DEVELOPMENT OF A WEB-BASED DIGITAL TWIN DASHBOARD FOR THE CILIWUNG RIVER BASIN FOR FLOOD RISK MONITORING AND MITIGATION

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ABSTRACT

Flooding remains one of Indonesia's most critical environmental challenges, particularly in urban areas traversed by major river basins such as the Ciliwung watershed. The increasing frequency and intensity of flood events are driven by rapid urbanization, land-use changes, population growth, and climate variability. Conventional flood monitoring systems typically provide static information and often lack the integrated visualization capabilities needed to support real-time decision-making. Recent advancements in Digital Twin technology offer new opportunities to represent the physical environment through dynamic virtual models linked to real-time data sources.

This research aims to design and develop a Digital Twin dashboard for the Ciliwung watershed that integrates real-time flood monitoring features with flood predictions based on historical data. The dashboard was developed using a user-centered design approach and implemented as a web-based platform. The system combines geospatial visualization, environmental monitoring indicators, flood risk mapping, and predictive analytics to provide a comprehensive situational overview. The proposed dashboard enables stakeholders to monitor water levels, rainfall intensity, flood-prone areas, and historical flood trends through an interactive interface.

The research results demonstrate that the dashboard effectively visualizes environmental conditions within the watershed and improves accessibility to flood-related information. Furthermore, the integration of historical flood prediction capabilities supports disaster preparedness and early warning strategies. Applying the Digital Twin concept to watershed management contributes to the creation of a smarter environmental monitoring system and enhances decision-making processes for flood mitigation.

Keywords: Digital Twin, Flood Monitoring, Flood Prediction, Smart Environment, Watershed Management

1. Introduction

Geographically, Indonesia is situated in a tropical region characterized by high annual rainfall intensity. Consequently, flooding is one of the most frequent natural disasters affecting various parts of the country. Disaster management reports indicate that floods account for a significant percentage of total annual natural disasters, often resulting in substantial economic losses, infrastructure damage, and disruptions to community activities. One of the most vulnerable river systems in Indonesia is the Ciliwung River Basin, which flows through the Bogor, Depok, and Jakarta areas.

The Ciliwung River plays a vital role in supporting urban and environmental systems. However, rising population density and urban development have significantly altered the basin's natural hydrological characteristics. The conversion of green open spaces into residential and commercial areas has reduced water infiltration capacity and increased surface runoff. As a result, even moderate rainfall can cause river water levels to rise and heighten the

* Corresponding author.
Received: xxx, xxx. Revised: xxx, xxx. Accepted: xxx, xxx.
Available online: January 1st, 2999.

DOI: https://doi.org/10.12962/j24068535.v23i1.aXXXX

risk of flooding in downstream areas.

Flood monitoring has traditionally relied on manual observation and fragmented information systems. Although various agencies provide rainfall and water level data, this information is often disjointed, making it difficult for the public and policymakers to interpret quickly. In emergency situations, the lack of integrated visualization can hinder response times and reduce the effectiveness of mitigation efforts.

The emergence of Digital Twin technology offers a promising solution to these challenges. A Digital Twin is a virtual representation of a physical object, system, or environment that continuously receives and processes real-world data. By integrating sensor data, environmental datasets, and analytical models, Digital Twins provide capabilities for real-time monitoring, simulation, and prediction. Originally developed for manufacturing and industrial applications, Digital Twin technology has now expanded into diverse fields such as smart cities, transportation systems, healthcare, and environmental management.

In watershed management, a Digital Twin can create a dynamic representation of river conditions by combining hydrological data, Geographic Information Systems (GIS), and predictive analytics. Such a system enables users to monitor environmental conditions in real-time while predicting various potential future scenarios. This capability is crucial for flood risk management, where early detection and prediction can significantly mitigate the impact of disasters.

This research focuses on designing a Digital Twin dashboard for the Ciliwung watershed that integrates real-time flood monitoring features with flood prediction based on historical data. The dashboard is designed as an interactive platform to visualize environmental conditions, support disaster preparedness, and facilitate data-driven decision-making. The proposed design employs modern web technologies and user interface principles to ensure the system's accessibility, usability, and scalability.

The objective of this study is:

Designing a Digital Twin dashboard for the Ciliwung watershed.
Integrating real-time environmental monitoring features into the dashboard.
Implementing flood prediction visualizations based on historical data.
Evaluating the effectiveness of dashboard-based environmental monitoring from a user interface perspective.

This research contributes by demonstrating the application of Digital Twin technology in watershed management through a practical and interactive dashboard prototype. It also highlights the role of visualization technology in raising public awareness and strengthening disaster response strategies.

2. Literature review

2.1. Digital Twin Technology

The Digital Twin concept was first introduced by Michael Grieves in the context of product lifecycle management. A Digital Twin is a digital replica of a physical system that continuously exchanges information with its real-world counterpart. The integration of physical and virtual environments enables monitoring, analysis, optimization, and prediction.

A Digital Twin system generally consists of three main components:

1. Physical entity
2. Virtual representation
3. Data connection layer

Physical entities represent real-world systems, while virtual representations provide digital models capable of simulating environmental behavior. The data connection layer ensures synchronization between the physical and digital environments.

Various recent studies indicate that Digital Twin technology can enhance operational efficiency, predictive maintenance, and decision-support systems. Its application in the environmental sector encompasses water resource management, smart city monitoring, climate resilience, and disaster risk reduction.

2.2. Pengelolaan Daerah Aliran Sungai

A watershed (or river basin) is a geographic area where rainfall collects and flows toward a common outlet, such as a river, lake, or reservoir. Effective watershed management requires continuous monitoring of hydrological variables, including rainfall, water levels, runoff, and land use.

The Ciliwung watershed covers an area of approximately 347 square kilometers and serves millions of residents across various urban areas. Due to rapid urbanization, the watershed faces mounting challenges regarding flood control and environmental sustainability.

Real-Time Monitoring Systems

Real-time monitoring systems utilize sensors and communication technologies to continuously collect and transmit environmental data. Such systems enable stakeholders to monitor current conditions without significant delay.

Common parameters monitored in flood management systems include:

1. River water level
2. Rainfall intensity
3. Flow velocity
4. Water discharge

The integration of Internet of Things (IoT) technology has further enhanced the capabilities of real-time monitoring systems by enabling automated data acquisition and remote accessibility.

3. RESEARCH METHODOLOGY

3.1. Research Method

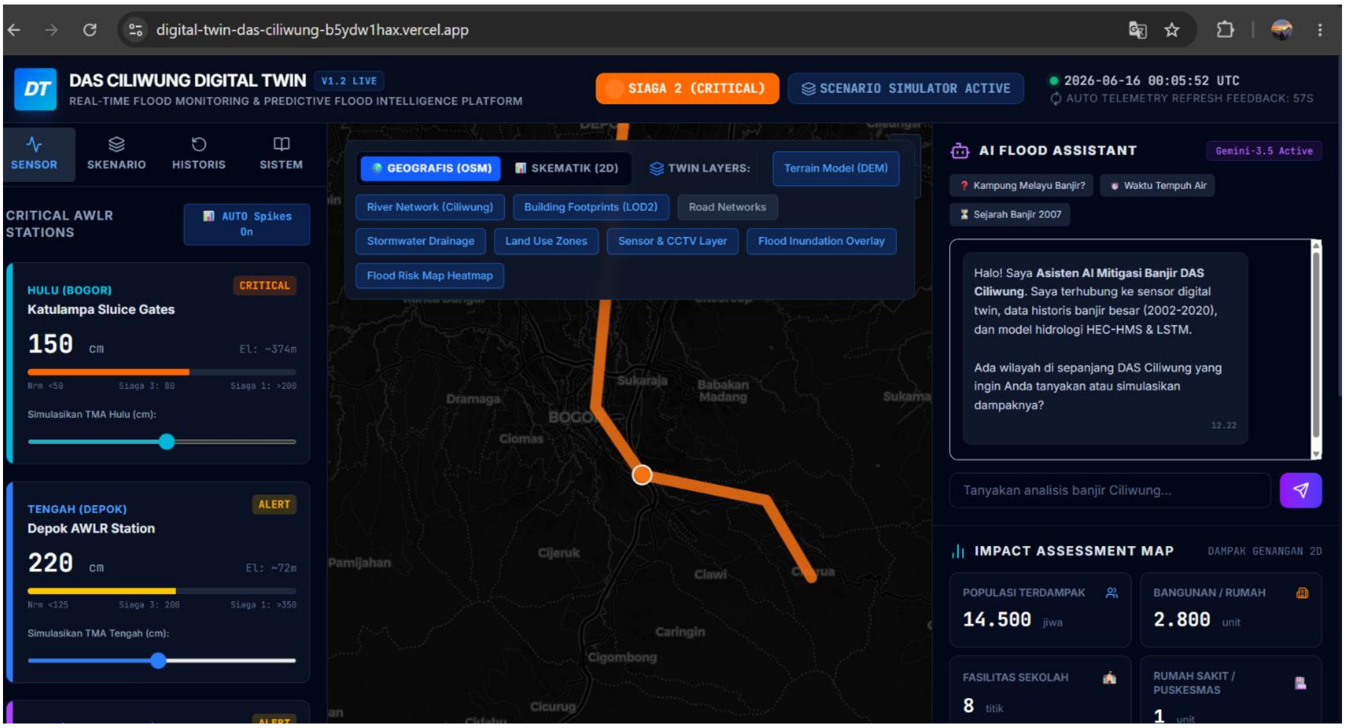
This study employs a Research and Development (R&D) approach focused on the design and prototyping of a Digital Twin Dashboard for the Ciliwung River Basin. The objective is to develop an interactive, web-based platform capable of visualizing environmental conditions in real-time while providing information on historical flood predictions.

The research process consists of five stages:

1. Literature Review
2. Requirements Analysis
3. UI/UX Design
4. Prototype Development
5. Evaluation and Analysis

The methodological framework is illustrated in Figure 1.

Figure 1. Research Framework



3.2 Requirement Analysis

The requirement analysis stage was conducted to identify system functionalities and user needs. The dashboard was designed for stakeholders such as:

- Government agencies
- Disaster management authorities
- Environmental researchers
- General public

The functional requirements of the proposed system are presented in Table I.

Table I. Functional Requirements

No	Requirement	Description
FR1	Real-Time Monitoring	Display water level information
FR2	Rainfall Monitoring	Visualize rainfall intensity
FR3	Flood Risk Mapping	Display flood-prone areas
FR4	Historical Prediction	Show flood prediction trends
FR5	Data Analytics	Present statistical information
FR6	Interactive Visualization	Enable map interaction
FR7	Dashboard Accessibility	Accessible through web browsers

3.3 Arsitektur Sistem

The proposed Digital Twin architecture consists of three layers:

A. Data Acquisition Layer

The data acquisition layer collects information from various environmental sources, including:

1. Water level sensors
2. Rainfall sensors
3. Historical flood datasets
4. Meteorological information

B. Data Processing Layer

The processing layer handles:

1. Data cleaning
2. Data integration
3. Predictive analysis
4. Flood risk classification

C. Visualization Layer

The visualization layer presents information through a web dashboard comprising:

1. Interactive GIS maps
2. Monitoring cards
3. Prediction charts
4. Analytics panels

This architecture enables continuous synchronization between physical environmental conditions and their digital representations.

3.4 UI/UX Design Method

The dashboard interface was designed using User-Centered Design (UCD) principles. The process included:

1. User Analysis
2. Wireframe Design
3. High-Fidelity Prototype Development
4. User Experience Evaluation

The interface prioritizes:

- Simplicity
- Consistency
- Accessibility
- Responsiveness

The design is implemented using ReactJS and Tailwind CSS.

3.5 Tumpukan Teknologi

Table II presents the technologies used in the development process.

Table II. Technology Stack

Component	Technology
Frontend	ReactJS
Styling	Tailwind CSS
Build Tool	Vite
Mapping	Leaflet
Chart Visualization	Recharts
Deployment	Vercel
Version Control	GitHub

Tabel II menyajikan teknologi yang digunakan dalam proses pengembangan.

Tabel II. Tumpukan Teknologi

Komponen	Teknologi
Frontend	ReactJS
Penataan Gaya	Tailwind CSS
Alat Build	Vite
Pemetaan	Leaflet
Visualisasi Grafik	Recharts
Deployment	Vercel
Kontrol Versi	GitHub

4. RESULTS AND DISCUSSION

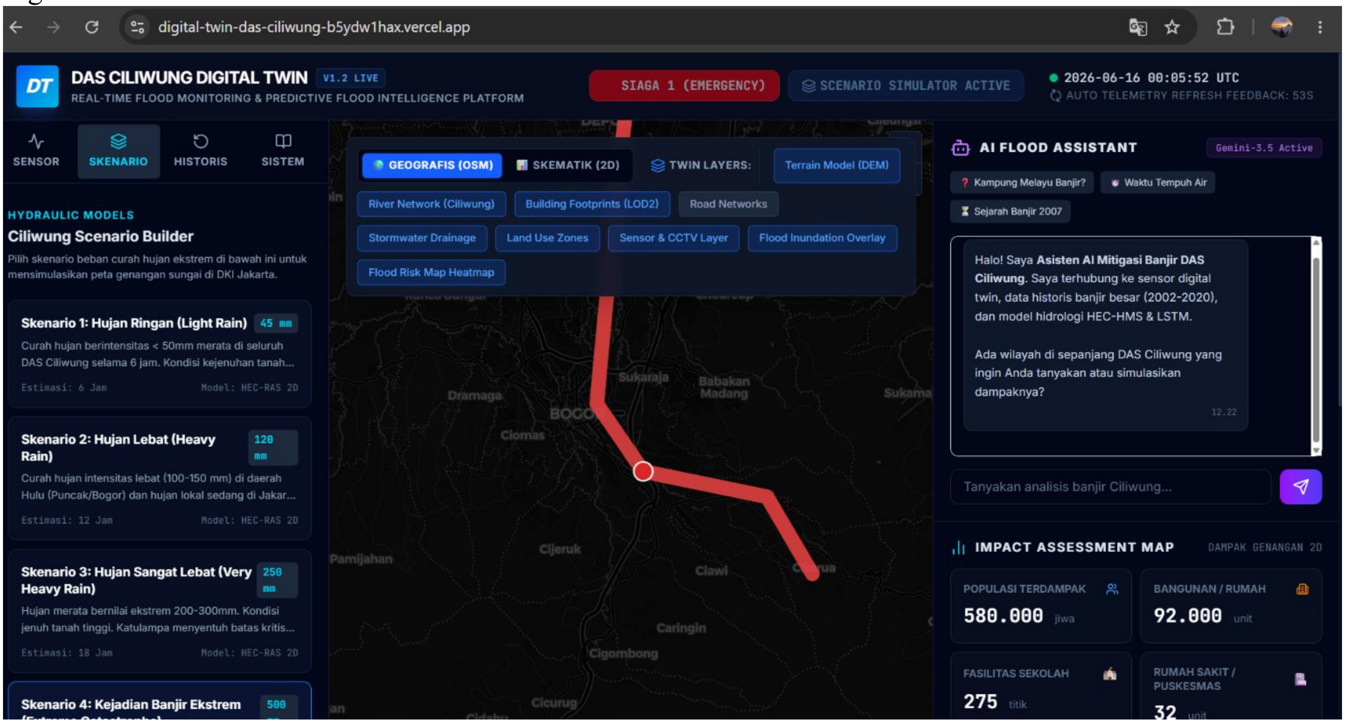
The developed Digital Twin dashboard provides an interactive environment for monitoring hydrological conditions in the Ciliwung River Basin.

The prototype has been successfully launched online and can be accessed via:
https://digital-twin-das-ciliwung.vercel.app
This dashboard integrates visualization techniques with the Digital Twin concept to represent the condition of the river basin in near real-time.

Main Dashboard Interface
The main dashboard serves as a centralized monitoring interface.
This interface displays:

1. Current water level
2. Rainfall conditions
3. Flood warnings
4. Environmental indicators

Users can quickly assess environmental conditions via visual status indicators.
Figure 2. Main Dashboard Interface

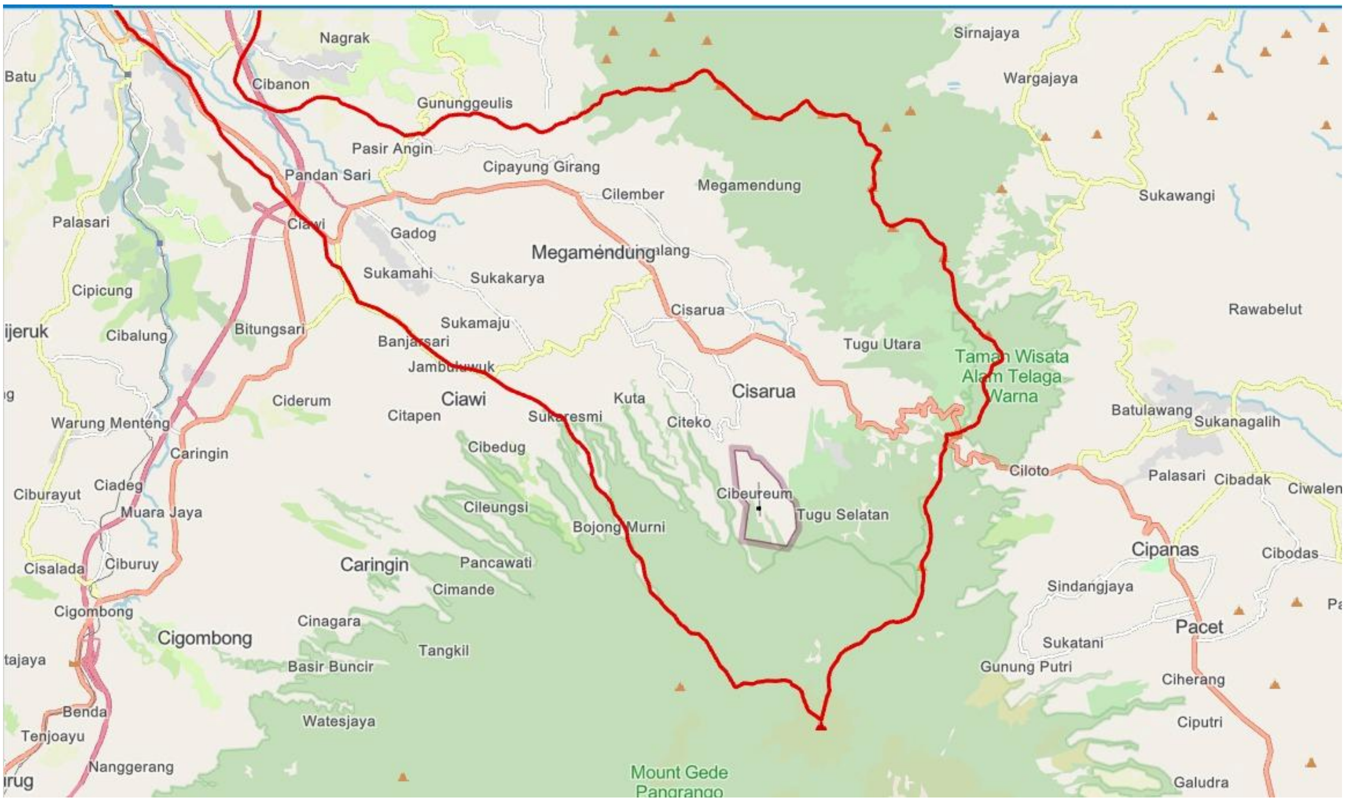


This design employs a card-based layout to enhance information readability and reduce cognitive load.

Interactive Watershed Visualization
One of the system's key features is an interactive watershed map.
This map allows users to:

1. Identify monitoring locations
2. View flood-prone zones
3. Observe watershed boundaries
4. Access environmental information

1. Figure 3. Interactive Watershed Map



Geospatial visualization significantly enhances situational awareness during potential flood events.

Real-time monitoring is a key component of the Digital Twin concept.

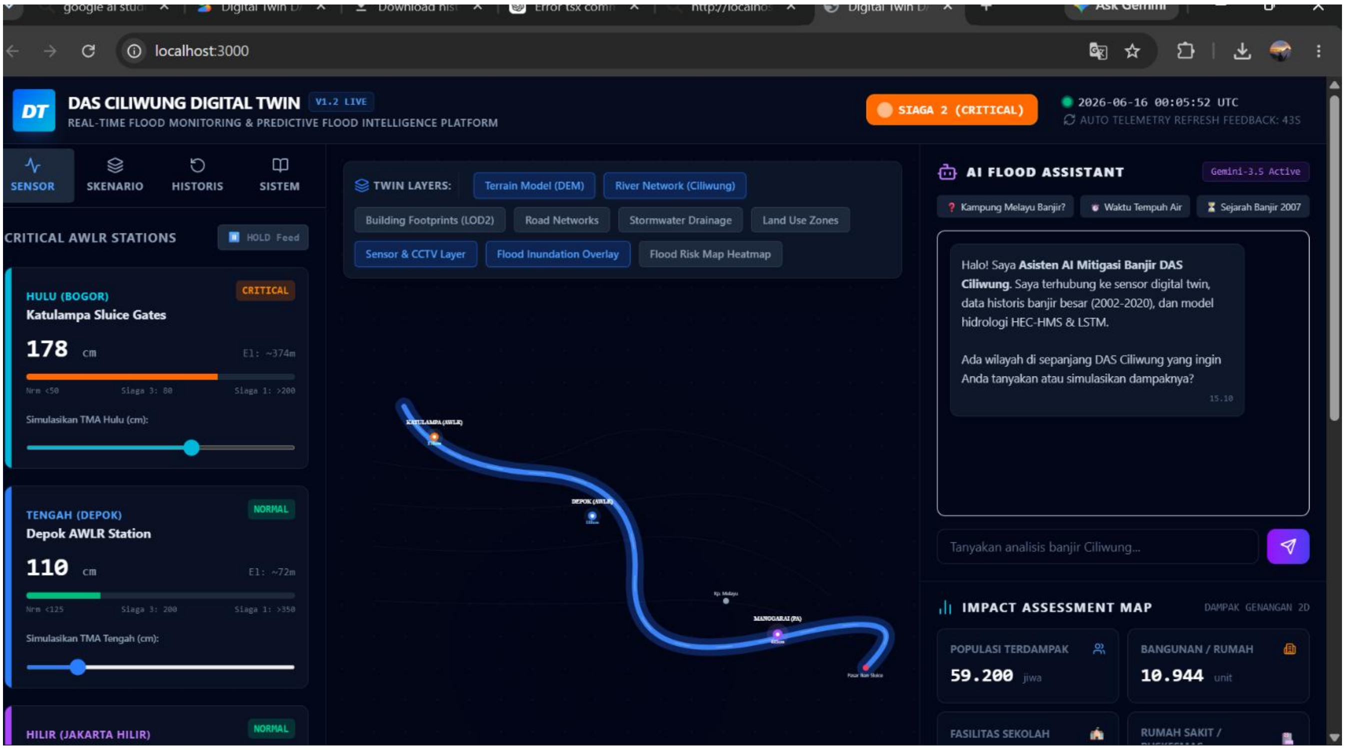
- Dashboards display:
- Water level status
- Rainfall intensity
- Environmental conditions
- Warning indicators

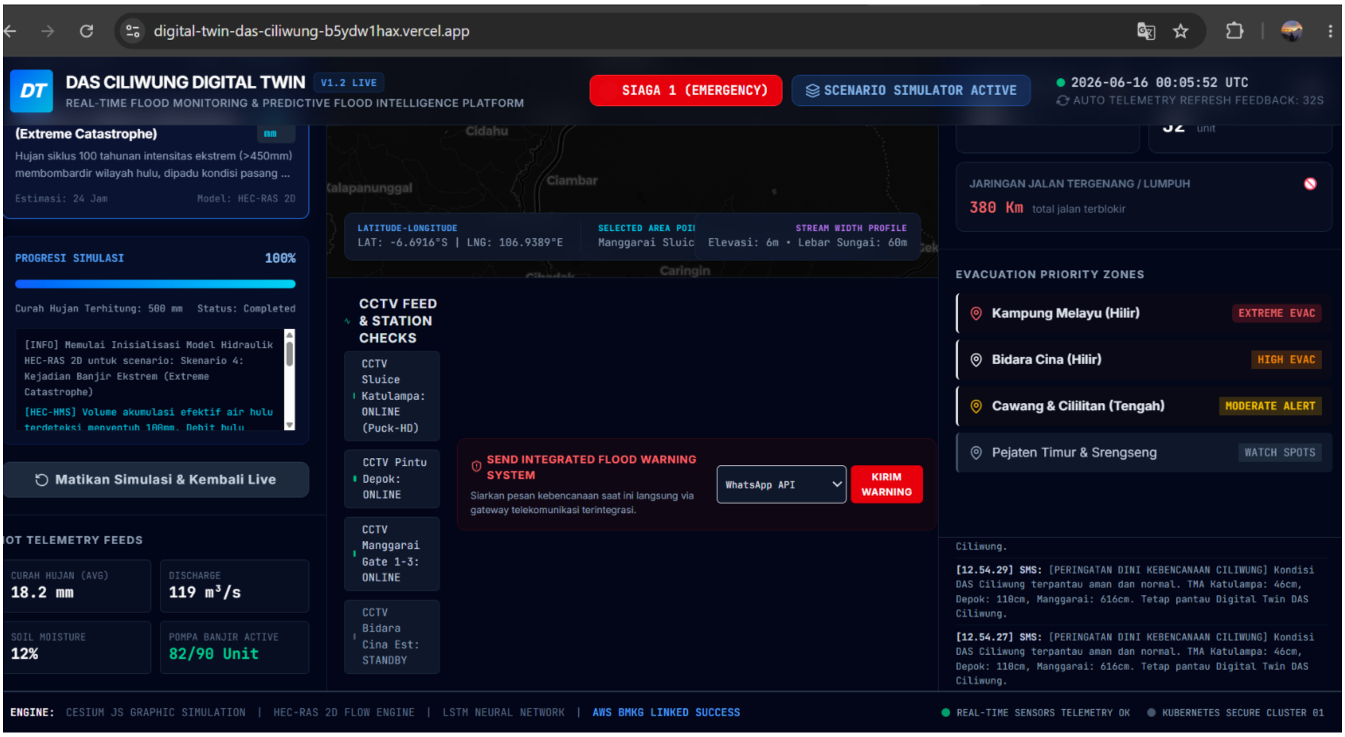
Flood status is categorized into four levels:

Table III. Flood Alert Levels

Status	Description
Safe	Normal conditions
Alert	Rising water levels
Watch	Potential for flooding
Danger High	risk of flooding

Figure 4. Real-time Monitoring Panel





Visual indicators use color coding to facilitate decision-making.

Historical Flood Prediction

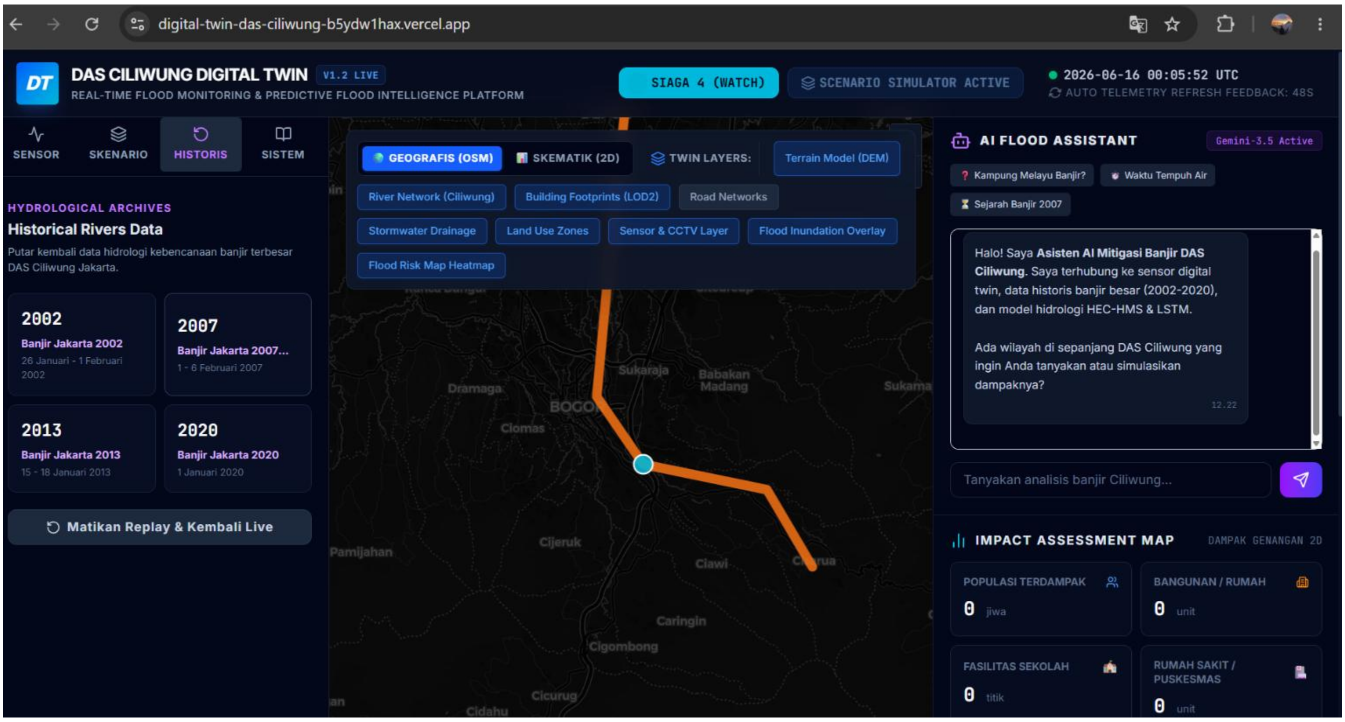
The historical flood prediction feature presents analytical information based on past flood records.

This prediction module analyzes:
Historical rainfall patterns
Water level trends

Past flood events

The analysis results are presented through graphical visualizations that help users identify future risks.

Figure 5. Historical Flood Prediction Dashboard



This predictive visualization helps enhance disaster preparedness and supports proactive flood management.

UI/UX Analysis
The UI/UX evaluation was conducted based on Nielsen's fundamental usability principles.
This dashboard demonstrates several strengths:
Learnability
Users can quickly understand the interface thanks to its simple navigation structure.
Efficiency
Key information is accessible from a single screen without requiring multiple interactions.
Memorability
The consistent use of icons, colors, and layout patterns fosters user familiarity.
Error Prevention
Visual alerts help users immediately recognize critical situations.
Satisfaction
The modern dashboard design creates a positive user experience and enhances engagement.

Pembahasan
This implementation demonstrates the practical application of Digital Twin technology in watershed management.
Dibandingkan dengan sistem pemantauan konvensional, dasbor yang diusulkan menawarkan:

- Integrated information visualization
- Real-time environmental condition monitoring
- Flood prediction based on historical data

- Interactive geospatial analysis

The combination of the Digital Twin concept and dashboard visualization provides a comprehensive approach to environmental monitoring and disaster management.

Future developments may include:
- Integration of IoT sensors
- AI-based predictive models
- Mobile applications
- Automated early warning systems

5. CONCLUSION

This study successfully designed and developed a Digital Twin dashboard for the Ciliwung River Basin, integrating real-time flood monitoring features with flood predictions based on historical data.

The dashboard provides an effective platform for visualizing environmental information through interactive maps, monitoring panels, and predictive analytics. Implementing the Digital Twin concept enables a continuous representation of the river basin's conditions and supports data-driven decision-making.

The research findings indicate that the proposed system has the potential to enhance flood preparedness, environmental awareness, and disaster mitigation efforts. Future research should focus on integrating real-time IoT data and machine learning models to improve prediction accuracy and operational effectiveness.

CRediT Authorship Contribution Statement

Akmal Haikal Hamzah: Conceptualization, Methodology, Software Development, Visualization, Data Analysis, Writing – Original Draft, Writing – Review & Editing.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest regarding the publication of this journal.

THANK-YOU NOTE

The author extends their gratitude to UIN Sultan Maulana Hasanudin Banten and the National Research and Innovation Agency (BRIN) for the academic support provided during the completion of this research. Appreciation is also expressed to all parties who contributed to the development and evaluation of the Ciliwung Watershed Digital Twin dashboard prototype.

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