allowing for efficient decision-making and resource allocation in high-risk areas.

5. Conclusions

This study concludes with developing and implementing an advanced flood disaster prediction system using IoT technologies and intelligent data analysis methods. The system's user-friendly interface facilitates effective communication between authorities, stakeholders, and the public by facilitating data access and interpretation. The results show the system's effectiveness in improving flood forecasting and mitigation. The system facilitates proactive decision-making and response planning by facilitating timely alerts and notifications, thereby contributing to improved preparedness, response, and overall resilience in flood-prone areas. However, it is essential to recognize the study's limitations, such as data availability and association rules' precision. It is necessary to conduct additional research and refine the system's algorithms and predictive models to improve its accuracy and robustness.

The measurement of river water levels in the Intelligent Flood Disaster Prediction System project has substantially contributed. It allows for real-time monitoring and accurate tracking of water levels, providing crucial data for flood prediction and risk assessment. This information enables authorities and the community to take proactive measures in preparation for potential floods, including timely alerts about rising water levels. Such prompt information facilitates effective decision-making, evacuation planning, and resource allocation to mitigate flood risks. The project's emphasis on river water level measurement is instrumental in enhancing flood preparedness and minimizing the impact of floods on vulnerable regions.

The Intelligent Flood Disaster Prediction System project has several limitations that merit consideration. Firstly, the system is dependent on a stable internet connection, and any disruptions in connectivity can hinder real-time monitoring and data updates. Secondly, as a web-based system, its responsiveness is influenced by the user's device and internet speed, potentially impacting the user experience and system performance. Additionally, data availability and quality play a critical role in the system's accuracy and effectiveness, highlighting the importance of reliable data sources. These limitations underscore the need for further research and improvements to enhance the system's reliability, performance, and utility in addressing flood-related challenges.

To address the limitations of the Intelligent Flood Disaster Prediction System project, future work should focus on developing a mobile application. This would enable users to access real-time flood alerts and information on their smartphones, reducing dependency on stable internet connectivity. The mobile application should be designed to be responsive, ensuring optimal performance across different devices and network conditions, thereby enhancing user experience and system accessibility.

Additionally, efforts should be directed toward improving data availability and quality. This can be achieved by exploring additional data sources, such as satellite imagery and sensor networks, to gather more comprehensive and accurate information about flood-prone areas. Collaborations with relevant stakeholders, including meteorological agencies and local authorities, can facilitate access to real-time and historical data, enabling more precise flood predictions and risk assessments. Moreover, implementing data validation processes and incorporating quality assurance measures will help ensure the reliability and integrity of the data used in the system.

By developing a mobile application and enhancing data availability and quality, the Intelligent Flood Disaster Prediction System project can overcome its limitations and become a more robust and effective flood management and risk mitigation tool.

The developed flood disaster prediction system has considerable potential for enhancing flood forecasting and early warning capabilities. It is essential for reducing flood-related damages, safeguarding lives and livelihoods, and facilitating effective flood risk management. Future work may concentrate on expanding the system's scope by incorporating additional environmental parameters and integrating them with existing disaster management frameworks to improve its capabilities further and contribute to comprehensive flood disaster management strategies.

Author contributions

Conceptualization, NAA and AAA; methodology, NAA and AAA; writing—original draft preparation, NAA and AAA; writing—review and editing, WAM; supervision, AAA. All authors have read and agreed to the published version of the manuscript.

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Abbreviations

AI: Artificial Intelligence

ANN: Artificial Neural Network

CNN: Convelutional Neural Network

IoT: Internet of Things

Conflict of interest

The authors declare no conflict of interest.

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