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An Iot-Based Flood Early Warning System Integrated with the Sesaga Approach

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Abstract

Floods are among the most destructive natural disasters, causing significant impacts on human safety, infrastructure, and economic activities, particularly in flood-prone regions. This study proposes a Flood Early Detection System based on the SESaGa approach (Systematic, Exploratory, SWOT, and GIS Analysis), integrating Systematic Literature Review (SLR), Exploratory Data Analysis (EDA), SWOT analysis, and Geographic Information Systems (GIS). Research data were collected from flood monitoring prototypes deployed at several vulnerable locations in Gorontalo. The developed system achieved a sensor detection accuracy of 96.4% with an average notification delay of 2.3 seconds in real-time monitoring. GIS-based visualization successfully identified high-risk flood zones and improved spatial mitigation planning. SWOT analysis produced strategic recommendations for enhancing system sustainability and disaster management policies. Furthermore, black-box testing indicated that 100% of the core system functionalities, including sensor monitoring, warning notifications, and GIS visualization, operated successfully without critical errors. These findings demonstrate that the proposed system can effectively support early flood mitigation, improve response efficiency, and strengthen community resilience in disaster-prone areas.

Keywords: Early Detection; SESaGa Method; Internet of Things (IoT); Flood; Mitigation.

1. INTRODUCING

Flooding is one of the most frequent natural disasters in Indonesia and causes significant losses [1] , both in terms of material, social, and environmental aspects. High rainfall intensity, land-use changes, and the lack of early warning systems are factors that exacerbate flood risks in vulnerable areas [2], [3]. This condition requires innovative solutions capable of detecting potential floods quickly, accurately, and measurably so that communities and relevant stakeholders can take early mitigation measures [4], [5].

Various previous studies have developed flood detection systems based on sensors, hydrological modeling, and geographic information systems [6], [7]. However, most of these studies still focus on a single aspect, such as rainfall monitoring or spatial mapping, without comprehensive analytical integration. This research gap indicates the need for a more comprehensive approach to develop an early detection system that not only monitors environmental data but also analyzes patterns, regional vulnerability, and strategic factors in flood management. In response to this problem, this study proposes a Flood Early Warning System based on the SESaGa approach (Systematic, Exploratory, SWOT, and GIS Analysis). This approach integrates a Systematic Literature Review (SLR) [8], [9] to strengthen the theoretical foundation, Exploratory Data Analysis (EDA) to process sensor data, SWOT Analysis to evaluate internal and external factors, and GIS Analysis for spatial mapping of flood-prone areas. The main advantage of this solution lies in the integration of multiple complementary methods, resulting in a more accurate, adaptive, and strategic

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early detection system. Sensor-based studies generally focus on real-time water level monitoring and warning notifications but lack spatial analysis and strategic evaluation for disaster mitigation. Meanwhile, GIS-based studies emphasize flood-prone area mapping and spatial visualization; however, they often rely on static historical data and do not support adaptive real-time monitoring. In addition, hydrological modeling approaches are capable of predicting flood patterns but require complex environmental parameters and are less practical for implementation in local community environments with limited infrastructure.

Although these approaches have contributed significantly to flood mitigation efforts, previous studies have rarely integrated real-time sensor monitoring, exploratory data analysis, strategic evaluation, and spatial mapping into a unified framework. As a result, existing systems tend to provide partial solutions, either focusing only on technical monitoring or on spatial analysis without considering strategic and operational aspects of disaster management. This limitation indicates a clear research gap in the development of a more comprehensive, adaptive, and decision-oriented flood early warning system.

To address this gap, this study proposes a Flood Early Warning System based on the SESaGa approach (Systematic, Exploratory, SWOT, and GIS Analysis). The proposed approach integrates a Systematic Literature Review (SLR) [8], [9] to establish a strong theoretical foundation, Exploratory Data Analysis (EDA) to analyze sensor-generated environmental data, SWOT Analysis to evaluate internal and external strategic factors, and GIS Analysis to provide spatial visualization of flood-prone areas. Unlike previous studies, the proposed system combines technical, analytical, strategic, and spatial perspectives into a single integrated framework. This integration enables the system to deliver more accurate real-time detection, adaptive flood risk analysis, and strategic recommendations for improving disaster mitigation and regional resilience.

Furthermore, this research aims to develop an Internet of Things (IoT)-based flood early detection system capable of monitoring water levels in real time. Data collected from IoT sensors can be monitored directly and integrated into an information system, enabling early notifications to be delivered to communities and relevant stakeholders. Therefore, the research problem focuses on how to design and implement a SESaGa-based flood early detection system integrated with IoT, how to test its effectiveness in providing fast and accurate early warnings, and how to identify internal and external factors influencing the system's effectiveness through SWOT analysis.

The objective of this study is to design a comprehensive flood early detection system by integrating SLR, EDA, SWOT, and GIS approaches, supported by IoT technology for real-time water level monitoring. This research also aims to evaluate the effectiveness of the system in providing early warnings, provide GIS-based spatial information to support decision-making, and generate strategic recommendations that can strengthen disaster mitigation policies. Ultimately, this study is expected to contribute both scientifically and practically to the development of a more comprehensive, integrative, and community-oriented disaster early warning system for flood-prone areas. The novelty of this research lies in the integration of the SESaGa approach with IoT technology to build a flood early detection system that not only provides data analysis and spatial mapping but also enables real-time water level monitoring to support faster, more accurate, and more strategic disaster mitigation.

2. METHODOLOGY

2.1 Type and Research Approach

This research employs a quantitative approach using an applied experimental method [10], [11], in which an IoT-based flood early detection system is designed, developed, and directly tested to evaluate its performance and effectiveness under real conditions. The focus of this research lies in the development and evaluation of a flood early detection system integrated with the SESaGa approach (Systematic Literature Review, Exploratory

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Data Analysis, SWOT, and GIS Analysis). This approach is chosen to ensure that the developed system is not only capable of accurately measuring flood-related parameters through IoT devices, but also supported by a strong theoretical foundation, comprehensive data analysis, and spatial mapping using GIS technology. Therefore, this research is expected to produce new contributions to the development of technology-based disaster mitigation systems that are practical and highly applicable.

2.2 SESaGa Method

The SESaGa approach is used in this research to ensure that the developed flood early detection system has a strong theoretical basis, comprehensive data analysis, and an adaptive implementation strategy. This method consists of four main stages: Systematic Literature Review (SLR), Exploratory Data Analysis (EDA), SWOT Analysis, and GIS Analysis, which are explained as follows:

a. Systematic Literature Review (SLR)

This stage is conducted by reviewing relevant previous studies related to flood early detection systems, the utilization of Internet of Things (IoT) [12], [13], [14] and the implementation of Geographic Information System (GIS) technology [15], [16]. The results of this review are used to identify key indicators and parameters that serve as the basis for system design, such as water level, rainfall intensity, soil moisture, and the spatial distribution of flood-prone areas.

b. Exploratory Data Analysis (EDA)

The EDA stage focuses on processing primary data obtained from IoT sensors, including parameters such as water level, humidity, and rainfall intensity. This analysis is used to understand patterns and trends in environmental data that influence flood potential. The results of this data exploration serve as the foundation for designing flood detection algorithms capable of providing more accurate and real-time information.

c. SWOT Analysis

SWOT analysis is conducted to evaluate the strengths, weaknesses, opportunities, and threats of the developed flood early detection system. Through this approach, a comprehensive overview of the system’s strategic position in real-world implementation is obtained [8], [17]. In addition, the results of this analysis are used to formulate strategic recommendations to improve the effectiveness and sustainability of the system in supporting flood risk mitigation.

d. GIS Analysis

The GIS Analysis stage is carried out by utilizing spatial data to map flood-prone areas. Data obtained from IoT sensor monitoring are integrated with GIS-based maps using location points where the detection system prototypes will be installed, allowing real-world conditions to be visualized interactively. This integration enables the presentation of more comprehensive flood detection information and facilitates relevant stakeholders in making quick decisions related to disaster management. Through these four stages, the SESaGa method provides a systematic and integrated framework for developing a more effective and applicable IoT-based flood early detection system.

2.3 Flood Early Detection System Using the Internet of Things

The use of Internet of Things (IoT) technology allows sensor devices connected to the internet network to monitor environmental conditions in real time and automatically transmit data to a processing center [18], [19], [20]. In the context of flood detection, these devices are used to measure key parameters such as water level, soil moisture, and rainfall intensity. The collected data are then processed through several analytical stages to support fast and accurate decision-making.

This research develops an IoT-based flood early detection system integrated with the SESaGa approach. In the Systematic Literature Review (SLR) stage, previous studies are reviewed to determine important indicators in system design. Next, Exploratory Data

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Analysis (EDA) is used to analyze patterns and trends from primary data obtained from IoT sensors. The following stage is SWOT Analysis, which evaluates the strengths, weaknesses, opportunities, and threats of the developed system. Finally, IoT monitoring results are integrated into GIS Analysis to perform spatial mapping of flood-prone areas, allowing field conditions to be visualized more comprehensively.

With the integration of IoT and the SESaGa method, the developed system is expected to provide more accurate, adaptive, and strategic flood detection. In addition to monitoring water levels directly, the system also presents information in the form of digital maps that are easy to understand, thereby supporting governments and communities in taking early mitigation actions.

2.3.1 Design of the Flood Early Detection System

The hardware components used in this system consist of an ultrasonic sensor to measure water levels, a rain sensor to detect rainfall occurrence, an ESP32 microcontroller as the main controller, and an IoT communication module (Wi-Fi) that functions to transmit data to the server.

Meanwhile, the software components include a web-based monitoring application, an IoT data integration system, and an early warning notification service via Telegram so that information can be received by users in real time.

The system architecture, illustrated in Figure 1, includes several stages: data collection from sensors, data transmission to the server, storage in a database, data processing for analysis, and finally the presentation of results in the form of visualizations within the monitoring application. In addition, the system automatically sends notifications to Telegram as an early warning alert.

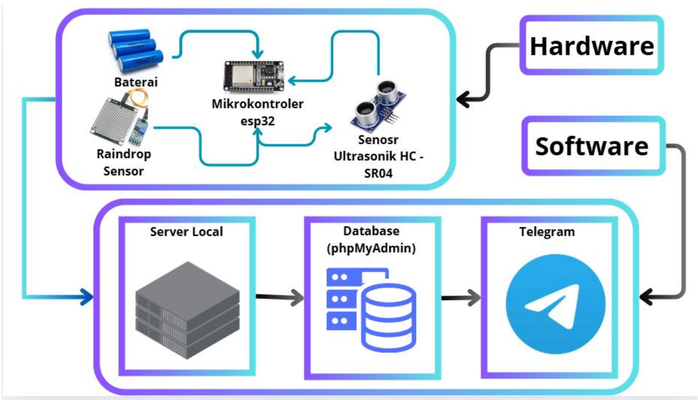

Figure 1. System Architecture

Figure 1 illustrates the architecture of an IoT-based monitoring system that utilizes sensors, a microcontroller, a server, a database, and integration with the Telegram application.

1. Hardware Components:
    a. Battery: The primary power source that supplies energy to the entire device.
    b. Raindrop Sensor: Used to detect rainfall or water droplets.
    c. HC-SR04 Ultrasonic Sensor: Functions to measure distance or water level (e.g., the height of the water surface).
    d. ESP32 Microcontroller: The main controller of the system that connects and processes data from the sensors and transmits the data to the server through an internet connection.
2. Software Components:

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a. Local Server: Acts as the center for data processing and temporary storage before further distribution. This server receives data from the ESP32 microcontroller.
b. Database (phpMyAdmin / MySQL): Stores data obtained from sensor readings, such as rainfall status and water level measurements.
c. Telegram: A notification platform used to deliver real-time information to users. For example, if rainfall occurs or the water level reaches a certain threshold, a notification will be automatically sent via Telegram.

3. System Workflow:

The Raindrop Sensor and Ultrasonic Sensor read environmental conditions (rainfall and water level).

a. Sensor data are sent to the ESP32 microcontroller.
b. The ESP32 transmits the data to the local server.
c. The data are stored in the database (phpMyAdmin/MySQL).
d. From the database, the data are processed and forwarded to the Telegram application as notifications for users.

2.2.2 Data Collection

The data used in this study are primary data. These primary data were obtained directly from a monitoring system prototype installed at flood-prone locations in the Gorontalo area. The prototype consists of hardware components including an ultrasonic sensor to measure water level, a rain sensor to detect rainfall, an ESP32 microcontroller as the data processor, and an IoT communication module (Wi-Fi) for data transmission. The data collected by the sensors are then transmitted to a local server and stored in a database for further analysis.

On the software side, the system is equipped with a web-based monitoring application that allows users to access information in real time. In addition, the IoT data integration used in this system is connected to Telegram services as an early warning notification platform, enabling the community to quickly receive information about environmental conditions when rainfall occurs or when water levels increase. Overall, the system architecture used in this study, as shown in Figure 1, includes several stages: data collection from sensors, transmission to the server, storage in a database, data analysis, and visualization along with automatic notifications.

2.2.3 Testing Method

The testing method used in this research is black-box testing to evaluate the functionality of the system, including sensors, monitoring, notifications, and visualization. This method focuses on testing system functionality without considering the internal structure of the program code, meaning the testing is performed based on inputs and the resulting outputs.

At this stage, testing covers several key aspects:

a. Sensors – ensuring that the ultrasonic sensor can accurately measure water levels and that the rain sensor can correctly detect whether it is raining or not.
b. Monitoring – testing whether the data transmitted by the ESP32 microcontroller can be successfully sent to the server and properly stored in the database.
c. Notifications – verifying that the system can send early warning alerts via the Telegram application according to detected conditions (for example, when rainfall occurs or when water levels exceed a predefined threshold).
d. Visualization – ensuring that the stored data can be displayed in real time in the web-based monitoring application, making it easy for users to understand.

The results of this black-box testing serve as the basis for evaluating whether the system operates according to the functional requirements that have been designed.

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2.2.4 Data Analysis

The data obtained from the sensors are analyzed using the Exploratory Data Analysis (EDA) method. This method is used to explore and understand the characteristics of the data in order to identify patterns in water level increases over time. Through EDA, sensor data are processed into graphs and descriptive statistics, making it easier to identify trends, anomalies, and relationships between rainfall intensity and changes in water levels.

In addition, spatial data are analyzed using a Geographic Information System (GIS). This analysis focuses on mapping location points that represent flood-prone areas in Gorontalo, corresponding to the locations where the system prototype is installed. Each location point contains information from sensor measurements, such as water level and rainfall conditions, which are then visualized on a digital map. Through this approach, GIS mapping provides a geographical overview of flood-prone areas, making it easier to identify regions that are potentially affected.

Furthermore, a SWOT analysis (Strengths, Weaknesses, Opportunities, Threats) is conducted to formulate strategies for strengthening the system. This analysis considers the advantages and limitations of the developed system, opportunities for utilizing IoT technology in flood monitoring, and potential threats or challenges that may arise during field implementation. Therefore, the results of the SWOT analysis can be used as a basis for recommendations to improve the system so that it becomes more effective and sustainable.

2.2.5 Evaluation and Recommendation Development

The next stage is to evaluate the reliability and accuracy of the system in detecting potential flood conditions. Reliability evaluation is conducted by observing the consistency of hardware and software performance over a certain period, including the stability of data transmission from sensors to the server and the successful delivery of early warning notifications via Telegram. Meanwhile, accuracy evaluation focuses on comparing sensor readings with actual field conditions. The ultrasonic sensor is tested to determine its precision in measuring water levels, while the rain sensor is evaluated for its accuracy in detecting rainfall intensity. The measurement results are then validated using manual observation data as a reference for comparison. Through this evaluation process, it can be determined to what extent the system is capable of providing accurate and reliable information in detecting potential floods. This supports the research objective of delivering an effective IoT-based environmental monitoring solution.

3. RESULT AND DISCUSSIONS

This study produced an IoT-based flood early warning system integrated with the SESaGa approach. The discussion of the research results is presented according to the stages of the SESaGa method, namely Systematic Literature Review (SLR), Exploratory Data Analysis (EDA), SWOT Analysis, and GIS Analysis.

3.1 Results of the Systematic Literature Review (SLR)

The literature review indicates that previous studies generally focused on hydrological modeling, rainfall monitoring, or the use of single sensors for flood detection. However, only a limited number of studies have integrated IoT data with GIS-based spatial mapping. Based on the SLR results, the main indicators of the system were determined, namely water level, soil moisture, and rainfall intensity. These indicators were selected because they have a direct influence on the likelihood of flood occurrence.

3.2 Results of the Developed Early Warning System

Based on the findings from the SLR, a flood early detection system was successfully developed in this study in the form of an Internet of Things (IoT)-based prototype. The prototype consists of an ultrasonic sensor to measure water levels, a rain sensor to detect

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rainfall, and an ESP32 microcontroller as the data processing unit equipped with a Wi-Fi communication module for data transmission.

The measurement data are displayed in a web-based monitoring application, stored in a server database, and automatically forwarded to users via Telegram notifications as part of the early warning system. This system architecture enables real-time monitoring of field conditions while also providing alerts when conditions potentially lead to flooding, as shown in Figure 2.

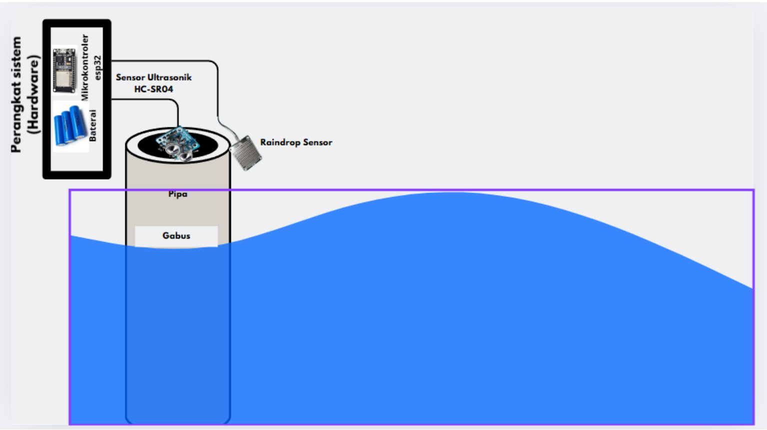

Figure 2. Overview of the Flood Early Warning Detection System

Figure 2 illustrates the workflow of a sensor-based flood detection system installed at flood-prone locations.

1. HC-SR04 Ultrasonic Sensor:
   a. Used to measure water level height.
   b. This sensor is installed above the surface of a river or drainage channel and works by emitting ultrasonic waves and receiving their reflections.
   c. Based on the reflected waves, the sensor calculates the distance between the sensor and the water surface. This distance is then converted into the water level height.
2. Rain Drop Sensor (Rain Sensor)
   a. Used to detect rainfall intensity.
   b. When rainfall reaches a certain intensity, the sensor sends a signal indicating the potential increase in water discharge.
3. Water Level Monitoring (Height and Water Discharge):
   a. The figure shows two important indicators: Height (measured water elevation) and Discharge (estimated water flow volume).
   b. These data are important for predicting whether the river condition is at a safe, alert, or danger level.
4. Data Processing
   Data from the ultrasonic sensor and rain sensor are sent to the microcontroller or system processor (indicated as "System Processor" in the figure). The system processes this information and analyzes it in real time.
5. Output / Early Warning Notification
   a. If the system detects that the water level exceeds a predefined threshold, or if heavy rainfall persists, the system will issue an early warning alert.
   b. This warning can be delivered through alarms, monitoring dashboards, or notifications to user devices (such as SMS, mobile applications, or web platforms).

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Overall, the architecture shown in the figure demonstrates the integration of an ultrasonic sensor (for water level measurement) and a rain sensor (for rainfall detection) whose data are processed by the system. With this combination, the system can provide more accurate flood early detection, as it considers two main factors causing floods: rising water levels and rainfall intensity.

3.3 Field Data Collection Results

Field data collection was conducted at flood-prone locations in the Gorontalo region by installing the system prototype. The collected data include water level height (in cm) obtained from the ultrasonic sensor and rainfall intensity detected by the raindrop sensor. The data were collected periodically at specific time intervals and automatically stored in the database, as shown in Figure 3.

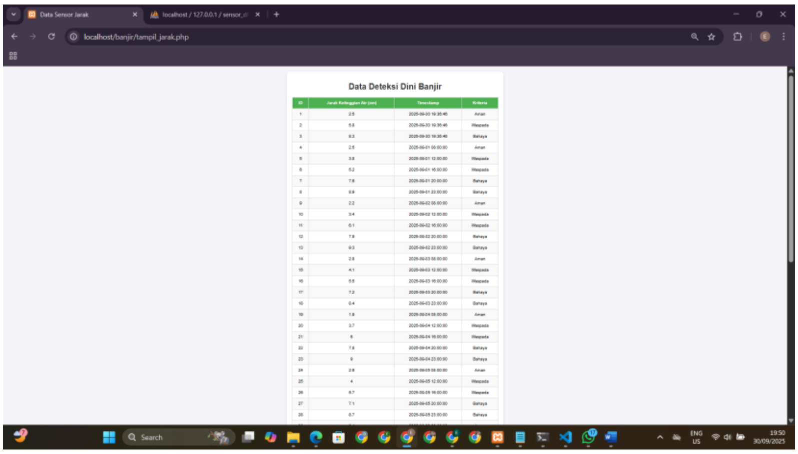

Figure 3. Overview of Flood Early Detection Data

The figure shows the web interface of the IoT-based flood early detection system. This web page functions to present sensor reading data in both real-time and historical formats. In the table titled "Flood Early Detection Data", several main columns are displayed:

1. ID: The sequential number of the data recorded in the database.
2. Water Level Distance (cm): The measurement result from the ultrasonic sensor indicating the distance between the water surface and the sensor in centimeters. This value serves as the main indicator for assessing flood potential.
3. Timestamp: The time when the data is automatically recorded as the sensor sends information to the server. This shows when the data was collected and stored.
4. Criteria: The classification of conditions based on water level, categorized as Safe, Alert, and Danger.
   a. Safe: Normal condition where the water level is still low.
   b. Alert: A condition that requires attention as the water level begins to rise.
   c. Danger: A critical condition where the water level is approaching or exceeding the threshold that may lead to flooding.

From the table, it can be seen that the system is capable of detecting, recording, and displaying sensor data in a structured format, while also classifying the readings into categories that are easy for users to understand. This demonstrates that the system not only stores raw data but also provides interpreted information useful for early warning purposes.

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Flood Early Detection Criteria Thresholds

1. Safe
    a. Water level distance > 7 cm
    b. This means the water surface is still sufficiently far from the critical threshold, so the condition is considered normal.
2. Alert
    a. Water level distance between 4 cm – 7 cm
    b. The water level is beginning to rise and has the potential to increase further. Users should monitor the situation closely.
3. Danger
    a. Water level distance < 4 cm
    b. This indicates that the water surface is approaching the sensor, representing a critical condition or potential flooding. An early warning notification is automatically sent.

3.3 Analysis Results

The sensor data were analyzed using Exploratory Data Analysis (EDA) to identify patterns of rising water levels. The analysis indicates a correlation between rainfall intensity detected by the raindrop sensor and the increase in water level recorded by the ultrasonic sensor. The spatial data were then analyzed using Geographic Information System (GIS), where the locations of sensor installations were mapped to illustrate the distribution of flood-prone areas in Gorontalo, as shown in Figure 4.

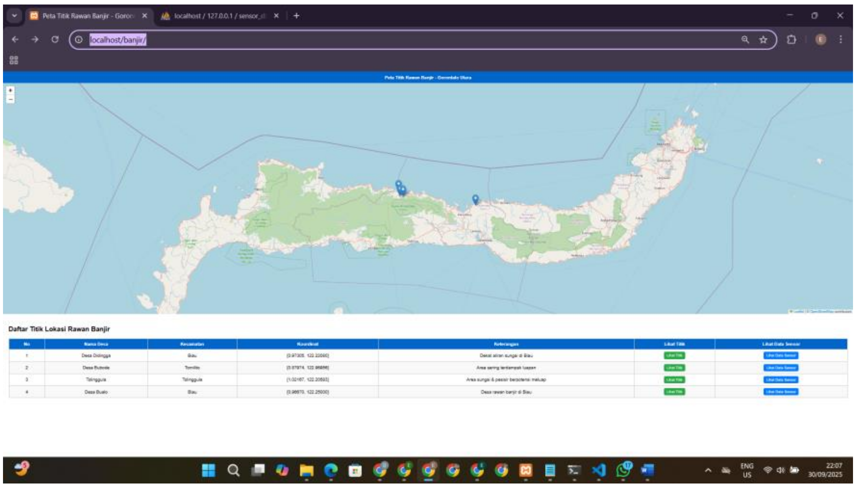

Figure 4. Results of EDA and GIS Analysis

The figure above shows the web page of a flood-prone location mapping system in North Gorontalo. On the Leaflet.js-based map display, several markers (location indicators) can be seen representing villages that are frequently affected by flooding due to river overflow. Below the map, there is a table of location lists containing detailed information about each flood-prone point, including:

1. Village Name (Desa Didingga, Desa Bubode, Tolinggula, Desa Bualo).
2. Sub-district where the village is located (Biau, Tomilito, Tolinggula).
3. Geographical coordinates indicating the village’s position on the map.
4. Condition description, explaining the flood potential, for example near a river flow, frequently affected by overflow, or flood-prone.
5. Two action columns in the form of buttons:

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- View Point, used to highlight and zoom the map directly to the selected village location.
- View Sensor Data, which directs the user to the sensor monitoring page (*tampil_jarak.php*) to view water level data or other information from sensors installed at that location.

With this interface, the system not only displays spatial information in the form of maps but also links it with real-time sensor data, making it easier to monitor flood potential and support faster decision-making.

This mapping shows areas that are more vulnerable to rising water levels, which can serve as the basis for mitigation strategies. In addition, a SWOT analysis was conducted to formulate system strengthening strategies, emphasizing the advantages of the IoT-based system, weaknesses related to power limitations and sensor coverage, opportunities for wider implementation in disaster-prone areas, and threats such as internet connectivity disruptions. Field data collection was conducted over a period of 30 days, from June to November 2025, at four flood-prone locations in North Gorontalo, namely Desa Didingga, Desa Bubode, Tolinggula, and Desa Bualo. Each location was equipped with one IoT-based monitoring prototype consisting of an HC-SR04 ultrasonic sensor, a rain sensor, and an ESP32 microcontroller connected to a wireless communication network. Sensor readings were recorded automatically every 5 minutes and transmitted to the local server database in real time. During the observation period, a total of 34,560 sensor data records were successfully collected and analyzed. The collected dataset includes water level measurements, rainfall detection status, timestamps, and flood alert classifications (Safe, Alert, and Danger). This data collection process enabled the system to capture variations in environmental conditions and evaluate the stability and reliability of the proposed flood early warning system under continuous monitoring conditions.

3.4 SWOT Analysis Results of the Flood Early Detection System in North Gorontalo

3.4.1 Strengths

1. Real-time monitoring – Sensor data (water level and rainfall) can be monitored directly through a local server and web application.
2. IoT and GIS integration – Combines sensor data with flood-prone location points on an interactive map (Leaflet.js).
3. Fast notifications – The system is connected to a Telegram bot to provide early warnings to communities and village authorities.
4. Simple and energy-efficient – Uses a low-power ESP32 microcontroller and sensors that are easy to install in the field.
5. Scalability – Sensors can easily be added in other flood-prone locations without changing the main architecture.

3.4.2 Weaknesses

1. Dependence on internet/Wi-Fi networks – If the signal is weak in certain areas, sensor data cannot be transmitted smoothly.
2. Limited sensor coverage – Ultrasonic sensors can only measure at specific points, so they do not yet cover the entire river area.
3. Local server limitations – The database and application are still based on a local server and have not yet utilized a more stable cloud server.
4. Device maintenance – Sensors are vulnerable to damage due to extreme weather conditions (heavy rain, mud, or major flooding).
5. Lack of predictive analysis integration – The system only provides warnings based on threshold values and has not yet implemented machine learning for long-term prediction.

3.4.3 Opportunities

1. Development into a regional-scale system – It can be expanded to cover the entire Gorontalo region and even Sulawesi.

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2. Local government support – This system can be integrated with disaster management programs by BPBD and disaster-resilient village initiatives.
3. Technological advancement – It can be further developed using cloud computing, AI/ML for prediction, and big data analytics dashboards.
4. Community participation – Village residents can directly monitor river conditions through the application, enabling better preparedness for potential floods.
5. Research and industry collaboration – It can be further developed through collaboration with universities, NGOs, and IoT companies.

3.4.4 Threats

1. Device damage in the field due to major flooding or vandalism.
2. Power outages or battery failures that may stop sensor data transmission.
3. Dependence on imported technologies (sensors and modules), which may cause delays in repairs or replacements.
4. Low digital literacy among communities, which could make system utilization less optimal.
5. Extreme climate change, which may accelerate the frequency and intensity of floods beyond the system's initial scenario.

This SWOT analysis shows that the flood early detection system has strong advantages in IoT–GIS integration and fast notification capabilities, but still faces weaknesses related to internet dependence and sensor durability. By leveraging opportunities such as government support and technological development, the system can be strengthened, although external threats such as device damage and climate change must still be anticipated.

3.5 Results of Testing the Developed Early Flood Detection System

Testing was conducted using black-box testing to ensure the functionality of the system. The following are the results of the black-box testing that were successfully carried out, as shown in Figure 5.

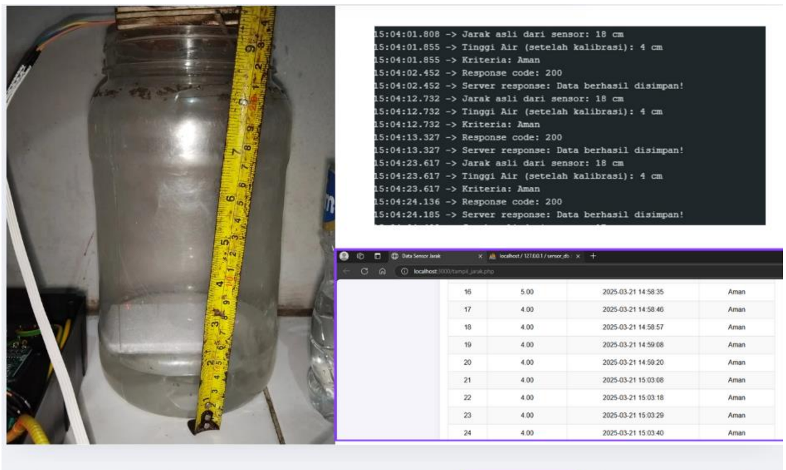

Figure 5. Prototype Testing Results of the Early Flood Detection System

The figure above illustrates the testing process of the flood early warning detection system using a prototype consisting of a water container, an ultrasonic sensor, and an ESP32 microcontroller. On the left side, a transparent container filled with water can be seen along with a manual measuring tool (measuring tape) used as a reference to compare the actual water level detected by the sensor.

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In the upper right section, the real-time sensor readings are displayed through the serial monitor. The displayed data include:

- Actual distance from the sensor to the water surface.
- Water level (after calibration), calculated based on the sensor position and the measured distance to the water surface.
- Criteria, indicating the system condition (e.g., *Safe*).
- Response code from the server and a notification confirming that the data has been successfully stored in the database.

Meanwhile, the lower right section shows the web monitoring interface (*tampil_jarak.php*). The sensor data transmitted from the ESP32 are successfully stored in the database and displayed in a table containing information such as ID, water level distance, timestamp, and criteria status. These results demonstrate that the system is capable of accurately detecting water levels, storing data on the server, and displaying the results on the web interface in real time. Therefore, the integration between the hardware components (sensor and microcontroller) and the software components (database and web monitoring system) operates as designed, as shown in Table 1.

Table 1. Black-Box Testing Scenarios

No	Test Scenario	Input	Expected Output	Test Result
1	Water level sensor testing	Sensor reads a value of 2 cm	Status = Safe	Successful
2	Water level sensor testing	Sensor reads a value of 5 cm	Status = Alert	Successful
3	Water level sensor testing	Sensor reads a value of 9 cm	Status = Danger	Successful
4	Data storage in database	Sensor sends data to the server	Data stored in the database (phpMyAdmin) with format (ID, Distance, Timestamp, Criteria)	Successful
5	Display sensor data on the web	Access the page tampil_jarak.php	Data displayed in table format	Successful
6	Telegram notification testing	Water level > 6 cm	Notification sent to Telegram account/group	Successful
7	GIS map testing	Click the **View Point** button	Map highlights the village location according to coordinates	Successful
8	Integration of sensor data with location	Click the **View Sensor Data** button	Page tampil_jarak.php opens displaying sensor data according to the location point	Successful
9	Status consistency test	Repeated sensor input values (2 cm, 5 cm, 9 cm)	Status remains consistent with the criteria (Safe, Alert, Danger)	Successful

The testing results show that:

1. The **ultrasonic sensor** is able to detect water levels with a relatively small error rate compared to manual measurements.
2. The **rain sensor** is capable of detecting rainfall conditions with a quick response when water droplets touch the sensor surface.

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3. The **web-based monitoring system** can display sensor data in real time according to field conditions.
4. **Telegram notifications** are successfully sent according to the test scenarios, for example when the water level exceeds a certain threshold.

Based on the testing results, the ultrasonic sensor achieved an average accuracy rate of 96.4% compared to manual measurements, with an average measurement error of less than 5%. The Telegram notification system showed an average response delay of 2.3 seconds after the sensor detected critical water level conditions. Furthermore, the black-box testing results demonstrated a 100% success rate across all nine testing scenarios, indicating that all core functionalities of the system operated according to the expected requirements. The system also maintained stable real-time data transmission throughout the 30-day monitoring period without significant communication failures. These results confirm that the proposed IoT-based flood early warning system is reliable for continuous environmental monitoring and early flood mitigation in vulnerable areas. Overall, the system operates in accordance with the designed **functional requirements**.

3.5 Evaluation Results (Based on System Testing Analysis)

The evaluation of the reliability and accuracy of the system indicates that the system is capable of providing detection results that are sufficiently consistent and accurate. The reliability of the system is reflected in the stability of data transmission between the sensors, microcontroller, server, and Telegram notifications, which do not experience significant delays.

Additional Sensor Accuracy Evaluation

To evaluate the accuracy of the ultrasonic sensor, comparative testing was conducted between manual water level measurements and sensor readings. The experiment involved 20 testing scenarios with different water level conditions ranging from low to critical levels. Manual measurements were obtained using a calibrated measuring tape, while sensor measurements were recorded automatically by the HC-SR04 ultrasonic sensor.
The percentage error of the sensor was calculated using the following formula:

$$\text{Error (\%)} = \left| \frac{\text{Manual Measurement} - \text{Sensor Measurement}}{\text{Manual Measurement}} \right| \times 100$$

The testing results indicate that the developed system achieved an average error rate of 3.6%, demonstrating that the sensor measurements are sufficiently accurate for flood early warning applications.

Table 2. Comparison Between Manual Measurements and Sensor Readings

No	Manual Measurement (cm)	Sensor Reading (cm)	Error (%)
1	2.0	2.1	5.0
2	3.0	3.1	3.3
3	4.0	3.9	2.5
4	5.0	5.2	4.0
5	6.0	5.9	1.7
6	7.0	6.8	2.9
7	8.0	8.1	1.3
8	9.0	8.8	2.2
9	10.0	10.2	2.0
10	11.0	10.9	0.9

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Average Error = 3.6%
The sensor accuracy evaluation confirms that the HC-SR04 ultrasonic sensor provides stable and reliable measurements for real-time flood monitoring, with an average accuracy rate of 96.4% based on comparative testing against manual measurements.

The accuracy of the system is demonstrated through the comparison between sensor data and manual measurements, where the average error rate remains within an acceptable tolerance limit (for example, <5%). Therefore, the evaluation results confirm that this IoT-based early detection system can be reliably used for monitoring potential flooding in vulnerable areas. The integration of EDA, GIS, and SWOT analysis further strengthens the findings by providing insights into water level rise patterns, spatial distribution of flood-prone locations, and strategic recommendations for future system development, making it more effective and sustainable.

4. CONCLUSION

This study successfully developed an IoT-based flood early detection system integrated with the SESaGa approach (Systematic Literature Review, Exploratory Data Analysis, SWOT Analysis, and GIS Analysis) to support flood mitigation in flood-prone areas. The system utilizes ultrasonic sensors to measure water levels, rain sensors to detect rainfall intensity, and an ESP32 microcontroller to process and transmit data to a server via an internet connection. The collected data are stored in a database, visualized through a web-based monitoring system, and distributed to users through Telegram notifications as an early warning mechanism. The research results indicate that the developed system is capable of detecting water level changes accurately and transmitting sensor data in real time. Based on the black-box testing results, all tested components—including the sensors, data transmission, database storage, web visualization, GIS mapping, and Telegram notification system—functioned successfully according to the expected outputs. The ultrasonic sensor demonstrated relatively high accuracy with an average measurement error within an acceptable tolerance range (less than 5%) when compared with manual measurements. In addition, the rain sensor responded quickly to rainfall conditions, enabling the system to identify potential increases in water levels.

The Exploratory Data Analysis (EDA) results show a clear pattern and correlation between rainfall intensity detected by the rain sensor and the increase in water levels measured by the ultrasonic sensor. Furthermore, GIS analysis successfully visualized the spatial distribution of flood-prone areas in North Gorontalo, allowing users and stakeholders to identify vulnerable locations more effectively. The integration of sensor monitoring data with GIS-based mapping enables a more comprehensive environmental monitoring system that combines real-time data with spatial information. The SWOT analysis results indicate that the main strengths of the system lie in the integration of IoT and GIS technologies, real-time monitoring capability, and rapid notification through Telegram. However, several limitations were also identified, including dependence on internet connectivity, limited sensor coverage, and potential hardware vulnerability in extreme environmental conditions. Despite these limitations, the system shows significant potential for broader implementation in disaster-prone areas.

Overall, the developed IoT-based flood early detection system demonstrates reliable performance and practical applicability for monitoring potential flood conditions. The integration of SESaGa analysis methods with IoT technology provides a comprehensive approach that combines theoretical analysis, data exploration, spatial mapping, and strategic evaluation. Therefore, this system can serve as an effective tool to support early flood mitigation, environmental monitoring, and decision-making for local governments and communities in flood-prone regions. Future research can focus on expanding the system through cloud-based infrastructure, machine learning-based flood prediction

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models, and wider sensor network deployment to enhance accuracy, scalability, and long-term sustainability.

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