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Environmental Study for Flood Risk Management Case Based on Socio-Economic Vulnerability, Flood Hazard, and Exposurein Jakarta, Indonesia

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Abstract. *Flooding is a significant environmental problem in Jakarta, Indonesia, driven by high rainfall, flat topography, and land subsidence. These hazards directly impact socio-economic vulnerability (population density, settlement quality, and economic levels) and urban exposure (exposed residents, economic assets, and public facilities). This environmental study integrates flood hazard factors, socio-economic vulnerability, and exposure metrics using a descriptive qualitative research approach to determine localized flood risk levels. Utilizing secondary data integrated with GIS frameworks, data analytics, and digital monitoring dashboards, this study maps spatial risk distributions across Jakarta's administrative regions. The empirical findings reveal that integrating socio-economic parameters with hydrological indices supports the development of an intelligent, proactive Smart Flood Risk Management System (SFRMS). This combined tech-driven infrastructure provides actionable risk monitoring and visual priority mitigation matrices, forming a resilient foundation for modern urban disaster risk management.*

Keywords: environmental study, flood exposure, flood hazard, socioeconomic vulnerability, flood risk management.

INTRODUCTION

Flooding remains a major environmental challenge for rapidly urbanizing metropolitan areas worldwide, posing severe risks to urban infrastructure, economic activities, and community livelihoods (Savic, 2025). As a low-lying delta plain traversed by thirteen rivers, Jakarta is highly vulnerable to both riverine and coastal flooding due to its flat topography, coastal proximity, and severe land subsidence (Bennett et al., 2023; Roro et al., 2022). Driven by climate change and rapid urban development, the city faced extreme hydrometeorological pressure in early 2026, with rainfall peaking at 267 mm/day on January 18 (BMKG, 2026). However, this flood risk is structurally exacerbated not only by natural factors but also by socio-economic dimensions, including population density, deficient settlement quality, and community economic status, which directly lower adaptive capacity (Samsuddin et al., 2021). Consequently, contemporary disaster management paradigms must shift from purely structural infrastructure toward integrated approaches that combine physical hazards with localized socio-economic vulnerability and asset exposure metrics (O'Neill et al., 2016).

Proceedings of the Perbanas International Seminar on Economics, Business, Management, Accounting and IT
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While modern technology like Geographic Information Systems (GIS), sensor networks, and big data analytics enable high-resolution spatial tracking (Kusratmoko et al., 2016), local deployments remain fragmented. The DKI Jakarta Provincial Government has utilized information technology via the Jakarta Smart City platform to monitor water conditions and predict potential flooding in real time (Jakarta Smartcity, 2026). Nevertheless, unlike proactive smart frameworks being developed in regions like Brunei Darussalam that leverage integrated IoT intelligence (Lawal et al., 2024), Jakarta currently lacks an intelligent decision support system capable of dynamically integrating socio-economic vulnerability models directly into its real-time digital monitoring architecture.

The SFRMS proposed for Jakarta outperforms conventional platforms like Jakarta Smart City by mathematically integrating physical flood hazards with high-resolution demographic data, including population density, poverty indices, and infrastructure vulnerability. This integration of spatial socio-economic variations allows the system to provide actionable, localized emergency prioritizations based on predicted real-time socio-economic impacts rather than uniform sensor reporting.

This study implements flood risk management by integrating environmental hazards, socio-economic vulnerability, and infrastructure exposure in Jakarta. The specific objectives are:
1. Integrating environmental factors (flood hazards) with socio-economic factors (socio-economic vulnerability) within a single analytical framework.
2. Developing a Smart Flood Risk Management System, a flood risk management system utilizing information technology.
3. Integrating a flood risk analysis model with a Monitoring Dashboard.

LITERATURE REVIEW

Environmental studies explore the interdisciplinary relationships between human societies and their natural, built, and social environments to resolve complex ecological issues by combining natural sciences, public policy, and sustainability ethics (Sadiku et al., 2020).

Theoretical Framework of Flood Risk Management

Disaster risk in urban environments is theoretically framed as a function of hazard, vulnerability, and exposure (Savic, 2025). Managing these dimensions requires transitioning from reactive infrastructure toward proactive platforms that leverage artificial intelligence, real-time spatial analysis, and IoT infrastructure to build urban climate resilience (Lawal et al., 2024).

Flood Hazard, Vulnerability, and Exposure

1. **Flood Hazard:** Represents the physical probability and severity of an event, determined by rainfall intensity, topography, drainage capacity, and land subsidence (Roro et al., 2022).
2. **Socio-economic Vulnerability:** Explores the susceptibility of communities to harm driven by high population density, deficient settlement quality, and low economic levels (Biswas & Nautiyal, 2023).
3. **Flood Exposure:** Refers to the spatial presence of human lives, environmental assets, and public infrastructure within geographically demarcated flood-hazard zones (Bidadian et al., 2024).

METHODS

This study applies a descriptive qualitative research approach using secondary data integrated with GIS frameworks and information technology models to evaluate the smart flood risk management infrastructure in Jakarta.

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Data Collection
Secondary data were compiled via literature studies and documentation from national statistical, geospatial, and environmental monitoring institutions, as classified in Table 1.

TABLE 1. Sources of Study Data Collection

No	Main Data	Indicator Data	Data Source
1	Flood hazard	Rainfall, Topography/elevation, Land Subsidence	▪ Meteorology, Climatology, and Geophysics Agency (BMKG), ▪ National Disaster Management Agency (BNPB), ▪ Regional Disaster Management Agency (BNBD), ▪ Geospatial Information Agency (BIG)
2	Socio-Economic Vulnerability	Population Density, Settlement Quality, Community Economic Level	Central Statistics Agency (BPS)
3	Exposure	Exposed Population, Economic Assets and Infrastructure, Public Facilities	▪ Ministry of Public Works, ▪ Regional Development Planning Agency (BAPPEDA)

This dataset is obtained from publicly available sources, including national statistical agencies, environmental monitoring institutions, and previous academic studies.

Data Analysis
The analysis synthesizes environmental, social, and technological data across three progressive stages:
1) Risk Level Analysis: Indicators are mathematically calculated using ordinal assessment criteria: Low (1.00–1.50), Medium (1.51–2.00), High (2.01–2.50), and Very High (2.51–3.00). The spatial composite is computed via Equation 1 (Sigit et al., 2023; Bidadian et al., 2024; Albers & Evers, 2024):

$$\textit{Flood Risk} = \textit{Flood Hazard} \times \textit{Vulnerability} \times \textit{Exposure} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The final risk classification limits are defined as Low (1.00–6.99), Medium (7.00–13.99), High (14.00–20.99), and Very High (21.00–27.00).

2) Analysis of the Development of a Smart Flood Risk Management System
The analysis of the development of a Smart Flood Risk Management System (SFRMS) includes various stages, including:
- Analysis of the development of the Smart Flood Risk Management System Architecture.
- Analysis of the development of the System's Main Features.

3) Risk Model Integration Analysis with the Monitoring Dashboard
The final stage involves analysing the integration of the risk model with the Monitoring Dashboard, resulting in an integrated system capable of displaying real-time flood condition information while simultaneously conducting comprehensive flood risk analysis.

Proceedings of the Perbanas International Seminar on Economics, Business, Management, Accounting and IT
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Conceptual Framework

The integrated risk analysis workflow linking data acquisition to the smart system output is systematically diagrammed in Figure 1.

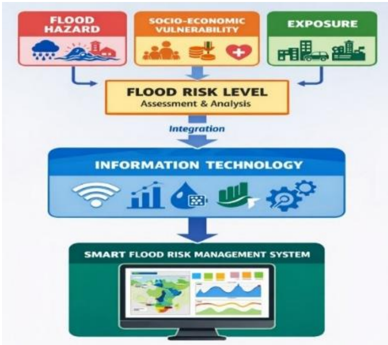

FIGURE 1. Flood Risk Management Conceptual Framework

Figure 1 shows a diagram of the Flood Risk Analysis Integration Model, which combines three main components: Flood Hazard, Socio-Economic Factors, and Geographic Information System (GIS), to produce an integrated Flood Risk analysis. This model illustrates how environmental and socioeconomic factors interact to determine the level of flood risk.

RESULTS AND DISCUSSION

Spatial Variations and Empirical Assessments

Multidimensional calculations across Jakarta's administrative regions reveal deep-seated hazard, vulnerability, and exposure variations, as itemized in Tables 2, 3, 4, and 5 (Budiyono et al., 2016).

Flood Hazard

According to Sejati *et al.* (2023) Flood hazards arise from both natural processes and anthropogenic activities, requiring comprehensive management and careful analysis, especially in areas vulnerable to flooding. The results of the assessment of flood hazard factors in the Jakarta region are presented in Table 2.

TABLE 2. Flood Hazards Assessment in Several Areas in Jakarta

Jakarta Region	Rainfall	Topography/ Elevation	Land Subsidence	Average Flood Hazard Factor	Assessment Results
North Jakarta	3	3	3	3	Very High
West Jakarta	3	2	2	2.3	High
East Jakarta	2	2	2	2	Medium
Central Jakarta	2	2	1	1.7	Medium
South Jakarta	2	1	1	1.3	Low

Source: Environmental Study (2026)

Proceedings of the Perbanas International Seminar on Economics, Business, Management, Accounting and IT
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Budiyono *et al.*(2016)revealed that changes in land use and land subsidence could increase the volume of floodwaters by up to 36.8% by 2050.

Socio-economic Vulnerability

Socio-economic vulnerability represents a community's susceptibility to harm from hazards due to low adaptive capacity, poverty, and limited resources (Biswas & Nautiyal, 2023). Driven by social, economic, and political factors, these dynamics diminish the capacity to recover from adverse impacts, with Jakarta's localized assessment results detailed in Table 3.

TABLE 3. Socio-economic Vulnerability Assessment in Several Areas in Jakarta

Jakarta Region	Population Density	Settlement Quality	Community Economic Level	Average Socio-economic Vulnerability Factor	Assessment Results
North Jakarta	3	3	3	3	Very High
West Jakarta	3	3	2	2.6	High
East Jakarta	3	3	2	2.6	High
Central Jakarta	3	3	2	2.6	High
South Jakarta	2	2	2	2	Low

Source: Environmental Study (2026)

Jakarta’s high population density reaching 10,000 to 18,000 people per square kilometer significantly amplifies flood impacts. This extreme concentration in areas with dense settlements and limited infrastructure severely elevates local structural vulnerability to flood hazards (Abidin et al., 2011).

Flood Exposure

Flood exposure represents the presence of populations, properties, and environmental assets situated within areas susceptible to inundation (Bidadian et al., 2024). As a critical component of overall risk, this exposure is frequently exacerbated by population growth and urban expansion, with Jakarta's localized factor assessments detailed in Table 4.

Proceedings of the Perbanas International Seminar on Economics, Business, Management, Accounting and IT
[June 2026] [ISSN 3047-0951]

TABLE 4. Flood Exposure Assessment in Several Areas in Jakarta

Jakarta Region	**Exposed Population**	**Economic Assets and Infrastructure**	**Public Facilities**	**Average Flood Exposure Factor**	**Assessment Results**
North Jakarta	3	3	3	3	Very High
West Jakarta	3	3	3	3	Very High
East Jakarta	3	3	2	2.6	High
Central Jakarta	3	3	2	2.6	High
South Jakarta	2	2	2	2	Low

Source: Environmental Study (2026)

BNPB disaster data indicates that flooding in the Jakarta metropolitan area regularly impacts tens of thousands of residents and thousands of homes, severely elevating exposure levels within high-activity commercial and industrial sectors (BNPB, 2025). To evaluate these spatial dynamics, Table 5 provides a synthesized flood risk analysis integrating localized hazard, vulnerability, and exposure dimensions (Sigit et al., 2023; Bidadian et al., 2024).

TABLE 5. Results of Flood Risk Analysis for Several Areas in Jakarta

Jakarta Region	***Flood Hazard***	***Vulnerability***	***Exposure***	***Flood Risk = (H × V × E)***	**Risk Level**
North Jakarta	3	3	3	27	Very High
West Jakarta	2.3	2.6	3	17.9	High
East Jakarta	2	2.6	2.6	13,5	Medium
Central Jakarta	1.7	2.6	2.6	11.5	Medium
South Jakarta	1.3	2	2	5.2	Low

Source: Environmental Study (2026)

Spatial analysis reveals regional flood risks across Jakarta (Table 5). North Jakarta faces very high risk from lowland topography, severe land subsidence, and tidal floods (Abidin et al., 2011). West and East Jakarta present high risk due to river networks and dense settlements, Central Jakarta maintains moderate risk from better drainage, and South Jakarta remains low risk due to elevated topography.

Proceedings of the Perbanas International Seminar on Economics, Business, Management, Accounting and IT
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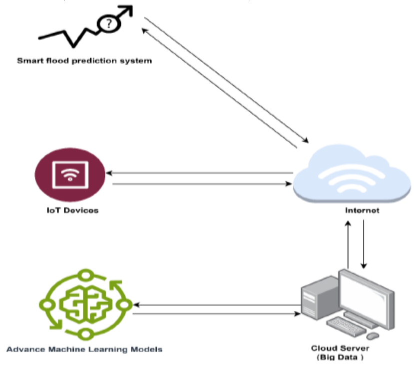
Smart Flood Risk Management System

The proposed SFRMS integrates real-time monitoring, data-driven risk analysis, and GIS visualization for proactive mitigation. Unlike conventional sensor-only platforms like the Brunei model (Lawal et al., 2024), this system couples physical hazards with localized socio-economic vulnerability metrics to enhance municipal response (Hatta et al., 2020).



Source: Lawal et al., (2024).

FIGURE 2. Proposed Smart Flood Risk Management System in Brunei Darussalam

In the context of urban areas such as Jakarta, this system is designed to help local governments and stakeholders monitor flood conditions more quickly, identify flood-prone areas, and formulate data-driven mitigation strategies (Hatta et al., 2020).

Smart Flood Risk Management System Architecture

The SFRMS framework consists of four functional layers mapped out in Figure 3 (Benade & Pretorius, 2012):

(1) Data Acquisition Layer
This layer functions to collect various data needed for flood analysis. This data can be obtained from environmental IoT sensors, hydrological observation or weather stations, satellite imagery, river gauges, and government databases.

(2) Data Processing and Analysis Layer
This layer functions to process and analyze data using various flood risk analysis methods, such as big data analytics, hydrological modeling, and machine learning. The analysis process includes:
a. Flood Hazard analysis based on rainfall, topography, and drainage capacity
b. Vulnerability analysis based on the community's socioeconomic conditions
c. Exposure analysis based on the number of residents and exposed assets
The analysis results are then used to calculate the Flood Risk Index using the model Flood Risk = Hazard × Vulnerability × Exposure (Albers & Evers, 2024):

(3) GIS-Based Visualization Layer
Maps risk index distributions, flood-prone borders, population density, and impacted assets.

(4) Decision Support System (DSS) Layer
Outputs automated early warnings, real-time tracking dashboard parameters, and emergency mitigation routing. Figure 3 shows the proposed smart flood risk management system architecture.

Proceedings of the Perbanas International Seminar on Economics, Business, Management, Accounting and IT
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FIGURE 3. Smart Flood Risk Management System Architecture

Main Features of the System

The digital interface (Figure 4) consolidates three core operations into a single platform:

1. **Flood Monitoring Feature:** Tracks real-time water levels, rainfall data, and inundation trends.
2. **Flood Risk Analysis Feature:** Computes the dynamic local risk indices by combining environmental models with socioeconomic variables.
3. **Flood Risk Map Visualization:** Renders interactive, high-resolution spatial maps classified by risk severity.

The SFRMS integrates monitoring, risk analysis, and GIS visualization into one platform. The dashboard tracks real-time hydrological data, dynamically calculates a localized Flood Risk Index from hazard, vulnerability, and exposure parameters, and maps spatial risk levels with estimated socio-economic impacts across Jakarta.

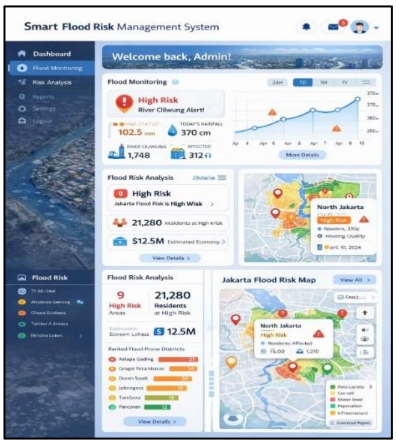

FIGURE 4. Smart Flood Risk Management System

INTEGRATED FLOOD RISK MONITORING DASHBOARD

The dashboard architecture (Figure 5) serves as the primary system interface, bridging technical data streams with data-driven administrative decision-making through three essential operational features:

1. **Integration of Monitoring Data and Risk Models:** Streams real-time hydrological sensor data directly into the analytical framework to output the immediate Flood Risk Index.

Proceedings of the Perbanas International Seminar on Economics, Business, Management, Accounting and IT
[June 2026] [ISSN 3047-0951]

2. **Risk Analysis-Based Panels:** Organizes telemetry into a Real-Time Monitoring Panel, a GIS-based Spatial Risk Map, and an automated Socio-Economic Impact Panel estimating affected assets.
3. **Decision Making Support:** Eliminates operational lag, enabling stakeholders to rapidly isolate localized crisis points and distribute assets based on predicted socio-economic exposures.

FIGURE 5. Integrated Flood Risk Monitoring Dashboard

CONCLUSIONS

Conclusion of this Environmental Study

This environmental study underscores that integrating hazard, exposure, and socioeconomic vulnerability analysis supports sustainable spatial planning, infrastructure development, and disaster mitigation in Jakarta. Empirical data reveals extreme spatial variations, marking North Jakarta with the highest vulnerability profile. Transitioning to a dynamic SFRMS backed by an integrated dashboard bridges the technical gap in real-time response, validating spatial algorithms as reliable mechanisms for data-driven municipal interventions.

Recommendations in the Environmental Study Results

1. **Sensor Network Scale-up:** Expand IoT sensor grids across thirteen major river basins for continuous hydrological monitoring.
2. **Dashboard Deployment:** Establish a central GIS dashboard to eliminate administrative data silos and accelerate crisis coordination.
3. **Public Warning Integration:** Embed automated early warning platforms into mobile applications to ensure rapid public evacuation.
4. **Cross-Sector Collaboration:** Strengthen data transparency and algorithmic open sourcing across municipal agencies to cultivate climate resilience.

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